The McGraw-Hill Companies

Railway Track Engineering

Fourth Edition

The McGraw-Hill Companies

Railway Track Engineering

Fourth Edition

J S Mundrey

Consultant

Tata McGraw-Hill Education Private Limited

NEW DELHI

McGraw-Hill Offices

New Delhi New York St Louis San Franscisco Auckland Bogotá Caracas
Kuala Lumpur Lisbon Madrid Mexico City Milan Montreal
San Juan Santiago Singapore Sydney Tokyo Toronto

Tata McGraw-Hill

Published by Tata McGraw Hill Education Private Limited,
7 West Patel Nagar, New Delhi 110 008.

ISBN (13): 978-0-07-068012-8
ISBN (10): 0-07-068012-4

Managing Director: *Ajay Shukla*
Head—Professional and Healthcare: *Roystan La'Porte*
Executive Publisher—Professional: *R Chandra Sekhar*
Manager—Production: *Sohan Gaur*
Manager—Sales and Marketing: *S Girish*
Deputy Marketing Manager—Science, Technical & Computing: *Rekha Dhyani*
General Manager—Production: *Rajender P Ghansela*
Assistant General Manager—Production: *B L Dogra*

Typeset at DigiConv Technology, J-6, Street No. 3, Near Vijay Chowk, Laxmi Nagar, Delhi 110 092, and printed at Gopsons, A-2 & 3, Sector 64, Noida, UP 201 301

Cover Design: Kapil Gupta, New Delhi

RXDLCRRBFLZRXZ

To
The Track Men & Women
of Indian Railways

The McGraw-Hill Companies

सत्यमेव जयते

S.K. VIJ

सदस्य इंजीनियरी, रेलवे बोर्ड
और पदेन सचिव,
भारत सरकार
रेल मंत्रालय
नई दिल्ली-110 001
MEMBER ENGINEERING, RAILWAY BOARD
&
EX-OFFICIO SECRETARY,
GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
NEW DELHI-110 001

18th August, 2008

FOREWORD

Economic liberalization and subsequent globalization has thrown a major challenge before the Indian Railways. Many new initiatives need to be taken in future to bring improvements in rail infrastructure. Railways have been trying to maintain its pre-eminence by improving the quality infrastructure through a combination of technical upgrading and operational improvements besides improving services. A modern railway track is a prerequisite for development of transport infrastructure.

Modernization essentially means keeping up with the times. A modern railway system necessarily brings to mind safe, fast and efficient railway system where everything is in position and is reliable and inspires the customers. If a country wants its rightful place in the world, it cannot afford to lag behind in putting in place a modern world class rail network. Indian Railways is moving forward in becoming No.1 railway in.the world.

Indian Railways has already decided to construct dedicated line for freight traffic on two critical routes on Western and Eastern sectors comprising about 2760 km of double line for 32.5 T axle load trains. Indian Railways is now rightly studying High Speed Passenger Corridors equipped with state-of-the-art modern systems.

The present work titled 'Railway Track Engineering' advances the theory and practices of modern railway track in many important ways. Besides emphasizing the basic elements of railway track engineering, it also covers recent developments in areas, as diverse as, high speed track, Metro lines, rail grinding, mechanized track constructions etc. It is a guide for crafting good and reliable track. This comprehensive book furthers the theory and practice of modern track and educates track engineers in meaningful and insightful ways.

Shri J. S. Mundrey, an ex-Indian Railway elite engineer, has vast experience in area of track technologies not only on Indian Railways but has acquired the same on many other Railways of the world. The book reflects many years of diligent work done by the author in studying track related issues in India and in countries around the world.

I have no doubt that latest edition of this book will further enrich the knowledge of Railway Track Engineers.

(S.K. VIJ)

Preface to the Fourth Edition

With the India's GDP growth of 8–9 %, the transport needs of both passengers and goods are increasing rapidly. To meet the increasing traffic requirement, rail transport system in India, which provides the most economic and environment friendly option, is being strengthened. Apart from upgrading the existing network, dedicated freight corridors have been planned. Separate high-speed lines are also being proposed where super high-speed trains will be running at a speed of 300–350 kmph. Existing metro rail networks are being expanded, new metros are being planned. To meet these growing demands, rail technology in India is being continuously upgraded to bring it at par with the world standards. This new edition of the book, while retaining all the basic elements of railway track engineering, brings about the technical advancements that have come up on Indian railways, since the publication of the last edition.

Rails in railway track are synonymous with the railway transport system. Heavier, high-speed traffic causes great wear and tear of rails. Rail rolling contact fatigue was relatively unknown phenomena till the year 2000 when it attracted worldwide attention after the notorious Hatfield rail disaster in UK. Against these developments, measures being taken in India for improving the service life of the rails have been described in the new edition. Indian railways are likely to adopt 68 kg/m rail section in their dedicated freight corridors. Important details of this new section have been included. In India, M/S Jindal Steel & Power Ltd. (JSPL) have set up a new rail rolling facility, among the best in the world, where 120 metre long rails of very high quality are being rolled, further converted into 480 metre long panels in an integrated flash butt welding plant. This quantum jump in rail manufacturing technology has been described.

Well-designed elastic fastening systems play a very important role in improving the maintainability of the railway track. Advancement made in this field have been included particularly the introduction of G Clip, designed and manufactured by an Indian Company.

Turnouts in railway track have always remained the weakest link. Turnouts adopted by Delhi metro incorporate the latest technology available over the world railways. Main features of this turnout have been brought out in this book. The author had the privilege of being associated with this development, working as a consultant with M/S Cogifer of France who designed and manufactured these new turnouts.

In view of the major technological improvements that have occurred in the field of high speed operation and the possibility of its use in India, the chapter on high speed track has been completely overhauled. Among other items, it also brings out the track parameters suitable for high speed operation in India.

A new chapter on modern track construction has been added. In this chapter, technology being adopted in world railways on mechanized track construction has been explained. In India, mechanized track construction is still in an infant stage. Simple to advanced track machines that can be used in track construction work in India have been described.

Some of the other important items included in the new edition are: (a) the working of the ground penetrating radar in determining the sub-grade condition of the railway track (b) new technology of single crucible alumino thermic welding (c) Rail Scan Equipment for determining locked up stresses in LWR (d) the description of a modern, state of the art, track recording car, brought about by M/S Plasser & Theurer an Austrian company (e) track standards likely to be adopted on DFC (f) Ballast-less track assemblies adopted by metros in India

The author had the privilege of participating in many conferences and exhibitions on track technology held around the world. Important innovations noticed at these events, relevant to Indian conditions, have been included in the new edition. Railway track technology is developing at a fast pace. It will be the author's endeavor to update this book from time to time to keep the readers well informed of the latest developments. Any suggestions in this direction will be welcomed.

I am thankful to Shri Ankush Krishan for making valuable contribution in formulating the new chapter on 'Modern Track Construction'.

I am highly grateful to Shri. S. K.Vij, member engineering Indian railway board and ex- officio secretary to Govt. of India and an eminent trackman, for writing the foreword for this new edition of the book.

The author wishes to gratefully acknowledge the keen interest that has been taken by the publishers, particularly Mr. R. Chandrasekar in improving the presentation and the overall standard of this publication.

J S Mundrey

Preface to the First Edition

The past few years have witnessed many changes in track technology on Indian Railways. The changes have come in the form of laying down of new track standards for broad gauge and metre gauge systems, development of new track components, evolution of new designs of points and crossings, rationalization in the methods of track maintenance and renewals, and an increased awareness of the limitations of various methods of track monitoring systems.

This book encompasses, in one volume, information on all the relevant areas of railway track technology and essentially caters to railway track engineering students, the teaching faculty, new entrants to railway technology, professional track men, and to research workers.

All the subjects in the book have been dealt with from the very fundamentals so that the engineering students studying for the Diploma and Degree courses may get the desired grasp of the subject. This book will therefore, be quite useful in Technical Institutions where 'Railways' form the subject of their curriculum. The book is expected to fully meet the requirement of permanent way men working on Indian Railways on the design, construction and maintenance of broad gauge, metre gauge and narrow gauge tracks. Permanent way men of many of the developing countries of the Indian subcontinent, Africa, Middle East, Latin America and Far East, who are at a similar stage of development, will find the book useful in seeking solutions to their track problems.

The track man of today is the product of a society which stimulates enquiry. It is, therefore, not unnatural, if he does not feel motivated in his work, till he gets a satisfactory answer to his doubts and misgivings about track construction and maintenance operations that he is required to perform. Efforts have been made in this book to fulfil this important need of the contemporary track man.

In addition to providing the necessary technical details about the track, the theory behind its development has also been presented in a simple way. For this purpose basic calculations for the design of track components have been included at appropriate places. A chapter on Track Stresses' has been added to provide the readers with sound knowledge on the design of the track as a civil engineer- . ing structure.

Track men often get baffled when derailments occur on a reasonably well-maintained track. An insight into the phenomenon of rail-wheel interaction leading to derailment investigations would help them on such occasions. I have included a chapter on derailment investigations to explain lucidly this phenomenon. Rolling stock tolerances have also been dealt with. This would not only equip them to identify precisely the causes of derailments, but also enable them to attend to vulnerable portions of their tracks. The chapter on 'Special Tracks' deals with tracks that are to be provided at places where conventional ballasted tracks cannot be accommodated on account of physical and technical constraints. While it is always desirable to have track standards matching the requirements of the traffic it carries, situations often arise—on account of resource constraint—when permanent waymen are required to maintain old and worn out tracks to keep the traffic moving. Methods used on Indian Railways to deal with such situations and to rehabilitate such tracks have been discussed in the chapter on ‘Track Standard and Rehabilitation’.

Over the years, I have had the opportunity to work with RDSO, where new track designs are evolved and standardized; in the Railway Board, where track policies are formulated; and as Chief Track Engineer of zonal railway, where real-life track problems overshadow all track technicalities. I have participated in various high level committees appointed by the Railway Board, to evolve new permanent way manuals, track components, track maintenance methods and procedures. During these tenures, I have had the good fortune of meeting eminent track men, who were experts in their own fields. I acknowledge with gratitude the contributions of these individuals, authors and institutions which have gone into the making of this book.

I am grateful for the assistance given to me by Mr. Tribhuvan Gupta, who went through the complete text and gave many valuable suggestions.

I would also welcome any suggestions for additions and improvements.

J S Mundrey

Contents

Chapter 1

Indian Railways and Its Track Structure

1.1 EVOLUTION OF THE RAILWAY TRACK

Railway transportation system is, no doubt, a great invention of the 19th century. It opened a new horizon for the mankind, enabling closer interaction between communities and faster movement of materials and goods. The essential elements in its development are simple. In order to reduce the friction between the wheels of carriages or wagons and the road surface, stone slabs and wooden beams were laid flush with the road surface in the tramways of collieries in the United Kingdom in the middle of the eighteenth century. Wrought iron plates were later fitted to the wooden beams. Subsequently, an angle iron with one leg vertical was fixed to the iron plate to guide the wheels. A further improvement was the replacement of the wooden beams by those made of cast iron supported at the ends. Modern railway system employs high quality steel rails for heavy hauls and high speed operations.

For years, attempts were made to build a steam engine. In 1776, Watts perfected one. In 1814, Stephenson converted the stationary steam engine into a rail locomotive. For obtaining greater efficiency and reliability, modern railways deploy high horse power diesel and electric locomotives.

1.2 STRUCTURE OF THE RAILWAY TRACK

The railway track is a structure consisting of parallel lines of rails with their sleepers, fittings and fastenings, ballast, etc., to provide a road for the movement of locomotives and coaches/wagons for the transportation of passengers/freight, etc.

1.3 GAUGE

The gauge of track is the distance between the inner edges of the heads of rails in a track, measured at 16 mm below the top surface of the rail.

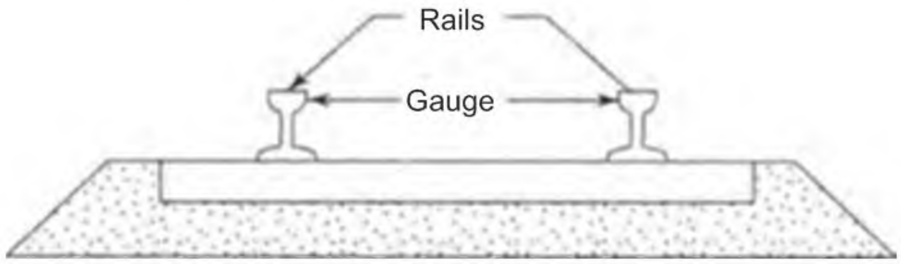


Fig. 1.1 Gauge

The most widely used gauge in the world is the standard gauge, which is equal to 1435 mm. However, in India, we have three gauges:

1. Broad gauge (BG) 1676 mm
2. Metre gauge (MG) 1000 mm
3. Narrow gauge (NG) 762 and 610 mm

A wider gauge has the advantage of greater traffic capacity, speed and safety. It, however, requires flatter gradients and curves. The cost of constructing a railway line increases with increase in gauge.

1.4 CHANGE OF GAUGE

Wherever there is a change of gauge, its non-uniformity creates an imbalance in the transhipment of passengers and freight because of capacity variation. Hence, the uniformity of gauge became an inevitability which the Indian Railway realised way back and started with the conversion of MG/NG to BG. Currently, about 850 km of MG/NG are being converted into BG every year.

1.5 AXLE LOADS AND TRAIN RESISTANCE

Axle load is the weight on the two wheels joined by an axle. The hauling capacity of locomotives is limited by the axle loads (W) of the powered axles and the coefficient of friction (U) between the wheels and the rails. The value of the U is the highest at the start and progressively decreases as speed increases. On the other hand, train resistance is minimum at about 5 km/h, beyond which it increases in proportion to the square of the speed.

The power of locomotive has to be slightly in excess of the hauling capacity to take care of the climatic conditions, power required for auxiliary systems and acceleration reserve at the maximum defined speed of the locomotive. Increasing the power without increasing the axle loads does not help in pulling heavier loads, but only results in wastage of power. Axle loads are linked with the track structure. Heavier axle loads require stronger track structure, which, is expensive. It requires several years to renew or strengthen a track. Moreover, heavier axle loads also affect the bridge structure. Therefore considerable thought has to be given while fixing maximum axle loads of the locomotive to run on Indian rail tracks. Maximum locomotive axle loads are generally limited to 22.5 tonnes on the BG system and 13.0 tonnes on the MG system. Heavier axle loads have, however, been permitted for some of the freight locomotives required to run at less than permissible speed of the sections.

While pulling a train, a locomotive has to overcome various resistances, which depend upon the friction of wheels on rails, journal friction, wave action of rails, speed, and the sharpness of the curves and gradients. The grade resistance is equal to Grade multiplied by the Weight of the train in tonnes. Resistance on the curves varies with the degree of the curvature and the gauge. The following values have been considered appropriate on the Indian railways.

0.4 kg/tonne/degree of curvature for BG
0.3 kg/tonne/degree of curvature for MG
0.2 kg/tonne/degree of curvature for NG

For computing the starting capability of locomotive, the value of the coefficient of friction (*U*) at the starting point is important. The value of the coefficient of friction is normally taken between 0.3 and 0.25, depending upon the driving axle configuration. In the case of mechanically coupled driving axle locomotives such as WDM-3, WDM-4 and YDM-2 locomotives, and monomotor electric locos such as WAG-1 and WAG-3, the value of *U* is generally taken as 0.3. In the case of independently driven axle diesel-electric locomotives such as WDM-2, YDM-4 and electric locomotives such as WAG-5, WAM-4, WAP-1, etc., *U* is taken as 0.25 to 0.27.

Wherever possible, the values of starting resistance and rolling resistance of the locomotive and the rolling stock at various speeds are determined on the basis of actual field trials. Based on these values, the hauling capacity of locomotive for a particular type of rolling stock is determined.

For instance, the hauling capacity of a WDM-2 locomotive having an axle load of 18.8 tonnes with 6-powered axles and intended to haul passenger (ICF) coaches is worked out as under:

Maximum starting effort H = No. of axles × Axle load × Static friction
$= 6 \times 18.8 \times 0.27$
$= 30{,}450$ kg

Loco resistance at start = 615 kg (observed value on the basis of trials)

Draw bar pull available at the start = 30,450 – 615 = 29,835 kg

Starting resistance for ICF coach = 3.86 kg/tonne (value based on field trials)

$$\text{Capacity of the locomotive at start for ICF} = \frac{29,835}{3.86} = 7{,}729 \text{ tonnes}$$

1. On a tangent level track at a speed of 100 km/h the tractive effort of this locomotive is 5,000 kg. The value is based on the performance trials (Fig. 1.2). Due to ageing of the power equipment, 90 percent of the above is considered as the available tractive effort.
   Therefore, the available tractive effort = 5,000 × 0.9 = 4,500 kg.
   Loco resistance at the speed of 100 kmph = 940 kg (as observed during the performance trials).
   Therefore, draw bar pull available = (4,500 – 940) = 3,560 kg
   Rolling resistance of ICF coaches load at 100 khph = 3.617 kg/tonne (based on trials)
   Therefore, the weight of the train, which this locomotive can haul on a level straight track at 100 km/h:

$$= \frac{\text{Draw bar pull}}{\text{Rolling resistance of the trailing stock}} = \frac{3{,}560}{3.617} = 985 \text{ tonnes}$$

$$\text{No. of coaches that can be hauled} = \frac{\text{Total tonnage}}{\text{Average weight of a coach}} = \frac{985}{50} = 19.7 \text{ (say19)}$$

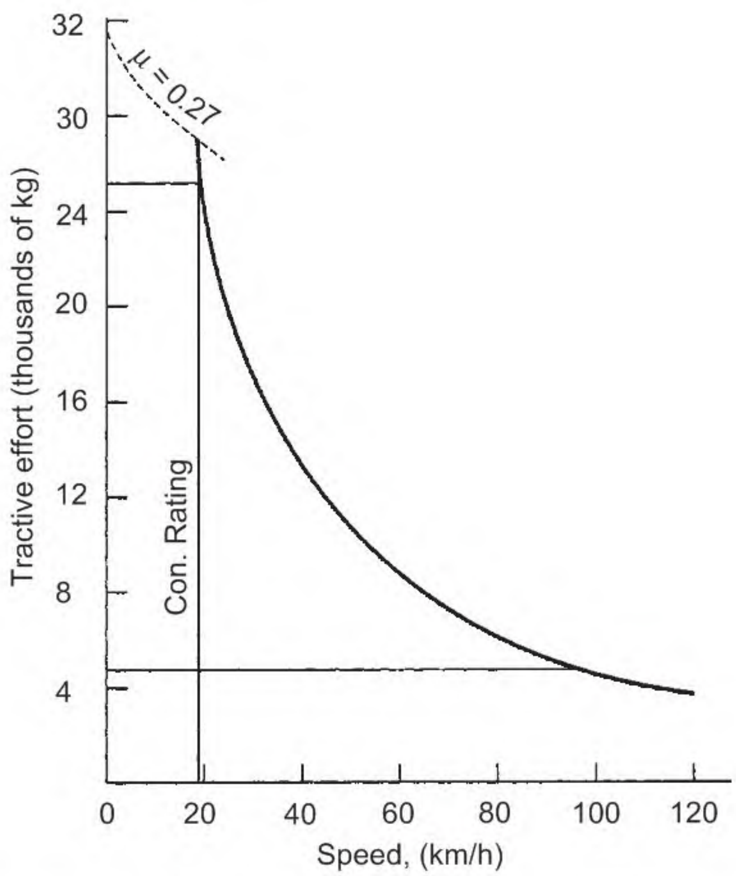


Fig. 1.2 Tractive effort vs. speed curve WDM_2 loco

2. On a 1° curve and 1 in 400 gradient, the trailing load which the same locomotive can haul would be reduced due to the grade and the curve resistance.

Grade resistance of the locomotive = Grade × Weight of the locomotive

$$= \frac{1}{400} \times 112.8 \times 1000 = 282 \text{ kg}$$

Curve resistance of the locomotive = 0.4 × Degree of curve × Weight of the locomotive

$$= 0.4 \times 1 \times 112.8 = 45.1 \text{ kg} = 45 \text{ kg.}$$

Therefore, available draw bar pull = 3,560 – 282 – 45 = 3,233 kg.

Curve resistance of trailing load = 0.4 kg/tonne

$$\text{Grade resistance of trailing load} = \frac{1}{400} \times 1000 = 2.5 \text{ kg/tonne};$$

Therefore, total rolling resistance at a speed of 100 km/h of the trailing load = Rolling resistance on a tangent level track + curve resistance + grade resistance

$$= 3.617 + 0.4 + 2.5 = 6.517 \text{ kg/tonne}$$

Therefore, the load which the same

$$\text{locomotive can haul at 100k/h} = \frac{3{,}233}{6.517} = 502 \text{ tonnes}$$

$$\text{No. of coaches} = \frac{502}{50} = 10 \text{ (say)}$$

Salient features of typical locomotives used on the BG and MG on Indian railways are tabulated in Table 1.1.

Table 1.1 Salient Features of Typical Indian Locomotives

		Broad Gauge					
S. No.	*Description*	*Electric Locos*			*Diesel Locos*		
		WAP5	*WAP7*	*WAG7*	*WAG9*	*WDG4*	*WDP4*
1.	Wheel Arrangement	BO-BO	CO-CO	CO-CO	CO-CO	CO-CO	A-A-1
2.	Axle Load (t)	19.5	20.5	20.5	22.5	21.0	19.5
3.	Maximum Permissible Speed (km/h)	160	130	100	90	100	160
4.	Max. Tractive Effort (t)	26.3	32.9	42.00	52.0	53.00	27.55
5.	Horse Power (HP)	5442	6120	5000	6000	4000	4000

		Metre Gauge			*Narrow Gauge*
S. No.	*Description*	*Electric Locos*		*Diesel Locos*	*Diesel Locos*
		YAM 1	*YDM 2*	*YDM 4A*	*ZDM 4A*
1.	Wheel Arrangement	BO-BO	BO-BO	CO-CO	1 B'-B' 1
2.	Axle Load (t)	13.00	12.00	12.0	7.00
3.	Maximum Permissible Speed (km/h)	80.0	75.0	96.0	50.0
4.	Max. Tractive Effort (t)	19.50	14.40	18.93	7.80
5.	Horse Power (HP)	1,620	700	1,400	700

1.6 GRADES

1.6.1 Ruling Gradient

The steepest grade which exists in a particular section is called ruling gradient as it limits the maximum weight of the train which can be hauled by a locomotive on that particular section.

1.6.2 Momentum Gradient

It is the grade steeper than the ruling gradient. This can be overcome by a train due to its own momentum gathered on its run.

1.6.3 Pusher Gradient

When the grade is so steep as to necessitate the help of an extra engine for pushing the train, it is called the pusher grade. The extra engine so used is called banking engine.

1.6.4 Ghat Sections

Sections, which have a considerable length of grades of 1 in 200 or steeper, are called ghat sections.

1.6.5 Grades in Station Yards

The grades in station yards have to be sufficiently flat in order that:

(a) Unconnected vehicles, left standing on the tracks, do not start moving on their own due to the effect of gravity, coupled with the effect of a strong wind and/or a gentle push.
(b) Locomotives, which have to overcome a higher starting resistance are not encumbered with further resistance due to steep grade.

In the Indian railways, the maximum gradient permitted for all gauges in station yard is 1 in 400, whilst a gradient of 1 in 1,200 is recommended.

On a single line, the length of station yard, where this flatter grade is required to be provided shall be 50 m beyond the outermost points at either end. On a double line, it shall be from home signal to the last stop signal of each line.

1.6.6 Grade Compensation on Curves

If curve happens to fall on a ruling grade, it will not be possible for a train to overcome the resistance caused by the gradient and the curve. In such cases either the trainload is decreased or the gradient is flattened. This flattening of the grade is called grade compensation on curves. For example, the compensated grade for a BG 3° curve on 1 in 100 ruling grade section can be determined as follows:

Ruling grade = 1 in 100 = 1.0 percent
Curve resistance of BG = 0.04 percent per degree of curve
Curve resistance for 3° = $0.04 \times 3 = 0.12$ percent
Therefore, Compensated (maximum) = $1.00 - 0.12 = 0.88$ percent
Grade that shall be permitted on 3° curve = 100/0.88 = 1 in 113.6
So that grade and curve resistance do not exceed ruling gradient resistance.

1.7 SCHEDULE OF DIMENSIONS

To ensure uniform degree of vehicular movement safety over any gauge system, certain dimensions for railways have been laid down in each country. The Indian Railway board has specified these dimensions in the booklet 'Schedule of Dimensions'. These dimensions are stated in two schedules which are as follows:

1.7.1 Schedule I

The dimensions given in this schedule are mandatory for new works and alterations in ongoing works. However, exceptions can be made in the observance of these with the permission of Commissioner of Railway Safety.

1.7.2 Schedule II

This schedule gives the dimensions which violate the dimensions of Schedule I, yet they have been permitted to continue, of course with restrictions of speed as are considered necessary. The structures when altered shall however be rebuilt to comply with Schedule I.

The standard dimensions in India, among other things, specify the minimum track centres, minimum clearances required for safety, degree of sharpest curves, minimum angle of crossing and maximum sizes of the rolling stock.

1.7.3 Loading and Construction Gauge

The loading gauge represents the maximum width and height to which a vehicle may be built or loaded. Bridges, tunnels, platform sheds and other structures are so built, that their sides and top remain clear of the loading gauge. The construction gauge is obtained by adding necessary clearance to the loading gauge. On BG in India, the maximum height and width of the vehicles recommended in the loading gauge are 4,725 (15′ 6″) and 3,660 mm (12′ 0″), respectively; for MG the dimensions are 3,430 (11′ 3″) and 2,745 mm (9′ 0″), respectively. Appendix I gives a set of important dimensions for BG and MG as prescribed by the Indian Railway Board. Standard dimensions that are being adopted on the BG and MG system in Indian Railways are given in Figs 1.3 and 1.4, respectively.

1.8 OVER DIMENSIONAL CONSIGNMENT

A consignment when loaded on a rolling stock; whose length, width, height or anyone of these exceeds the Standard Moving Dimensions, it is categorized as Over Dimensional Consignment (ODC) or Out of Gauge Load.

1.8.1 Package Dimensions

Taking into account the dimensions of the rolling stock generally used on Indian Railways, the packages, exceeding the following dimensions are treated as ODCs.

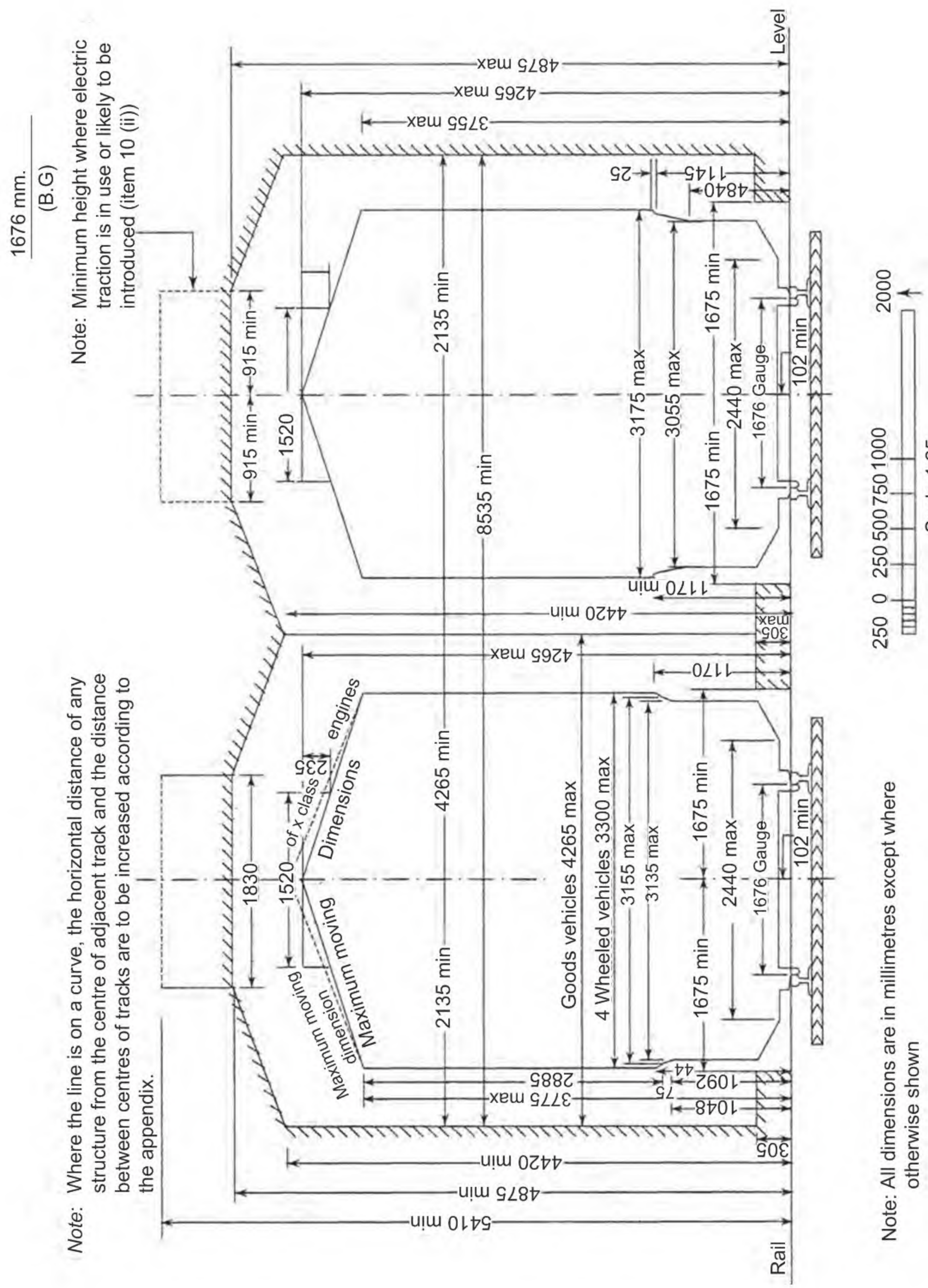


Fig. 1.3 Standard dimensions out of stations (B.G.)

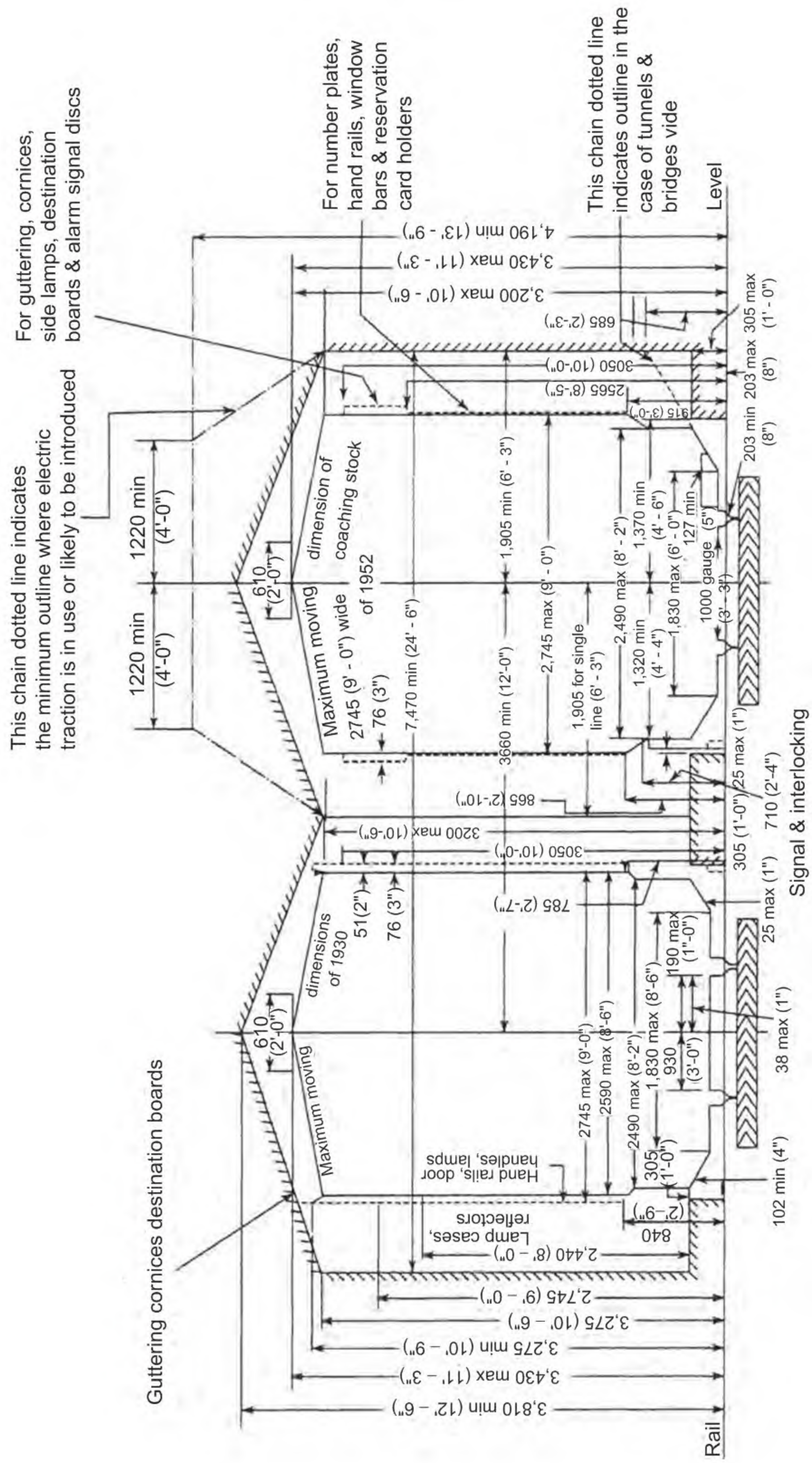


Fig. 1.4 Standard dimensions out of stations (M.G.)

Package Dimensions (mm)	*Gauge*	
	BG	*MG*
(a) Length	*13716	*12192
(b) Height		
(i) At centre	2743	2540
(ii) At corners	2134	2134
(c) Width	2997	2540
(d) Top width	610	610

*Length over headstock of flat bogie wagons.

1.8.2 Classification of Over-Dimensional Consignment

ODCs are classified into A, B and C, as below:

Class	*Clearance to the fixed structures measured under static conditions*
A	229 mm (9") and above
B	152.4 mm (6")—229 mm (9")
C	76.2 mm (3")—152.4 mm (6")

Movement of an ODC is allowed only after carefully scrutinizing the structural clearance available on its route.

1.9 CONING OF WHEELS AND CANTING OF RAILS

The head or run of wheels of railway vehicles are not made flat but sloped, and this sloping of the surface along the circumference forms a part of a cone (Fig. 1.5). On straight tracks, the coning of the wheels keeps them central, thereby reducing the wear of wheel flanges. If, at any moment, the wheels go out of their central position, they have to tread unequal distances on the rails. The wheels, therefore, retreat till they are at the central position again. This helps in smooth riding.

On curves, the outer rail is longer than the inner rail. The coning of the wheel helps them to take up position, where greater diameter is available, to tread longer distances of outer rail and wheels of smaller diameter cover the smaller distances of the inner rail. This reduces slipping and skidding of wheels, a phenomenon which not only increase resistance in haulage and speed but also causes lot of extra wear on rails and wheels.

On rails laid flat, coning of rails will subject the rails to eccentric loading at the inner edge. This would create problems in both rail design and maintenance. To avoid these, rails are not laid flat but are tilted inwards at the slop of 1 : 20, which is the slope of the wheel cone. This is called canting of rails.

Rails in switches and crossings are generally not canted for certain reasons, which will be explained later.

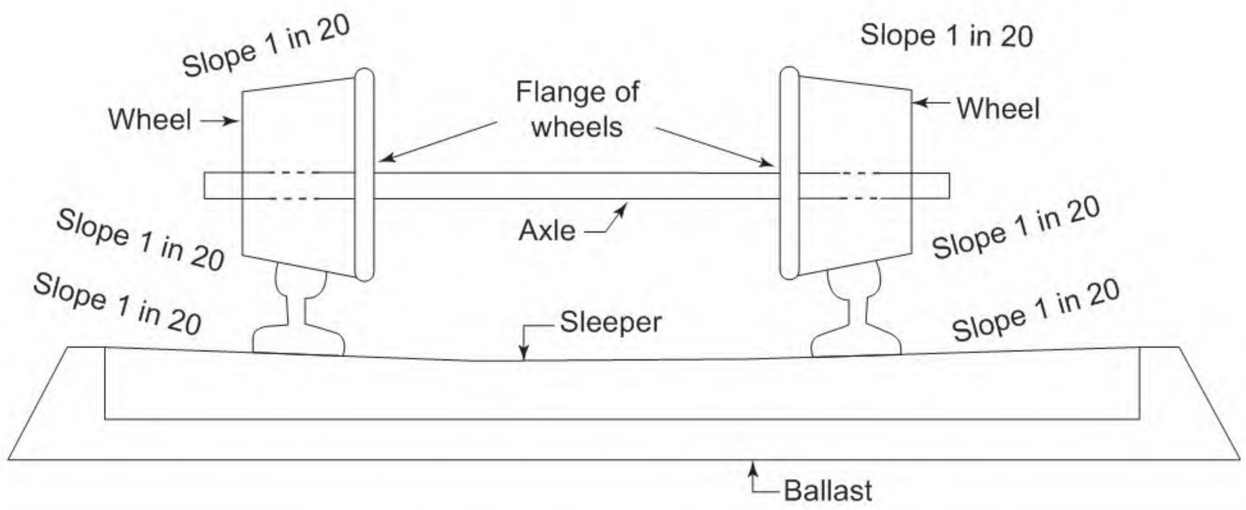


Fig. 1.5 Coning of wheels

1.10 INDIAN RAILWAYS: AN OVERVIEW

The Railways are the principal mode of transport in India. In 2006-07, Indian Railways carried about 17.0 million passengers per day and about 2 million tonne freight traffic, on a network spread over 63,327 route km, touching 7,000 stations.

The network consists of Broad, Metre and Narrow gauges, totaling 109, 996 track km. Gauge wise break up as on March 31, 2005, is given in Table 1.2.

Table 1.2

Gauge	*Route (km)*	*Running track (km)*	*Total (km)*
Broad Gauge (1676 mm)	49,820	71,015	93,386
Metre Gauge (1000 mm)	10,621	11,487	13,412
Narrow Gauge (762 and 610 mm)	2,886	2,888	3,198
Total	**63,327**	**85,390**	**109,996**

Indian Railways is a fully government owned system, functioning under the Ministry of Railways through the Railway Board, whose members are also ex-officio secretaries to the Government of India. Indian Railways is presently divided into 16 zones, each zone headed by a General Manager. The zones are further divided into 68 operating divisions, each division working under the Divisional Railway Manager.

In a zone, the functional heads of departments are responsible for the efficient functioning of their department. The departments are: finance, personal, civil engineering, mechanical engineering, electrical engineering, signal and telecommunication engineering, operation, stores, medical, security, etc. Similar delegation of responsibility exists at the divisional level.

Indian Railways is among the few railway systems in the world, which earns a profit. In 2006-07 with a total earning of 627 billion rupees, it made a modest profit of 43 billion rupees, after paying a dividend of 42.4. billion rupees and making allocation to depreciation reserve fund, development fund, pension fund etc.

Broad gauge, constituting 75% of the route length, generates 99.5% of the freight output and carries 95% of the passenger traffic. With the unigauge policy adopted by Indian Railways, metre and narrow gauge tracks are being progressively converted into broad gauge.

Indian Railways is constantly acquiring advanced railway technology which include: modern track structure consisting of continuously welded high UTS rails, mechanised maintenance monitoring and renewal of track (these have been discussed in various chapters of the book), modern signalling and telecommunication system, induction of modern high output rolling stock, adoption of modern technique in railway operation such as containerisation, unit train movement, heavy haul trains, etc.

The maximum permissible speed of Indian Railways is 150 kmph for passenger trains and 100 kmph for goods trains. A passenger train with a maximum permissible speed of 150 kmph has been introduced on New Delhi–Agra section. Research and development work is always in process to increase the speed to international level.

Indian Railways is the single largest user of manpower in the country. It has about 1.47 million persons on its rolls. Another 0.1 million would be engaged in railway related activities. To train such a large workforce, Indian Railways has set up the following five centralized training centres besides large number of training institutes for various disciplines, located in the zonal railways.

- Railway Staff College Vadodra.
- Indian Railway Institute of Civil Engineering Pune.
- Indian Railway Institute of Signal Engineering and Telecommunication Engineering Secundarabad.
- Indian Railway Institute of Mechanical engineering Jabalpur.
- Indian Railway Institute of Electrical Engineering Nasik.

With the mechanisation and modernisation of Indian Railways a gradual decrease of 3% per year in the workforce, mainly in the unskilled category, is contemplated.

For research and development, Indian Railways has its own captive unit: Research, Design and Standard Organisation (RDSO) at Lucknow. It has on its rolls more than 300 qualified personnel whose function is to provide input support of almost all disciplines to R&D wing of Indian Railways.

Following Public Sector Undertakings operate under the control and guidance of the Ministry of Railways:

1. *Rail India Technical and Economic Services Limited* (*RITES*) RITES provides comprehensive consultancy services from concept to commissioning in the field of railways, urban transport, roads and highways, airports, inland waterways, ports and harbours, rope-ways, manufacturing industry and information technology. It has established itself as a leading international consultancy organization in the public sector, with recognition

by multilateral funding agencies and experience in over 65 countries in Africa. Middle east, Latin America etc. Rites is also engaged in export packages in rolling stock and spares.

2. *Ircon International Limited* (*IRCON*) IRCON has built itself as an international railway construction company. In the last few years, Ircon has also diversified into the construction of roads, buildings, bridges, flyovers, airports etc.
3. *Indian Railways Finance Corporation Limited* (*IRFC*) IRFC was set up in 1986 to partly finance the development of Indian Railways. It raises funds through market borrowing by issuing bonds and taking long terms loans from banks/other financial institutions/Life Insurance Corporations and other external sources.
4. *Container Corporation of India Limited* (*CONCOR*) The business conducted by CONCOR is characterised by three distinct activities, i.e. of a carrier, a terminal-operator and a Container Freight Station (CFS) operator.
5. *Konkan Railway Corporation* (*KRC*) The 760 km long Konkan Railway Corporation (KRC) manages its own affairs as a partner with the Ministry of Railways. KRC was commissioned recently, with the four Indian states, viz. Maharashtra, Goa, Karnataka and Kerala being the beneficiary states.
6. *Indian Railway Catering and Tourism Corporation Ltd.* (*IRCTC*) IRCTC has been set up to look after the catering and tourism sector of the Indian Railway's business operation. The corporation manages the departmental catering business on many divisions and also awards contracts for on-board catering services.

   IRCTC is also providing facility for booking railway tickets through internet. It has also set up two plants for the manufacture and bottling of mineral water, Railneer, for supply to the railway passengers.
7. *Railtel Corporation of India Ltd* (*RailTel*) Incorporated in September 2000, the main object of the company, inter alia, include building a nation wide telecom multimedia network for laying of Optical Fibre Cable (OFC) along the railway tracks. It will help to modernize Indian Railway's communication systems for safe and efficient train operation and will generate revenue through commercial exploitation of the system. Till March 2007, OFC system has been commissioned on a total of 30,790 route kms.
8. *Rail Vikas Nigam Limited* (*RVNL*) RVNL is a special purpose vehicle to execute two vital components of National Rail Vikas Yojna, launched by the Government of India. Its main objectives are to undertake project development, financial resource mobilisation and execution of projects on a commercial format using largely non budgetary funds. The projects are expected to remove the capacity bottlenecks on the golden quadrilateral and its diagonals and to augment port connectivity.

Appendix 1.1 Important Schedule of Dimensions for BG and MG

1	*2*	*3*	*4*
S No.	*Description*	*BG (mm)*	*MG (mm)*
1.	Minimum distance centre to centre track		
	(I) For existing works	4,725	3,660
	(II) For new works or alteration to existing works	5,300	3,960
2.	Minimum radius of curve	175	109
3.	Minimum clearance of check rails for a curve	44	41
4.	Minimum clearance of check rails at level crossing	51	51
5.	Maximum clearance of check rails at level crossing	57	57
6.	Minimum depth of space of wheel flange from RL	38	35
Buildings and Structures			
7.	Minimum horizontal distance from centre of track to any structure from RL to 305 mm above RL		
	(i) For existing works	1,675	1,370
	(ii) For new works alteration to existing works	1,905	
8.	Minimum horizontal distance from centre of track to any structure except a platform from 305 mm above RL for BG and 3,200 mm for MG such as water column etc.	2,135	1,905
9.	Minimum horizontal distance of any telegraph post measured from centre and at right angle to the nearest track	Ht + 2,135	Ht + 1,980
10.	Minimum height above rail level		
	(a) For a distance of 915 mm on either side of centre of track for overhead structures (for BG)	4,875	—
	(b) At centre of track for overhead structures (for MG)		3,810
	(c) With DC electric traction, this dimensions for BG and minimum height above RL or for a distance of 1,220 mm on either Side of centre of track for MG	5,410	4,190
	(d) Where 25 kV, AC, traction is likely to be used min. height above AC wire for a distance of 1,600 mm on either side of the centre track for		
	(i) Light overhead structures such as foot over bridge	6,250	6,250
	(ii) Heavy overhead structures such as road overhead or flyover bridge	5,870	5,410
11.	(a) Minimum height above RL to the lowest wire of any portion of a guard or guard cradle under conditions of max. sag.	6,860	6,100
	(b) The minimum horizontal distance measured at right angle to the nearest track to any part of rigid and well founded post, carrying electrical conductors		

1	*2*	*3*	*4*
	(i) From RL to 305 mm above RL		
	(a) For existing works	1,675	1,370
	(b) For new words of alteration to existing works	1,905	—
	(ii) From 305 to 4,420 mm for BG 3,200 mm for MG above RL	2,135	19,1905
12.	Minimum height above RL for telegraph, telephone and other such low tension wires crossing a railway	6,100	6,100
Interlocking and Signal Gear			
13.	Maximum height above RL of any part of interlocking or signal gear for a width of 1,600 mm for BG and 1,320 mm for MG Tumnes, through and seem throw garder bridges	64	25
14.	Minimum distance from centre to centre of track		
	(i) For existing works	4,495	3,960
	(ii) For new works and alteration to existing words	4,725	—
15.	Minimum horizontal distance from centre of track to any structure. Height above RL		
	(a) From 0 to 305 mm	1,905	1,370
	(b) From 305 to 1,065 mm for BG and and 685 mm for MG	1,905 to 2,360	1,370 to 1,905
	(c) From 1,065 to 3,355 mm for BG and from 685 to 3,503 mm for MG	2,360	2,135
	(d) From 3,355 to 4,420 mm for BG and from 3,505 to 4,420 for MG	2,360 to 2,135	2,135 to 1,065
	(e) From 4,420 to 5,870 mm for BG	2,135 to 915	
***Safety Refuges**			
16.	Maximum distance apart of refuges in tunnels	100 m	100 m
17.	Maximum distance apart of trolley refuges		
	(a) On bridges with main span of less than 100 m	100 m	100 m
	(b) On bridges with main span of 100 m or more	a refuge over each pier	a refuge over each pier
	(c) On ballasted deck bridges	50 m	50 m
***Station Yard**			
18.	Minimum distance c/c of track		
	(i) For existing words	4,265	4,265
	(ii) For new works or alteration to existing was	4,725	4,420
19.	Maximum gradient in station yard	1 in 400	1 in 400
	(a) Recommended gradient in station yard	1 in 1,200	1 in 1,000
***Platform**			
20.	Horizontal distance from centre of track to face of passenger or goods platform coping	Max. 1,680 Min. 1,670	1,345

(Contd.)

1	2	3	4
21.	Horizontal distance from centre of track to face of any platform wall	Max. 1,905 Min. 1,675	1,345
22.	Height above RL for high passenger platform	Max. 840 Min. 760	405 305
23.	Maximum height above RL for low passenger platform for BG	455	—
24.	Maximum height above RL for good platform	1,065	685
25.	Height above RL for end loading platform for BG	1,295	—
***Buildings and Structure**			
26.	Minimum horizontal distance of any building on a passenger platform from centre of track:		
	(a) From platform level to 305 mm above platform	5,180 to 5,330	4,850 to 5,000
	(b) From 305 mm above platform level to 3,430 mm for above RL for BG and 2,970 mm for MG above RL	5330	5000
	(c) From 3,430 to 4,115 m for BG and 2,970 to 3,200 mm for MG	5,330 to 3,810	5,000 to 4,550
27.	Maximum horizontal distance from centre line of track to pillar, column, isolated structure on passenger platform or any building on goods platform.		
	(a) From platform level to 305 mm above platform level	4,570 to 4,720	3,020 to 3,180
	(b) From 305 mm above platform level to 3,705 above RL for BG and 3,200 mm of MG above RL	4,720	3,180
	(c) From 3,705 to 4,115 mm above	4,720 to 3,180	—
28.	Minimum horizontal distance from centre line of track pillar, column, isolated lamp or similar structure on goods platform.		
	(a) From platform level to 305 mm above platform level	3,960 to 4,110	3,020 to 3,180
	(b) From 305 mm above platform level to 3,980 mm for BG and 3,200 mm of MG above RL	4,110	3,180
	(c) From 3,980 mm above RL to 4,115 mm above RL for BG	4,110 to 3,810	—
29.	Minimum height above rail level for a width of 1,600 mm for BG and 1145 mm for MG on either side of centre of track, of the roof or any continuous covering in passenger station	6,250	5,485
30.	Minimum height above RL for a width of 1,600 mm for BG and 1,145 for MG on either side of centre of track of a signal gantry or FOB in a passenger station	6,250	4,420

1	2	3	4
31.	Minimum horizontal distance centre of track to any structure:		
	(a) From RL to 305 above RL	1,675	1,370
	(b) From 305 to 3355 mm for BG and 3,200 mm for MG	2,135	1,905
	(c) From 3,355 to 4,115 mm for BG and 3,200 to 3,960 mm for MG above RL	2,135 to 1,980	1,905 to 1,145
	(d) From 4,115 to 6,248 mm for BG and 3,960 to 5,485 mm for MG above RL	1,600	1,145
***Points and Crossings**			
32.	Maximum clearance of check rail opposite nose of crossing or wing rail at nose of crossing	48	44
33.	Minimum clearance of check rail opposite nose of crossing and at heel of switch rail and of wing rail at nose of crossing	44	41
34.	Maximum radius of curvature for slip points turnouts of cross-over roads	218 m	116 m
35.	Minimum angle of ordinary crossing	1 in 16	1 in 12
36.	Diamond crossing not to be flatter than	1 in 8 ½	1 in 8 ½
37.	Minimum length of tongue rail	3,660	2,145
38.	Minimum length of train protection, point locking or fouling treadle bar	12,800	12,200
39.	Clearance between toe of open switch and stock rail	Min. 95	Min. 89
40.	Recommended Clearance	Min. 115	Min. 100
Workshop and Running Sheds			
41.	Minimum distance from centre to centre of track	4,570	3,810
42.	Recommended distance from centre to centre of track	5,260	4,570
43.	Minimum clear distance from centre of track to any isolated structure such as a pillar in:		
	(i) Workshops	2,285	1,980
	(ii) Running sheds	2,515	2,135

2 Chapter

A. Iron and Steel

2.1 IMPORTANCE OF IRON AND STEEL IN TRACK

Rails, rail-fastenings and many other track components are made from iron and steel due to their certain fundamental characteristics which enable them to withstand varying stresses and strains which these components are subjected to.

The properties of iron are influenced by heating and cooling. Thus, indiscrete heating and cooling can create problems. Furthermore, the formation of iron alloys with other elements such as carbon, manganese, silicon, etc. too, change the properties of iron. Hence, it is expedient to have a reasonable idea about the metallurgical behaviour of these materials and how they are produced.

2.2 IRON FROM IRON ORE

Traditionally, iron is produced from iron ore. Iron, which is mainly iron oxide, is mixed with carbon (coke) and a flux (lime-stone) and the mixture is heated in a blast furnace. The carbon (coke) burns to produce carbon monoxide (CO) and heat. CO is a highly reducing gas which reduces the iron oxide to iron. The iron melts due to the high temperature generated as the coke burns in the blast of hot air. Other impurities are absorbed by the flux to form a slag which being lighter than iron floats on the surface. The slag also protects the iron from further re-oxidation. The molten iron is tapped from blast furnace and cast into pigs. This is called pig iron and this process of producing iron from iron ore is known as smelting of Iron Ore.

2.3 ELEMENTAL IRON

Pure iron exists at room temperature in a crystalline form known as Alpha Iron. It is the magnetic allotrope of iron, moderately hard and ductile. When heated to 760°C it loses its magnetic property, and at

910°C its crystalline structure is transformed into Gamma iron. The iron undergoes a significant change as a result of this rearrangement of atoms. It becomes softer and more ductile. The process is reversed if the iron is allowed to cool slowly to its original temperature.

2.4 CARBON: ROLE IN IRON AND STEEL

As a liquid metal from the blast furnace solidifies, it takes up the Gamma form and in this state it can take up to 1.7% solid carbon into solution. The iron in this form is called AUSTENITE. If there is excess of carbon in the liquid, it combines with iron to form a compound called CEMENTITE (Fe_3 C). With carbon level of 3% and above and dependent upon the cooling rate, free GRAPHITE – also called GREY IRON – will be precipitated from solidifying liquid at the same time as the formation of austenite. On further cooling, the austenite itself transforms into Alpha Iron (a low carbon content phase) called FERRITE and a lamellar structure called PEARLITE. PEARLITE is composed of alternating layers of FERRITE and CEMENTITE. When final cooling has been achieved and dependent upon cooling rate and presence of other elements particularly silicon, pig iron can have a structure of PEARLITE and GRAPHITE called GREY IRON or of PEARLITE and CEMENTITE called WHITE IRON, or of PEARLITE, GRAPHITE and CEMENTITE, called MOTTLED IRON.

Blast furnace pig iron is generally not suitable for the production of castings. It is further re-melted and refined to obtain steel.

2.5 STEEL FOR RAILS

Steel is an alloy of the element iron with a very small percentage of carbon and other elements such as manganese. Steel is made from pig iron by heating it once again till it melts. Then oxygen is blown through the melt which combines with some of the carbon to reduce the proportion of this element in the alloy. To produce steel the carbon content must be brought below the percentage at which free graphite will be formed in austenitic phase (i.e. less than 3%).

With a carbon content as high as 2%, the steel consists of granules of cementite in a matrix of pearlite. As the carbon content decreases to 0.8%, the proportion of free cementite in the alloy reduces until at 0.8%, the steel – if slowly cooled through the austentic-pearlite transformation – consists entirely of pearlite. Below this carbon content, the steel takes the form of a mixture of ferrite and granules of pearlite, considered ideal for rail steel.

Normal and wear resisting rail steel of grade A and B contain 0.45% to 0.8% by weight of carbon. Hence, the rail steels are usually referred to as pearlite steel with medium to high carbon content.

2.6 CONVENTIONAL RAIL MAKING

After conversion from pig iron to steel, the steel is traditionally in the form of an ingot, formed by pouring the molten steel into mould and allowing it to cool slowly. In producing a rail, the steel passes through two further processes. In the first, the ingot is reheated until it is white hot and then rolled out into a strip having a rectangular cross section and about three to four times as long as the original ingot. This strip is then cut into sections called blooms, which are either further processed immediately or allowed to cool for storage. The final process involves heating again the bloom to white heat and further rolling it through a series of specially shaped rollers to produce the final rail section. A bloom which started off around 4 metre long will roll out at least 36 m of finished rail.

2.7 MODERN STEEL MAKING PROCESS: CONCAST ROUTE

In the modern steel making process through concast route, the newly smelted iron from the blast furnace is taken in the liquid form to the convertor by employing "ladles" (heavy steel cylinders with refractory lining). The convertors through a continuous concast process, convert the liquid steel directly into blooms. The process eliminates energy loss, which normally occurs in the conventional steel making and thus is quite cost effective, apart from its other technical advantages. Such a process route for rail production has been adopted in a modern rail rolling mill in India, put up by Jindal Steel & Power Ltd.

2.8 CONTINUOUS CASTING PREVENTS PIPING

Piping, a common defect in conventionally produced rails, gets completely eliminated in the rails produced through concast route. Piping occurs because when the liquid steel is poured into an ingot mould, cooling and solidification sets in immediately. The parts of the ingot which cool first are the sides which are in contact with cold walls of the mould and even more so the free surface at the top of the mould which is exposed to the natural atmosphere. Quite quickly a skin of solid steel begins to form at these surfaces and as soon as this happens, the exterior form and dimensions of the ingot are determined. However, as the molten steel continues to cool, it shrinks. Since the centre of the ingot cools and solidifies last, liquid steel is constantly being drained towards the colder outward region, until the originally level top surface of the ingot is sucked inwards in the shape of solid vortex and in the middle of this surface a narrow tube or pipe leads down into the upper part of the ingot. As a result of this, nearly 10 percent of upper portion of ingot is not fit for rolling; hence, it is cut off and fed back into the stock of refined steel. Even so sometimes the vortex extends further down the ingot than usual and when this happens it persists through the bloom and rail rolling process to finish up as a very narrow pipe shaped void in the body of the rail.

In the continuous cast process there is no ingot and thus no piping can occur. A potential rail defect is therefore completely eliminated.

2.9 SIGNIFICANCE OF ROLLING PROCESS IN RAIL MAKING

Rolling process in the making of rails imparts many beneficial effects to the properties of rail steel. During rolling, the grain structure of steel is refined and the oriented cast structure (harmful to steel) is destroyed. The metal becomes more homogeneous, diffusion of segregated alloys is promoted and undesirable brittle films are broken up. The cracks, blow holes, porosity (provided the metal around them has not got oxidized) get welded. The toughness and ductility of steel gets enhanced. During rolling, steel properties acquire some direction bias in as much as it has better properties along the rolling direction.

2.10 EFFECT OF OTHER CONSTITUENTS OF RAIL STEEL

Normal grade steel has the following chemical composition:

Element	*Percentage*
Carbon	0.45–0.60
Silicon	0.05–0.35
Manganese	0.95–1.25
Phosphorous	0.04 max.
Sulphur	0.04 max.

The implication of carbon in rail steel has already been discussed.

Phosphorous and Sulphur are present as impurities mainly because they form a proportion of the naturally occurring iron ore and it is difficult to eliminate them altogether in the smelting and refining process.

Silicon is also present in most steels obtained from the refractory materials used in the lining of blast furnace and steel convertor. Siliceous materials are also generally present in most of iron ores. Generally, silicon at controlled level is beneficial to the properties of steel and is added deliberately to liquid steel prior to making ingots or continuous castings to remove excess oxygen from steel. This process is called killing of the steel and is most essential. The other common element used for killing steel is aluminium. But silicon is preferred for rail steel production, as oxides of silicon which solidify as inclusions in the solidified steel are less harmful than aluminium derivatives during subsequent service life of rails.

In contrast, sulphur is a highly injurious impurity. At high temperatures, involved in steel making, sulphur combines with iron to form iron sulphide (FeS). This is soluble in molten steel, but is incapable of blending with steel in the solid state. Consequently, as the molten steel solidifies, FeS is ejected from the solid part of the ingot and is deposited as a thin layer along the grain boundaries of steel renderning it useless. To prevent the formation of FeS, manganese (Mn) is added to the steel at the conversion stage. The sulphur manages to form Manganese sulfide, most of it floats off the surface of the molten steel in the slag. The remaining MnS forms independent globules which get distributed throughout the steel during solidification. Unlike Fes, MnS, is harmless.

Manganese readily combines in solution with steel and its derivatives; so, it has no disadvantageous effect on the properties of steel. On the contrary, it is advantageous as it increases the hardness of steel thereby improving its strength and toughness.

2.11 NITROGEN AND HYDROGEN

There are two other impurities in steel making. Both these impurities make the steel brittle but in different ways. The nitrogen gas, which forms four-fifths of the atmosphere, tends to be absorbed by molten steel during the manufacturing process. This was particularly so when the steel was made in Bessemer Convertor, because the blast used was air. In the open hearth or other steel making processes where pure oxygen is used for the blast, the problem of nitrogen gas impurity in steel does not exists.

Nitrogen dissolves in the liquid steel and because of its small atomic size, the nitrogen atoms are located between the iron and carbon atoms, making up the bulk of the steel. As such, it increases the strength of steel, but there is corresponding reduction in ductility. This is responsible for the reduced carbon level specified for Acid Bessemer rail steel (0.4 to 0.5%) compared to Open Hearth rail steel (0.5 to 0.6%). The reduced carbon level in Acid Bessemer steel is compensated by the nitrogen content.

Water (either as vapour or chemically combined as for example in rust) can come in contact with steel at various times during the purification process. The hydrogen formed by the break down of water during steel making is in the form of atomic hydrogen. The hydrogen atoms are the smallest elemental atoms, but they are interstitial; so, they move freely by diffusion within the liquid and solidified steel. Solidified steel contains many cavities (on microscopic and sub microscopic level) and the hydrogen atoms diffuse preferentially to those sites forming molecular hydrogen. As more and more hydrogen molecules gather in the cavities, they exert an increasing pressure on the metal surrounding the cavities. If sufficient hydrogen is present in the steel, the build-up of the pressure causes small fracture within the steel. These fractures are known as hydrogen flakes or shatter cracks, which, under the influence of various forces acting on the rail in service, initiate fatigue cracks. These cracks grow and finally cause a brittle fracture of the rail. This type of failure with its characteristic fracture feature is known as a "Tache ovale'. Higher strength steels are more prone to hydrogen embrittlement than low strength steels. Therefore, the higher strength wear resistant rail steel requires more careful control procedures to reduce the risk of fractures. Although modern steel making techniques—combined with controlled cooling of the finished products—reduce the hydrogen content of modern rails to 1-2 parts per million, this defect still remains. Analytically seen, it is manufacturing defect, the track engineers should be even wary of.

2.12 CARELESS HEATING AND COOLING OF RAIL STEEL

One of the most important and fascinating features of the behaviour of steel is that if a piece of ordinary carbon steel is made red hot and then immersed in water, it becomes extremely hard.

The process of cooling a hot metal quickly is called quenching. It may be achieved with cold water, oil, by a blast of cold air and in several other methods. In metallurgical terms, it can be explained that steel above a temperature of 910°C consists of austenite based on the crystalline structure known as Gamma iron and that it changes to ferrite and/or pearlite based on the alpha iron as it cools slowly to normal temperature. When it is rapidly quenched, the iron crystals still change from the Gamma form to the alpha form, but the carbon atoms do not have sufficient time to combine with iron atoms as cementite; hence, the formation of pearlite is no longer possible. The surplus carbon atoms become trapped in the crystalline structure and distort it. The amount of the type of distortion depends on the proportion of carbon in the steel, but in all cases the resultant steel becomes harder than either pearlite or austenite. If sufficient carbon is present in the alloy, extremely hard material is produced known as MARTENSITE. Under the microscope it looks like a uniform mass of needle-shaped crystals, but in fact it is disc-shaped.

The problem with martensite is that it is not only very hard, but also very brittle. In the making of steel tools etc., the finished product can be made less brittle by tempering, which involves reheating the steel slightly to induce the carbon atoms to rearrange themselves. During tempering, the martensitic structure changes towards to equilibrium structure of ferrite and cementite.

Rail steel contains sufficient carbon for a fully martensitic structure to develop if it is cooled rapidly enough. However in the manufacturing of rails, the objective throughout is to achieve a fully pearlitic structure. It is an important part of the rail-maker's skill to ensure that at each stage in the processing the product is allowed to cool slowly enough to ensure a return to the desired crystalline structure.

When in track, the rails sometimes have to be made very hot (e.g. for welding) and sometimes become very hot by accident (as in wheel burns). In such situations, if the rail gets hot enough to change to austenitic structure, and then is carelessly allowed to cool quickly, there is every likelihood of the formation of martensite in place of pearlite/ferrite, in the heat-affected zones. This will soon crack under traffic, leading to a complete rail fracture. This can occur more often with wheel burns, where the volume of steel affected is very small in comparison with the rest of the rail. In alumina-thermic welding, it can be prevented by suitable measures to control the rate of cooling of weld.

2.13 AUSTENITIC MANGANESE STEEL (AMS) FOR CROSSINGS

Austenitic manganese steel (AMS) is produced by adding a comparatively large dose (around 12.5%) of manganese to high carbon steel (i.e. steel containing about 1.2% carbon) during the steel making process. This steel which possesses austenitic structural properties at normal ambient temperature is extremely tough and shock resistant. In the 'raw' state AMS is relatively soft (Brinell hardness is 200, slightly softer than normal grade rail steel) but in use it becomes extremely hard very quickly (BH of 400 to 500). AMS is extensively used by railways throughout the world in the form of castings to make monoblock crossings.

B. Rails

2.14 FUNCTION OF A RAIL

The main function of the rail is to offer the rigid tyred wheel rolling on it a hard and unyielding surface. The other prime functions are to act as beam and transmit the wheel loads to the sleepers, and act with the tyres in steering the vehicles in the desired direction.

Besides the above, the secondary functions of the rail are to convey return traction current and to carry electric current for signaling purposes in track circuited areas.

2.15 REQUIREMENT OF RAIL SECTION

The basic principle for the design of rail section is to have optimum weight of steel, consistent with maximum possible stiffness, strength and durability to provide continuous level surface and adequate lateral guidance for the wheels rolling on it.

2.15.1 Optimum Weight

A rail section is designed for normal weight, which provides for the most efficient distribution of metal in the various components, each of which is designed to perform its function. The main components of the rail are:

1. *Head*: The depth of the rail head is kept adequate enough to bear the wear during the service of the rail.
2. *Web*: The web should be sufficiently thick to bear the load coming on it and allow for loss due to corrosion.
3. *Foot*: The foot should be so wide that the rail is stable against overturning and the load on it is distributed over a large area of the sleeper. Its thickness should give the rail adequate vertical and lateral stiffness and allow for loss due to corrosion.

2.15.2 Stiffness

The moment of inertia of the rail section is the true index of its stiffness. An efficient and economical design provides for the maximum moment of inertia per unit weight of rail consistent with all other factors. Vertical stiffness of the rail should be adequate to enable the load to be transmitted to several sleepers underneath. The lateral stiffness should be sufficient to enable the rail to withstand the lateral forces it is subjected to, under the moving traffic loads.

2.15.3 Strength

The strength of the rail section is reflected in the modulus of its section. The section modulus of the rail and that of the fishplates should be adequate to keep the rail and fishplate stresses within the permissible limits. An efficient rail design provides the highest possible ratio of the section modulus of the fishplate to the rail. For a well-balanced design, the disparity between the tension and the compression section modulus values of the rail and a pair of fishplates should be minimum.

2.15.4 Durability

Some of the factors having a direct or indirect bearing on the design, and affect the service life of the rail are:

1. *Wear*: The head thickness of the rail should allow adequate margin for vertical wear. The rail table and gauge face should have hard wearing surfaces to give longer rail life.
2. *Rail end batter*: Batter is caused by the continuous hammering action of the wheels at rail ends. The amount of batter depends upon the width and hardness of the rail head, stiffness of the joint, type of joint support, and quality of maintenance of joints.
3. *Hogging*: Vertical stiffness of the rail section plays an important role in reducing hogging of rails.

In addition, an efficient rail section also provides for: (a) certain wearing out of the finishing planes in service, (b) ease of rolling and cooling in rail mills, (c) weldability into long welded rails.

Some of the requirements of rail section conflict with each other. A compromise has, therefore, to be struck to evolve an integrated and economic design.

2.16 TYPES OF RAILS

For a long time, double-headed and bull-headed rails were popular in the world railway systems (see Fig. 2.1).

As rails wear mainly on the head, it was thought that double-headed rail could be inverted after one side head had worn out. However, it was found that the old foot had also worn out at the sleeper supports, and did not produce good running after it was inverted to become the head. Bull-headed rails with the head appreciably larger than the foot were then introduced. These rails maintained better alignment but were expensive.

About 70 years ago, flat-footed rails were introduced. The performance of these rails on the track has been found to be superior to the other two types for the same weight. Flat-footed rails have more lateral strength, the number of fastenings are few and their tendency to get loose is less. Presently, these rails are being used all over the world.

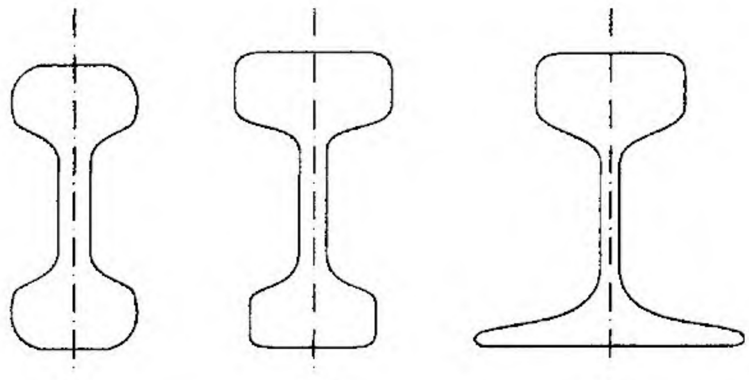


Fig. 2.1 Type of rails: (a) double-headed; (b) bull-headed; (c) flat-footed

2.16.1 Nominal Weight of Rails

The evolution of the rail section can be linked to its normal weight in pound per yard or kilogram per meter. In the early days, the axle loads were small and the rails were light. As the traffic density increased axles loads were increased and heavier rails were introduced. Heavier rails are also being introduced on high-speed routes, as it has been found that track geometry can be better maintained with them.

2.17 STANDARD RAIL SECTION—MAIN FEATURES

The rail section has been standardized for all main line railways as the flat bottom (FB) rail. Fig. 2.2 shows a typical cross section of a wheelset on a railway track, with the names given to the different components. The reason for the shapes of the various parts of the rail are discussed in the paragraphs that follow, with particular reference to 60 kg U.I.C. rail [Fig. 2.3(c)].

2.17.1 Rail Head

The shape of the railhead is a combination of curves of three radii varying from quite sharp to very flat. These are designed to fit with the shape of the wheel tyre to form a combination which will both have good riding qualities and minimize contact stresses. One of the features of a well matched combination of wheel tyre and rail head is that, when the axis of the wheelset coincides with the longitudinal axis of the track and the rail is at its correct inclination, the point of contact between the two is very close to the centre of the rail, since it minimizes the twisting effect which an eccentrically applied wheel load will have on the rail. By keeping the wheel/rail contact area away from the gauge corner, shelling and fatigue damage is reduced. Side-wear is also reduced. It also implies a practical limit to the overall width of the rail head, which in the case of 60 kg. U.I.C. rail is 74.3 mm. The rail head has sides which slope outwards at 1:20. This is to compensate for 1:20 inwards slope of the rail. This makes it simpler to control gauge and also ensures that when side wear takes place, the associated gauge widening is minimized.

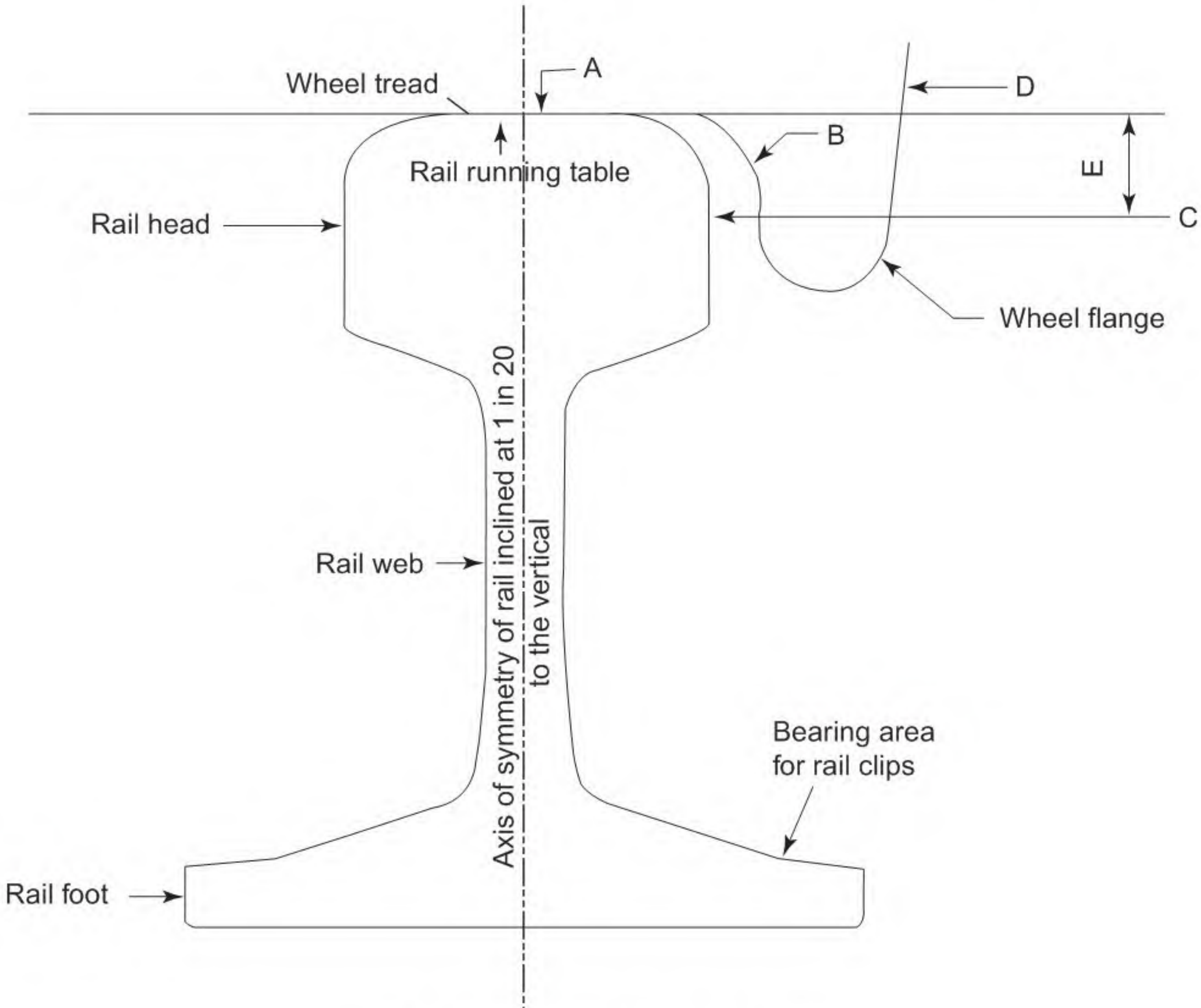


Fig. 2.2 Wheel set on rail

Notes

A. Point of contact between wheel and rail
B. Flange clearance 13 mm approximately
C. Track gauge measured between vertical inner faces of rail 1676 mm for BG
D. Back to back gauge measured between vertical inner faces of wheel types
E. Plane of measurement of gauge 16 mm below plane of rail running table

Even when the rail are welded into CWR, it is often necessary to join them together by fishplates. The lower faces of the head and the inner part of the upper faces of the foot are so designed as to maximize the efficiency of the fishplates in transmitting the longitudinal forces associated with the bending of the rail end under wheel loads, and to allow wear on the mating surfaces to be taken up by retightening of the fishbolts. The design of the fishing surfaces also ensures alignment of the rail ends without any contact between the rail web and the fishplates.

2.17.2 Rail Web

The thick, sturdy web of the rail is designed to give the rail adequate shear strength to guard against failure, particularly around fishbolt holes, even under impact loading over dipped joints. Another feature to note here is the generous radii of the transitions between the head and the web and between web and the foot. These fillet radii, as they are called are necessary to combat the curving forces, which may be as high as 35% of the axle load. The obliquity of the direction of application of the resultant wheel load and the asymmetry of the point of application of resultant wheel loads results in the development of the secondary stresses within the rail itself, particularly at the fillets between the head, web and foot. The comparatively large fillets radii are provided to keep down these secondary stresses to avert the possibility of fatigue failure.

2.17.3 Rail Foot

The rail foot is kept broad enough to give stability to the rail against overturning and provide ample space for the clips to hold the rails effectively. The rail base is made flat from underneath to distribute the oncoming wheel loads on the sleepers properly. The much flatter slope of the surface towards the outer edge of the foot is provided as a table upon which the rail clips may rest. The surface is kept plane rather than curved to enable precise control over deflection of the clip, and to minimize contact stresses between clip and the rail.

2.18 RAIL SECTIONS ON INDIAN RAILWAYS

The following rail sections have been standardized on the Indian Railways for the BG, MG and NG system (Table 2.1 below).

Table 2.1 Rail Sections

Broad Gauge	*Meter Gauge and Narrow Gauge*
60 kg/metre (UIC section)	90 lbs/yard (RBS)
52 kg/metre (IRS section)	75 lbs/yard (RBS)
90 lbs/yard (RBS section)	60 lbs/yard (RBS)
	50 lbs/yard (RBS)

Figures 2.3 (a) to (c) and Tables 2.3 and 2.4 give the dimensions and properties of these rail sections.

2.18.1 Evolution of Rail Section on Indian Railways

Rail section from 50 to 90 lb/yard are based on the Revised British Sections (RBS) except that with the introduction of metric systems, their dimensions and weight in IRS specification have been indicated in metre equivalents up to two decimal places.

Prior to 1957, the 90 lb/yard rails with N + 3 (N is the length of rail in yards) sleeper density was considered adequate for BG main lines for steam locomotives up to 22.9 tonnes axle loads at 96 kmph for an annual traffic density of 10 GMT.

In 1959, the 52 kg/m rail section was designed for 128 kmph and annual traffic density up to about 20 GMT.

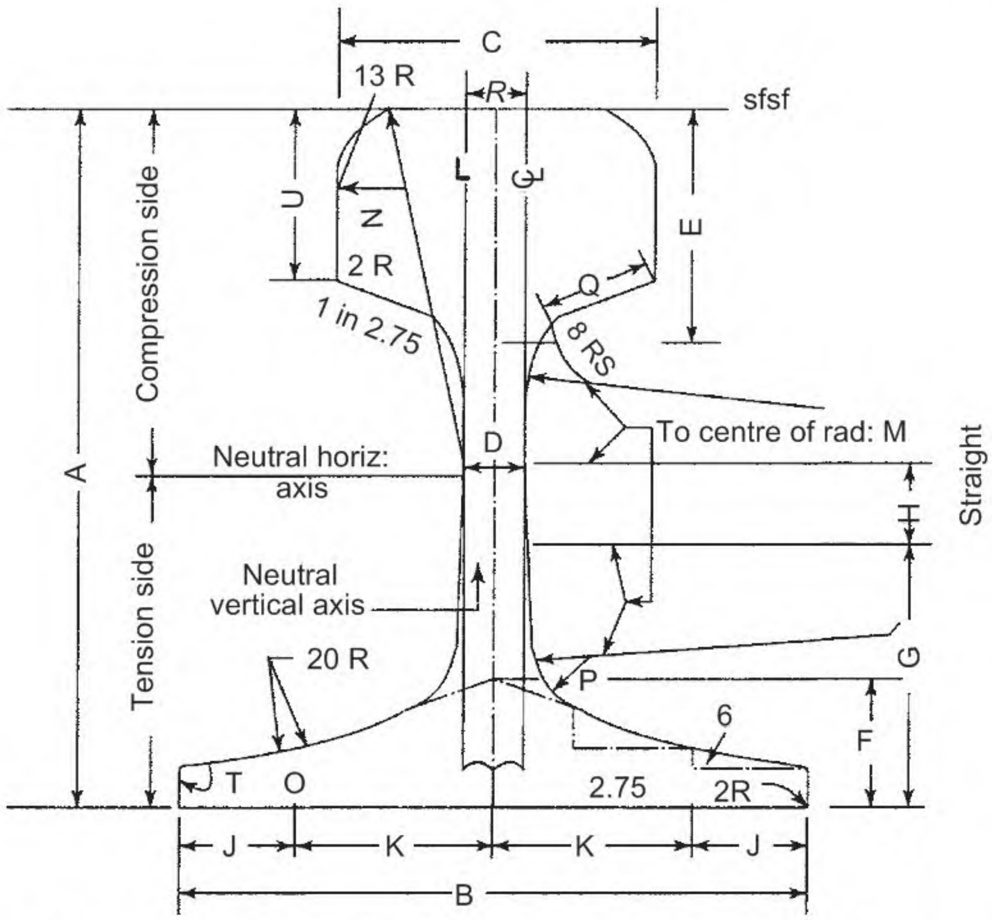


Fig. 2.3(a) I.R.S 52 kg F.F. rail section—key to table of dimensions

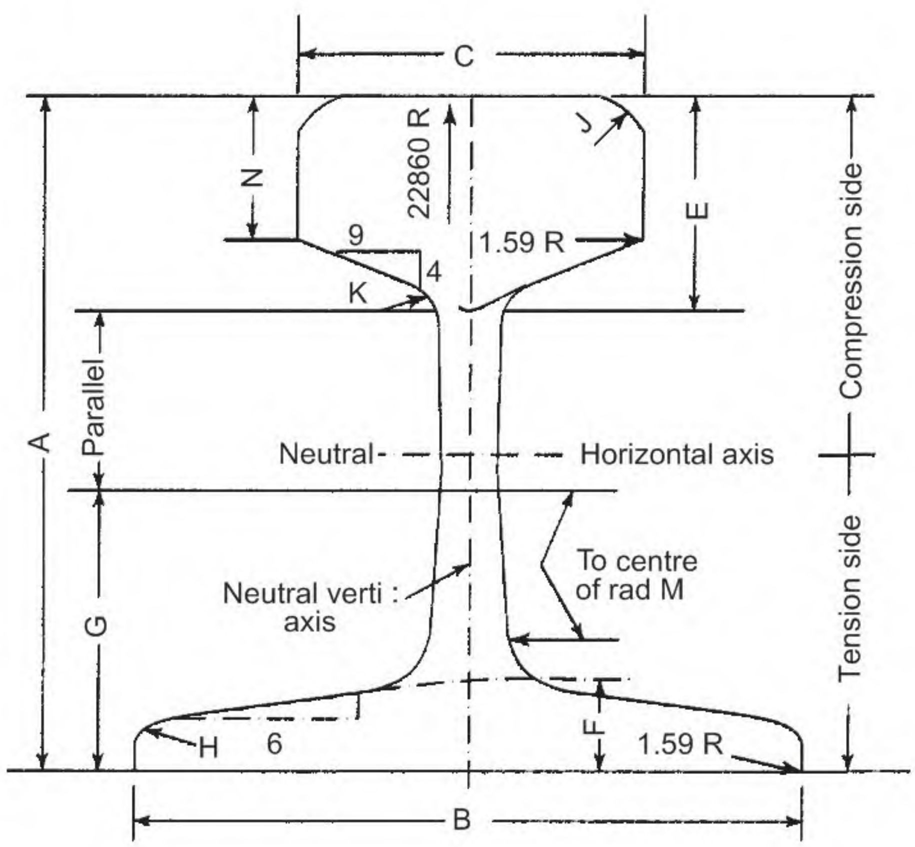


Fig. 2.3(b) British Standard F.F. rail section—key to table of dimensions

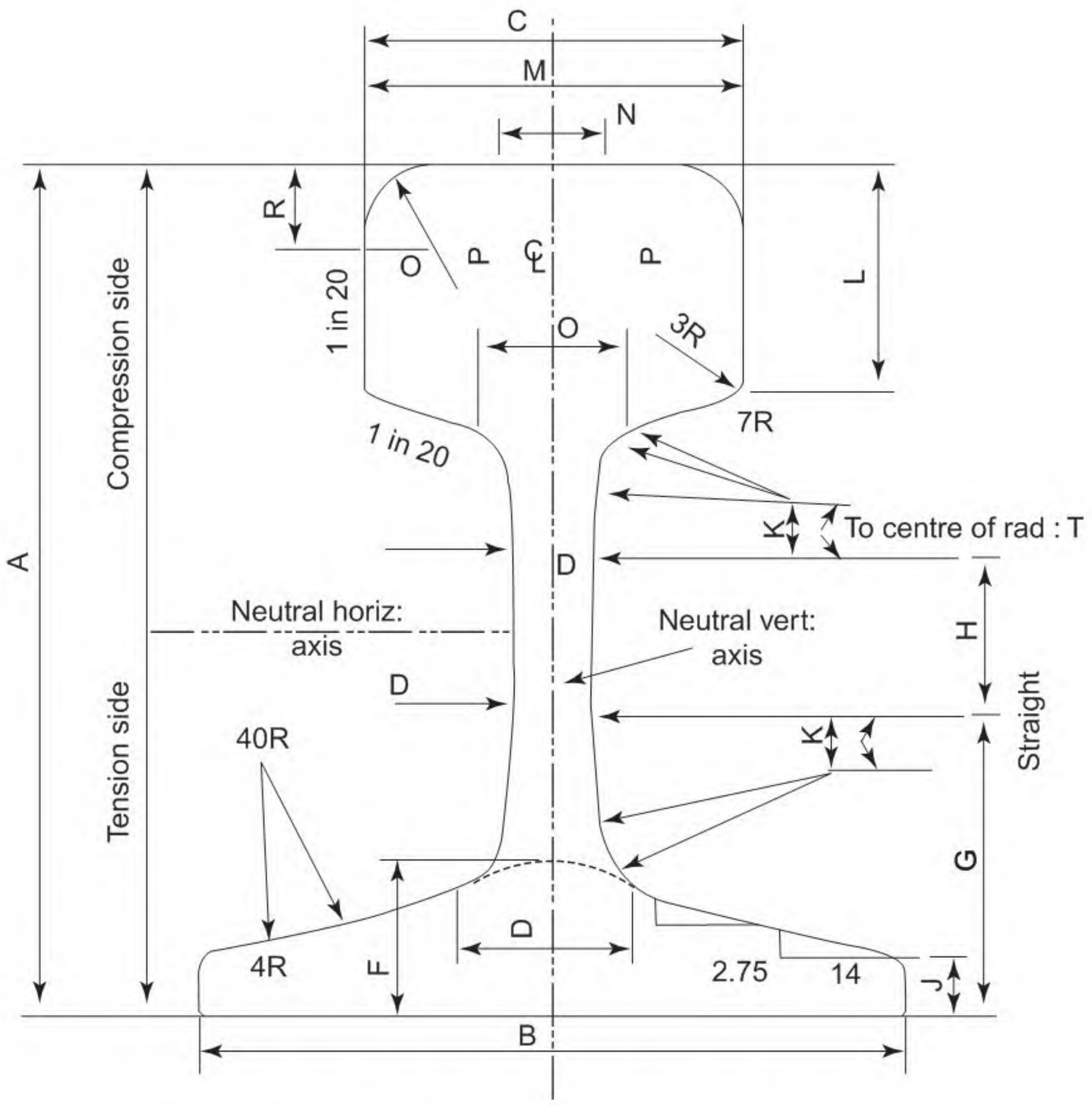


Fig. 2.3(c) UIC 60 kg F.F. rail section—key to table of dimensions

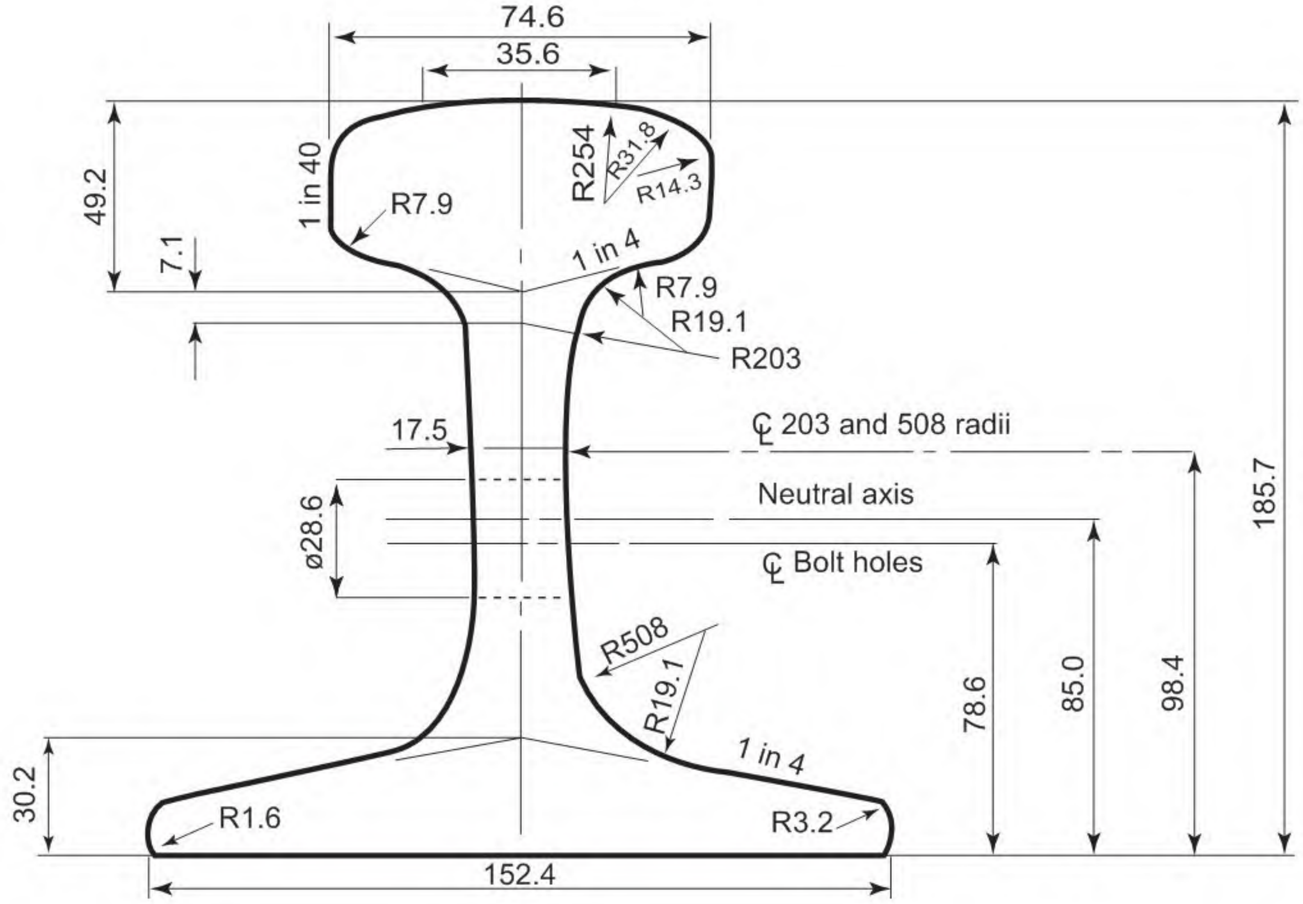
The 52 kg/m rail section is an Indian Railways design. This section, besides being heavier, has many improved features over the 90 lb rail section, such as thicker head for greater wear, greater height for more stiffness, and steeper equal fishing planes for the even wear of fishing surfaces. Foot width of the 52 kg/m rail section has been kept almost same as that of the 90 lb/yd section for easy rail renewal on old sleepers. For high-speeded lines and for lines with heavy traffic density, the UIC standard 60 kg/m section has been adopted. Having a foot-width greater than the 52 kg/m section, it can be used only sleepers designed for this rail section.

2.18.2 Rails for Dedicated Freight Corridors (DFC) for Indian Railways

There is a proposal to use 68 kg rail section on Dedicated Freight Corridors (DFC). Details of one such rail section and its mechanical/chemical properties are given in Fig. 2.3 (d).

68 KG RAIL

RT 19



MECHANICAL PROPERTIES			
Area of Head	3125 mm^2	**Horizontal Axis**	
Area of Web	2335 mm^2	Second Moment of Area	39.4×10^6 mm^4
Area of Foot	3142 mm^2	Section Modulus Head	391.7×10^3 mm^3
Total Area	8602 mm^2	Section Modulus Foot	463.8×10^3 mm^3
Standard Lengths	**12.5m**	**Vertical Axis**	
Calculated Mass	**67.5 kg/m**	Second Moment of Area	6.02×10^6 mm^4

TYPICAL MECHANICAL PROPERTIES (Minimum)

0.2% Proof Stress MPa	Tensile Strength MPa	% Elongation Gauge length = 5.65 $\sqrt{S_0}$	Surface Hardness H.B.
420	880	8	260

CHEMICAL COMPOSITION (%) Ladle Analysis

Carbon	Silicon	Manganese	Phosphorus	Sulphur
0.65–0.82	0.15–0.58	0.70–1.25	0.025 max	0.01–0.025

Figure 2.3(d) 68 kg rail as adopted on Australian heavy haul railway

2.19 MARKING ON RAILS

Each rail has certain marking on its web and in case of rail failures, the data on the rail are included in the failure report. These markings are generally in the following form:

60 kg, 880, HSL, X–97–0 →

This marking indicates that it is a 60 kg/m rail, made of grade 880 steel, manufactured by Hindustan Steel Ltd. Bhilai, in October 1997, employing the open hearth basic process of manufacturing steel. The arrow indicates the direction of top of the ingot from which the rail was rolled.

The first rail rolled from the top side of the ingot has star marked on one side of the rail, about 25 mm from the rail end. Each rail also has the cast number distinctly stamped on one side, in the lower portion of the head, at about 150 mm from each end.

Each rail, produced through continuous cast route will have hot stamping on one side of the web giving information about:

(i) The number of the cast from which the rail has been rolled with letter 'C' and
(ii) The position of the rail in relation to the top of the bloom or continuous cast strand.

2.19.1 Colour Code

Colour Code of Accepted Rails to Indian Railways

Sl. No.	Grade	Colour Code
1.	880	Only common lengthwise colour code and paint on WEB surface.
2.	1000	Besides common lengthwise colour code, yellow paint on both sides of web surface for a distance of 500 mm from each end.
3.	T-18/69	In addition to common lengthwise colour code, red paint on both sides of WEB surface for a distance of 1000 mm from each end.
Colour Code of Rails for Industrial Use		
4.	Grade-I	Apart from common lengthwise colour, green paint on end faces of flange and on both sides of flange for a distance of 500 mm from each end.
5.	Grade-II	In addition to common lengthwise colour code, blue paint on end faces of flange and on both sides of flange for a distance of 500 mm from each end.

Common Lengthwise Colour Code

1. Yellow paint on each end face on WEB region indicates – 13 m length
2. Blue paint on each end face on WEB region indicates – 12 m length
3. White paint on each end face on WEB region indicates – 11 m length
4. Green Paint on each end face on WEB region indicates – 9 m length

Table 2.2 Dimensions

Rail section	*Weight per metre*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	*S*	*T*	*U*
	kg	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*	*mm*
52 kg	51.89	156	136	67	15.5	51	29	60	19	24	44	305	381	80	13	13	17.5	18	22.5	5	38.82

Properties

Rail section	*Weight per metre*	*Area of section*	*Moment of inertia*		*Section modulus (horizontal axis)*		*Max. distance from neutral horizontal axis*	
side			*Horizontal axis*	*Vertical axis*	*For compression*	*For tension*	*Compression side*	*Tension*
	kg	*cm²*	*cm⁴*	*cm⁴*	*cm³*	*cm³*	*mm*	*mm*
52 kg	51.89	66.15	2,158	363	268.50	285.50	80.41	75.59

Table 2.3 Dimensions

B.S.R.S.	Weight per metre	A	B	C	D	E	F	G	H	J	K	L	M	N
	kg	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
50R	24.80	104.78	100.01	52.39	9.92	32.94	15.08	43.66	3.97	9.53	5.56	8.73	228.60	24.21
60R	29.76	114.30	109.54	57.15	11.11	35.72	16.67	47.63	3.97	9.53	5.56	8.73	228.60	26.20
75R	37.18	128.59	122.24	61.91	13.10	39.69	16.65	53.98	4.76	11.11	6.35	9.53	304.80	29.37
90R	44.61	142.88	136.53	66.68	13.89	43.66	20.64	58.53	4.76	12.70	9.53	9.53	381.00	32.55

Properties

B.S.R.S.	Weight per metre	Area of section	Moment of inertia		Section modulus (horizontal axis)		Max. distance from neutral horizontal axis	
			Horizontal axis	Vertical axis	For compression	For tension	Compression side	Tension side
	kg	cm^2	cm^4	cm^4	cm^3	cm^3	mm	mm
50R	24.80	91.68	476.17	106.97	89.98	93.08	53.59	51.18
60R	29.76	36.00	576.79	145.68	115.36	121.92	58.67	55.63
75R	37.13	47.37	1,055.56	230.18	159.28	169.44	66.29	62.30
90R	44.61	56.95	1,600.00	320.81	213.85	235.65	74.93	67.95

Table 2.4 Dimensions

Rail section	Weight per metre	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T
		mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
UIC 60 kg	60.34	172	150	74.3	16.5	51	31.5	60.25	32	11.5	19.5	37.5	72	21	33	300	80	14.3	35	120

Properties

Rail section	Weight per metre	Area of section	Moment of inertia		Section modulus (horizontal axis)		Max. distance from neutral horizontal axis	
			Horizontal axis	Vertical axis	For compression	For tension	Compression side	Tension side
	kg	cm^2	cm^4	cm^4	cm^3	cm^3	mm	mm
UIC 60 kg	60.34	76.86	3055	512.9	335.5	377.4	91.05	80.95

Note: The dimension and properties of the UIC 60 kg rail section have been adopted from UIC code 861-3 (3rd edition).

2.20 RAIL LENGTH

The length of rail depends upon the maximum length-size that manufacturers can produce at a reasonable cost. Longer rail lengths require expensive arrangements at the rail mills for their controlled cooling, stacking and handling. Another limiting factor is the problem of transport. Traditionally, for Indian Railways, the rails are being supplied by the rail mills in standard lengths of 13 m to 12 m for BG and MG respectively.

Longer rail lengths have the advantage of requiring less number of rail welds. Rail weld is a known source of weakness in track structure and is therefore to be avoided to the extent possible. The rolling of rails in longer lengths is therefore encouraged. The new rail rolling mill set up by Jindal Steel & Power Ltd (JSPL) in India, is rolling rails to a length of 120 m each. JSPL has put up an integrated flash-butt welding plant to weld the rolled rails into longer panels of up to 480m. Bhilai rail rolling mill will also be rolling long rails of 65 m each. They will be further welded into longer rail panels in a flash-butt welding plant located near by.

For the transport of long rail panels, special rail transport trains are being deployed. These trains will transport long rail panels to the rail laying sites at a speed of over 80 km/hr, cutting out zonal flash-butt welding plants from the transport circuit. This system will, not only save considerable cost but will also reduce damage, presently occurring in handling and transport of rails.

A rail piece of less than the standard length used in the track for closing a rail gap, is called "rail closure". For smooth running it is essential that:

1. Any rail closure likely to remain permanently in the track is longer than 5.5 m.
2. Closures should be located neither near to each other nor in proximity to:
   (a) Junctions of different types of rails and/or sleepers;
   (b) Bridges, level crossings and ash pits.

2.21 RAIL SPECIFICATIONS

Rails for use in track have to comply with certain rigid specifications to ensure the safety of trains running over them at high speed. Among other things, rail specification lays down the quality of dimensional tolerance and the acceptance tests that are required to be carried out at the rolling mills.

Important provisions of the Indian Railway specifications for flat bottom rails serial No. T-12-96 (updated) are presented in the following sections.

2.21.1 Quality of Rail Steel

The steel rails on analysis shall show that it conforms to the chemical composition and mechanical properties to the limits given in Table 2.5.

Tolerances in Sectional Dimensions (For First Quality Rails)

1. Height of the rails +0.8 mm
   −0.4 mm

Table 2.5

Grade	Chemical composition (percentage)						Mechanical		Properties	
	C	Mn	Sl	S (Max.)	P (Max.)	Al (Max.)	Mo (Max.)	Hydrogen content in liquid steel (Max.)	UTS MPA minimum	Elongation % on gauge length gth= 5.65 √ minimum	Running surface hardness (BHN)
880	0. 80–0.80	0. 80–1.30	0.10–0.50	0.035 *	0.035 *	0.02	–	3.0 ppm	80	10.0	Min. 260 **
1,000	0.60–0.80	0.80–1.30	0.10–0.50	0.035 *	0.035 *	0.02	0.25	3.0 ppm	1,000	10.0	300–350 **
1,080	0.70–0.82	0.75–1.05	0.15–0.30	0.035	0.035	0.02	–	3.0 ppm	1,080	10.0	340–390

So = Cross sectional area of tensile test piece in mm^2.

* 0.040 maximum for finished rail.

** Desirable values.

Note: Any other micro alloying element can be added in grade 1000 rails with the purchaser.

2	Width of the head	±0.5 mm (measured 14 mm below the rail top)
3.	Width of flange	±1.0 mm for less than 60 kg
		+1.2 mm, −1.0 mm } for 60 kg and above
4.	Thickness of web	+1.0 mm −0.5 mm
5.	Verticality/Asymmetry	±1.2 mm
6.	Flange	The base of the rail shall be true and flat; But a slight concavity not exceeding 0.40 mm can be permitted.
7.	Fishing surfaces	Deviation from the standard template not to exceed (a) 1.20 mm at a web (b) 0.2 mm at the fishing surfaces.

Tolerances in Sectional Dimensions (For Second Quality Rails)

Overall height of rails	:	+1.60 mm	
	:	– 0.80 mm	
Width of head	:	+1.20 mm	This will be measured 14 mm
		– 0.60	below the rail top.
Width of flange	:	±1.0 mm	For sections less than 60Kg/m
	:	+ 1.2 mm	For sections
	:	– 1.0 mm	60Kg/m and above
Thickness of web	:	+ 1.60 mm	This will be
	:	– 0.60 mm	measured at the point of minimum thickness.
Verticality/Asymmetry	:	±1.2 mm	
Flange	:	The base of the rail shall be true and flat, but a slight concavity not exceeding 0.40 mm shall be permissible	
Fishing surface	:	The standard template for rail fishing surface shall not stand away from the contour of web by more than 1.20 mm and the clearance at the fishing surfaces shall not exceed 0.2 mm at any point.	

Note: (i) These rails shall be used only on loop lines/private sidings and shall be of length equal to or less than 13 m.

(ii) One hole of 6 mm dia. champhered at both ends should be drilled at the centre length of the rail and at the middle of the web for clear identification of such rails.

(iii) These rails should also be painted with orange colour on both sides of the web for a distance of 1 metre from each end, for easy identification.

(iv) These rails should be loaded in one wagon and should not be mixed with other rails for dispatch.

8.	Length of rails	The manufacturers are permitted to supply pairs of short

		lengths (not less than 8.0 m length in multiples of 1.0 m of rails), up to 10% weight. Tolerances in length of rails shall be + 20.0 mm – 10.0 mm
9.	End squareness	The deviation from square in both horizontal and vertical deviation shall not exceed 0.6 mm on a length of 200 mm
10.	Straightness	Maximum deviation measured on a straight edge of 1.5 m shall not exceed 0.7 mm.
11.	End straightness	Rails will be classified into A and B categories as per the tolerances given in table below.

	Straightness	*Tolerances* *Class 'A' rails*	*Class 'B' rails*
(a)	Horizontal	Deviation of 0.5 mm measured as maximum ordinate from the chord of 2.0 meters standard Straight edge.	Deviation of 0.7 mm measured as maximum ordinate from the chord of 1.5 meters standard straight edge.
(b)	Vertical		
	(i) Up sweep	Deviation of 0.4 mm measured as maximum ordinate from the chord of 2.0 metres standard straight edge.	Deviation of 0.5 mm measured as maximum ordinate from the chord 1.5 metres standard straight edge.
	(ii) Down sweep	Nil	Nil

12. Freedom from defects
    The rails must be uniform section throughout and be sound, straight and free from all detrimental defects having unfavorable effect on the behaviour of rails in service. Such defects include, among others, cracks of all kinds, flaws, piping or lack of metal etc. The absence of harmful internal defects shall be ensured by continuous on-line ultrasonic examination.
13. Surface quality
    (a) *Hot marks*: Depth of rolling guide marks any where on the rail should not exceed 0.5 mm. A maximum of two guide marks are allowed per rail. The width of each rolling guide marks should not exceed 4.0 mm.
    Depth and width of guide marks must conform to the following:

Depth mm	Minimum width mm	Maximum width mm
0.5	1.5	4.0
0.4	1.2	4.0
0.3	0.9	4.0

(b) *Cold marks*: Depth of longitudinal or transverse cold formed scratches anywhere on the rail should not exceed 0.5 mm.

(c) *Seams*: Rails with seams greater than 0.2 mm in depth are not acceptable and shall be ground. On the running surface of the rail, dressing shall be limited to 0.3 mm deep and in other places, it shall be limited to 0.5 mm deep.

(d) *Protrusions*: All protrusions in the head or foot of the rail shall be ground to match the parent contour.

Protrusions on web greater than 1.5 mm height and 20 mm square shall be ground. All protrusions affecting the fitment of the fishplate shall be ground.

During examination on the inspection banks, any shrinkage cavity, inclusion and segregation visible to the naked eye shall result in rejection of such rail or cutting out of the defective portion and re-examination.

14. Qualifying criteria

The following tests shall be done for each rail section, grade and class, annually or after any change in the process of manufacture which may affect the results.

(a) Residual stress measurement.
(b) Fracture toughness measurement.
(c) Fatigue test.
(d) Inclusion rating level.

2.21.2 Second Quality Rails

Rails which do not comply with IRS specification no. T-12 are rejected. But if these rejected rails conform to all specification-except the dimensional tolerance, they can be accepted as second quality rails for use in industrial sidings.

In second quality rails, in addition to the marking specified for nominal quality rails, 'C II' is marked on both the end faces of the rails and on one side of the head. Besides they are painted red on both sides of the web for a distance of 1 m from each end, for easy identification.

2.21.3 Industrial use Quality Rails

In view of the acute shortage of new or released rail in India, rails not conforming to the dimensional tolerances of first or second quality, are permitted for use in some types of industrial sidings.

In addition to marking specified for normal quality rails, 'C III' is stamped on both the end faces of these rails. Third quality rails are also painted with white paint on end faces and on both sides of the flanges for a distance of 500 mm from each end for easy identification.

2.22 DEFECTS IN RAILS

These can be divided into three broad categories:

1. ***Defective Rail Steel***
   These may be defects in the rail steel such as unsatisfactory chemical composition, heavy segregation, inclusion, piping or flakes.
2. ***Surface Defects***
   These defects appear on the rail surface during rolling in the steel mills. Some of the prominent defects are:
   (a) *Seam*: Seams on the rail surface appear as very fine lines and may be caused by blow holes near the surface, cracks in the ingot or by faulty rolling.
   (b) *Lap*: A lap is caused in the rolling mill when some protruded piece of metal is rolled on the surface of the rail section.
   (c) *Guide mark*: This is surface mark, usually straight and caused by the guidance in the rolling mill striking against the rail section.
   (d) *Mill defects*: These are other defects which may originate in the steel mills. They may include deformations, cavities or entrapped foreign material.
3. ***Service Defects***
   Imperfection, damage or deformation develop in rails during their service life leading at times to their premature renewals. Some of the important ones are described here.

   (a) *Battered and crippled rail ends* The impact of running wheels causes the rail end to be hammered down and flattened. Such flattened rail ends are called battered or crippled rail ends. This occurs particularly when the joint gaps are excessive, fish-plates do not fit snugly thereby not supporting the rail end firmly. Rail ends battering is measured as the difference between the height of the rail at the rail end and a point 30 cm away from the rail end. Rail end battering up to 2 mm is classified as average and beyond that up to 3 mm as severe.
   (b) *Hogged rails* A hogged rail is one which is having its end or ends bent downwards in a permanent set. Correct spacing and firm packing of joint and shoulder sleepers can help minimize the development of hogged joints. Hogging is measured at the centre of the joint, with 1 m straight edge placed centrally on the rail table, after loosening the fish bolts.
   (c) *Wheel burns, scabbing, flaking, shelling and squat or black spots* These are often associated with abnormal traffic effects such as heavy axle loads, high density of traffic, flat spot on tyres and skidding of wheels due to severe braking.

Slipping and skidding of loco driving wheels cause wheel burns. They invariably give rise to hardened spots often accompanied with cracks which lead to rail fractures. The rails under all the driving wheels are simultaneously affected with wheel burns.

Scabbing is a defect in which patches of metal of varying dimensions get dislodged from the surface of the rail table, not necessarily confined to gauge corners.

Shelling is the progressive fracture in the form of horizontal separation of metal from the rail head near the upper gauge corner.

Flaking is similar to shelling but occurs near the gauge corner on the rail surface.

Squat or black spot is a progressive cracking of the visible running surface of the rail on sections of track used both by fast and heavy slow trains. In its final stage, it develops into transverse cracking which eventually leads to rail fractures.

Although definite causes have yet not been established for shelling and flaking, these are associated with differential work hardening of the rail table and the flow of metal depending upon varying pattern of loading.

2.23 ROLLING CONTACT FATIGUE (RCF)

RCF is a natural consequence of bodies in rolling contact. In rails, it manifests itself in the form of Gauge Corner Cracking (GCC) and "Head Checking". While head checking is located towards the rail centre line, usually 15 to 25mm from the gauge face, GCC, in contrast, is found at the gauge corner itself.

RCF is not an unknown phenomenon to branches of engineering focused upon bodies in rolling contact, such as bearing design or tribology (the study of frictional contact). Essentially, any two bodies in rolling contact have the potential to damage one another in several ways, depending upon the severity of the contact pressure and the shear or "tearing" forces in the contact patch. The contact patch in rail-wheel interaction is about the size of a 25p coin.

Damage can be in the form of surface cracks, wearing away or plastic flow of the materials themselves.

In Fig. 2.4 the basic process is described graphically. For the sake of explanation, the rail is depicted as composed of adjacent plates or laminates. Since the pressure and forces are high enough to cause plastic distortion of the laminates near the surface, an accumulation of metal dislocation occurs with each wheel pass until cracks occur at the surface.

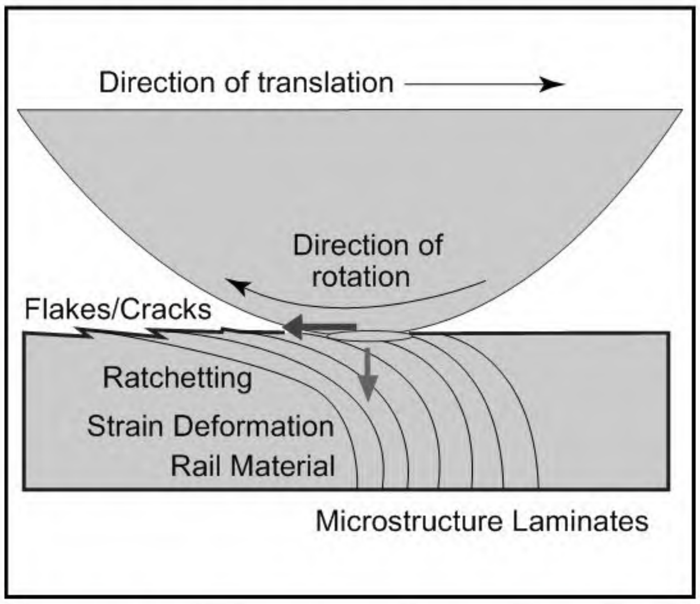


Fig. 2.4 Contact patch pressure and forces causing surface elastic deformation of the rail microstructure, loading to RCF (See also Color Plate 1)

In the initial stages of growth, the cracks are quite short and grow at the shallow angle. On occasion, some can grow quite long and change from a shallow to a steep angle following a path similar to the laminate boundaries as depicted in Fig. 2.4. This tends to occur when the surface length approaches 30mm and represents a great increase in the chances of a rail fracture.

2.23.1 Practical Steps for Permanent Way Engineers to Deal with RCF

Figure 2.5 depicts the three RCF modes as a function of curvature and also briefly lists the primary recommended actions to minimize RCF.

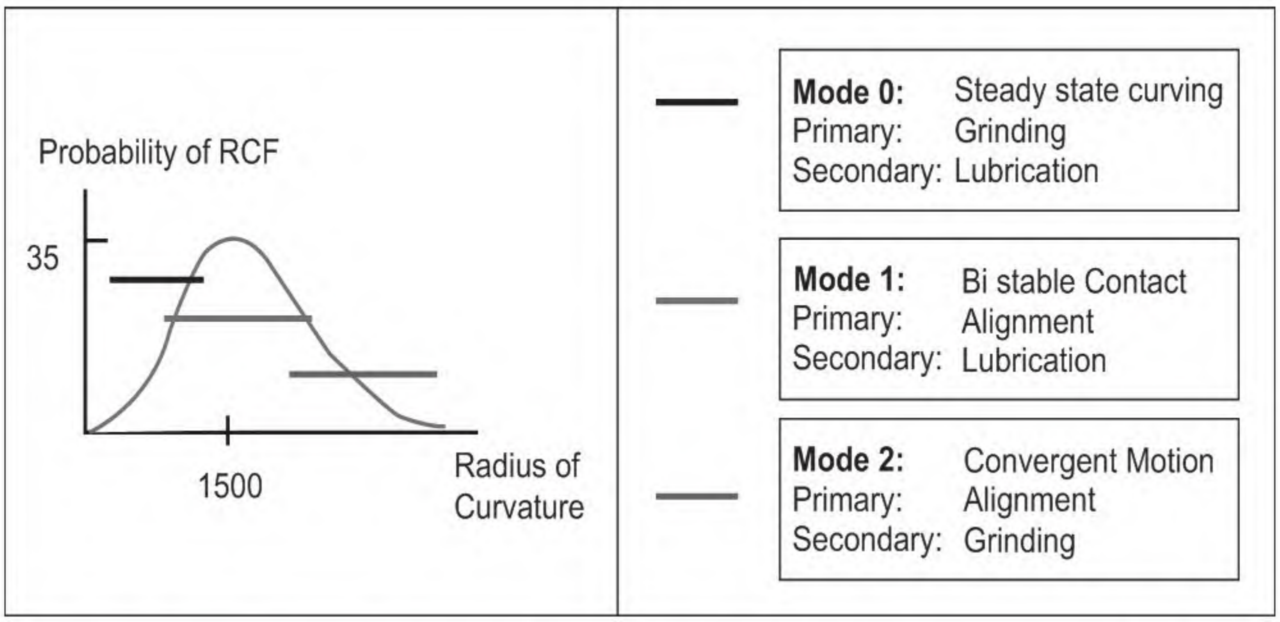


Fig. 2. 5 RCF initiation modes as a function of curvature and recommended track based remediation. Overlapping influence rather than distinct boundaries exist between modes (See also Color Plate 1)

- ***Tight curves—Mode 0 (Radius of curvature up to 800 metre):*** Since the prime factors are the curve radius itself and the stiffness of the bogies, the primary tactic is to grind the rails so that contact in the gauge corner area is reduced. This will increase the amount of gauge face contact and must be addressed by proper lubrication.
- ***Mid range curves—Mode 1 (Radius of curvature 800 metre to 2000 metre):*** Since the prime factor in this mode is the conformality of the wheel and rail, the system is extremely sensitive to small alignment changes. The primary tactic therefore remains grinding since it will reduce the conformality by the metal removal process. Track alignment is also important since small changes when coupled with conformality can produce high forces. As usual, any ground curve should be lubricated.
- ***Shallow curves and straight track—Mode 2 (Radius of curvature above 2000 metre):*** The primary factor in this mode is track geometry, especially lateral alignment since it can lead to the 'converging' of the wheel and rail and subsequent RCF forces. Twist can also cause a lateral reaction in the bogie and is often noted in crossings.

2.24 RAIL CORRUGATION

Rail corrugations are periodic undulations which form under traffic on the running table of a rail. They vary in wavelengths, from 20 mm to 3000 mm or even longer. In the case of shorter wavelength corrugation, it becomes troublesome at amplitudes from peak to trough of 0.1 mm or less. Amplitudes of 1 mm or more occur over the longer wavelengths. The interaction between the wheel and the rail, when passing over short wave corrugation, produce an unpleasant high noise level. Such rails are called roaring rails. The corrugated rails are also subjected to excessive vibrations under moving wheel loads. Track with corrugated rails need frequent maintenance and the track components wear out faster, causing severe damage to concrete sleepers, in particular.

Considerable research has been carried out on the cause of rail corrugation and the present findings are as follows.

The wheel set and the rail, are parts of two independent mass-spring-damper systems. The two systems are connected at the contact area. The corrugations form when the interaction between the two independent damper systems affect the adhesive conditions across the contact area in an unfavourable manner.

In ballasted track, rail corrugations can be prevented to a certain extent by:

(a) Procurement of new rails with smoother surface finish
(b) Better rail weld geometry particularly the top surface
(c) Welding of rails into continuous lengths including switches and crossings
(d) Selection of rails with appropriate head hardening
(e) Use of more resilient rail pads
(f) Rolling stock with better suspension characteristics particularly in respect to primary suspension of wagons
(g) Reduction of unsprung mass on locomotives/E.M.U. stock
(h) Increasing the sleeper density and ballast cleaning

In controlled condition (e.g. on ballast less track), there are prospects of designing a corrugation proof track. But on conventional ballasted track, the variability of the stiffness and damping of the ballast is such that occasional corrugation is inevitable. The only remedy therefore lies in its correction by grinding.

2.24.1 Rail Grinding

To remove corrugations, pitting, scabbing and other surface defects, grinding of rails is being done on many railway systems. Rail grinding trains equipped with a number of rotating grinding wheels are able to remove rail corrugations and other rail surface defects. These grinding trains are also equipped for complete reprofiling of the rail table, often needed to treat the worn-out rails at curves. However, grinding of rails does not offer any permanent solution to the rail corrugations as the corrugations reappear and need regrinding again.

The earlier version of grinding trains were all equipped with rotating grinding wheels. But on account of environmental and output considerations, new types of grinding trains equipped with milling and rubbing equipment have come into the world market. The trains provided with oscillatory rubbing equipment have particularly found favour in metros and suburban rail networks, as their operation is less noisy and free from any sparking hazard.

Figure 2.6 (a) and (b) show a Rail Grinder marketed by Harsco Track Technologies designed to grind the top and sides of running rails of mainlines, switches and crossings. The Model RGHC Rail Grinder is a self-contained machine consisting of main cabin, auxiliary cabin, engine, systems enclosures and the grinding carriage. The machines can be utilized individually as eight stone machines or in multiple unit configuration, as sixteen stone machines. The units

Fig. 2.6 (a) (See also Color Plate 2)

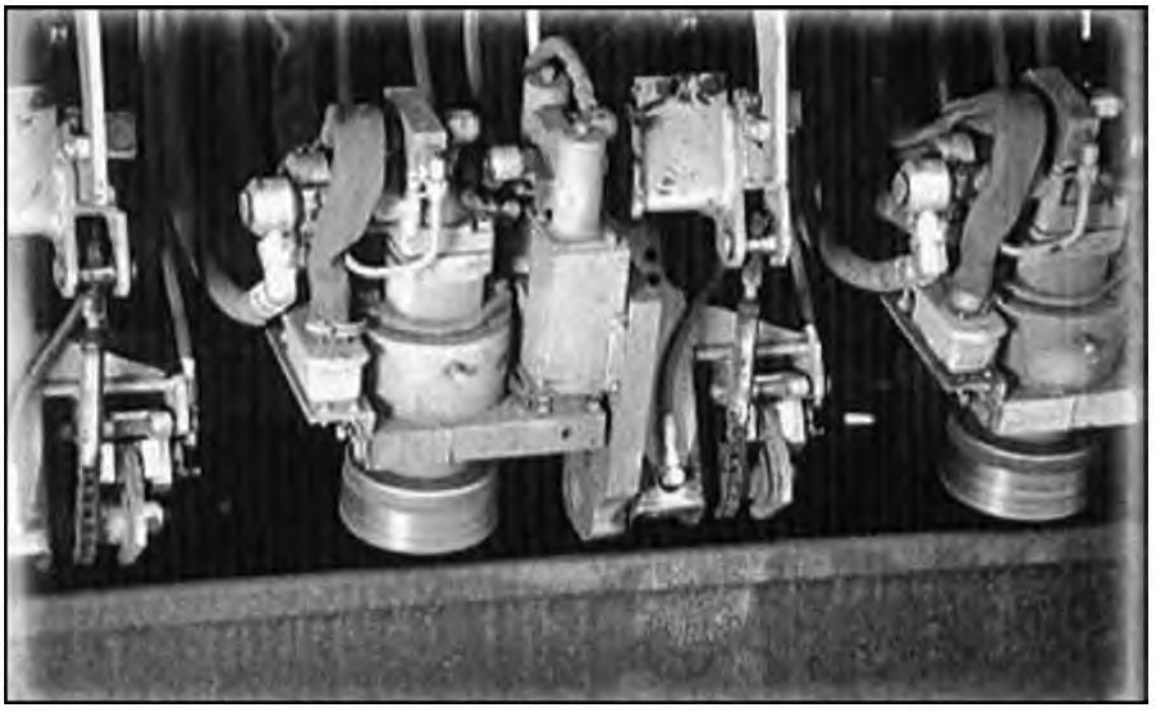


Fig. 2.6 (b) (See also Color Plate 2)

are powered by a diesel engine and incorporate a hydrostatic propulsion system, pneumatic braking system, hydraulically powered and positioned grinding heads, a filtered grinding dust collection system, water spray fire control system, comfortable control cabins and full computerized control of all functions.

During the grinding operation, all grinding unit movement; vertical, horizontal, and angular, are computer controlled using a set of rail grinding patterns which are programmed by the operator to accomplish the grinding method required. The computer system is capable of storing 99 grinding patterns, each consisting of 4 or 8 stone positions per rail.

The machines can grind in either direction at speeds up to 19-Km/hr and can travel at speeds up to 100-km/hr.

2.24.2 Types of Grinding

Rail grinding can be classified essentially into three different types: ***Initial, Preventive and Corrective.***

Initial grinding is performed on rails that are freshly laid during new construction or after rail renewal. Initial grinding corrects construction damage and removes the "decarbonised" surface area of the rail head where the mechanical properties are poorer than the rail's deeper layers. The removal of 0.30 mm from the surface layer of the rail guards against the formation of squats.

Preventive grinding involves intervening before damage has matured. The idea is to treat the rail when damage is at the embryonic stage. This approach is based upon cyclical timing. The grinding campaigns are steered in accordance with cumulative track loading.

Corrective grinding is based on symptom-related interventions. Campaigns are directed by monitoring damage against preset levels, such as removing short pitch corrugation once it reaches 0.05 mm depth.

2.24.3 Longitudinal Rail Profile Measuring Equipment

The evolution of longitudinal rail profile measuring equipment has resulted in highly accurate measurement, which can be used to monitor rail noise problems and to assure the quality of rail grinding and weld straightening. Recent European standards have indicated the wavelengths of interest for the different types of corrective maintenance. This has been given in Table 2.6.

2.25 FLATTENING OF RAIL TABLE

This mostly occurs in the low rail on curves. It is usually caused by combination of high contact stresses and high lateral forces which are produced by heavy axle loads, smaller diameter wheels, large unsprung weights, under equilibrium speed, running on canted tracks. Flattening or piping

Table 2.6 Wavelength ranges considered in recent draft standards for longitudinal rail irregularities

Purpose	*Reference*	*Wavelength range (m)*
Acoustics (grinding)	prEN ISO 3095	0.00315 to 0.63 (1) (2)
Reprofiling, grinding	prEN 13231-3	0.01 to 1 (3)
Track geometry	prEN 13848-2	3 to 150

(1) One-third octave band centres
(2) Desirable range; 0.008 to 0.1 m is essential
(3) Desirable range 0.1 to 3

of rails is an indication that the rails are unequal to the task they are meant for. Under such conditions, heavier rails with a higher UTS are the right solution.

2.26 CORROSION OR RUSTING

Corrosion is caused not so much by dampness but by the acid gases dissolved in the film of moisture coating the rail. These gases are present everywhere in small quantities, but they are in abundance in industrial and coastal areas. Incidence of corrosion of rails is high near water columns, ash-clearing pits, wet tunnels and in passenger yards receiving excessive discharge of night soil from trains. Rails subjected to regular fast traffic corrode less than disused rails. For protecting rails against corrosion, the practice on Indian Railways is to apply one coat of zinc chromate/red oxide primer followed by three coats of bituminous emulsion. Before the coats are applied the surfaces are thoroughly de-scaled and cleaned.

2.27 WEAR OF RAILS

Wear of rails is divided into two categories: (a) on top or table of the rail head, and (b) on the sides of the rail head.

Top table of the rail gets worn out due to the abrasive action of rolling wheels over the rails. In dry areas where there is a constant blowing of sand or dust, extra wear occurs due to the grinding action of the sand or dust particles between the wheel and the rail table. In wet weather, the rails are lubricated by rain water and wearing is diminished. Rail-wear also occurs when brakes are applied. On curves, wear on rail-table occurs due to skidding and slipping of wheels rigidly connected by the axle, as it has to cover unequal distances at outer and inner rail.

Side wear of rail occurs on curved tracks. The centrifugal thrust of the wheel flanges against the side of the outer rail results in the grinding action that causes the side wear of rail. Guiding force on curves depends upon the degree of the curve, the rigid wheel base on the rolling stock, the angle of attack of the wheel flange on rail, etc.

Rolling stock with a low centre of gravity exerts greater wheel flange pressure on the sides of the rail head, especially if heavy traction motors are laterally unsprung. This explains the heavy side wear of rails on curved tracks of electrified suburban lines worked by multiple unit stock.

2.27.1 Permissible Limit of Rail Wear

1. The following three factors are considered in determining the maximum limit of vertical rail wear.
   (a) The limit based on the strength of worn out rails to carry maximum axle loads at safe speeds.
   (b) Reduction in the depth of head of rail to a point beyond which there would be risk of the wheel flange striking the collar of fishplates.
   (c) The head being worn down to a cross-section so as to risk the shearing of the under edge.

   For passenger trains the permissible limit is based on strength i.e. (a) same as stated above. The other two limits would apply to unimportant yard lines and sidings.
2. Limits of lateral wear and angle of wear are fixed considering the strength of worn out rail and the risk of wheel mounting the rail causing derailment.

2.27.2 Measuring Wear of Rails

Rail-wear is determined by (a) actual weighment, (b) taking rail-profiles at ends after opening the joint and taking rail-profiles with special profile-measuring gadgets, which can measure rail-profile while the rails are still in track.

The reduction found in the area of worn-out rail-profiles indicates the loss of rail section caused by wear.

Computerized rail-wear measuring devices are now available in the international market. They are fitted with sensors, which on contact with rail, plots its profile and indicate the wear in the rail section.

2.27.3 Rail Profile Measuring Car

Indian Railways have recently procured a rail profile measuring car, which can measure the rail profile, when hauled by a locomotive or put in the consist of a fast train. Illuminating the railhead through a laser slot and recording it digitally, usually stereoscopically, the car measures the rail profile. The measured rail profile is determined by comparing it to stored target profiles. Subsequently, the measured actual profile is compared to the target profile to calculate the railhead wear. With the help of these digital photographs it is also possible to determine the rail inclination and track gauge.

Typical output from the rail profile-measuring car is given below.

Gap	:	1.0 mm	Gap	:	0.5 mm
Vertical Wear	:	1.8 mm	Vertical Wear	:	2.2 mm
Lateral Wear (Gauge)	:	1.0 mm	Lateral Wear (Gauge)	:	0.0 mm
Rail Rollover	:	– 0.2 deg	Rail Rollover	:	– 0.9 deg
Lip Flow (Gauge)	:	0.0 mm	Lip Flow (Gauge)	:	0.1 mm
LEFT RAIL	**:**	**90 R**	**RIGHT RAIL**	**:**	**90 R**

2.27.4 Methods of Reducing Rail Wear

Rail wear is less on a well-maintained track with fittings and fastenings in perfect order, as the vehicles on such a track have a smoother roll. Other methods employed to reduce rail wear are:

1. *Maintaining Track to 3 mm Tighter Gauge*: This reduces hunting of rolling stock thereby reducing rail wear. For various reasons, particularly with the occurrence of gauge corner defects, this is no longer a preferred method.
2. *Provision of Check Rail on Curves*: Check rails are provided along the inner rails of curve. The inner face of the wheel rubs against the check rails and the flange of outer wheel is prevented from coming in contact with the outer rail head.
3. *Rail Lubricators*: An important method of reducing wear on curves is by the use of lubricators. The function of the lubricators is to grease the gauge face of the rail head where excessive wear occurs. This reduces the friction and consequently wear. Rail life is increased and even doubled in some cases, lubrication can be carried out manually or by mechanical devices attached either to locomotives or to rails, the latter being more common. In rail-lubricators, grease is ejected along the gauge side of the rail-head and is carried forward by the flange of passing wheels. On long curves, more than one lubricator are installed on suitable locations to get the optimum results. On Indian Railways Rail and Flange lubricators have been installed on many sections. These sections use graphite grease for lubrication which has been found very effective in reducing wear.

In the last few years, interest in the lubrication of rails has considerably increased, as it can make a significant contribution in the saving of energy in heavy haul operations. Box ′N wagons in use in Indian Railways have been found quite aggressive on track, leading to wear of rails and the wheel flanges. Lubrication on rail gauge-faces in continuous lengths on Box ′N routes, which include straight tracks as well, has helped in:

(i) Energy saving in the form of less locomotives fuel/power bill due to the reduced rail/wheel friction;
(ii) Obtaining longer life from rails and wheels; and
(iii) Reducing derailments, as wheels have less chances of mounting on lubricated rails.

Some of the railway systems abroad claim an energy saving of 10-15%, with the rail/wheel flange lubrication. A proper assessment of energy saving on Indian Railways is yet to be made.

Whereas the frequency of rail lubrication adopted on tangent tracks of Box ′N routes differs from one zonal railway to the other, a weekly cycle of rail lubrication is generally adopted on curves, SEJ's and points and crossings.

2.28 TURNING AND TRANSPOSING OF RAILS

On sharp curves the outer rail becomes side-worn to an extent that it can no longer remain in service. Since the wear is limited to gauge face only, it is a common practice to turn the rails, end of end, thus exposing the unworn face to traffic. This method can be adopted only on jointed tracks as turning of L.W.R. is not physically possible.

On L.W.R. tracks, the same purpose can be served by transposing of the rail. In this process, the outer face of the inner rail becomes the gauge face of the outer rail and vice-versa.

While carrying out the work, it is necessary to take into account the differences in the lengths of the two rails and take suitable measures to adjust the same.

2.29 USE OF WEAR RESISTANT RAILS

Due to vertical and lateral wear, the life of rails on curves, particularly on curves sharper than 5° gets very much reduced. On such curves, it is sometimes advantageous to use special wear resistant rails. Wear resisting rails are produced by any of the following three methods.

(i) By modifying the chemical composition of steels
(ii) By careful heat treatment, or,
(iii) By a combination of both

The first method is used to produce what are termed "naturally hard" steels of which 'wear resistant grade A' and 'wear resistant grade B' rails of U.I.C. 60 specifications are the examples. The Brinell hardness (BHN) value of these rails is about 270-290 compared with 230-250 of normal grade rails.

However hard steel can be produced by using an alloy containing 1.20% of chromium (Cr). The UTS of such a steel is about 30% higher than grade A and its BHN is about 330 to 350. Such rails are being used on heavy haul railways and selectively on conventional railways where service conditions are extremely harsh. Rail made from 1.2% Cr steel are however very difficult to weld and tend to get damaged during handling. They are therefore not normally recommended for use.

In a rail, the rail head undergoes maximum wear. This can be economized by hardening the rail head to make it wear-resistant. It can be achieved by reheating the rail head to austenitie stage (910°C) by electromagnetic induction followed by passing the rail under a series of hoods through which a mixture of water and cold air is blown. By controlling the force of this blast, it is possible to obtain the required degree of hardness in the rail.

Technological developments have helped to obtain head hardened rails during the rail rolling process itself. In this process, the rail is subjected to a computer controlled air/water quenching system as it emerges from the final shaping rolls. Hereby, it is possible to achieve hardness level of 300 to 390 BHN with this method.

The thermal cycle induced during welding of rail ends modifies the metallurgical structure developed during the process of hardening, and creates softened areas in the heat affected zone (HAZ) at the weld. This would lead to excessive wear at these positions. Special cooling treatments are therefore required while welding head hardened rails to reinduce hardness level similar to that in the unaffected parts of the rail. Technology is also available for in-situ restoration of hardness in HAZ

The rate of wear in the rail with the hardness of 370 BHN has been found to be one-fifth of that experienced in the rail of 260 BHN thereby providing an economic advantages in areas where service conditions are harsh.

However, it has to be noted that as the rate of surface wear reduces, the tendency towards rolling-contact-fatigue increases.

2.30 SERVICE LIFE OF RAILS

The rail section committee of the Indian Railways while assessing the life of 52 kg/m rails considered that the Belgian method gave a rational basis for computing the service life of rails. This method is based on limiting the vertical wear of the rail to the extent that the wheel flange of worn out tyres do not graze the fishplates. For 90 lb/yd rails, such limiting rail wear is taken as 6 mm. It is also assumed that under normal traffic conditions, 20 GMT of traffic wears down the rail table by about 0.5 mm. On this assumption, the service life of 90 lb rails is taken as $20 \times 6/0.5 = 240$ GMT (say 250 GMT).

The majority of rail failures have their origin in fatigue. Fatigue is a cumulative process accelerated by corrosion and wear, so that the longer the rail remains in track, the more fatigue damage it accumulates leading to development of fatigue cracks or fracture if not detected in time. Rails are therefore often removed from the tracks as an insurance against fatigue failure long before they have worn down to a section too weak to carry the maximum permitted axle loads. In the absence of any reliable measure of cumulative fatigue damage, rails are usually renewed after a certain GMT of traffic.

Experience with 90 lb/yd rails in the Indian Railways has shown that although the wear limit of 6 mm taken for computation of service life of rails in the Belgian formula is not reached in many cases, rails are reported to have accumulated enough fatigue damage to warrant renewal after 250 GMT of traffic. In practice, therefore, the Belgian formula of determining service life of rails hold ground as a workable criterion of rail renewal. On this basis the service life of various rail sections on Indian Railways is indicated in Table 2.7.

Table 2.7

Rail section	*Total GMT carried*
60 kg/m	500 GMT
52 kg/m	300 – 350 GMT
90 lb/yd	250 – 350 GMT
75 lb/yd	150 – 350 GMT
60 lb/yd	125 – 350 GMT

Note: The service life of the rails indicated above is for standard quality rails with a UTS of 72 kg/sq mm. For rails with a UTS of 90 kg/sq mm, the service life is taken as 1½ times that of standard quality rails.

For high-speed lines, the present trend is to link the service life of rails with the cost of track maintenance, (including the cost of spot renewals of rails) sleepers and fastenings. The rails released from main lines are used on secondary lines, sidings and yards. Thus, the new rails are planned to be retained on high-speed, heavy-density routes for a period of about 20 years and later use them in secondary lines for the rest of their service life.

2.31 FRACTURE TOUGHNESS AND FATIGUE IN RAILS

The most common cause of failure of rails is fatigue. Failure by fatigue mostly occurs in three stages:

(i) The initiation of the crack.
(ii) The growth of the crack.
(iii) Final fracture.

Stages (i) and (ii) of the fatigue process occur by repeated loading of the rails due to the passage of wheels. Stage (iii) is caused by one loading event which may be abnormally severe or the final occurrence under normal load.

The initiation of a crack Stage (i) may require millions of repeated loadings. During this time, there is no way of detecting the forthcoming crack. The growth of the crack, particularly in its early stages, may also require the application of million or more loading cycles. Stages (i) and (ii) therefore take place over a period of time-often years-and during this period, there being no perceptible change in the shape or dimension of the rail, it is just not possible to observe any fatigue failure. It appears all of a sudden as a brittle fracture during a period of increasing load. Such an incidence can only be detected by applying flaw detection techniques from time to time to enable the removal of defecting rails in time.

The stresses in the rail are, generally, just a fraction of the Ultimate Tensile Strength. However, fatigue failure occurs at stress levels below the ultimate tensile strength. This is caused by the gradual accumulation of fatigue damage with each stress cycle. As the range of stress (the difference between the maximum and the minimum stress level in the cycles) decreases, more stress cycles are required before the failure occurs. This phenomenon continues till the stress range reaches a point where no further fatigue occurs. This range is known as rail's fatigue strength. Its value for new normal quality rails is about 45% of ultimate tensile strength i.e. 32 kg/mm^2.

The fatigue strength of rail steel is established at about 2 million stress cycles and for this stress range and below this the fatigue life of the rail steel may be considered to be infinite.

The fatigue strength of the rail may appear to be high compared to nominal bending stress in the rail. However, the rail presents many localized high stress areas (stress concentration) where these nominal stresses are substantially increased. These stress concentrations are caused by features that disturb the smooth flow of stress contours. Some are caused by the design of the rail itself, such as:

(i) Fishbolt holes
(ii) Radii between the head and web, and foot and web

Other stress concentrations may be caused during the manufacturing process:

(i) Hydrogen shatter cracks
(ii) Non-metallic inclusions
(iii) Roller guide marks
(iv) Scores and scratches
(v) Pits caused by indented mill scale

Some stress concentrations are caused intentionally by the user:

(i) Drilled holes for cables and other attachments.
(ii) Stamp marks.

Stress concentrations are also caused during use of rail:

(i) Damaged hole surface cased by poor drilling or using crow-bars or badly filled bolts.
(ii) Rail surface damage caused by hitting rail with unsuitable tools.
(iii) Wheel burn cracks.
(iv) Plastic flow of the rail head.
(v) Foot galling.
(vi) Corrosion pitting.

Apart from stress concentrations, other features occur in track which raise nominal stresses. These include:

(i) Track irregularities such as bolted and welded joints.
(ii) Wheel burn depressions.
(iii) Poor support conditions.
(iv) Rail head depressions caused by dripping water in wet tunnels.

Residual, or locked-in stresses, which are originally produced during rail manufacture (roller straightening) and subsequently modified by service loadings, also play a role in determining the fatigue performance of the rail and possibly add to the stress causing final fracture of the rail.

Fracture toughness is measured in tests based upon the principles of fracture mechanics, and it is found that it decreases with decreasing temperature and, in general, decreases with increasing loading rate. Consequently, fracture will occur in a fatigue cracked rail more readily at low temperatures and with impact loads (caused for example by wheel flats and badly dipped joints).

As noted above the only practical way of controlling rail fatigue failure in service is by ultrasonic inspection. Any periodic ultrasonic testing policy should:

(i) Ensure that detection techniques will detect cracks which are less than the critical size.
(ii) The time period between inspection should not allow a crack to grow to its critical size,
(iii) Sizing of cracks should be accurate enough to allow logical withdrawal criteria to be determined

Development in steel technology has reduced and in some cases eliminated some traditional fatigue failure types, while improved ultrasonic test methods and a better understanding of fatigue mechanism and fatigue life prediction are helping to contain the problem in service.

2.32 CLASSIFICATION OF RAIL FAILURES

A rail is said to have failed if it is considered necessary to remove it from the track due to its defects, except when it is replaced after it has completed its normal service life in track.

For the convenience of classification and easy processing of statistical data, the reporting of failure is done in a codified form. The code comprises two portions. The first portion consists of three code letters and the second portion of three or four digits. The three code letter in the first portion denotes (a) the type of rail being renewed, (b) the reason for withdrawal of the rail, and (c) the probable cause for the failure of the rail. The digits in the second portion of the code denote the location and characteristic of the fracture.

2.32.1 First Portion of the Code:

1. *Type of rails being renewed*:

	Type of Rails	*Code Letter*
(a)	Plain rail	0
(b)	Points and crossing rail	X

2. *Reasons for withdrawal of rail*:

		Code Letter
(a)	*Fracture rail*: A rail which has broken into two or more portions or pieces.	F
(b)	*Cracked rail*: A rail which actually has not split into two or more portions in the track but has developed a visible external crack on any part.	C
(c)	*Defective rail*: A rail removed from track for defects which Do not fall under any of the above two categories.	D

3. *Probable cause of failure*:

		Code Letter
(a)	Inherent in the rail	R
(b)	Fault of the rolling stock	S
(c)	Excessive corrosion	C
(d)	Badly maintained joint	J
(e)	Other maintenance conditions	M
(f)	Derailments	D
(g)	Associated with welding	W
(h)	Other causes	O

(a) *Inherent in the Rail* (*R*) The defects include unsatisfactory chemical composition, harmful segregation, piping, seams, laps, guide marks, flakes etc.

(b) *Fault of the Rolling Stock* (*S*) Such defects include shelling, black spots, scabbing, wheel burns, etc. These can be reasonably associated with abnormal traffic effects such as flat spot on tyres, skidding or slipping of wheels, etc.

(c) *Excessive Corrosion* (*C*) Corrosion may reduce the rail section to the extent of warranting its withdrawal from the track. It may lead to cracking or fracture of the head web, head foot junctions or bolt holes, which are regions of high stress concentration on the rail section.

(d) *Badly Maintained Joints* (*J*) These failures invariably occur at the rail ends and take the form of horizontal longitudinal split through the head web, foot junctions, diagonal cracks from bolt holes, etc.
(e) *Other Maintenance Conditions* (*M*) Generally speaking, failures falling under this category are due to combinations of factors and it is not always easy to determine the relative importance of bad maintenance visa-vis other factors.
(f) *Derailments* (*D*) These are failures which develop as a result of derailment.
(g) *Associated with Welding* (*W*) These are failures which occur through or adjacent (within 10 mm) to a weld joining two rails, or close to a welded attachment, i.e. a bond terminal.
(h) *Other Causes* These are failures which are not due to defects mentioned form (a) to (g).

2.32.2 Second Portion of the Code

This portion of the code, consisting of three or four digits, gives the location of failure in the rail as well as its characteristics as explained in the following section.

The location of fractures on the length of the rail or failure which occur due to special reasons are indicated by the first code figure.

Code Figure	*Meaning of Code*
1	Within fishplate limits
2	Other location on the rails
3	Failure arising from damage done to rail
4	Failure that can be reasonably associated with welding (within 10mm of a weld)
5	Corrosion

The second code figure gives the position in the rail section from which failure has started except in the case of failures associated with welding.

For case not associated with welding:

Code Figure	*Meaning of Code*
0	Origin of failure unknown
1	Within rail head
2	On surface of rail head
3	In web
5	In foot

For cases associated with welding

Code Figure	*Meaning of Code*
1	Flash butt joint

2	Thermal joint
3	Electric arc joint
4	Oxy-acetylene joint
7	Building up by welding
8	Traction bond

The third code figure is interpreted in relation to the first figure, such as given in Table 2.8.

Table 2.8

Code figure	*Case (i)*	*Case (ii)*	*Case (iii)*
0	—	Corrugation	—
1	Transverse	Shallow surface defect	Bruising or arcing
2	Horizontal	Breaking out	Incorrect machining Drilling or flame cutting
3	Vertical-Horizontal	Crushing (continuous)	—
4	—	Battering (local)	—
5	Diagonal at a hole	Wheel burn	—
8	Diagonal not at a hole	—	—
9	—	Lap, seam, roll mark	—

Case (*i*) If the failure is due to an internal defect (first figure 4 or second figure 1, 3, 5), it shows the direction of the crack of fracture.

Case (*ii*) If it is a surface defect (second figure 2,3 or 5), it shows the nature of the defect.

Case (*iii*) If failure is by damage (first figure 3), the cause of the damage is known.

The fourth code figure is employed where it is necessary to provide for further subdivision, which may be seen from the list of failures – subdivision. This may be seen from the list of failures – code groups give.

On the basis of the above system of classification, a list of the failures – code groups to be followed is given in Table 2.9 with the meaning of the codes.

Two cases of rail failures have been shown in Figs. 2.7 (a) and (b). The classification of the defect as per code number has also been mentioned under the figure for guidance.

2.33 RAIL FLAW DETECTION

Rails with flaws if allowed to remain in track may fracture which at times can have dangerous consequences. Therefore, detection of these flaws is important and being increasingly adopted by railways throughout the world. Both visual and instrumental methods are employed for this purpose.

1. *Visual method*: Rails in track are subjected to searching examinations by trained men. Rail ends, particularly the area around bolt holes, are examined more thoroughly. For this purpose, the fishplates are removed, the area is cleaned with kerosene oil, and cracks are located with the help of magnifying lenses. Reflecting mirrors and torches are also used.

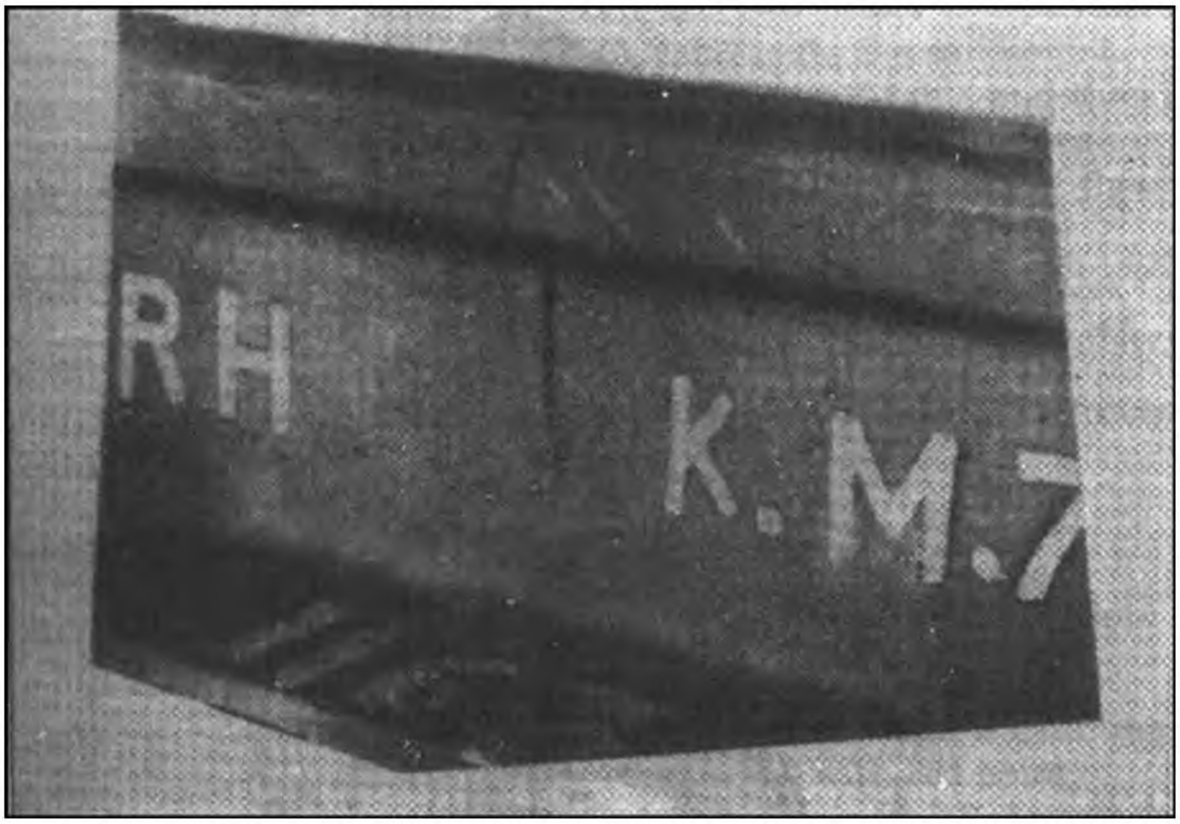


Fig. 2.7 (a) Transverse fissure on plain rail (not broken in service) CODE No. OCR-111

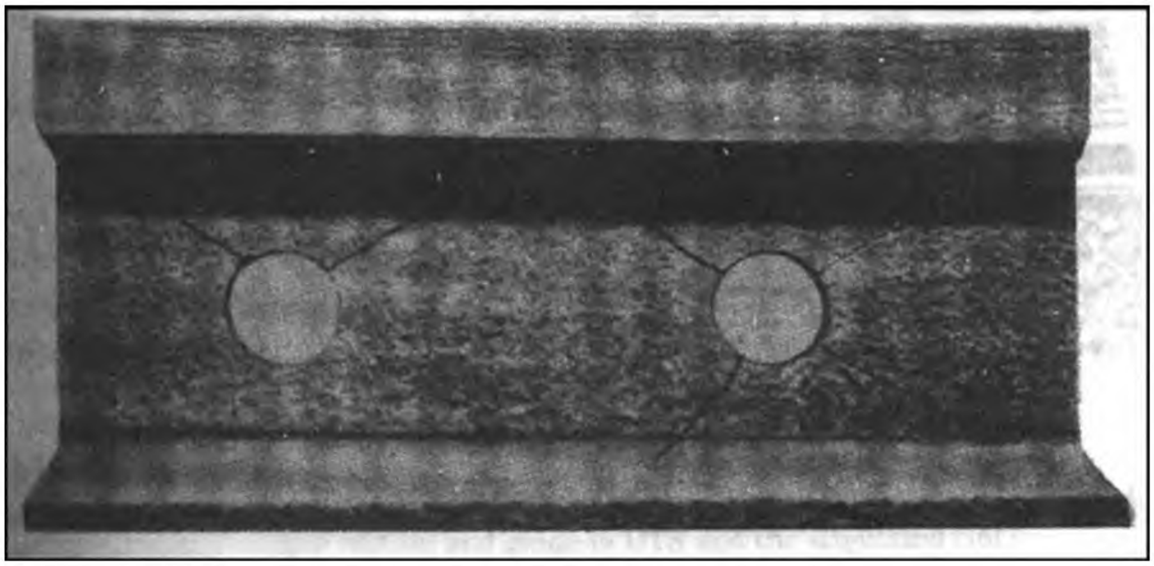


Fig. 2.7 (b) Rail ends (fishplate limits, web, cracking at hole) (Points and crossings) CODE No. XEJ-135

Whenever a crack is noticed, the rail is replaced at the earliest opportunity.
Such inspections by trained men have a marked effect in the reduction of rail failures in service.

2. *Instrumental method*: A more efficient and effective method of rail flaw detection is with the help of ultrasonic rail flaw detecting instruments. This has been discussed in the succeeding paragraphs.

Table 2.9

	With the fish plate limits (i.e., rail ends)	*Elsewhere on rail*
Transverse breakage without apparent origin (i.e. sudden fracture)	100	200
Internal flaw in head, transverse breakage	111	211
Internal flaw in head, horizontal crack	112	212
Internal flaw in head, vertical longitudinal split	113	213
Head, surface, corrugation, short pitch	—	2201
Head, surface, corrugation, long pitch	—	2202
Head, surface, shallow surface defect (flaking)	1211	2211
Head, surface, shallow surface defect (line)	1212	2212
Head, surface, breaking our running surface	1221	2221
Head, surface, breaking out gauge corner	1222	2222
Head, surface, crushing (continuous)	123	223
Head, surface local batter	124	224
Head, surface, wheel burn isolated	—	2251
Head, surface, wheel burn repeated	—	2552
Web, horizontal crack, at top fillet radius	1321	2321
Web, horizontal crack, at bottom fillet radius	1322	2322
Web, horizontal crack, not at fillet radius	1323	2323
Web, vertical longitudinal splitting	133	233
Web, cracks at hole	135	235
Web, diagonal cracks not at hole	—	238
Web, lap	139	239
Foot, transverse break at rail seat	1511	2511
Foot, transverse break not at rail seat	1512	2512
Foot, vertical longitudinal split	153	253
Damage to rail by bruising or arcing	301	—
Damage to rail by bad machining, drilling or flame cutting	302	—
Welding, flash but joint, transverse crack	411	—
Welding, thermit joint, transverse crack	421	—
Welding, thermit joint, horizontal crack	422	—
Welding, electric arc joint, transverse crack	431	—
Welding, Oxyacetylene joint, transverse crack	441	—
Welding, building up, transverse cracking of head	471	—
Welding, building up, built-up part breaks away	472	—
Welding, traction bond, weld, crack at weld	481	—
Corrosion	500	—

2.33.1 Ultrasonic Rail Flaw Detectors (URFD)

These are trolley mounted instruments which detect flaws in rail using ultrasonic waves. Vibration in the form of sound waves and having frequency of more than 16000 cycles per second are called ultrasonic waves. In URFD, sound waves of frequencies ranging from 2 to 4 megahertz are used. These waves are generated, transmitted to the rail and received from the rail by small pieces of piezoelectric crystals which are fitted in probes and they move over the rail. For the generation of

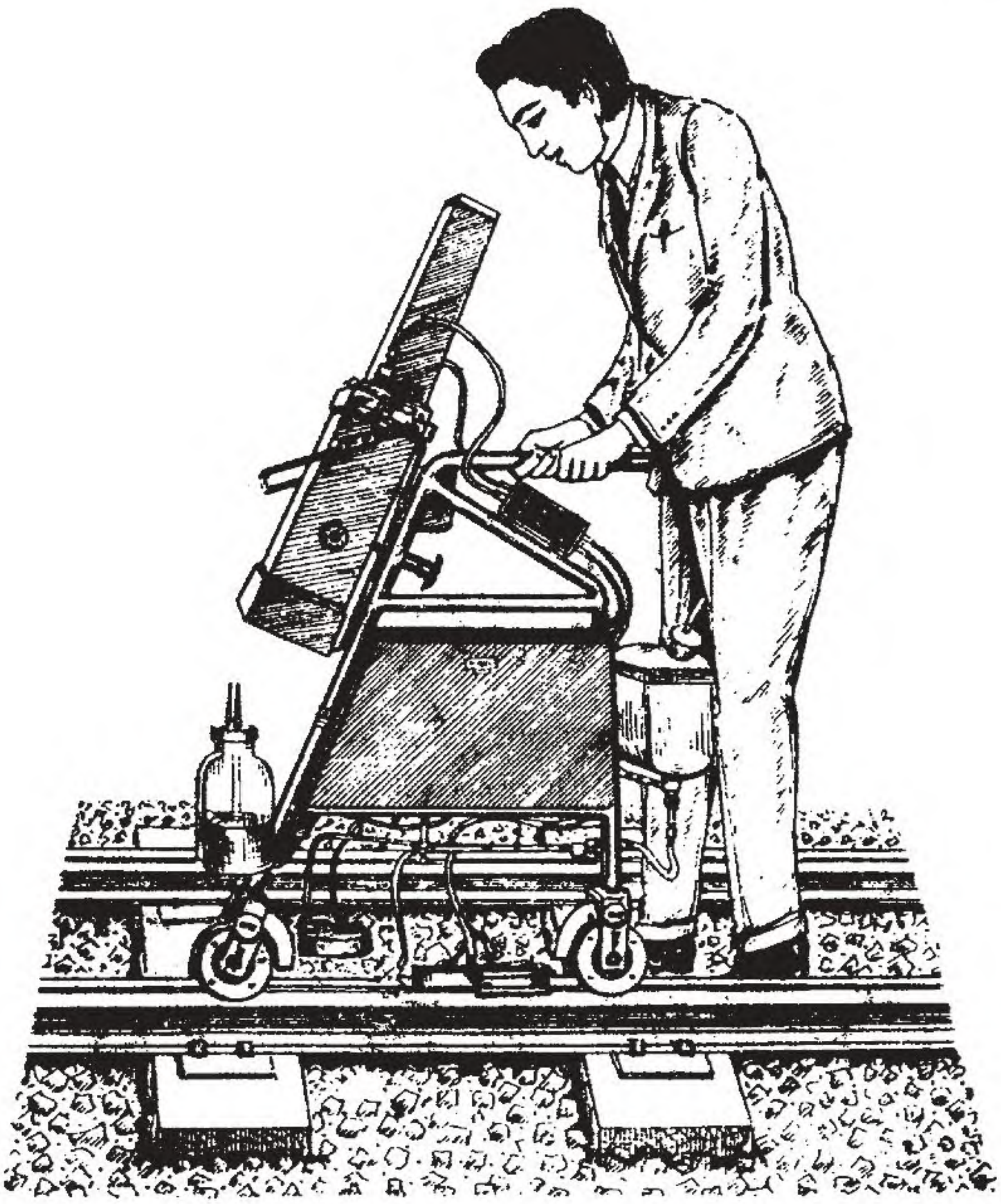


Fig. 2.8 Krautkramer rail flaw detector

ultrasonic waves, the crystals need electric energy which is supplied through a transistorized circuit from a storage battery fitted in the trolley.

The instruments consists of the following:

1. A transistorized circuit capable of producing, transmitting and receiving electric current to and from the probes and depicting them in the form of bright peaks or echoes on an oscilloscope screen.
2. Probes which hold piezoelectric crystals and move over the rail. Probes are of two types:
   (a) *Normal probes*, which transmit waves at right angles to the surface of contact.
   (b) *Angle probes*, which transmit waves at an angle. Angle probes are useful for detecting flaws not located by normal probes.
3. A storage battery for supplying current. The battery is required to be charged at certain intervals. For this purpose spare batteries are kept for replacement.
4. A jar containing water which serves as a couplant to avoid air gap between the probe surface and the rail table.

Ultrasonic waves transmitted form the probes get reflected backward whenever they encounter any change in medium. On a flawless rail, the waves are reflected from the rail table and later from the rail bottom. On the oscilloscope screen, these reflections appear in the form of two peaks. The distance between the two peaks is equivalent to the time interval between the reflections which indirectly represents the rail height.

On a defective rail, the waves are reflected from the table and then from the flaw surface. They seldom reach the rail bottom. In this case, the second peak is nearer to the first peak and the interval between the peaks indicates the depth of flaw from the rail table.

With proper calibration of the instrument it is possible to ascertain:

(a) The type of flaw,
(b) Magnitude of the flaw, and
(c) Location of the flaw.

USRD operators are trained in correct interpretation of peak pattern on the screen to determine the nature of flaw.

2.33.2 Modern Rail Flaw Detectors

Modern rail flaw detecting equipment use probe wheels for detection. Two probe wheels are deployed for each rail. One probe wheel is fitted with five crystals: zero, 38 degree (Forward and Reverse) and 70 degree (Forward and Reverse). The second wheel is fitted with two crystals shooting into the gauge and field sides of the rail head at 45 degrees laterally.

These are the defects which they target.

Probe degree	*Primary target*	*Secondary target*
Zero	Horizontal split head Horizontal split web Pipe Weld defects	Bolt Hole cracks Massive inclusions Hydrogen flakes
38	Bolt Hole Crack Weld defects in head, web and central foot horizontal split web Hydrogen flakes	Horizontal split head Pipe
70	Transverse defects in head Horizontal Split head Weld defects in head and upper web	Massive inclusions Hydrogen flakes
45	Vertical split head	All head defects

2.33.3 Frequency of Need-based Testing of Rails and Welds

After the initial testing of rails in rail manufacturing plant, the first retesting need not normally be done until the rails have undergone 15% of the service life in GMT as given in the Table 2.10.

Table 2.10 Assessed Service Life of Rails

Gauge	*Rail section*	*Assessed G.M.T. service life for T-12 72 UTS rails*	*Assessed GMT service life for T-12 90 UTS rails*
B.G.	60 kg	550	800
	52 kg	350	525
	90 R	250	375
M.G.	75 R	150	225
	60 R	125	–

For rails rolled in April 1999 and later, the test free period shall be 25% instead of 15%.

Frequency of testing for all BG and MG routes is given as under in Table 2.11. For other sections Chief Engineer of the Railway may adopt a frequency at his discretion.

Table 2.11 Frequency of Testing for All BG Routes

Route	*Routes having GMT*	*Testing Frequency Once in*
All MG routes	< 2.5	5 Years
	2.5 – 5.0	3 Years
	>5	2 Years
All BG routes	≤ 5	2 Years
	$>5 \le 8$	12 Months
	$>8 \le 12$	9 months
	$>12 \le 16$	6 months
	$>16 \le 24$	4 months
	$>24 \le 40$	3 months
	>40	2 months

Testing of AT welded joints shall comprise testing by probes as per Table 2.12.

Table 2.12

S.No.	*Probes*	*Scanned area*	*Remarks*
1.	0° 2 MHZ	Head, web	-
2.	70° 2 MHZ	Head, web foot	-
3.	70° 2 MHZ (8 mm × 8 mm)	Weld foot (Half Moon Defect)	-
4.	45° 2 MHZ	Weld foot (Half Moon Defect)	To be done as an alternative to S. No. 3 whenever feasible.

The frequency of testing AT welds with above listed probes is given in the Table 2.13.

Table 2.13 Frequency of Testing of AT Welds

S. No.	*Types of welds*	*Type of testing*	*Testing schedule*	
1.	Conventional AT	Initial acceptance test	Just after execution of weld as per A T welding manual	
2.		First periodic test	On completion of one year service life by weld	
3.		Subsequent periodic tests	Every 40 GMT after first periodic test	
4.	SKV	Acceptance test	Immediately after welding	
5.		First periodic test		
			Routes having GMT	Frequency
6.		Further periodic test	>45	2 Years
7.			$>30 \leq 45$	3 Years
8.			$>15 \leq 30$	4 Years
9.			0–15	5 Years

The USFD testing can be dispensed with in case of those welds which are more than 15 years old and protected by joggled fishplates with two far end tight bolts.

Through Weld Renewal should be planned after the welds have carried 50 percent of the stipulated GMT of rails. Among the various section, due for Through Weld Renewal (TWR) as per this criteria, Chief Track Engineer will decide inter se priority based on incidences of defects detection and weld failures.

Flash Butt Welds In case of flash butt welds normally there is no need for hand testing (with 45° and 70° probes), however, Chief Engineer may order hand probing with these probe in case failure rates are high in his opinion.

2.33.4 Classification of Defective Rails

Depending upon the nature of flaw, the defective rails are classified into the following categories.

1. *IMR rails* (*Immediate Removal*): These are rails which indicate defects warranting their removal from track. The defects on these rails are marked with red paint.
2. *OBS rails* (*Observe*): These are rails which have defects not warranting their removal from track. But the rails are to be kept under observation to watch the development of flaw. These defects are marked with yellow paint of the rail.

2.33.5 Classification of Rail/Weld Defects under Need Based Concept of USFD

For Rail Defect (*Table 2.14*)

Table 2.14

Probe used	*Nature of defect*	*Oscillogram pattern*	*Classification*

Normal probe
4 MHz (Sensitivity set with 5 mm dia standard hole at rail web foot junction)
	Within fishplated area:
	(i) Any defect connected with the rail end in any location (head, web, foot junctions) of the rail end covering both the bolt hole length or covering first bolt hole
	(ii) Any defect connecting both bolt holes
	(iii) Any defect originating from bolt holes and extended upto head web junctions or web/foot junctions
		For (i) and (ii)
		No back echo flaw echo with or without multiples
		OR
		Drop in back echo with flaw echo with or without multiple
		For (iii)
		No back echo with or without flaw echo
			IMR

Normal probe 4 MHz (Sensitivity set with 5 mm dia standard hole at rail web foot junction)	Outside fish plated area: (A) Any horizontal defect progressing at an angle in vertical plane in the rail head at the following locations: 1. In tunnel 2. On major bridges and bridge approaches (100 m) 3. In the vicinity of holes near the weld	For A 1, 2 and 3 No back echo with shifting flaw echo OR No back echo and no flaw echo	IMR
	(B) Any horizontal defect progressing transversely toward the rail head or foot at any other location	For B No back echo with or without shifting flaw echo	OBS
70° Probe 2 MHz (Sensitivity set with 12 mm dia Standard hole at rail head 25 mm from rail top)	1. Any transverse defect in the rail head	Flaw echo of 50% horizontal scale movement and 60% of full scale height or more	IMR
	2. Any transverse defect in the rail head at the following locations: (i) In tunnel (ii) On major bridges and bridge approaches (100m) (iii) In the vicinity of holes near the weld	Flaw echo of 30% horizontal scale movement and 20% of full scale height or more	IMR
	3. Any transverse defect in the rail head at any other location.	Flaw echo of 30% to 50% horizontal scale movement and 20% to 60% of full scale height	OBS

(Contd.)

Probe used	*Nature of defect*	*Oscillogram pattern*	*Classification*
Normal probe 4 MHz (Sensitivity set with 5 mm dia standard hole at rail web foot junction)	Vertical longitudinal split (piping)	In case of partial/complete loss of back echo, side probing shall be carried out 0° probe, if any flaw echo with/without multiples is observed (in any length)	IMR

For Weld Defect (AT + FBW)–(Table 2.15)

Table 2.15

Probe used	*Nature of defect*	*Oscillogram pattern*	*Classification*
Normal probe 4 MHz (Sensitivity set with 5 mm dia standard hole at rail web foot junction)	(A) Any horizontal defect progressing at an angle in vertical plane in the rail head at the following locations: 1. In tunnel 2. On major bridges and bridge approaches (100 m)	No back echo with shifting flaw echo	For A 1 & 2 IMRW
	(B) Any horizontal defect progressing transversely in the rail head at any other location	For B No back echo with shifting flaw echo	OBSW
70° probe (Sensitivity set with 12 mm dia. Standard hole at rail head 25 mm from rail top	1. Any transverse defect in the rail head	Flaw echo of 50% horizontal scale movement and 60% of full scale height or more	IMRW
	2. Any transverse defect in the rail head at the following locations: (i) In tunnel (ii) On major bridges and bridge approaches (100 m)	Flaw echo of 30% horizontal scale movement and 20% of full scale height or more	IMRW
	3. Any transverse defect in the rail head at any other location.	Flaw echo of 30% to 50% horizontal scale movement and 20% to 60% of full scale height	OBSW
70° 2 MHz probe (flange testing for AT welds)	Any defect in the weld	A moving flaw signal of 50% or more height observed in any one of the six zones OR A moving flaw signal of 40% or more height observed in any of the two zones	DFW

2.33.6 Action to be Taken after Detection of Defects under Need-based System

Following action shall be taken in respect of defective rails and welds (Table 2.16).

Table 2.16 Rail and Welds

S. No.	*Classification*	*Painting on both faces of web*	*Action to be taken*	*Interim action*
1.	IMR IMRW	Three cross with red paint	The flawed portion should be replaced by a sound tested rail piece of not less than 6 m length within 3 days of detection	PWI/USFD shall impose speed restriction of 30 kmph or stricter immediately and to be continued till flawed rail/weld is replaced. He should communicate to sectional PWI about the flaw location who shall ensure that clamped joggled fishplate is provided within 24 hrs.
2.	OBS OBSW	One cross with red paint	Rail/weld to be provided with clamped joggled fishplate within 3 days. PWI/USFD to specifically record the observations of the location in his register in subsequent rounds of testing.	PWI/USFD to advise sectional PWI within 24 hrs about the flaw location. Keyman to watch during daily patrolling till it is joggled fish plated.

2.33.7 AT Welds

Action to be taken for defects in AT welds shall be same as at Sec. 2.33.6 above. In addition, the following shall also be applicable for welds classified as defective (DFW) in periodic testing of AT welds with 0° 2 MHz, 70° 2 MHz, 45° 2 MHz, 70° 2 MHz (8 mm × 8 mm) probes:

Table 2.17

Classification	*Painting on both faces of weld*	*Action to be taken*
Defective weld 'DFW', with 0° 2 MHz, 70° 2 MHz, 45° 2 MHz or 70° 2 MHz (8 mm × 8 mm) probe	Two cross with red paint	SE/JE (P. Way)/USFD shall imposed speed restriction of 30 kmph or stricter immediately. He should communicate to sectional PWI about the flaw location who shall ensure following:

(Contd.)

Classification	Painting on both faces of weld	Action to be taken
		(i) Protection of defective weld by joggled fishplates using minimum two tight clamps/ 2 far end tight bolts one on each side after which speed restriction can be relaxed up to 75 kmph for goods train and 100 kmph for passenger trains on BG and 30 kmph for goods train and 60 kmph or passenger trains on MG.
		(ii) In case the protection of weld has been done using joggled fishplates with clamps, the defective weld shall be replaced within 15 days. However, in case the protection has been done using joggled fish plates with 2 far end tight bolts, the speed restriction imposed in (i) above shall continue till the defective weld is replaced which should not be later than 3 months. The defective weld with speed restriction as (i) above may be continued in track if the track is to be renewed within 12 months.

Action to be taken for flash butt and gas pressure weld defect shall be same as given in Sec. 2.33.6 above.

2.33.8 Action to be Taken after Detection of Defects in AT Weld:

Action to be taken for defects in AT welds shall be same as at Para 1 above and in addition to the following shall also be applicable for weld foot defects:

Table 2.18

Classification	*Painting on both faces of web*	*Action to be taken*	*Interim action*
Defective weld with 70° 1.25 MHz probe	Two cross with red paint	(i) The defective weld shall be replaced within 15 days.	(i) PWI USFD to advise PWI within 24 hours about the flaw location. Sectional PWI to impose speed restriction of 30 kmph till defective weld is replaced and post a watchman till joggled fishplates with clamps are provided.
		(ii) However, on track stretches where rail renewal is sanctioned, the defective welds shall be joggled fishplated	(ii) PWI/USFD to advise sectional PWI within 24 hours about the flaw location. Sectional PWI to impose

		and provided with 4 tight bolts and supported and visually inspected every month by an employee not lower than key man.	speed restriction on 30 kmph till joggled fishplating and provision of four tight bolts and supporting of the defective weld has taken place.

2.34 REPORTING OF RAIL FAILURE

Any failure of a new rail within 10 years of its laying in track is analytically investigated. Permanent-Way-Inspectors are therefore required to submit a detailed rail failure report of such rails on a proper proforma. Sketches indicating the gauge face and illustrating fractures usually accompany failure reports. Where metallurgical examination is needed, fractured rail pieces are sent to the chemist and metallurgist along with a copy of the report.

2.35 RAIL LIFTING AND HANDLING

The high carbon and alloy steel used in the manufacture of 90 and higher UTS rails renders the rails very sensitive to shock or impact loading, bruising, notching or marking on the surface, and point or line loading. This is especially true in handling the longer rails being produced in the rail mills welding plants. The staff handling such rails are required to:

1. Use strings made of flat link chains. Use of magnetic devices is preferable.
2. Use multipoint slinging for lifting of rails.
   Recommended locations for lifting points for various lengths of rail are given in the Table 2.19
3. Stack the rails on firm, level and well drained ground.
   Stack subsequent layers on uniformly placed spacers.
4. Place rails of shorter length in upper layers.
5. For flame cutting preheat minimum of 10 cm of rail length on either side of the cut about 250 – 350°C by uniform movement of heating torch.
6. Handle rail gently without sudden impact.
7. Use protective clothing, gloves and helmet of distinctive colour.

Table 2.19

Rail length (*m*)	*No. of lifting points*	*Distance between lifting points* (*m*)	*Max. rail end overhang* (*m*)
13	2	6.5	3.25
26	4	6.5	3.25
39	6	6.5	3.25
130	20	6.5	3.25
260	40	6.5	3.25

3 Chapter

Rail Joints

3.1 NEED FOR RAIL JOINT

As explained in the previous chapter, rails produced by manufacturers are of standard lengths. After laying the rails in the track, they are joined together to provide a continuous track. Over the years several methods of joining rails have been tried out to obtain such a joint as could provide continuity equal to that of the rail.

Presently, rail joints throughout the world employ two solid steel bars called fishplates. The fishplates are used to fasten the rail lengths together with fishbolts and nuts. At the time of fastening, the rail-ends between the fishplates are held in required position via-à-vis their horizontal and vertical planes.

3.2 REQUIREMENT OF RAIL JOINT

An ideal rail joint should be able to perform the following functions:

1. It should hold the rail ends in the correct position, both in the horizontal and vertical planes.
2. It should provide elasticity equal to that of the rail.
3. It should allow free expansion and contraction of the rail.
4. As the contact surfaces wear out under traffic, necessary adjustment in the joint should be possible to retain level and line.
5. The joint components, i.e. fishplates, bolts and nuts, should not be very heavy.
6. It should be easy to maintain and the cost of maintenance should be minimal. The cost factor should always be borne in mind because nearly 25 percent of the track maintenance cost in other than LWR tracks is for the joints alone.
7. It should permit easy replacement of any single rail from the track.

Some of the above mentioned requirements are at variance with each other. Thus, efforts are made to arrive at the best possible design.

3.3 DESIGN OF FISHPLATED JOINTS

The structural objective of a fishplated joint is to transmit the bending moment and shearing force developed in the members by the action of external loads from one member to the other. If the combined moment of inertia of the fishplates is equal to that of the members on either side, and the connections between the fishplates and the members are 100% efficient, then the bending moment and shearing force in the fishplates will be such as though the beam is continuous. For obvious reasons, when rails are butt jointed it is impracticable to attach plates to the head or foot of the rails, and the size and shape of plates to be attached to the web is limited by the need to keep them out of the way of the wheel flanges. Consequently, no one has yet succeeded in designing a fishplated joint which has more than a small fraction of the moment of inertia of the rails. The moment of inertia of a pair of fishplate of 60 kg UIC rails is 875 cm^4, as compared to moment of inertia of 3055 cm^4 of the rail.

Nevertheless, the bending moment actually transmitted across a standard fishplated joint, assuming that the connections are 100% efficient, is 90% or thereabout of what it would be, if the rails were continuous. The bending moment in the fishplate in the gap between the rails is produced by a couple exerted on the fishing surfaces of the fishplate by the rail and vice versa, as shown in the Fig. 3.1.

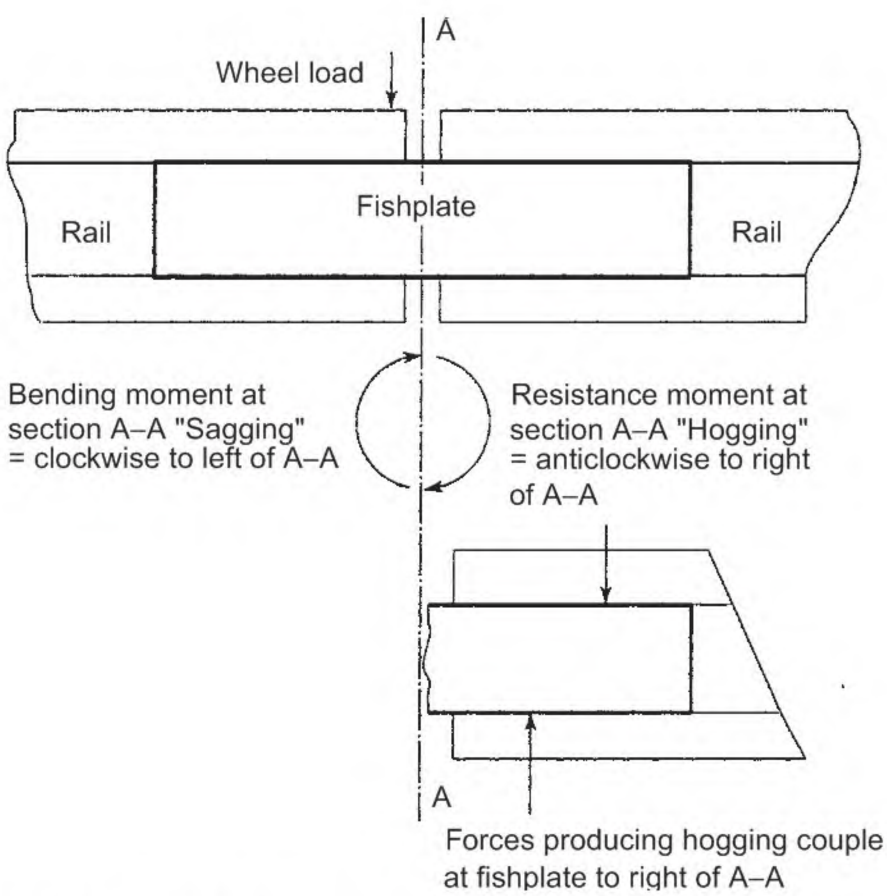
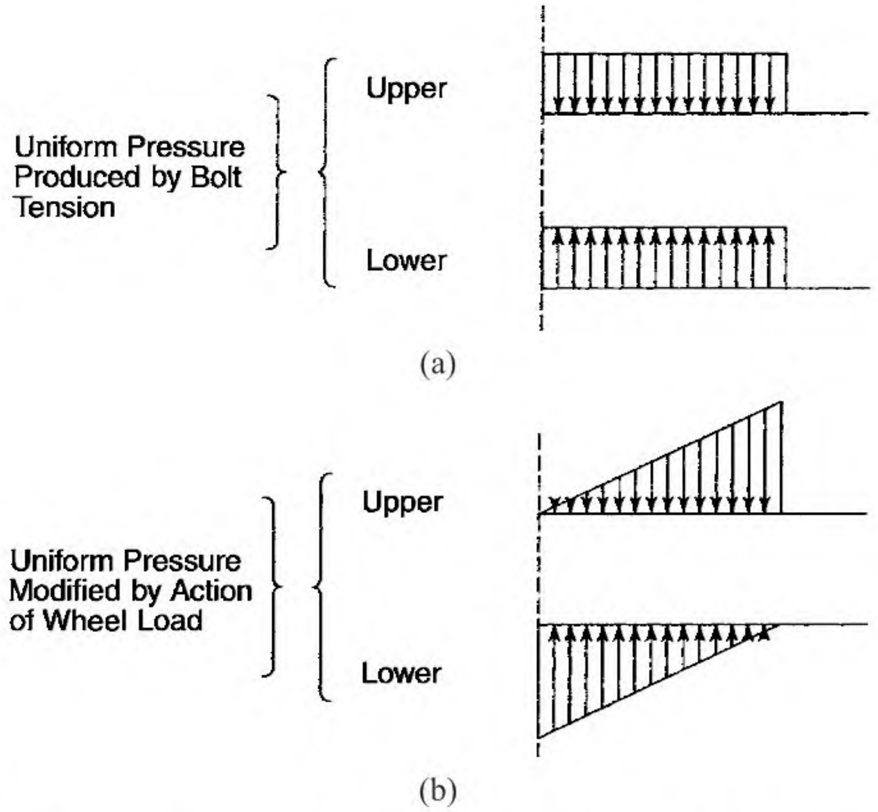


Fig. 3.1 Couple exerted on the fishing surfaces by wheel load

In practice, the forces across the fishing surface are not concentrated at a point but are distributed along the fishing surface. This distributed force varies in intensity, in somewhat triangular fashion, as shown in Fig. 3.2.



Note: The forces and pressure distribution reverse when the wheel crosses the gap

Fig. 3.2 Pressure distribution on fishing surfaces under wheel load

These forces are applied across the fishing surfaces, and are balanced by an equal and opposite force provided by the fishbolts. It is important to realise that the total force in the fishbolts is established when the bolts are torqued up; and it is the change in the distribution from uniform to triangular pattern-not change in the tension in the bolts-which provides the resistance moment to balance the bending moment produced by the wheel load. The peak value of the pressure depends upon the general condition of the joint, and it reverses with the passage of each wheel. It is this features which leads to wear and crushing of the fishing surface, and to correct this rail joint shims have been designed. Provided that bolts are properly torqued up to their full working load, the 25 mm diameter bolts in a standard four-hole 60 kg UIC fishplated rail joint provide sufficient clamping force to develop the bending moment required to be transmitted across the joint. Also, if the number of bolts is reduced to two, and the fishplate halved to match, the capacity of fishplate will be reduced to a quarter of the strength of the four bolt plate. Similarly, if the joint is adequate with four bolts, there is no reason to increase the number of bolts to six.

3.4 FEATURES OF FISHPLATE DESIGN

It would have been noted that the ability of the fishplate to develop the necessary bending moment at the gap between the rails depends on the clamping force exerted by the bolts. It is emphasised that it is not at all intended that the couple should be developed by interaction between the bolts and the holes in the rail web. Both, for this reason and to make provision for thermal expansion and contraction to take place, the holes in the rail web are made to 32.0 mm diameter about 7 mm larger in diameter than the diameter of bolts. For similar reasons, the fishbolt holes are also made larger than the bolts. In the current standard design they are drilled to 27 mm dia. The degree of slope of the fishing surface is an important parameter. This numeral data makes clear that the shallower the slope, the larger the force across the fishing surface for the same bolt tension, and therefore, the more efficient the joint. On the other hand, the shallower the angle, the greater is the pull required to maintain the clamping force when the fishing surfaces wear.

In most modern fishplates, the fishing angles slope at about 1 : 2.5 to 1 : 2.75 (the angle 60 kg UIC rail is 1 : 2.75). This angle has been found by experience to be a better compromise between good initial performance and maintainability. The top and bottom surface slope are at the same angle, as it has been observed that if they are different, the fishplates pull is irregularly ambiguous. The torque applied to standard fishbolts during tightening is not usually monitored or controlled by a torque limiting spanner. It has been found that when the bolt is tightened to refusal by a man of average strength using ordinary fishbolt spanner, a torque of about 50 kg-m can be applied. This is sufficient to develop the required bolt tension as indicated above. High strength bolts should be tightened with a torque limiting spanner set at 90 kg-m, unless specified otherwise.

3.5 STANDARD FISHPLATED JOINTS

Figures 3.3 (a–e) and Tables 3.1–3.5 give the details of the fishplated joints standardized for various rail sections in the Indian railways. Their broad features are discussed below.

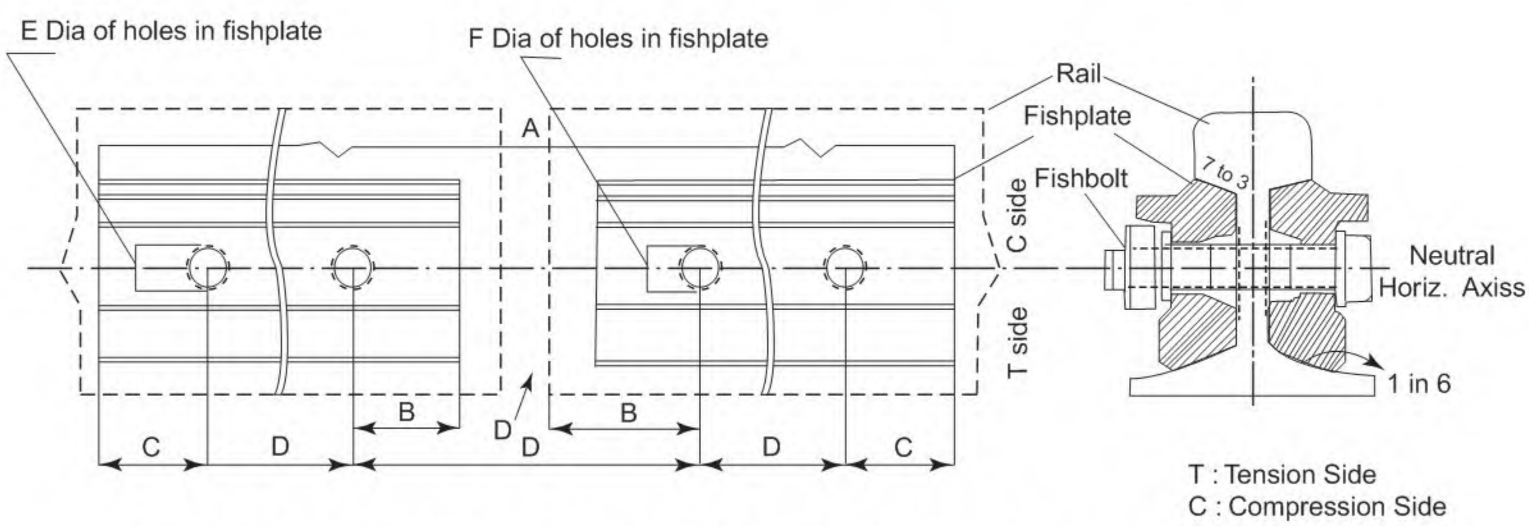


Fig. 3.3 (a) Fishplates for 50 R, 60 R, 75R and 90R rails (refer Table 3.1)

3.5.1 Fishplates

Whereas the "Revised British Standard" rail sections have been adopted for use in the Indian Railways, the British Standard Fishplates designed for these sections have not been considered suf-

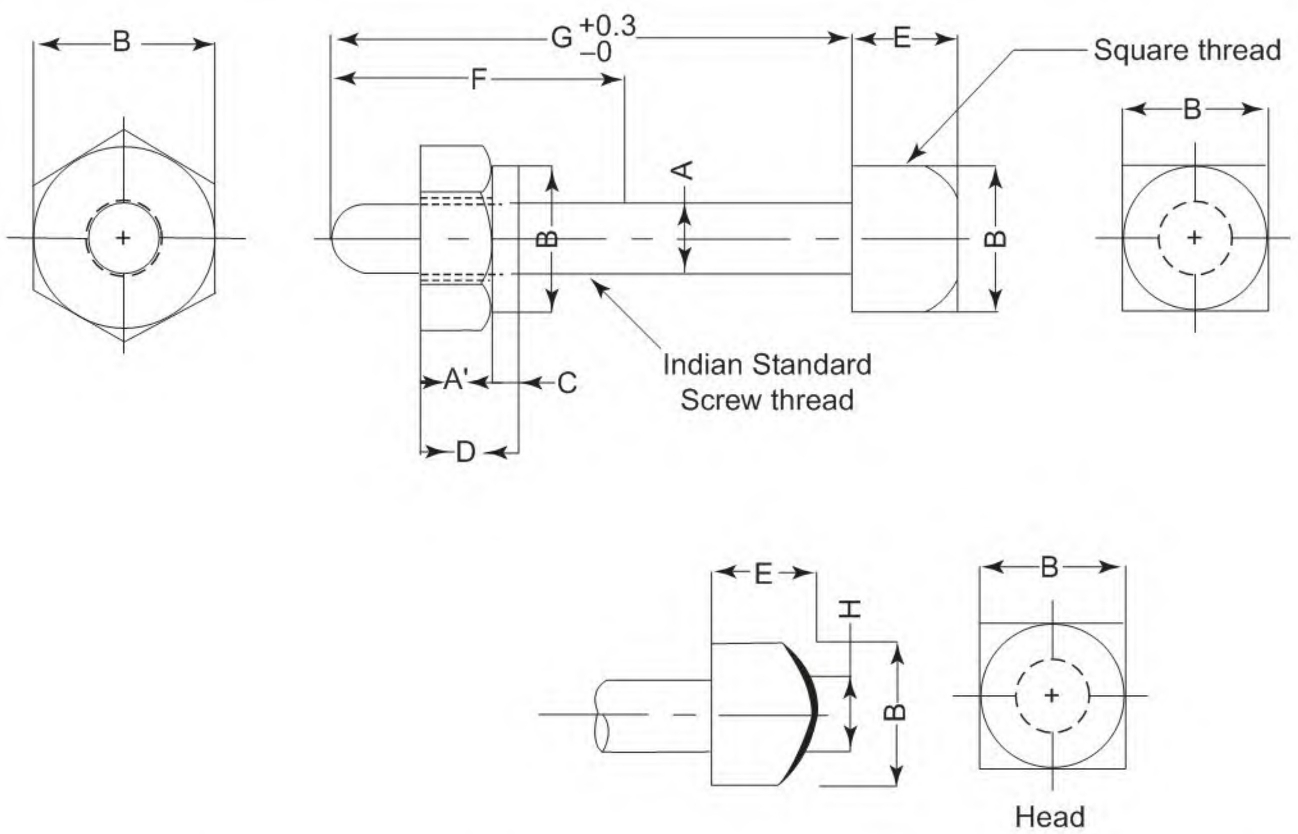


Fig. 3.3 (b) Fishbolts and nuts for 50 R, 60 R and 75 R 90 R and 52 kg rails (refer Table 3.2)

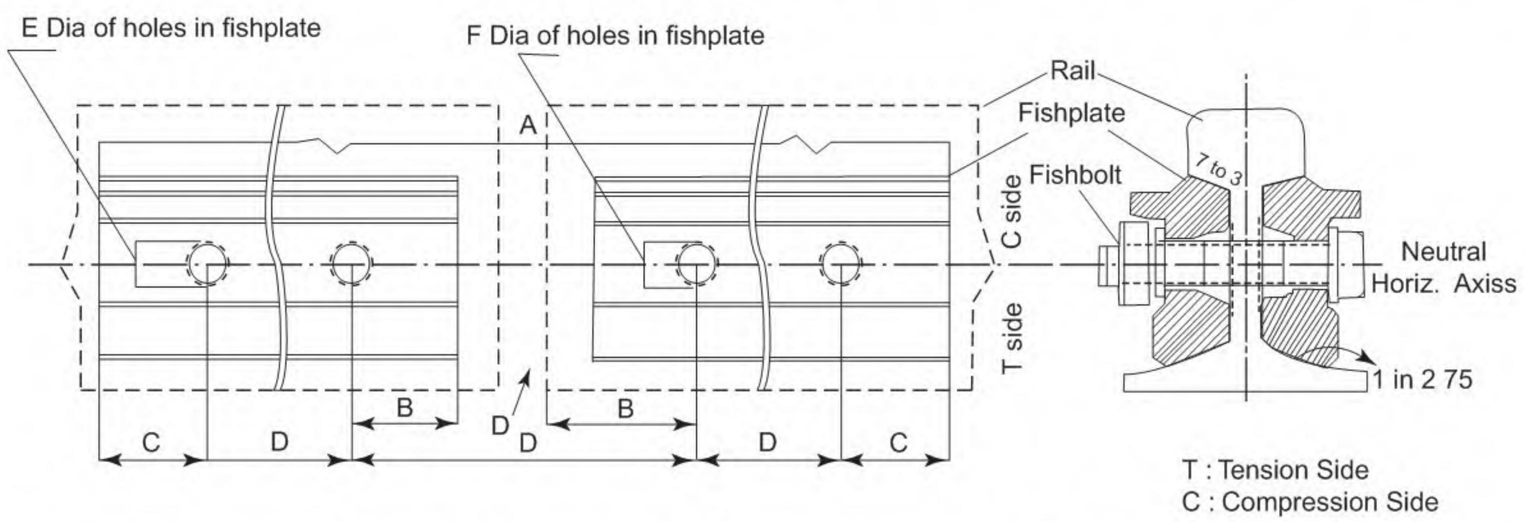


Fig. 3.3 (c) Fishplate for 52 kg rails (refer Table 3.3)

ficiently strong for adoption as standard in India. For this reason stronger and heavier fishplates have been designed and standardised. Extra metal has been provided at the top and bottom of the plates to lend additional stiffness and strength to them. For 90 R and heavier rail section, 610 mm long fishplates are used. Longer fishplates give added strength to the joint and reduce bolt hole stresses.

M-37 carbon steel billets with minimum UTS of 57 kg per square mm are used for rerolling into fishplates. The bolt holes in the fishplates can be either drilled or hot punched. The holes should be clean and without burrs on either side. The following tolerances are permitted in the positioning and diameter of the bolt holes.

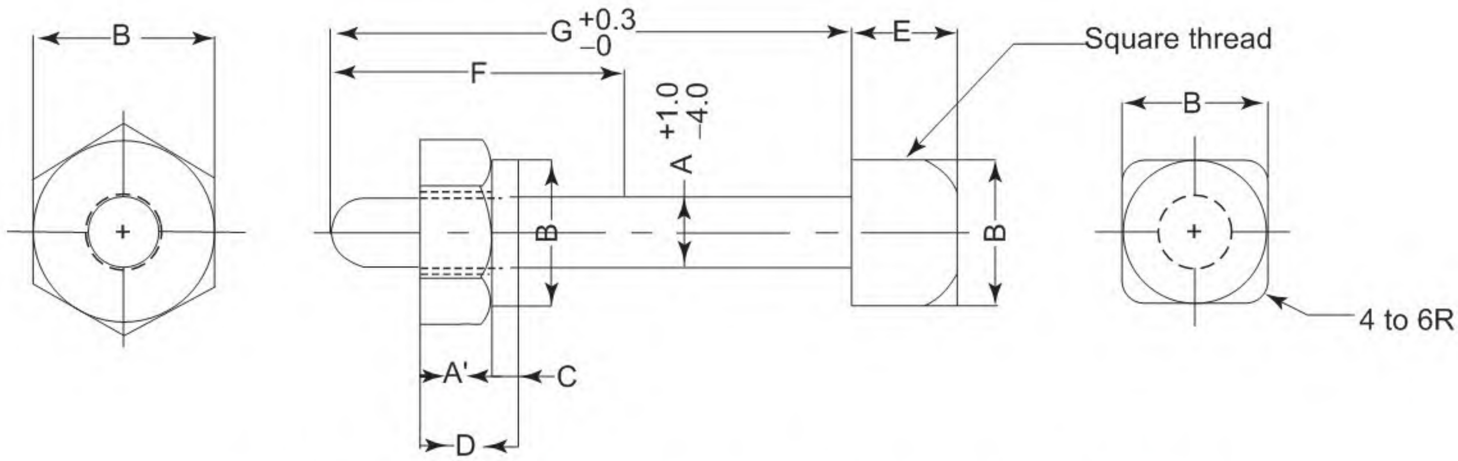


Fig. 3.3 (d) Fishbolts and nuts for 60 kg rails (refer Table 3.4)

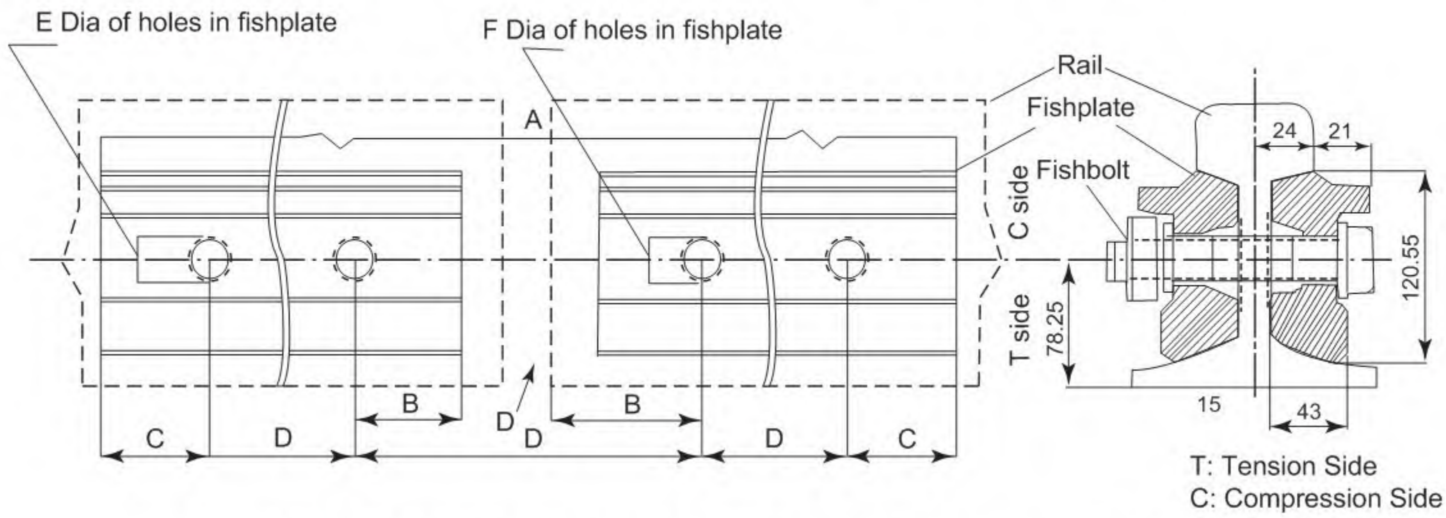


Fig. 3.3 (e) Fishplate for 60 kg rails (refer to Table 3.5)

1.	Position of the holes	−0.4 mm
		+0.4 mm
2.	Diameter of the hole	+0.8 mm
		−0.0 mm

3.5.2 Fishbolts and Nuts

Due to vibrations, fishplates are apt to get loose, and unless timely action is taken to tighten them, considerable wear occurs at the fishing planes. To prevent the bolts from getting loose, thicker nuts with thickness about 1 × 1/3 times the dia are used. Some railway systems use spring washers or lock nuts along with ordinary nuts for this purpose. The diameter of the holes in the fishplates is kept 2 mm more than the bolt diameter. The diameter of the corresponding holes in rails is kept 7 mm more than the bolt to allow for free expansion and contraction.

In India, bolts have square heads which can be held by a second spanner while tightening. In practice, the second spanner is often dispensed with by putting a wedge, consisting usually of a dog spike, between the bolt head and the rail foot.

Table 3.1 Main Dimensions and Properties of Fishplates

Rail Section BS No.	*Part No.*	*Dimensions* A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	*Weight approx (per pair)* (kg)
90R	T1 (M)	610	80	56	166	32	27	26.11
90R	T2 (M)	610	80	56	166	32	27	25.93
90R	T059 (M)	460	54	59	114	32	27	19.54
75R	T060 (M)	420	48	57	102	32	27	13.58
60R	T061 (M)	410	48	52	102	28	24	9.975
50R	CSO/C 1898 (M)	410	48	52	102	25	20	8.307

Table 3.2 Main Dimensions of Fishbolts and Nuts

Rail section	*Part number*	*Dimensions* A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)	H (mm)	*Weight approx. (with ordinary head)* (kg/piece)
52 kg, 90R and 75R	T11501	25 Dia	$41^{+0}_{-1.0}$	8	33 ± 0.80	22 ± 0.85	65	130	20.5	0.940
60R	T11502	22 Dia	$36^{+0}_{-1.0}$	7	29 ± 0.85	19 ± 0.65	51	105	18	0.654
50R	T11503	18 Dia	$32^{+0}_{-1.0}$	6	22 ± 0.65	17 ± 0.55	44	90	16	0.420

Table 3.3 Main Dimensions and Properties of Fishplate

Rail section	*Part number*	*Dimensions* A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	*Weight approx (per pair)* kg
52 kg	T090 (M)	610	80	56	166	32	27	28.71

Table 3.4 Main Dimensions of Fishbolts and Nuts

Rail section	*Part number*	*Dimensions* A (mm)	B (mm)	C (mm)	D (mm)	E (mm)	F (mm)	G (mm)
UIC 60 kg	RDSO/T-1899	25	$41^{+}_{-1.0}$	8	33 ± 0.80	22 ± 0.65	65	140

Table 3.5 Main Dimensions and Properties of Fishplate

Rail section	*Part number*	*Dimensions*						*Weight approx (per pair)*
		A (mm)	*B (mm)*	*C (mm)*	*D (mm)*	*E (mm)*	*F (mm)*	*(kg)*
UIC 60 kg	RDSO T-1898	610	80	56	166	32	27	35.20

Overtightening of the nuts causes jamming of fishplates and higher bolt hole stresses. It should therefore be avoided. Fishbolt spanners of standard length, i.e. 680 to 760 mm on BG and 530 to 610 mm on MG, are prescribed for this purpose.

The UTS of steel used for the manufacture of bolts should be between 55 to 65kg/mm^2 and for nuts between 47 and 63 kg/mm^2.

3.6 PROBLEMS OF THE RAIL JOINT

1. *Bolt Hole Rail Failures*

   The continuity of the rail is broken at the joint and even the best fishplated joint is hardly able to make good the loss of continuity. The strength of a pair of fishplates in bending does not, in practice, exceed 30 percent of that of the rail. In addition, the rail joints are subjected to severe knocking with the passage of each wheel. The condition is further worsened by (a) loose joint sleepers, (b) loose or overtight fishbolts, (c) wearing of the fishing planes, (d) battering and hogging of rail-ends and (e) excessive expansion gaps. Under such adverse conditions, when the stresses included in the rails at the joints are otherwise excessive, fishbolt holes act as stress raisers and serve as a focal point for the start of fatigue failure of rails. It has been estimated that rail-ends failures account for more than 60 percent of the total rail failures and quite a large number of these failures are due to bolt holes.

   The remedial measures include; (a) proper packing of joint sleepers, (b) tightening of fishbolts to optimum level, (c) use of shims on re-pressed fishplates, (d) welding of battered rail-ends and dehogging of rails, and (e) adjustment of gaps.

   In addition, fatigue resistance of the rail and the bolt holes is improved in the following ways.

   (a). *Reducing the stress concentration at the rail hole* This is possible by increasing the fishplate length and by reducing the bolt hole size. For BG in the Indian Railways, fishplate length has been increased from 460 to 610 mm. Trials with reduced bolt hole size and smaller dia. high tensile steel bolts are going on.

   (b). *Increasing the fatigue resistance* For this purpose two methods are being adopted:

1. *Chamfering*

(i) This is achieved by applying a pressure of 12.5 tonnes on both sides of rail holes with the help of a hard rounded tool. The tool when compressed rounds up the sharp corners of the hole and introduces compressive stresses in that region. With this method fatigue life of the rails at the hole has shown an increase of three to four times. A simple screw type arrangement for applying adequate pressure has been developed with which it is possible to do the job in the track itself.

(ii) *Cold expansion of bolt holes* With this method, a residual compressive stress field is set up in the steel, immediately surrounding the bolt hole. In the process an oversized mandrel is pulled through a disposable stainless steel liner inserted in the hole. It is important to ensure that the hole is truly circular and correctly formed with an internal finish of very high quality. This is achieved by two stage drilling.

The finished diameter of the holes after cold expanding is 0.7 mm wider. This process is not to be confused with Broaching. It is no longer in practice because of the damage it would cause while pushing of the oversize mandrel through the bolt holes.

In the cold expansion technique normal size bolt holes are treated. It is important that standard equipment be used and the proper procedure followed. The equipment is presently a patent of M/s Fatigue Technology INC. Seatle, Washington, USA.

2. *Wearing out of the Fishing Planes*

When wear takes place at the planes of rails and fishplates, the joint dips down. The wear is generally maximum at the centre of the top of fishplates and minimum at the ends.
Two types of devices are used for compensating the wear of the fishing planes:

(a) *Re-pressed fishplate*

The re-pressed fishplates are those which are hotforged to form a bulge in the middle part of the fishplate.

(b) *Tapered liners or shims*

Tapered shims are steel plates shaped to fit the usual pattern of wear between the two fishing surfaces. These are made in varying thicknesses. Each size is designated in mm according to the wear and this size between the fishing surfaces is multiplied by 10.

Thickness of shim is varied in the multiples of 0.5 mm, from 1.5 to 4.0 mm. Length of the shims is determined by the actual wear pattern of different sections of rails. Figure 3.4 indicates the type of tapered shim recommended for use in the Indian Railways.

3.7 LUBRICATION OF RAIL JOINTS

The purpose of lubricating rail joints is to facilitate expansion of rail and to retard wear on the fishing planes of the rail and fishplates. Reduced wear is one of the preventives for low joints.

A thick paste of plumbago (graphite) and kerosene oil in the proportion of 3 : 2 is used as a lubricant. Black oil or reclaimed oil is used for oiling fishbolts and nuts.

Rail joints are lubricated once a year during the winter months. The procedure to be followed is as under:

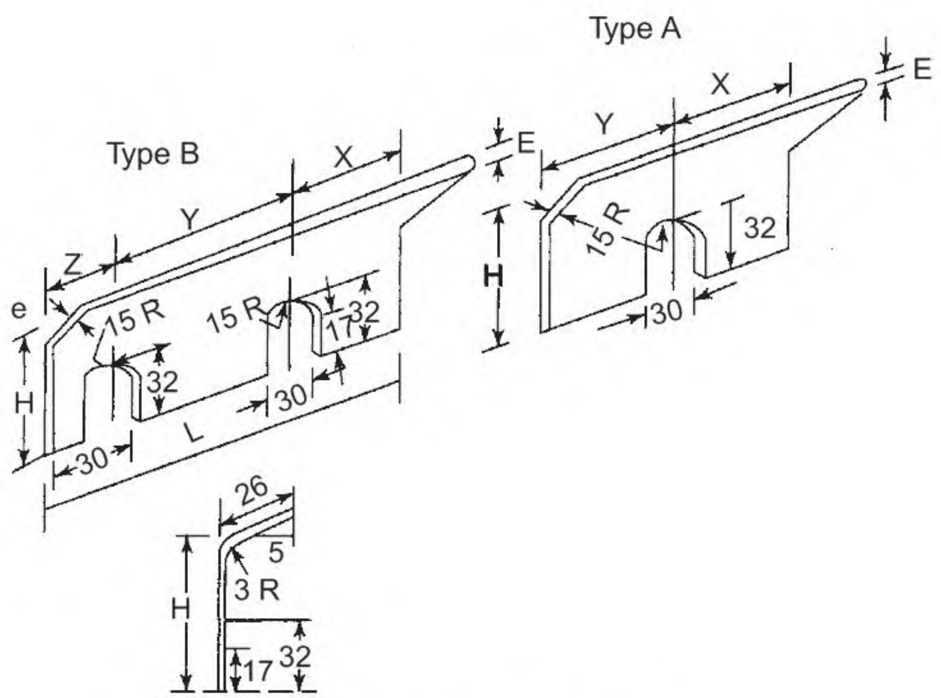


Fig. 3.4 Tapered shim

1. Unscrew the nuts and remove the fishbolts.
2. Clean the fishing surfaces of the fishplates and rail with a wire brush.
3. Inspect the rail-ends for cracks, and fishing surfaces of rails and fishplates for wear. Select appropriate size of shims, it is readily available and considered necessary.
4. Lubricate the fishing surfaces of the rails and fishplates and replace the latter with shims in case shims are to be provided.
5. Oil the fishbolts and nuts and put them back in the reverse position. Tighten them using a standard fishbolt spanner; the inner two bolts being tightened first.

If the traffic conditions so warrant, an alternate procedure of lubrication is adopted wherein at no time during the operation is there less than one fishplate and three fishbolts without nuts connecting the two rails.

3.8 SUSPENDED OR SUPPORTED JOINTS

On the basis of sleeper spacing adopted at the joints, rail joints are classified into the following categories:

3.8.1 Supported Joint

In this type the rail-ends are supported directly on a single sleeper or on two sleepers bolted together. On some railway systems a common bearing plate for the two joint sleepers is used [Fig. 3.5 (a)].

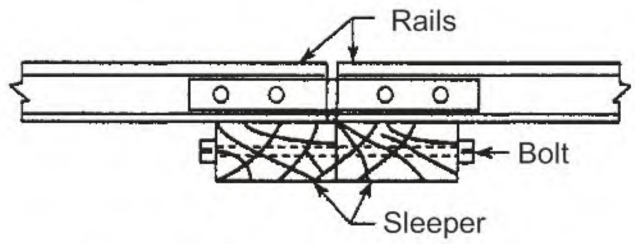


Fig. 3.5 (a) Supported joint

3.8.2 Suspended Joint

In this the rail-ends project beyond the joint sleepers. Usually, enough space is available for packing the joint sleepers from both sides [Fig. 3.5 (b)].

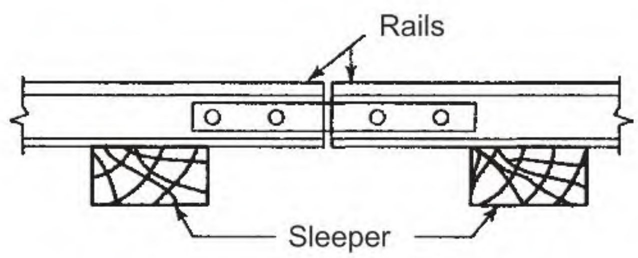


Fig. 3.5 (b) Suspended joint

3.8.3 Bridging Joint

It is a joint where a bridging plate is placed between the rail and joint sleepers. The joint is similar to the suspended joint in all other aspects [Fig. 3.5 (c)].

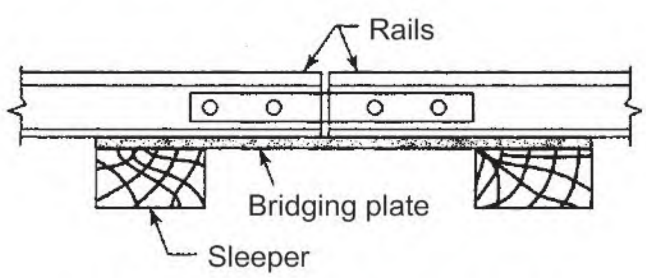


Fig. 3.5 (c) Bridging joint

3.8.4 Semi-supported/Suspended Joint

This is a kind of joint wherein the joint sleepers are brought closer to each other, but the rail-ends remain suspended between the bearings [Fig. 3.5 (d)].

This type of joint has been adopted as standard in the Indian Railway. On BG wooden joint sleepers, the suspended length of rail with and without bearing plates is 45 and 25 mm, respectively.

Which type of joint gives better performance? This will remain a debatable issue. The supported joints can stand more maintenance neglect, but they slow down the output of tamping

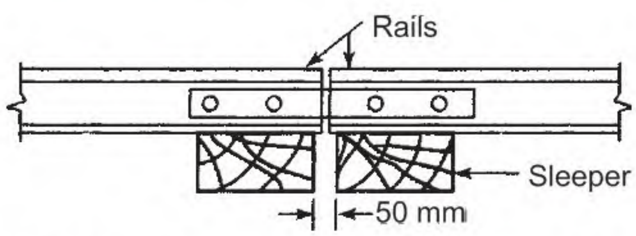


Fig. 3.5 (d) Semi-supported/suspended joint

machines, and cause greater incidence of rail-end batter. Suspended joints provide greater elasticity to the track and cause less disturbance to the wave motion of the track, but they require more maintenance. Perhaps, the semi-supported joints adopted in the Indian Railways provide a good workable via-media.

3.9 EXPANSION GAPS AT THE RAIL JOINTS

Expansion gaps are the gaps which are left between the rail-ends at the time of laying the rails in a track. It is done with the object to permit expansion from heat when the temperature rises.

For single rail fishplated track, the width of expansion gaps depends upon the length of the separate rail, temperature at the time of linking the track and the maximum annual rail temperature.

The expansion gap should correspond to the linking temperature. If the gap is less than required, the track may buckle in hot weather. Contrariwise, if the gap is more than required, the rail ends may get damaged.

Expansion gaps are kept in such a way that even at maximum rail temperature the rail ends have a gap of 1 mm. Expansion gaps at other temperatures are calculated by the formula as follows:

$e = L\,\alpha\,t \times 10^3$
e = expansion in mm
L = length of the rail in m (say 13 m)
α = coefficient of expansion of rail steel, which is equal to 0.00001152 per degree centigrade
t = change in temperature in centigrades.

Assuming a max. Rail temperature of 70°C, the expansion gap at 40°C will be:

$$= 1 \text{ mm} + (70 - 40) \times 0.00001152 \times 13 \times 10^3 \text{ mm}$$
$$= 1 \text{ mm} + 30 \times 0.01152 \times 13$$
$$= 1 \text{ mm} + 4.5 = 5.5 \text{ mm}$$

Data representing the expansion gaps vis-à-vis change at every 5°C rail temperature are tabulated and given to Junior Engineer/Senior Engineer (Permanent Way) in charge of linking. These JEs/SEs (P. Way) are provided with steel liners of varying thicknesses. Each liner is stamped to indicate the expansion gap is millimetres. The liners corresponding to prevailing rail temperature are inserted between the rail ends at the time of linking (Table 3.6).

Table 3.6 Table for 13 m Rail

Temperature range (°C)	*Expansion gap (mm)*
70–65	1
64–59	2
58–53	3
52–47	4
46–41	5
40–35	6
34–29	7
28–23	8
22–17	9
16–11	10
10–5	11

The expansion gaps are to be provided with rail free fastenings such as dog spikes/screw spikes on wooden sleepers. No change is required to be made in other fastening systems because the total resistance offered by the sleepers in those systems gets neutralized and the rail behaves as a free rail.

3.10 STAGGERING OF JOINTS ON CURVES

Rail joints are called "square" when a joint on one rail is exactly opposite to the joint on the parallel rail. With square joints on curves, there is a tendency for shoulders or kinks to form at the joints. This happens due to the inherent weakness of the track at the joint because the centrifugal force tends to push out the track more at the joint than elsewhere. On sharp curves, the rails always have a tendency to spring back and form kinks at the joints. To lessen this tendency, joints on sharp curves with radius of less than 400 M on B.G. and 300 M on M.G. are often staggered. The joint at one rail is kept facing the centre of the opposite rail, also called mid-stagger. This reduces the possibilities of forming shoulders or kinks at joints and indeed reduces the vertical disturbance of wheels at the joints. With staggered joints, the number of impacts at joints are doubled but their intensity is halved. The number of sleepers per rail length is also increased by one.

Staggering of joints on straight track is not favoured as it is reported to cause excessive rolling of vehicles.

3.11 AVOIDANCE OF JOINTS

To obtain better running surfaces, rail joints are avoided in (a) a level crossing, (b) within 3 m of the approach of a bridge abutment and (c) on bridge spans of 6 m and below. Rail joints on ash-pits are provided without any expansion gaps.

3.12 COMBINATION FISHPLATES

When rails of different sections have to be joined together, special fishplates are used. These are known as combination, junction or compound fishplates.

The Indian Railway Standard (IRS) combination fishplates have been designed with an adequate thickening up of the section in the middle portion, where the change in rail section takes place. Another feature of these designs is the elimination of the expansion gap, i.e. the rail ends are made to butt. This helps in making the joint considerably stronger than would be the case with ordinary joints.

A uniform system of marking the right or left hand and the inner or outer fishplates has been adopted. This illustrated in the key plan (Fig. 3.6).

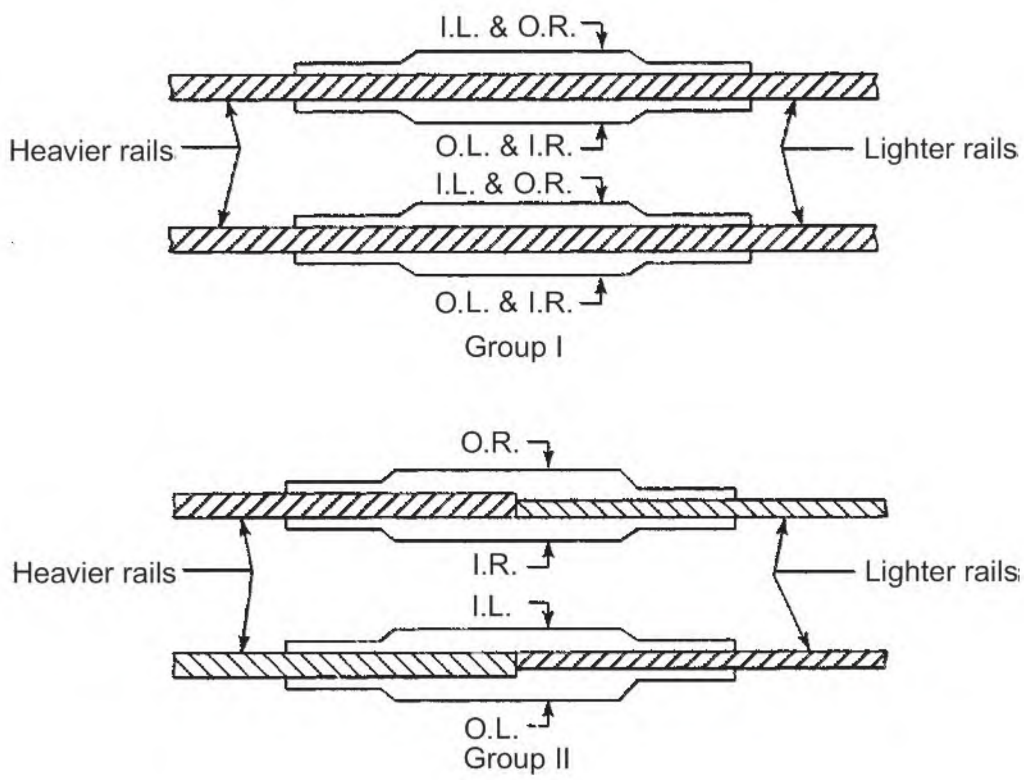


Fig. 3.6

The IRS design of combination fishplates comprises two main groups or sections:

Group I: Where the rails to be joined have the same head width. The combination fishplates in this group have identical IL and OR or OL and IR fishplates. These are 90 R–90 BS, 75 R–75 BS, 52 kg–90R, 52 kg–90 BS, 52 kg–60 kg.

Group II: When the rails to be joined have different head width. All the plates, i.e. IL, OR, OL and IR in this group, are different. These are 90R–75R, 90R–75 BS, 75R–60R, 75R–60 BS, 60R–50R.

IL – inside left	IR – inside right
OL – outside left	OR – outside right

3.13 COMBINATION WELDED RAIL JOINTS

Combination welded rail joints provide a good substitute to combination fishplates. For a combination weld, it is desirable to have rail pieces of 4 metre length each of the two rail sections. Thermit welding process is usually employed for making the combination weld. The mould and the portion used for the thermit weld are specially designed. Special moulds ensure the continuity of gauge face and evenness at the rail table. The 8 metre long combination rail so formed can be thermit welded to normal rails at either end.

It is preferable to have a longer combination rail of standard rail length-half rail length pieces welded together—particularly when the rail ends are to be fishplated. The longer length helps in minimizing the effect of rail-end disturbances on the rail stress—at the combination weld—which are usually high because of the change of modulus.

Flash butt welding can also weld rail sections that are not much different. In fact, the strength and durability of these welds exceeds that of thermit welds.

3.14 JOGGLED FISHPLATES

Joggled fishplates are usually made out of old/released standard fishplates by providing a suitable bulge in the central part of the plates (Fig. 3.7). This helps in avoiding interference with the weld collars of thermit welds. Elongated holes are made in the fishplates to take care of varying degrees of gaps that may exist at the weld fractures. A full complement of four clamps is provided for firm grip at the rail-ends in case of undrilled rails.

Joggled fishplates are commonly used at:

1. *New thermit weld* till it is ultrasonically tested, additional support of wooden blocks is given at the welded joint. If weld is categorised as 'good' the joggled fishplates and wooden blocks are removed. In case the weld is declared defective and placed in IMR or OBS category, the joggled fishplates are left permanently in the track to ensure safety in train operation in the event of sudden fracture of the weld.
2. *Old defective weld* categorised as IMR or OBS after ultrasonic testing.
3. *Weld fractures* where joggled fishplates are used to hold the rail-ends together and pass the traffic at restricted speed till proper repair work is carried out.

3.15 MITRED RAIL JOINTS

These are used as rail expansion joints of bridges. To avoid the thermal stresses of the bridge girders being transferred to the rails and vice versa, rails on bridges are laid with rail-free fastenings. The rails are also welded into span lengths. Mitred rail joints are provided on bridges at the abutments and piers to accommodate wider expansion gaps of rails.

Two types of mitred joints have been designed:

1. With the rail-end mitred.

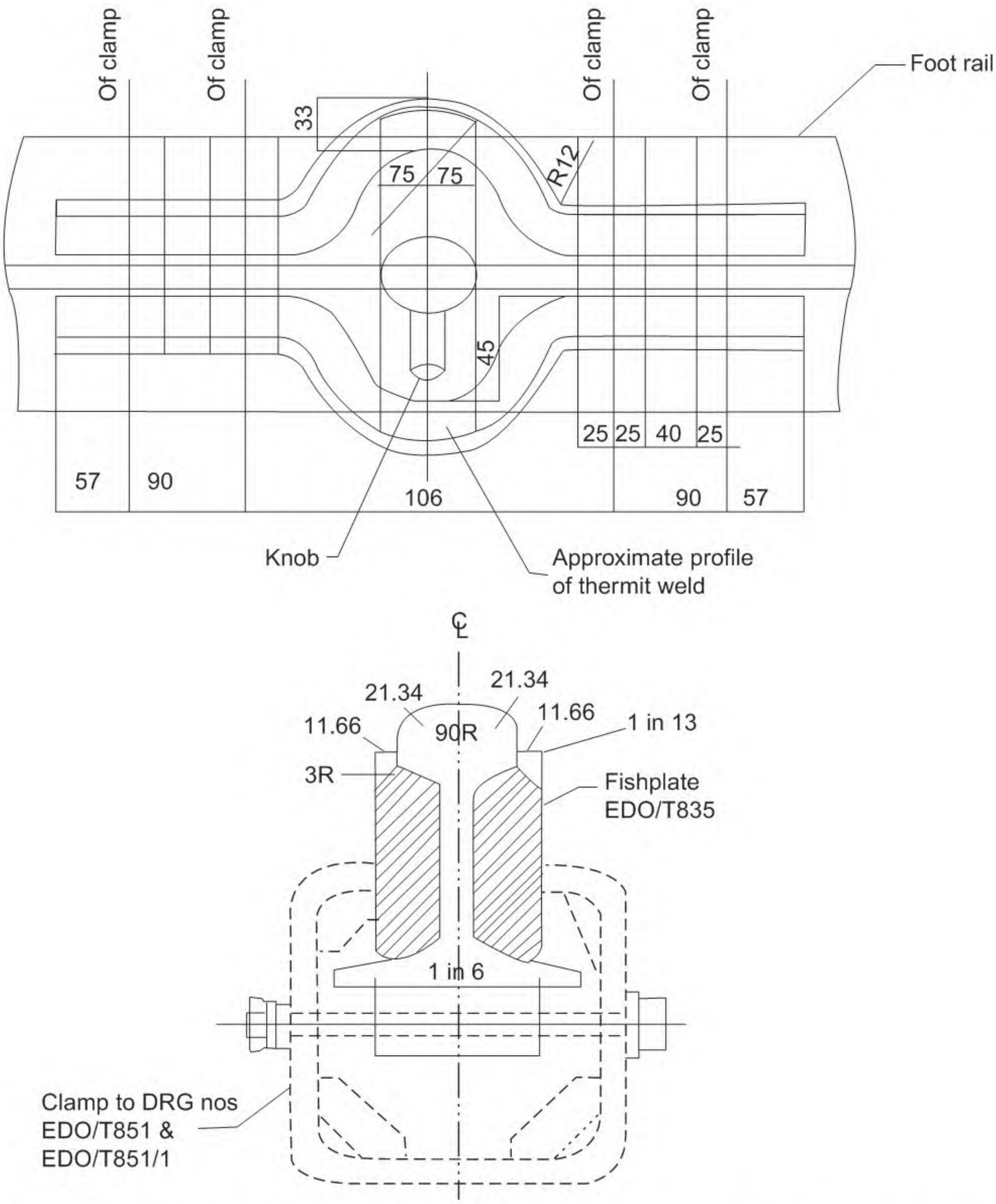


Fig. 3.7 Joggled fishplates and clamps for rail fractures BG for BS No. 90R

2. With the rail-end mitred with a central rail piece in between.

Type 1 is used for short span bridges up to 30.5 m and Type 2 on long spans above 30.5 and up to 76.2 m. In both the types, the outer fishplate is of special section, whose top face is at level with the rail table, to support the wheel tread over the expansion gaps. This gap is 26 mm in Type 1 and 33 mm between the rail end and the central piece making a total of 66 mm in Type 2. For canted or uncanted rails suitable types have been made.

3.16 INSULATED RAIL JOINTS

Modern signaling system depends on track circuits wherein a portion of the track is insulated from the adjoining track. This is accomplished with the help of insulated rail joints. Presently various types of insulating joints being used in being Indian Railways are described here.

3.16.1 Conventional Insulated Joint

In these the standard fishplates have to be skimmed on the fishing planes to accommodate channel type insulation between the rail and the fishplates (Fig. 3.8). Other insulating features are an end post between the rail-ends and bushes around the fishbolts. Nylon/fibre glass is used as an insulating material.

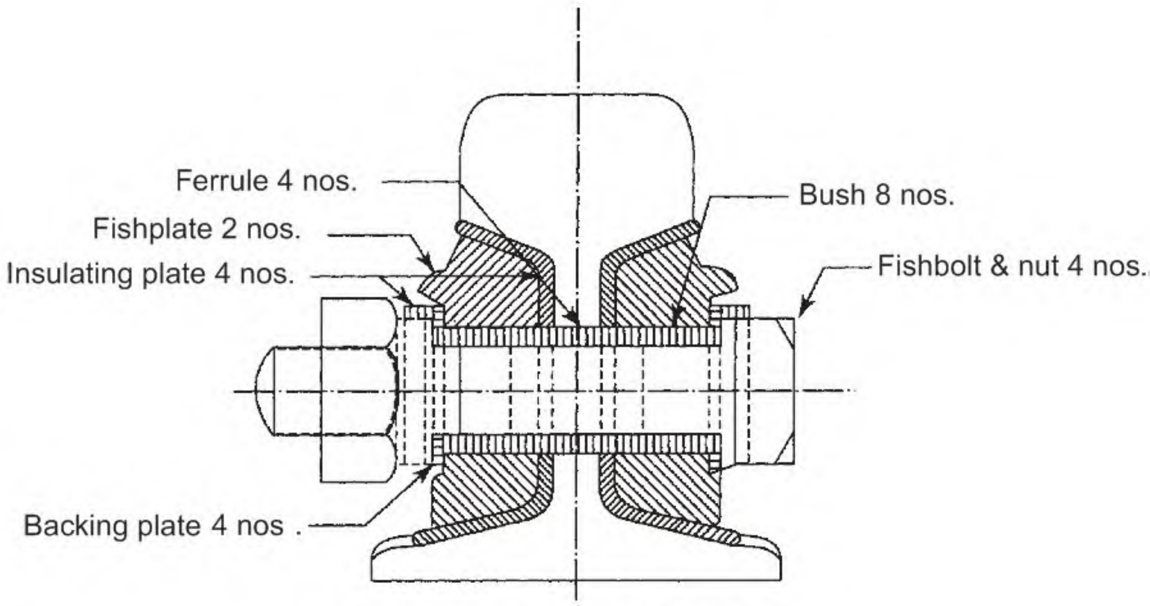
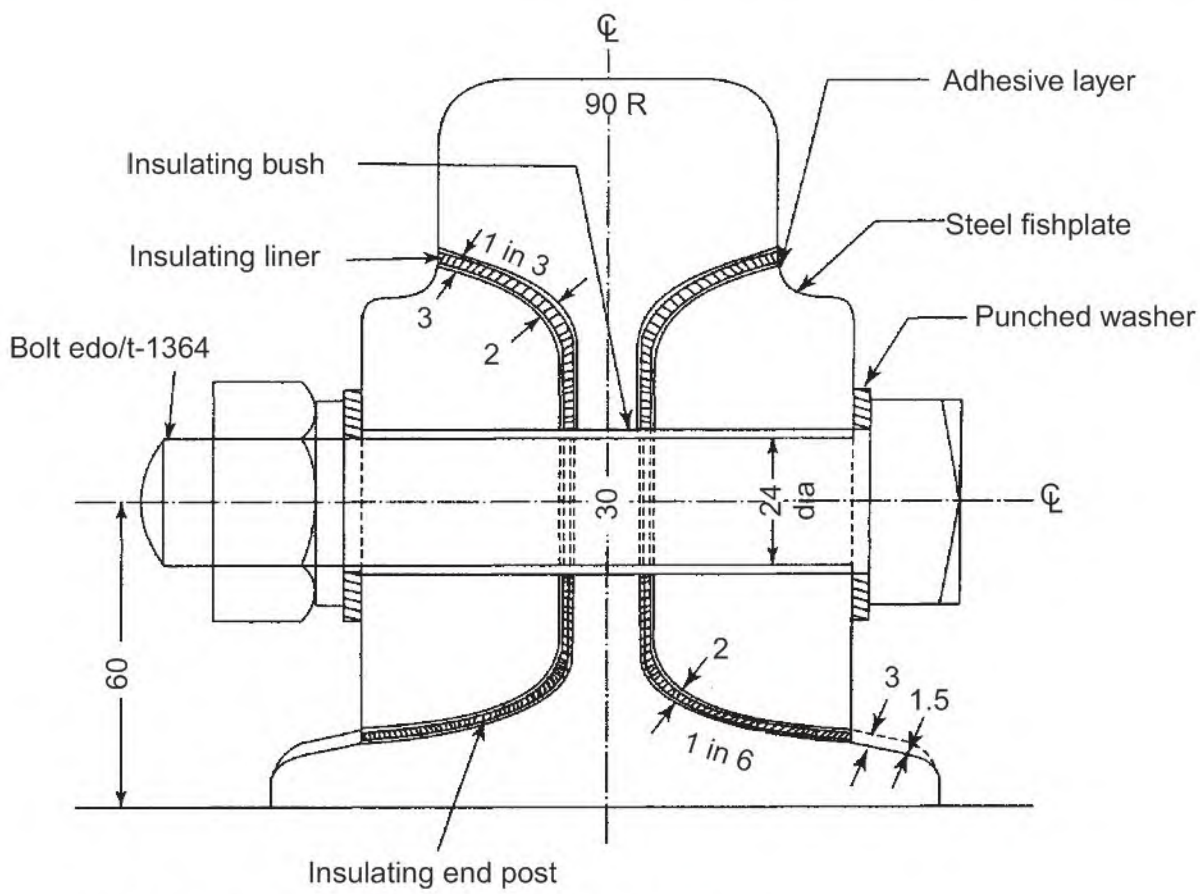


Fig. 3.8 Insulated rail join

An important designing feature of these insulation joints is that there is no allowance for expansion/contraction of rail. Conventional insulated joints require considerable care vis-à-vis their track maintenance during service. Joint packing and creep has to be specially looked after. These joints should not butt against an SWR, but have at least one rail length on either side and it should be box anchored.

3.16.2 Glued Insulated Joints

Glued insulated joints consist of special web fitting fishplates glued to the rails by a high strength adhesive. High tensile steel bolts are used to ensure that rail and fishplates behave as one monolithic mass under high frequency vibrations. Although glue gives sufficient insulation separate fibre glass insulating liners are used to give additional safety margin. Suitably designed fibre glass end-post is used between the rail-ends. Fishbolts are provided with fibre glass insulating sleeves (Fig. 3.9). After the glue is fully set, no relative movement between the rail and other component is possible and thus for all practical purposes the joint behaves like a welded joint.



(i) All bolts shall be tightened to 20 tonne tension
(ii) All radii shall be 2 mm except where otherwise shown
(iii) All dimensions are in mm

Fig. 3.9 Glued insulated rail joint for BG BS No. 90R G-3 (L)

Two types of joints meant for different locations are in use:

(a) *G3 (L) for use with LWR/CWR track*
One metre long fishplates with 6 HTS bolts are used on this joint. It has pull-out strength of more than 160 tonnes and can safely carry high thermal forces of LWR/CWR through the joint.

(b) *G3 (S)*
This is similar to G3 (L) but has a smaller fishplate with only 4 HTS bolts. It has pull-out strength of about 100 tonnes and is best suited for fishplated and SWR track.

Great care is required to be exercised in the preparation of glued joints. Detailed guide lines issued for the selection of rails, sand blasting, chemical cleaning and proper assembling of joint should be scrupulously followed.

3.17 MODERN DEVELOPMENT IN INSULATED RAIL JOINTS

The advanced railway systems have developed two kinds of insulated rail joints to meet the specific functional requirements in track. They are easier to install, economical to maintain and give long years of trouble free service life.

3.17.1 Category I

These are high strength bolted and bonded insulating rail joints fit for continuous welded rail (CWR) on heavy density lines. These are fabricated in workshops and are delivered as a fitting piece having 4 m overall length. The insulating joints can also be fabricated with thicker fishplates for use on heavier axle load lines. The joint assembly is made with four high strength bolts for all applications and hence fishplates are of shorter length as compared to Indian six-bolted assemblies.

Measures adopted to improve service life are:

(a) Head hardening of rail-ends.
(b) High quality polymer for end-post and bushes.
(c) Superior glue technology.
(d) Cold expansion of bolt-holes for improving fatigue life.
(e) Forged fishplates of thicker section and superior steel.
(f) Improved thermit welding techniques.

With these measures, the service life of the glued insulated joint is claimed to be comparable to the service life of the parent rails themselves. The joints are taken out of the track only at the time of rail renewal, thereby leading to considerable savings in track maintenance. Furthermore, these joints reduce the incidence of traffic disruptions.

3.17.2 Category II

These are non-bonded type of insulated rail joints, where the fishplates are non-conducting. These are supplied as web fitting fishplates with 4 or 6 fishbolts and can be fitted in track in place of ordinary fishplated joints. There is no application of glue or additional insulating liners except the insulating end-post between the butting rail ends.

Presently, two kinds of non-conducting fishplates are used in rails all over the world. These are made of:

(a) Solid fibre glass reinforced plastic, scotch-ply or polyurethane or
(b) Steel core encapsulated with rubber, polyurethane, resin or such other high strength non-conducting material

Their service life being more than 10 years, these joints are extensively used in their four-holed fishplate version in jointed tracks throughout the developed railway systems. The author has seen one such fishplated joint in Helsinki railway yard Finland, performing satisfactorily albeit one derailment over this joint.

The longer, i.e. six-holed nonconductive fishplates can be used in place of glued insulated joints in LWR territory. They derive their longitudinal resistance on account of surface friction which is enhanced by the roughness of their contact surfaces besides the shear strength of the bolts. The use of such fishplates provides an economical alternative to the glued joint on lines subjected to less arduous conditions.

3.18 MAINTAINABILITY OF RAIL JOINTS

The following guidelines have been laid down for achieving better maintainability of rail joints on BG tracks.

1. Fishplated joints will have wooden and concrete sleepers. The spacing of joint sleepers will be 300 mm for wooden and 340 mm for concrete sleepers. Wooden sleepers will be provided with rail free fastenings usually of canted bearing plates with full complement of four rail screws. Concrete sleepers at joints will be provided with ERC-J clips (RDSO/T-4158) specially developed for use at rail joints.
2. Welded joints will have normal sleeper spacing i.e. the same as at mid rail.
3. Defective welds, both in OBS category, will be provided with joggled fishplates and IMR category weld to be removed within three days of detection.
4. Glued joints will have normal sleepers spacing with a joint gap to be symmetrical to the adjoining sleepers.

4 Chapter

Sleepers

4.1 HISTORICAL DEVELOPMENT

Sleepers in railway track perform two important functions: (a) hold the track to gauge and (b) transmit and distribute the oncoming loads to the ballast underneath.

In the past, sleepers for railway track consisted of slabs of stones or longitudinal timbers laid continuously under the rails. With the evolution of better rail design, it was not considered necessary to give a continuous support to the rails. Intermittent supports, with a positive means of holding the gauge, were found to be more advantageous. This led to the adoption of cross sleepers, which were first introduced in Britain in 1835, and are now employed universally.

4.2 REQUIREMENTS

Modern railway systems require much more in the sleeper than mere load distribution or holding of the gauge, although these remain the most important functions of the sleeper.

The main requirements are:

1. *Good hold over track geometry*: The sleepers should be able to provide good hold on track geometry and retain in perfect order the five essential track parameters, viz. gauge, cross-level, longitudinal levels, alignment and twist. Furthermore, sleepers should afford easy adjustment of gauge, whenever considered desirable.
2. *Fitness for modern track structure*: Sleepers should be fit for use in LWR/CWR track. Essential requirements for their fitness are: (a) heavy weight to lend stability to packing to track, (b) fastenings which have adequate continuous toe load, and (c) long retentivity to packing to avoid frequent attention to track.
3. *Maintenance with modern methods*: It should be possible to maintain the track with modern methods of track maintenance such as shovel packing and on-track tamping machines. The retentivity of packing with modern methods should also be reasonably good.

4. *Ability to absorb energy and vibrations*: Modern high-speed trains transmit considerable amount of impact energy to the track. High frequency vibrations are also generated in the rails. Thus sleepers should be able to absorb the impact energy and damp the vibrations to a considerable extent and transmit the rest to the ballast to take care of.
5. *Long life*: To obtain full benefits of LWR track, sleepers should have life span equal to rails, if not more.
6. *Economical in annual cost of service*: The sleeper should prove economical vis-a-vis the initial cost, cost of maintenance, the longevity and the scrap value.
7. *Easy to manufacture, transport and lay*: The machinery and plant required to manufacture sleeper should not be very costly. The methodology of transport and laying of sleepers, should be simple and economical.
8. The fastenings should be secure enough to forestall *theft* and *sabotage*. However, they should permit easy release of rails for distressing of LWR.
9. Should provide *good track circuiting*.
10. Should have as *few components as possible*.
11. Should be able to *withstand derailments* without excessive damage.

It would be seen that some of the requirements are at variance with each other. Therefore the search for an optimal sleeper design has to continue.

4.3 SLEEPER SPACING AND SLEEPER DENSITY

Sleeper spacing provided on a particular railway line depends upon (a) the strength of the rail, (b) the type and design of sleeper, (c) depth of the ballast cushion, (d) the bearing capacity of the formation and (e) the axle loads, volume and speed of traffic.

However, the sleeper density on a standard track structure is based on the volume (GMT) of traffic and the maximum permissible speed, the two factors which affect the maintainability of track. Although closer sleeper spacing is considered desirable but in some cases this spacing proves too narrow to allow for effective use of maintenance tools in-between the sleepers.

Sleeper density is denoted as M + 1, M + 2, M + 3 and so on where M represents a rail length in metres. It is also expressed as a number of sleepers per kilometer of track. For a standard 13 m rail, M + 4 density would mean 17 sleepers per rail length, including the joint sleepers. It is also equivalent to 1308 sleeper per kilometer of track.

The minimum sleeper density to be adopted on all future track renewals, as has been laid down on Indian Railways are given in Chapter 20.

Closer spacing is provided at the joint sleepers of the fishplated track and between the joint sleepers and the shoulder sleepers. This helps in providing adequate sleeper support at the joints and improves their maintainability.

The following sleeper spacing have been standardized (Table 4.1). For track laid on metal sleepers, it is preferable to use wooden sleepers at the joints.

Table 4.1

Item No.	*Sleeper location*	*Centre to centre spacing (maximum) in cm*			
		Wooden sleepers		Metal sleepers	
		BG	MG	BG	MG
1.	Between joint sleepers	30	25	38	33
2.	Between joint sleepers and first shoulder sleepers	61	58	61	58
3.	Between first shoulder sleeper and second shoulder sleeper	Mean of item 2 and 4			
4.	Between intermediate sleepers	To be equal on all the intermediate sleepers and in whole number of cm			

4.4 TYPES OF SLEEPERS

For decades, wood alone was used for railway sleepers, but the scarcity, escalating prices and shorter longevity of good timber gave way to other materials for making sleepers.

Sleepers now commonly used are (a) wooden sleepers, and (b) metal sleepers. The latter are further divided into cast iron sleepers, steel sleepers, and (c) concrete sleepers.

4.5 WOODEN SLEEPERS

Wooden sleepers are also called crossties and are mostly made from logs of hard wood. Depending upon the girth of log, one to four crossties are made out of a single log. As regards the life of a crosstie it depends upon its ability to resist (a) wear from the rail and rail to sleeper fastenings, (b) wear caused by the track maintenance tools, (c) decay, and (d) attack by vermin.

Softwood sleepers too are used but they become unserviceable earlier because of in their inability to resist the various aging factors. Timbers most commonly used for sleepers in India are sal (hardwood), chir and deodar (softwood). Softwood sleepers are treated in a creosoting plant before putting them in service, whereas sal sleepers are generally used untreated.

In the Indian Railways, the old classification of hard and softwood sleepers or durable and non-durable sleepers, has now been changed into untreated (U) and treated (T) sleepers.

4.5.1 Size of Wooden Sleepers

The depth of the sleeper governs its stiffness, the length and width provide the necessary bearing area on the ballast. Width also plays its part in offering adequate bearing area to the rails.

A sleeper is not packed with ballast throughout its length; hard packing is done under the rail seat only. The overall packed length extended from the rail to the end of the sleeper with an equal distance in the inner rail space. Each rail is thus supported uniformly on either side. In India, a 275 cm long sleeper is assumed to have 46.2 cm bearing length on either side of the gauge face of the rail. This gives a bearing area of 4,645 sq. cm per sleeper. The end 7.5 cm is not considered effective (Fig. 4.1).

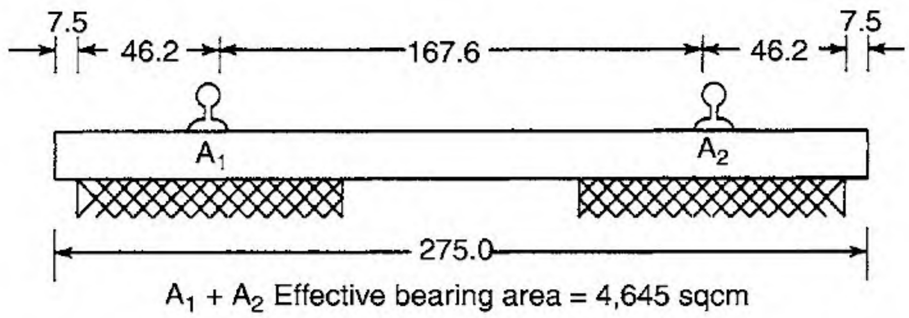


Fig. 4.1 BG wooden sleeper

The standardized size of the wooden sleepers for use on various gauges in Indian Railways is given in Table 4.2.

Table 4.2

1	*2*	*3*	*4*	
Gauge	*Size in cm*	*Bearing area Per sleeper in cm²*	*Approx. Weight in kg*	
			U	*T*
BG	275 × 25 × 13	4645	73	56
MG	180 × 20 × 11.5	3096	33	26
NG	150 × 18 × 11.5	2100	24	19

Sleepers of 16 and 18 cm thickness are used at points and crossings and bridge girders, respectively, for BG and 13.5 and 15 cm thickness for MG.

4.5.2 Wooden Sleeper Terminology

Definitions of some of the important items used in the specification for wooden sleepers are as follows.

1. *Sapwood*—a dyewood yielding red colour—is taken for use from beneath its bark. It is perishable and because of its colour, it is quite distinct from heartwood, which is a hard central wood of an exogenous tree. After the treatment process sapwood too becomes as durable as heartwood (Fig. 4.2).
2. The way the sleeper is taken out of the timber log defines the type of sleepers, i.e., *centre cut, centre heart* and *quartered sleeper* [Figs. 4.3–4.5].
3. *Knot* can be live or sound, loose or hallow, decayed or unsound. Presence of sound knots within certain limit is not harmful.
4. *Crook* or *spring* is a curvature of the narrow face of the sleeper along its length (Fig. 4.6).
5. *Cup* is a curvature of the broad face of the sleeper along its width (Fig. 4.7).

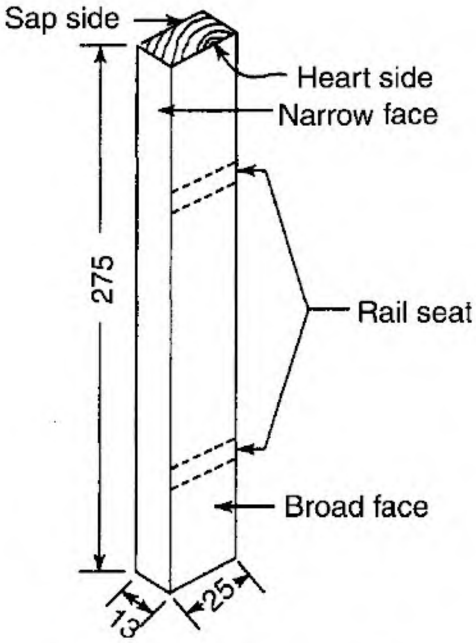


Fig. 4.2 BG wooden sleeper

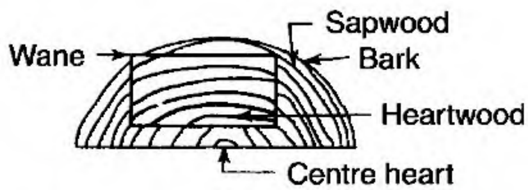


Fig. 4.3 Centre cut sleeper

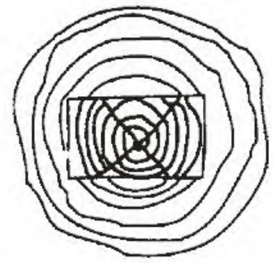


Fig. 4.4 Centre heart sleeper

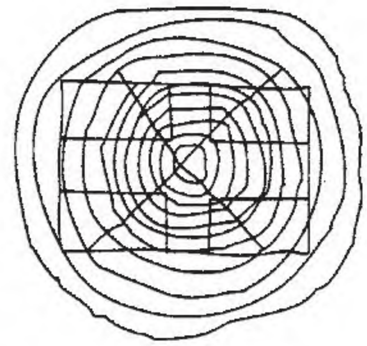


Fig. 4.5 Quartered sleeper

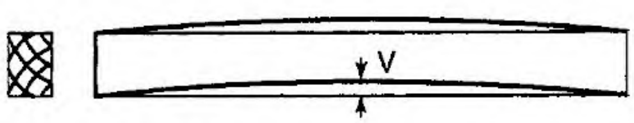


Fig. 4.6 Crook or spring

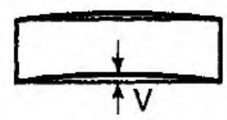


Fig. 4.7 Cup

6. *Warp* is a curvature of the sleeper along its length (Fig. 4.8).

Fig. 4.8 Warp

4.5.3 Composite Sleeper Index

The strength of timber varies in different directions and under stresses of different types. The Forest Research Institute (FRI), Dehradun (India), has published strength coefficients of various timber species as percentage of teak, which is a well-known all-purpose timber in India.

To arrange various species of timber in order of their suitability for use as a sleeper, the FRI has also evolved a formula by taking into account a few basic strength properties of timber, which are of importance in a sleeper. This formula brings out an index number which reflects the sum total of properties of a particular timber for fitness as a railway sleeper. This index is termed as Composite Sleeper index (CSI). CSI values for some of the well-known timber species used as railway sleepers are:

1. Sal 112
2. Teak 82

3.	Deodar	63
4.	Fir	58
5.	Chir	54

Indian Railways have prescribed the following minimum values of Composite Strength Index (CSI) for any species of timber to be used as railway sleeper:

1	Track Sleeper	54
2.	Specials	
	(a) Bridge sleepers	102
	(b) Crossing sleepers	94

Bearing-plates are invariably used on all 'treated' and 'untreated' sleepers having a CSI value of 82 or less.

4.5.4 Specifications for Wooden Sleepers

Indian Railways have laid down detailed specifications for the procurement of wooden sleepers. These specifications include permissible defects which can be accepted in its Ist and IInd class sleepers. In the latter case, there is further relaxation while laying in track.

The permissible defects in Ist class track sleepers are as follows:

1. *Live* or *sound knots*: The diameter of all knots put together should not exceed 7.5 cm, individually not to exceed 2.5 cm in diameter.
2. *Crook* or *spring*: Value of versine should not exceed 6 mm for 30 cm length of sleeper.
3. *Cup*: Value of versine should not exceed 12 mm.
4. *Warp*: Value of versine should not exceed 6 mm per 30 cm length of sleeper.
5. *Twist*: 6 mm adzing should be able to remove the twist.
6. *Sapwood*: Under rail seat up to 25% of any surface dimension and elsewhere up to 33 %.
7. *Splits*: Splits of only a certain type and up to a certain size are permitted.
8. *Size tolerances*: Oversize permitted up to 2.5 % in length, width and depth. Undersize up to 2.5 in length and up to 5 % in width and depth.
9. *Wane*: Under rail seat up to 12.5 % of any surface dimension and elsewhere up to 15 % is permitted.

The Indian Railway specifications also lay down the permissible defects for IInd class track sleepers and for special sleepers. Special sleepers (crossing and bridge sleepers) are all Ist class.

4.5.5 Treatment of Wooden Sleepers

The life of certain species of timber can be prolonged by treatment. An additional life varying from 30 to 50 percent has been estimated for treated sleepers over the same variety of untreated sleepers.

In the fibres of timber there are millions of cells, which contain juices. As these juices ferment, the fibres decay. Treatment involves maximum possible removal of juices from cells to be impregnated with a preserving solution. The commonly used preservative is coaltar creosote, which can be diluted with fuel or furnace oil to the extent of 50 : 50 to reduce cost.

All timbers do not accept or require treatment to the same extent, e.g. sal wood is usually not treated.

4.5.6 Seasoning of Timber

A living tree contains juices known as sap and after the tree is cut, the sap has to be dried up before using the timber. This is known as seasoning. Unless the sap is removed, the sleeper tends to bend, twist, warp and decay. Seasoning is done by exposing the cut timber to air. Timber is stacked in such a way that air circulates all around it. Stacking methods commonly used for seasoning are discussed. Stacking under cover is preferable.

(1) ONE-IN-NINE METHOD In this method, triangular gaps are available for air circulation [Fig. 4.9 (a)]. The method is suitable for all conifers including chir, kail, deodar and fir, and also for all species in the moist areas of Assam and South India.

(2) OPEN CRIB METHOD This method is almost the same in purpose and effect as one-in-nine method, but is space saving. By adjusting the space between sleepers, it is possible to control the drying rate, particularly for moderately refractory timbers [Fig. 4.9 (b)].

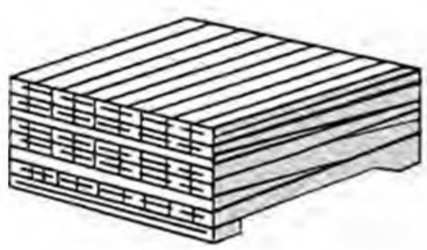


Fig. 4.9 (a) One-in-nine method

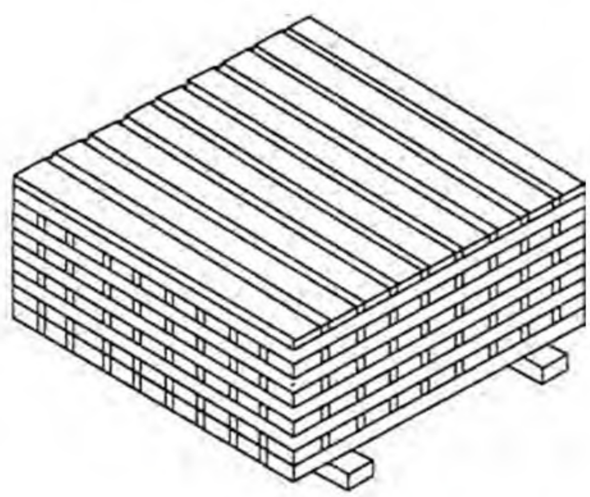


Fig. 4.9 (b) Open crib method

(3) CLOSE CRIB METHOD The method is suitable for species of timber belonging to the refractory class in the hot dry areas particularly of UP and Bihar. The refractory timbers are very hard and develop cracks if controlled drying is not done during seasoning. Sal is one of the kind.

4.5.7 Preparation for Impregnation

(1) SEASONING An essential prerequisite of effective impregnation is seasoning. In the pressure treatment methods commonly used, the timber moisture content should not exceed 25 %.

(2) PROPHYLACTIC TREATMENT After the sleepers are sawn and before they are given impregnation treatment, there is usually a time interval of few months. During this period, decay-producing organisms may attack the timber and seriously impair the strength and life of the sleeper in service. To prevent this occurrence, sleepers are sprayed with chemicals as a prophylactic measure.
(3) MECHANICAL PREPARATION Before impregnation the seasoned sleepers are mechanically prepared by adzing, boring, marking and incising, where necessary.

In 'deodar' and 'kail' wood, incision improves the intake of creosote oil during impregnation. 'Chir' sleepers which have enough absorption of their own are not incised.

4.5.8 Impregnation

This is achieved by injecting creosote oil by a pressure process into the interstices of wooden sleepers. Various pressure processes adopted on world railways are as follows:

(1) *Full Cell-Bethell Process*: This process is usually applied in timbers which normally do not accept much oil, as in 'deodar', 'kail' and 'fir'. In this process, an attempt is made to push as much oil as possible into the sleeper cells. This is achieved by first sucking the air from the cells, creating a vacuum and then pushing the oil under pressure.
(2) *Empty Cell-Rueping Process*: Before impregnation air is pushed into the sleeper cells under pressure. This reduces the intake of creosote oil in the highly absorbant species of wood such as Chir.
(3) *Empty Cell-Lowry Process*: In this process, the creosote oil is pushed into the sleeper cells under pressure without creating any vacuum or air pressure. This process is also used for highly absorbant species of wood such as chir.

In the above mentioned processes, a vacuum is created in the charging cylinders at the end of process to collect the unattached oil.

4.5.9 Service Life of Wooden Sleepers

The useful service life of sleepers depends upon a variety of factors: (a) the quality of wood (b) the efficiency of the preservative treatment (c) the GMT and speed of traffic, (d) the type of formation, condition of ballast and sleeper density, (e) the degree of curvature of the track, (f) the type of fastening, (g) protection against mechanical wear, (h) method of packing, and (i) climatic conditions.

The normal service life of wooden sleepers in the Indian Railways is 10–14 years for treated sleepers and 16–22 years for untreated sleepers.

The following measures enhance the service life of wooden sleepers in track:

1. While there should be free circulation of air around seasoned untreated sleepers, treated sleeper should be stacked compactly to forestall the free circulation of air which will dry them leading to crack formation in the sleepers.
2. Bearing plates are known to increase the service life of the sleepers by as much as 30 %.

3. Elastic fastenings maintain a firm grip between the rail and the sleeper. This reduces the impact effect. They also damp the rail vibrations. A sleeper is thus subjected to less wear and tear.
4. Clean ballast reduces shock loads on an individual sleeper and thus prolongs its life.
5. Mechanized maintenance and MSP do not damage the sleeper and thus should be adopted to the extent possible.
6. Both T and U sleepers should be laid in track with the heart side up.
7. Adzing of sleepers to 1 : 20 cant, should always be done with the help of a proper template. On T sleepers, the adzing should be done before treatment.
8. Boring of holes for dog/screw spikes should be of proper size, which depends upon the species of timber. The holes after boring should be given a coating of coaltar or creosote. For T sleepers, holes should be bored before treatment.
9. A box spanner should be used with screw spikes.
10. Frequent driving in of prised up spikes should be avoided. It is to be remembered that rigid fastenings like dog/screw spikes are primarily meant for holding the gauge.
11. Adequate number of creep anchors should be used for arresting creep.

4.5.10 Merits and Demerits of Wooden Sleepers

MERITS

1. With its natural elasticity, it has good energy and vibration absorption capacity which helps in obtaining longer retentivity of packing.
2. The fastening system is simple and easy to maintain.
3. Track circuiting can be done.
4. Mechanized maintenance and MSP are possible.
5. It can be obtained in different sizes and lengths for easy adaptability at special locations such as bridges, points and crossings, washable aprons, ash pits, etc.
6. Gauge widening is possible with wooden sleepers.
7. With a large bearing area, it has an edge over other types of sleepers, when used over yielding formations.
8. Damage is less during derailments.

DEMERITS

1. Timber species available in India have relatively short life.
2. For modern LWR track, it is lighter sleeper.
3. Gets worn out faster under beater packing.
4. Needs special treatment for fire protection.
5. Less scarp value.
6. Prone to fire hazard.

4.6 CAST IRON SLEEPER

4.6.1 Salient Features

CST-9 cast iron plate sleeper has been extensively used in the Indian Railways in the last seven decades. It is essentially a composite sleeper, with cast iron plates jointed by a flexible steel tie bar. This sleeper is the last of the series of experimental sleepers tried out in the Indian Railways between the year 1926 and 1935, under the recommendation of the Track Standard Committee; and its name CST-9 is an abbreviation of Central Standard Trail No. 9. The sleeper has the best features of its forerunners, and also includes the unique feature of pockets for retaining packed ballast. Its satisfactory behaviour has resulted in the withdrawal of all previous designs.

Some of the salient features of the CST-9 sleepers are as follows (Fig. 4.10 and Table 4.3):

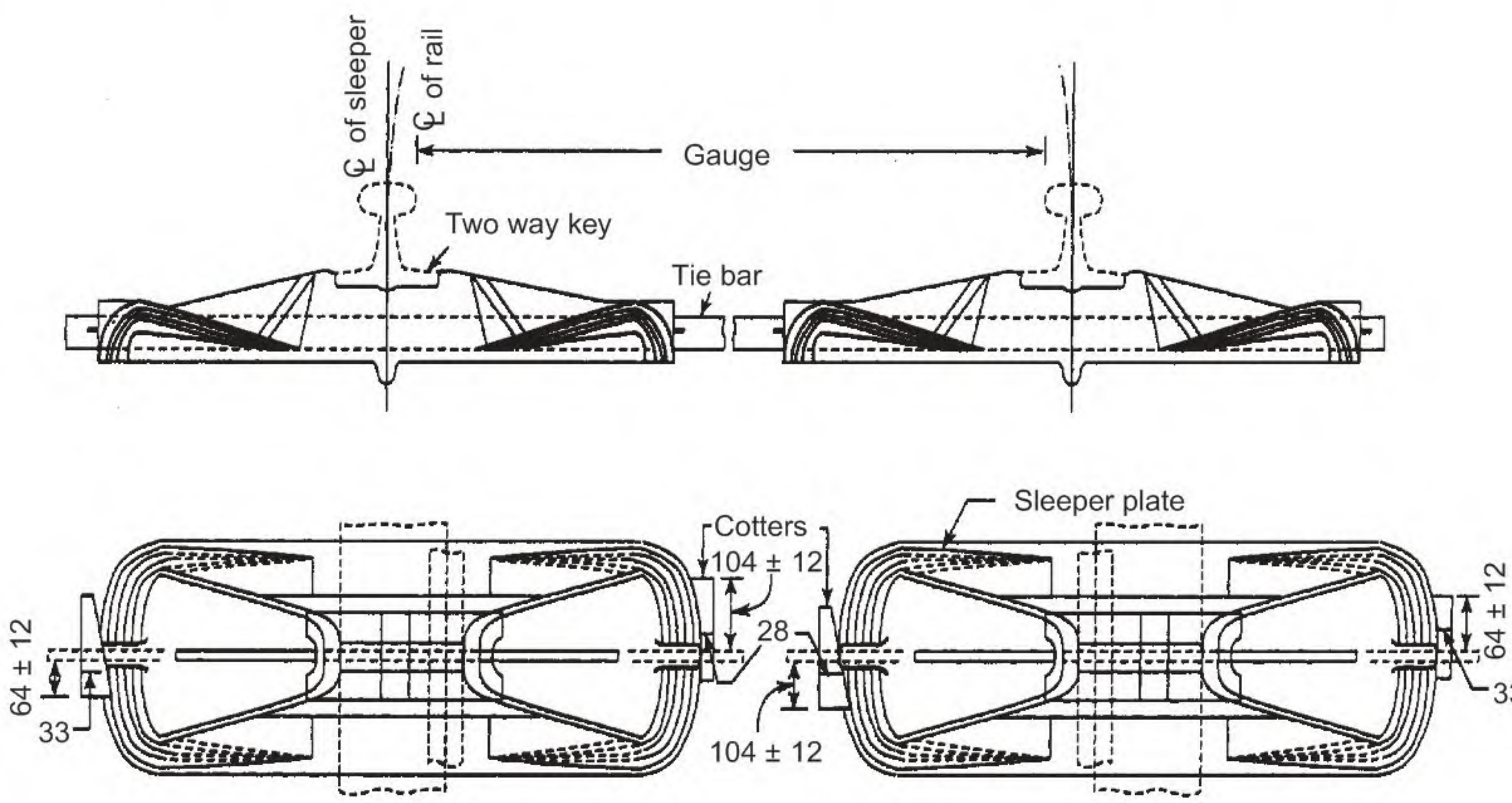


Fig. 4.10 CST-9 type assembly of sleeper

1. *Long tie bar*: It has a long through tie bar, which is fastened to the plates with the help of four standard cotters. Long tie bars prevent tilting of plates and thus the gauge is not much disturbed while packing. Adjustment in gauge to the extent ±5 mm is possible with the help of cotters. Slight tilting of bowls by overpacking at the outer or inner ends can also help in minor gauge adjustment. Gauge widening of curves has not been provided in the design.
2. *Small rail seat*: The rail seat which is canted to 1 : 20 is only 114 mm wide along the rail, and this narrow bearing tends to reduce the rocking of the sleeper plate under the wave motion of the rail.

Table 4.3 Part Numbers and Weights CST-9 Sleepers

Rail section	Gauge	Assembly Drg. No.	Plate	Part number Tie bar	Two-way key	Cotter	Approx. Weight (kg) Plates (2)	Tie bar (1)	Two-way keys (2)	Cotters (4)	Comp: sleeper
52 kg and 90R	BG	TA9(M)	T478(M)	T404(M)	T405(M)	401 T404(M) or T423(M) or T424 (M) or T432 (M) or	87.10	12.62	0.97	1.48	102.17
90R	MG (Heavy)	T2367	T23666	T2368	T405(M)	Do	64.00	900	0.97	1.48	80.45
75R	MG	TA20(M)	T498(M)	T433(M)	T405(M)	Do	49.00	6.45	0.97	1.48	57.90
60R	MG	TA20077	T10257	T433(M)	T413(M)	Do	50.14	6.45	0.86	1.48	58.93
50R	MG	TA20078	T10258	T433(M)	T413(M)	Do		6.45	0.86	1.48	

3. *Two way keys*: A single two-way key is provided on the gauge side jaw. By virtue of the double tapered jaw and the two-way key, the direction of the key can be fixed to arrest creep in the track.
4. *Central keel*: Apart from the lateral stability provided by the keying up of the ballast in the pockets, a keel is provided centrally along the rail to give an additional anchorage.
5. *Sleeper bearing area*: The bearing area on the ballast provided by the sleeper is approximately equal to the effective bearing area of the standard mainline wooden sleeper.
6. *Reverse jaw sleeper*: The reverse jaw sleeper has been designed with the key side jaw reversed in position, i.e. on the outside of the rail. When a few of these are introduced in each rail length, they provide effective anti-sabotage medium, as they prevent the removal of rail from the track without the removal of the tie bar fastenings.
7. *Easy to transport and assemble*: Although the CST-9 sleeper is heavier than wooden sleepers, but on account of the ease with which it can be dismantled and assembled, its transport and laying is not difficult.
8. *Longitudinal and lateral resistance*: When properly packed, the cast iron pots dig into the ballast and provide good longitudinal and lateral resistance, enough for LWR tracks.
9. *Sturdy sleeper*: It is a sturdy sleeper that can tolerate considerable amount of rough handling. The shape is well suited for beater packing. The skill required for track maintenance is minimal.
10. *Depth at rail seat*: Sleeper depth at rail seat is 140 mm for BG sleepers, which compares favourably with that of wooden sleepers. Interchange of sleepers from one to the other type is thus possible without disturbance of ballast or rail levels.
11. *High scrap value*: The sleeper has a high scrap value. The same material can be recycled without any extra burden on the natural resources of the country.
12. *Free from fire hazard*: Erratic dropping of fire by steam engines does not affect the sleeper much.

4.6.2 Service Life

The life of CST-9 sleeper is reckoned to be 35 to 50 years. Measures that should be taken to obtain full service life from the sleeper are:

1. *Proper packing*: Imperfect packing is the cause of the majority of breakages of cast iron plates. The packing of plates from all sides should be uniform and firm.
2. *Clean ballast*: The ballast should have sufficient resilience to reduce shock loads on individual sleepers. For this purpose, periodical deep screening of ballast is necessary.
3. *Use of standard keying hammer*: A standard keying hammer (weight 1.8 kg) should only be used for driving the keys. Heavy hammers can damage the jaws.
4. *Use of oversize keys*: After the jaws and the rail seat get worn out and the standard size keys do not hold on to the sleeper, the life of the sleeper in track can be prolonged with the use of oversized keys.
5. *Proper splitting of cotter*: Cotters should be properly driven through the hole and then split to prevent the cotter from working loose and getting out.

6. *Coal taring of tie bar*: Under adverse climatic conditions, tie bars tend to corrode. Coal taring of tie bars should be done where corrosion tendency is noticed.

4.6.3 Limitations

1. *Poor retentivity of packing*: With its rigid fastenings it is a poor damper for high frequency vibrations generated by the moving loads at high speed. They shake up the whole assembly and disturb sleeper packing.
2. *Poor joint sleeper*: Rails have longer unsupported length when CST-9 sleepers are used at joints. The impact caused by the moving wheels at the joints, poor retentivity of sleeper packing, and longer overhang of rails, all lead to battering and ultimately hogging of rail-ends. To counter this problem, use of wooden sleepers at the joints of metal road is prescribed in the Indian Railways.
3. *Wear at rail seat*: Small bearing area at the rail seat, difference in hardness of rail and sleeper metal and undamped high frequency vibrations, all cause early wear of the sleeper at the rail seat. This results in the falling of keys. Under such conditions, there can be no reliability of the sleeper's hold on the rail, which is an important requisite for modern LWR track.
4. *Unsatisfactory for LWR track*: CST-9 sleeper track has adequate longitudinal and lateral resistance against buckling when fully packed. This resistance however gets considerably reduced under routine maintenance operations such as lifting, levelling and packing and unreliable hold on the rail. This makes the sleeper unsatisfactory for LWR track.
5. *Not suitable for modern methods of maintenance*: The sleeper cannot be maintained by MSP. Trails with MSP are so far not conclusive. The standard of maintenance with on-track tamping machine is also not of high order.
6. *Longer time for consolidation*: After complete track or sleeper renewal, the track takes as long as six months for proper consolidation. During this period, the track behaviour even under SWR is so erratic that conversion into LWR is out of question.
7. *Misalignment correction is difficult*: The keel and bowls provided in the sleeper do not permit easy realignment of track. Any significant re-alignment operation much be preceded by lifting and followed by firm packing.
8. Damage during derailment is excessive with CST-9 sleepers. Time required for restoration is also long.
9. It is not fit for track circuiting because the sleeper is all metal.

4.7 STEEL SLEEPERS

Non-availability of durable timber besides the poor life of wooden sleepers in tropical regions led to the laying of lengths of track with steel sleepers in Africa, India and the Far East.

Broadly, steel sleepers are of two types: (a) steel trough sleepers for use on main line and (b) steel sleepers, for turnouts.

4.7.1 Steel Trough Sleepers for Main line

These are made from rolled trough sections of steel, cut to proper length and hot pressed to obtain the desired shape and cant of 1 : 20 at the rail seats. There are three different rolled sections of sleeper plates wherefrom the standard sleepers for various BG and MG rail sections are pressed.

1. Plate 13 mm thick at rail seat for 52 kg and 90R rails (BG), weighing 28.66 kg/m length. Total weight: 79 kg.
2. Plate 11 mm thick at rail seat for 75R rails BG, weighing 26.15 kg/m length. Total weight: 72 kg.
3. Plate 9 mm thick at rail seat for 75R, 60R and 50R rails (MG) weighing 17.55 kg/m length. Total weight: 33 kg.

In these sleepers, holes are drilled and punched in the plate to accommodate loose jaws or modified loose jaws. Standard two-way keys are used with loose jaw type of sleepers. Oversize keys are used when holes get elongated. Elastic rail clips are used with modified loose jaws.

Main dimensions, weight of the sleeper, dimensions of rail seat together with part numbers for 52 kg/90R/75R for BG and 75R, 60R, 50R, for MG sleepers are given in Fig. 4.11 and Table 4.4.

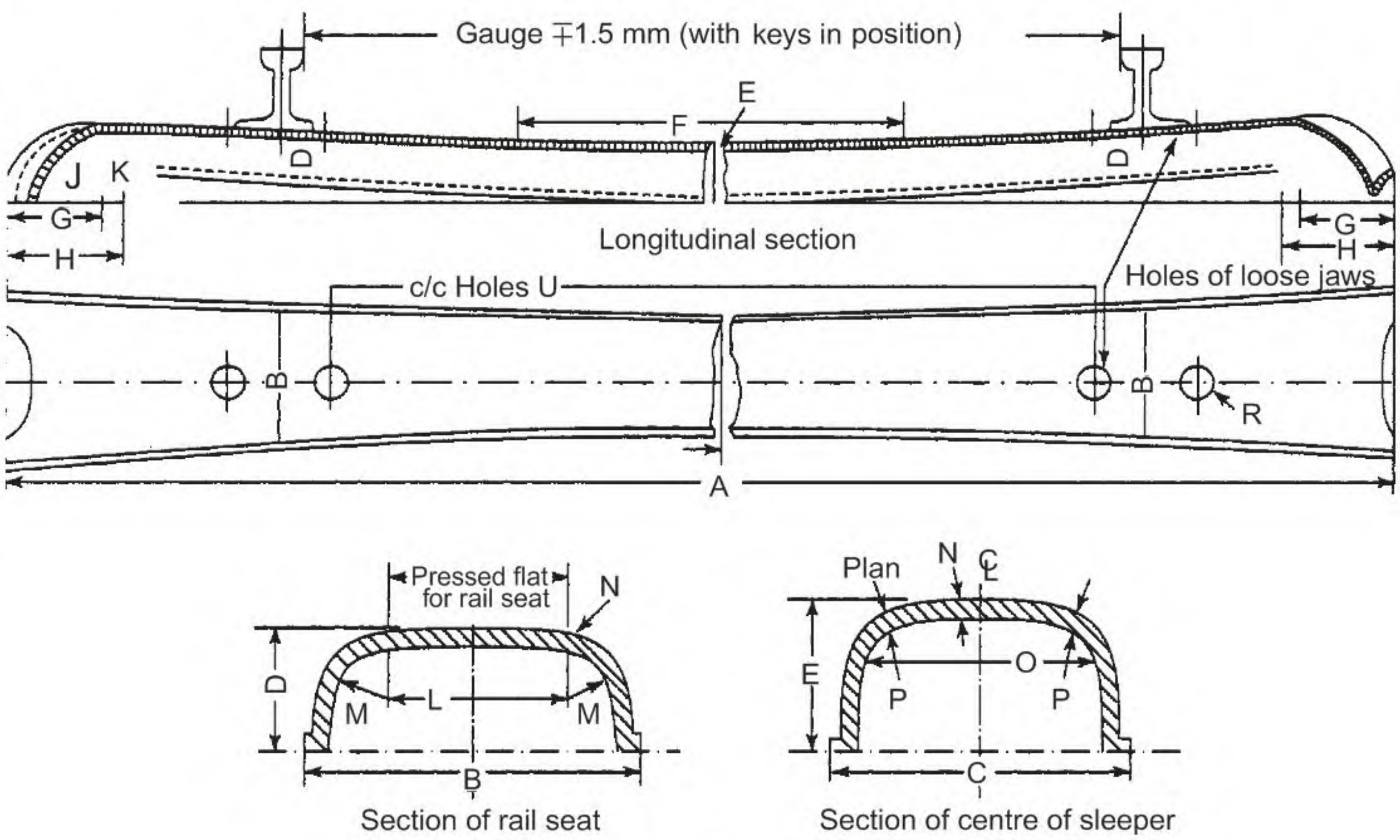


Fig. 4.11 BG and MG steel trough sleepers

4.7.2 Salient Features

The salient features of a steel trough sleeper (main line) are as follows:

1. The sleeper holds the gauge firmly, much better than wooden or cast iron sleepers. No

Table 4.4 Part Numbers and Main Dimensions of Steel Sleepers

Rail section	*Gauge*	*Approx. Wt of each trough (kg)*	*Part number*
52 kg and 90R	BG	78.69	T460 (M)
75R and 50R	BG	71.80 33.01	T10273 T10272 T10277

gauge widening for curves is provided in the design. Minor gauge correction can be done by adjusting the position of four keys. Manufacturing specifications permit a tolerance in gauge of +2.0 mm, –1.5 mm.

2. It is a good anticreep sleeper while the keys are held in position.
3. Being in one piece, the rail cant is well maintained. Manufacturing tolerance permit a tolerance in cant from 1 in 18 to 1 in 22, but rails usually adjust themselves to position within this tolerance.
4. The sleeper offers good longitudinal, lateral and frame resistance, ample to meet the needs of the LWR track.
5. Spring steel loose jaws along with steel sleepers provide some degree of elasticity and thus the menance of falling of keys is not as serious as with CST-9 sleepers. With modified loose jaws, rubber pads and Pandrol Clips, the position is considerably improved.
6. Its behaviour on yielding formation is good as compared to wooden sleepers.
7. Steel sleeper is sturdy enough to withstand beater packing and can be maintained without much skilled labour. Despite certain limitations, the results of mechanized maintenance on these sleepers have been reported to be satisfactory.
8. It occupies comparatively less storage space and being similar to the wooden sleeper in shape, the track labour finds it easier to handle during transport and laying.
9. It has a long life of 30 to 40 years; and can be reconditioned to have a fresh lease of life.
10. It is easy and economical to manufacture.
11. It is free from fire hazard.
12. It has good scarp value.

4.7.3 Service Life

The life of steel trough sleepers has been estimated at 30–40 years. Instances of their premature withdrawal from track are not uncommon. Measures which help in obtaining full service life are as follows:

1. The holes and the loose jaws that go into them, are the most sensitive parts of the sleeper. Overdriving of keys damages both. Use of standard keying hammer (weight 1.8 kg) should therefore be insisted upon.

2. Once the holes get elongated, they should be fitted with liners to obtain further lease of life from the sleeper. These liners can be easily manufactured from thin steel sheets in P. Way depots.
3. If standard keys are unable to hold, oversize keys can be used to prolong the service life of the sleeper.
4. Earth, sand, ash or dirty ballast besides the industrial gases conduce to corrosion of sleepers, thereby reducing their life. Therefore, exposure to corrosive conditions should be avoided, and painting with coaltar resorted to. This will help sleepers to combat corrosion.
5. Rail seat, bottom and sides of sleeper are subjected to abrasion and wear. Absence of play at the rail seat and firm packing of sleeper help to reduce wear. Use of rubber pads at rail seat are quite effective and reducing wear.
6. Cracks generally originate from holes. Rounding of the sharp corners of the hole reduces crack formation.
7. Old worn out sleepers can be reconditioned by welding new pad plates at the rail seat. BG sleepers badly damaged at the rail seats and at the ends can be converted into MG sleepers.

4.7.4 Limitations

1. Key type fastenings subjected to high frequency vibrations under the influence of traffic get loose and need frequent tightening. This results in enlarged holes, opening of the jaws, and play between rail and the sleeper, affecting the track geometry quite adversely. Use of modified loose jaws, rubber pads and Pandrol Clips help to overcome these limitations to some extent.
2. Steel sleepers have a tendency to centre binding as the central portion is lower than the ends.
3. Manufacturing tolerances in the positioning of holes and canting of rail seat are not usually found within close limits to produce track of high standard.
4. Steel sleepers with their close spacing at the rail joints are difficult to pack. Their poor packing conditions coupled with longer rail overhang cause greater knocking at the joints resulting in battering and hogging of the rail-ends. To overcome this problem, wooden sleepers are recommended at joints of steel sleeper track.
5. MSP is not applicable to steel trough sleepers. Trials made so far by introducing stone chips through holes have not been conclusive. Results obtained with on-track tamping machines are satisfactory, but retentivity of packing is less than wooden or concrete sleepers.
6. Not fit for track circuiting.
7. Excessive damage in case of derailments.
8. Prone to corrosion.

4.7.5 Steel Sleepers for Turnouts

In Indian Railways, rails are laid vertically, i.e. without cant on turnouts. Steel turnout sleepers are made from special rolled sections of steel, whereon no processing is done except for flaring out the ends. Considering the extra vertical and lateral loads to which they are subjected to during service, the steel sections used for BG turnout sleepers is 35.5 kg/m and that for MG 23.60 kg/m. Main features of these sleepers are given in Fig. 4.12. Loose jaws and keys used for turnout sleepers of various rail sections are tabulated in Table 4.5.

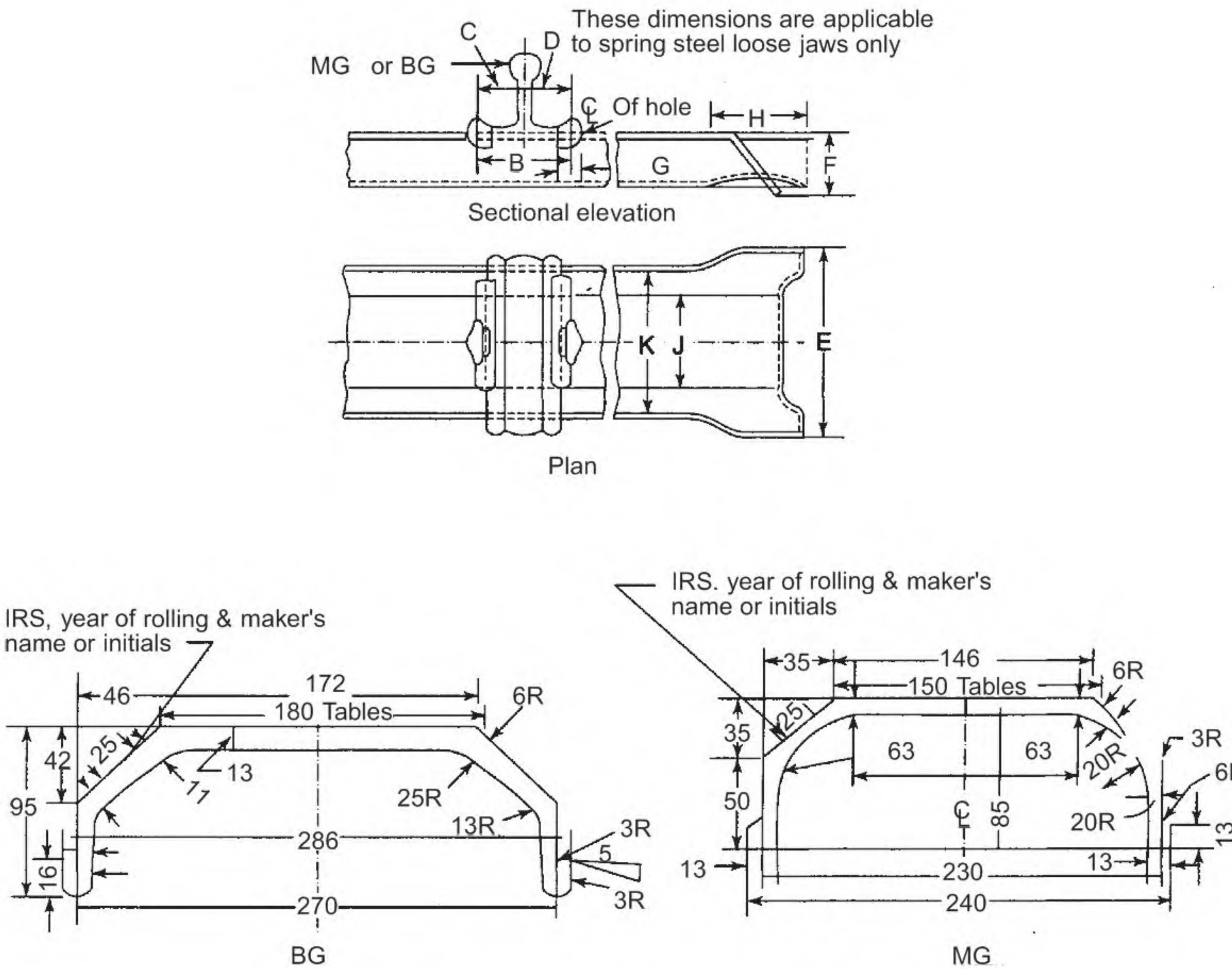


Fig. 4.12 Steel sleepers for turnouts—BG and MG

Table 4.5 Part Number and Main Dimensions

Rail section	*Gauge*	*Part Numbers*		
		Turn out sleepers	*Two way key*	*Spring steel loose jaw*
52 kg and 90R	BG	T455 (M)	T405 (M)	T415 (M)
75R	BG	T455 (M)	T405 (M)	T10003
75R	MG	T358 (M)	T405 (M)	T419 (M)
60R	MG	T358 (M)	T413 (M)	T10002
50R	MG	T358 (M)	T413 (M)	T10002

4.7.6 Steel Sleepers with Elastic Fastenings

Much of the shortcomings of steel sleepers are overcome with the introduction of elastic fastenings.

The methods employed in the Indian Railways are (a) with the use of modified loose jaws and (b) with the welding of the base plate. These methods are discussed in detail in Chapter 5.

4.8 CONCRETE SLEEPERS

Concrete sleepers appeared as a viable alternative to wooden sleepers after the Second World War. Earlier, Monier—a Frenchman—patented his concrete sleeper design in 1884, but without much consequence.

The advent of modern track in the form of long welded rail, wherein the heavy weight of the sleeper became a positive asset, filliped the development of concrete sleeper in countries like France, Britain and West Germany.

Mass scale production of concrete sleepers in India was undertaken in 1967–68. Presently, the figure touches 9–10 million sleepers, per year.

4.8.1 Type of Concrete Sleepers

The majority of concrete sleepers produced in India are monoblock pre-stressed sleeper though the design for the production of two block reinforced concrete sleepers—suitable for use in yards—is available. Monoblock sleepers are of different designs. They differ in their strength characteristics, method of manufacture, quality of prestressing steel, and in the prestressing method. The depth of sleepers at the rail seat also varies, which is of significance while carrying out sleeper renewals. Though the elastic rail clip (earlier known as Pandrol Clip) fastening system has been adopted in all designs of concrete sleepers, the trials with other fastening systems continue. Broad details of the various types of concrete sleepers are given in tabular from in Appendix 4.1. Typical BG monoblock sleeper is shown in Fig. 4.13 (a)–(d).

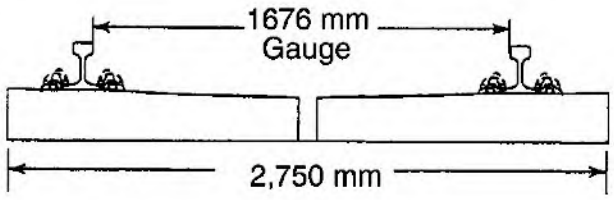


Fig. 4.13 (a)

4.8.2 Advantages

1. *Heavy weight*: Concrete sleepers are heavy, thus they lend stability to track. This is a salient feature for their use in modern LWR track. Heaviness is due to materials like sand, gravel,

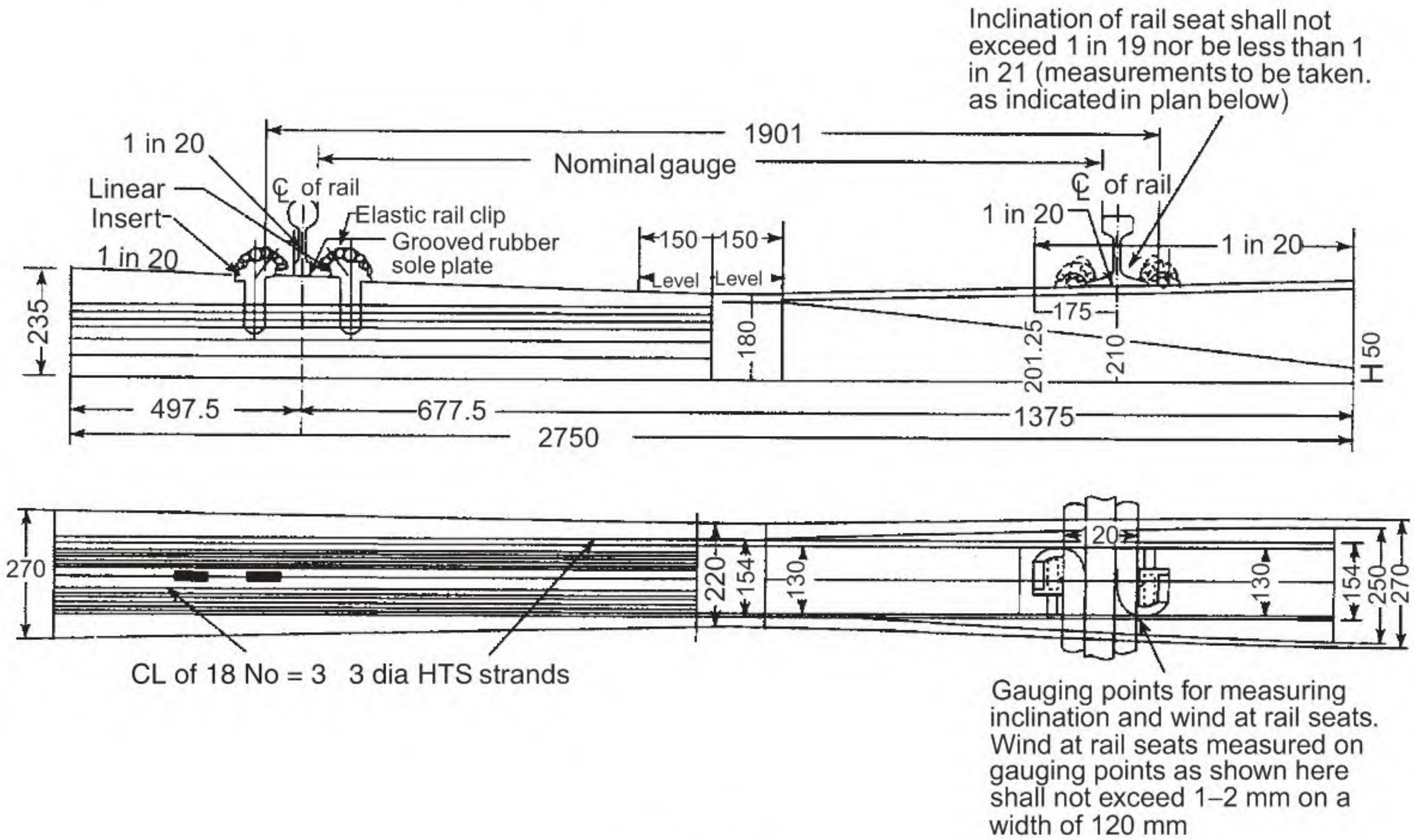


Fig. 4.13 (b)

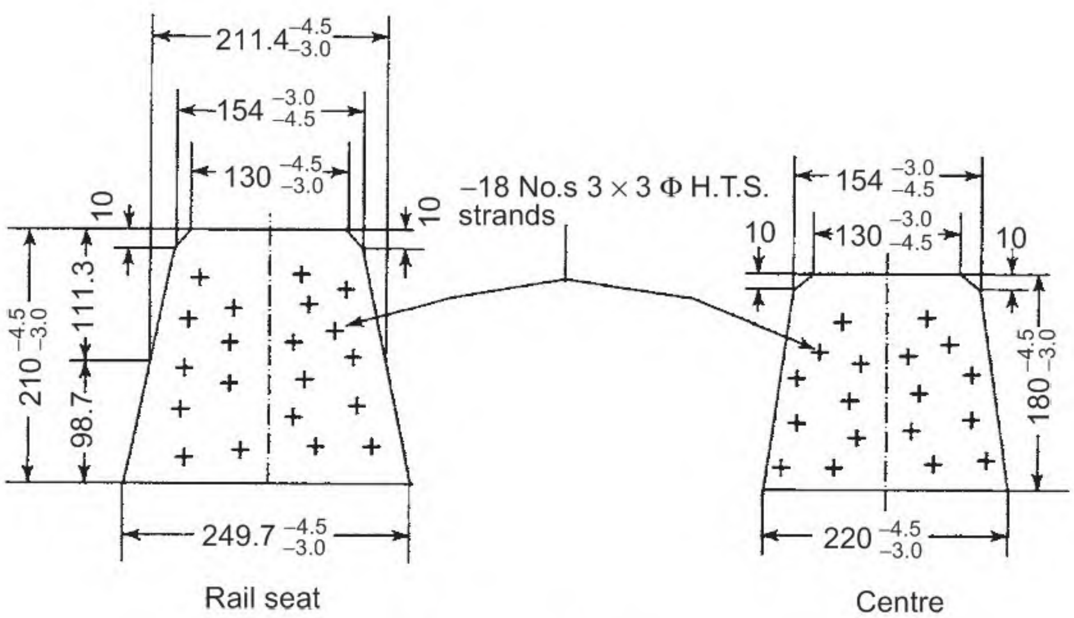


Fig. 4.13 (c)

cement and steel. It is steel that provides the necessary cohesion, resistance, strength and elasticity, to the whole mass but represents only a small part of the total weight.

2. *Good longitudinal and lateral resistance*: The sleeper offers good longitudinal and lateral resistance, ample to meet the requirements of the LWR track.
3. *Flat bottom*: Because of their flat bottoms, modern methods of track maintenance like MSP and machine maintenance can be applied with advantages.

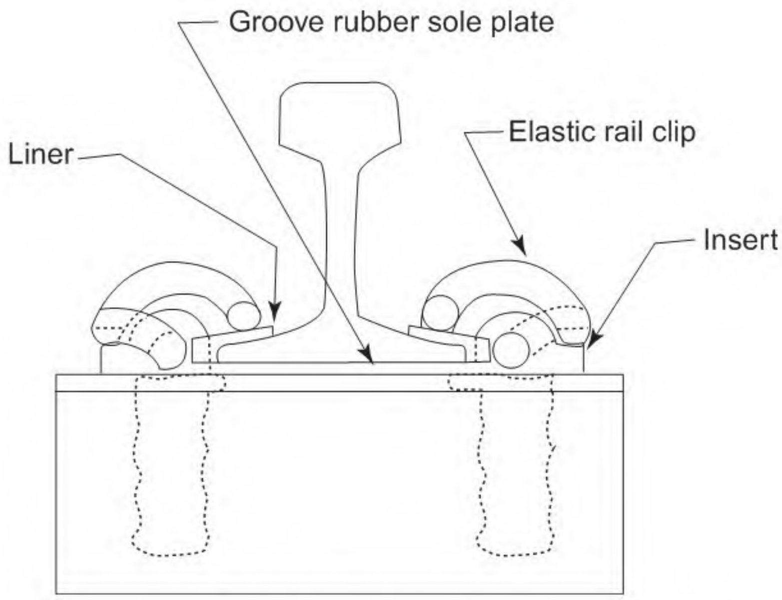


Fig. 4.13 (d) Details at the rail seat

4. *Long life*: Concrete sleepers are neither inflammable nor vulnerable to termite or corrosion. Their long life enables the permanent way engineers to draw full benefits out of expensive LWR track. Rail and sleeper renewals can be matched. Assuming a life of 50 years, CTR can be done at 50 years interval with an intermediate rail renewal after 25 years.
5. *Better track geometry*: Concrete sleepers with their elastic fastening system provide better safeguard for all track parameters, viz. gauge, cross-level, twist, alignment, longitudinal level unevenness.
6. They can be used in track circuited areas.
7. They can be mass produced from local resources.

4.8.3 Disadvantages

1. The manufacturing of concrete sleepers, their transport, laying and maintenance requires superior technology, which is not readily available in developing countries. The manufacturing plants generally have a heavy initial outlay.
2. The sleeper being heavy, complete mechanization in handling, laying and maintenance has to be resorted to.
3. Damage during derailment is excessive.
4. No scrap value.

4.8.4 Special Precautions in Laying and Maintenance

Permitted Locations

1. In the Indian Railways, concrete sleepers are not permitted to be laid at the following locations:
   (a) New formation in banks unless specially consolidated,

(b) On track in cutting, unless minimum ballast of 300 mm in depth has been provided,
(c) Unballasted lines in yards,
(d) Troublesome formations,
(e) Near ash pits and other locations where drivers disgorge fire.

2. Concrete sleepers are not to be used on unballasted bridges. They may however be used on arch bridges with a minimum ballast cushion of 1 m. For slab bridges, the minimum ballast cushion should be 300 mm.
3. Two block sleepers should not be laid on locations where excessive corrosion is expected.

Ballast Section Ballast section shall be the same as prescribed for LWR. In tracks with two block RCC sleepers, a central trough in the ballast section, about 1033 mm wide at the top, is desirable for reducing the possibility of corrosion of tie bar.

The spacing of concrete sleepers shall be the same as for conventional sleepers under identical conditions. BG concrete sleepers at the joints will have centre-to-centre spacing of 340 mm.

Laying Mechanical equipment will be used for the laying of concrete sleepers. Manual laying shall be resorted to only in exceptional circumstances. For manual laying interlacing method will not be adopted as concrete sleepers are likely to suffer damage in handling and by the uneven bearing on the disturbed ballast. The existing rails and sleepers will be completely removed and the concrete sleepers laid on well prepared ballast bed. The work should be done under traffic block.

Packing Procedure after Laying Packing will be done with on-track tamper. For the first two rounds "design lifting" and packing will be attempted instead of 'smoothening' tamping which is normally done during maintenance operations. After the initial rounds of packing, traffic shall be allowed to pass at a speed 70 kmph. Next rounds of 'on track' tamping and lining shall be undertaken after 6 to 10 days or after laying LWR and of speed restriction removed.

Maintenance

1. As far as possible, concrete sleepers shall be maintained by on-track tampers only. When on-track tamping is not practicable for some reason, MSP shall be adopted.
2. In case signs of corrosion are seen, the ends of HTS wires of monoblock sleepers shall be printed with anticorrosive paints. Exposed tie bars of two block sleepers showing signs of corrosion shall be repainted with one coat of red oxide paint.
3. Rail to sleeper fastenings shall be periodically inspected and timely action taken for damaged or missing fastenings.

4.9 CONCRETE SLEEPERS FOR RAIL JOINTS

The following guidelines have been laid for the use of standard concrete sleepers as joint sleepers:

1. Centre-to-centre spacing of sleepers will be 340 mm for BG tracks.
2. Rubber pads shall be affixed to the sleepers with a glue of approved specifications.
3. Special elastic rail clips ERC-J, which do no foul the fish plates will be used at joint sleepers.
4. Track packing will be done with machines or MSP.

4.10 CONCRETE SLEEPERS FOR CURVES

RDSO have evolved designs and issued tentative drawings for the manufacture of concrete sleepers for use on curves. The board features of these designs are:

1. Four types of sleepers, each providing a gauge of 1,675, 1,677, 1,679 and 1,681 mm (without check rail) to drawing no RDSO/T-4170 is 4173 for 60 kg rails, and similar four types for 52 kg rails, have been developed.
2. Sleeper profile is similar to PSC sleeper for normal track except – H.T.S strand disposition and inserts location.
3. Gauge widening can also be achieved by using special sleeper of wider rail seat for curves, with the combination of liners of different thickness.
4. Instruction with respect to gauge widening on curves are as under:

Track	*Widening*
(a) Straight including curves of 350 m radius and more	No gauge widening
(b) Curves with radius less than 350 m and more than or equal to 250 m	5.0 mm
(c) Curves with radius with less than 250 m and more than or equal to 175 m	10.0 mm

4.11 WIDER CONCRETE SLEEPERS FOR HEAVY DENSITY ROUTES

Track standards laid down for heavy haul routes, where 22-T axle load wagons ply, prescribe a sleeper density of 1880 sleepers per km. For such routes, RDSO have come up with a better techno-economic solution with the design of a wider concrete sleeper, which could be laid to standard density of 1,660 sleepers per km. These sleepers can also be used on comparatively weaker formation where the use of concrete sleepers was hitherto prohibited.

RDSO's drawing No. RDSO/T-3735, evolved for the manufacture of wider sleepers, has the following main features:

1. The design is only for use with 60 kg 90 UTS rails.
2. Special track type inserts, 10 mm thick rubber pad, 8 mm thick liners, have been used in the fastening system.
3. Sleeper density will be 1660 per km.
4. A cushion for 30 cm ballast, preferably mechanically crushed, has been prescribed.

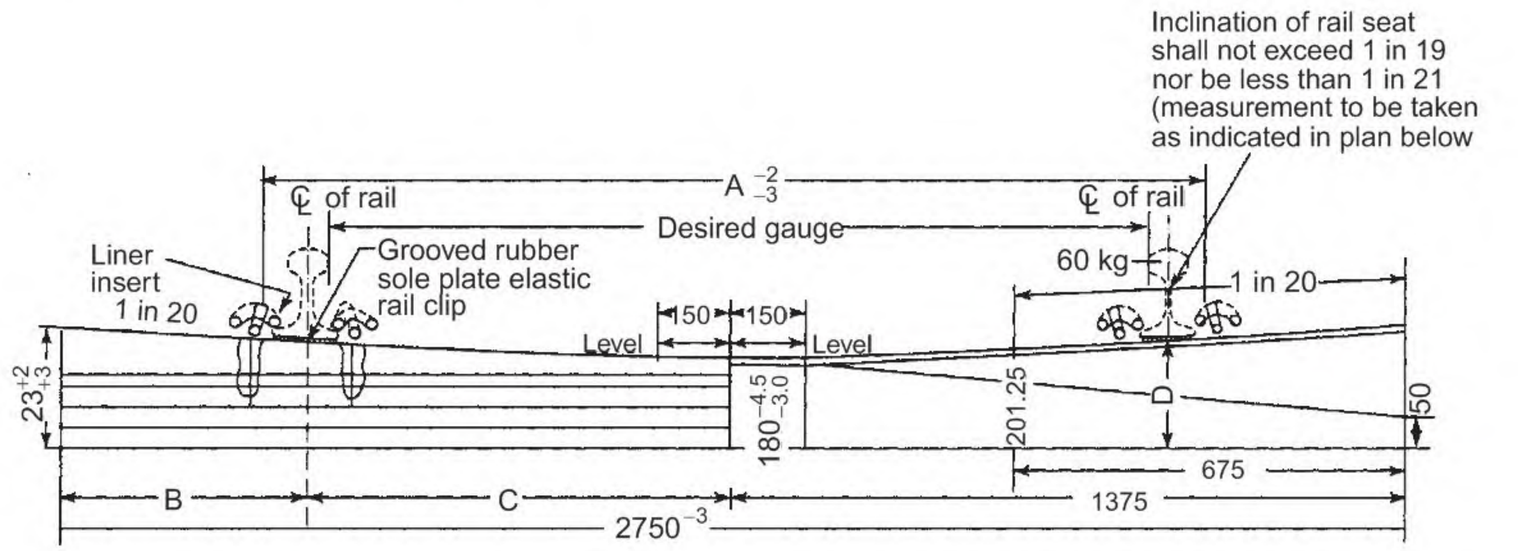


Table of dimensions

Desired Gauge	A	B	C	D
1675	1923.5	493.5	831.5	210.33
1677	1925.5	492.5	882.5	210.38
1679	1927.5	491.5	883.5	210.48
1681	1929.5	490.5	831.5	210.48

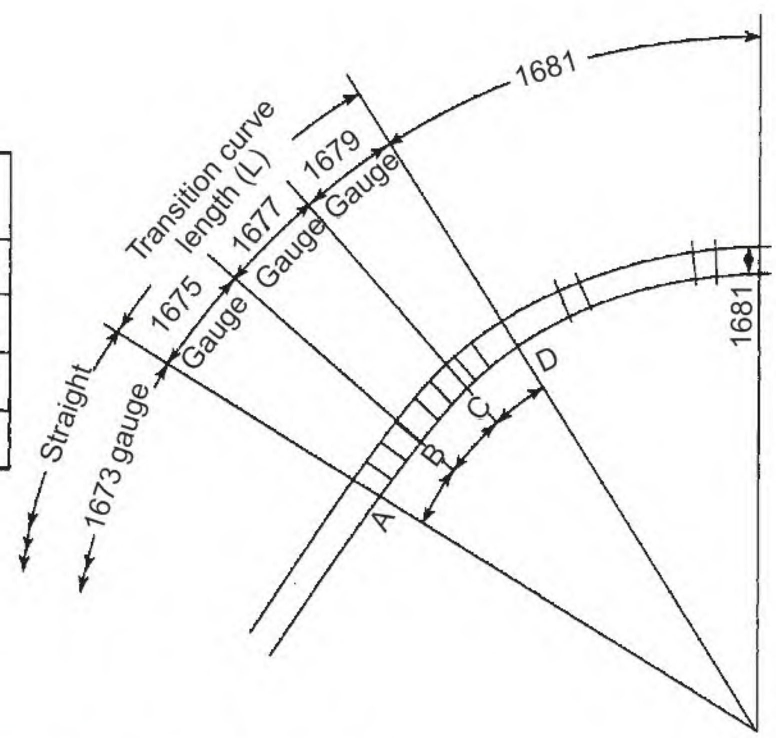


Fig. 4.14 Concrete sleepers for curves

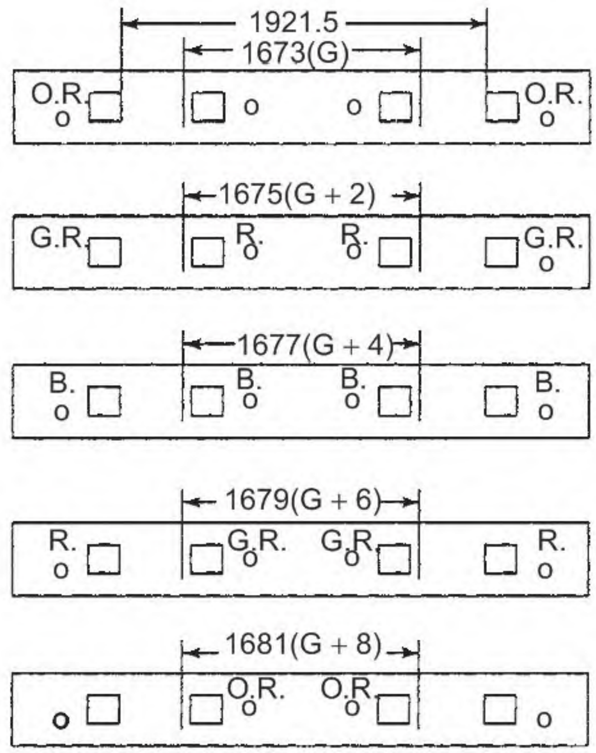
4.12 CONCRETE SLEEPERS FOR TURNOUTS

The main features of the design are as under:

1. Trapezoidal sections have been adopted, with the following main dimensions

Width (top)	–	240 mm
Width (bottom)	–	260 mm
Thickness	–	210 mm
Length (m)	–	2.75–4.90

2. Concrete with a cube strength of 600 kg/cm^2 at 28 days has been specified.
3. 10 × 9.5 mm dia 7 ply (4.35 kg/m) or 27 × 3 × 3 (4.48 kg/m) are used as prestressing steel.



Desired track gauge	Liner thickness (mm)		Colour code for liner thickness
	Nongauge face side	Gauge face side	
1673(G)	9.5	5.5	9.5 - Orange
1675(G + 2)	8.5	6.5	8.5 - Green
1677(G + 4)	7.5	7.5	7.5 - Black
1679(G + 6)	6.5	8.5	6.5 - Red
1681(G + 8)	5.5	9.5	5.5 - 0

Fig. 4.15 PSC sleeper for providing slack gauge on curves (identical sleepers different liners)

4. Mild steel stirrups 6 mm at 250 mm c/c are provided.
5. MR (tm) is 3.21 at bottom and 2.35 at top. Mf (tm) is 6.00.
6. On the switch portion, sleepers will be laid perpendicular to the main line. Same design of sleepers can be rotated in the horizontal plane and used for left hand and right hand turnouts.
7. In the lead portion, the sleepers will be laid equally inclined to straight and turnout tracks. This means that all the sleepers shall be in a fan shaped pattern.
8. In the crossing portion, the sleepers will be laid perpendicular to the bisecting line of the crossing.
9. At some locations where the two rails come very close and two MCI inserts cannot be provided, only one insert has been provided. The rails at such locations are held at alternate sleepers.
10. Five approach sleepers are used in the approach track to run out the cant from 1 in 20 to level and for installation of lock-bar arrangement at switch end. Similarly on the crossing end, four special exist sleepers are to be provided for each of the diverging track to accommodate the change of cant.

11. Since 1,673 mm gauge is provided in turnout also, no transition is assumed for change in gauge value.

Table 4.5(a) Design of Turnout Concrete Sleeper

Gauge (mm)	*Turn out type*	*Rail section*	*LH/RH fan shaped (FS)*	*Brief description*	*No. of sleepers excluding approach sleeper*	*Drawing No. of Layout*	*Drawing No. of Sleeper*
Broad	Gauge						
1,673	1 : 12	60 kg	FS	Switch: 10,125 mm Xing: CMS	83	RT-4,218	RT-,4,512 to RT-4,594
1,673	1 : 12	52 kg	FS	Switch: 10,125 Xing: CMS	83	RT-4,732	do RT-4,512 & 4,513
1,673	1 : 8.5	60 kg	FS	Switch: 6,400 m Xing: CMS	54	RT-4,865	RT 4,793 to RT-1,512 4,844 &
1,673	1 : 8.5	52 kg	FS	Switch: 6,400 mm Xing: CMS	54	RT-4,865	do
1,673	1 : 8.5	90 R	FS	Switch: 6,400 mm	54	RT-4,865	do
1,673	1 : 16	60 kg	FS	Switch: 11,200 mm Xing: CMS	101	T-5,691.	RT-1,513 to 4,517. RT-5,595 to 5,690
Metre	Gauge						
1000	1 : 12	90 R		Switch:7,130 mm Xing: CMS	53	RT-4,623	RT-463el to 4,683
1000	1 : 8.5	90 R		Switch:5,500 mm Xing: CMS	38	RT-4,623	RT-4631 to 4,634 & RT-4918 to 4,951

Table 4.5(b) Quantities of Materials as Per Set of PSC Sleepers for Turnouts

S. No.	*Item*	*1 : 16*	*1 : 12*	*1 : 8.5*
1.	No. of sleepers in a set:			
	(a) Turn out	101	83	54
	(b) Approach	5	.5	5
	(c) Exit	2×4	2×4	2×4
2.	Total length of sleepers (m)	396.88	326.29	225.84
3.	Cement (kg)	11,006	9,048	6,264
4.	HTS (kg)			
	(a) 3×3 ply	1,970	1,620	1,121
	(b) 9.5 dia 7 ply	1,913	1,573	1,089
5.	MS Steel for stirrups in sleeper with (kg):			
	(a) 3×3HTS	304	250	164
	(b) 9.5 dia 7 ply	299	246	162
6.	Inserts	638	489	350
7.	Dowels	222	233	145

4.13 CONCRETE SLEEPERS FOR LEVEL CROSSINGS

A design has been evolved for fixing the guard rails to the concrete sleepers with the help of steel brackets and plate screws. With this arrangement, standard concrete sleepers can be used at level crossings. As may be seen from Fig. 4.16 the foot of the guard rail is cut to avoid interference with the Pandrol Clips. Polythene dowels for fixing the plate screws can be installed at the time of casting of sleepers. As an alternative, the brackets can be fixed to concrete sleepers by drilling holes at site and using grip expansion bolts. Conventional check blocks have been replaced by CI distance brackets to avoid drilling of holes in the running rail.

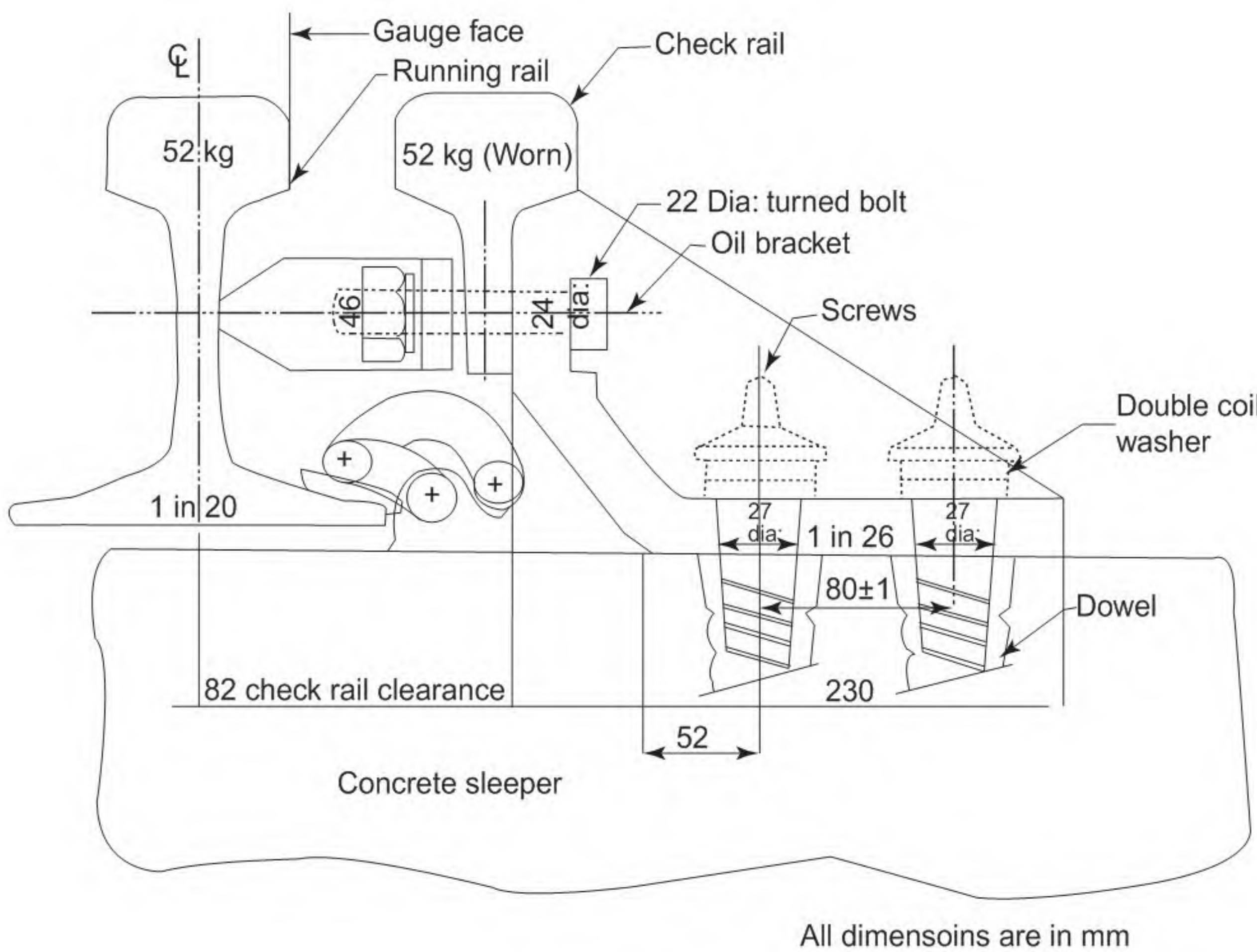


Fig. 4.16

4.14 CONCRETE SLEEPERS FOR GUARD RAILS

Following are the salient features of these sleepers:

1. These are suitable for 60 kg/52 kg running rails with 52 kg, 90 lb guard rails.
2. Base plan and thickness at rail seat is same as that of normal sleeper. Top surface in central portion of sleeper has been made level and grooved rubber sole plates are provided under guard rails for limiting the difference in rail levels of running and guard rail up to 25 mm.
3. For fixing guard rails, dowels are provided. To protect sleeper top against damage due to derailed wheel, provision of mild steel protecting plates is made.

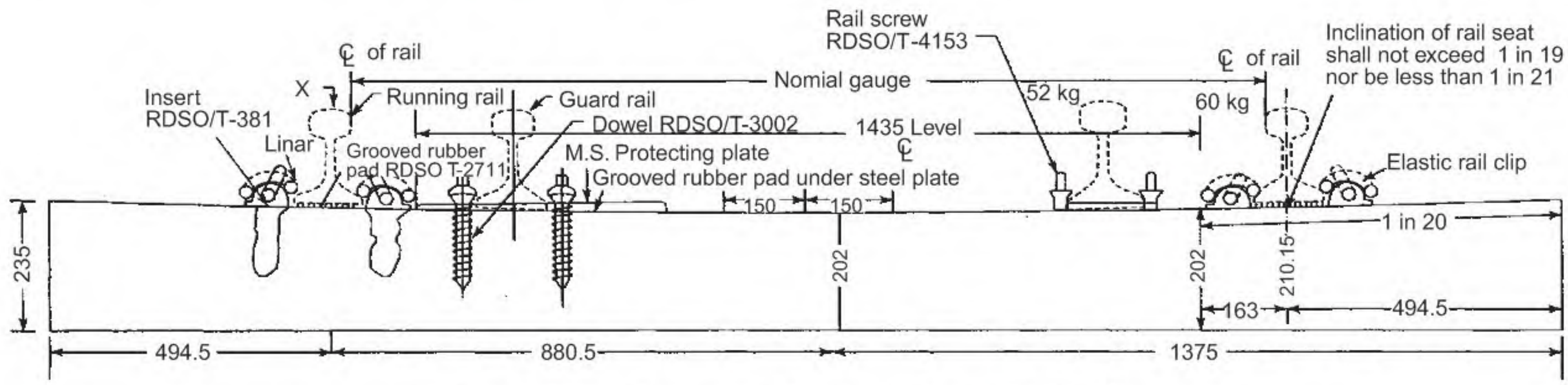


Fig. 4.17 Concrete sleepers for guard rails

4. Flared portion of guard rail on bridge approaches will span on total of eight sleepers. Dowels are provided at different locations on each sleeper to achieve the desired flare of guard rails. These eight sleepers are to be treated as a set of approach sleepers for the purpose of ordering, manufacturing, transporting and laying in track.
5. Both ends of sleepers are out fitted with dowels for fixing MS strips to maintain squareness of sleepers.

4.15 SHALLOW SLEEPER

Design of shallow PSC sleeper has been developed for use under ROBS/FOBS in the electrified areas to avoid their raising during track renewals, where existing 52 kg rails with wooden sleepers are renewed with 60 kg rails on concrete sleepers and full ballast cushion is provided.

Shallow sleeper (RDSO/T-4858) has a depth of 160 mm at rail seat as against 210 mm of normal sleeper.

The reduction in depth has been compensated by increasing the width of section to accommodate the required number of HTS strands. Even with the additional width, additional quantity of HTS and using M-60 concrete the shallow sleeper has lower factor of safety than the standard BG sleeper.

A list of all the various concrete sleeper design prepared by RDSO for special are listed in Appendix 4.1.

4.16 GFN LINERS

Standard GFN liners for use on 60 kg concrete sleepers are as under, along with substituted ones when 52 kg rail is laid on these sleepers (Table 4.6):

4.17 DESIGN OF SLEEPERS

In the design of sleepers, the external loads imposed on the rail seat and the support reaction offered by the ballast are the most important factors. They depend upon (a) vertical and lateral stiffness of the rail, (b) sleeper spacing and (c) track maintenance methods.

Table 4.6

S. No.	*Rail Section*	*Drg No.*	*Identification Mark: Colour band*	*Identification Mark: Print on colour band*	*A*	*B*	*C*	*Slope*
1.	60 kg UIC	RDSO/T-3706	WHITE	60 kg Rail on 60 kg Sleeper	8.0	5.5	50.5	1 in 6
2.	52 kg	RDSO/T-3707	YELLOW	52 kg Rail on 60 kg Sleeper (GS)	9.5	9.0	54.0	"
3.	52 kg	RDSO/T-3708	LIGHT GREEN	52 kg Rail on 60 kg Sleeper (NGS)	10.5 10.5	15.0 15.0	60.0 60.0	" "

GS—Gauge Side;
NGS—Non Gauge Side

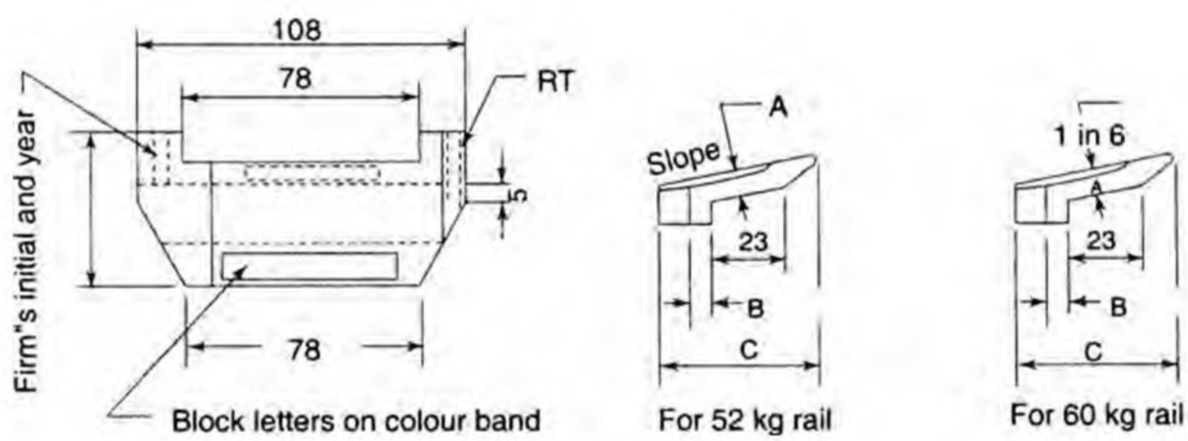


Fig. 4.17a GF N-66 Liner

The variables being so many, it is no surprise to find that the ratio of load on individual sleeper seat to the total wheel load varies from 40 to 100 percent. Under such conditions, empirical assumptions are made to decide the loading standard to which the sleeper should be designed.

4.18 STRESS IN WOODEN SLEEPERS

Stress calculations for BG wooden sleeper in the Indian Railways have been made on the assumption that the entire wheel load is carried by one sleeper seat, but without any dynamic effect. Figure 4.18 shows the loading conditions assumed for the design.

Let

p = wheel load
G = gauge
h = width of rail table
b = width of bearing plate
p_1 and p_2 = ballast reaction per unit length
l_1 = packed length
l_2 = unpacked length

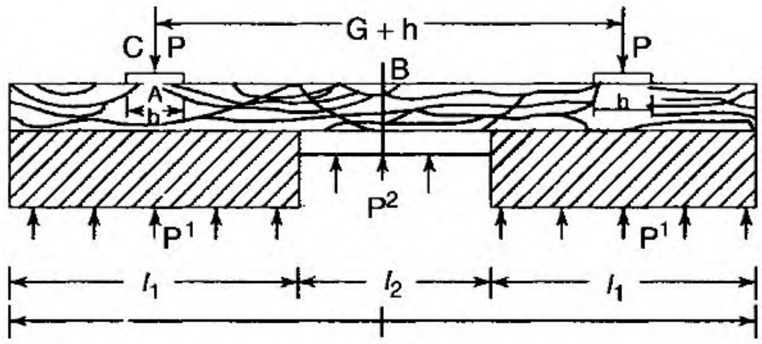


Fig. 4.18

We know from the general formula that $P = p_1\, l_1 + \dfrac{p_2\, l_2}{2}$

Bending moment at $A = \dfrac{p_2\, l_1^2}{8} - \dfrac{P \times b}{2 \times 4}$ (x)

Bending moment at $B = p_1\, l_1\, \dfrac{(l_1 + l_2)}{(2)} + \dfrac{p_2\, l_2^2}{8} - P\left(\dfrac{G + h}{2}\right)$

Bending moment at $C = \dfrac{p_1\,(l_1 - b)^2}{8}$ (y)

For BG track in the Indian Railways

p = 11.43 tonnes
b = 28.6 cm
p_1 = 0.11 tonne/cm
p_2 = 0 (no centre binding)
l_1 = 100.03 cm
l_2 = 74.27 cm

BM at A = 96.72 tonnes as per (x)
Corresponding fibre stress = 1.51 kg/mm^2
BM at C = 69.17 cm tonnes as per (y)
Corresponding fibre stress = 1.07 kg/mm^2

Safe fibre stress in various species of timber used for the sleeper is as follows:

Sal = 2.003 kg/mm^2 (With a factor of safety of 5)

Deodar = 1.02 kg/mm^2
Chir = 0.84 kg/mm^2 } (With a factor of safety of 6)

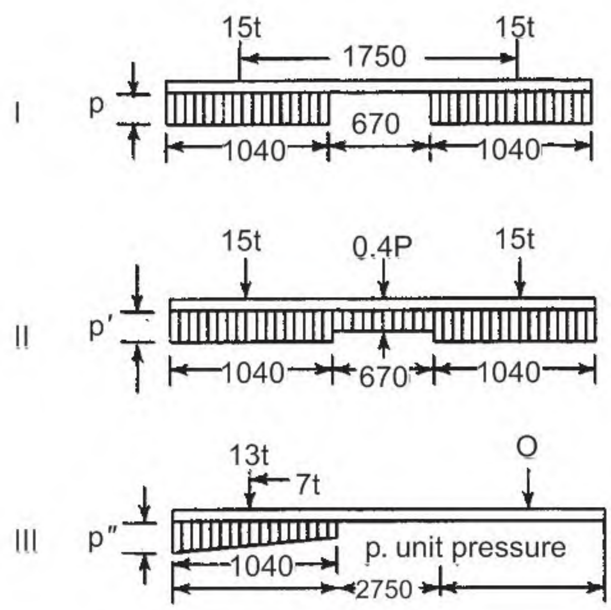
This indicates that Sal sleeper will be quite suitable, but in deodar and Chir the safety factor will be affected.

With the method described, stress in the wood under various conditions of loading and with or without bearing plates can be calculated. It will be seen that:

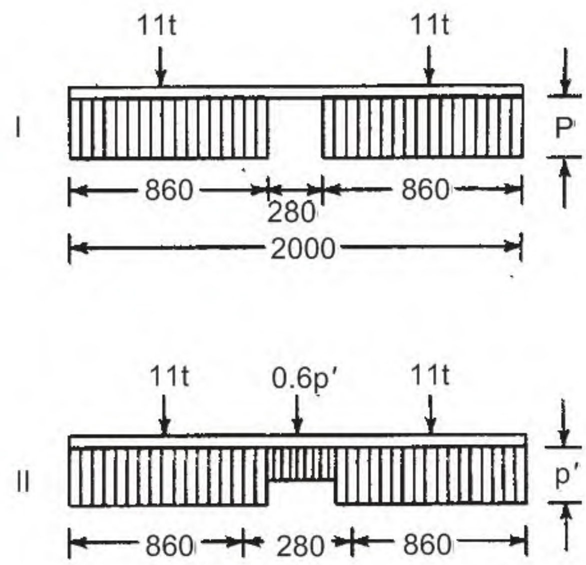
1. The bigger the cross-section of the sleeper, the lower the fibre stress.
2. Centre binding reduces the maximum fibre stress under the rail seat.
3. Bearing plate reduces maximum fibre stress by about 30 percent.

4.19 STRESS IN CONCRETE SLEEPERS

West German Railways are among the advanced railway systems where a large number of concrete sleepers are used. Concrete sleepers designed by them have stood the test of time. Indian Railways have therefore adopted the loading standard followed by German Railways with slight modifications. Concrete sleepers in India are designed to meet the following conditions, [vertical and lateral loads assumed for the design are indicated in Fig. 4.19 (a) (b)].



(a)



(b)

Fig. 4.19(a) BG sleeper-loading diagram **Fig. 4.19(b)** MG sleeper-loading diagram

1. *BG sleeper*: The design provides a safety factor of 1.55 at first crack and 3.13 against collapse.
2. *MG sleeper*: The design provides for a safety factor of about 1.5 at first crack and 2.5 against complete collapse.

Note: Detailed design of concrete sleepers is beyond the scope of this book.

Important details of the various designs adopted on Indian Railways are given in Appendix 4.1.

Appendix 4.1 Concrete Sleepers for Special Location

Location	*Rail Section*	*Drawing No.*	*Remarks*
Level crossing	60 kg/52 kg	RDSO/T-41 48-4148-A	
Switch expansion joint	do	RDSO/T-41.49	
Curves	60 kg	RDSO/T-3670	Slack gauge up to 1681 mm obtained by using liners of different thickness.
Curves	60 kg	RDSO/T-4170-4173	4 different sleepers for gauge 1,675, 1,677, 1,679 & 1,681 mm with the use of normal liners.
Curves MG	90R	RDSO/T-4909-4913	4 different sleepers with gauge 1,002, 1,004, 1,006 & 1008 mm
Curves BG	60 kg with 52 kg check rail	RDSO/T-4183-4186	Specially designed for KK line.
	52 kg with 52 kg 90 R check rail	RDSO/T-5738 to 5740	Gauge widening up to 1679 mm
For deck bridges	(a) 60 kg	RDSO/T-4088-4097	With 52 kg guard rail
	(b) 52 kg	do	With 52 kg/90R guard rail
For rail joints (BG)	60 kg	RDSO/T-4511	Mainline sleeper to be used with ERC "J" clip.
-do-	52 kg	RDSO/T-4322	
For rail joints (MG)	90R	RDSO/T-4779	On manline sleeper, ERC Mk. II clip to be used in reverse position.
Shallow sleeper	60 kg	RDSO/T-4852	For location with restricted headway.
Wider sleeper	60 kg	RDSO/T-3735	For trial on heavy haul routes.
For mixed gauge (3-rail seat)	90R	RDSO/T-4857	Specially developed for Southern Railway
For use without liners	60 kg/52 kg	RDSO/T4306-4307	For economy and better maintainability.

Chapter 5

Rail to Sleeper Fastenings

5.1 CONVENTIONAL FASTENINGS FOR WOODEN SLEEPERS

Conventional fastenings for wooden sleepers used in the Indian Railways are divided into three main systems :

1. Direct laying and direct fastening system.
2. Indirect laying and direct fastening system.
3. Indirect laying and indirect fastenings system.

5.1.1 Direct Laying and Direct Fastenings System

In this system (Fig. 5.1), the rail is laid and fixed on the sleeper directly with spikes, screws or bolts. No bearing plate is used between the rail and the sleeper. Its main advantage is its low cost. Its disadvantages are : (a) in the absence of a bearing plate, there is abrasion between the rail foot and the sleeper, and the rail tends to cut into the sleeper, (b) the vertical load on the rail is directly transmitted to the sleeper only over the area covered by the rail foot. The compressive forces on the sleeper are thus relatively high, causing crushing of wood particles underneath, (c) the lateral forces are directly transmitted to the fastening, which they are unable to resist for a long period, thus affecting the track gauge.

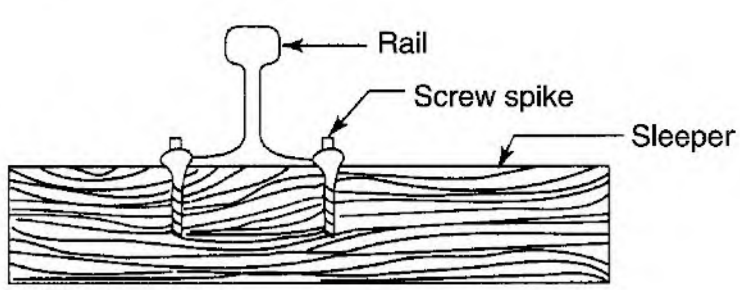


Fig. 5.1

In the Indian Railways, direct laying and direct fastening system is adopted with hardwood (*U*) sleepers only on plain track (not on points and crossings). Direct fastening of rail to sleeper is accomplished either with dog spikes or rail screws.

Dog Spike Figure 5.2 and Table 5.1 give the broad dimensions of the dog spike used in the Indian Railways. On the spike's head, lugs are provided for extraction. It is on account of the shape of its head that is known as "dog spike". The head and point of all sizes of dog spikes are identical and the shank is a uniform 16 mm square section. The length under the head is varied to suit sleepers with or without bearing plates for various gauges, viz. broad, metre and narrow.

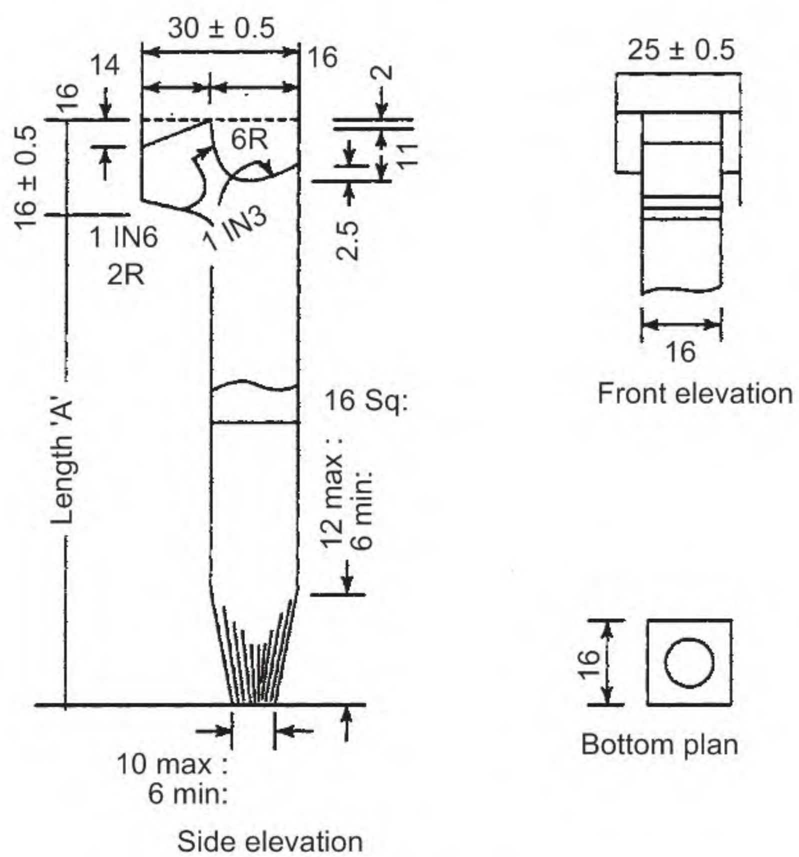


Fig. 5.2 Dog spike

For fixing dog spikes into the sleepers, holes are bored with augers right through the sleeper. Hole sizes of 16 mm for hardwood (*U*) sleeper and 14 mm for softwood (*T*) sleepers have been standardized on the Indian Railways.

The wave-motion of the rail under traffic pulls up the spikes slightly. If there is no prising up of the head by more than 3 mm, the spike is not to be driven back, because the frequent hammering of the spikes loosens its grip. When the spike becomes too loose, it is pulled out, the hole is plugged with a wooden plug, another hole is bored and the spike is redriven.

Rail Screws Figure 5.3 and Table 5.2 give the broad dimensions of rail screws used in the Indian Railways. Rail screws are employed for fastening the rail and sleeper and are an alternative to dog spikes. It is however a more effective method of fastening, its pull-out resistance being almost double to that of dog spikes. The head and the point of all sizes of rail screws are

Table 5.1 Dog Spike

Description	BG		MG		NG		Calculated weight per 100 spikes	
	Length "A"	*Part No.*	*Length "A"*	*Part No.*	*Length "A"*	*Part No.*	*Part No.*	*Weight (kg)*
For use with Xing							T276 (M)	38.51
timbers (special)	160 ± 3	T276 (M)	135 ± 3	T277 (M)	120 ± 3	T278 (M)	T277 (M)	33.49
For use with bearing plates	135 ± 3	T227 (M)	120 ± 3	T278 (M)	110 ± 3	T279 (M)	T278 (M)	30.48
For use without bearing plates	120 ± 3	T278 (M)	110 ± 3	T279 (M)	110 ± 3	T279 (M)	T279 (M)	28.47

Table 5.2 Rail Screw

Gauge	*Description*	*Drawing number*	*Dimensions (mm)*									
			A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*
BG	For use without bearing plates	RDSO/T-488	120 ± 3	20 ± 5	30	22	11	$34\pm^{2}_{1}$	4	6	35	50 ± 0.5
MG	For use without bearing plates	RDSO/T-488	110 ± 3	20 ± 5	30	22	11	$34\pm^{2}_{1}$	4	6	355	0 ± 0.5
BG	For use with bearing plates	RDSO/T-490	135 ± 3	30 ± 5	30	22	11	$34\pm^{2}_{1}$	4	6	35	50 ± 0.5
MG	For use with bearing plates	RDSO/T-491	120 ± 3	30 ± 5	30	22	11	$34\pm^{2}_{1}$	4	6	35	50 ± 0.5

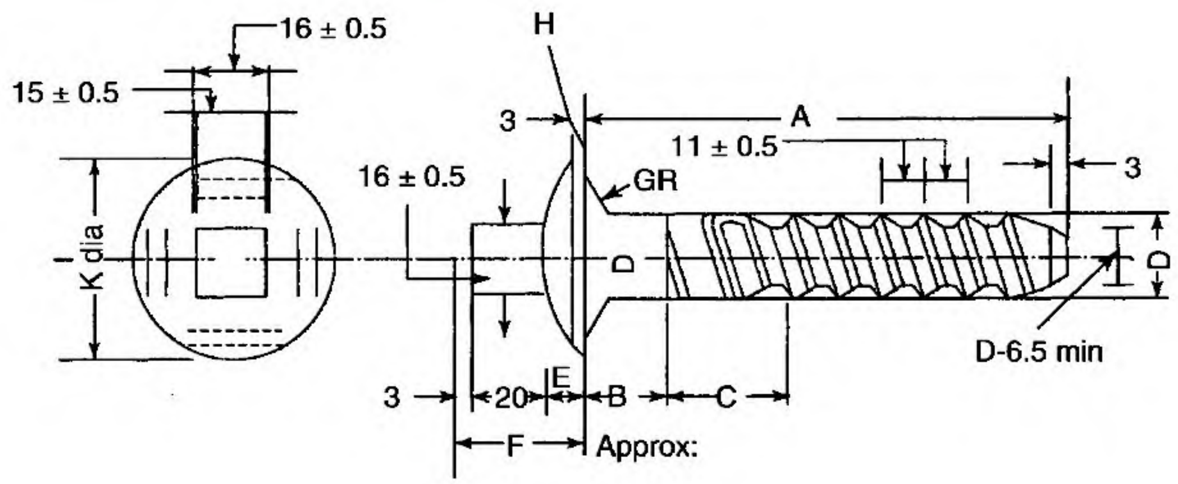


Fig. 5.3 Rail screws

identical and the shank is of a uniform 22 mm diameter. The overall length under the head and the length of the unthreaded portion are varied to suit sleepers with or without bearing plates, of various gauges. The rail screw is provided with greater head-width and a sloping surface under its head to get a better hold on the rail. Because of their firmer grip, rail screws are preferred to dog spikes in Indian Railways.

5.1.2 Indirect Laying and Direct Fastening System

In this system (Figure 5.4), a common fastening fixes the bearing plate to the sleeper body and the rail to bearing plate. The bearing plate whether of cast iron or steel serves to distribute the load on the rail over a large area of the sleeper. This limits the compressive stress on the sleeper. The bearing plate is essential for softwood (*T*) sleepers and advantageous for hardwood sleepers.

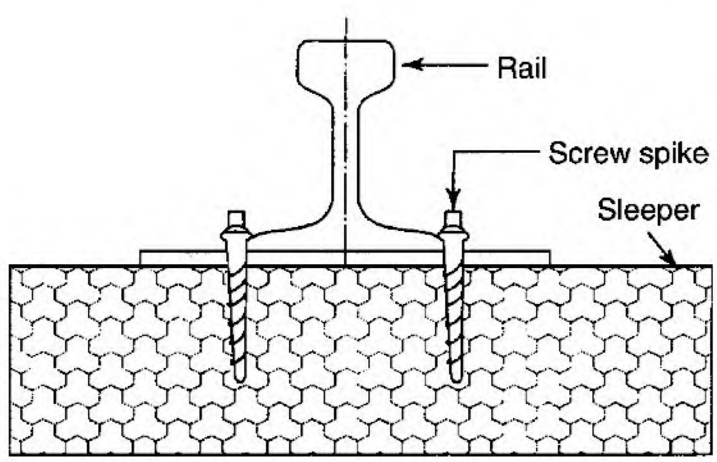


Fig. 5.4 Flat MS bearing plate

Because of the friction between the bearing plate and the sleeper, the lateral forces on the spikes are reduced, thus improving the gauge holding capacity of the sleeper.

The system is adopted in the Indian Railways in the following three assemblies.

Single Rail Mild Steel Bearing Plate (*Flat*) Figure 5.5 and Table 5.3 give the broad details of the bearing plate and the fastening system adopted with it. These bearing plates are only used in turn-outs tracks, on the portion where combined bearing plates are not required. The combined bearing plates vary in dimensions depending upon the gap between the two rails resting on them.The system of indirect laying and direct fastening is also used here.

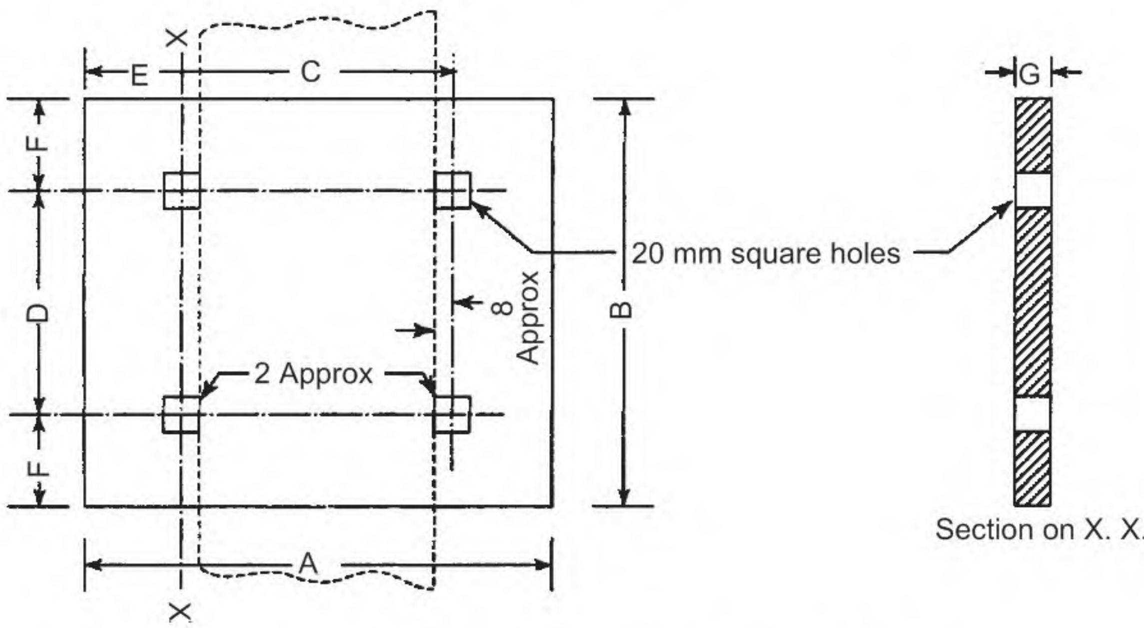


Fig. 5.5 Single rail mild steel bearing plate–flat

Table 5.3 Part Number and Dimensions (Mild Steel–Flat)

Rail section	*Part number*	*Gauge*	*Approx. weight of each in kg*	*Dimensions (mm)*						
				A	*B*	*C*	*D*	*E*	*F*	*G*
52 kg and 90R	T1,994(M)	BG	8.72	260	220	152	120	54	50	20
75R	T12,545	MG	3.57	200	150	138	80	31	35	18
60R	T12,581	MG	3.57	200	150	125	80	38	35	16

Both dog spikes and rail screws can be used with this system, but the spikes are required to be of a longer length. For dog spikes, square holes of 20 mm × 20 mm are provided; whereas for rail screws, 26 mm dia circular holes are to be provided.

Single Rail, Mild Steel Bearing Plate (*Canted*) In the Indian Railways, rails are laid with a cant of 1 : 20 except on points and crossings where they are laid flat. Single rail, mild steel canted bearing plates are used for laying the rails on a 1 : 20 cant, following the indirect laying and direct fastening system. See Fig. 5.6 and Table 5.4.

The salient features of these bearing plates are (a) a shoulder on the outside of the rail foot, (b) a recess under the middle of the rail seat to prevent rocking of the rail on its seat, (c) a cant of 1 : 20 incorporated in the rolling of the plate.

Table. 5.4 Part Number and Dimensions (Mild Steel–Canted)

Rail section	*Weight per metre of rolled section in kg (approx.)*	*Part number*	*Gauge*	*Weight of each (approx.)*	*Dimensions (mm)*												
					A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*
52 kg and 90R	29.59	RDSO/T-516	BG	6.21	260	220	49.5	160	60	26	21	11	11	62	32	68	16
75R	22.48	RDSO/T-664	MG	3.34	220	160	37.5	146	40	23	18	10	9.5	50	36	50	13

Table 5.5 Part Number and Dimensions

Rail section	*Part number*	*Gauge*	*Appprox. weight of each in kg*	*Dimensions (mm)*										
				A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*
90R	T211(M)	BG		285	204	60	27.5	157	95	44	48	45	29	13

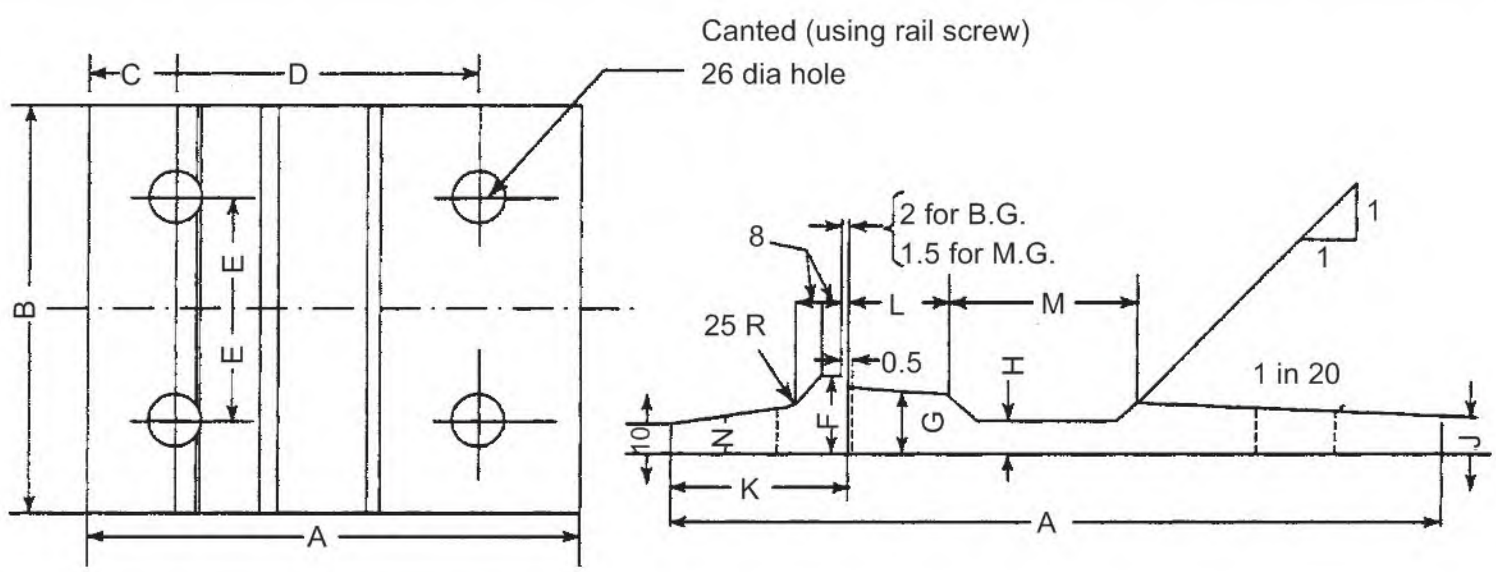


Fig. 5.6 Single rail MS bearing plate (canted)

Single Rail Bearing Plates, Cast Iron Ordinary, Canted The bearing plates serve the same purpose as the mild steel canted bearing plates. But they are more suitable when used in conjunction with anticreep cast iron bearing plates which have the same thickness and overall dimensions. In tracks laid with single/three rail panels, the joint sleepers are required to be rail-free sleepers. These bearing plates can be efficiently used at these sleepers when all the intermediate sleepers are laid with anticreep bearing plates. The present design in the Indian Railways is only for 90 R rail section, and is suitable for use with dog spikes only. The design can be suitably modified for use with other rail sections and with rails screws. See Fig. 5.7 and Table 5.5.

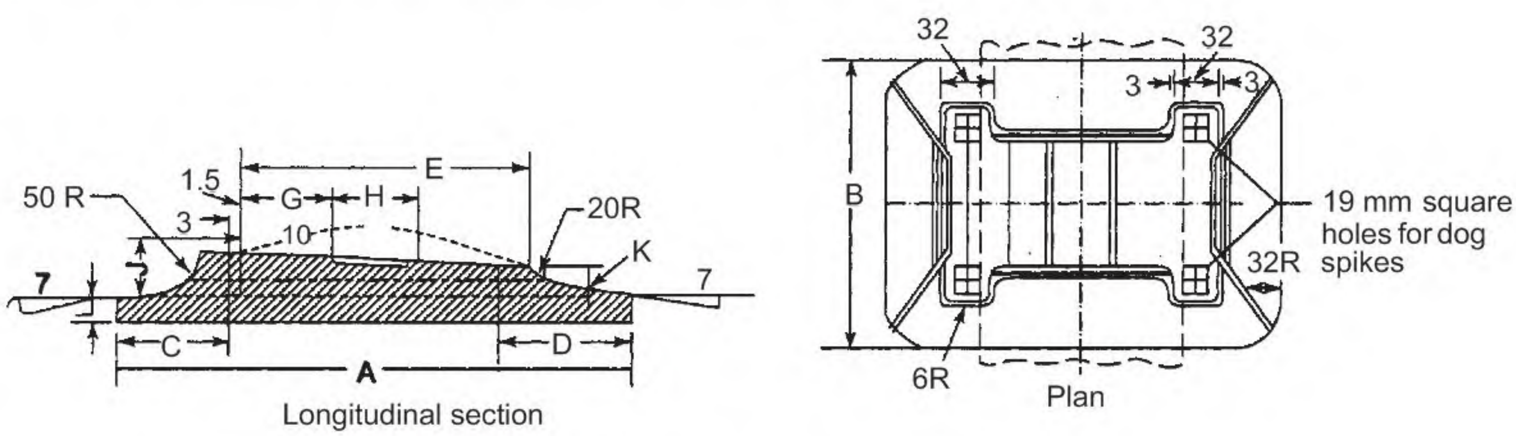


Fig. 5.7 Bearing plate cast iron

5.1.3 Indirect Laying and Indirect Fastening System

In this system (Fig. 5.8), the bearing plate is fastened to the sleeper with plate screws/round spikes, but the rail is fixed to the bearing plate with two-way keys. With this arrangement, rail grip is not affected by the wave action of the rail and thus it is an effective anticreep fastening. The lateral force coming on to the spike is less, thereby improving its gauge holding capacity.

Cast iron anticreep bearing plates used with this system are two types : (a) one-key bearing plates and (b) two-key bearing plates.

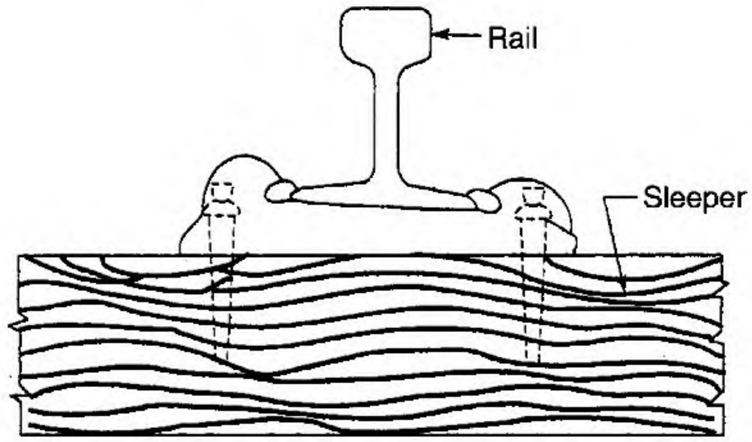


Fig. 5.8 Anti-creep nearing plate

One-key anticreep bearing plates have a single two-way key provided on the gauge side jaw only. On prebored sleepers, these plates do not permit any gauge adjustment. As railways experienced difficulty in obtaining chaired sleeper true to gauge, designs of two-key bearing plates were evolved, which allow adjustment in gauge. The design features of two keys bearing plates are illustrated in Figs 5.9 and 5.10. Broad dimensions of bearing plates used with various rail sections have been tabulated. (Fig. 5.9; Table 5.6 and Fig. 5.10; and Table 5.7).

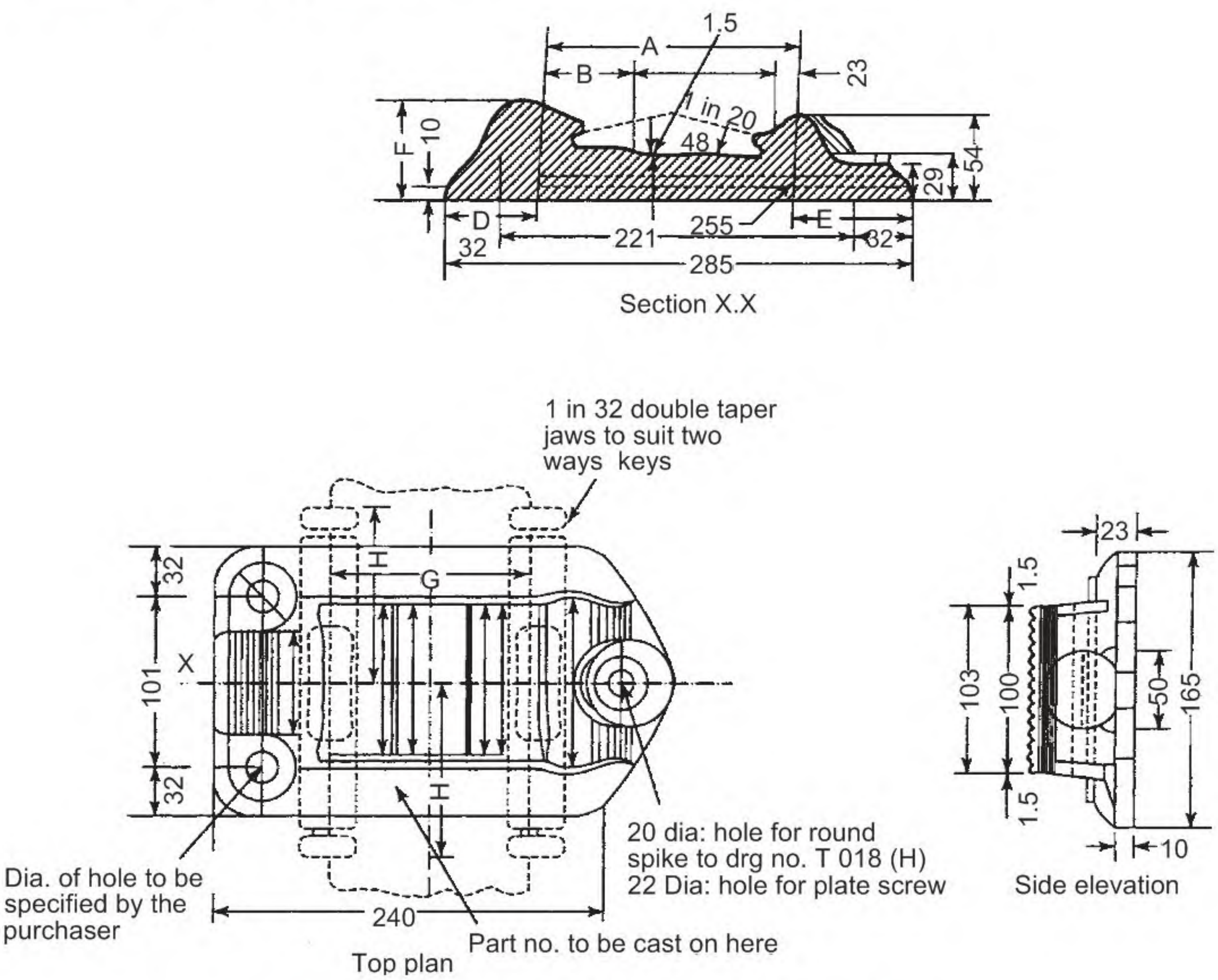


Fig. 5.9 Bearing plates, anti-creep CI (MG)

Table 5.6 Part Number and Dimensions (MG)

Rail section	*Gauge*	*Part number*	*Approx. weight of each in kg*	*Dimensions (mm)*							
				A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
75R	MG	T10146	8.84	158.5	57	12.5	55.5	71	63	133	156.5
60R	MG	T10148		142.5	50	11	66.5	76	63	120	156.5
50R	MG	T10150		136	45	11	72.5	76.5	62	111	130.5

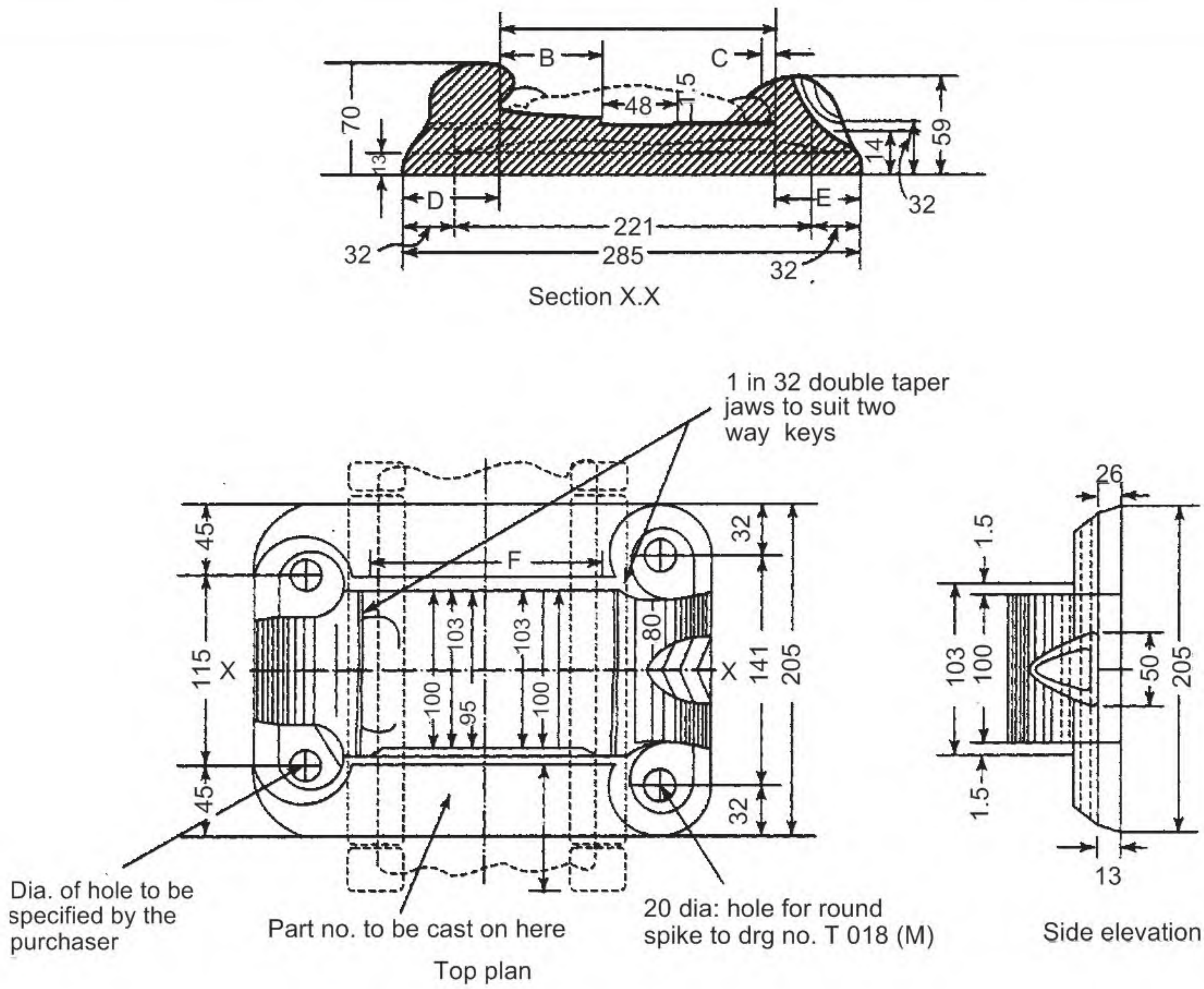


Fig. 5.10 Bearing plate, anticreep CI (BG)

Table 5.7 Part Number and Dimensions (BG)

Rail section	*Gauge*	*Part number*	*Approx. weight of each in kg*	*Dimensions (mm)*						
				A	*B*	*C*	*D*	*E*	*F*	*G*
52 kg and 90R	BG	T10142	11.26	173	59	11	57	55	145	85
75R	BG	T10144		158.5	57	12.5	67.5	59	133	68

In two-key bearing plates, round spikes or plate screws are used for fastening the bearing plates to the sleeper. Two-way keys are employed for fixing rails to the bearing plates. Main features of these fastening items are given in the succeeding paragraph.

Round Spikes Figure 5.11 delineates the main features of round spikes used on Indian Railways. Like the dog spikes, shank too has been standardized vis-à-vis the shape of the head, the point and the dia (18 mm). The length of course is varied in relation to use under different conditions.

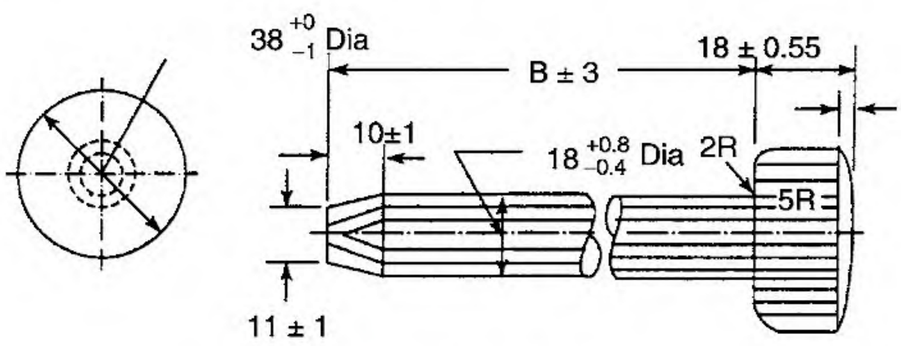


Fig. 5.11 Round spikes

Plate Screws The broad features of the plate screws used on Indian Railways are given in Fig. 5.12; Table 5.8. Plate screws are now extensively used with all types of bearing plates to fasten the bearing plates to the wooden sleepers. Its use has completely replaced round spikes in all new track installations. Head and point of all sizes of plate screws are identical and the shank is a uniform 20 mm dia. The overall length under head is varied to suit the thickness of wooden sleepers.

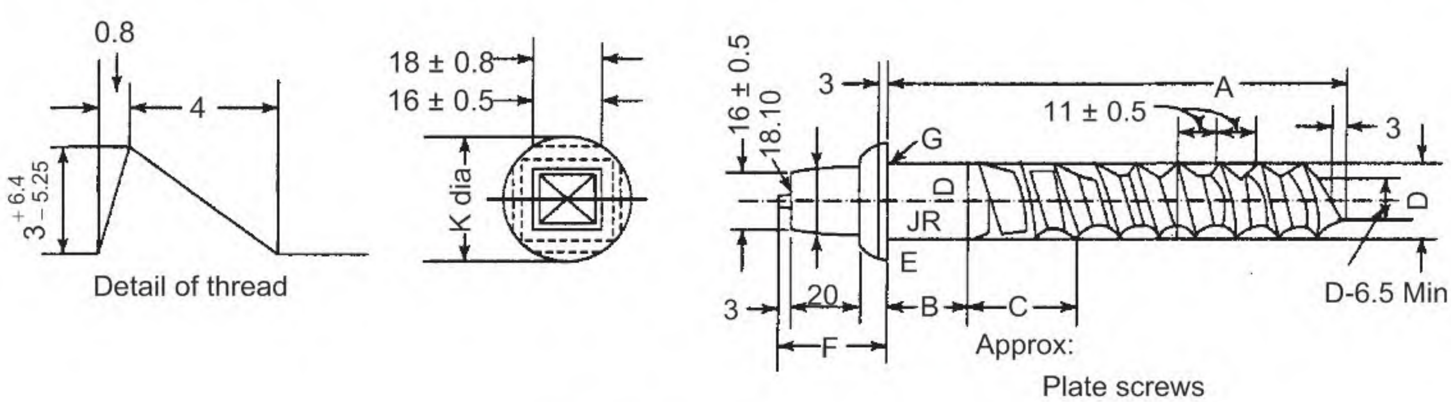


Fig. 5.12 Plate screw

Two-way Keys In the Indian Railways, the two-way keys are extensively used with various rail to sleeper fastening assemblies, to provide an effective rail gripping device. The dimensions and the taper have been adjusted to suit cast iron bearing plates, cast iron sleepers, and steel sleepers alike. Their two-way features, enables them to be used both as left handed or right handed keys, depending of course, upon the direction of creep. See Fig. 5.13; Table 5.9 and Fig. 5.14; Table 5.10.

The keys are obtained from a special rolled bar section of the shape sketched in Fig. 5.15.

Three sections have been designed for Indian Railways : for 52 kg/90R/75R rails; for 60/50 R rails; and of oversize two-way keys for 52 kg/90R/75R rails. The horizontal taper in all the designs

Table 5.8 Plate Screw

Gauge	*Description*	*Drawing number*	*Dimensions (mm)*								
			A	*B*	*C*	*D*	*E*	*F*	*G*	*J*	*K*
BG	For use with crossing timbers (special)	RDSO/T-1443	160 ± 3	30 ± 5	30	20	7	$30 \pm ^{2}_{1}$	1	25	35 ± 0.5
BG	For use with CI anti-creep bearing plates	RDSO/T-1444	135 ± 3	30 ± 5	30	20	7	$30 \pm ^{2}_{1}$	1	25	35 ± 0.5
MG	For use with crossing timbers (special)	RDSO/T-1444	135 ± 3	30 ± 5	30	20	7	$30 \pm ^{2}_{1}$	1	25	35 ± 0.5
MG	For use with CI anti-creep bearing plates	RDSO/T-1445	120 ± 3	30 ± 5	30	20	7	$30 \pm ^{2}_{1}$	1	25	35 ± 0.5

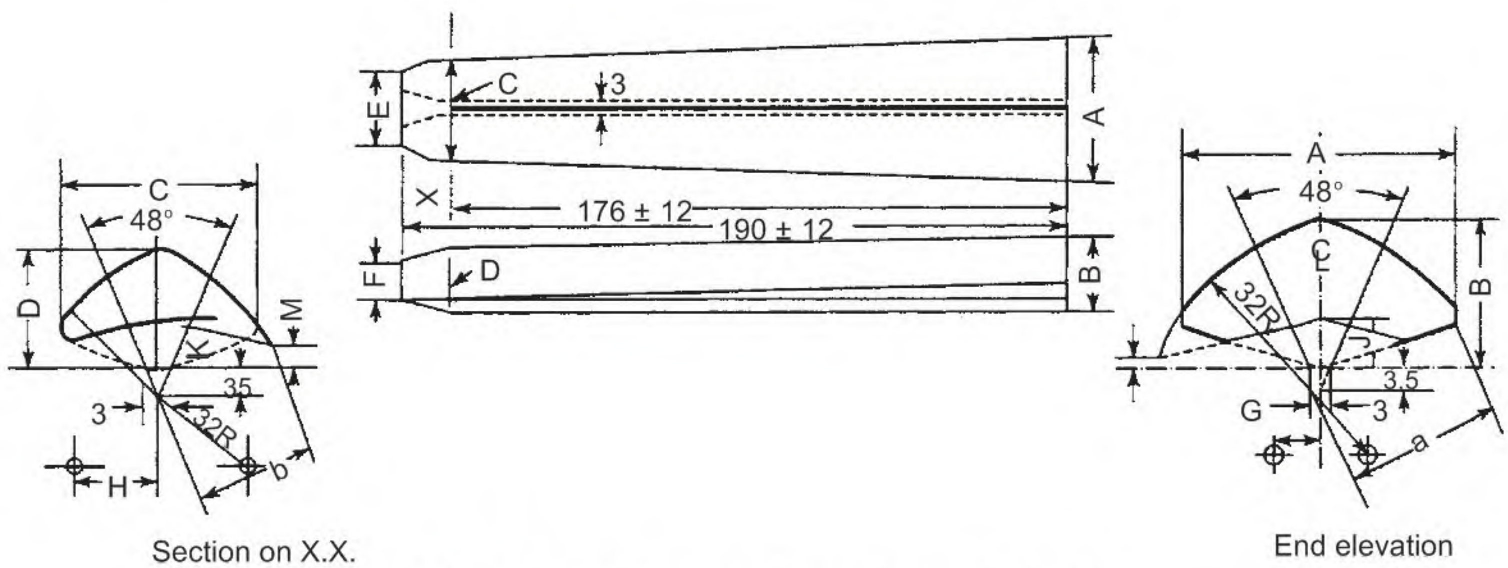


Fig. 5.13 Two-way keys (normal size)

Table 5.9 Part Number and Dimensions

Rail section	*Part number*	*Wt. of 100 keys in kg (approx.)*	*Dimensions (mm)*											
			A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*
52 kg 90 R and 75 R	T405(M)	48.5	39	20.5	28.5	16.5	21	9	6.5	11	7	7	1.5	3
60R and 50R	T413(M)	43.0	35.5	18	25.5	14.5	19	8	4	9.5	5.5	5.5	1	1

is 1 in 32. Oversize keys are required to be used when the normal size keys are not held in position on account of excessive wear at the key bearing surfaces.

The number of spikes/screws required to be used per rail seat with or without bearing plates are as follows :

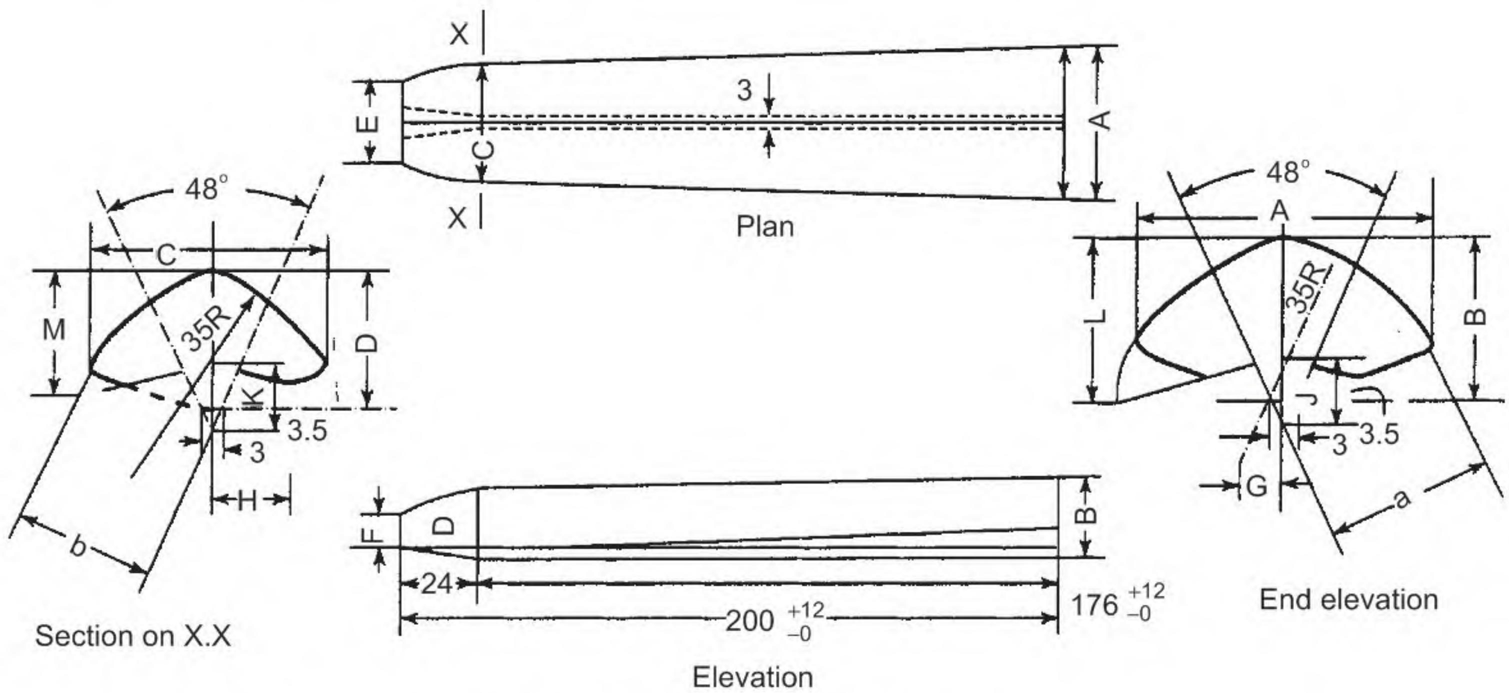


Fig. 5.14 Two-way keys (oversize)

Table 5.10 Part Number and Dimensions (over size)

Rail section	*Part number*	*Wt. of 100 keys in kg (approx.)*	*Dimensions (mm)*											
			A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*
52 kg 90R and 75R	RDSO/T-580	79.7	45	25	35	21	25	11	7	12	7	7	25	19.5

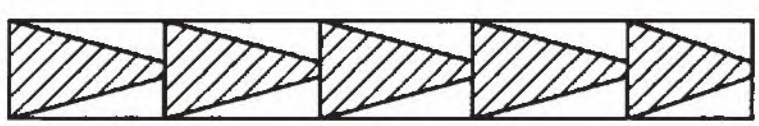


Fig. 5.15

1. All joint sleepers, bridge timbers, turnout timbers and ash pit timbers – *four*
2. Intermediate sleepers, on curves

   Group A, B, C and D lines on BG
   Trunks line on MG } *two outside* and *one inside*
3. Intermediate sleepers on other lines—*one inside* and *one outside*

These should be provided as per the arrangement shown in Fig. 5.16.

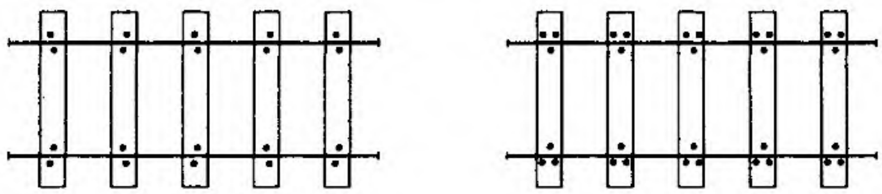


Fig. 5.16 Rail seat

5.2 CONVENTIONAL FASTENINGS FOR STEEL TROUGH SLEEPERS

Figure 5.17; Table 5.11 indicate the general arrangement for rail to sleeper fastenings on steel trough sleepers. Spring steel loose jaws and two-way keys are used for fastening the rail to the sleepers. For holding the jaws, steel sleepers are provided with round holes. In these holes the jaws are positioned to provide necessary vertical and lateral support to the rail foot with the help of the two-way keys.

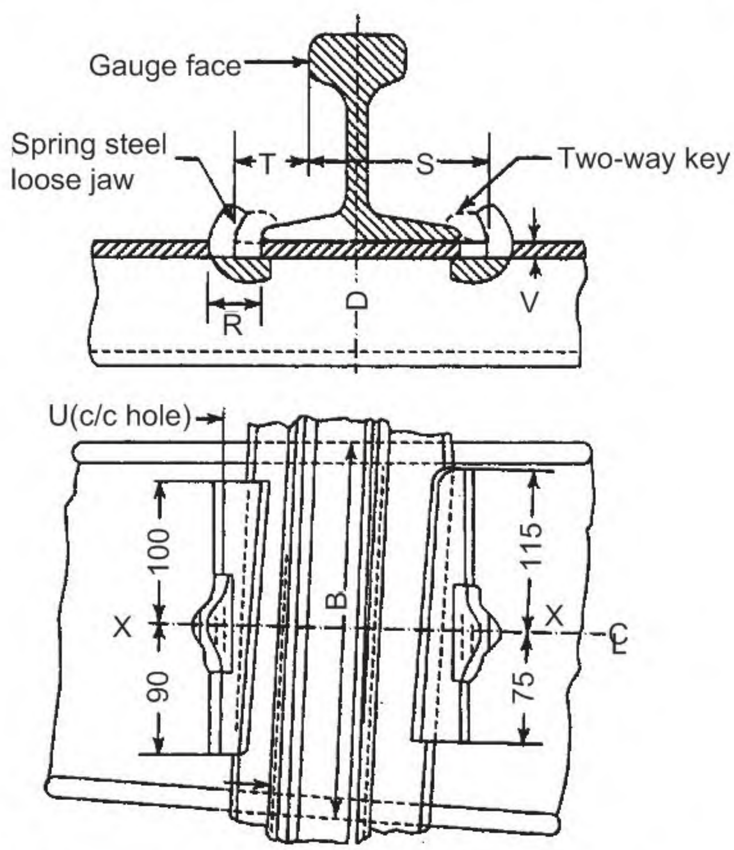


Fig. 5.17 BG and MG steel trough sleepers (plan at rail seat)

Figure 5.18; Table 5.12 give the broad dimensions of loose jaws. Spring steel loose jaws form an efficient fastening for steel sleepers and have replaced the pressed up jaws of the older type, which were liable to get easily damaged, cracked or permanently deformed.

With the passage of time, even spring steel loose jaws open up and the sleeper holes get elongated, thus loosening their grip on the keys. Consequently, keys fall out, leaving the rail free. Such a situation can be remedied either singly or in combination by any of the following four ways.

Table 5.11 Part Number and Main Dimensions

Rail section	*Gauge*	*Part number*	*Two way key*	*Spring steel loose jaw*	*Dimensions (mm)*						
					B	*D*	*R*	*S*	*T*	*U*	*V*
52 kg and 90R	BG	T460(M)	T405(M)	T415(M)	257	89	36.5	118.5	50.5	1586.5	13
75R	BG	T10273	T405(M)	T10003	257	89	36.5	110	47	1,591	11
75R	MG	T10271	T405(M)	T419(M)	215	79	32	109	47	917	9
60R	MG	T10272	T413(M)	T10002	215	79	32	101	43	924	9
50R	MG	T10277	T413(M)	T10002	215	79	32	93	40	929	9

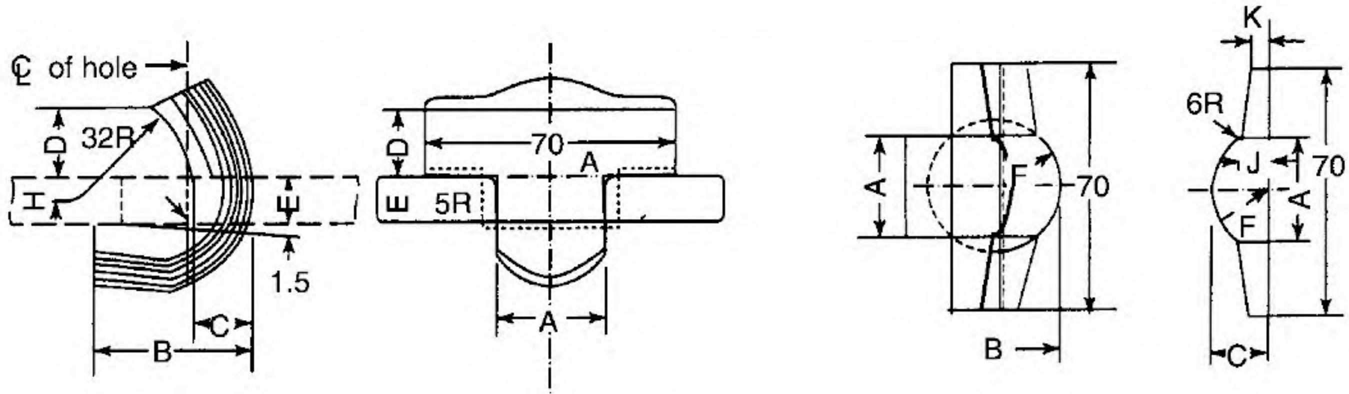


Fig. 5.18 Spring steel loose jaws

Table 5.12 Part Number and Dimensions

Rail section	*Gauge*	*Part number*	*Wt. of 100 jaws in kg (approx.)*	*Dimensions (mm)*									
				A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*
52 kg and 90R	BG	T415(M)	28.8	30	43	16	19	13	19	7	6	9	6
75R	BG	T10,003	28.1	30	43	18	18	11	19	7	7	8	6
75R	MG	T419(M)	23.1	27	35	13.5	19	9	16.5	4.5	6.5	6.5	5
60R and 50R	MG	T10,002	21.5	27	35	13.5	16	9	16.5	6	9.5	6.5	5

1. *Use of oversize keys* : When normal keys start working loose, the use of oversize keys is helpful, particularly when the looseness is on account of opening of jaws.
2. *Use of steel liners* : These steel liners, which are made from plain steel sheets, are so formed as to fill in the space formed by the elongation of holes. They are provided with lips which hold them in position (Fig. 5.19).
3. *Use of oversize loose jaws* : These jaws, which are made from thicker metal, make up for the elongation of holes when placed in position.
4. *Use of rubber or hydolignam (compressed wood) pads* : These pads when provided under the rails, lift the rails to a position that the jaws and keys regain their grip despite the opened up jaws. The pads also impart elasticity to track and are a good vibration absorption medium.

The problem of opening up of jaws usually arises with indiscriminate driving in of keys with non-standard heavy hammers. The use of standard keying hammers should therefore be insisted upon.

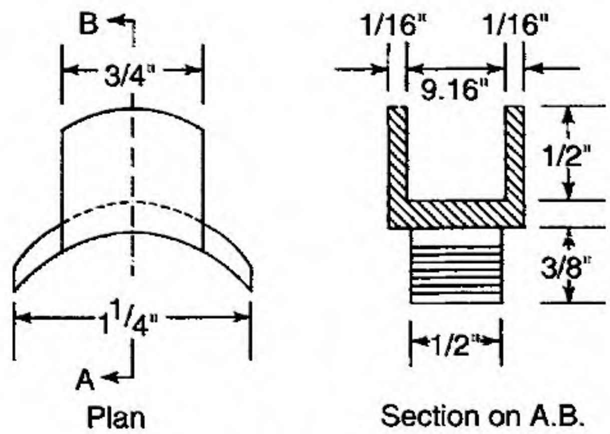


Fig. 5.19 Mota Singh liner

5.3 CONVENTIONAL FASTENINGS FOR CAST IRON SLEEPERS

CST-9 cast iron sleepers consist of two cast iron plates jointed together with a tie bar, which is held in position with the help of four cotters. Rails are fastened to sleeper plates with two-keys. Cotters and tie bars are the fastenings peculiar to CST-9 sleepers. Whereas two way keys are common with steel and wooden sleepers.

5.3.1 Tie Bars

Tie bars are mild steel flats, which tie the two cast iron plates together with the help of cotters. Dimensions of the tie bars used with BG and MG sleepers are given in Fig. 5.20.

Tie bar section for BG is 50 mm × 12 mm and that of MG is 45 mm × 10 mm.

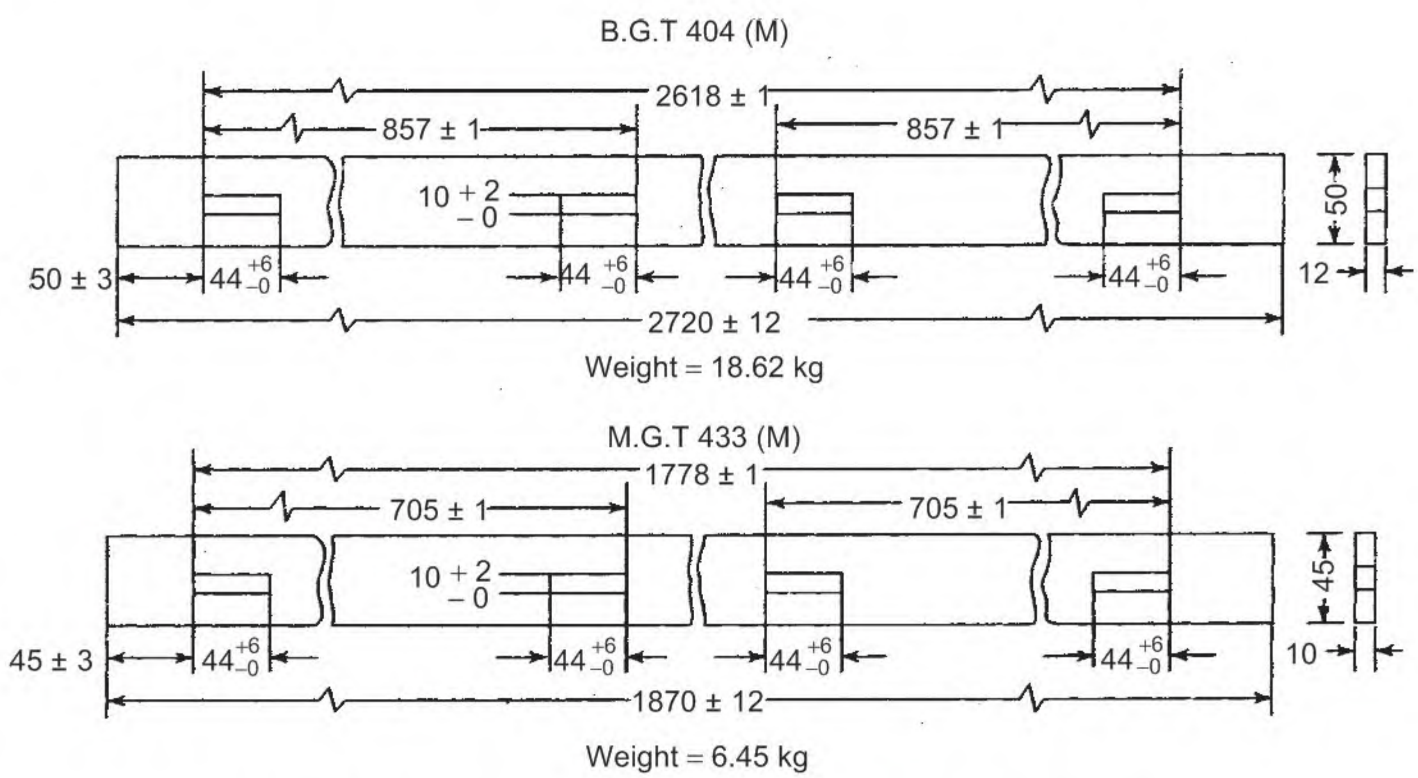


Fig. 5.20 Cast iron sleeper fastenings (MS tie bars)

5.3.2 Cotters

Cotters are mild steel flats, cut and bent to the desired shape. There are four different types of cotters standardized in the Indian Railways (Fig. 5.21).

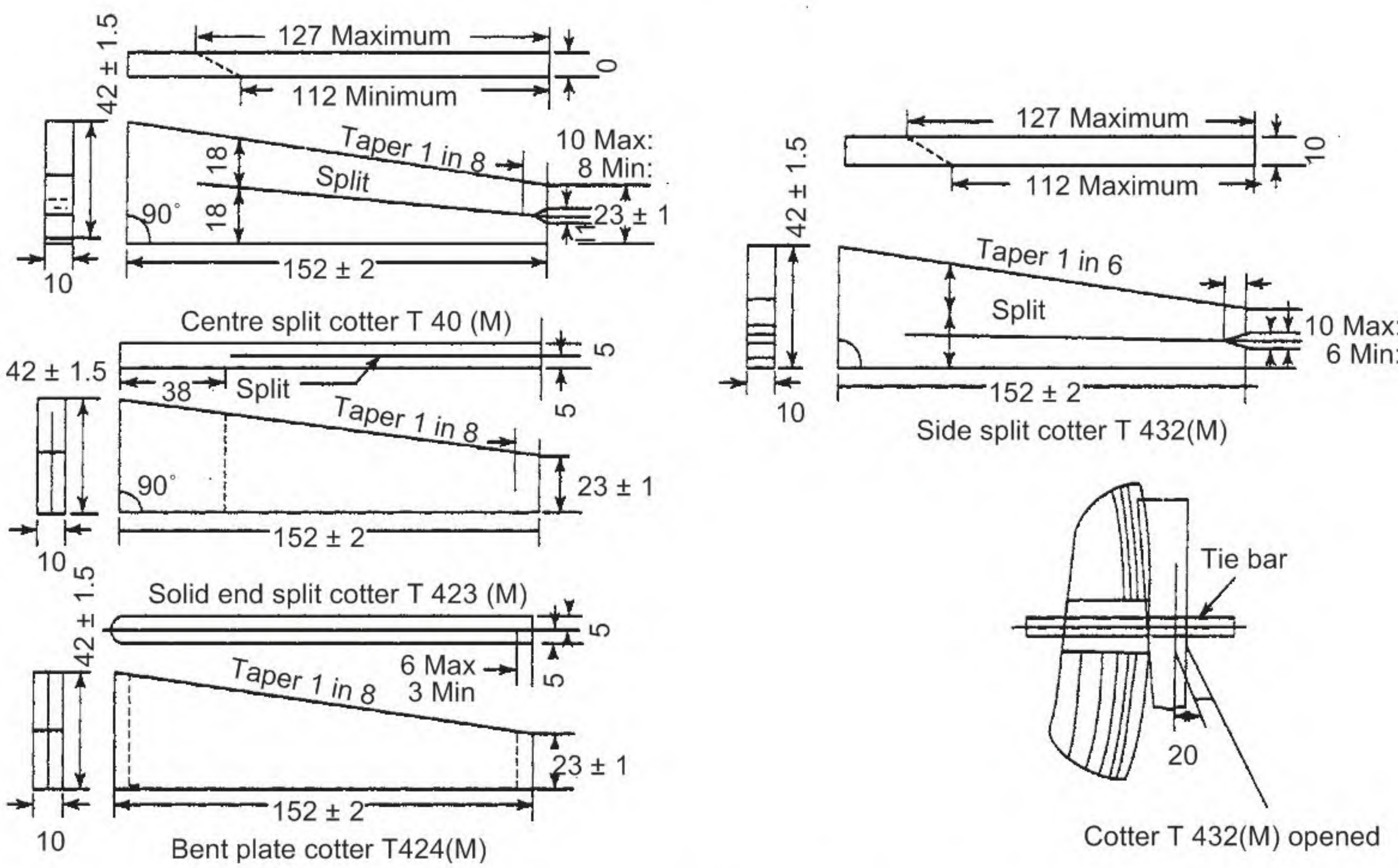


Fig. 5.21 CI sleeper fastening MS cotters (dimensions are in mm)

Overall dimensions, taper, etc. in all the four are nearly the same and interchangeable; the difference is in the manner of forming and splitting the cotter. Out of these four, the side split cotter is the most commonly used one because of its easy splitting facility and relatively longer life.

Wear and tear of rail bearing surfaces of the CI plates is a concomitant effect of their constant use in track. This leads to working loose of keys, thus leaving the rail free. Such situations can be remedied by taking recourse to methods 1, 2 and 4 suggested in Sec. 5.2; Fig. 5.22.

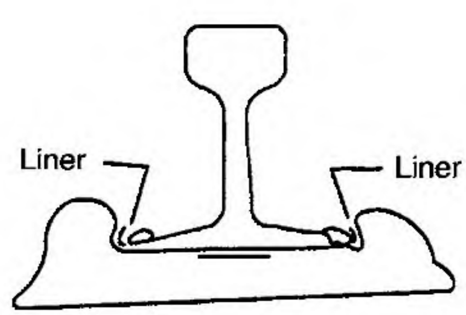


Fig. 5.22

5.4 ELASTIC FASTENINGS

5.4.1 Phenomenon of Vibration

Reasonably good service as the conventional railway fastenings seem to provide, they are beset by an inherent flaw, i.e. within a short span of their tightening on the rails, fastenings work loose-resulting in play between fastenings and the rails and grip loss on rails-leading to deterioration in the overall track assembly. Detailed study lays open the fact that higher frequency of vibrations is the principal cause of working loose these rigid fastenings. Further investigations reveal that these vibrations are a concomitant effect of the rolling wheel/rail contact surface irregularities-of both. It is also found that whatever be the nature of rail/wheel interacting forces, the track will vibrate corresponding to the natural frequency of its components. These frequencies in the rail are always about 800 cycles per second and their acceleration is of the order of 100 times of gravity for moderate speeds up to 100 kmph and they increase rapidly at higher speeds.

5.4.2 Effect on Track

The high frequency vibrations shake up the entire track assembly sleeper packing is the first to be affected by these vibrations to be followed by the wear and tear of whole track assembly. Therefore, sleeper packing and other track disorders need to be rectified from time to time to maintain them at the safety level.

5.4.3 Effect on Rolling Stock

Vibrations are transmitted to the rolling stock through wheels, leading to the bouncing of the vehicles, wear and tear of the rolling stock components and discomfort to the passengers.

5.4.4 Functions of Elastic Fastenings

Elastic fastenings keep a firm grip on the rail, damp the rail vibrations and rail precussion waves. Besides, they are quite effective against the rail creep. These functions of elastic fastenings help the track to withstand heavy traffic with minimal adverse effects on its assembly.

5.4.5 Ideal Rail to Sleeper Fastening

An ideal rail to sleeper fastening is expected to satisfy the following requirements :

1. *Safeguard track parameters* : Rail fastening should provide adequate resistance against track deterioration which depends upon the vertical and lateral hold of the fastening on the rail under static and dynamic conditions.

2. *Resistance to longitudinal forces* : Fastenings should be rail creep preventers so that the rails can safely be welded into a long length. For this purpose, the rail/sleeper creep resistance is required to be more than the sleeper/ballast resistance. The fastenings must therefore, have sufficient contact pressure, which should not weaken considerably during the service life of the rail and fastenings. A figure very much beyond the ballast resistance is obviously not of much use.
3. *Few components* : It should have as few components as possible.
4. *Fit and forget* : It should preferably be of the fit-and-forget self-tensioning type and should maintain its toe-load during its service life.
5. *Safeguard against theft and sabotage* : It should have sufficient extraction resistance and be safe against theft and sabotage.
6. *Retain toe-load on reuse* : It should retain its holding power when used and reused a number of times.

5.4.6 Essential Components of the Elastic Fastening System

For the elastic fastening assembly to perform its function effectively it must have two essential components, (a) an elastic rail pad and (b) an elastic rail clip.

5.4.7 Elastic Rail Pad or Sole Plate

Elastic rail pads (Fig. 5.23) are usually made from natural/synthetic rubber, cork, nylon, polythene or similar elastic materials. They form an integral part of all elastic fastening assemblies. Their functions are as follows :

1. *Absorb shocks and damp out vibrations* : They possess a special property of absorbing energy by internal friction and dissipating the same in the form of heat. When placed under the rail, they do not follow the rail vibrations closely but have a small lag, which is favourable in damping out high-frequency vibrations. To avoid any hammering effect, they ensure that there is no separation between the rail and the pad under dynamic conditions.
2. Increase frictional resistance to the longitudinal or lateral movement of rail.
3. Help to distribute the loads uniformly over the sleeper and prevent crushing of sleeper material.
4. Provide insulation between the rail and the sleeper.
5. Reduce the noise level.

In the Indian Railways, grooved rubber pads of 4.5 mm thickness have been in use since the time of introduction of concrete sleepers. In view of the poor service life of these pads, thicker pads of 6 mm thickness have been designed and are being adopted in all future assemblies. They are also being provided with horns, which hold the pad in position against slippage. For wider concrete sleepers for heavy density routes, 10 mm thick pads are being used.

Rubber pads compress under loads by about 0.5–0.7 mm and expand in the lateral direction. The grooves provided in the pad help in accommodating lateral expansion of rubber.

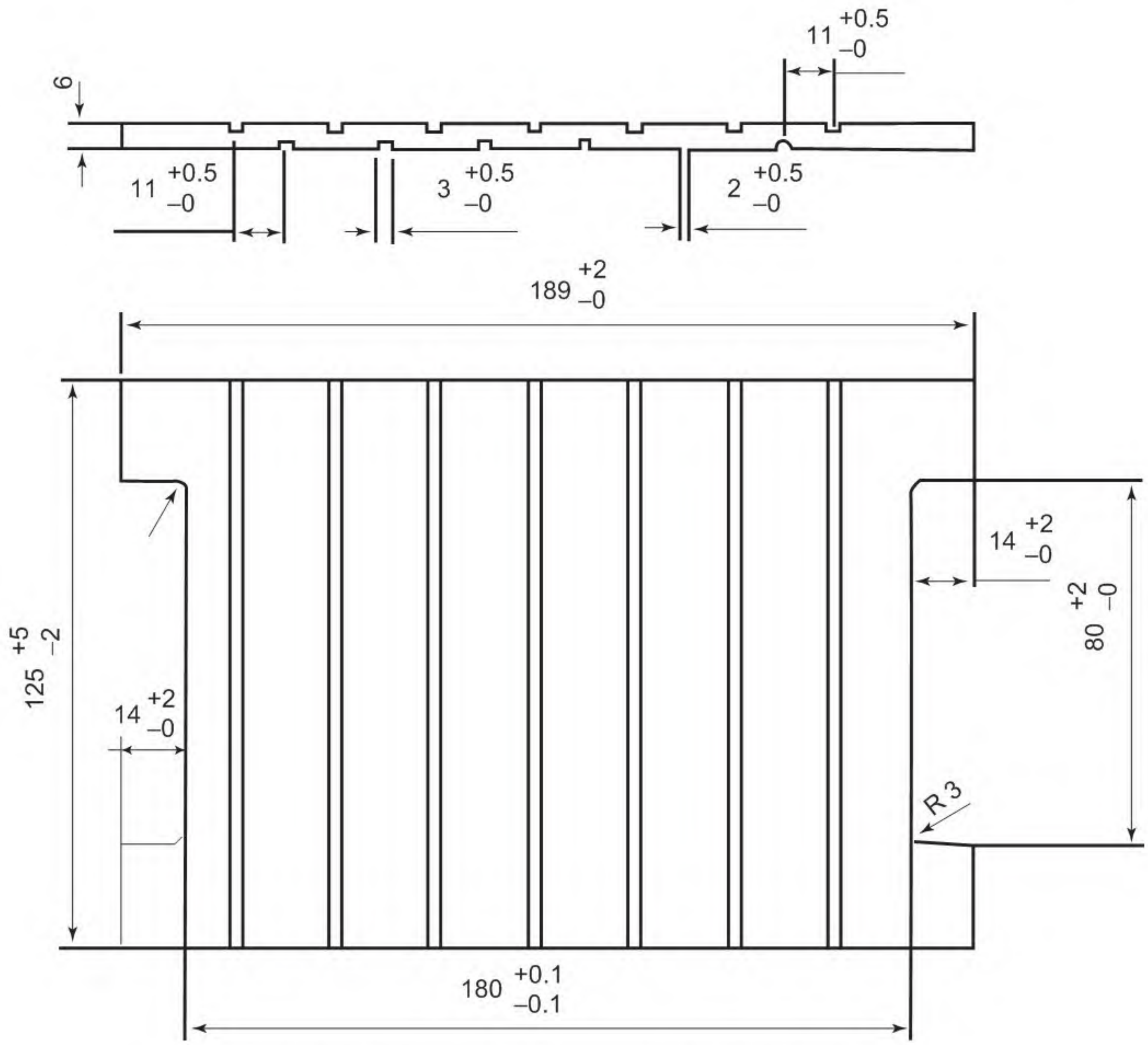


Fig. 5.23 6 mm thick grooved rubber pad with horns

In elastic fastening assemblies used with wooden sleepers, the use of rubber pads is dispensed with at times, as wood with its inherent elasticity is able to perform the function of a rubber pad to a certain extent.

5.4.8 Elastic Rail Clip

Elastic clip forms the main components of an elastic fastening assembly.

There are two categories of elastic rail clips in use in the world railways viz. *adjustable rail clips* and *fit-and-forget*. In the former the desired toe-load is obtained by positive anchorage system either with the help of a screw or a bolt and nut arrangement. The clip load can be further adjusted whenever considered necessary, on account of the looseness of the fastening due to wear and tear or vibrations. The correct adjustment of such clips, however, requires special equipment and skill, which may not be always available.

In the "fit-and-forget" category of elastic fastenings, the clips are of the self-tensioning type. The design of the clip provides sufficient allowance for the variation in manufacturing tolerances of rail, sleeper and other fastening components; and for the wear and tear of the assembly components during service. Under field conditions, however, it is noticed, that on account of the above mentioned factors, the clip toe-load at times is irreclaimably affected.

The main functions of elastic rail clips are :

1. To keep sufficient continuous toe-load on the rail, under static and dynamic conditions.
2. To ensure that no separation takes place between rail and rubber pad.
3. To ensure that uplift of the rail under percussion wave is kept to the minimum.

5.4.9 Elastic Rail Clips in the Indian Railways

Pandrol Clips: Pandrol Clips of British origin (Fig. 5.24)—also called elastic rail clips—are extensively used in the Indian Railways. These are "fit-and-forget" type of fastenings. Once fixed in position, the Pandrol Clip is expected to maintain its desired toe-load without any subsequent attention. It is applied parallel to the rail and is driven and removed with an ordinary hammer. When driven, one leg of the clip is housed into a groove, and the clip deflects from its original shape to exert a heavy toe-load on the rail. The friction grip of the clip in the housing is two to three times that of clip on the rail, so that rail creep forces are unable to dislodge the clip. The creep is resisted in both directions, an essential requirement of long welded rail fastenings. The Pandrol Clip PR 401, standardized in the Indian Railways, is manufactured from 20.6 mm dia silico-manganese steel rods heat treated to proper specifications. It weighs about 1 kg and gives an average toe-load of 710 kg under 11.4 mm of deflection. The static toe-load of 710 kg per clip gives a total rail to sleeper load of 2840 kg. Assuming 0.5 as the coefficient of rail to pad friction, this provides a rail to sleeper resistance of about 1420 kg, which is well above the average sleeper to ballast resistance of about 1000 kg per sleeper in the direction of traffic. The chances of relative rail to sleeper movement are therefore less.

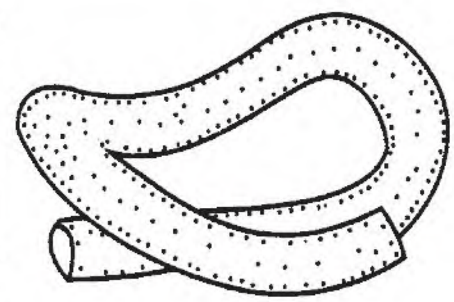


Fig. 5.24 Pandrol clip

The up-to-date experience with standard Pandrol Clips of PR 401 series has not been very satisfactory. Over the years, they tend to loose their toe-load, thus allowing the rails to creep. The life of the rubber pads and liners in the assembly has also been poor. By following a different space curve, new series of improved elastic rail clips have been designed, using about the same length and dia of the steel rod, and thus within the same weight of steel. ERC mark III version of the clip has higher toe-loads of 800–1000 kg, providing a creep resistance of about 1000 kg per rail seat. Round toe has been modified to flat toe to distribute the point load on a wider area. This reduces the indentation on the liner and enhances its life. It also helps in maintaining the toe-load of the clip. See Fig. 5.25 (RDSO/T/3701). The main properties of the various types of ERC clips developed by RDSO are given in Table 5.13.

Herbert Meir (HM) Fastenings : (Vassloh Clip or W. Clip in German Railways) HM is a positive anchorage system where the desired toe-load is obtained with the help of a plate screw tightened over the clip. The screw is tightened against the corresponding grooves provided in a polyethylene

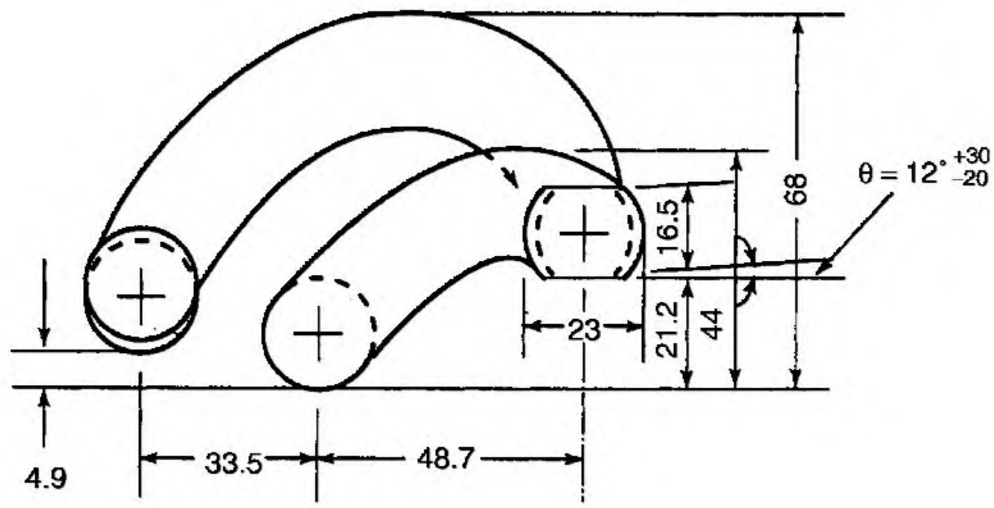


Fig. 5.25

Table 5.13 Properties of Elastic Rail Clips

Drawing No. of clip	*Type of clip*	*Dia (mm)*	*Approximate weight of clip (kg)*	*Toe deflection (mm)*	*Toe load range (kg)*	*Contact of surface for flat toe clips*	
						Major axis (mm) minimum	*Minor axis (mm) minimum*
RDSO/ T-1892	ERC round toe	20.64	1.0	11.4	645–800	—	—
RDSO / T-3700	ERC flat toe	20.64	1.0	11.4	645–800	28	9.5
RDSO / T-3701	ERCMk-III Flat toe	20.64	0.91	13.5	850–1100	28	9.5
RDSO / T-3722	ERC.MK-II Flat toe	18.0	0.60	11.2	700–900	20	8
RDSO /	ERC-j	20.64	1.0	3.5	300	—	—

insert embedded in the concrete sleeper. W. Clip used in this system is forged to the desired shape out of a 13 mm silico manganese spring steel rod and heat treated to proper curvature to fit around the shank of the screw. The outer bends lodged are in the groove of the angled guide plate while the free ends deflect and press against the rail foot. With a weight of 425 g, its toe-load is 1100 kg with 13.5 mm deflection. The creep resistance of HM fastening system per sleeper is claimed to be much above the average sleeper to ballast resistance per sleeper. HM type of fastenings have several advantages over Pandrol clip fastenings. These are :

1. Higher toe-load, creep and torsional resistance.
2. Better vibrational damping property on account of double slip of toe-load/deflection curve.
3. Possibility of retainment with sections of different foot widths during the service life of the sleeper by changing the angled guide plates.
4. Offers advantage of quick tightening and loosening while in position which is important for the destressing of LWR.

5. Provides better insulation.
6. Comparatively more pilfer proof.
7. Can be fixed on the sleeper in the concrete sleeper plants before the sleepers are despatched to relaying sites.

Its fixing in position, underscores the need for special equipment and skill, which is a definite disadvantage vis-à-vis the Pandrol clip.

5.4.10 Elastic Fastening for Wooden Sleepers

Pandrol Rail Fastening Assembly This consists of Pandrol rail clips, a rubber pad and steel or cast iron bearing plates. The base plate is fixed to the sleeper with standard plate screws of 20 mm dia. Two Pandrol clips are used per base plate, one on each side of the rail [see Figs. 5.26 (a) and (b)].

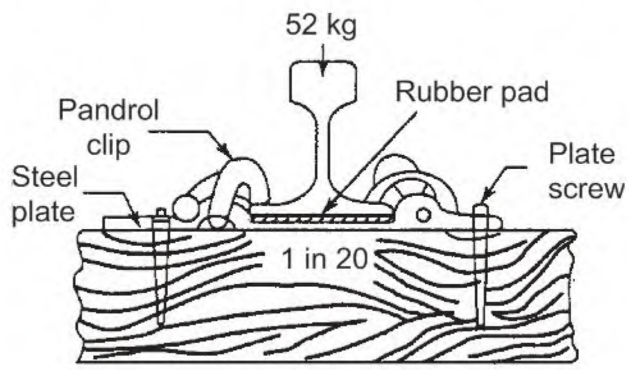


Fig. 5.26 (a) Pandrol clips with wooden sleeper and steel pad

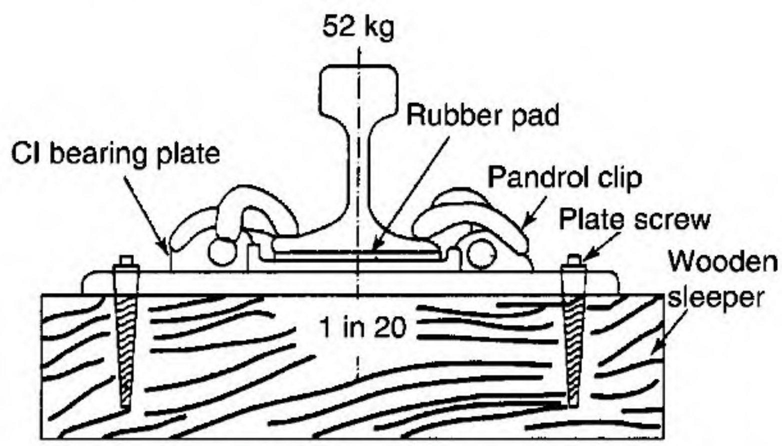


Fig. 5.26 (b) Pandrol clips with wooden sleepers and CI bearing plate

5.4.11 Elastic Fastenings for Steel Trough Sleepers

In the Indian Railways, Pandrol clips are used with steel trough sleepers in the following two ways :
With Welded Pad Plates : A steel pad plate with grooves (Fig. 5.27) is welded onto the steel sleeper. The pad plate is of mild steel either pressed or rolled into the desired shape. It has to conform to rigid dimensional tolerances so that Pandrol clips, when fixed in position, give the desired toe-load.

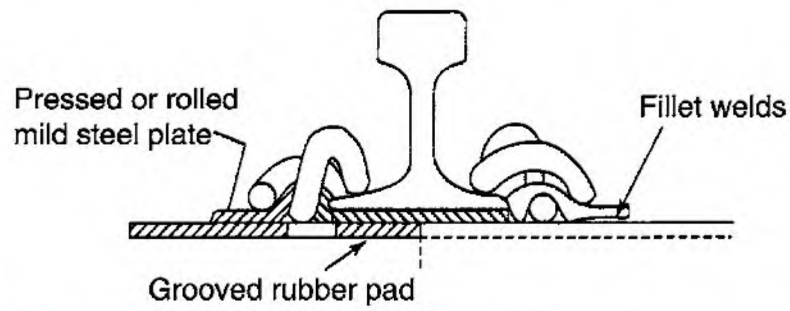


Fig. 5.27 Pandrol clip with old steel sleepers

The method is quite useful in the rehabilitation of old steel sleepers, whose rail seats have corroded or cracked. The method is also being employed for making use of new steel sleepers, which were earlier rejected on account of dimensional tolerances in respect of location of holes, but had cant at the rail seat within accepted limits. Steel sleepers having cant outside the accepted limits are not welded with pad plates and are used as such on unimportant lines in the yards.

Steel sleepers with pad plates and Pandrol clips are being extensively used on high-speed lines in the Indian Railways and are giving good service.

With Modified Loose Jaws Modified loose jaws are made from silico-manganese spring steel either rolled or forged to the desired shape (Fig. 5.28). They take their position in the steel sleeper holes meant for ordinary loose jaws, and hold the Pandrol clips in position, which in turn exert the desired toe-load on the rail foot. MLJ's made of rolled section have been found to be weak in fatigue strength. They open out in service, affecting the Pandrol clip toe-load. A forged section with increased metal at critical points would provide the right solution.

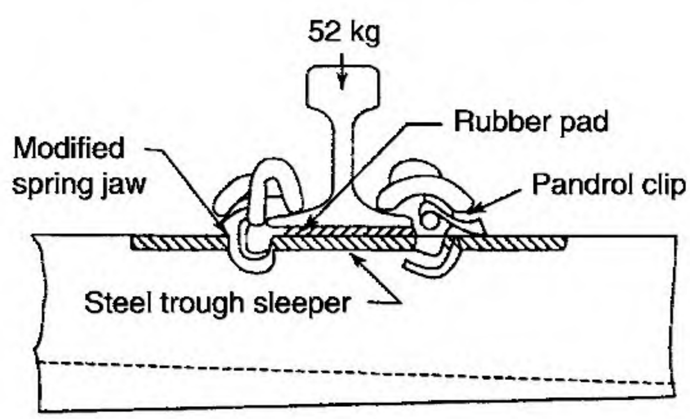


Fig. 5.28 Pandrol clips with modified spring jaws

5.4.12 Elastic Fastenings for Concrete Sleepers

Elastic Rail Clip Assembly An elastic rail clip assembly for concrete sleepers (Fig. 5.29), for each rail seat consists of :

1. Two malleable cast iron inserts, which are cast in concrete during manufacture of the sleeper.
2. Two Pandrol clips/ERC.

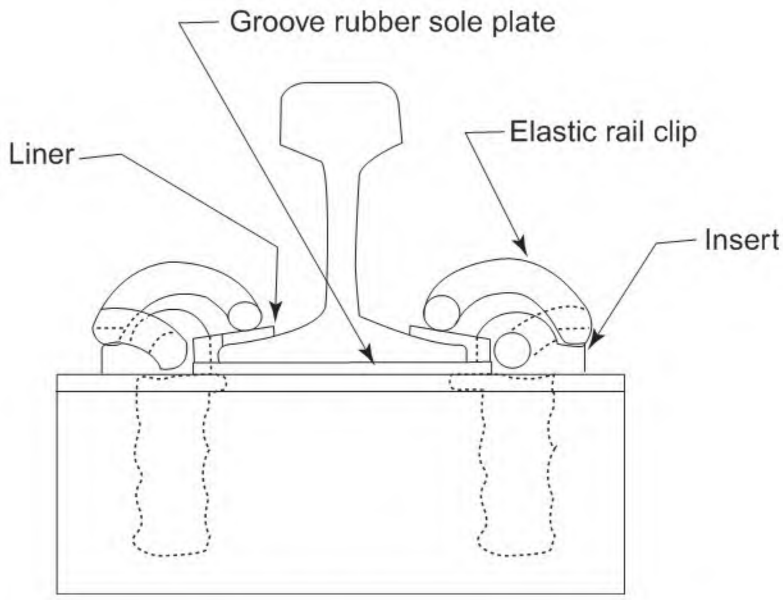


Fig. 5.29 Pandrol clips with concrete sleepers

3. Two insulating liners.
4. One elastic pad/Grooved Rubber sole plate (GRS).

At each rail seat, the rail rests on a resilient rubber pad between two cast iron inserts, which provide the rail a precise and robust, lateral location. Elastic rail clips, when driven into the housing of the insert, exert the necessary toe-load on the rail foot. A nylon insulator is interposed at the edge of the rail foot. Rubber pad and nylon insulators together provide an all-round insulation of rail.

When track circuiting is not needed, a steel liner of the shape and size of the nylon liner is substituted. Insulating liners of earlier design—made of nylon alone—have been found to crack in service within a short period of time.

Glass filled nylon liners (Fig. 5.30) have now been developed. These liners, which have an increased thickness of 8 mm, have shown satisfactory performance particularly with the change over of elastic rail clips from round toe to flat toe.

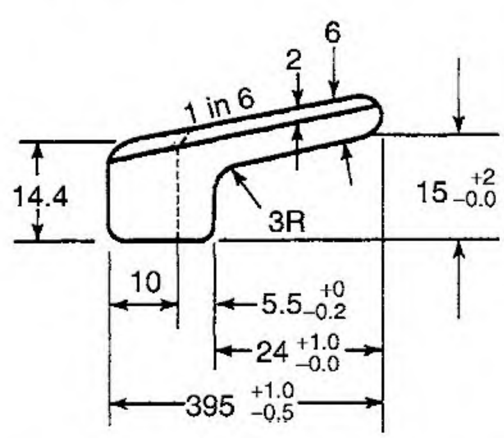


Fig. 5.30 Glass nylon insulating liner RDSO/T-2505

Elastic rail clip assembly is a "fit-and-forget" assembly having no provision for adjustment of gauge or toe-load. Attempts are being made to provide scope for such adjustments with the use of insulating liners of varying thicknesses.

RDSO has developed a number of rail seat assemblies, using ERC clips of various types of different rail/sleeper combinations. Table 5.14 gives the relevant RDSO drawing number of these assemblies.

Table 5.14

Assembly with	*Name of component and relevant RDSO drawing number*				
Type of clip	*Elastic rail clip*	*SGCI Insert*	*GR soleplate*	*Liner*	
				GFN-66	*Metal*
(A) 52 kg rail on 52 kg concrete sleeper (BG)					
1. ERC ROUND TOE	RDSO/T-1892	RDSO/T-381	RDSO/T-3703	RDSO/T-2505	RDSO/T-645
2. ERC FLAT TOE	RDSO/T-3700	RDSO/T-381	RDSO/T-3703	RDSO/T-3702	RDSO/T-3738
3. ERC Mk-III	RDSO/T-3701	RDSO/T-381	RDSO/T-3703	RDSO/T-3702	RDSO/T-3738
(B) 52 kg rail on 60 kg concrete sleepers (BG)					
ERC Mk-III	RDSO/T-3701	RDSO/T-381	RDSO/T-3711	RDSO/T-3707 (GS) & RDSO/T-3708 (NGS)	RDSO/T-3741 (GS) & RDSO/T-3742 (NGS)
(C) 60 kg rail on 60 kg concrete sleeper (BG)					
1. ERC-Mk-III	RDSO/T-3701	RDSO/T-3781	RDSO/T-3711	RDSO/T-3706	RDSO/T-3740
(D) 90Rrail on concrete sleeper (BG)					
ERC Mk-II	RDSO/T-3722	RDSO/T-3087	RDSO/T-3724	RDSO/T-3723	RDSO/T-3739

GS—Gauge side
NGS—Non gauge side

5.4.13 Maintenance of Elastic Fastenings System of Concrete Sleepers

1. *Loss of Toe-load in Elastic Rail Clips* This occurs either on account of poor quality control during manufacturing or by over stretching in field. Poor toe-loads lead to :

   (a) Rail to sleeper movement which can cause buckling of track
   (b) Hammering action on the sleeper, destroying the elastic assembly, damaging the sleeper.

   ERC toe-load can be measured using Toe-load measuring device, which essentially consists of a calibrated helical spring. The pulling force required to lift the toe of the ERC is indicated by a pointer on a graduated scale.
   It is necessary that on suspect locations, toe-loads of ERCs are measured and ERC's with poor toe-loads replaced.

2. *Ineffective Rubber Pads* Rubber pads wear out during service, get displaced or have a permanent set. Such pads should be replaced to ensure efficient functioning of the assembly.
3. *Breakage of insulating liners* Insulating liners are comparatively a weaker component of the elastic fastening assembly. Liners can crack or break if adequate care is not taken during clip driving. Cracked liners should be replaced before they affect the track circuiting operation.
4. *Corrosion and seizure* of ERCs with MCI inserts. The phenomenon is more noticeable in the coastal areas. Its remedy lies in the application of grease (I S : 408 1981) at the contact area after cleaning them thoroughly.

HM Clip Assembly HM clip assembly for concrete sleepers consists of four plate screws, which, when tightened against a plastic dowel, press the W. clip in position. The plastic dowels are embedded in the concrete sleeper at the time of casting. Gauge is maintained with the help of angled guide plates. Grooved rubber pad is provided under the rail seat to give necessary resilience. Rubber pad, insulating plate and plastic dowel insulate the assembly (see Fig. 5.31).

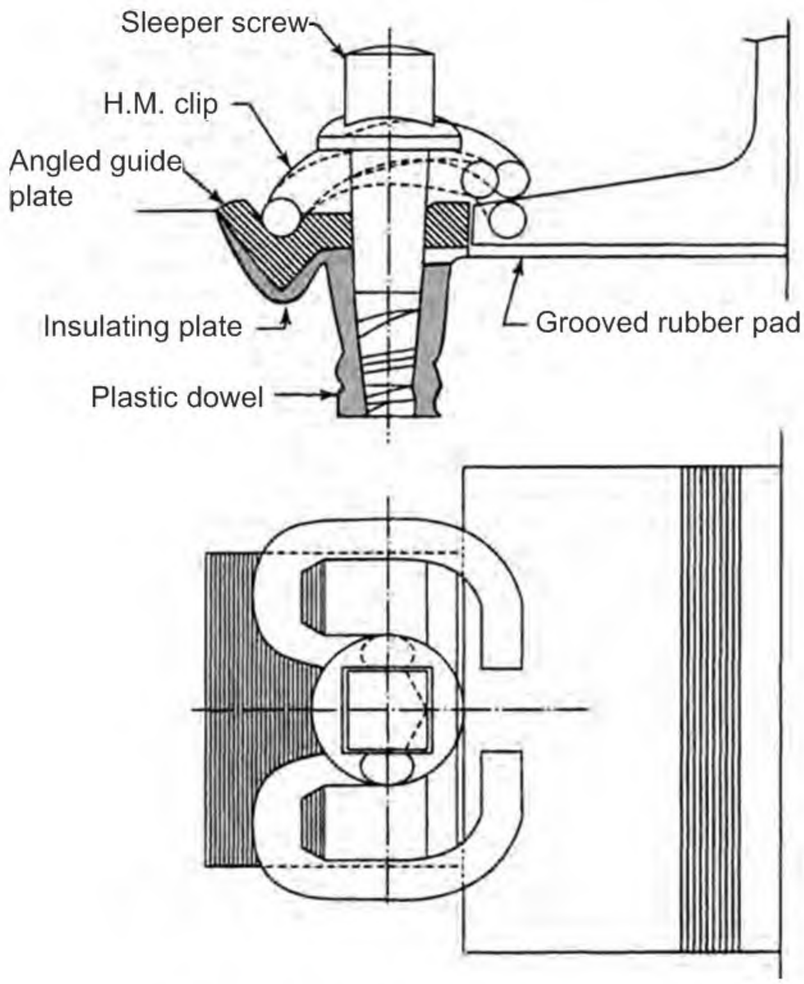


Fig. 5.31 HM fastening

With the use of appropriate sizes of angled guide plates and insulating plates, the same concrete sleeper can be designed for laying 52 or 60 kg rail sections.

5.5 LOGWELL FORGE G CLIP

Logwell Forge Ltd., an Indian company has developed an elastic rail clip—G Clip which is an improved version of internationally used Pandrol E-Clip. Important characteristics of a standard G Clip are as under :

Important Characteristics of a Standard G Clip

1.	Material	251A 58-BS 970
2.	Hardness	44-48 HRC
3.	Toe load	1000-1300 kgf
4.	Deflection	11.5 mm
5.	Diameter	20.64 mm
6.	Weight	Approximately 825 gms.
7.	Flat toe bearing area	15 MM × 36 MM
8.	Ease of installation	Very easy
9.	Suitable Design for all types of rails and sleepers	Yes

Figure 5.32 shows a standard G Clip. Figure 5.33 shows a concrete sleeper elastic fastening assembly with G Clip.

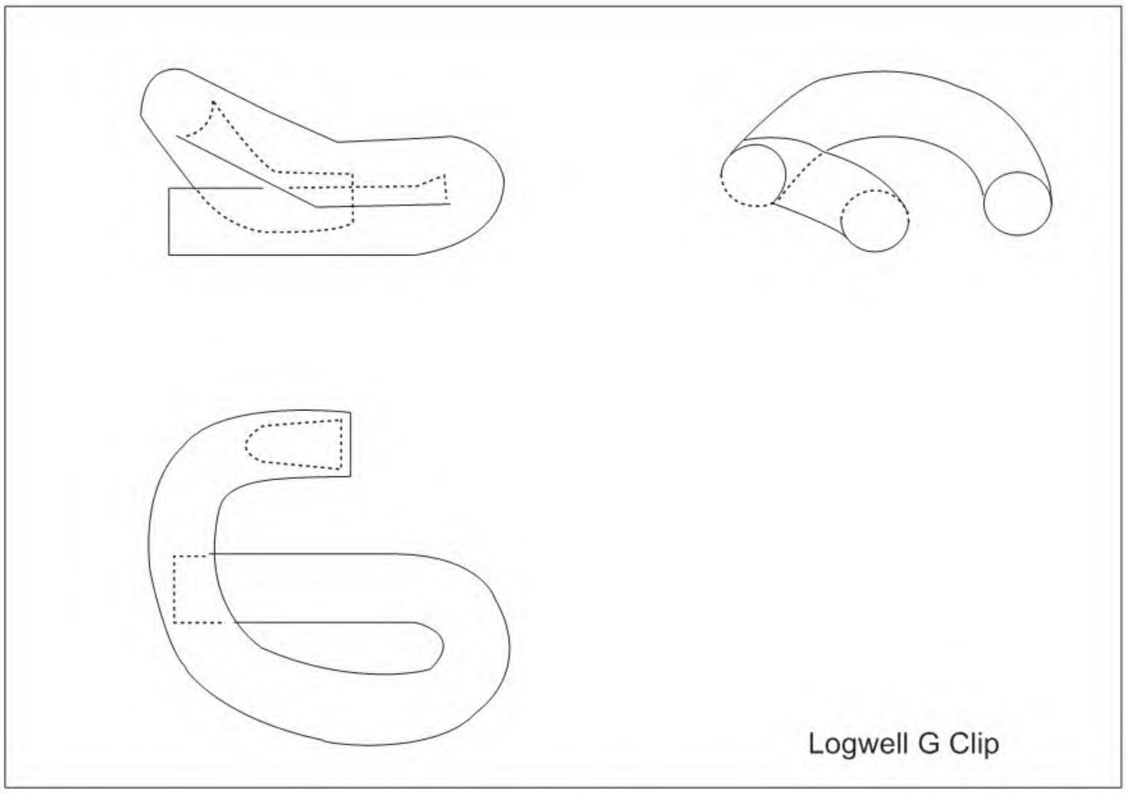


Fig. 5.32

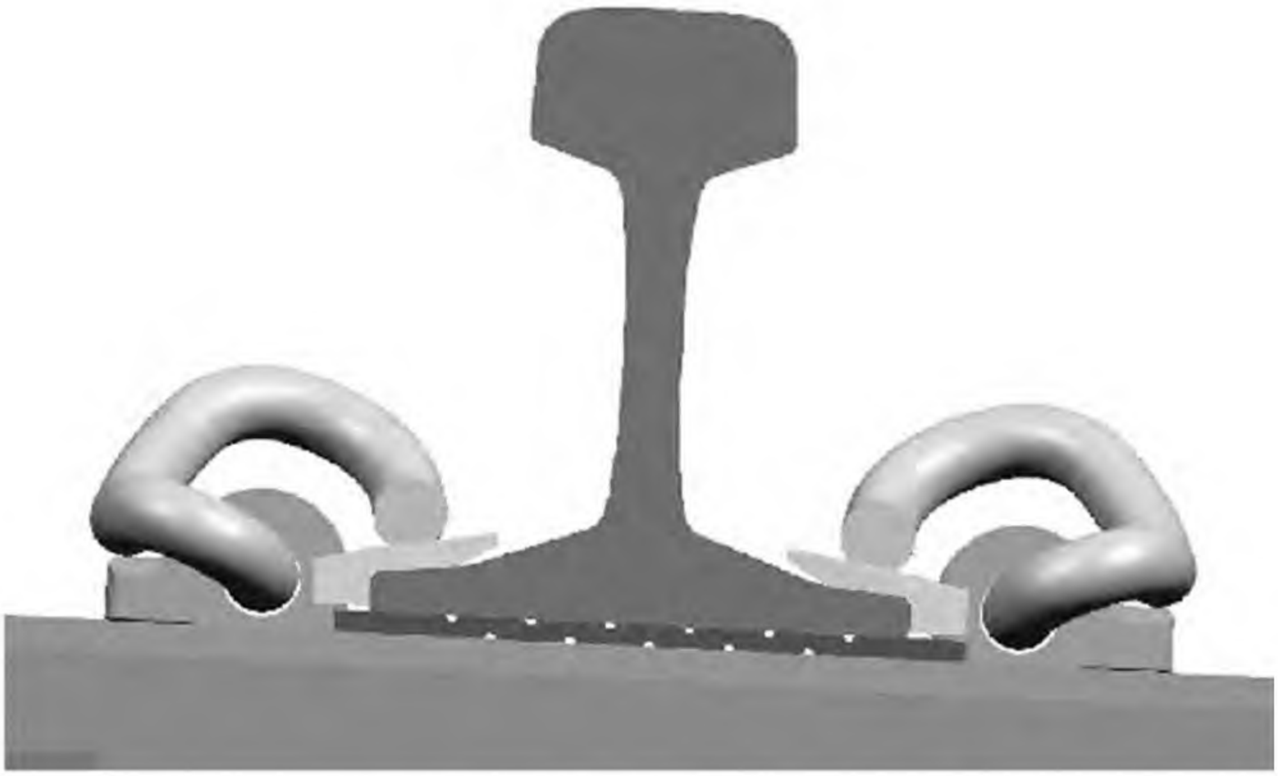


Fig. 5.33 (See also Color Plate 3)

After trials on long lengths of Indian Railway tracks, G Clip has been cleared for universal adoption on Indian Railways.

5.6 TRACK ACCESSORIES FOR SPECIAL LOCATIONS

1. *Fang and Bolt* Fang and bolt is employed for fastening slide chairs to sleepers laid under switches of turnouts and is an alternative to the round spike. It is, however, a more effective fastening and its use is advisable particularly on sleepers carrying switch tie plates. The cast iron fang, the bolt head and the diameter of the shank are standard but the length of the bolt varies depending upon the thickness of the sleeper with which it is used (see Fig. 5.34).
2. *Hook Bolt* There are two types of hook bolts :
   - (a) With straight lip meant for securing sleepers to plate girders.
   - (b) With sloping lip meant for securing sleepers to joists.

In both cases (Figs 5.35 and 5.36), the hook is an integral part of the bolt. With the help of an arrow head stamped on the top end of the bolt, maintenance staff is able to check the position of the hook on the underside of the sleeper.

5.6.1 Fastening for Ash Pits and Examination Pits

On ash pits and examination pits, rails are held in position by either of the following two methods :

1. Rails are fastened to blocks of timber, about 300 mm × 200 mm in size. The timber blocks are held in position with the help of Lewis or rang bolts anchored in the masonry underneath.
2. By burying an old released rail in the masonry in an inverted position and fixing the running rail direct to the foot of such inverted rail.

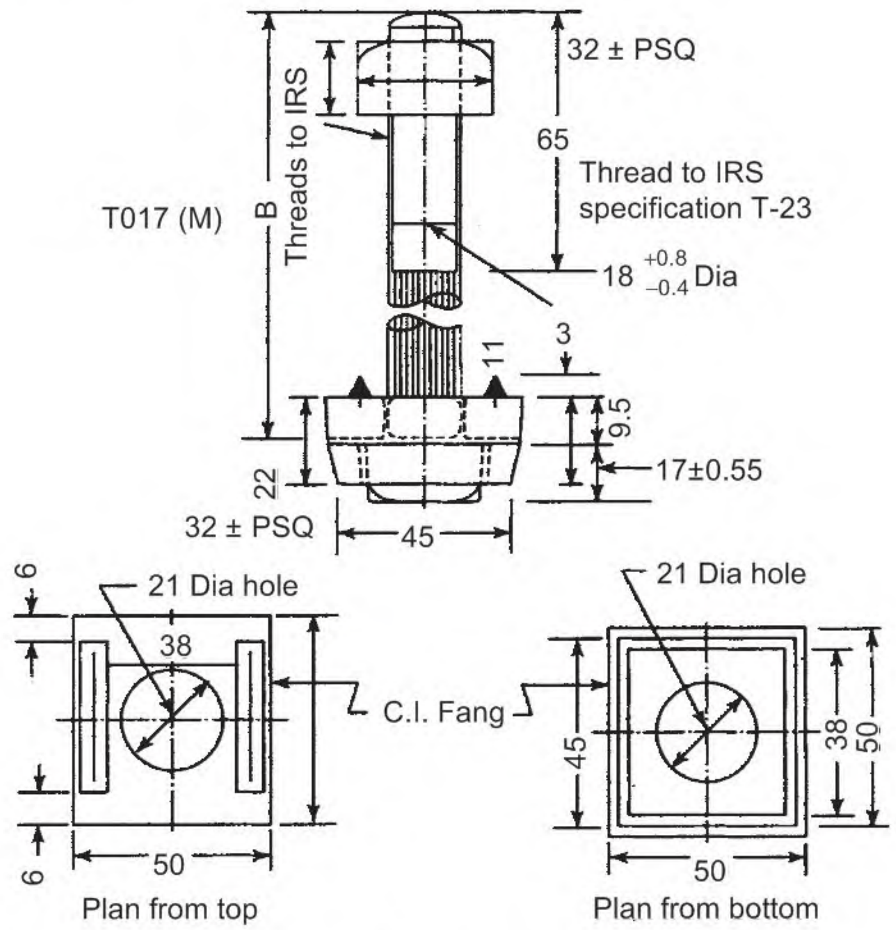


Fig. 5.34 Fang and bolt

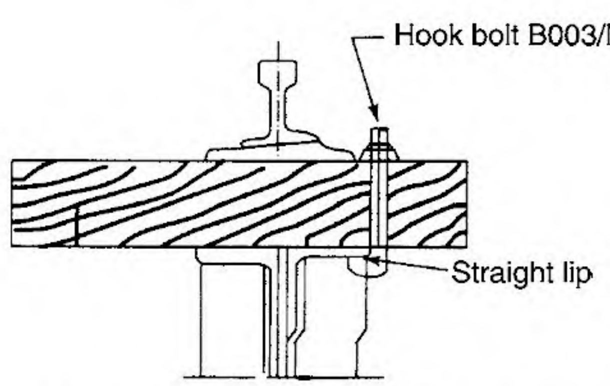


Fig. 5.35 Method of fastening wooden sleepers on plate girder spans

5.6.2 Creep and Rail Anchors

Creep is the longitudinal sliding movement of the rails. It is resisted by (a) the friction between the rail and the sleeper. (b) the grip of the rail to the sleeper fastening assembly.

When this resistance is insufficient rail anchors are used. They are secured to the base of the

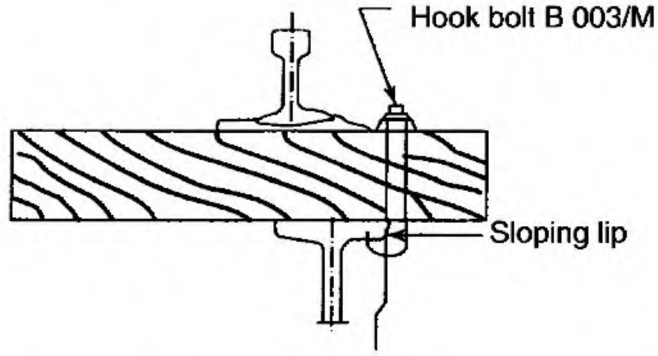


Fig. 5.36 Method of fastening wooden sleepers on joist spans

rail and bear against the side of the sleepers towards which the rails is creeping. Their design is such that rail to anchor resistance is much more than sleeper to ballast resistance per rail seat. The movement of rails vis-à-vis sleeper is therefore completely arrested.

The most widely used anchors are : the one-piece spring tensioned friction grip anchors. (See Fig. 5.37; Table 5.15.)

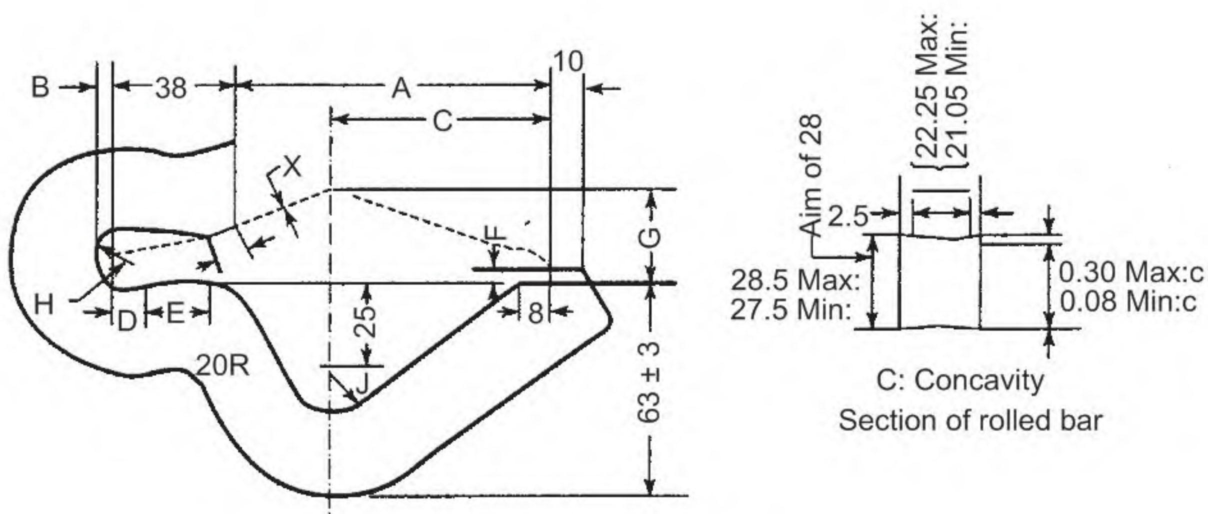


Fig. 5.37 Rail anchors

Table 5.15 Table of Dimensions

Rail section	*Drawing number*	*Dimensions (mm)*								
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*
52 kg	T10327	98.00	4.0	68	10	20	$5^{+0}_{-0.8}$	29	9	14
90R	T10313	98.53	6.5	68.26	8	22	$4^{+0}_{-0.8}$	20.64	8	14
75R	T10314	84.24	5.5	61.12	8	16	$4^{+0}_{-0.8}$	18.65	7	13

The creep anchors are applied to the rail foot and clipped on by a blow from a spiking or other heavy hammer. When it is necessary to prevent *movement* of rail in both directions as in the case of short welded rails or breathing lengths of long welded rails, anchors are applied to rails on both sides of the same sleeper. This is termed as "box anchoring".

There can be no hard and fast rule for a precise number of rail anchors to be applied. What is of importance is that the rails should hold against movement. And, if this does not happen, additional anchors should be applied.

5.6.3 Spring Washers

To ensure that track fastenings do not loosen early, spring washers are used under the nuts or under the head of plate screws. To make it effective, spring washers must to have double slope in their deflection graph. While the coil of the springs close down at a relatively low compressive force of about 1/2 tonnes, the washers retain their elastic properties even under a force of 4 to 5 tonnes on account of the bending pitch incorporated in their design. With their use, the fishbolt nuts do not work loose under high frequency vibrations. Plate screws maintain their hold better when provided with spring washers. See Figs 5.38 and 5.39.

Fig. 5.38 Simple, double and triple spring washers of the DB

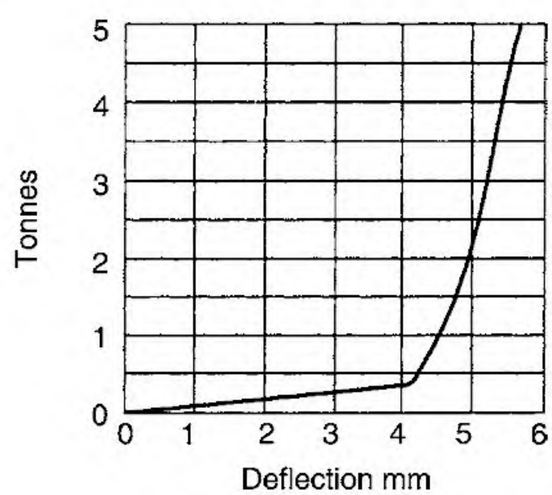


Fig. 5.39

Based on the German design, two types of spring washers, viz. single coil (RDSO Drg. No. T-10773) and double coil (RDSO-Drg. No. T-1878) have been evolved by RDSO for the Indian Railways.

Single coil spring washers are to be used at the following locations :

1. In fishplated joints.
2. With fittings and fastenings of points and crossings.
3. With plate screws on wooden sleepers.

Double coil spring washers will find their use in 'K' type fastenings proposed to be adopted in modern turnout designs.

5.7 CHECK RAILS AND GUARD RAILS

Check rails and guard rails are lengths of rails laid parallel to a track. They are either attached to the track or laid apart at a fixed distance and then fastened to the track.

Check rails are used in location as follows :

1. On points and crossings at the crossing assembly where they serve the purpose of guiding the wheels through the narrow clearance available at the nose.
2. On sharp curves where they prevent the curving wheels from causing excessive wear of the outer rails.
3. On curved bridge approaches as a positive safeguard against derailment.

Guard rails whereas, are employed at the under-mentioned as follows :

1. On level-crossings where they help in providing pathway clearance to the running wheels. The gap between the extended portions of the guard rails beyond the roadway should be filled with ballast or other suitable material to level with the contiguous road surface.
2. On all girder bridges, including prestressed concrete girder bridges without deck slab, with open floor.
3. In all major and important ballasted deck bridges as also on such other minor ballasted deck bridges where derailments may cause serious damages.
4. On high banks or deep cuttings where a derailment could produce serious consequences.

In the case of 2, 3 and 4 guard rails prevent the derailed rolling stock from leaving the rail road bed.

Check rails and sometimes guard rails are held to flat footed running rails with bolts through distance pieces of cast iron known as check blocks. The size of the check blocks gives the requisite clearance. The foot of the check rails is usually planed on one side to enable the required clearance to be obtained (Fig. 5.40).

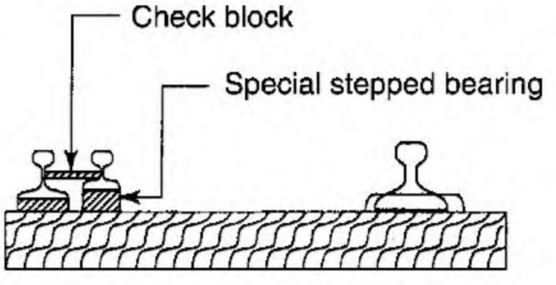


Fig. 5.40

Guard rails on bridges usually consist of old rails at a distance of 250 mm from each running rail and in the inter rail space. They are fastened to the sleepers independent of the running rails. The top of the guard rail is kept at the same level as the head of the running rail; if kept lower it should not be more than 25 mm below the running rail. Guard rails are joined together with fishplates. The two guard rails coverage at a point about 6.7 m in BG and 5.48 m in MG beyond each end of the bridge. The ends are also bent down to prevent the hanging parts of the rolling stock from fouling them (Fig. 5.41, refer Sec. 20.2 and Sec 4.14).

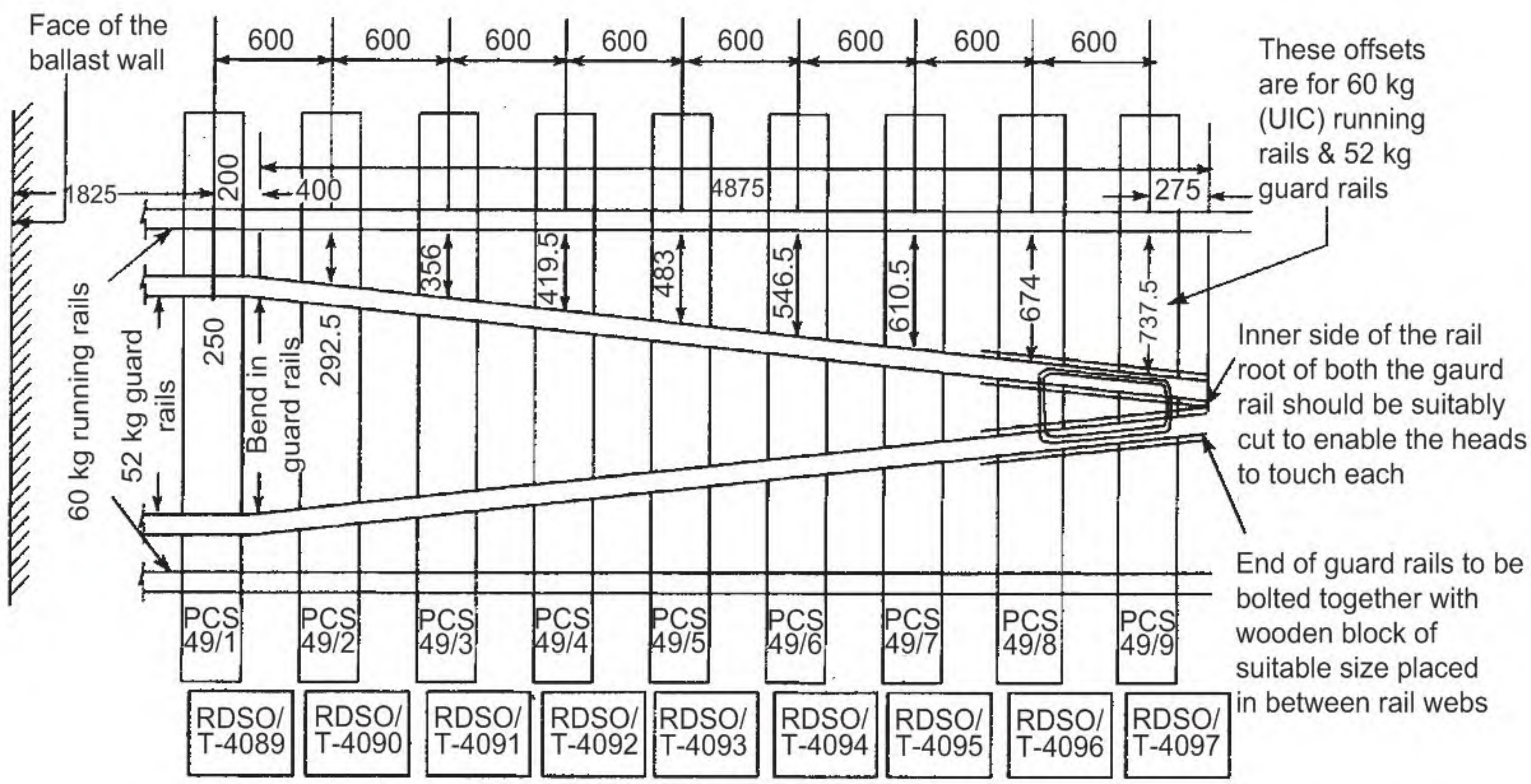


Fig. 5.41 Guard rails for bridges

6 Chapter

Railway Curves

6.1 NECESSITY OF CURVE

As far as possible, railroads are constructed in straight lines except where a change in direction is necessary to get the desired grade or to reach such a point that is not in a straight line. This is accomplished by curves. Railway curves except transition curves are uniform in nature, i.e. for any unit of length travelled round the Curve, there is the same amount of change of direction. The only curve which has this property is the circumference of the circle. Railway curves are precisely like circumference of a circle. In relation to curves, it is expedient to understand the following geometrical terms.

1. *Circumference*: The outer boundary of a circle is called circumference.
2. *Radius*: It is a straight line extending from the centre of circle to the circumference.
3. *Tangent*: A line drawn at right angles to the radius at the point at which it meets the circumference is a tangent to the circle. For any point outside a circle, only two tangents to the circle can be drawn and these tangents are equal in length. The line joining the intersection point of the tangent and the centre of the circle bisects at right angle the line joining the tangent points.
4. *Chord*: Any line drawn across the circle from one point on the circumference to another point on the circumference is called a chord.
5. *Arc*: Any unbroken part of the circumference of a circle or other curved line is called an arc.
6. *Versed sine or Versine*: The distance measured at right angles from the middle point of a chord to the arc is called the versed sine or middle ordinate.

They are all shown in Fig. 6.1.

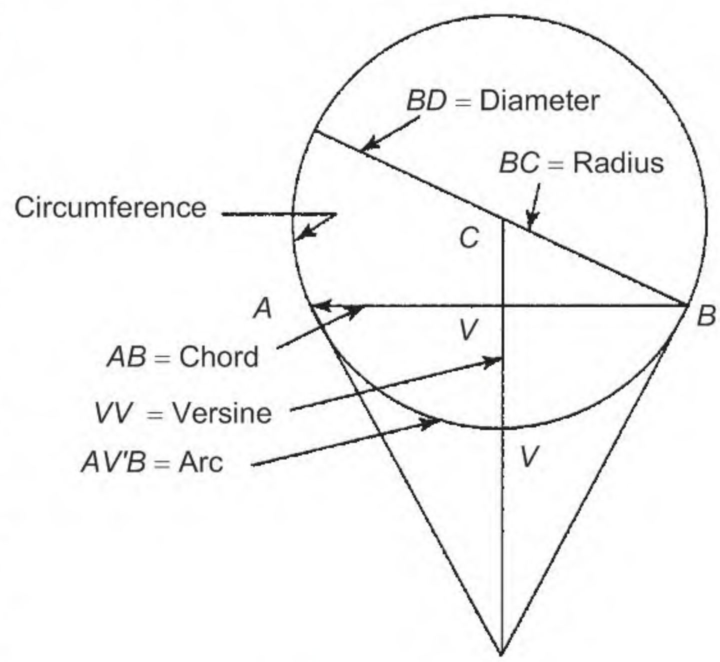


Fig. 6.1

6.2 CLASSIFICATION OF CURVES

Railway curves are classified as:

1. *Simple curve*: This has only one radius throughout [Fig. 6.2 (a)].
2. *Compound curve*: This comprises two or more simple curves, both curving in the same way or similar flexure [Fig. 6.2 (b)].
3. *Reverse curve*: This is made up two or more simple curves of contrary flexure [Fig. 6.2 (c)].

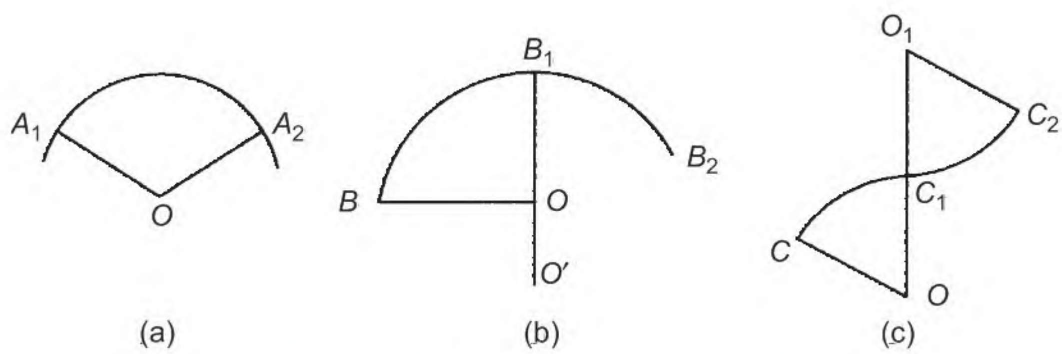


Fig. 6.2 Classification of curves: (a) Simple curve (b) Compound curve (c) Reverse curve

6.3 DEGREE OF A CURVE

Railway curves are described by the length of their radius or by the angle subtended at the centre by a chord of 100 ft (30.5 m), Fig. 6.3. The latter system can be further understood if we consider the whole circumference of a circle to be made of 360 sections of 100 ft each. Since the sum of the total angle subtended by all the chords at the centre of the circle is 360°.

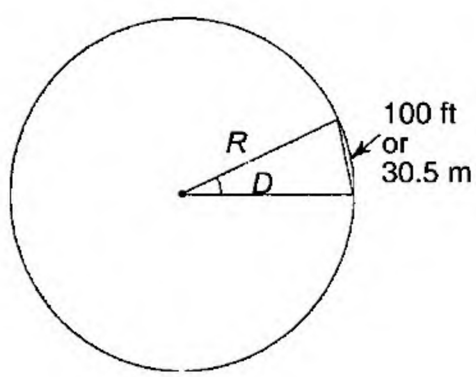


Fig. 6.3

Each chord of 100 ft will in this case subtend on angle of 1° at the centre, and the curve will be called a 1° curve.

Circumference in this case $= 360 \times 100$ ft

$= 36{,}000$ ft

(Chord and arc assumed as equal)

This is also equal to $2\pi R$.

Thus $$2\pi R = 36{,}000 \text{ ft}$$

$$R = \frac{36{,}000}{2\pi}$$

$$= 5730 \text{ ft}$$

A 1° curve, thus, has a radius R_1 of 5730 ft or 1750 m.

In a similar way, it can be found that a 2° curve will have a radius R_2 of 5730/2 ft; a 3° curve will have a radius R_3 of 5730/3 ft; and a D° curve will have a radius R of 5730/D ft. Thus, R (in metre) = 1750/D (in degree) or 1750/D m. It may be noted that degree of a curve varies inversely as its "radius".

6.3.1 Maximum Degree of Curve

The maximum degree of curve is the smallest radius on which a railway curve may be laid. It depends upon:

1. wheel base of the vehicle
2. maximum superelevation that can be permitted
3. increase in operation and maintenance costs of track and rolling stock on sharp curves. The maximum degree of curvature as permitted for various gauges in the Indian Railways, are:

Broad Gauge 10°	or	175 m radius
Metre Gauge 16°	or	109 m radius
Narrow Gauge (2′ – 6″) 762 m 40°	or	44 m radius

6.4 DEGREE AND RADIUS OF CURVES, TAKING OFF FROM MAIN LINE CURVE

Normally, turnout curves take off from the straight main line as shown in Fig. 6.4 (a). However, there are many situations when a turnout is required to take off from a curved main line. They are:

Similar Flexure: When the turnout curve take off in the same direction as the main line curve, it is known as a curve of similar flexure [Fig. 6.4 (b)].

Contrary Flexure: When the turnout curve takes off in opposite direction to the main line curve, it is known as a curve of contrary flexure [Fig. 6.4 (c)]. When the radii of the main line and the turnout curves in the contrary flexure are the same, it is known as a symmetrical split.

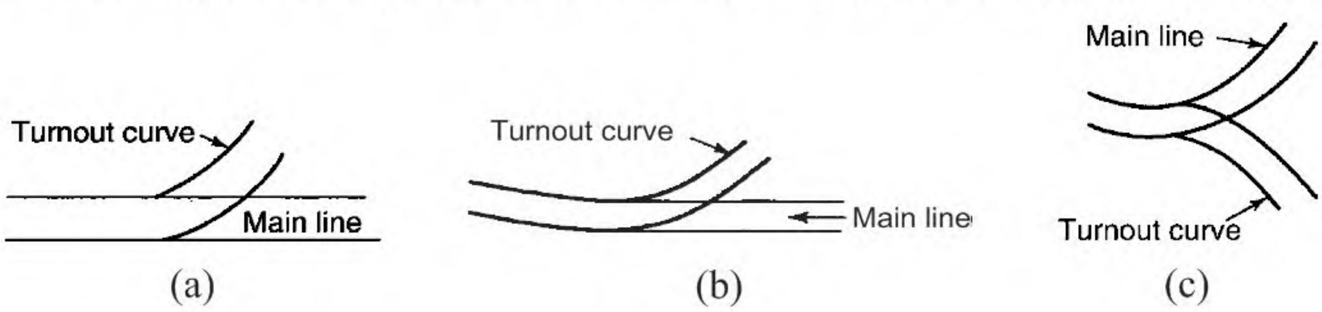


Fig. 6.4

For instance let D and R be the degree and radius of turn-out curve, respectively, when taken from a straight line D_M and R_M the degree and radius of main line curve; and D_R and R_R the degree and radius of resultant curve.

From Fig. 6.4, it can be seen that for similar flexure $D_R = D_M + D$ and for contrary flexure $D_R = D_M - D$.

Since the degree of curve is in inverse proportion to the radius, the above equations for radii are:

For similar flexure $$\frac{1}{R_R} = \frac{1}{R_M} + \frac{1}{R}$$

or $$R_R = \frac{R \times R_M}{R + R_M}$$

For contrary flexure $$\frac{1}{R_R} = \frac{1}{R_M} - \frac{1}{R}$$

or $$R_R = \frac{R \times R_M}{R - R_M}$$

The two standard turnouts, i.e. 1 : 8½ and 1 : 12 as used in the Indian Railways, have degrees of curvature if 7.855°, say 8°, and 3.95° say 4°, respectively.

To illustrate an example, if a 1 : 12 turnout takes off from a 5°curve, the resultant curve will have a degree of curvature of 5° + 4° = 9° when laid in similar flexure and 5° – 4° = 1° when laid in contrary flexure. Their radii will be 1750/9 = 194.4 m and 1750/1 = 1750 m, respectively.

6.5 RELATIONS BETWEEN THE PARTS OF A CIRCLE

6.5.1 Between Circumference and Diameter

The length of the circumference of a circle is 22/7 times the length of its diameter. This value is usually denoted by the greek letter π (pronounced as pie), so that the circumference will be πD or $2\pi R$, where D is diameter and R is the radius.

6.5.2 Between Versine, Chord and Radius

From Fig. 6.5, it can be seen that:

$$OC = R$$
$$V = C'B = CD$$
$$AD = C/2$$
$$OD = OC - CD = R - V \quad (1)$$

From ΔOAD,

$$OA^2 = OD^2 + AD^2$$

$$R^2 = (R - V)^2 + \frac{(C)^2}{4}$$ [From Eq. (1)]

$$R^2 = R^2 + V^2 - 2RV + \frac{C^2}{4}$$

$$2RV = V^2 + \frac{C^2}{4}$$

(Omitting V^2, which is relatively very small vis-à-vis R and C),

$$2RV = \frac{C^2}{4}$$

or

$$V = \frac{C^2}{8R}$$

If C and R in metres and V is to be found in cm, then

$$V = \frac{C^2 \times 100}{8R}$$

$$= 12.5\frac{C^2}{R} \text{ cm} \qquad (2)$$

If instead of radius, the relationship is to be found out $D°$ the degree of curve, then:

$$R = \frac{1750}{D°}$$

Substituting for R in Eq. (2), we get

$$V = 12.5 \times \frac{C^2 \times D}{1750} \qquad (3)$$

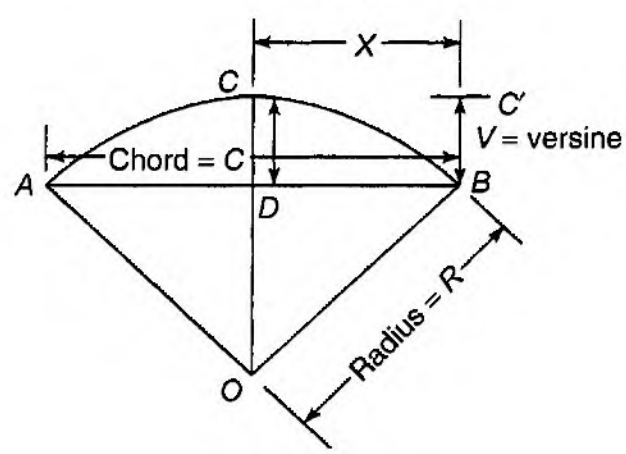


Fig. 6.5

If we choose a chord length $C = 11.8$ m then V in Eq. (3) will be

$$V = \frac{12.5 \times (11.8)^2}{1750} \times D$$

$$= 1 \times D \text{ or } V = D$$

(where V is in cms and D is in degrees).

Thus, for a 11.8 m chord, the versine in cm gives the degree of the curve. This relationship is frequently made use of in the field by measuring versine of a curve on a 11.8 m chord and thereby getting the degree of the curve.

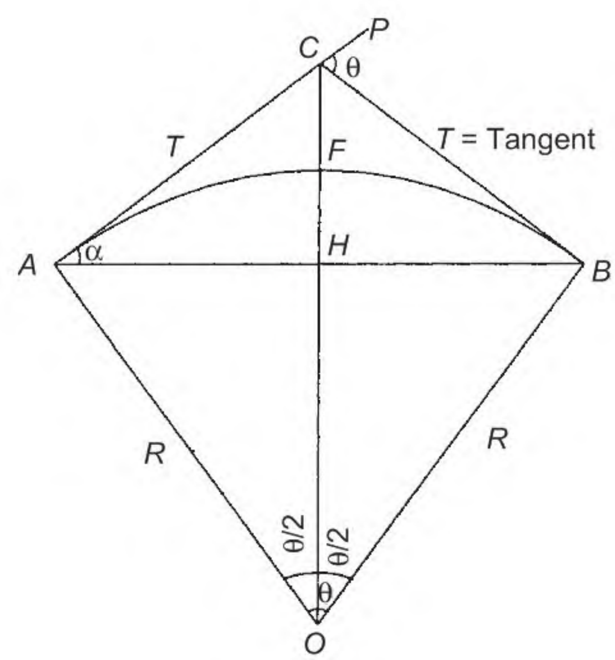


Fig. 6.6

6.5.3 Other Important Relationships (See fig. 6.6)

1. Central angle $\angle AOB = \theta°$
2. Deflection angle $\angle PCB$ is also equal to $\theta°$
3. Intersection angle $\angle ACB = 180° - \theta°$
4. Length of the curve $= R\theta$ when θ is in radians,

$$= R \times \frac{\theta \times 2\pi}{360} \text{ when } \theta \text{ is in degrees,}$$

$$= \frac{R \times \theta°}{57.3} \text{ when } \theta \text{ is in degrees.}$$

By definition, 1° curve has a length of 30.5 m with a deflection angle of 1°.
$D°$ curve with a deflection angle of 1° will have a length of $30.5/D$ m
$D°$ curve with a deflection angle of $\theta°$ will have a length of $30.5 \times \theta/D$ m

5. Tangent length $T = R \tan \theta/2$
6. Chord length $AB = 2\,AH = 2R \sin \theta/2$
7. Middle ordinate

   or versine $FH = OF - OH$

$$= R - R \cos \theta/2$$

$$= R\,(1 - \cos \theta/2)$$

8. Apex distance $FC = OC - OF$

$$= AO \sec \theta/2 - R$$

$$= R \sec \theta/2 - R$$

$$= R\,(\sec \theta/2 - 1)$$

One or more of these relationships are useful, depending upon the method used for setting out the curves.

6.6 SETTING OUT CURVES

Simple methods of setting out curves often adopted by permanent way men are described in the succeeding paragraphs.

6.6.1 Setting out Curve of Radius *R* from a Tangent Point *T*

Method A Figure 6.7 (a): Choose a convenient chord of length C (20 m chord is generally adopted). Then versine $V = C^2/8R$ (Section 6.5)

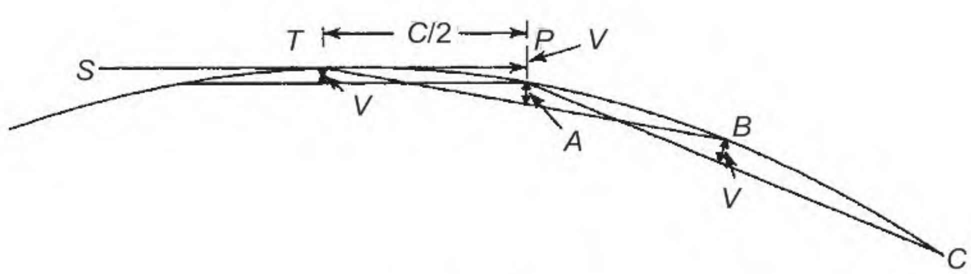


Fig. 6.7 (a)

Take $TP = C/2$ along the tangent and mark P.

Then with string line, mark the point A, which is $C/2$ from T and V from point P. The point A is on the curve. From T extend the string to point B, by making TB equal in length to C and the distance between the middle of the length TB and point A equal to V. The Point B is then on the curve. Similarly, further points on the curve can be set out.

Method B Figure 6.7 (b): Point A is defined on the curve as in method A. A string is then stretched from point T and extended to P_2 (TP_2 = chord length C), $P_2B = 2\,V$ is marked at right angle to TP_2. B

is the point on the curve. Further point C can be marked in the same way. For getting tangent BP'_3 the offset $P_3P'_3$ is taken equal to V and the curve can be further progressed from the tangent BP'_3.

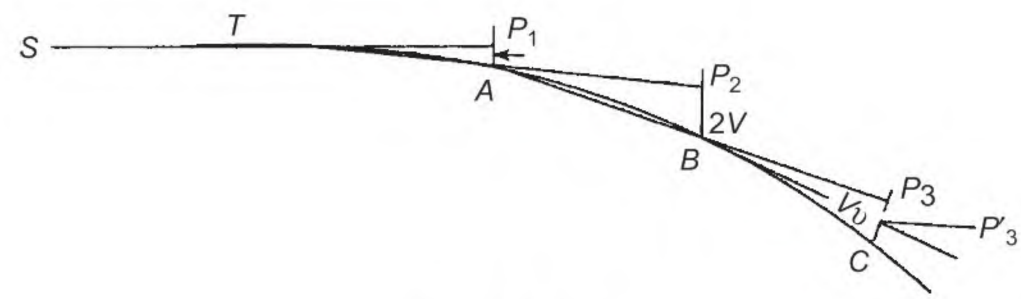


Fig. 6.7 (b)

Method C Figure 6.8: A short curve can be set out direct from the tangent line. Calculate the versine V for a convenient chord length C. Extend the tangent to A, B and C when TA, AB and BC are all equal to $C/2$. At A mark the offset $AA_1 = V$, at right angle to TA. The point A_1 is on the curve. The method of fixing the remainder points depends upon the fact that, within certain limits, offset to a curve from a tangent is very nearly proportional to the square of the distance from the tangent point. Thus BB_1 is $4V$ and CC_1 is $9V$.

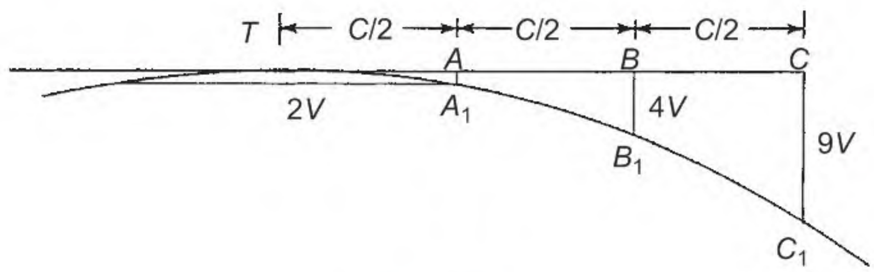


Fig. 6.8

6.6.2 Setting Out a Curve from Two Intersecting Tangents

There are a number of circular curves that can be set out tangential to two tangents intersecting at a given angle. However, when one tangent point on a tangent or tangent length is fixed, only one circular curve can be set out. Similarly, when the radius of the circle is fixed, there is only one position in which the circle will be tangential to both the tangents.

In Fig. 6.9, OS and OS_1 are two tangents, which are to be connected by a circular curve. The two tangent points are T and T_1.

Tangent length $OT = OT_1$

From the figure, $$\frac{TP}{OT} = \frac{TM}{OM}$$

Radius $= TP = OT \times TM/OM$

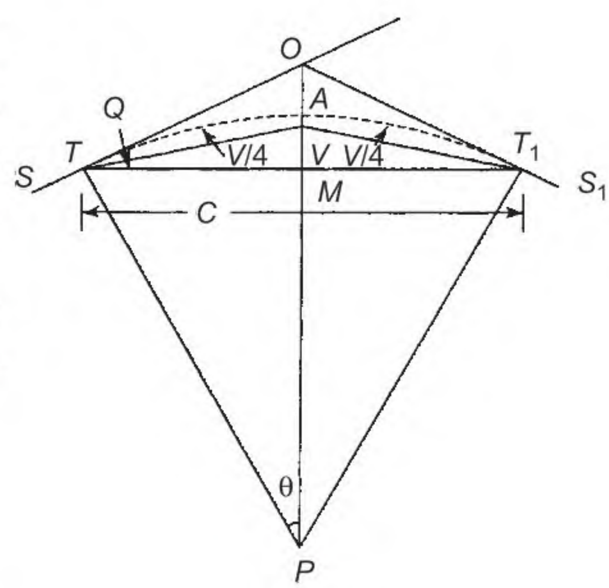


Fig. 6.9

OT, *TM* and *OM* can be measured at site, and thus, the radius can be calculated.

Versine $= V = C^2/8R$

With V known, point A can be marked on the curve. Versines at midpoints X and Y are $V/4$. The process can be repeated and more points can be obtained on the curve to mark its position.

6.6.3 Theodolite Method

AC is the tangent with tangent points at *A*. From Fig. 6.10, it may be seen that for a 30.5 m chord *AD*, the deflection angle is

$\angle BAD = D/2$ (D is the degree of the curve)

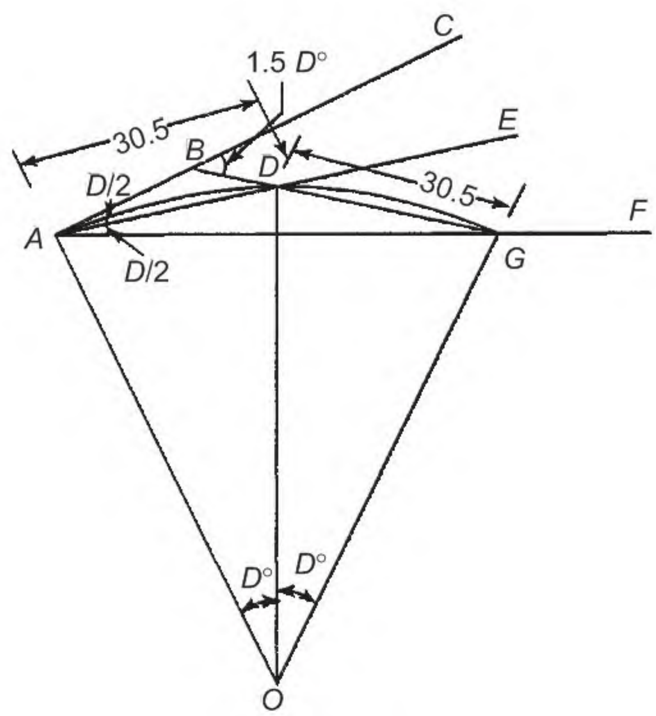


Fig. 6.10

Theodolite is set at *A* reading zero in the direction *AC*. The theodolite is swung towards *E* reading $CAE = D/2$. With *A* as centre point, *D* is located with a string at 30.5 m from *A* in the direction *AE*. *D* is the point on the curve. Again deflect theodolite by another angle $D/2$ in the direction *AF*. With *D* as centre and radius of 30.5 m, *G* is located in the direction *AF*. The process is continued further to locate more points on the curve. Similar procedure can be adopted from other tangent points to meet at the centre of the curve.

6.7 SUPERELEVATION OR CANT FOR RAILWAY TRACK

A body moving in a straight line continues to do so unless forced to change its direction by an outside force. The outside force is equal and opposite to the force, that arises when a body is compelled to follow a circular path, against its normal tendency to continue on a straight path. The force which is set in the body because of following the circular motion, is called centrifugal force. The centrifugal force is equal to the mass *M* of the moving body, multiplied by the square of the speed (*V*) of its movement and divided by the radius (*R*) of the circular curve. This is given by the formula.

$$\text{Centrifugal force } = \frac{MV^2}{R}$$

For a steady circular movement, the centrifugal force must be fully balanced by an outside force called centripetal force.

In a railway vehicle moving on a curved track, the forces acting on its centre of gravity are:

1. The centrifugal force acting outward.
2. Its weight acting downward.

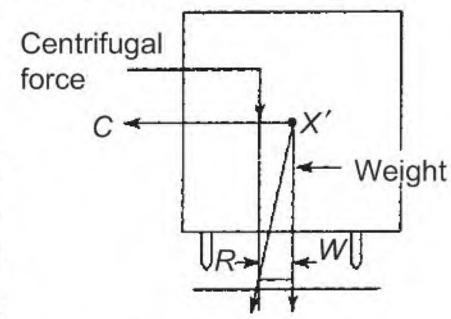


Fig. 6. 11(a)

These forces are indicated graphically in Fig. 6.11 (a), where *X* is represents the centre of gravity of the vehicle, *XC* represents in direction and scale the amount of centrifugal force for a certain speed and radius of curve and *XW* represents in the same scale, the weight (*W*) of the vehicle. *XR* will represent by its direction and length which is the resultant of the force *XC* and *XW*.

The resultant force *XR* acts toward the outer rail and thus exerts a greater load on the outer rail than the inner one. Further, if speed *V* is increased or radius, *R* is reduced, the centrifugal force will be greater, *XC* will be longer, while *XW* will remain the same and so *XR* will get nearer to the outer rail. When the conditions become such that the resultant passes through the outer rail; there is no load on the inner rail, and the vehicle is on the point of overturning.

In the case of railway vehicles, the force which directs the vehicle along the curved path is provided by the pressure of the outer rail against the flange of the leading wheel. This force can also reach a stage when the wheel starts mounting the rail and gets derailed.

It would not be possible to say which form of derailment would occur first. It has however been observed that while derailments due to overturning are rare, those caused by wheel climbing are not infrequent.

The centrifugal force causes irregular stressing of rails and other track components, both in the vertical and lateral modes; in the former by increased vertical loads on the outer rail and in the latter by the curving force it is required to provide. The method adopted for counteracting the centrifugal force is, to make the plane of the tops of rails normal (at right angles) to the resultant of the centrifugal force and the weight. This means that the outer rail is raised above the inner rail or that the track is "canted". The term "cant" or superelevation is used to represent the amount by which one rail of a track is raised above the other. It is considered positive when the outer rail on a curved track is raised above the inner rail and is negative when the inner rail is raised above the outer rail.

Figure 6.11 (b) indicates the method of determining the superelevation. In this figure,

XC represents the centrifugal force,

XW represents the weight,

E represents the superelevation,
G is the distance between the centre of rails,
∴ From similar triangles

$$\frac{E}{G} = \frac{XC}{XW} = \frac{MV^2}{R \times W}$$

As $$M = \frac{W}{g}$$

$$\frac{E}{G} = \frac{W}{g} \times \frac{V^2}{R \times W} = \frac{V^2}{gR}$$

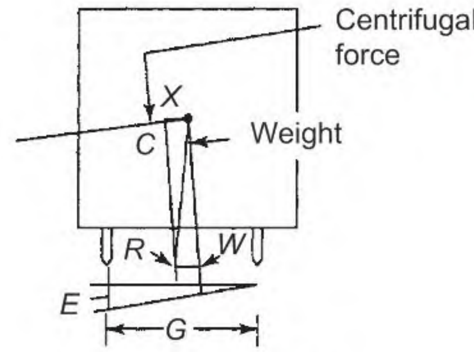


Fig. 6.11 (b)

(g is the acceleration due to gravity)

$$E = \frac{GV^2}{gR}$$

When V = Speed in km/hour
R = radius of curve in metres
g = 981 cm/s^2 and
E = superelevation in mm

The formula is reduced to

$$E = \frac{V^2}{127R}$$

For the Indian Railways, G is taken as 1,750 mm for BG and 1057 mm for MG. The superelevation calculated from the above formula is called the equilibrium cant for radius R and speed V.

6.7.1 Equilibrium Speed

It may be seen from the formula that for a curve of radius R, the superelevation will vary in proportion to the square of the speed. When the speed goes up, say from 30 to 60 kmph, the superelevation required will be four times. In a section where goods, passenger and express trains run at different speeds, cant (superelevation) provided will be in excess for some trains and less for others.

Excess cant can cause overloading of lower rail while less cant causes more weight to be thrown on higher rail. Unbalanced radial acceleration causes discomfort to passengers. Improper cant can cause excess wear of rails and greater disturbance to track geometry. The amount of superelevation thus depends upon the maximum speed of the fastest trains and indeed on the speed and volume of the slow goods traffic on a particular section. Excess superelevation is reported to have contributed to overturning of empty goods rolling stock when exposed to high velocity winds. Therefore, a compromise is required to decide the speed for which superelevation is to be provided. This speed is called "equilibrium speed" and is arrived at by determining the maximum speed which can actually be attained by fast and slow trains, stopping places and gradients. Gradients markedly reduce the speed of goods trains, while there is no apparent effect on the speed of fast trains. For determining the "equilibrium speed" an entire section may be divided into a number of subsections, on the basis of speeds which can actually be attained on an individual subsection.

6.7.2 Maximum Superelevation or Cant

The limits of maximum superelevation or cant as laid in the Indian Railways are as follows:

1. Broad gauge
   Group *A*, *B*, and *C* routes: 165 mm
   (A value of 185 mm may be adopted for future planning of works on all Group *A* routes).
   Group *D* and *E* routes: 140 mm.
2. Metre gauge: 90 mm
   (100 mm with special permission on high speed routes).
3. Narrow gauge (762 mm) : 65 mm
   (75 mm with special permission).

6.7.3 Cant Deficiency

Cant deficiency occurs when a train travels at a speed more than the equilibrium speed. It is the difference between the theoretical cant required for such higher speed and the actual cant provided.

The following values of maximum cant deficiency are permitted:

1. Broad gauge: 75 mm
   (For speeds in excess of 100 kmph on Group *A* and *B* routes; 100 mm with special permission).
2. Metre gauge: 50 mm

6.7.4 Cant Excess

Cant excess on the other hand occurs when a train travels round a curve at a speed less than the equilibrium speed. It is the difference between the actual cant and the theoretical cant required for such lower speed. Maximum values of excess cant as laid down are:

1. Broad gauge : 75 mm
2. Metre gauge : 65 mm

Booked speeds of the goods trains should be taken into account for working out "cant excess" for a particular section.

6.7.5 Negative Superelevation/Cant

When a main line is on a curve and a branch line branches off from with a curve in contrary flexure to the main line, the outer rail vis-à-vis the inner rail has to remain lower up to a certain distance from the takeoff point. This is necessary because of (a) canted curve of the outer rail of main line and (b) the turnout sleeper being in the same inclined plane. This continuity of the plane makes the inner rail of the branch line higher than its outer rail [Fig. 6.12 (a) and (b)]. The lower amount of cant of the outer rail vis-à-vis the inner rail in a branch line is called "negative cant" or "negative superelevation".

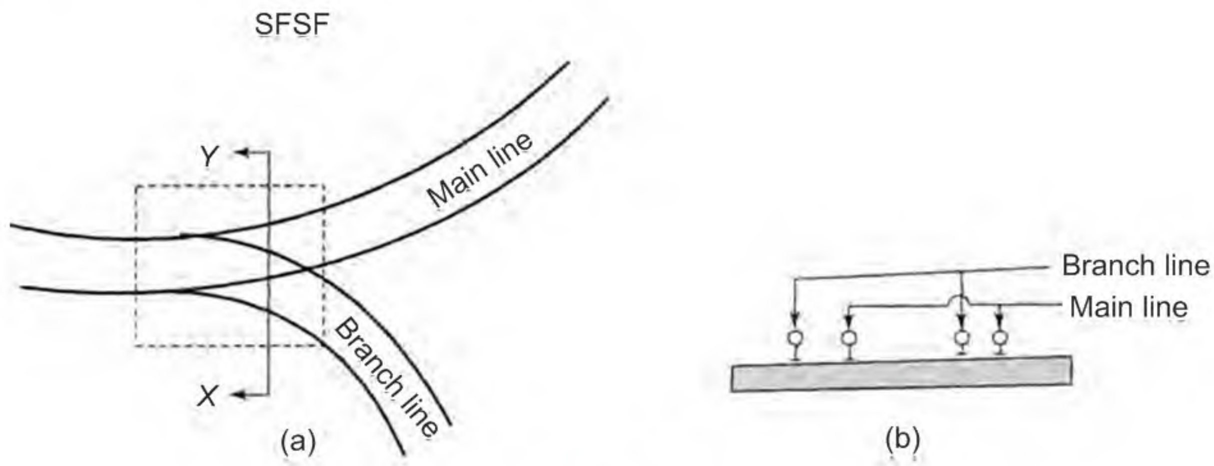


Fig. 6.12

To ensure that laid down norms of maximum cant and cant deficiency are not violated, the speeds of trains, both on the main line and branch line have to be regulated at such junction points. Unless particularly indicated, the branch line speed is assumed as 30 kmph at take-off point for determining the cant and permissible speeds of main line and branch line.

6.8 TRANSITION CURVES

To counteract the centrifugal forces on the curves, superelevation has to be provided throughout the length of the curve. When a circular curve joins the straight track, such a condition exists at the tangent point, that at one moment no superelevation is needed while in the next full superelevation is required. It is neither possible nor desirable to have such a sudden change on track. The only method of overcoming this difficulty is to insert another curve between the straight and the circular curve. In the inserted curve the radius is gradually decreased from infinity (radius of straight line) to that of a circular curve. Such a curve is called "transition curve" or easement curve, and the curve usually employed is a cubic parabola. In this curve the offsets from the straight increases in cubical proportion to their distance from the point of origin and the radius at any point on the curve, varies almost inversely as the distance of that point from the point of origin.

As the centrifugal forces starting from straight, gradually build up on the transition curve, the cant increases corresponding to the curvature thereby attaining its full value at the commencement of circular curve. Centrifugal forces therefore continue getting fully compensated as the radius changes.

A transition curve such as this cannot be inserted between an existing straight and an existing circular curve. The curve has to be displaced or shifted to a position parallel to its original alignment (Fig. 6.13).

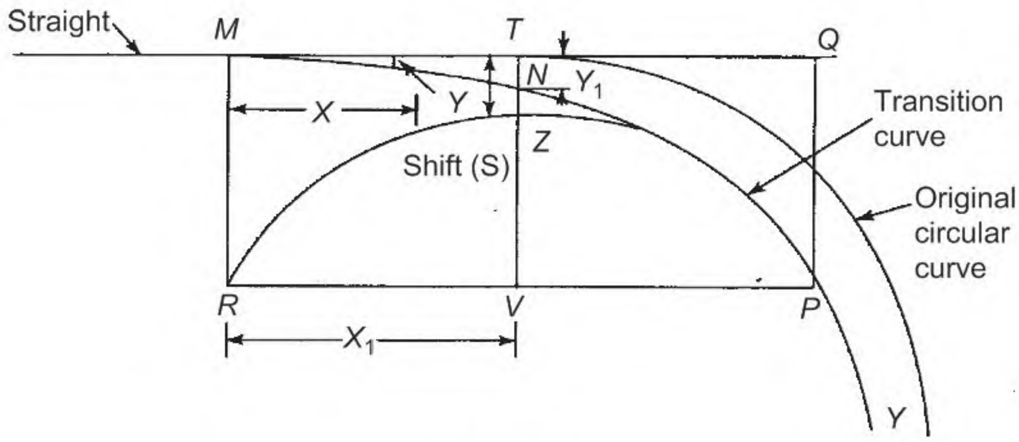


Fig. 6.13

In Fig. 6.13, the original circular curve is tangential to the straight at *T*. The curve is shifted to *ZPY* and *TZ* is the amount of shift (*S*). The transition curve *MNP* bisects the shift *TZ* at *N*. The total length of the transition curve (measured along the straight) is *MQ* and *MT* is equal to *TQ*. The transition curve being a cubic parabola, the offset *Y* is in proportion to X^3. The offset at *Q*, i.e. *QP*, at twice the distance from *M*, is eight times the offset at *T*, i.e. *TN*, or four times the shift, i.e. 4*S*. With the value of shift known, the offset at any point from the straight can be found out by a simple equation.

$$\frac{Y}{X^3} = \frac{Y_1}{X_1^3}$$

where X_1 = 1/2 transition length and
Y_1 = 1/2 shift *S*.

6.8.1 Length of Transition Curve

Empirical formulae have been laid down for determining the length of transition curve. They take into account internationally accepted norms for permissible rate of change of cant, cant deficiency and radial acceleration.

The desirable length of transition shall be the maximum of the following three values:

1. $L = 0.008\ C_a \times V_m$
2. $L = 0.008\ C_d \times V_m$
3. $L = 0.72\ C_a$

where

L = Length of transition is metres,
V_m = Maximum permissible sped in kmph,
C_a = actual cant on curve in mm and
C_d = cant deficiency in mm.

Formulae 1 and 2 are based on rate of gain of cant and of cant deficiency of 36 mm per second. The third formula is based on the maximum cant gradient 1.4 mm per metre or 1 in 720.

It is generally preferred to give as long a transition as possible because this will give a margin for some increase of speed at a later date. For designing layout on curve on high speed routes, future high speeds (160 kmph for Group 'A' and 130 kmph for Group 'B' routes) may therefore be considered for determining the transition length.

In exceptional cases, where room is not available for providing transition length in accordance with the afore mentioned norms, the length may be reduced to (a) a maximum of 2/3 of the desirable length worked out on the basis of formulae (1) and (2) of (b) 0.36 C whichever is greater. This is based on the criteria that the rate of gain of cant deficiency will not exceed 55 m/s and the maximum cant gradient will be limited to 2.8 mm per metre or 1 in 360. This relaxation applies to broad gauge only.

6.8.2 Transition for Compound Curves

In case of a compound curve which is formed by joining two circular curves of different radii curving in the same direction, transition curve is provided between the two circular curves. The length of such transition is obtained from (a) $L = 0.008\ (C_{a1} - C_{a2}) \times V_m$ or (b) $L = 0.008\ (C_{d1} - C_{d2}) \times V_m$, whichever is greater;

L = length of transition in metres,
V_m = maximum permissible speed in kmph,
C_{a1} and C_{a2} = cant for curve No. 1 and No. 2, respectively in mm.
C_{d1} and C_{d2} = cant deficiency for curve No. 1 and No. 2, respectively, in mm.

In case of a reverse curve formed by two circular curves curving in opposite direction, the transition length between the curves is obtained from (a) $L = 0.008\ (C_{a1} + C_{a2}) \times V_m$ or (b) $L = 0.008\ (C_{d1} + C_{d2}) \times V_m$, whichever is greater.

In compound curves, where the radii of curvature between the two curves differ by more than 20 percent, transition curves should be provided.

For high speed routes, a straight with a minimum length of 50 m for BG and 30 m for MG, should be provided between two transition or reverse curves. If provision for such a minimum length of straight is not possible, it should be eliminated altogether by extending the transition lengths. Speeds over 130 kmph on BG and over 100 kmph on MG should not be permitted, where the aforementioned stipulation cannot be met with.

6.8.3 Longitudinal Profile of Transition on Reverse Curve

The following three alternatives may be adopted for longitudinal profile (Fig. 6.14).

In case I, the level of one of the rails is maintained and the superelevation is carried out on the other rail by raising it over half the transition and lowering it over the remaining half.

In case II, the inner rail on the curve acts as the base rail and the superelevation is carried out on the outer rail. Both the rails are thus raised to full amount of cant in the portion where one of them acts as an outer rail.

In case III, the level of centre line of track is uniformly maintained throughout; cant is provided by raising one rail by half the amount and lowering the other rail by the equal amount.

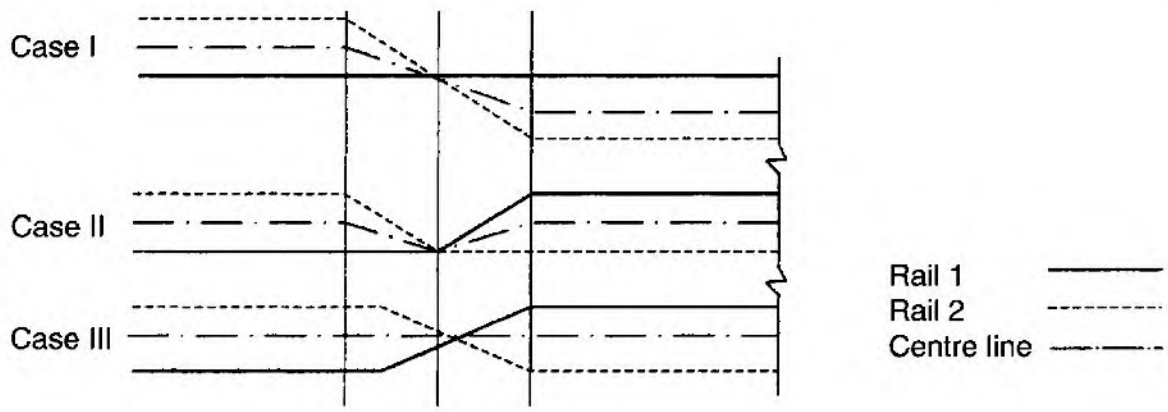


Fig. 6.14

In cases I and II, the level of the centre line of track gets disturbed whereas in case III, it remains uniform throughout. Case II is more widely accepted by field staff for its ease of adoption in manual maintenance of track.

6.8.4 Laying Transition

As mentioned earlier, the transition curve is laid out as a cubic parabola, and to accommodate this, the main circular curve is moved inwards by an amount called the shift.

Shift is calculated from the formula:

$$S = 4.20\, L^2/R$$

where S = shift in centimeters

L = length of transition in metres and

R = radius of the circular curve in metres.

The offset in centimetres, from the tangent to any point on the transition curve, can be calculated from the formula:

$$Y = 16.70\, X^3/LR$$

where Y = offset from the straight in centimeters and

X = distance from the commencement of curve in metres

The offset Y at any point X can also be found out from the equation:

$Y/X^3 = Y_1/X_1^3$ as explained earlier (Fig. 6.13).

6.8.5 Safe Speed on Curves

1. *Fully Transitioned Curves*

The maximum permissible speed for transitioned curves is determined from the following formula:

(a) Broad gauge $V = 0.27\sqrt{(C_a + C_d)R}$

(b) Metre gauge $V = 0.347\sqrt{(C_a + C_d)R}$

The above two formulae are based on the basic formula

$$C = \frac{GV^2}{127R} \text{(Sec. 6.7)}$$

On the assumption that G, the centre to centre distance between rail heads, is 1750 mm for BG and 1057 mm for MG.

(c) Narrow Gauge (762 mm)

$V = 3.65\sqrt{R - 6}$ (subject to a maximum of 50 kmph).

In all the above formulae

V = speed in kmph
R = radius of curve in metres
C_a = actual cant in mm
C_d = cant deficiency in mm

2. *Non-transitioned Curves*

(a) *Non-transitioned Curves with Cant on Virtual Transitions*: The determination of maximum permissible speed on curves without transition involves the concept of virtual transition. A vehicle moving with uniform velocity into angular velocity on the straight tract begins to change its linear velocity into angular velocity as soon as the front bogie of the vehicle reaches the tangent point. The change continues till the rear bogie of the vehicle reaches the tangent. At that stage, the vehicle acquires full angular velocity. The change in motion of the vehicle from the straight to curved condition takes place over the shortest distance between the bogie centers, which is considered as the "virtual transition". Normally, this distance is 14.8 m on BG, 13.7 m on MG and 10.3 m on NG, commencing on the straight at half the distance beyond the tangent point. The deficiency of cant is considered as being gained in the length of the virtual transition and cant has to be gained in the similar manner; the cant gradient in any case not being steeper than 1 : 360 for BG and 1 : 720 for MG and NG. The safe speed is worked out on the basis of cant, which can actually be provided on the above basis, increased by the permissible amount of cant deficiency.

(b) *Non-transitioned Curves with No Cant*: In such cases, the safe speed is calculated on the basis of cant deficiency that can be permitted on the curve.

(c) *Curves Laid with Inadequate Length of Transition*: The safe permissible speed is arrived at on the basis of actual cant deficiency, which can be provided taking into consideration limiting cant deficiency gradient.

The speed as determined above should not exceed the maximum permissible speed of the section, which may have been laid down on the track or as per rolling stock characteristics of the section.

6.8.6 Turnouts on Transitions

On the Indian Railways, no change in superelevation is allowed between the points: 20 m on BG, 15 m on MG, and 12 m on NG, outside the toe of the switch, and nose of the crossing, respectively. Consequently, turnouts are not normally located in the transition portion of curve.

6.8.7 Crossover between Curved Tracks

When crossovers are provided between curved tracks, the superelevation and speed on both the curves are determined by the radius of the inner curve where the crossover forms a curve of contrary flexure. Permissible speed and superelevation for the inner curve shall be calculated in terms of Sec. 6.7. The same speed and superelevation shall be allowed for the outer curve. To achieve this objective, the top of the formation for the double line, shall be laid as an inclined plane. Where this is not possible, the two curves shall be laid flat without any superelevation.

6.8.8 Diamond Crossing on Curves

Diamond crossings being straight and rigid are not located on curves. They do not take the curvature, and thus cause a kink in the track. When a diamond crossing exists on a straight track in the vicinity of a curve, a minimum distance of 50 m must be maintained between the beginning of the curve and the acute crossing of the diamond. And, when a diamond crossing exists on a curve, the curve for a distance of 20 m on either side of the diamond crossing must be laid flat without superelevation. The superelevation of such a curve should be carried out uniformly at the rate specified in the para above. A speed restriction is imposed on such a curve, taking into account the curvature, cant deficiency and lack of transition; the speed in any case is restricted to 65 kmph on BG, 50 kmph on MG and 40 kmph on NG.

6.8.9 Examples of Speed on Curves

Example 1. *From a BG main line curve of 2°, a 1 : 12 turn out takes off in contrary flexure for a Branch line. Find out the permissible cant on main line and the speed that can be permitted on the main line.*

Solution

Degree of 1 : 12 turn out curve	= 4°
Degree of main line curve	= 2°
Thus degree of branch line curve	= 4° – 2° = 2°

Radius of branch line curve $= \dfrac{1750}{2} = 875$ m

Speed on branch line = 30 kmph

(assumed for all turnouts if not specifically mentioned)

Cant needed for branch line $= \dfrac{1750\ V^2}{127 \times R}$ mm

$$= \frac{(1750 \times 30^2)}{(127 \times 875)} \text{ mm}$$

= 14.17 mm

To round off to the nearest 5 mm = 15 mm

To ensure that negative cant for branch line does not increase the limit of cant deficiency of 75 mm, maximum cant that can be permitted on main line = 75 – 15 = 60 mm. This will be negative cant for branch line.

Allowing a cant deficiency of 75 mm for main line, maximum speed that can be permitted on main line is

$$V = 0.27\sqrt{(60 + 75)875}$$

= 92.8

= Say 90 kmph

Example 2. *A 600 m radius curve is introduced between two tangent portions of BG lines intersecting to form a deviation angle of 70°. The booked speed for goods train in the section is 50 kmph and the maximum sanctioned speed is 110 kmph. Calculate the equilibrium cant, maximum permissible speed, length of transition and the offsets for setting out the transition curve. Limits of maximum cant and cant deficiency are 165 and 100 mm, respectively.*

Solution

Cant for maximum permissible speed

$$= \frac{1750 \times (110)^2}{127 \times 600} \quad \text{(i)}$$

= 277.88 mm

$$\text{Cant for 50 kmph} = \frac{1750 \times (50)^2}{127 \times 600} \quad \text{(ii)}$$

= 57.41 cm

With a cant deficiency of 100 mm, the cant required for 110 kmph from (i) is

= 277.88 – 100 (iii)

= 177.88 mm

With a cant excess of 75 mm, the cant permitted in the section

$= 57.41 + 75$

$= 132.41$ mm (iv)

On excess cant amount (iv) is

Adopted, rounded off to nearest 5 mm = 130 mm (v)

$$\text{Maximum permissible speed} = 0.27\sqrt{R(130 + 100)} \quad \text{(vi)}$$

$$= 0.27\sqrt{600 \times 230}$$

$= 100.3$ say 100 kmph

Length of transition

(a) $L = 0.008 \times C_a \times V_m \quad = 0.008 \times 130 \times 100$

$= 104$ m

(b) $L = 0.008 \times C_d \times V_m \quad = 0.008 \times 100 \times 100$

$= 80$ m

(c) $L = 0.72\ C_a \quad = 0.72 \times 130$

$= 93.6$ m

Maximum value obtained for (a), (b) and (c) is 104 m assuming $L = 100$ m
Cant gradient for 130 mm cant in 100 m length

$$= \frac{130}{100 \times 1000} = \frac{1}{769} \text{ i.e. } 1{:}769$$

Rate of change of cant at 100 kmph

$$= \frac{\text{Speed in mm per second}}{769}$$

$$= \frac{100 \times 1000 \times 1000}{60 \times 60} \times \frac{1}{769}$$

$= 36$ mm/s

$$\text{Shift} \quad = \frac{4.20L^2}{R} = \frac{4.2 \times 100^2}{600} = 70 \text{ cm}$$

CF in Fig. 6.15 = 600 + 0.7 = 600.7 m

$FA = 600.7 \times \tan 35° = 420.61$ m

$$OF = \frac{L}{2} = \frac{100}{2} = 50 \text{ m}$$

$OA = 420.61 + 50 = 470.61$

The point—the beginning of transition curve also called transition tangent point—can thus be fixed.

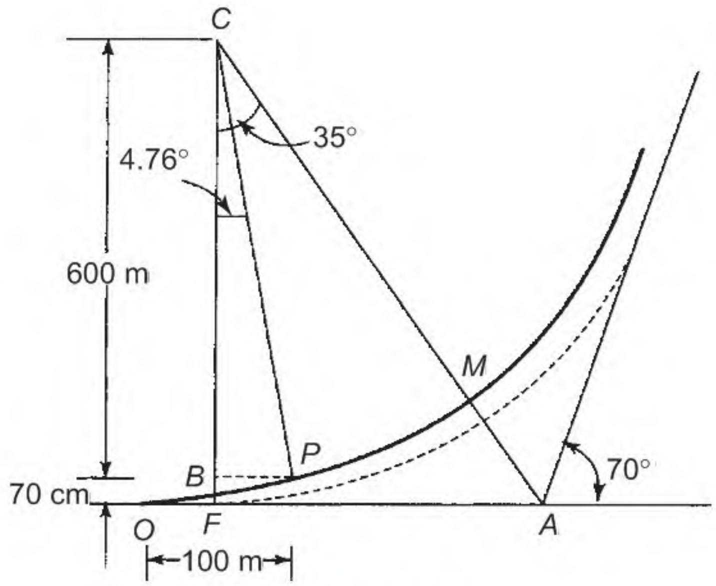


Fig. 6.15

Deviation angle for each transition length is

$$\angle FCP = \tan^{-1} \frac{1/2 \text{ transition length}}{\text{Curve radius}} = \tan^{-1} \frac{100}{2 \times 600}$$

$$= 4.76°$$

Deviation angle for circular curve = $70 - 2 \times 4.76°$

$$= 60.48°$$

Length of circular curve = $R \times \theta$ (in radians)

$$= 600 \frac{60.48 \times \pi}{180} \text{ m}$$

$$= 633.7 \text{ m}$$

Offset at every 20 m from transition from the formula

$$\frac{Y}{X^3} = \frac{Y^1}{X_1^3}$$

At $X = 50$ m (half the transition length) Y_1 is 70/2 cm

$$= 35 \text{ cm}$$

At $X = 0$ $\quad Y = 0$

At $X = 20$ m $\quad Y = \frac{35 \times 20^3}{50^3} = 2.24$ cm

At $X = 40$ m $\quad Y = 35 \times \frac{40^3}{50^3} = 17.9$ cm

At $X = 60$ m $\qquad Y = 35 \times \dfrac{60^3}{50^3} = 60.48$ cm

At $X = 80$ m $\qquad Y = 35 \times \dfrac{80^3}{50^3} = 143.36$ cm

At $X = 100$ m $\qquad Y = 35 \times \dfrac{100^3}{50^3} = 280$ cm

280 cm is four times the shift *S*.

The transition curve can thus be set out by measuring offsets from the straight.

Example 3. *For a BG main line curve of 2°, a 1 in 12 turnout takes off in similar flexure for a loop. The turnout is immediately followed by a reverse curve. Find out the permissible cant on the main line and the speed that can be permitted.*

Solution

Standard degree of 1 in 12 turnout curve = 4°
Degree of main line curve = 2°
Degree of 1 in 12 turnout curve in similar flexure = 4° + 2° = 6°

$$\text{Radius} = \frac{1750}{6} = 291.67 \text{ m}$$

Equilibrium cant required for a speed of 15 kmph $= \dfrac{GV^{\circ}}{127R}$

Assuming speed on turnout track as 15 kmph $= \dfrac{1750 \times 15^2}{127 \times 291.67}$

$= 10.63$—say 10 mm

Permitting a cant deficiency of 75 mm for the turnout track, the maximum cant for main line will be 75 – 10 = 65 mm.

Speed on the main line curve, permitting a cant deficiency of 75 mm for main line track

$$= 0.27\sqrt{(C_a + C_d)R}$$

$$= 0.27\sqrt{(65 + 75) \times \frac{1750}{2}}$$

$= 94.5$ kmph—say 90 kmph

6.9 REALIGNMENT OF CURVES

Railway curves lose their original alignment with the passage of traffic. Unbalanced centrifugal forces generated by the vehicles running at varying speeds, are the main cause, but irregularities in track geometry and defects in suspension system of the rolling stock also contribute considerably in distorting the curve alignment.

For smooth and satisfactory running on curves, there should not be any abrupt change of curvature and the cant should be proper. To ensure this, surveys are conducted on curves, in which versine and cant are recorded all along the curve at 10 m interval and on 20 m chord. Based on these surveys, commonly known as versine surveys, the decision for local correction or complete realignment of curve is taken.

6.9.1 Criteria for Realignment of a Curve

Imperfect curve conditions get easily reflected in the running quality of rolling stock. The curve is checked and taken up for realignment whereas a result of foot plate inspection, oscillograph car, accelerometer, or track recording car runs, the curve is found to be unsatisfactory.

A method for deciding the need for curve realignment is by drawing a cumulative frequency diagram. It shows the cumulative frequency—indicated as percentage—of occurrence of stations having versine variation, over the average versine on circular portion and theoretical versines over transition. Realignment of curve is taken up if the cumulative percentage having variations within the prescribed limit falls short of 80 percent of the prescribed limit. The limits of variations are 4 mm for BG group *A* Routes, and 5 mm for Group *B* and other main line routes. After realignment, the cumulative percentage should come within 90 to 95 percent.

The method lies in having a versine survey of the curve and statement (No. 1) is prepared indicating in various columns, the stations, the measured versine, the ideal versine and the difference between the ideal versine and the measured versine. In statement 2, the number of stations having differences of 0, 1, 2, 3, 4, 5 mm etc. are indicated, counting them from statement 1. Percentages of stations within each difference limit are found out and the cumulative percentage totaled. Cumulative frequency curve *A* is then drawn as shown in Fig. 6.16, from columns 1 and 4 of statement 2.

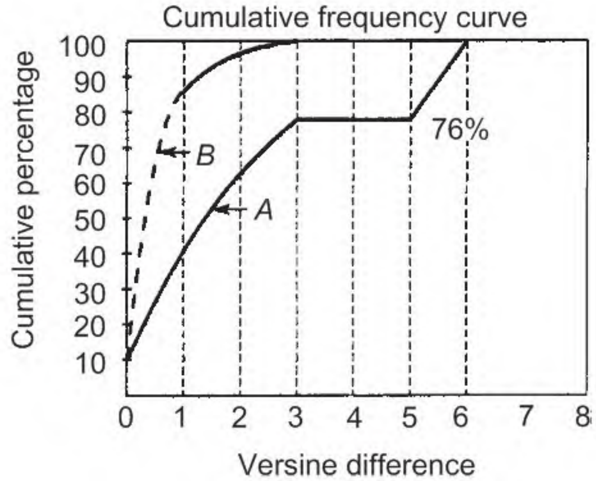


Fig. 6.16

Statement 1

Table 6.1

Station 1	*Measured versine* 2	*Ideal versine* 3	*Versine difference* 4 (3 – 2)
1	0	1	1
2	3	2	–1
3	7	4	–3
4	5	6	1
5	6	8	2
6	7	10	3
7	6	12	6
8	11	14	3
9	14	16	2
10	15	18	3
11	19	18	–1
12	24	18	–6
13	24	18	–6
14	24	18	–6
15	20	18	–2
16	12	18	6
17	22	16	–6
18	12	14	2
19	12	12	0
20	10	10	0
21	10	8	–2
22	5	6	1
23	3	4	1
24	1	2	1
25	0	1	1
	272	272	0

Total no. of stations = 25

Statement 2

Table 6.2

Versine (mm) difference 1	*No. of stations* 2	*Percentage of no. of stations in col. 2 to total no. of stations* 3	*Cumulative percentage* 4
0	2	8	8
1	8	32	40
2	5	20	60
3	4	16	76
4	0	0	76
5	0	0	76
6	6	24	100
	25	100	

The curve *A* shows that only 76 percent of the stations are within versine difference of 5 mm, and thus curve needs realignment. After realignment, the curve should be approximately equal to the position *B*.

6.9.2 Station to Station Variation of Versine

Service limit for station to station versine variation for 3 speed group viz. 120 kmph and above, below 120 kmph and up to 80 kmph and below 80 kmph and up to 50 kmph, should be considered as tabulated below:

Speed range	*Limits of station to station variation (mm)*
120 kmph and above	10 mm or 25% of the average versine on circular curve whichever is more
Below 120 kmph and down to 80 kmph	15 mm or 25% of the average versine on circular curve whichever is more
Below 80 kmph and down to 50 kmph	40 mm or 25% of the average versine on circular curve whichever is more.

The decision for complete realignment shall be taken on the basis of cumulative frequency diagram or when more than 20 percent of the stations are having versine variation beyond the prescribed limits, otherwise local adjustment may be resorted to.

6.9.3 String Lining Operation for Realignment of Curves

The work of realigning of curve consists of the following three main operations:

Operation 1

Survey of the existing curve by taking measurement of versines. Vesines are recorded 10 m apart on 20 m chord.

Important points to be kept in view are:

(a) The versine survey should be started at least 3 half chord lengths ahead of the apparent tangent point.

(b) Versine readings to be taken on gauge face of the outer rail. In case of reverse curve, the versine survey should be continuous but transferred to the outer rail at point where curvature changes sign.

(c) Obligatory points and the maximum slews possible at these points should be noted.

(d) Where there are two or more tracks, track centers at intervals should be recorded.

Operation 2

Determination of the revised alignment and computation of slews, including calculation for correct superelevation.

The basic principle employed in the computation of slews are:

(a) The chord length being identical, the sum total of the existing versine should be equal to the sum total of proposed versines.
(b) The slew in any direction at a station affects the versine at the adjacent station by half the amount in the opposite direction, when the track is not disturbed at the adjacent station.
(c) The second summation of versine differences represents half the slew ar any station.

Operation 3

Slewing of the curve to the revised alignment and provision of proper superelevation. In this operation care should be taken that:

(a) There should not be much time lag between the versine survey and the final slewing operation.
(b) The slewing is done to 2 mm accuracy and after the operation the actual versines are taken again to check up that they conform to the final versines of the realigned curve.
(c) Along with the slewing of the track to revised alignment, correct superelevation should be provided at each station with particular attention to the runoff at the transition.

Based on the above principle, various methods have been evolved to obtain the correct slew. These methods may be tabular, graphical, mechanical or electronic. Computer programmes have been evolved which work out a near ideal alignment with minimum slews. In tabular method, success largely lies on the proper selection of versines and in applying the appropriate correction couples. Example illustrated in Table 6.3 shows the process of arriving at the final slews.

6.9.4 Realignment of Curves on Double or Multiple Lines

On double or multiple lines, each curve should be stringlined independently. No attempt should be made to realign any curve by slewing it to a uniform centre to centre distance from a realigned curve of the adjacent track.

6.10 CURVE CORRECTOR

Measurement of versines at each and every station and calculation of slews has always been a laborious and time consuming process.

Curve corrector—a portable instrument—has been developed, which when moved on curved track gives a continuous recording of versines.

The equipment consists of two rigid aluminium alloy tube triangles *ABD* and *CBE* of 5 m base each (Fig. 6.17). The triangle *ABD* is fixed while the triangle *CBF* is movable with the point *B* as an hinge. The equipment is placed on the track with its rollers fixed at points *A*, *B* and *C* on the outer rail and point at point *F* on the inner rail. As the instrument is rolled over the track, a recording drum mounted at *D*, gives a continuous recording of versines on 10 m chord.

Table 6.3 Realignment of Curve by String Lining Method

					Correcting couple						
Station number	*Existing versine on 20 m chord (mm)*	*Proposed versine (mm)*	*Versine difference column 3- column 2*	*1st Summation of versine difference*	*2nd Summation of versine difference or half throw in mm*	*Correcting versine in (mm)*	*1st Summation of correcting versine*	*2nd Summation of correcting versine*	*Resultant half slew col. 9 + col. 6 (mm)*	*Resultant full slew (mm)*	*Resultant versine col. 3+ col.7 (mm)*
1	2	3	4	5	6	7	8	9	10	11	12
0	2	2	0	0	0	0	–1	–1	0	0	1
1	0	8	+8	8	–1	–1	–2	–1	–1	–2	7
2	14	16	+2	+10	+8	–1	–3	–3	+5	+10	15
3	28	24	–4	+6	+18	–1	–4	–6	+12	+24	23
4	30	32	+2	+8	+24	–1	–5	–10	+14	+28	31
5	36	32	–4	+4	+32	–1	–6	–15	+17	+34	31
6	36	32	–4	0	+36	–1	–7	–21	+15	+30	31
7	24	32	+8	+8	+36	–1	–8	–28	+8	+16	31
8	32	32	0	+8	+44		–8	–36	+8	+16	32
9	28	32	+4	+12	+52		–8	–44	+8	+16	32
10	36	32	–4	+8	+64		–8	–52	+12	+24	32
11	34	32	–2	+6	+72		–8	–60	+12	+24	32
12	32	32	0	+6	+78		–8	–68	+10	+ 20	32
13	34	32	–2	+4	+84	+1	–7	–76	+8	+16	33
14	36	32	–4	0	+88	+1	–6	–83	+5	+10	33
15	24	32	+8	+8	+88	+1	–5	–89	–1	–2	33
16	24	24	0	+8	+96	+1	–4	–94	+2	+4	25
17	28	16	–12	–4	+104	+1	–3	–98	+6	+12	17
18	0	8	+8	+4	+100	+1	–2	–101	–1	–2	9
19	6	2	–4	0	+104	+1	–1	–103	+1	+2	3
20	0	0	0	0	+104	+1	0	–104	0	0	1
Total	484	484	0			0					484

+ Slew inside –Slew outside

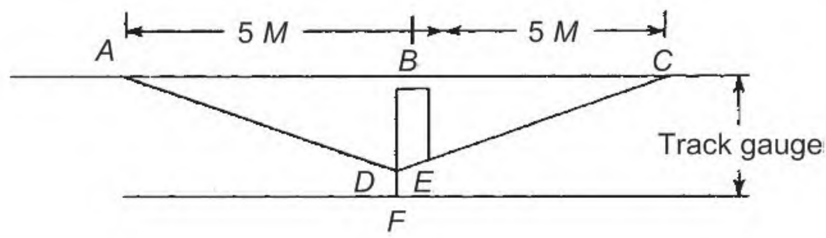


Fig. 6.17

The curve corrector has the following advantages.

1. The instrument is built of light metal. It comprises telescopic tubes foldable to half their length. Its weight being 35 kg only just three men can manoeuver it in and off the track.
2. It continuously records versines at full scale over a chord of 10 m with an accuracy of $\pm$ 0.5 mm. Due to continuous recording, defects at every unit length of curve can be located and rectified.
3. The equipment remains on the track as the slewing operation is carried out. The top of the pen at any time gives the position of track via-à-vis the median line of the curve. Therefore, the slewing can be done to the need based extent.
4. Pegging out of the curve and calculation of slews are not needed.
5. The instrument can be usefully deployed to get a continuous record of alignment in a straight track. Spots having misalignment beyond permissible limits can be attended to.

The instrument is still at a trial stage in the Indian Railways. Some P-way men have found it to be too cumbersome to use and prone to getting out of order too often.

Attachment for unevenness and gauge wherever provided have made the instrument difficult to handle.

6.11 EXTRA LATERAL CLEARANCE ON CURVES

To ensure that vehicles may travel with the same degree of safety all over the system of a particular gauge, certain minimum lateral clearances have been laid down in the booklet of Schedule of dimensions. On curves, the centre line of the vehicles moves away from the centre line track thereby necessitating extra clearance for structures. There is also leaning of vehicle on account of superelevation and swaying on account of speed.

Extra lateral clearances needed to meet with the above contingencies are worked out as follows.

6.11.1 End-Throw and Over-Throw

Figure 6.18 gives the position of a bogie on a curve of radius R. L is the end-to-end length of the bogie and C is the centre-to-centre distance of the two bogie centers.

1. Over-throw or extra clearance needed at the centre:

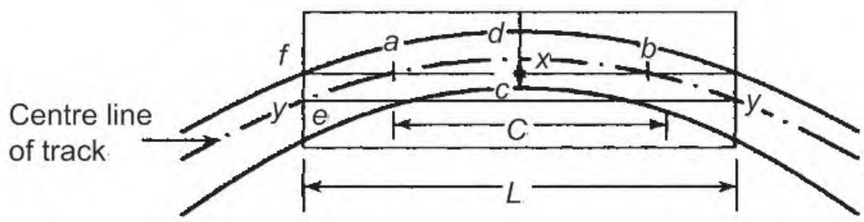


Fig. 6.18

$$x = cd = \frac{C^2}{8R}$$

2. End-throw or extra clearance needed at the ends:

$$y = ef = \frac{L^2}{8R} - \frac{C^2}{8R}$$

$$= \frac{L^2 - C^2}{8R}$$

On account of superelevation, vehicles lean toward the inner rail as shown in Fig. 6.19.

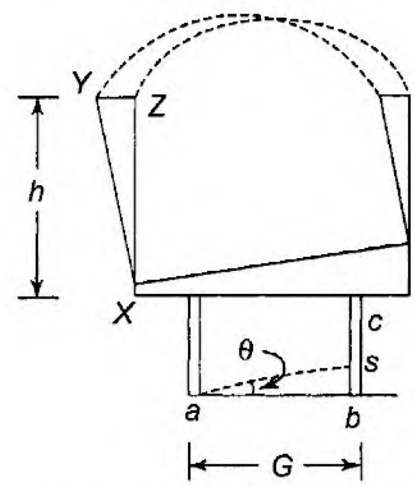


Fig. 6.19 Leaning of vehicles on curves

Since $\angle\theta$ is equal in the two triangles *abc* and *xyz*, effect of lean $= \frac{h \times s}{G}$

When h is height of the vehicle,

S = superelevation

G = gauge

6.11.2 Additional Lurch or Sway Inside the Curve

Additional lurch or sway on the curves will depend upon the unbalanced centrifugal forces and how the vehicle suspension system reacts to such forces. These lurches add to the effect of lean inside a curve. For present day speeds and vehicle, the extra clearance on account of sway has been empirically laid down as 1/4th of extra clearance required on account of lean as worked out earlier.

Lateral clearance on curves

1. Thus, total extra lateral clearance needed outside the curve are:

$$\text{End throw} = \frac{L^2 - C^2}{8R}$$

2. Total extra lateral clearance inside the curve are:

$$= \frac{C^2}{8R} + \frac{hs}{G} + \frac{1}{4} \times \frac{hs}{G}$$

For getting the result in mm, all dimensions are taken in mm.

R = radius of curve in mm,
L = end to end length of bogie which is taken as 21,340 mm for BG 19,510 mm for MG,
C = bogie centers taken as 14,785 mm for BG and 13,715 mm for MG,
h = Height of bogie, taken as 4,025 mm for BG and 3,355 mm for MG,
G = 1,676 mm for BG and 1,000 mm for MG,
S = superelevation in mm.

6.11.3 Extra Clearance between Adjacent Tracks

Assuming that both the tracks have the same superelevation, lean effect will get nullified. Thus, extra clearance required will be

Overthrow + twice sway + end throw

$$= \frac{C^2}{8R} + \frac{2 \times 1}{4}\frac{hs}{G} + \frac{L^2 - C^2}{8R}$$

6.11.4 Extra Clearance for Platforms

On the straight track, the clearance provided between the vehicle (i.e. the foot boards) and the platform coping is 152 mm. It is considered that extra clearances based on the above mentioned calculations would create excessive gap between the vehicle and the platform. It has therefore been decided that after taking all the extra clearance into account, the clearances should be reduced by 25 mm on platforms situated on the outside of curve, and by 51 mm on platforms situated on the inside of curves on BG. Reduction on the platform situated on the inside of curve has been allowed more as the sway effect at the centre of the bogie is less than that at the ends. In the case of MG, the deduction is 25 mm, both on the inside and outside of curves. The deduction is applicable for heights even beyond the platform height.

Example. *Work out the extra clearances needed on high level BG platform (840 mm height) for inside and outside of 2° curve and having a superelevation of 50 mm.*

Solution

$$R = \frac{1750}{2} \times 1000 = 875{,}000 \text{ mm}$$

$$S = 50 \text{ mm}$$

1. Extra clearance on inside of curve

$$E_1 = \frac{C^2}{8R} + \frac{hs}{G} + \frac{1}{4} \times \frac{hs}{G} = 51 \text{ mm}$$

Taking value of C, G and $h = 840$ as given earlier,

$$= \frac{(14785)^2}{8 \times 875000} + \frac{50 \times 840}{1676} + \frac{1}{4} \times \frac{50 \times 840}{1676} - 51 \text{ mm}$$

$$= 31.22 + 25.06 + 6.26 - 51 \text{ mm}$$

$$= 11.54 \text{ say } 10.0 \text{ mm (rounded up)}$$

2. Extra clearance on the outside of curve

$$E^2 = \frac{L^2 - C^2}{8R} - 25 \text{ mm}$$

$$= \frac{(21340)^2 - (14785)^2}{8 \times 875000} - 25 \text{ mm}$$

$$= 33.83 - 25 \text{ mm} = 8.83 \text{ mm}$$

$$= 10 \text{ mm (rounded up)}$$

6.12 MOVEMENT OF VEHICLES ON CURVES

6.12.1 Slipping and Sliding Wheels on Curves

On straight track, for any vehicle with two parallel axles, it can be assumed that the flanges are both clear of the rails and central between them, Fig. 6.20 (a).

Entering a curve, when the tangent point is passed, the vehicle continues in a straight line until the flange of the leading outside wheel rubs against the rail, Fig. 6.20(b). It continuously bears against the rail for the whole length of the curve and is therefore running on the wheel tread, which is slightly larger in diameter than that of the inside leading wheel tread, owing to the coning of the wheels.

If the axle could adjusts itself radial to the curve and the effect of coning fully compensated the difference in length of the inside and outside rails, the axle will run smoothly round the curve and there will be no tendency to slip. However, neither of these conditions are realised and consequently slipping between the tyre and the rail is inevitable.

To compensate the difference in length of rails, the inside wheel must slip backwards or the outside wheel must slide forward along the rail. This phenomenon is called slipping and sliding of wheels on curves and is one of the major causes of rail and wheel wear on curves.

6.12.2 Gauge Widening on Curves

Besides slipping and sliding along the rail, there occurs slipping across the rail to keep the front axle of the bogie always at right angle to the line of motion. If the radius of the curve is sharpened, a stage will reach where flanges on both axles of the bogie will begin to touch the rails and the curve will then be of minimum radius to accommodate the bogie (Fig. 6.21).

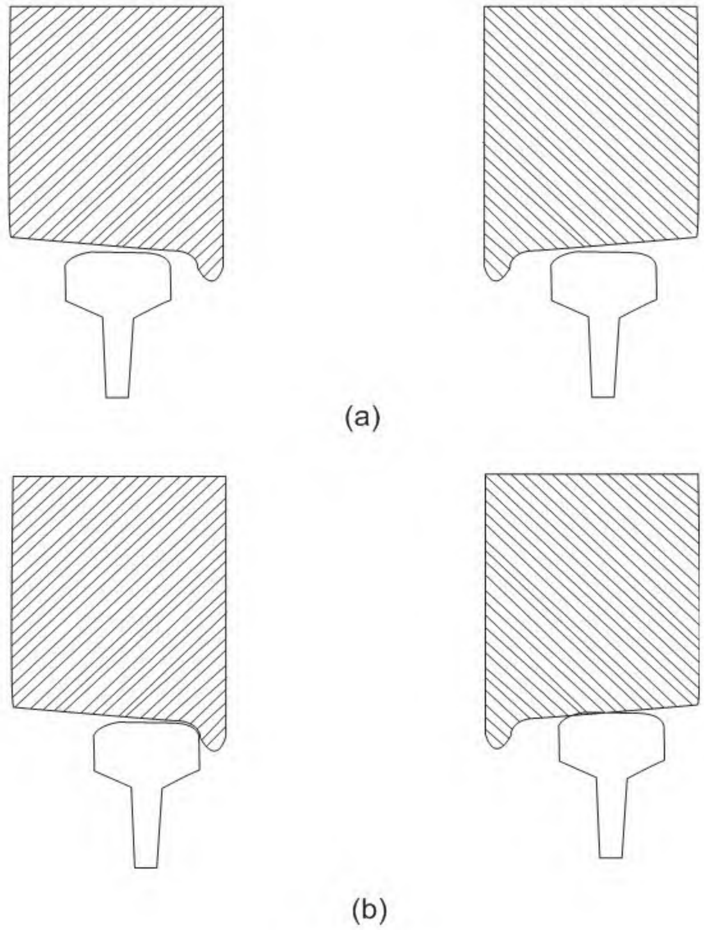


Fig. 6.20

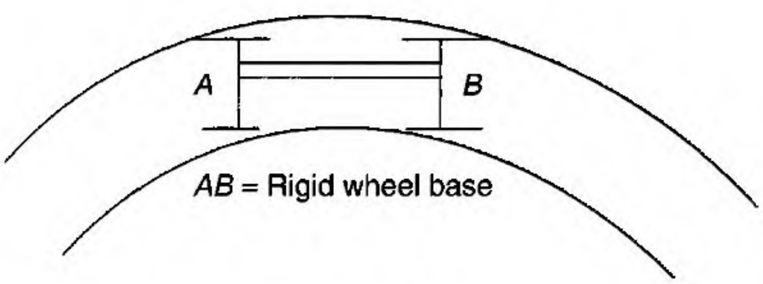


Fig. 6.21

It would be clear that the wear of flanges will ease the passage of the bogie round the curves, because it has the effect of increasing the play between the wheel flange and the rail. Widening of gauge has similar effect. The easier the passage of vehicle on curve, the less will be the wear and tear on both the vehicles and the track. However, any excess of gauge widening thereby increasing the play of the wheel could lead to an increase in the angle of attack of the wheel flange on the rail, leading again to excess wear of both rail and the wheel.

Therefore, to achieve the optimum results a compromise has to be reached upon the gauge widening on curves.

In the Indian Railways, the gauge on curves is laid and maintained to the following standards given in Table 6.4.

Table 6.4 Gauge Curves

Gauge	*Radius in (m)*	*Gauge*
1. BG (1,676 mm)	(a) Straight including curves of 400 m radius and more	3 mm tight i.e. 1,673 mm
	(b) Less than 400 mm	Up to 5 mm slack i.e. up to 1681 mm
2. MG (1,000 mm)	(a) Straight including curves of 300 m radius or more	exact, i.e. 1,000 mm
	(b) 200 to 300 m	Up to 5 mm slack, i.e. up to 1,005 mm
	(c) Less than 200 m	up to 15 mm slack i.e. up to 1015 mm

6.12.3 Check Rail on Curves

Rails laid on curves need more frequent renewals on account of the grinding, slipping and sliding actions to which they are subjected under moving vehicles. Worn-out outer rails show the effect of grinding on the inside rail head. Inside rail is often spread as a result of transverse slipping (Fig. 6.22).

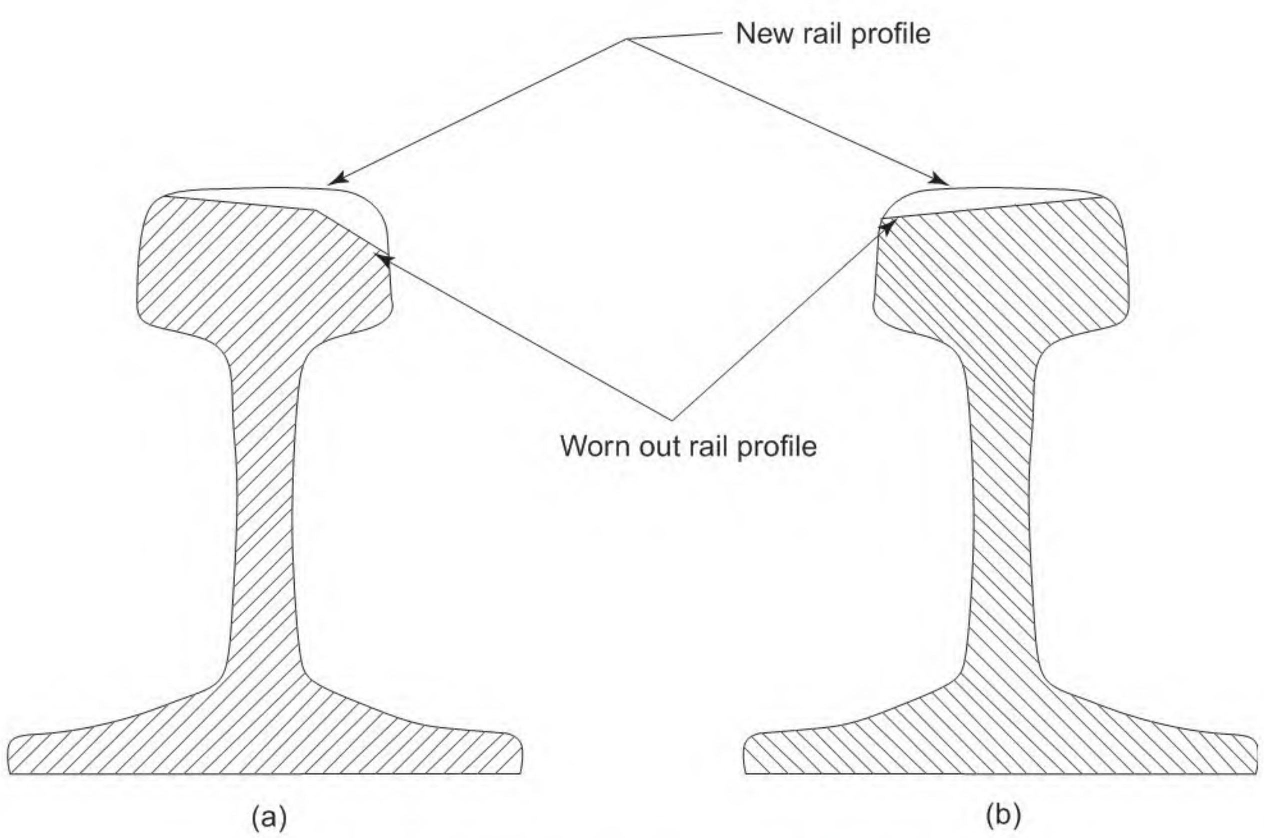


Fig. 6.22 (a) Outer rail (b) Inner rail

The pressure of the flange of the leading wheel against the outer rail leads not only to excessive wear but also to risk of the tyre climbing up over the rail. To minimise this risk, a check rail is fixed inside the inner rail and made parallel to it (Fig. 6.23).

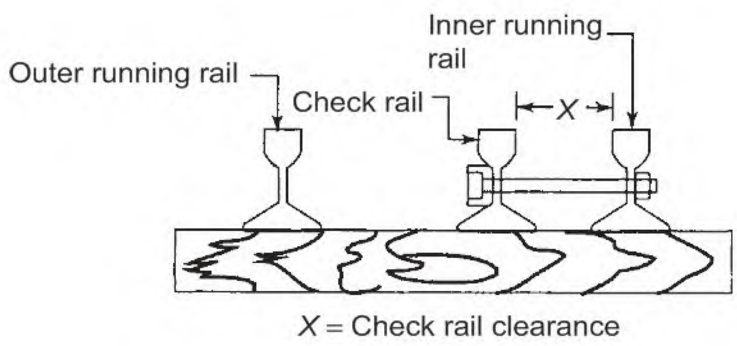


Fig. 6.23 (not to scale)

Check rails can perform the following functions.

1. Reduce the lateral wear on outer rail.
2. Prevent the outer wheel flange from mounting the outer rail.
3. Prevent the vehicle from derailment.

In the Indian Railways, check rails are provided on curves when the radius of curve is 218 m (8°) and less for BG and 125 m (14°) and less for MG. They may be provided on flatter curves to meet some specific needs.

Minimum clearance prescribed for check rail for a curve is 44 mm for BG, and 41 mm for MG to be increased by not less than half the amount of any difference between the nominal gauge and the actual gauge to which the curve is actually laid.

It should be noted that the Schedule of Dimensions prescribes the minimum check rail clearance. Actual clearance on a curve to be provided will depend upon the function that a check rail is supposed to perform. On 8° curve of KK line on S.E. Railway, check rail clearance has been increased to 74 mm where they mainly perform the function of preventing vehicles from derailment.

6.12.4 Gain of Inner Rail over the Outer Rail on a Curve (Fig. 6.24)

Let *OA* be the radius (R) of the outer rail in a curve and G be the gauge. Radius of the inner rail *OB* will be $(R - G)$.

Circumference of outer rail $= 2\pi R$

Circumference of the inner rail $= 2\pi (R - G)$

Difference (i – ii) $= 2\pi R - 2\pi (R - G) = 2\pi G$

This is called the gain of inner rail over the outer rail.

In length $2\pi R$, the gain $= 2\pi G$

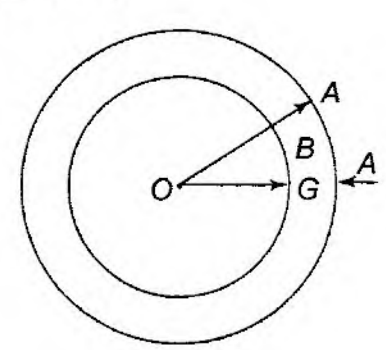


Fig. 6.24

In length L the gain $= \dfrac{2\pi G \times L}{2\pi R}$

$$= L \times \frac{G}{R}$$

Example

On a 2° BG curve, and curve length $L = 100$ m,

$$\text{Gain} = \frac{1.676 \times 100}{875} = 0.192 \text{ m}$$

In the Indian Railways, the normal practice is to lay square joints on curves. On sharp curves of less than 400 m radius on BG, and 300 m radius on MG, midstaggered joints may be laid on curves. In the case of square joints, the inner rail is permitted to gain over the outer rail by a maximum of half the distance between bolt holes, i.e. $p/2$, if p is the pitch or distance between bolt holes. When it exceeds the amount, the inner rail is cut by the full pitch. The inner rail then lags behind till it becomes square by covering a distance of $p/2$. When it leads the outer rail by $p/2$, it is again cut by the distance p. In this method, the joints on curve can be out of square by a maximum of $\pm p/2$.

For curves provided with transitions, the length L is taken as the length of the circular curve plus half the length of the transition curve.

With the extensive use of welded rails, the cutting of rails has becomes uncommon. The gain-length is adjusted by welding pieces of rail different lengths, which are usually available in the lot on account of the tolerance in length permitted in new rails.

6.13 VERTICAL CURVE

When the track laid at different grades meet, sharp summits and sags are formed. To avoid rough riding of vehicles at the junction point, these summits and sags are required to be remedied by suitably designed vertical curves. In the Indian Railways, vertical curves are provided at the junction of grades, when the algebraic difference between grades is equal to or more than 4 mm per metre or 0.4 percent. For example, if 1 in 100 (10 mm/m) rising grade meets 1 in 200 (5 mm/m) rising grade, the vertical curve will be needed, because the algebraic difference 10 – 5 = 5 mm/m is more than the prescribed limit of 4 mm/m.

For laying vertical curves, the tangent length is worked out with the help of deflection angle and the radius. Different points on the curve are then fixed by calculating their reduced level with respect to tangent points.

The minimum radius of the vertical curve is given in Table 6.5.

Table 6.5

BG		MG	
Group	*Minimum radius (m)*	*Group*	*Minimum radius (m)*
A	4000	High speed routes	3000
B	3000	Other routes	2500
C, *D* and *E*	2500		

6.13.1 Change of Grade and Provision of Vertical Curves

1. Vertical curves or any change of grade must not be provided in the transition portion of horizontal curves; because, then it would be very difficult to maintain track geometry.
2. Turnouts must not take off at locations where vertical curves exist because the maintenance of the turnout, especially the tongue rails, would pose a problem. The Schedule of Dimensions, both for BG and MG, therefore, prescribes that the same gradient in a station yard must extend for at least 45 m beyond the stock joint of the extreme turnout on either side and vertical curve, if any, to be provided beyond the point.
3. It is a good practice to avoid a vertical curve of the summit type in the circular portion of a curve when the track is with CWR or LWR. Under compression, the welded rails would then have a tendency of 'lift off' and decrease the stability of track against buckling.
4. A vertical curve of the 'Sag type' should not be located in a cutting or a tunnel as drainage is then affected.
5. Vertical curves must not be provided over unballasted deck bridges.
6. A vertical curve of the 'sag type' must be well maintained as it is a location which has the potential for causing accidents. At such locations, the front portion of a train (working against gravity) has relatively less speed than the rear portion (moving with gravity assisting). The wagons at the lowest point of the sag have, therefore, a tendency to bunch together and get lifted off the track.
7. Vertical curves of the 'summit type' must be avoided at the centre of long tunnels. Exhaust from the locomotives being lighter would tend to collect near the crown of the tunnels affecting ventillation.
8. A series of rising and falling gradients leads to what is usually termed as "rolling profile". In a rolling profile, if sags and summits are too close to each other, they can have an undesirable effect on train operation, specially on heavy haul operation, as the train may be over two or more summits with opposing forces of gravity, slack action of couplings, brake application and tractive force. The economy obtained in construction from closely changing grades may get offset by the operating problems likely to arise later.

7 Chapter

Switches and Crossings

7.1 SWITCHES AND CROSSINGS

To facilitate the transfer of trains from one track to another, switch and crossing assemblies are provided. All switch and crossing work, however complicated, is built up from three basic units joined together with necessary plain rails called closure or lead rails. These units are:

1. Switches
2. Acute angle or vee crossings
3. Obtuse angle crossings.

In Fig. 7.1 (a), track *B* takes off from track *A* and the arrangement is called a turnout. This consists of a switch assembly *S*, and a vee crossing assembly *V* joined with a few closure rails.

In Fig. 7.1 (b), track *B* crosses track *A*. The arrangement provides two vee crossing assemblies and two obtuse crossing assemblies joined with a few closure rails.

7.2 SWITCH ASSEMBLY (FIG. 7.2)

A set of switch consists of four rails, the outer two are known as stock rails and the inner two as switch or tongue rails. A stock rail and a tongue rail match together to form a switch. A pair of tongue rails with their stock rails are commonly known as points. The switch rails are firmly held by stretcher bars and can be set to give a passage for traffic to either one track or the other. The switch rails pivot about a point known as the heel.

The switch rails are machined out of plain rail sections and the details of machining vary with the type of switch. In some modern designs switch rails are formed out of special thick web rail sections. These have been provided in the new design of high speed passenger turnouts and discussed separately in this chapter.

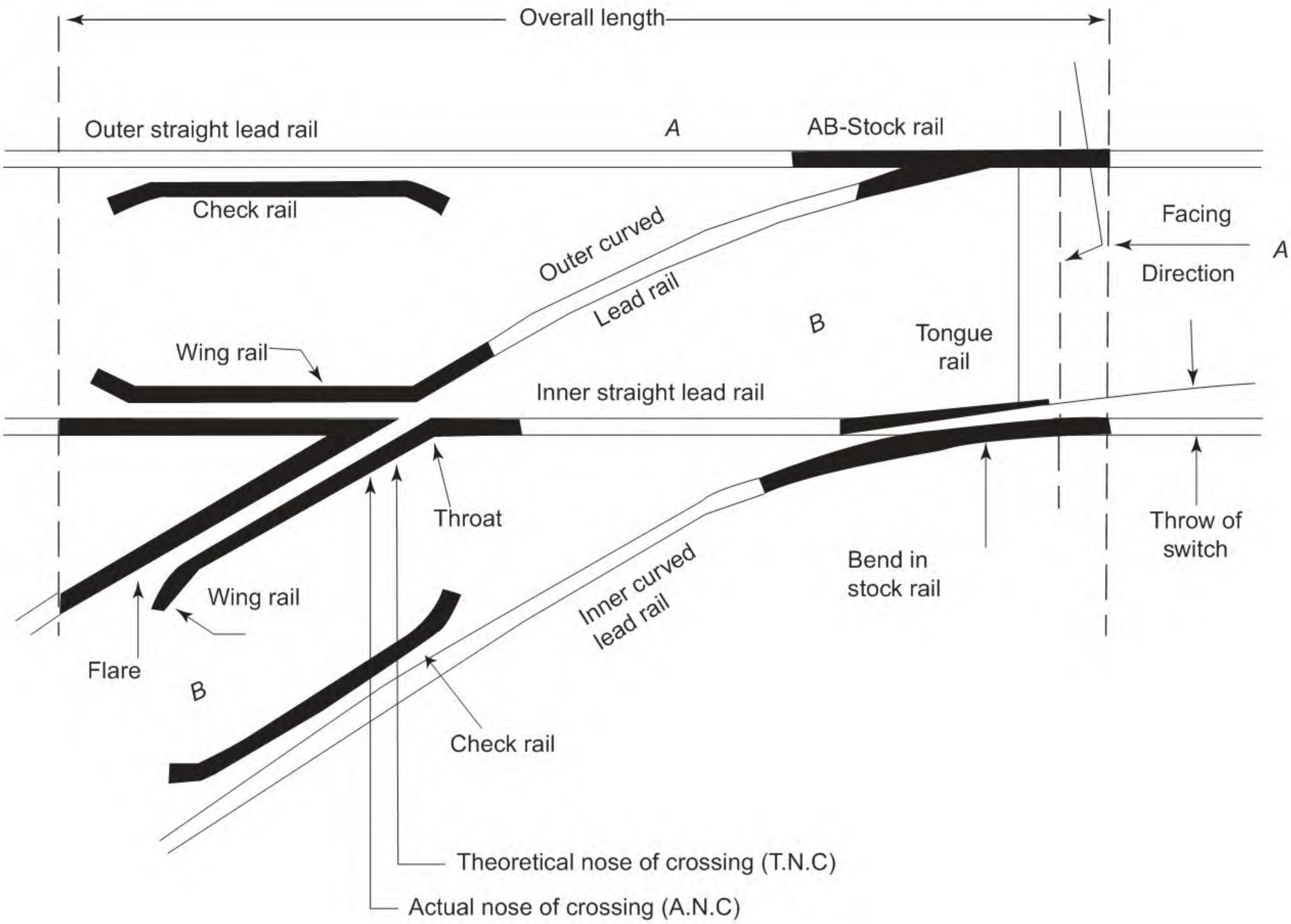


Fig. 7.1 (a) Left hand turnout

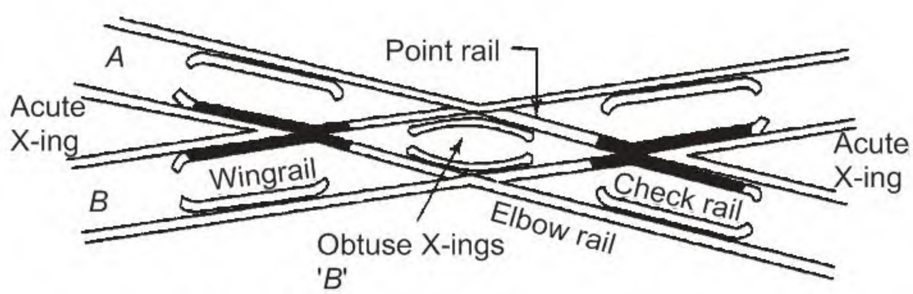


Fig. 7.1 (b) Diamond crossing

For switches, a number of designs exist: broadly, they fall into the following two categories.

7.2.1 Fixed Heel or Spring Switches (Fig. 7.3)

In this design, the tongue or switch rails are rigidly connected to stock rails at the heel by means of distance blocks, bolts and nuts. Movements of the switch blades is effected by springing from the first fixed block.

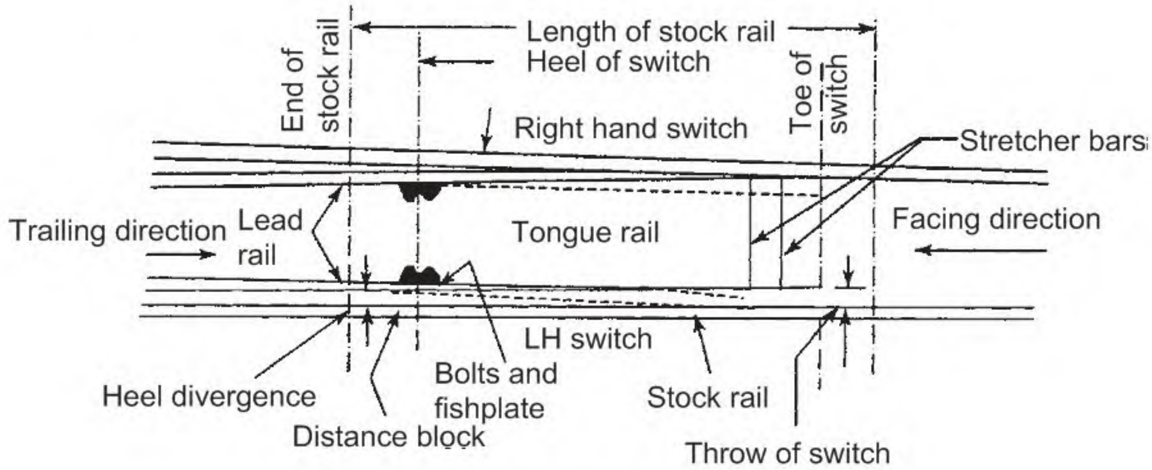


Fig. 7.2 Switch assembly

Fig. 7.3 Fixed heel switch

Fixed heel switches are of two designs:

1. *Straight Switches* In this type, the tongue rail is straight from the tip of the switch to the heel.
2. *Curved Switches* In this type, the switch rail is curved from the tip to the heel to the same radius as that of the turnout.

Both in the case of straight and curved switches, the tongue rail for left and right hand turnouts are interchangeable. In the case of curved switches, the switch rails are left straight by the manufacturers and are bent to the appropriate radii when laying in track.

A few designs of partly curved switches have also been developed by RDSO for the MG system.

7.2.2 Loose Heel Switches (Fig. 7.4)

The switch rails pivot about heel joints held by blocks and fishplates. The fishplate holding the switch rail is given an appropriate bend to permit free movement of switch rail. In view of comparatively sharper change of curvature and consequent knocking caused to the rolling stock, loose heel switches are not favoured in new layouts. Given this nature of loose heel switches, the following important factors are to be borne to determine the length of tongue and stock rails.

1. It is desirable that a tongue rail in loose heel switches should be longer than the greatest distance between adjacent wheels of four wheeled stock, be these wheels of the same or adjacent vehicles. If this is not so, the switch will tend to rise and gape at the toe everytime a wheel load bears on the heel of the switch.

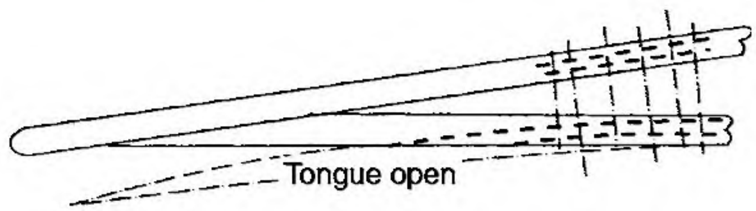


Fig. 7.4 Loose heel switch

2. The switch forms a virtual bend in the track and it is desirable to make the switch angle as small as possible. In straight switches, the longer the switch length, the smaller will be the switch angle.
3. A stock rail should be of sufficient length to remove the joint from the vicinity of the toe and heel of the tongue rail.

Taking into account the foregoing points and other practical considerations such as first cost and length of lead in the turnout, the following lengths of straight switches have been adopted in the Indian Railways.

1. 6400 and 4725 mm for BG.
2. 5485 and 4115 mm for MG and NG, respectively.

7.2.3 Design of Switch

They are generally of the following two types:

1. *The ordinary or undercut switch* In this the foot of the stock rail is planned to accommodate the tongue rail [Fig. 7.5 (a)].

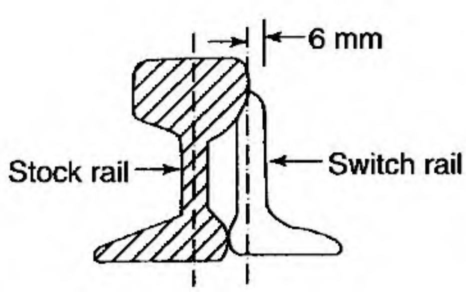


Fig. 7.5 (a) Undercut switch

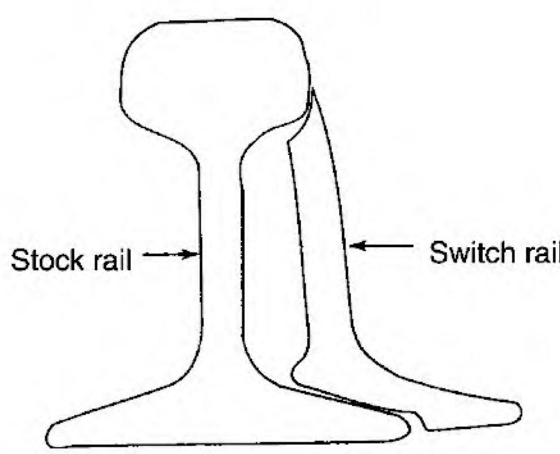


Fig. 7.5 (b) Overriding switch

2. *The overriding switch* In this type the foot of the tongue rail is planned to override the foot of the stock rail, which is maintained to full section. Overriding switches [Fig. 7.5 (b)] have been standardized in the Indian Railways, with the advantages as follows:
   (a) The stock rail being uncut is not a source of weakness.
   (b) As all the planning is confined to the tongue rail, its cost is less than planning of tongue and stock rails.

(c) Although the tongue rail in the overriding switch may appear to be weaker than in the ordinary switch, it is supported by the stock rail for the whole of the weakened portion of its length and the combined strength of the two rails between sleepers is greater than that of the tongue in the undercut switch.

In the overriding switch the head of the tongue rail for part of its length is kept higher than that of the stock rail by 6 mm, which reduces the amount of undercut in the foot of the tongue rail. This difference in height is adjusted by putting special machined bearing plates behind the heel. The main defect of overriding switch is its relatively thin blade tip which is liable to damage due to lateral forces imposed by the moving wheels.

7.2.4 Glossary of Switch Assembly

1. *Bending of stock rails* The two stock rails on a switch assembly converge from gauge face distance of $G + d$ at the heel to $G + t$ at the actual toe and to G at the theoretical toe of the switch. To make them parallel beyond the point of the theoretical toe, a bend is required to be given to the stock rail at the point of the theoretical toe (Fig. 7.6).

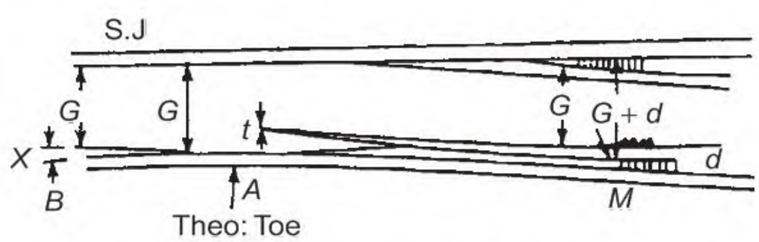


Fig. 7.6 Throw of switch

2. *Fixed heel* When the tongue rail does not form a joint with the lead rail at the heel of a switch, it is called a fixed heel switch.
3. *Gauge tie plates* Gauge tie plates of 12 mm thickness for BG and 10 mm thickness for MG made out of steel flats are provided over the sleepers directly under the toe of the switches, and under the nose of crossing to ensure exact gauge at these important locations.
4. *Heel divergence* Heel divergence is the shortest distance from gauge line of stock rail to gauge line of tongue rail.
5. *Heel of switch* It is an imaginary point on the gauge line midway between the end of lead rail and the tongue rail in case of loose heel switches. It is a point on the gauge line of the tongue rail opposite to centre of heel block in case of fixed heel switches. Heel block is the first block from the toe side fixing the tongue rail to the stock rail.
6. *Lead rails* Plain rails laid in a turnout between the switches and crossings assemblies are called lead rails.
7. *Left or right hand stock rails* Tongue rails, stock rails and other fittings are called left hand or right hand according to their position looking in the facing direction of points.
8. *Loose heel* When the lead rails from a joint with the tongue rail at the heel of a switch, it is called a loose heel switch.

9. *Mach switch protector* Head width of tongue rail near its toe is very small and is not strong enough to withstand high lateral forces. Mach switch protector, which is a high manganese cast steel piece, when fitted to a stock rail about 50 mm ahead of the toe, deflects the wheel away from the toe of the switch. Similar objective can be achieved by providing a special check rail ahead of the toe of the switch.
10. *Points* A pair of tongue rails and stock rails with necessary connection forms points.
11. *Slide chair* These are provided under the tongue rails to provide smooth lateral movement of tongue rails.
12. *Spherical washers* Spherical washers have been designed to take up uneven bearing of the head or nut of a bolt, where two inclined surfaces are required to be bolted together. In switch assembly they are used on all bolts in heel and distance blocks behind the heel on left hand side. They are also used in the crossing assembly.
13. *Stepped plates* The difference in height of switch and stock rails at heel of the switch is run off toward the lead by the use of stepped plates.
14. *Stock rail* Stock rail is a running rail to which a tongue rail is attached.
15. *Stretcher bars* Made of spring steel flats, they are rigidly fixed to the tongue rails by brackets and help to maintain the tongue rails at correct distance apart.
16. *Switch* A pair of tongue rails and stock rails matching together forms switch.
17. *Switch anchors* They are provided to maintain relative position of switch and stock rails longitudinally for efficient interlocking. These are steel flat pieces bent to the shape of extended Z and bolted to stock and tongue rails immediately behind the heel of the switch.
18. *Switch angle* Switch angle is the angle between the gauge lines of the tongue rail at its toe and the stock rail, when the switch is in the closed position. In the case of curved switch, gauge line at the toe of the switch is the tangent to the tongue rail at its toe.
19. *Switch length* It is the free length of tongue rail from the toe to the heel of a switch.
20. *Theoretical toe of switch* It is the point of intersection of gauge lines of tongue rails at its toe when extended, and the stock rail.
21. *Throw of switch* It is the distance through which a tongue rail moves at its toe from its closed to open position. The throw of any switch is fixed from the consideration of maximum flangeway clearance obtained between the tongue and the stock rail at the point where tongue rail attains the full head width and is closest to the stock rail in the open position, i.e. point P in Fig. 7.7. Throw has been fixed at 115 mm for BG and 100 mm for MG, to get a minimum flangeway clearance of 44 m and 41 mm, respectively at point P.

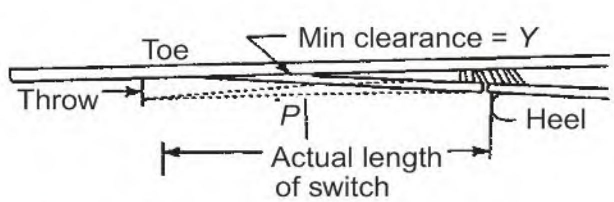


Fig. 7.7 Bending of stock rail

22. *Toe of switch* The thin tapering end of the tongue rail is called the toe.
23. *Tongue rail* Tongue rail is a tapered movable rail, which is attached at or near its thicker end to a running rail.

7.3 CROSSING ASSEMBLY

The purpose of the crossing is to permit wheel flanges of the rolling stock moving along one track to pass over one or both rails of the other track with maximum safety and minimum disturbance. Crossings are generally of two types:

1. *Common, acute angled or vee crossings,* in which the intersection of two gauge lines form an acute angle, [Fig 7.8 (a)].
2. *Obtuse crossings*, in which the intersection of two gauge lines form an obtuse angle [Fig. 7.8 (b)].

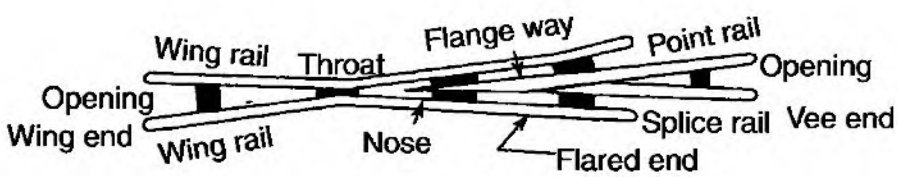


Fig. 7.8 (a) Acute crossing

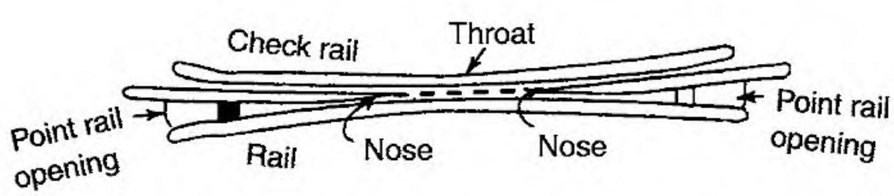


Fig. 7.8 (b) Obtuse crossing

7.3.1 Number of Crossing (Fig. 7.9)

The number of a crossing is defined as the ratio of the spread at the leg of the crossing to the length of crossing measured from its theoretical nose. In the Indian Railways, this number is taken as the cotangent of the angle formed by the crossing.

The smooth passage of the rolling stock from one track to another depends inter alia on the angle of the crossing, which is kept as small as possible for high speed traffic on the running lines. In the Indian Railways, four angles of crossing namely 1 in 8½, 1 in 12, 1 in 16 and 1 in 20 are generally used.

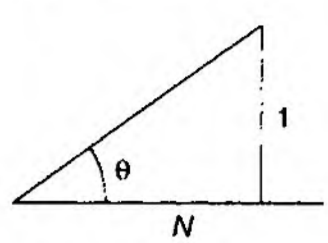


Fig. 7.9 cot $\theta = N$ = Number of crossing

7.3.2 Classification of Crossing according to Manufacturing Process

Built-up Crossing (*Fig. 7.10*) A crossing consists of point and splice rails, wing rails, and check rails suitably held together. The assembly is made out of rails normally used for track. The point and splice rails form the vee of the crossing and to avoid the junction of these components at the nose, which would obviously be a weakness, the splice rail is housed in a notch in the point rail. The point and splice rails are held together by turned bolts. Where the point and splice rails diverge, they are held in their relative position with the distance blocks and bolts. Wing rails which are provided on either side of the vee are rigidly held to the vee at the requisite distance, with distance blocks and bolts, which is 44 mm for BG and 41 mm for MG. Early damage to the nose of the crossing is prevented by planning up to 6 mm from the top of the rail at the nose and running out the cut in about 90 mm along the vee. The lowering of nose affects the wing rail to support the wheels as they pass over the narrow section at the nose. Wings have flared ends. Check rails, which are made from ordinary rail pieces, are secured to the running rail with distance blocks and bolts.

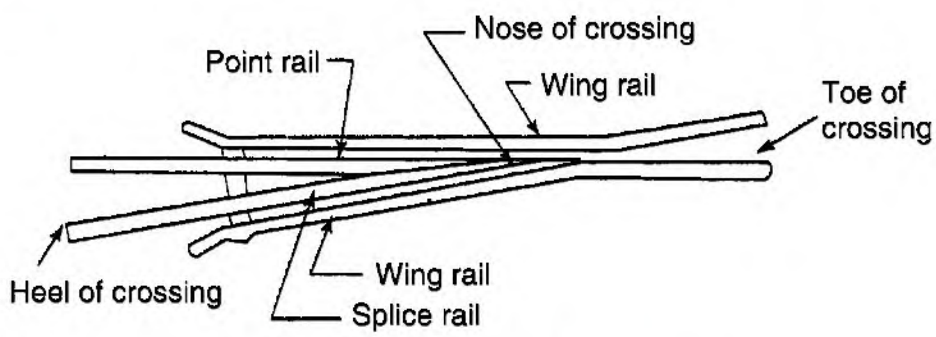


Fig. 7.10 Built-up crossing

Welded crossings are presently in use on some of the railway systems. These crossings are made by welding suitably machined rail pieces and in some cases enclosing a piece of high strength wear-resistant steel bar between the running rails. These crossings with less number of loose parts and made out of tougher steel are supposed to give much longer service life in tracks.

Cast Management Steel Solid (*CMS*) *Crossing* Built-up or fabricated crossing has a large number of separate units to which attention must be paid during service. The vee formed by the point and splice rails is weakened by heavy machining of the head and foot. To provide better resistance to wear and reduce the cost of maintenance and frequent renewals, cast manganese steel solid crossings have been developed. Other advantages of cast manganese steel solid crossings vis-à-vis common fabricated crossings are as follows:

1. Fabricated crossings demand higher maintenance labour to keep the bolts and fastenings tight.
2. When they work loose, high rail stresses develop.
3. They lack vertical stiffness.
4. The change of section points in the assembly of rails are stress raising features, which are not compatible with the best engineering practice.

5. CMS crossings are particularly useful in continuous welding of rails through points and crossings as they do not need any special strengthening necessary for fabricated crossings.

Technologies have been developed for butt-welding of CMS crossings with the plain line rails by interposing a compatible transition piece of alloy steel. Presently, it is being transferred to Indian Railways for use on high speed heavy density routes. CMS crossings are though, costlier they more than compensate the cost with their longer life.

7.3.3 Some New Developments in the Field of CMS Crossings

Explosive Hardening of CMS Crossings CMS, with high percentage of manganese, is initially soft, having a hardness value of 180 BHN as compared to the wheel hardness of 250–340 BHN. The crossing hardness increases with the work hardening under traffic, reaching a value of 300 BHN after the passage of 20 GMT of traffic and 400 BHN after 40 GMT. During the process of work hardening of the crossing nose gets depressed by 2 to 3 mm and this affects the service life of the crossing. A technique called explosive hardening has been developed in Russia in which the CMS crossings are explosive hardened in the manufacturing process itself. This is achieved by using adhesive strips of explosives which are attached to the wear prone areas and exploded in a closed chamber. The shock wave causes the area to harden to 300 BHN. When such crossings are laid in the track, they do not experience rapid initial wear, and thus have longer service life in track. Incidentally, the explosion also identifies invisible manufacturing flaws in the crossings, as they manifest themselves in the form of cracks. Such a crossing can be rejected in the shop floor itself, rather than leading to unsafe operation while in service.

Indian Railways are planning to bring this technology to India to manufacture CMS crossing in the country.

Modification in Track Bonding Arrangement As difficulties are being experienced in the field for welding mild steel bonding brackets to CMS crossings, following two methods are proposed for trial.

1. Welding of MS brackets at the manufacturing depots.
2. Providing MS inserts/projection cast integrally to the crossings,

After extensive field trials, one of the methods will be standardised.

CMS Crossings of Longer Lengths CMS crossings in use on Indian Railways are shorter in length vis-à-vis the standard built-up crossings. This creates problem during renewals. Hence, new designs for CMS crossing are being developed to match the standard built-up crossings.

7.3.4 Check Rails (Fig. 7.11)

Check rails are positioned opposite all common crossings to restrain the wheel flange from passing between the check rail and its running rail in such a way that the flange of the opposite wheel passing through the crossing is steered clear of the nose. The clearances at check rail are so fixed that the nose of the crossing is protected under all service conditions. For this purpose, maximum and minimum check rail clearances for BG have been fixed at 48 and 44 mm, respectively. For MG the figures are 44 and 41 mm, respectively. To ensure safety, it is very important that track gauge at the crossing, particularly opposite the nose, is maintained exact. The provision of gauge tie plate on the sleeper at the nose helps achieve this objective.

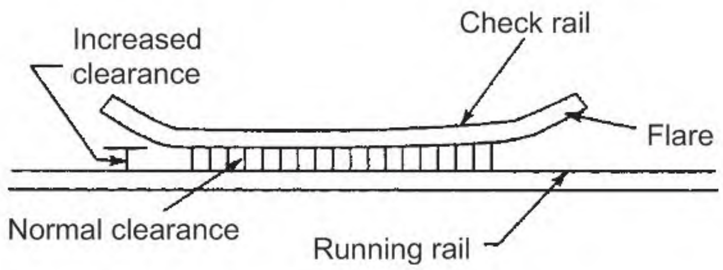


Fig. 7.11 Check Rail

Check rails are designed to give the minimum clearance when used with 'flare' at the ends, but should any appreciable wear take place, the check rails can be moved toward the running rail by removing one or both of the 3 mm packing provided with the distance blocks between the check rail and the running rail.

The intersection of diamond crossings are almost opposite to each other. Therefore, the check rails provided in diamond crossings are not as effective as in common crossings. To increase their effectiveness, check rails on all 1 in 8½ diamond crossings both on BG and MG are raised by 25 mm by welding a MS flat over their top table. For diamond crossings flatter than 1 in 8½, switch diamonds are required to be used.

7.3.5 Special Crossings for Snag Dead Ends or Sand Humps

It is a common practice to use 1 in 8½ symmetrical split layouts for laying snag dead ends—also known as sand humps—to provide isolation and adequate distance for train reception as prescribed in the General Rules of Indian Railways. On these turnouts the traffic is over the loop line only and very rarely over the snag dead end side. This occurs only when a train runs out of control after entering the loop. The crossing laid at this point gets worn out on the loop side only and is replaced when called for. To meet with this situation, a special crossing design has been evolved. In this design a normal running rail is provided, without any gap, for the passage of wheels for the loop line traffic. The other lead rail is raised by 13 mm when approaching the crossing position. The wheels going to the snag dead end pass over the loop running rail in raised position and land over a raised wing rail and crossing nose provided on the other side of the running rail. The life of this crossing is reported to be many times longer than the normal crossing provided at these locations.

7.3.6 Spring Crossing (Fig. 7.12)

In all normal crossings the wheels have to negotiate a gap in the continuity of running rail while going on the straight or in turnout direction. With the use of spring crossing the gap in the straight direction can be avoided. In such a crossing one wing rail is movable and is held against the vee of the crossing with a strong spring. When vehicles pass over the main track, there is no gap to be negotiated at the crossing nose. In the case of vehicles moving on the turnout track, the sliding wing is forced out by the wheel flanges and the movement beyond the wing is no different than on normal crossing.

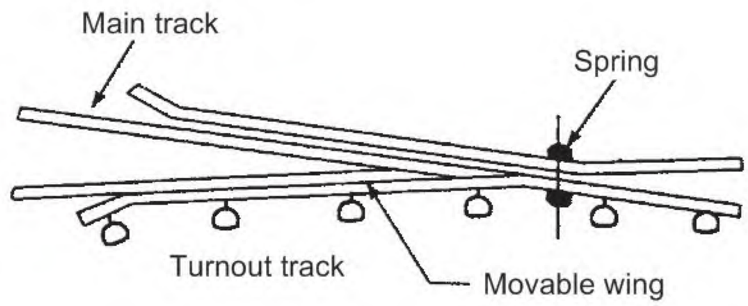


Fig. 7.12 Spring crossing

Spring crossings are of great advantage at locations where bulk of the traffic passes over straight road and only a little slow traffic on the turnout side. Such locations are emergency crossovers on double line at wayside stations and slip siding points.

7.3.7 Glossary of Crossing Assembly

1. *Actual nose of crossing* (*ANC*) This is a point at which the spread of the gauge lines is sufficient to allow for an adequate thickness of the point, for consideration of manufacture and strength. For built-up crossings, the thickness of the nose is generally kept equal to the web thickness of the rail section used.
2. *Flat bearing plates and canting of rails* In the Indian Railways, all rails on points and crossings are kept vertical. Flat bearing plates are therefore used under rails on turnouts.
3. *Theoretical nose of crossings* (*TNC*) It is the point of intersection of the gauge lines of a crossing and is used as a reference point for all calculations for turnouts or other track connections.
4. *Throat of obtuse crossing* It is the point at which the converging elbow rail and the check rail of the obtuse crossing are closest.
5. *Throat of vee crossing* It is the point at which the converging wing rails of the crossing are nearest to each other.

7.4 TURNOUTS (Fig. 7.13)

A turnout is a track structure composed of a switch, a crossing and closure rails permitting a train to leave a given track for branching off to another track.

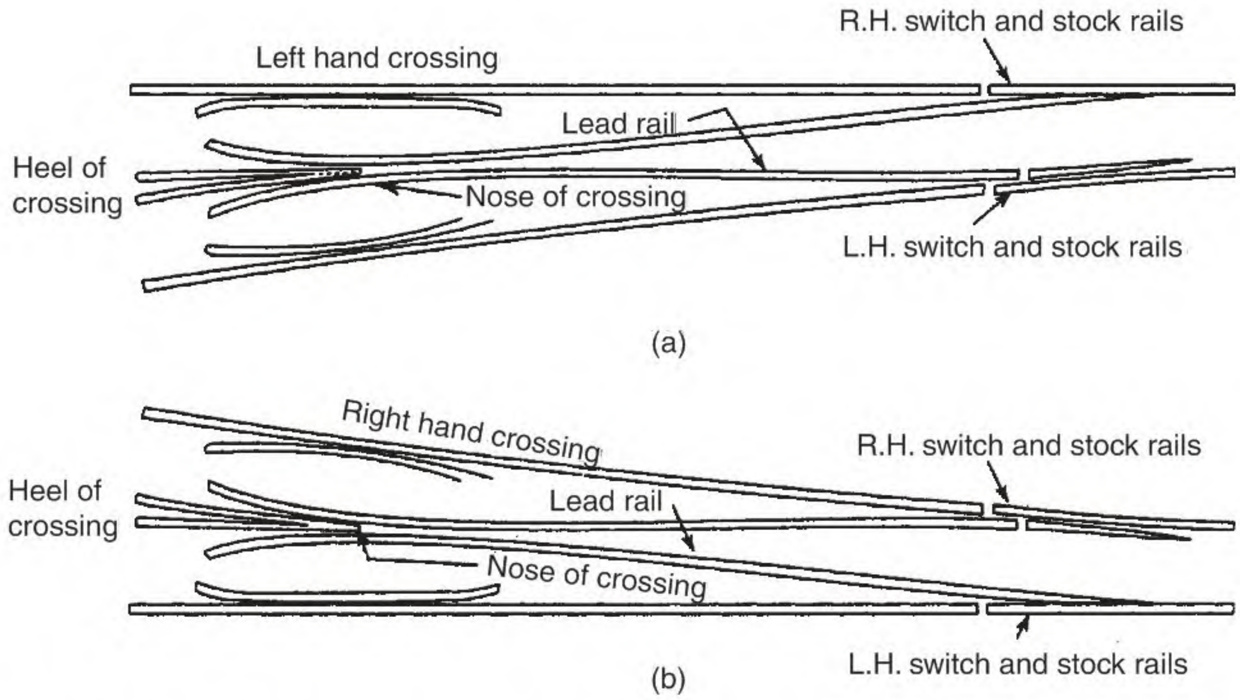


Fig. 7.13 Turnouts-crossings and switches: (a) left hand; (b) right hand

7.4.1 Glossary of Turnouts

1. *Cant runoff* All rails on points and crossings are kept vertical. At either end, it is desirable that changeover from vertical to 1 in 20 cant should be runoff on 3 to 4 sleepers. This is achieved by providing a gradual reverse cant on wooden sleepers when using standard 1 : 20 canted bearing plates. Special concrete sleepers are cast for this purpose.
2. *Lead of turnout* It is the distance from the theoretical nose of the crossing to the heel of the switch measured along the straight.
3. *Left hand turnout* It diverts a train to the left of the straight main line or of the more important line in the case of a turnout from a curve. A right hand turnout does the same in the right direction. In both LH and RH turnouts, the built-up crossing used is left handed, i.e. it has the splice rail on the left.
4. *Overall length* It is the distance from the end of stock rail to the heel of the crossing measured along the straight.
5. *Turnout timbers and fastenings* Turnout timbers are thicker, i.e. 15.0 cm thick for BG and 13.0 cm for MG and NG. Fastenings used on these timbers are stronger as compared to normal sleeper fastenings.

7.4.2 Layout of Indian Railway Standard (IRS) Turnout with Straight Switch

In the calculation for lead and radius, the curve in IRS layouts is placed tangential to the tongue rail at its heel and to the front straight leg of the crossings. In Fig. 7.14,

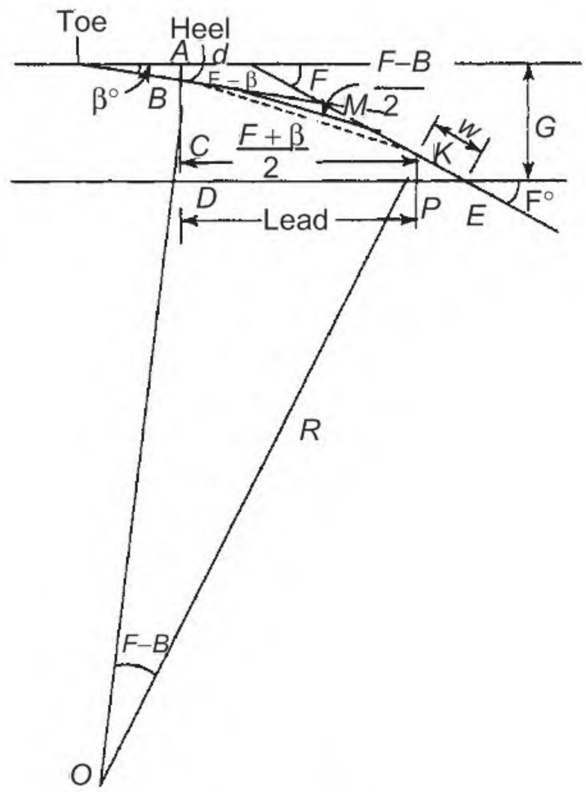


Fig. 7.14

ω = straight leg of the crossing ahead of TNC

β = switch angle

In ΔBMK; $BM = MK$ (each being tangent),

$$\angle MBK = \angle MKB = \frac{F-\beta}{2}$$

In ΔBKC; $\angle BKC$

$$F - \frac{F-\beta}{2} = \frac{F+\beta}{2}$$

$$\begin{aligned} BC &= AD - AB - CD \\ &= AD - AB - KP \\ &= G - d - \omega \sin F \end{aligned}$$

and $KC = BC \cot \frac{F+\beta}{2}$

$$= (G - d - \omega \sin F) \cot \frac{F+\beta}{2}$$

$$\text{Lead} = DE = DP + PE = CK + PE$$

$$= (G - d - \omega \sin F) \cot \frac{F+\beta}{2} + \omega \cos F$$

In ΔOBK, $\angle BOK = F - \beta$
and $OB = OK = R$

$$BK = 2\,R \sin \frac{F-\beta}{2}$$

also in ΔBKC;

$$BK = \frac{BC}{\sin \frac{F+\beta}{2}}$$

$$= \frac{G - d - \omega \sin F}{\sin \frac{F+\beta}{2}}$$

Equating; $2R \sin \frac{F-\beta}{2}$

$$= \frac{G - d - \omega \sin F}{\sin \frac{F+\beta}{2}}$$

$$R = \frac{G - d - \omega \sin F}{2\sin\frac{F+\beta}{2}\sin\frac{F-\beta}{2}}$$

Lead and radius for BG, 90*R*, 1 in 8½ turnout with straight switches, as per above determined formula are as follows:

$F = 6° - 42' - 35''$, $\beta = 1°34'27''$

$G = 1676$ mm, $d = 136$ mm, $\omega = 864$ mm

$$\text{Lead} = (G - d - \omega \sin F) \cot \frac{F+\beta}{2} + \omega \cos F$$

or lead $= (1676 - 136 - 864 \times 0.1168) + 864 \times 0.993$

$= 20730.13$ or say 20730 mm

$$\text{Radius} = \frac{G - d - \omega \sin F}{2\sin\frac{F+\beta}{2}\sin\frac{F-\beta}{2}}$$

or $$= \frac{1676 - 136 - 864 \times 0.1168}{2 \times 0.07223 \times 0.0448} = 222360$$

7.4.3 Offsets to Lead Curves of IRS Turnouts with Straight Switches

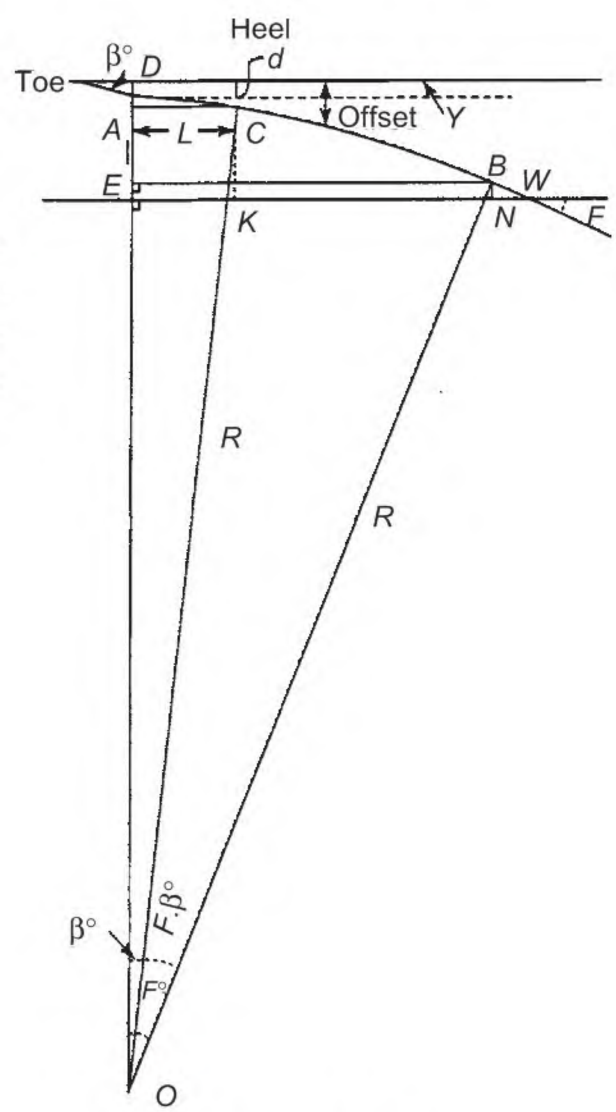


Fig. 7.15

The lead curve is extended from heel at *C* to a point *A* so that the tangent to the curve runs parallel to the gauge line on the main line at a distance *Y* as shown in Fig. 7.15. Point *A* may be outside the track and in that case *Y* will be negative. The distance *AC* is denoted by *L*.

In ΔOBE; $OB = R$, $\angle BOE = F°$

$\angle OEB = 90°$, $BE = R \sin F$

$L = AC = BE - BK$

$= R \sin F - (G - d - \omega \sin F) \cot \frac{F+\beta}{2}$

$OD = OA + AD = R + Y$

$OD = OE + ED$

$= R \cos F + G - \omega \sin F$

By equating we have

$Y = R \cos F + G - \omega \sin F - R$

$= G - \omega \sin F - R(1 - \cos F)$

For 1 in 8½ IRS layout

$$L = R \sin F - (G - d - \omega \sin F) \cot \frac{F+\beta}{2}$$

$$= 222360 \times \sin 6° - 42' - 35'' - (1676 - 136 - 864 \sin 6° - 42' - 35'')$$

$$\times \cot \frac{(6° - 42' - 35'') + (1° - 34' - 27'')}{2}$$

$$= 6108.6 \text{ mm}$$

$$Y = G - \omega \sin F - R\,(1 - \cos F)$$

$$= 1676 - 864 - \sin (6° - 42' - 35'') - 222360\,(1° - \cos 6° - 42' - 35'')$$

$$= 52.0716 \text{ mm}$$

Offset at everyone metre = 1000 mm from heel; can be found out as

$$O_{\text{IM}} = \frac{(L+1000)^2}{2R} + Y$$

To get the values in mm all figures should be in mm. The Indian Railways Track Manual gives figures of offset for various layouts. These have been reproduced in Table 7.1.

7.4.4 IRS Layout for Turnout with Curved Switches (Fig. 7.16)

The lead curve in these layouts starts at the toe of switch tangential to switch angle and meets the straight leg of crossing at a distance ω from TNC of the crossing.

$$AB = (G - t - \omega \sin F)\ \frac{F+\beta}{2}$$

and

$$R = \frac{G - d - \omega \sin F}{2 \sin \frac{F+\beta}{2} \sin \frac{F-\beta}{2}}$$

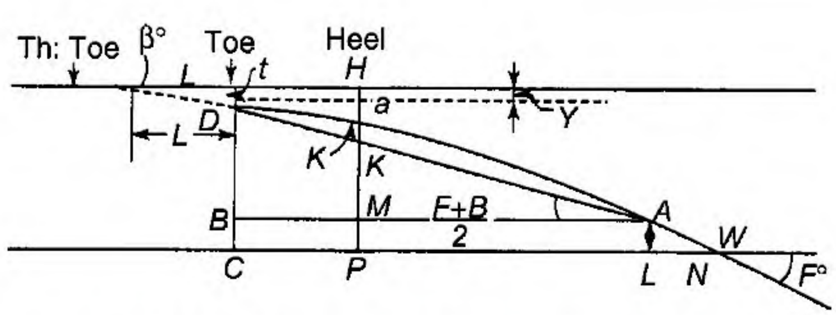


Fig. 7.16 IRS layout with curved switch

The deviation being the same as for straight switch turnouts substituting t (toe thickness) for d (heel divergence).

For fixing the position of heel H it is necessary to find the point where offset to the curve from the gauge face of the main line is equal to heel divergence d. For this, the same principles are ap-

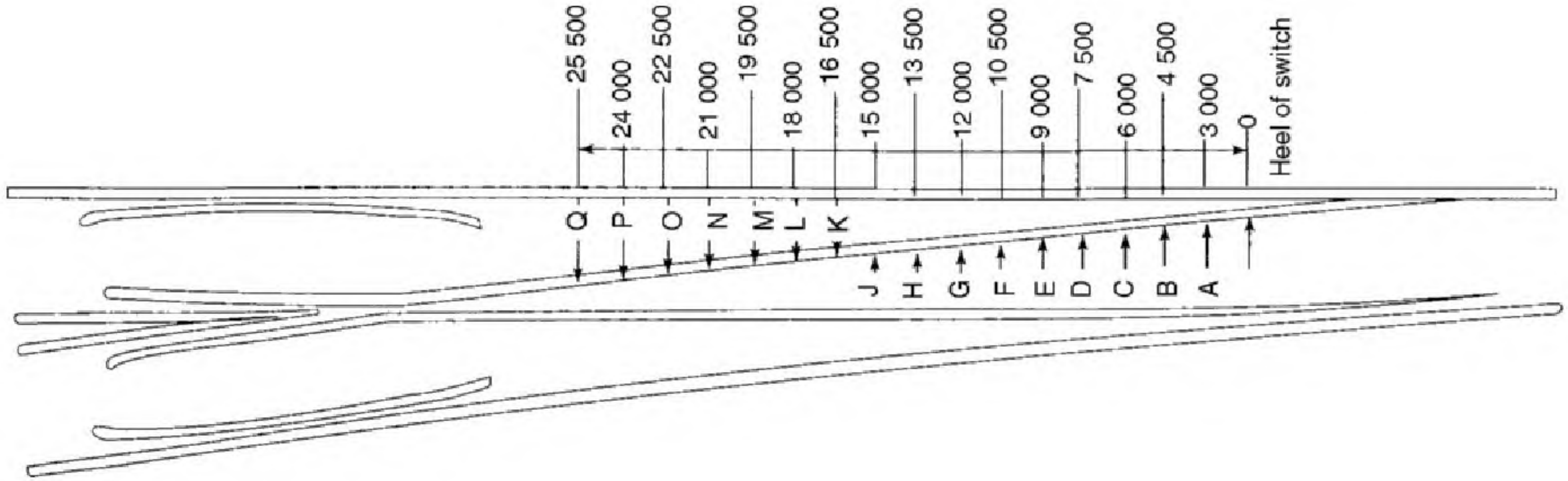


Table 7.1 Offsets with Straight Switches

Gauge	*Crossing number*	*Switch length*	*Turnout radius*	*Offsets from gauge face of straight trace to gauge face of curved track (mm)*															
				A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*	*N*	*O*	*P*	*Q*
BG	1 in 8½	4,725	2,22,360	–	–	382	469	565	672	790	917	1,055	1,202	–	–	–	–	–	–
BG	1 in 12	6,400	4,42,120	–	–	293	345	403	466	532	606	685	767	856	950	1,847	1,151	1,260	–
MG	1 in 8½	4,115	1,19,610	241	330	437	564	709	–	–	–	–	–	–	–	–	–	–	–
MG	1 in 12	5,485	2,40,600	–	–	313	386	468	559	659	769	–	–	–	–	–	–	–	–
NG	1 in 12	5,485	1,67,340	–	–	346	437	541	–	–	–	–	–	–	–	–	–	–	–

plied as those for finding offsets to lead curve for straight switch turnouts. In this formula d will also be substituted by t on the same analogy. Thus,

$$L = R \sin F - (G - t - \omega \sin F) \cot \frac{F + \beta}{2}$$

and $$Y = G - \omega \sin F - R(1 - \cos F)$$

Switch length $$= \left[\sqrt{2R(d-y)-(d-y)^2}\right] - L$$

Lead $$= (G - t - \omega \sin F) \cot \frac{F+\beta}{2} - \text{Switch length} + \omega \cos F$$

Offsets are calculated on the same principles as for straight switches except that in this case chord length is L + switch length + distance from heel. For 1 in 16, BG, 90R, IRS turnout, the results are as follows:

$$R = \frac{G - t - \omega \sin F}{2 \sin \frac{F+\beta}{2} \sin \frac{F-\beta}{2}}$$

$$= \frac{1676 - 6 - 1377 \sin 3°34'\,35''}{2 \sin 1°59'\,31'' \times \sin 1°35'4''}$$

$$= 824114.41 \text{ mm (exact value 824225 mm)}$$

$$L = R \sin \beta$$

$$= 824225 \times \sin 0° - 24' - 27''$$

$$= 5860.81 \text{ mm}$$

$$Y = G - [\omega \sin F + R(1 - \cos F)]$$

$$= 1676 - (85.8959 + 1605.1)$$

$$= 14.9958, \text{ say} - 15 \text{ mm}$$

Offset at heel = 15 + 133 (15 mm being on off side)

$$OH = 148 \text{ mm}$$

$$\text{Chord} = \sqrt{2RO - O^2}$$

$$= \sqrt{2 \times 824225 \times 148 - (148)^2}$$

$$= 15618.58 \text{ mm}$$

Hence length of switch,

$$SL = 1561.58 - 5860.81$$

$$= 9757.77 \text{ mm (exact figure is 9750)}$$

Lead $$= (G - t - \omega \sin F) \cot \frac{F+\beta}{2} - SL + \omega \cos F$$

$$= (1676 - 6 - 85.89) \cot 1° - 59' - 31''$$

$$- 9750 + 1377 \cos 3° - 34' - 25''$$

$$= 37{,}170.89 \text{ (exact figure } D \text{ is 37,170 mm).}$$

Figure 7.17 (a) and Table 7.2 fives offset for turnouts with curved switches both for BG and MG.

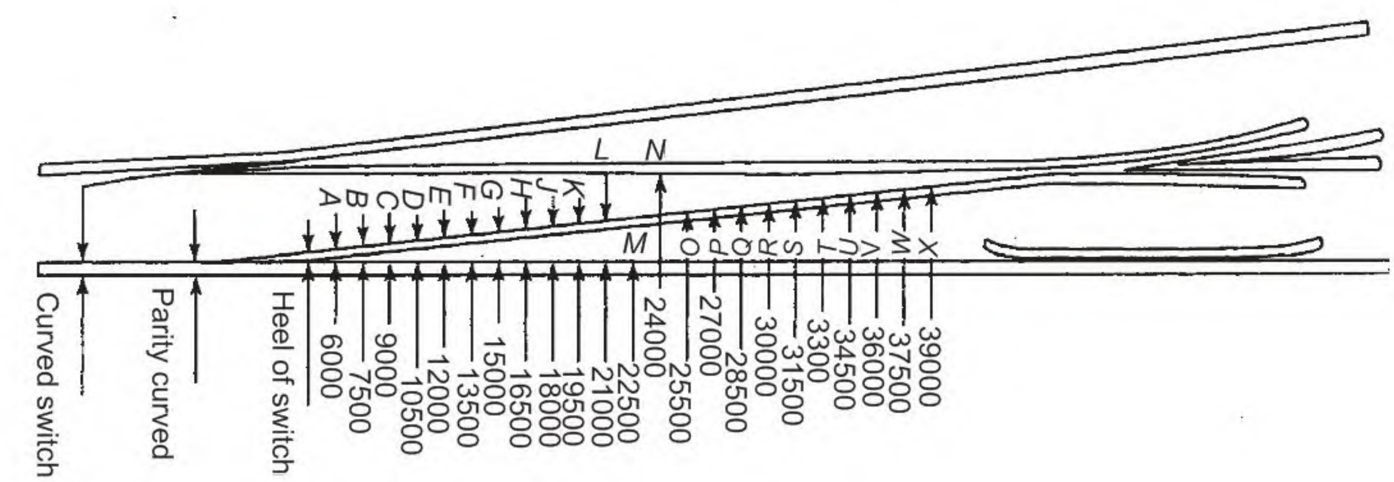
7.4.5 Setting Out of Turnout with Centre Line Method [Figs. 7.17 (b) and 7.18]

In Fig. 7.18, centre lines of the straight track and the turnout track have been marked intersecting at point P. From simple geometry it is seen that $\angle SPZ$ is equal to $\angle F$.

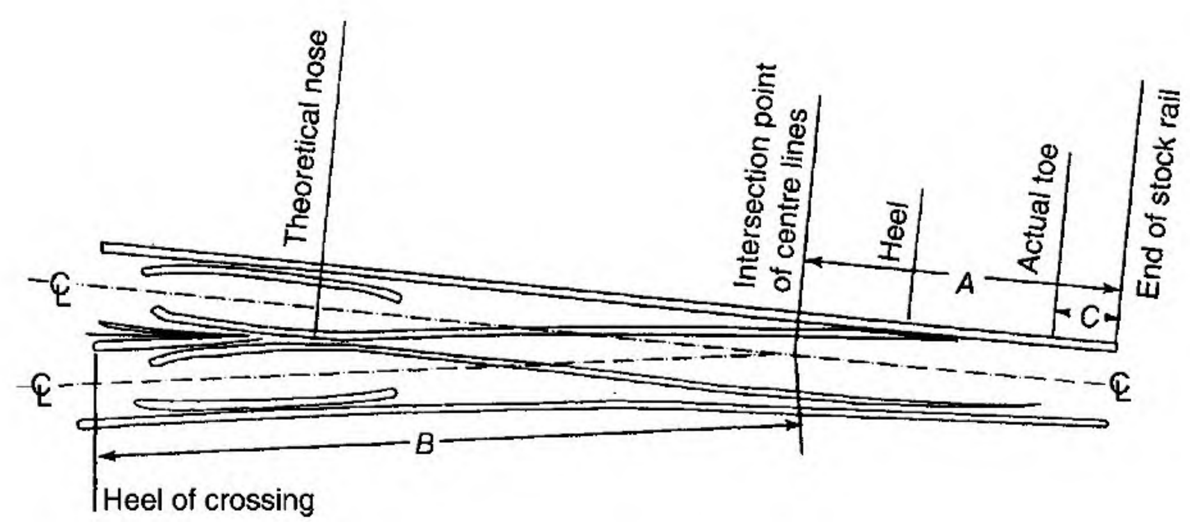
$$\text{Length } M = PS = \frac{G}{2}\cot\frac{F}{2}$$

(G is the gauge)

$$\begin{aligned} K &= SW = \text{back leg of the crossing} \\ PW &= M + K = B, \text{ denoted by the letter } B \\ OW &= \text{turnout length} = A + B \\ A &= OP = \text{Turnout length} - (M + K) = \text{turnout length} - B \end{aligned}$$



(a)



(b)

Fig. 7.17 Main dimensions for setting out turnouts (BG, MG and NG)

Once A and B are known, turnout can easily marked. The Indian Railway standard Track manual gives these details in a tabular form for various turnouts reproduced in Table 7.3.

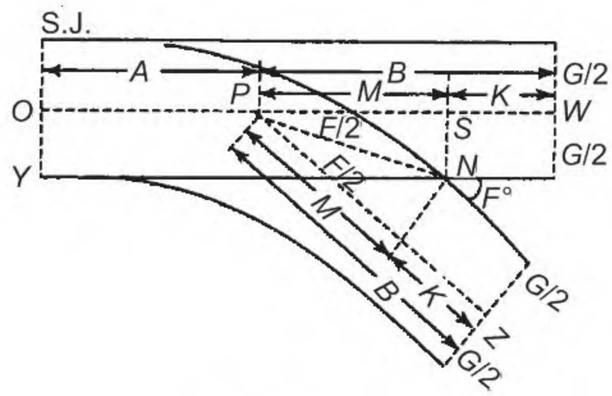


Fig. 7.18

7.4.6 Symmetrical Split Turnouts (Fig. 7.19)

In this layout the straight track is diverted in two opposite directions using the same radius for both the tracks of the turnouts. Since the direction is divided equally on both sides, the crossing centre line coincides with the centre line of the straight track. This is contrary flexure layout in which the degree of the turnout curve becomes half and the radius doubles up. Lead of the turnout remains the same. Further details can be worked out by applying the principles of ordinary turnout.

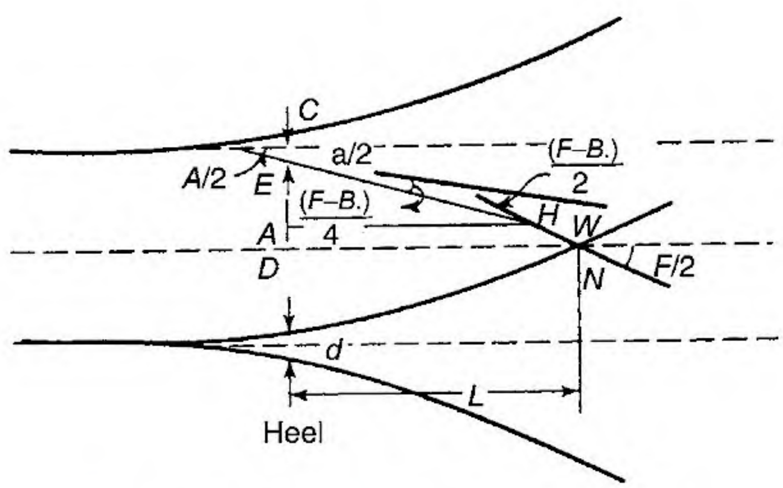


Fig. 7.19 Symmetrical split turnouts

This type of layout is used at wayside stations at the end loop lines to provide sand humps—also known as snag dead end. By using 1 in end 8 ½ layout, one gets the radius of 1 in 12 turnout, which is the minimum prescribed for the movement of passenger trains. The sand hump also diverts away the runway vehicles thereby improving the safety on the main line.

7.4.7 Crossover

The crossover between Two Straight Parallel Tracks with same angle of Crossing is shown in Fig. 7.20.

Table 7.2 Offsets of Turnouts BG and MG

Gauge	*Crossing number*	*Switch length*	*Turnout radius*	*Offsets from gauge face to straight track to*											
				A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*
BG	1 in 8½	6,400	2,32,320	508	614	729	854	989	1,133	1,287	841	935	033.5	1,137	1,246
BG	1 in 12	7,730	4,58,120	322	381	445.5	515	589	668	752					
BG	1 in 16	9,750	8,24,225	268.5	309	352.5	398.5	4,475	499	553.5	610.5	670.5	733	798	866
BG	1 in 20	11,150	13,03,810	241	272	305	340	376	414.5	454.5	496	539	584.5	631	679.5
MG	1 in 8½	5,500	13,0210	612	Offsets at 3,000 and 4,500 are 356 and					475		–	–	–	–
MG	1 in 12	6,700	2,58,300	362	445	537	636	747	–	–	–	–	–	–	–
MG	1 in 16	7,420	4,72,400	292	347.5	408	473.5	543	618	6975	781.5	–	–	–	–

Note: Offset for RH turnouts same as for LH

Gauge	*Crossing number*	*Switch length*	*Turnout radius*	*Gauge face of curved track (mm)*										
				N	*O*	*P*	*Q*	*R*	*S*	*T*	*U*	*V*	*W*	*X*
BG	1 in 8 ½	6400	2,32,320	–	–	–	–	–	–	–	–	–	–	–
BG	1 in 12	7730	4,58,120	1359	–	–	–	–	–	–	–	–	–	–
BG	1 in 16	9750	8,24,225	937	1010.5	1086.5	1165.5	1247	13315	–	–		–	–
BG	1 in 20	11,150	13,03,810	730	782	835.5	891	948	1007	1067.5	1130	1194	1260	–
MG	1 in 8 ½	5500	1,30,210	–	–	–	–	–	–	–	–	–	–	–
MG	1 in 12	6700	2,58,300	–	–	–	–	–	–	–	–	–	–	–
MG	1 in 16	7420	4,72,400	–					–	–	–	–	–	–

Table 7.3 Main Dimensions

Gauge	*Crossing number*	*Rail section*	*Assembly drawing numbers*	*Dimensions (mm)*			*Type of over-riding switch*
				A	*B*	*C*	
	1 in 8½	52 kg	TA20104 & TA20804	12,000	17,418	840	Straight, loose heel
		52 kg	TA20196 & TA20835	12,000	17,418	1,500	Curved, fixed heel
		90R	TA20110, TA20210, TA20211, 20212 TA20213 & TA20810	12,000	17,404	840	Straight, loose heel
		90R	TA20148 & TA20822	12,000	17,404	1,500	Curved, fixed heel
BG	1 in 12	52 kg	TA5268 (M) & TA20801	16,953	23,981	1,500	Straight, fixed heel
		52 kg	TA20171 & TA20831	16,953	23,981	1,500	Curved, fixed heel
		90R	TA5044(M) & TA20807	16,953	23,962	1,500	Straight, fixed heel
		90R	TA20125 & TA20839	16,953	23,962	1,500	Curved, fixed heel
	1 in 16	52 kg	TA20141 & TA20828	20,922	31,447	844	Curved, fixed heel
		90R	TA20138 & TA20813	20,922	31,421	844	Curved fixed heel
	1 in 20	90R	TA20122	24,664	39,470	844	Curved, fixed heel
	1 in 8½	75R	TA20404 & TA21004	7,986	11,632	840	Straight, loose heel
		75R	TA20451 & TA21019	7,986	11,632	1,500	Curved, fixed heel
		60R	TA20407, TA20460, TA20463 & TA21007	7,986	11,615	840	Straight, loose heel
		60R	TA20416	7,986	11,615	1,500	Curved, fixed heel
MG		75R	TA20401 & TA21010	11,287	15,166	1,500	Straight, fixed heel
	1 in 12	75R	TA20464 & TA21016	11,287	15,166	1,500	Partly curved, fixed heel
		60R	TA20410 & TA21010	11,287	15,143	1,500	Straight, fixed heel
		60R	TA20466	11,287	15,143	1,500	Partly curved, fixed heel
	1 in 16	60R	TA20413 & TA21013	12,309	19,635	844	Curved, fixed heel
NG	1 in 8½	60R	TA20604	6,736	9,585	840	Straight, loose heel
	1 in 12	60R	TA20601	9,548	12,282	1,500	Straight, fixed heel

$$AP_2 = D$$
$$AP_1 = AP_2 \cot F = D \cot F$$
$$X = AP_1 - 2M$$
$$= D \cot F - 2M \left(M = \frac{G}{2} \cot \frac{F}{2} \right)$$

(as given earlier in Sec. 7.4)

$$X_1 = D/\sin F - 2M$$

Overall length $= D \cot F + 2A$

Note: For A and M see Fig. 7.18.

7.4.8 Speed on Turnouts

Tests conducted by RDSO on BG turnouts have shown that the speed potential of the turnout track can be determined by considering the lateral guiding forces within acceptable limits. It has also

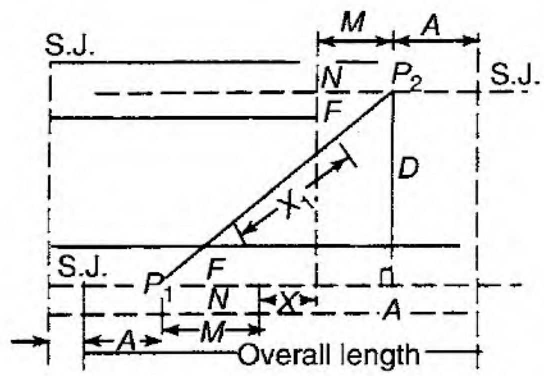


Fig. 7.20

been established that the lateral guiding forces mainly depend upon the switch entry angles. Based on the test results, permissible speed on BG and MG turnouts is listed in Table 7.4.

Table 7.4 Permissible Speeds on Turnouts and Dspecial Layouts

Description of turnouts	*Permisible speed (kmph)*			
	With straight switches		*With curved switches*	
	BG	*MG*	*BG*	*MG*
1 : 8.5	10	10	25	15
1 : 8.5 (symmetrical split)	15	15	40	25
1 : 12 (with ordinary OR tongue rails)	15	15	40	25
1 : 12 (with thick web tongue rails)	–	–	50	–
1 : 12 (with improved design on PSC sleepers)	–	–	50	–
1 : 12 symmetrical split with improved design on PSC sleepers	–	–	70	–

Conditions to be fulfilled before permitting 30 kmph:

1. All turnouts shall be 1 : 12 or flatter with furved switches.
2. Such turnouts shall be provided in a continuous stretch on a reasonably long section on all running lines.
3. All the turnout joints shall be welded except two joints at ends of tongue rails and four joints at ends of crossing (no panel should exceed 3-rail length). The stock joints shall invariably be welded.
4. Track structure in loops shall be minimum 90R, 3 rail panel M+4 sleeper density with 150 mm ballast cushion, out of which at least 75 mm should be clean.
5. Turn-in curves shall not be sharper than turnout curves.
6. Turn-in curves shall be of same rail section as turnout curves with PRC or ST sleepers at 60 cm (maximum) spacing with extra ballast shoulder of 15 cm on outside of curve. Wooden

and CST-9 sleepers may also be used in turn-in curves subject to provisions of Railway Board's letter dated 30.7.93 being fulfilled.

A certificate of compliance with above conditions shall be furnished to CRS when approaching him for raising speeds through loops to 30 kmph.

7.5 OTHER COMMON LAYOUTS

7.5.1 Diamond Crossings (Fig. 7. 21)

When one track crosses another at an angle, a diamond is formed comprising two acute and two obtuse crossings.

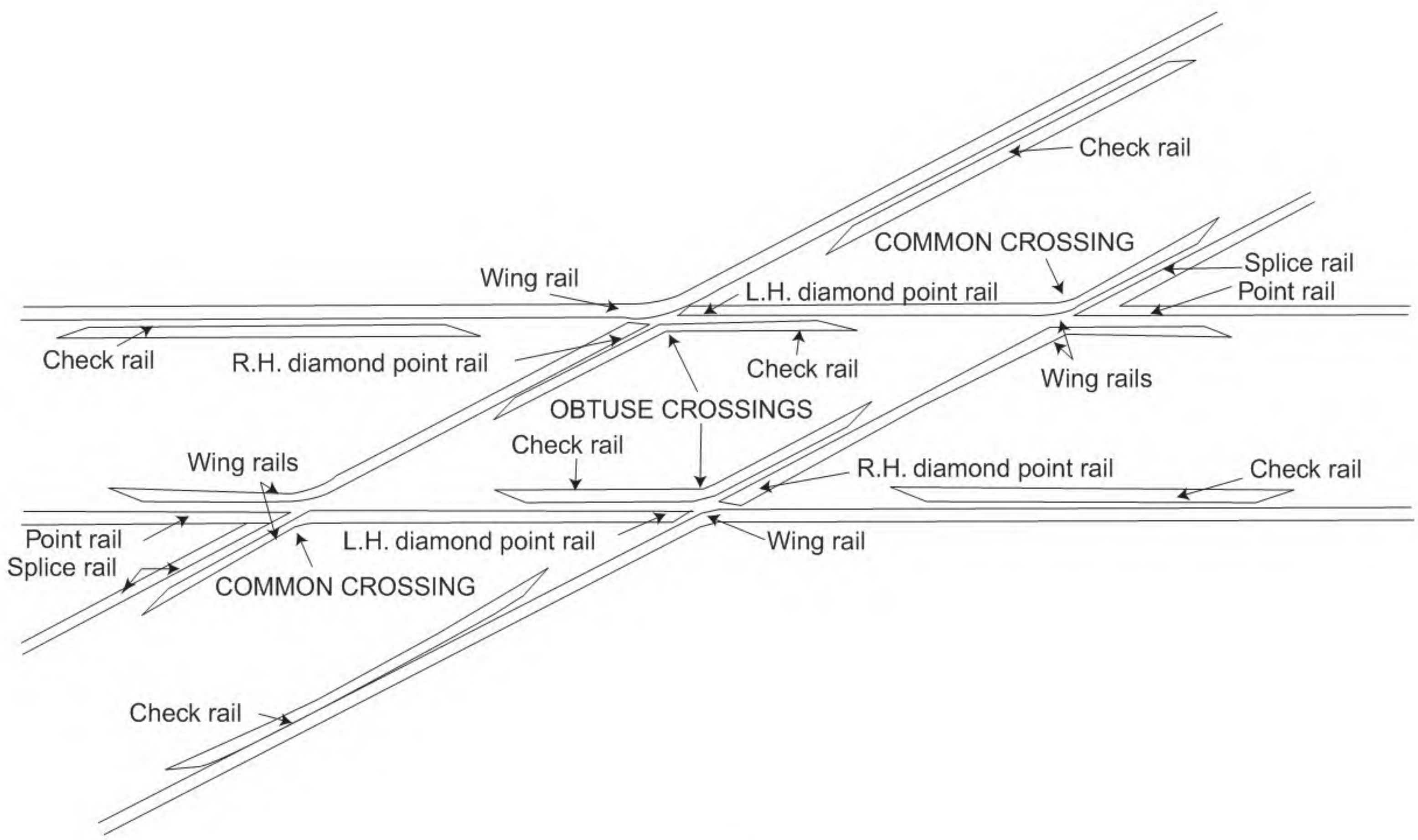


Fig. 7.21 Diamond crossing

7.5.2 Square Crossing (Fig. 7. 22)

When two tracks cross one another at right angles, a square crossing is required. Square crossings are generally avoided because the gap in the running rail for wheel flanges, is opposite to each other. This causes severe jolt to vehicles leading to rapid wear of the crossings and damage to rolling stock on account of the heavy impact.

7.5.3 Movable Switch Diamond

A vehicle passing over a diamond crossing, is beset by an inherent risk of derailment. This is due to (a) a large unguided gap at the elbow of the obtuse crossing and (b) the possibility of a wheel, particularly of a smaller diameter, being deflected to the wrong side of the nose. The position becomes worse when the angle of intersection is very acute. The Indian Railways, has therefore laid down that diamond crossings should normally not be flatter and less acute than 1 in 8½.

This risk can be eliminated by making the point rails of the obtuse crossing move in the same way as the tongue rail of the switches—these point rails being suitably joined together by stretcher bars. Such an arrangement is known as a movable switch diamond. With switch diamonds, it should also be possible to permit the use of diamond flatter than 1 in 8½.

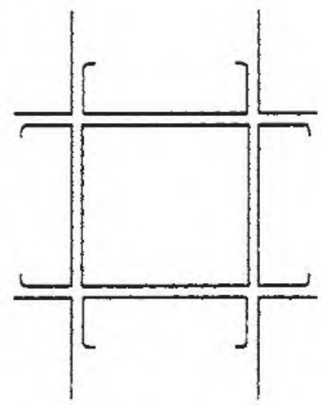


Fig. 7.22 Square crossing

7.5.4 Diamond Crossing with Slips (Fig. 7.23)

An arrangement of tracks to allow a train to cross to another track and diverted to that track, when required, can be achieved by installing diamond crossing slips. This is made by including two to four pairs of switches with the connecting lead rails. Such an arrangement is called 'Single slips', when the permitted diversion is one way only, and 'double slips' if it is two ways.

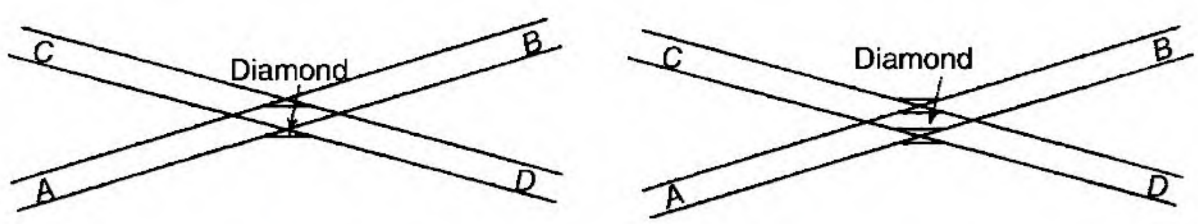


Fig. 7.23 Diamond crossing with slips

7.5.5 Scissors Crossover (Fig. 7.24)

When two crossovers overlap exactly opposite to each other, a scissors crossover is formed. It consists of four turnouts and a diamond crossing. The same function can be performed by two crossovers following one after the other, but the advantage in scissors crossover is the saving of space. This is commonly used in busy passenger yards when two trains are dealt with on a single long platform.

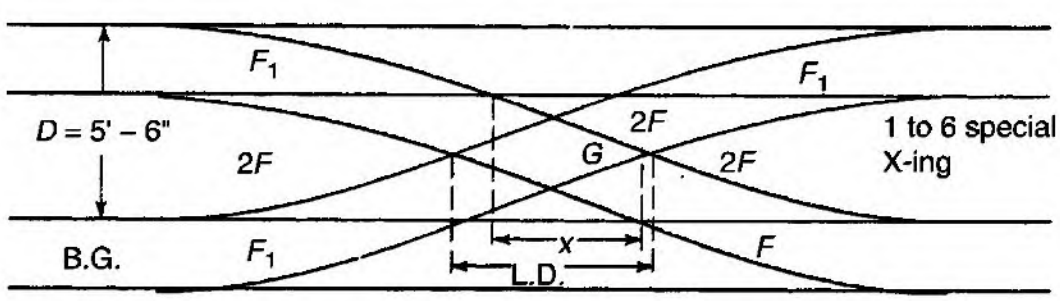


Fig. 7.24 Scissors crossover

Triangles Triangles are laid for turning engines, or vehicles end to end in place of turntables. These are laid when space is cheap. Its maintenance cost is less as compared to turn tables. It consists of two 1 in 8 ½ turnouts, one 1 in 8 ½ symmetrical split with connecting rails (Fig. 7.25).

Gathering lines A gathering line or a ladder track is one into which a number of parallel tracks merge. This layout is commonly used in goods yard (Fig. 7.26).

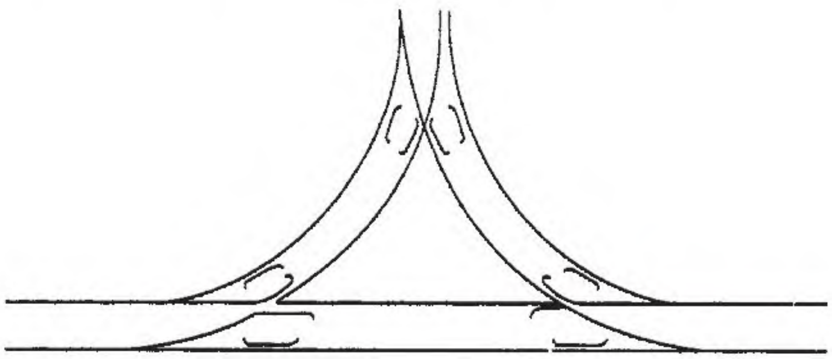


Fig. 7.25 Triangles

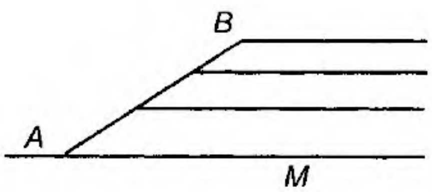


Fig. 7.26 Gathering line

Gauntlet track It is an arrangement in which two tracks of the same or different gauges are run together for a certain length. The arrangement is useful, when both BG and MG track is to be run together on the same bridge. Gauntlet track has two crossings of the same or mixed gauges, at either ends, without any switches (Fig. 7.27).

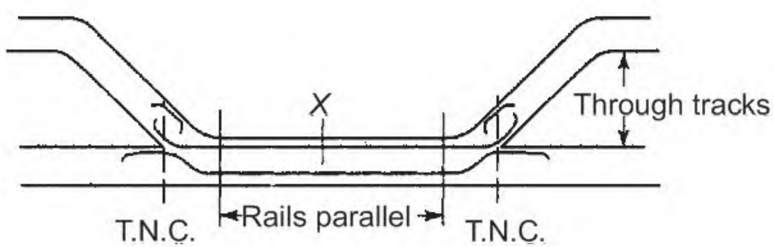


Fig. 7.27 Gauntlet track

7.6 INSPECTION AND MAINTENANCE OF SWITCHES AND CROSSINGS

7.6.1 Maintenance (General)

1. In big yards there should be regular check up of all points and crossings.
2. Cess should be kept low for proper drainage. Adequate ballast cushion should be provided.
3. Sleepers should be at correct spacing.
4. There should be no junction fishplates at stock rail joints or at the heel of crossings. At least one rail length on either side should be of the same section.

5. Use of spherical washers at appropriate places is important and must be ensured.
6. At all places in points and crossings, the gauge should be uniform except at a point just ahead of the toe of the switch, where it will be slightly slack (enough to house the tip).
7. The clearance at the toe of switch, at check rail and wing rails must be maintained within prescribed tolerances.
8. Adequate creep anchors should be provided to arrest creep. Box anchoring of at least one rail length ahead of stock rail is recommended.
9. It is desirable to weld stock and lead rail joints.

7.6.2 Maintenance of Switches

1. In case of straight switches, correct bend to stock rail at the theoretical toe of switch should be ensured.
2. Bent tongue rail should be straightened. Worn out and damaged stock and tongue rails should be replaced by serviceable ones. A tongue rail may be classified as badly worn or damaged when:
   (a) It is chipped or cracked over a length of 20 cm from its toe.
   (b) It does not house properly against stock rail causing a gap of more than 5 mm at the toe.
   (c) The wear on tongue rail should not exceed the following limits:
      (i) Vertical wear: 6 mm (ii) Lateral wear to be measured 13–15 mm below the rail table: 8 mm for 52 kg and 90*R* rail and 5 mm for 75*R* and 60*R* rail.
3. Tongue rail should bear evenly on all slide chairs. This will be ensured when all sleepers are well packed.
4. When the tongue rail is in closed position, it must bear evenly against distance studs and blocks.
5. All bolts on switches should be tight except at the heel of loose heel type switches, where the first two bolts in the switch rail should be finger-tight and the other two in the lead rail spanner-tight. On such switches a bend is given to the fishplate at loose heel joint equal to *throw of switch × half length of fishplate/length of tongue rail.*
6. Wear on switches can be reduced by lubrication of the gauge face of the tongue rail.
7. Plate screws and fang bolts should be used with slide chairs and not round spikes.

7.6.3 Maintenance of Crossings

1. Proper maintenance of gauge at crossings is very important. Any damage to the nose of crossing or excessive lateral wear to the wings or check rails may have its origin in poorly maintained gauge.
2. Maximum vertical wear on wing rail at the nose of crossing should not exceed 10 mm. Crossing should be reconditioned or replaced before reaching this limits.

3. When steel trough sleeper are used under crossings, the use of wooden blocks under them help in better maintenance.

7.6.4 Maintenance of Lead Portion and Turn in Curves

1. The curve lead should be laid by offsets from the gauge face of the straight track. Stations at 2.5 m intervals should be marked and the versines checked and track attended to when necessary. The turn in curve should also be checked for condition of sleepers and fastenings.
2. Schedule of inspections of points and crossings:
   (a) *PWI's inspection* PWI in charge and his PWI/Gr III should carry out inspection of points and crossings in passenger lines once in three months and other lines once in six months by rotation.
   (b) *AEN's inspection* The AEN should inspect points and crossings on passenger lines once a year and 10 percent of other points and crossings every year.
   (c) *Sr. DEN/DEN's inspection* Should inspect all such points and crossings in running lines, as recommended for renewals besides a random check.
   (d) All inspections should be done as per the performa laid down for this purpose.

7.7 REBUILDING/RESURFACING OF SWITCHES AND CROSSINGS

As per existing provision in the Indian Railways Permanent Way Manual the maximum vertical wear on wing rail and on the nose of the crossing is not permitted to exceed 10 mm. Once this wear occurs, the crossing will need replacement. To prolong the life of the crossing, resurfacing of crossings is done on extensive scale. It is executed by depositing metal from welding rods either by gas welding or by electric welding process. Easier though it is to weld at sites, it lacks quality due to non-availability of proper traffic blocks. Hence electric welding at depots is being resorted to more and more. Crossings are removed from track when the wear reaches the prescribed limit and are taken to the welding depots. In the depots, wings and noses are separated and resurfaced and vertical bends, if any, are removed and the crossing reassembled. Worn out or broken switches are also rebuilt with the help of properly designed templates. Quality entails:

1. Method of welding advocated by the electrodes supply company should be scrupulously followed.
2. Welders should be trained by the company with certified fitness for welding.
3. Product of one company should not be mixed with that of another.
4. Electrodes meant for use with normal crossings should not be used for CMS crossings or vice versa.

On Rajdhani/Shatabdi track crossings and wing rails are planned for reconditioning before reaching the following limits.

Built up crossings: 6 mm
CMS crossings: 8 mm

A manual for reconditioning of points and crossings, both of MM steel and CMS has been issued by RDSO for guidance.

7.8 TURNOUT RENEWALS AND PROVISION OF NEW TURNOUTS

The following methods are generally adopted for renewals of turnouts and provision of new turnouts.

1. *Slewing of Complete Turnout in Position* When enough space at the site and when sufficient traffic blocks are available this method of assembling and slewing it in position is followed. For renewals, ballast cleaning is executed in advance.
2. *Replacement by Parts* This method is followed when sufficient traffic block is not available or no space for preassembling can be found close by or it is difficult to get sufficient labour for complete slewing. In this method the sleepers are changed by interlacing with the old sleepers and other parts are replaced one by one during short traffic blocks.

It has been noticed that in both these methods, it is difficult to obtain the standard of perfection required for the laying of switches and crossings. The kinks formed at the time of laying are a source of perennial trouble throughout the life of the turnout. Much of the rough riding that is experienced on a high speed run is on badly laid turnouts. It is therefore desirable to lay the turnouts as accurately as possible. On many advanced railway systems, switches and crossings assembly depots are established, where complete layout is accurately assembled under competent supervision. After necessary checks the turnouts is divided into convenient panels which are loaded into flat bogie wagons. At the laying sites, the old assembly is accurately replaced by the new one with the help of cranes.

7.8.1 Turnout with Concrete Sleepers

With their distinct techno-economic advantages, Indian Railways have an ambitious plan of laying increasing number of turnouts with concrete sleepers. These sleepers are heavy, each weighing 346–700 kg, and can get damaged if not handled carefully.

For mechanised laying of points and crossings, Indian Railways have procured T-28 type of machine sets from Ameca of Italy. Each set comprises:

(a) Two of crawler mounted portal cranes which can move on rails as well as on ballast/firm earth. Each portal crane weighs 26.24t and is fitted with diesel engine of 175 HP with about 40 − 50t lifting capacity. Each portal crane has two crawlers for movement on other than rails and four small size railway wheels for movement on rails.
(b) Two motorised trolleys with rotating platforms—up to 10° either side—which can move on rail. Each weighs 1.466t with 25t carrying capacity.
(c) Two non-motorised trolleys which also move on rail, each, weighing 1.466t with 35t carrying capacity.

The weight of one BG 60 kg, 1 in 12 turnout with PSC sleepers is about 62 tonnes. A pair of Ameca Portal Cranes can easily lift the whole of fully assembled turnout in one lot. The equipment can be sued for dismantling the old turnouts, and for placing the new turnout in position. For this purpose, it is necessary to select a suitable site in the vicinity of the renewal site for assembling the new turnout and move that into position with the help of T-28 machines.

The machine can perform the following functions:

1. Two Portal Cranes of T-28 machines together can lift the entire turnouts weighing about 62 tonnes and move on rough ground on crawlers at a speed of about three km per hour.
2. For movement of assembled turnouts, trolleys—two motorised and two non-motorised—are used. They can travel at a speed of about 10 km per hour.
3. Both the Portal Cranes and the trolleys have the capability of shifting the turnout laterally up to a maximum of 1 m in the lifted condition and also have some degree of rotation. Maximum lift of turnout is so restricted as not to require any power block in traction territory.
4. The complete renewal of a turnout can be accomplished in a traffic block of 2 to 2½ hours. If dismantling of the old turnout is carried out manually, the requirement of traffic block is reduced about 1 to 1½ hour.

In Indian Railways at many locations, dismantling of the old turnout is carried out manually because:

(a) It is difficult to find a suitable nearby place where the old turnout can be lifted and stored—even temporarily.
(b) The duration of the traffic blocks is generally less than two hours.

A photograph of the Ameca machine is given in Fig. 7.28.

Although there is emphasis on laying of concrete sleeper turnouts by using T-28 machines only, alternate methods using road cranes and dip lorries are still in vogue at many locations. They are:

(a) Assembly of the complete turnout near the relaying sites and moving the assembly into position with the help of road cranes or rollers. This method demands the availability of adequate open space near the work site and 4–6 hours traffic block.
(b) Transporting the assembled turnout part by part on the dip lorries and carry out replacement during block period of 4/5 hours duration using rail/road mounted cranes.

The quality of work with such methods is generally not very satisfactory. There is every likelihood of damage to concrete sleepers during handling and laying.

7.9 LWR/CWR THROUGH POINTS AND CROSSINGS (FIG. 7.29)

In points and crossings, there is a discontinuity of track at two locations, viz. at the switch portion and at the crossing. LWR rail generates compressive/tensile forces of the order of 60 tonnes (in Zone VI) while track connections in normal points and crossings are not capable of transmitting such high magnitudes of forces through them. To ensure that points and crossings behave as a part

Fig. 7.28 A view of Ameca machine

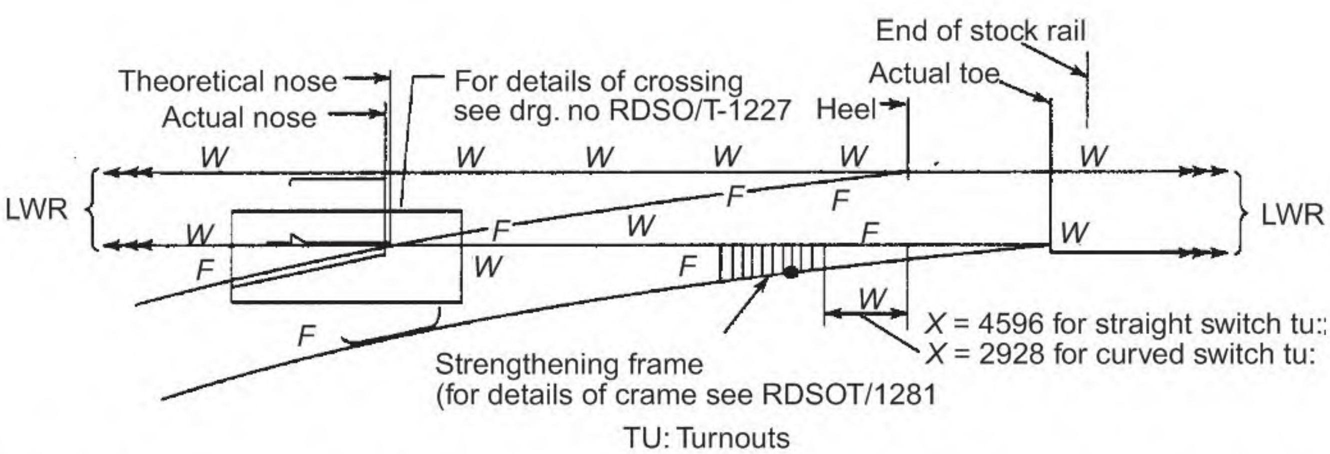


Fig. 7.29 LWR through points and crossings: W, welded joint; F, fishplated joint

of LWR track, the track connections at these places are stiffened. This is achieved in switch portion by providing steel straps between the two lead rails just behind the heel of the switch. And, in the crossing portion, it is accomplished day (a) Using CMS crossings linked to the rails on either side by glued joints or by strengthening of built-up crossings with straps between the vee and the extended wing rails.

These arrangements have been shown in RDSO drawing No. EDO/T-1571. Based on RDSO drawings and local adaptations, various Zonal Railways successfully carried LWR through switches and crossings.

7.10 DESIGN OF TURNOUTS FOR HIGHER SPEED IN INDIAN RAILWAYS

The policy laid down by the Railway Board specifies standardisation of four designs of BG turnout from the consideration of permissible speed.

1. Turnout for goods yards to permit a speed of 25 kmph.
2. Turnout for passenger yards to permit a speed of 50 kmph.
3. Turnout for the outskirts of big yards to permit a speed of 75 kmph.
4. Turnout of the junction between single and double line to permit a speed of 100 kmph.

Of the four designs, the turnout for passenger yards is of considerable importance. With the maximum speed of 130 kmph on the main line and its prospects of going up to 160 kmph, a speed of 50 kmph only on the turnout to be used in passenger yards may be considered low. However, a major constraint in their design is the overall length, which has to be kept at per with existing 1 in 12 turnouts to avoid large scale remodeling of passenger yards. Similar is the constraint in the design of new 1 in 8½ turnout for goods yards.

7.11 NEW 1 IN 12 TURNOUT FOR PASSENGER YARDS

A 1 in 12 turnout for passenger yards with a speed potential of 50 kmph has been developed by RDSO.

Its salient features are:

1. Its overall length is almost equal to the present standard 1 : 12 turnout, affording advantage of easy replacement.
2. Thick web tongue rail has been used to provide high lateral rigidity and longer life.
3. The top of the tongue rail is at level with the stock rail, eliminating twist at the switch assembly.
4. The stock rail head is prevented from lateral rotation by using a special spring leaf clip to fasten the inner foot of the stock rail. Additionally, sturdy fittings are used on the outside of stock rail to minimize dynamic gauge widening (Fig. 7.30).

The main features of the turnout are given in Table 7.5.

7.12 NEW GENERATION OF TURNOUTS ADOPTED BY DELHI METRO

Delhi Metro in their turnouts has adopted a number of new features to obtain superior riding quality and longer service life both 1 in 12 type and 1in 8.5 type turnouts. Main technical specifications of the turnouts are as under.

1. ***General***
   (i) Gauge: 1673 mm
   (ii) Rail section: UIC 60

Table 7.5

S.No.	*Item*	*Design parameter*	*Remarks*
1.	Speed potential	50 kmph	This is based on entry angle of 20′ and cant deficiency of 75 mm on turnout curve
2.	Gauge	1,673	As per recommendation of Director's Committee
3.	Rail section	52 kg/m	
4.	Sleepers type and spacing	Wooden 250 × 150 550–600 mm	
5.	Overall length	39,729 mm	Well within existing 1 in 12 turnout
6.	Rail joints	Welded except for switch and crossing joints	
7.	Rail sleeper fastening	Rail screws	An alternative design with the use of steel clips, plate screws and double coil washers has also been prepared by RDSO T-1917
8.	Switch		
	(a) entry angle	0′–20′ minuts-0″	
	(b) switch rail type	Non-overriding	this will avoid difference of level between stock and tongue rails
	(c) switch rail profile	ZU–2–49 thich web 8570 mm	
	(d) length		
9.	Lead curve radius	441.367 m	
10.	Crossing		
	(a) type	CMS	
	(b) angle	4°– 45′– 49″	Same as 1 in 12
11.	Wing rail clearance		
	(a) at throat	44 mm	
	(b) opposite nose	44 mm	
	(c) at the end of flare	64 mm	This is to provide better guidance to wheels
	(d) flare slope	1 in 31	
12.	Check rails		
	(a) clearance opposite nose	41 mm	
	(b) clearance at the end of flare portion	63 mm	This is for better wheel guidance
	(c) flare slope	1 in 68	TO RDSOT-1917 raised check rail has been adopted
13.	Check rail raised or level	level	

(iii) Speed potential on curved track
  (a) 1 in 12 type turnout: 50 kmph
  (b) 1 in 8.5 type turnouts: 25 kmph

(iv) Designed to take the LWR through turnouts

(v) Laid with canted rails with an inward rail slope of 1 in 20

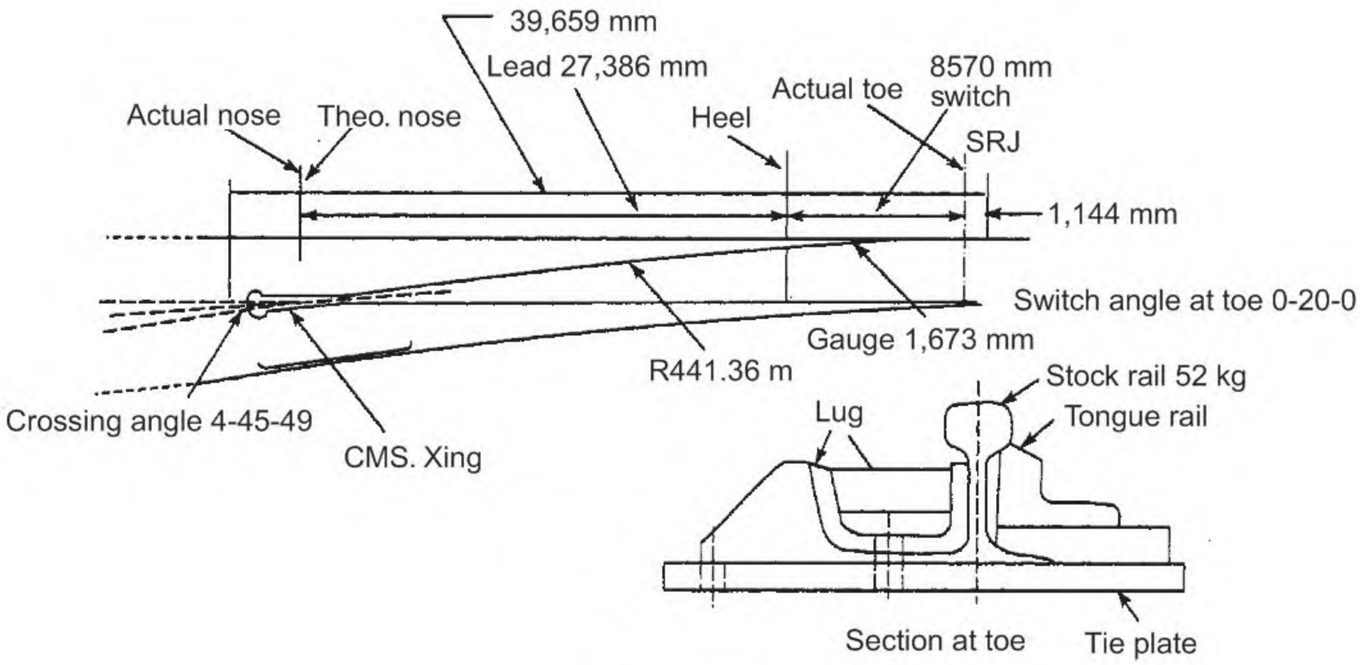


Fig. 7.30

2. ***Basic Geometry of Turnouts***

(i) 1 in 12 Turnouts

The design is tangential with a switch entry angle of 0° 10′ 42″. The radius of turnouts is 412. 671 m (outer rail) throughout. The distance between Stock Rail Joint (SRJ) and actual toe of switch is 1144 mm. The distance between SRJ and theoretical nose of crossing is 37100 mm. The crossing is straight. Overall length of the layout from SRJ to end of the crossing is 42200 mm (measured along the straight). The length of stock rail and switch rail is 15300 mm and 13580 mm, respectively.

(ii) 1 in 8.5 Turnouts

The design is secant with a switch entry angle of 0° 36′ 7″. The radius of turnouts is 218.00 m (outer rail) through out. The distance between SRJ and actual toe of switch is 1500 mm. The distance between SRJ and theoretical nose of crossing is 26295 mm. The crossing is straight. Overall length of layout from SRJ to end crossing is 31270 mm (measured along the straight). The length of stock rail and switch rail is 12650 mm and 10700 mm, respectively.

3. ***Switches***

(i) All switches (stock rail and switch rail) are of 1080 grade head hardened rails suitable of being welded by alumino-thermic welding.

(ii) Slide chairs in the switch portion are given a coating based on Ni-Cr, so as to reduce the point operating force and to eliminate the requirement of lubrication of sliding surfaces during service.

(iii) The minimum flange way clearance in switch portion is not less than 60 mm and is provided with second drive arrangement for 1 in 12 turnouts, whereas 1 in 8.5 turnouts are without second drive. The opening of switch at toe of switch is kept as 160 mm.

(iv) In the switch portion, the stock rail is held down by the elastic fastenings on both sides of the flange of the stock rail. The outside fastening clip is Vossloh SKL − 12, whereas the inside elastic clip is provided through in the slide chairs to have a toe load of at least 1100 kg per elastic clip.

(v) The switches are designed with an anti-creep device at the heel of switch.

4. ***Crossings***

(i) CMS crossings are provided with welded leg extensions of UIC 60, 1080 grade head hardened rails. This is achieved by flash butt welding of a buffer transition rail piece between CMS crossings and leg extension.

(ii) The wheel load transfer surfaces of CMS crossings are artificially hardened by explosive hardening to achieve a minimum hardness of 340 BHN before installation.

(iii) The provision of rail cant is taken care of on the top surface of the CMS crossings and the bottom surface of all CMS crossings is flat.

(iv) The CMS crossings used on Delhi Metro have longer lengths as compared to Indian Railways standard crossings. With weldable legs and the continuation of the continuously welded rails through turnouts, a much better riding quality is achieved. The comparative lengths of the Indian standard crossings and those adopted by Delhi Metro are given in Table 7.6.

Table 7.6 IRS CMS Crossings and Delhi Metro Crossings—Lengths in Metres

Item	*IRS*	*Delhi Metro*
1 in 8½ (Without weldable legs)	3.30	3.88
1 in 8½ (With weldable legs)	—	7.313
1 in 12 (Without weldable legs)	4.35	4.94
1 in 12 (With weldable legs)	—	9.392

5. ***Check Rails***

(i) The check rail section is UIC 33, without any direct connection with the running rails. Check rails have facility for the adjustment of check rail clearance up to 10 mm over and above the initial designed clearance. Each check rail is end flared by machining.

(ii) All the check rails are higher by 25 mm above the running rails.

6. ***Concrete Sleepers***

(i) The PSC sleepers are fanshaped through out the layout of the turnout.

(ii) Indian Railways standard sleepers for turnouts have been adopted except that the position of the fastening on the sleepers have been changed to match the new geometry.

(iii) 1 in 20 cant on rails has been achieved by providing a canted HD polythene pad between the rail pad and the PSC sleepers. SGCI inserts at these locations are suitably modified for getting the desired toe load on the rails.

7.13 TURNOUTS ON KONKAN RAILWAY

The turnouts for Konkan Railway have the following special features:

1. Provision of elastic fastening system in switch portion, consisting of K-type clips on the outside and a spring leaf arrangement to hold the stock rail from inside. A 6 mm track rubber sole plate is provided under the stock rail.
2. A spring operated setting device has been installed. Figure 7.31 shows that double pull arrangement.

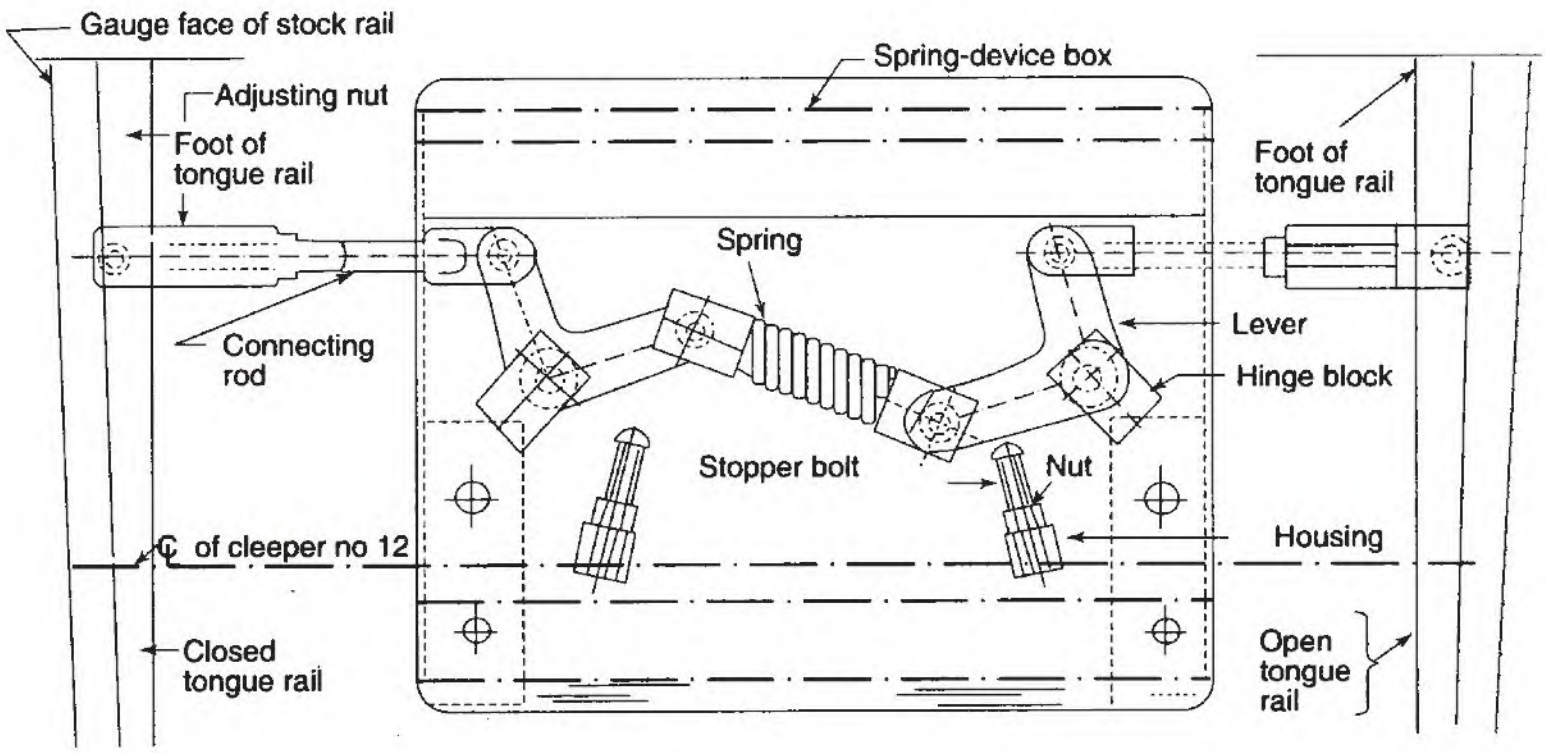


Fig. 7.31 Spring operated device

3. The throw has been increased to 145 mm.
4. A hardened steel (130 UTS) tongue rails, machined from thick web rails, has been adopted.

The design is expected to prove much superior to all other designs so far evolved by RDSO in terms of service life and retention of track geometry.

Chapter 8

Ballast and Formation

8.1 STANDARD TRACK NOMENCLATURE

Defined below is a set of terms, as those used in to ballast and formation. These are illustrated in Fig. 8.1 which shows cross-section of a railway track.

1. *Ballast* It is a high quality crushed stone with desired specifications placed immediately beneath the sleeper.
2. *Ballast section* A section of the ballast taken perpendicularly across the track in between the sleepers brings out the ballast section.
3. *Ballast profile* The diagram indicating the ballast position with respect to the formation and the track component is called the ballast profile.
4. *Ballast cushion* The depth of ballast below the bottom of the sleeper, normally measured under the rail seat, is termed as the ballast cushion (d in Fig. 8.1).
5. *Cess* It is that part of the formation which lies between the toe of the ballast and the edge of the formation.
6. *Crib ballast* Ballast provided in between sleepers, i.e. in the sleeper cribs, is called crib ballast (b in Fig. 8.1).
7. *Formation* It is the surface on which the ballast is laid. It is also known as the roadbed.
8. *Formation level* It is the level of the prepared surface on its centre line, including the blanketing material, if any.
9. *Formation width* It is the distance between the edges of the prepared surface.
10. *Shoulder ballast* Ballast provided beyond the sleeper edge is called the shoulder ballast. The distance by which the ballast top line projects beyond the edge of sleeper is called the shoulder width of ballast.
11. *Side slope* It is the inclined surface of an embankment on cutting.
12. *Side slope of ballast* The slope at which the ballast top line at the shoulders meets the formation line is termed as side slope of the ballast. It is usually kept as 1.5 : 1.

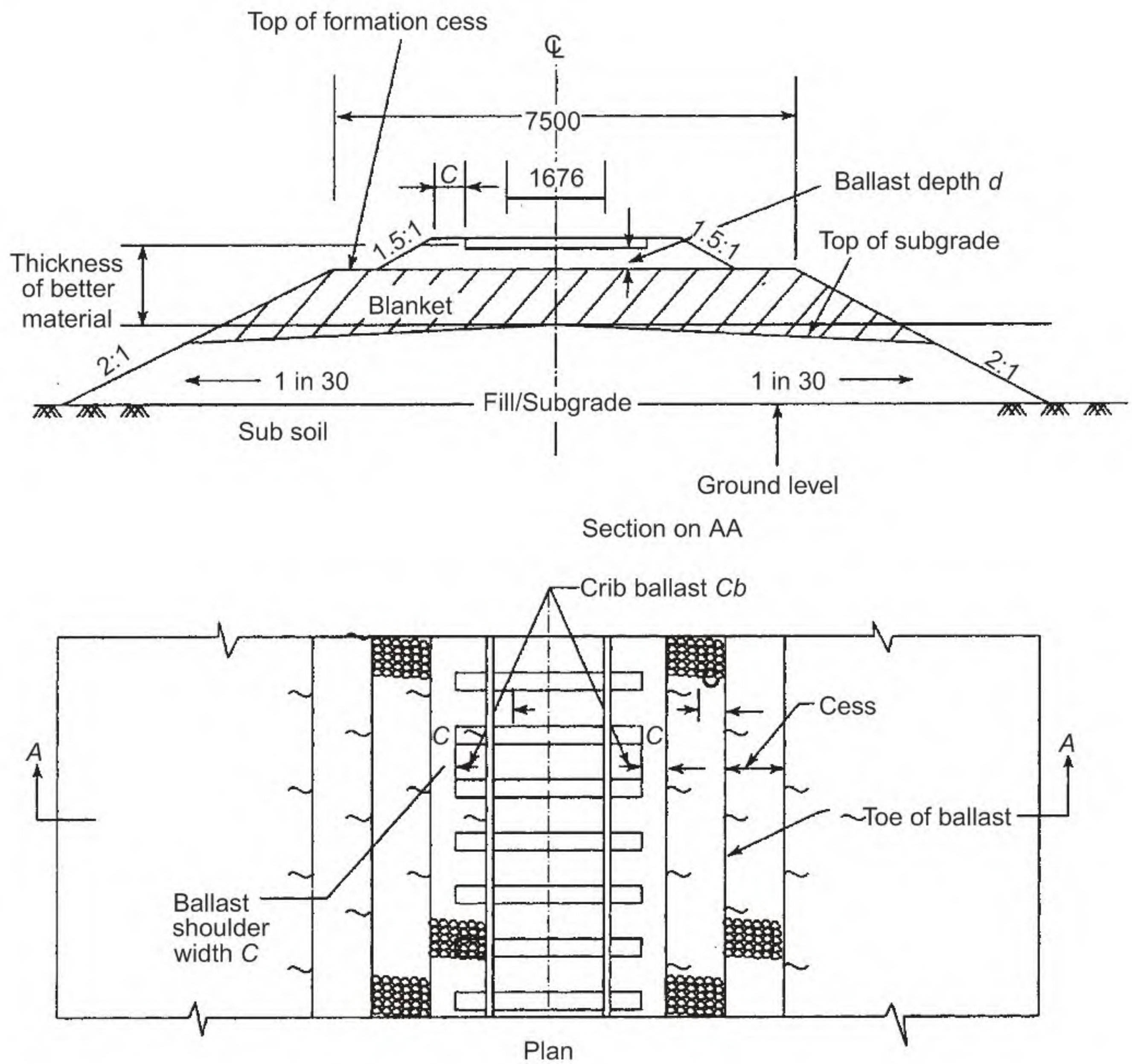


Fig. 8.1 Cross-section of a railway track

13. *Subgrade* It is the part of embankment cutting, on which track and its foundations are supported and is made of the same material as that of the embankment or the sub-soil in cutting.
14. *Subsoil* It is the soil immediately under the natural ground level.
15. *Track foundation* The blanket and other constituents placed between track structure and the subgrade to avoid failure of subgrade below, constitute the track foundation.
16. *Track structure* Rails, sleepers, their fastenings and ballast constitute the track structure.

8.2 BALLAST

Ballast is an important constituent of conventional track structure. Its importance has grown with the increasing axle loads and train speeds. Various types of materials such as aggregates of rock and boulder, natural gravel, shingle and sand, etc. are used according to the requirement, availability and cost to make ballast.

Granite, quartz, trap, sandstone, limestone, etc. have been used as stone ballast in India. The shape of the ballast should be cubic and/or angular. This would be automatically achieved if the parent rock material is non-stratified and has good compressive strength.

Even earth and ashes are used as packing material on some unimportant lines and sidings; however, these are not relevant to a normal track structure.

Ballast performs the following important functions in a track.

1. Carries the load and distributes it safely on to the formation.
2. Provides a firm, level and resilient bed for the sleeper.
3. Facilitates easy drainage.
4. Fills inequalities on the formation.
5. Provides lateral and longitudinal stability to track.
6. Protects formation against rains and winds.
7. Protects the sleepers from capillary moisture of formation.
8. Does not allow free vegetation growth.
9. Provides a medium for energy absorption of all impact forces coming from rolling stock by undergoing a temporary change in its contact relationship. The ballast particles can be lifted back to their normal level by manual packing or mechanical tamping. This is one of the most vital functions that the ballast performs in the track.

8.2.1 Ballast Specifications of Indian Railways

Ballast for track is procured through contracts for which detailed special conditions and specifications are laid down by the railway administration. This is to ensure proper and regular supply of quality ballast conforming to specifications. The various specifications are as follows:

General

1. *Basic quality* Ballast should be hard, durable and as far as possible angular along edges/corners, free from weathered portions of parent rock, organic impurities and inorganic residues.
2. *Particle shape* It should be cubical is shape as far as possible. Individual pieces should not be flakey and have generally flat faces with not more than two rounded/subrounded faces.
3. *Mode of manufacture* To ensure uniformity machine crushed ballast should be preferred for Broad gauge and Metre gauge routes. Hand broken ballast shall be used only with the prior approval of the Chief Engineer.

Physical Properties: Ballast sample should satisfy the following physical properties in accordance with IS: 2386 Pt. IV – 1963.

		BG & MG	NG
Aggregate abrasion value	–	30% Max.*	35% Max.
Aggregate impact value	–	20% Max.*	30% Max.

* Relaxable up to 35% and 25%, respectively on technoeconomic grounds by CTE/CE

The shape parameter 'Flakiness Index' as determined in accordance with IS: 2386 Pt. I – 1963. The water absorption tested as per IS: 2386 Pt. III – 1963 should not be more than 1%.

Size and Gradation Ballast should conform to the following size and gradation:

1.	Retained on 65 mm sq. mesh sieve	–	Nil
2.	Retained on 40 mm sq. mesh sieve	–	40–60%
3.	Retained on 20 mm sq. mesh sieve	–	Not less than 98% for machine crushed. Not less than 95% for hand broken

Oversize Ballast If the ballast retained on 65 mm square mesh sieve is at variance from the above stipulation, the stack shall be rejected.

Also, if the ballast retained on 40 mm square mesh sieve exceeds 60% limit prescribed in 2 above, payment at following reduced rates shall be made for the full stack:

(a) 95% of quoted rates if retention on 40 mm sq. mesh sieve is between 50% (excluding) and 65% (including).
(b) 90% of quoted rates if retention on 40 mm sq. mesh sieve is between 65% (excluding) and 70% (including).

Undersize Ballast The ballast shall be treated as undersized and rejected if retention on 40 mm sq., mesh sieve is less than 40% and the retention on 20 mm sq. mesh sieve is less than 98% for machine crushed and 95% for hand broken.

Method and Sieve Analysis (1) The screens for sieving of ballast shall be of square mesh and shall not be less than 100 cm in length, 70 cm in breadth and 10 cm in height on sides. (2) While carrying out sieve analysis, the screen shall not be kept inclined, but held horizontally and shaken vigorously. The pieces of ballast retained on the screen shall not be rushed through the screen openings. (3) The percentage passing through or retained on the sieve shall be determined by weight only.

8.3 BALLAST PROFILES/SECTIONS/DEPTH OF CUSHION

8.3.1 Depth of Ballast Cushion

One of the important functions of the ballast is to distribute the load coming to the sleeper safely onto the formation. The pressure on the sleeper spreads through the body of the ballast. For the coarse, rough, dry and clean ballast, this angle is about 45°, but becomes smaller for moist and dirty ballast. This brings out distinctly the advantage of clean ballast cushion and reducing the formation pressures.

To obtain uniform distribution of the wheel loads upon the formation, it is advantageous to have the longest and the broadest sleeper possible. The quality of the ballast should be such as to provide the widest possible angle of pressure spread, and deep enough to distribute the oncoming loads to the maximum area at the level of the formation.

Depth of ballast cushion as prescribed for various groups of tracks on Indian Railways is given in Table 8.1.

Table 8.1

Group	*Recommended depth* (mm)
BG Group A	300
BG Group B and C	250
BG Group D	200
BG Group E	150
MG Q routes	250 (300 mm when speed is 100 kmph)
MG R1 routes	250
MG R2/R3 routes	200
MG S routes	150
NG	150

8.3.2 Ballast Profile

It is mainly determined by (a) ballast cushion, (b) shoulder ballast, (c) crib ballast and (d) the side slope of ballast.

Deeper ballast cushion ensures better distribution of load onto the formation.

The main purpose of shoulder ballast is to restrain the lateral movement of track. Crib ballast gives resistance to the longitudinal movement of track. To retain the ballast to a certain section, it is essential to provide some stable side slopes. Years of experience of track maintenance, and the results obtained from research and experiments have helped the railways to arrive at the optimum ballast profiles for various track gauges and the types of sleepers.

On curves, extra ballast on the outer shoulder helps the track structure to cope with the centrifugal forces generated by the moving vehicles. In LWR, ballast plays a vital role in lending longitudinal and lateral stability to track under locked up compressive and tensile forces. To meet this situation, curves and LWR tracks, are heaped up with extra ballast.

Ballast profiles recommended for adoption for various groups of track in BG and MG are given in Fig. 8.2, Table 8.2 and Fig. 8.3, Table 8.3, respectively, for single line and double line.

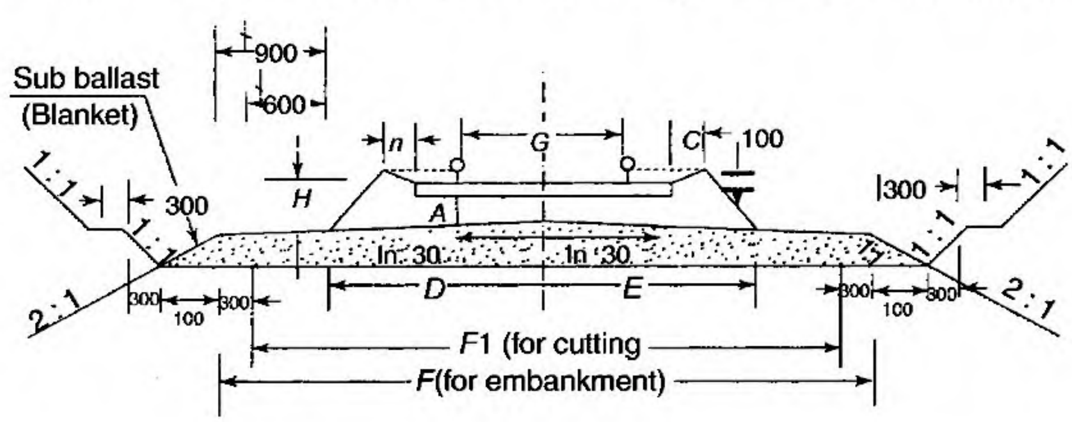


Fig. 8.2

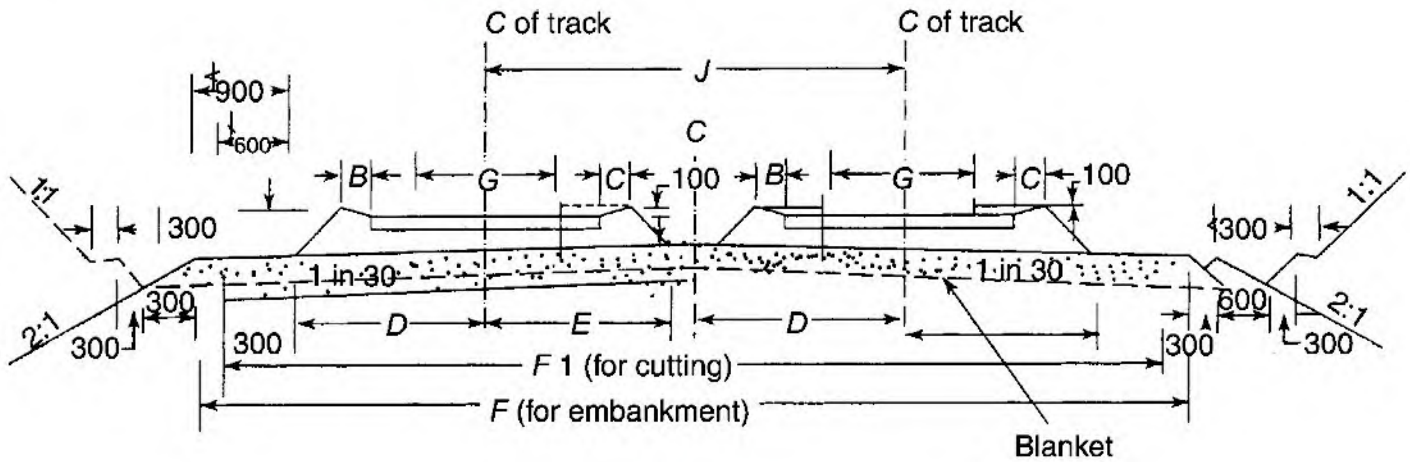


Fig. 8.3

8.4 BLANKET/SUB-BALLAST

The term sub—ballast and blankets are synonymous. It is layer of specified coarse grained material interposed between ballast and formation—commonly known as blanket. It serves the following objectives:

1. To distribute the load on formation reducing the subgrade stresses within the subgrade strength.
2. To eliminate mud pumping.
3. To contain the seasonal moisture content variations in subgrade.

The depth of ballast and blanket depends on the type of subgrade soil, axle load, speed of the train, traffic density, etc. To consider all these factors in designing the depth of construction is a complex problem. Studies reveal that cohesive soils under repetitive loading exhibit lesser shear strength. This is termed as *threshold shear strength* of the soil which increases with the increase in depth whereas the induced shear due to moving load decreases. The depth at which the two become equal determines the thickness of coarse gained material. This is made up of ballast cushion and thickness of blanket (Fig. 8.4).

It has been confirmed that the Boussinesq's and other empirical formulae predict these stresses with reasonable correctness.

For most of the cohesive soils, it has been observed that the required depth of coarse grained material lies between 80 cm to 120 cm. For BG, 20 tonnes axle load rolling stock, with a dynamic augment of 60%, the dynamic wheel load is

$$\frac{20(1+0.6)}{2} = 16 \text{ tonnes}$$

Shear strength of typical cohesive soil is 0.15 kgf/cm^2. From graph in Fig. 8.4, the depth of coarse grained material required is 82 cm.

Table 8.2 Dimension References (vis-à-vis Fig. 8.2)

G *Gauge*	*Type of sleeper*	*A*	*B*	**C*	*D*	**E*	*F*	F_1	*H*
1676 (B.G.)	Wooden	250	350	500	2270	2420	6100	5490	540
		300	"	"	"	"	"	"	590
		200 over 150 Sub-Ballast	"	"	"	"	"	"	640
	Steel Trough	250	350	500	2280	2430	6100	5490	550
		300	"	"	"	"	"	"	600
		200 over 150 Sub-Ballast	"	"	"	"	"	"	650
	PRC	250	350	500	2525	2675	6850	6250	640
		300	350	500	2525	2675	6850	6250	690
		200 Over 50 Sub-Ballast	"	"	"	"	"	"	740
1000 (M.G.)	Wooden	250	350	500	1760	1930	4880	4270	510
		300	"	"	"	"	"	"	560
		200 Over 150 Sub-Ballast	"	"	"	"	"	"	610
	Steel Trough	250	350	500	1790	1940	4880	4270	520
		300	"	"	"	"	"	"	570
		200 over 150 Sub-Ballast	"	"	"	"	"	"	620
	PRC	250	350	500	2025	2175	5850	5250	510
		300	350	500	2025	2175	5850	5250	560
		200 Over 150 Sub-Ballast	"	"	"	"	"	"	610
	CST-9	250	350	500	1730	1880	4880	4270	510
		300	"	"	"	"	"	"	560
		200 Over 150 Sub-Ballast	"	"	"	"	"	"	610

Table 8.3 Dimension References vis-à-vis Fig. 8.3

G Gauge	*Type of sleeper*	*A*	*B*	**C*	*D*	**E*	*F*	F_1	*H*	*J*
1676 B.G.	Wooden	250	350	500	2300	2340	10820	10210	570	4725
		300	″	″	″	″	″	″	620	″
		200 Over								
		150	″	″	″	″	″	″	670	″
		Sub-Ballast								
	Steel Trough	250	350	500	2310	2350	10820	10210	580	4725
		″	″	″	″	″	″	″	630	″
		200 Over								
		150	″	″	″	″	″	″	680	″
		Sub-Ballest								
	PRC	250	350	500	2525	2460	11580	10980	700	4725
		300	″	″	″	″	″	″	750	″
		200 Over								
		150	″	″	″	″	″	″	800	″
		Sub Ballast								
1000 M.G.	Wooden	250	350	500	1790	1850	8840	8230	535	3960
		300	″	″	″	″	″	″	585	″
		200 Over								
		150	″	″	″	″	″	″	635	″
		Sub-Ballast								
	Steel Trough	250	350	500	1810	1860	8840	8230	540	3960
		300	″	″	″	″	″	″	590	″
		200 Over								
		150	″	″	″	″	″	″	640	″
		Sub-Ballast								
	PRC	250	350	500	2025	1970	9810	9210	595	3960
		300	″	″	″	″	″	″	645	″
		200 Over								
		150	″	″	″	″	″	″	695	″
1000 M.G.		Sub-Ballast								
		250	350	500	1750	1810	8840	8230	535	3960
		300	″	″	″	″	″	″	585	″
		200 Over								
		150	″	″	″	″	″	″	635	″
		Sub-Ballast								

Note: Common to Figs 8.2 and 8.3

1. The minmum clean stone ballast cushion below the bottom of sleeper, i.e. A–250 mm.
2. For routes where speeds are to be more than 100 km/hr. A–300 mm or 200 mm along with 150 mm of sub-ballast.
3. Suitable slope shall be given for side slope of ballast profile.
4. Dimensions for formation width (F & F) are given for straight portion only this should be suitably increased taking into account extra ballast shoulder on outside of curves and for super elevation.
5. All dimenstions are in milimetres.

* On outer side of curves only.

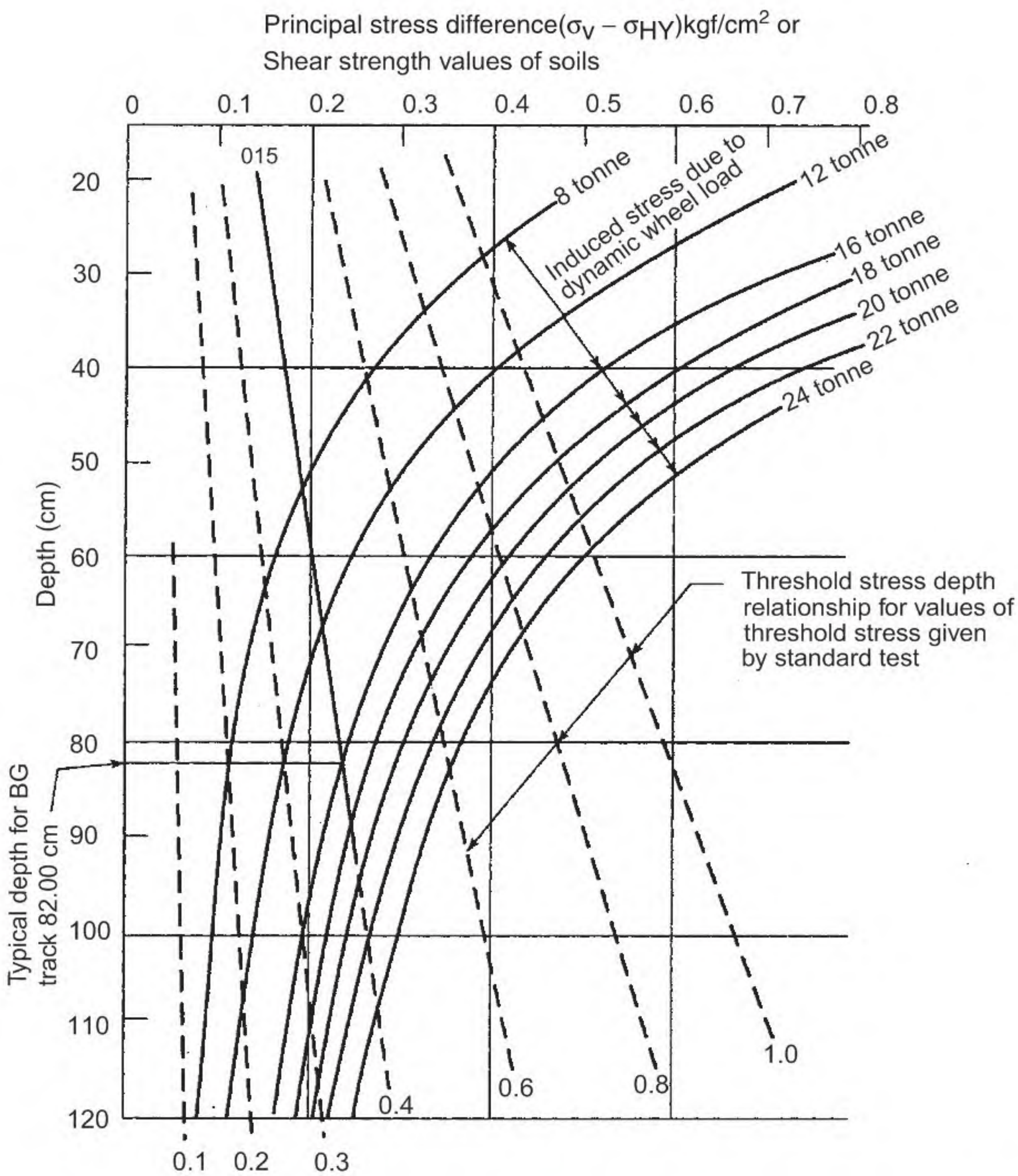


Fig. 8.4 Typical chart of induced stress and subgrade shear strength

8.4.1 Guidelines for Blanket/Sub ballast Thickness for New Construction on Indian Railways

Following guidelines have been issued:

Till such time precise method considering drop in strength under repetative loading and traffic characteristics is developed, a blanket layer for preferred soil should be provided as shown in Table 8.4 in all new constructions. Preferred soils are good soils. Roughly stating, a soil with an N value of 4 and above in Standard Penetration Test (SPT) can be considered a good soil.

For other avoidable soils, thickness is to be determined and increased depending on type of soil, traffic density, axle load, rainfall and other factors relevant to site conditions. For this purpose extensive testing of proposed subgrade soil is to be carried out using cyclic triaxial apparatus.

Table 8.4

Type of route	*Axle load (tonnes)*	*GMT*	*Depth of ballast (cms) + Depth of sub-ballast (cms.)* *Speed (kmph)* Up to 100	*100-130*	*More than 130*
1. Light Mineral Routes	20.32	up to 15	20 no sub ballast	25 + 15 (30)	25 + 15 (30)
		15 – 35	25 + 15 (35)	25 + 20 (45)	25 + 30 (55)
		More than 35	25 + 25 (50)	25 + 30 (55)	25 + 50 (70)
	(a) 22	Up to 15	25 + 15 (30)	25 +15 (35)	
		15 – 35	25 + 25 (50)	30 + 25 (55)	
		More than 35	25 + 50 (65)	30 + 50 (75)	
2. Heavy Mineral Routes	(b) 25	Up to 15	25 + 25 (45)	30 + 25 (50)	
		15 – 35	25 + 55 (70)	30 + 55 (80)	
		More than 35	25 + 70 (85)	30 + 70 (95)	
	(c) 30	Up to 15	25 + 80 (75)	30 + 60 (85)	
		15 – 35	25 + 85 (105)	30 + 85 (110)	
		More than 35	25 + 100 (120)	30 + 100 (125)	

Note: Figure in parentheses () indicate depth of ballast alone.

8.4.2 Specification for Blanket Material

The blanket should cover the entire width of the formation from shoulder to shoulder. The blanket material should be a well graded coarse grained material and the particle size distribution curve should fall within two of the enveloping curves shown in Fig. 8.5. If the material contains plastic fines, the percentage of fines, i.e. particles passing 75 microns sieve, should not exceed 5%. If fines are non-plastic, these can be allowed up to 12%.

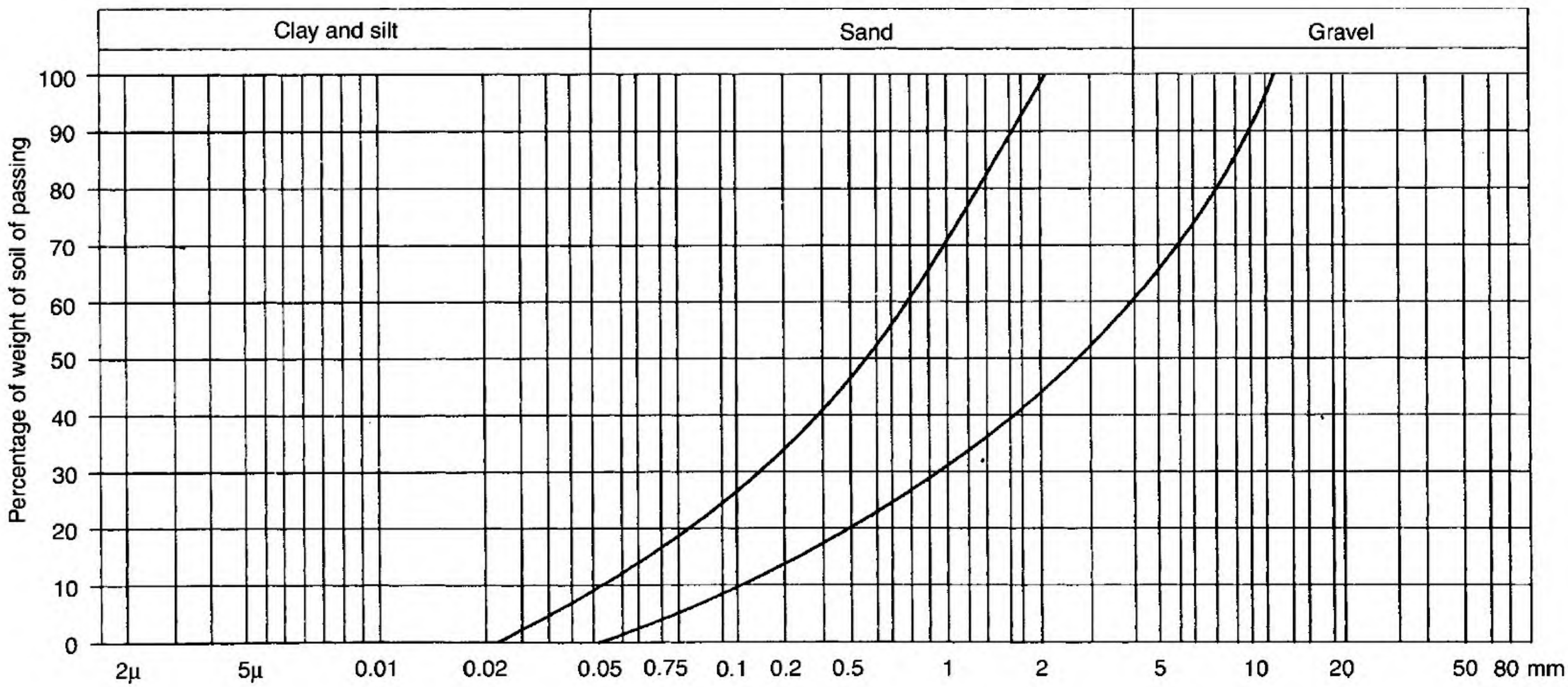


Fig. 8.5 Enveloping curves for blanket material

Note:

1. No skip grading to be allowed.
2. If fines in the proposed blanket material are plastic these shall not exceed 5%.
3. If fines are non-plastic the same can be allowed up to 12%.
4. Unformity coefficient (*D*-60/*D*-10) in no case less than 4–preferably more than 7.
5 The coefficient of curvature $(D30)^2/D_{60} \times D_{10}$ to be within 1 and 3.

8.5 FORMATION

8.5.1 Purpose of the Formation

The formation is required to serve the following purposes:

1. To provide support for a stable track structure, i.e. cumulative settlements under repeated loadings should be as uniform as possible and within limits so that track deterioration rate on account of formation is acceptable.
2. To provide desired line and level for track.
3. To provide a smooth and regular surface on which ballast and track can be laid.

8.5.2 Earthwork for Formation

To keep the permitted gradients and to avoid too frequent changes of gradient, it is usually necessary for the level of formation to be below or above the natural ground level in different places.

The natural ground must, therefore be lowered by a cutting, where it is high, or raised by an embankment where it is low. In extreme cases, where the depth of cutting would be excessive, tunnels are made through the ground. And, where an embankment is not possible, the track is supported on bridges or viaducts.

When a new railway line is planned, soil surveys and exploration must be undertaken according to the Guidelines for Earthwork described later. An effort is made to locate it in such a manner that the amount of material excavated from the cuttings is sufficient to form the necessary embankments. If this can be done, the expense of disposing of surplus excavated material or of obtaining material for embankments from other sources will be avoided.

If the material from excavation is not sufficient to form the necessary embankment, the required material will generally be obtained from the borrow pits located close to the railway alignment. In low lying flood prone country, the formation level is kept well above the highest known flood level of the site by forming an embankment with material obtained by excavating borrow pits on either side of the railway line.

The land purchased for the construction of the railway line is generally enough to accommodate the slopes, the borrow pits and the spoil banks, and for some margin between the toe of the bank and the borrow pits/soil banks [Figs 8.6 (a) and 8.6 (b)].

8.5.3 Formation Width

Formation widths generally adopted in the Indian Railways are given in Table 8.5. (Figs 8.2 and 8.3).

8.5.4 Guildelines for Execution of Earth Work

Classification of soils If the trackbed is laid on natural ground (i.e., either on level ground or in a cutting) the control of water in the trackbed is a major factor in designing the construction layers

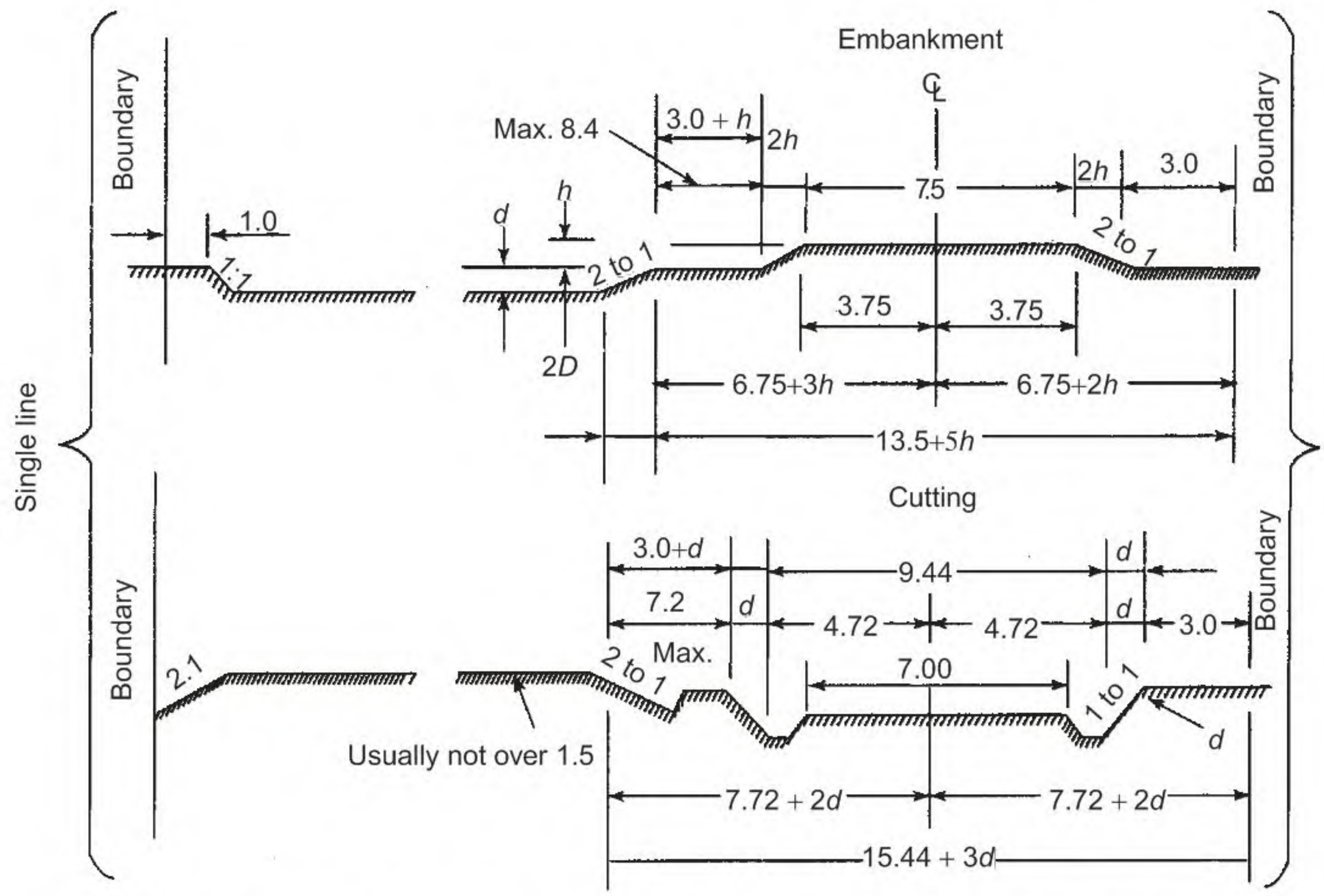


Fig. 8.6 (a) General cross-sections showing width of land to be taken up for BG

vis-à-vis the type of subgrade material. The types of material which are commonly encountered in subgrades are:

Non-cohesive soils	Gravel or sand
Cohesive soils	Silt or clay
Organic soils	Peat
	Organic clays and silts
Cemented sedimentary rocks	Sandstone, limestone
Metamorphic rocks	Slate
Igneous rocks	Granite or basalt

Soil Exploration and Surveys Soil exploration surveys are to be carried out as a part of preliminary and final location surveys for all doubling, conversion and new construction projects to enable identification and classification of soils. For this purpose, exploratory borings and soil sampling should be undertaken along the alignment and soil samples collected from the areas where borrow pits are to be located, at intervals of about 500 metres or at closer intervals wherever change of soil strata occurs. In case subsoil problems are likely to be encountered, the spacing of exploratory borings should be reduced for adequately covering the variations in the subsoil strata up to the concerned depths. On doublings, sampling should also be done at locations known to be troublesome in the existing track. Based on the track results of these rail samples, more detailed investigations may have to be undertaken at the time of the final location survey.

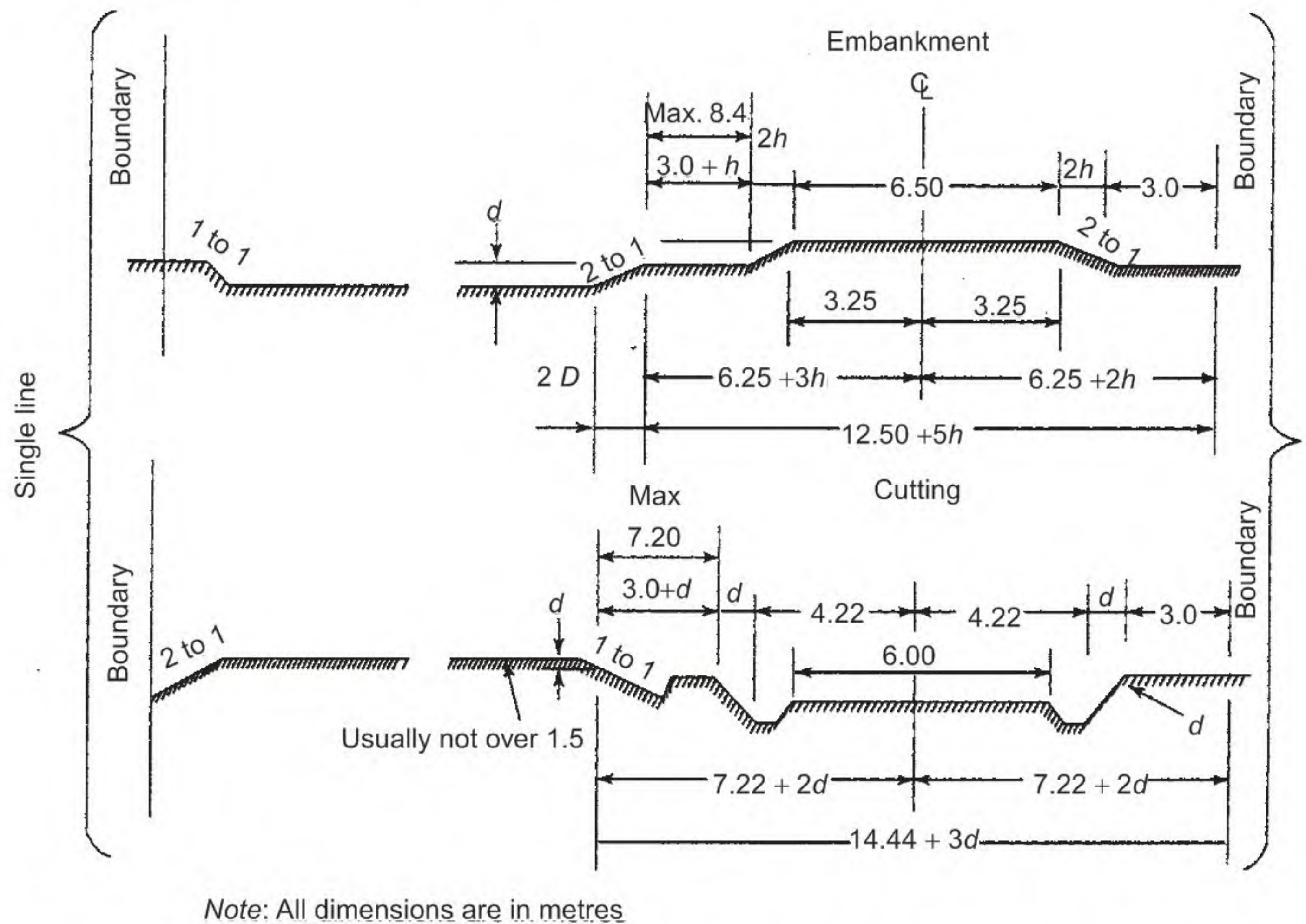


Fig. 8.6 (b) General-cross sections showing width of land to be taken up for MG

Table 8.5

Embankment	*BG*	*MG*
1. Single line	6,850	5,850
2. Double line	11,580	9,810
Cuttings (excluding side drains)		
1. Single line	6,250	5,250
2. Double line	10,980	9,210

Organic clays, silts and peat shall not be used for making of embankment. Cuttings in these types of soils should be avoided and if this is not possible, special investigations and measures will be necessary.

Design of Railroad Formation To ensure a trouble-free service from a railroad, the design and construction procedure should be such that the railway track is able to sustain the track geometry under anticipated traffic densities and axle loads during service under most adverse conditions of weather and critical condition of maintenance of track structure. It necessitates that

1. Bank/cutting is structurally stable.
2. Settlement in subgrade supporting soil mass are within permissible limit.
3. There are no bearing capacity failures.

The water content at which a soil is compacted has an effect on all the physical properties of compacted soil. Embankment soil shall attain a moisture density equilibrium during weather cycles and the bank-cutting should be safe for such service conditions. Therefore, design parameters should be commensurate with the most unfavourable conditions.

Compaction of Earthwork It has been realised that compaction of earthwork is essential for obtaining a uniform soil mass of desired density and known soil properties. The method of compaction should satisfy the conditions of economy and efficiency of earthwork construction. (The details of the earthworks design process are beyond the scope of this book.)

Although compaction of earthwork is a necessary condition to achieve a stable bank and subgrade, it cannot guarantee the stability of the formations, particularly in the following cases:

1. Excessive creep or slipping of slopes, because the long-term shear strength and water contents are not governed by compaction done at the time of construction.
2. Swelling and shrinkage of soils in wet and dry seasons, respectively, because physiochemical properties of a soil do not get altered by compaction.
3. Mud pumping at ballast soil interface.
4. Settlements due to consolidation of bank and sub-soils which can occur even for a few years after construction of the bank.

   Special measures are required to be taken in such cases. These have been discussed in Sec. 8.7.

Methods of Compaction The methods of compaction can be divided into three groups, viz.

1. Suitable for sandy or silty soils with moderate cohesion; these soils on drying do not form hard lumps of soils which could create difficulty in breaking under rollers.
2. Cohesive soils such a clayey sands (SC), clayey gravels (GC), silty sand mixture (SM), silty gravel mixture (GM) and other soils having predominantly clay fraction, which form hard lump of soil on drying and are difficult to break under rollers; and
3. Suitable for cohesionless soils which remain loose under dry and wet conditions.

The classification between the first and the second categories largely depends on the percentage of plastic fines and their properties.

Compaction of Sandy or Silty Soils with Moderate Cohesion

1. For soils with moderate cohesion, compaction in layers by rollers is most effective. Vibratory rollers have been found more effective than static rollers and greater thickness of layers can be allowed.
2. Water content and densities obtained in the field trials should conform to IS: 2720 (Pt. VIII)-1983 to determine thickness of layers, dry densities to be achieved and the optimum moisture content. Densities should be around Max. dry densities obtained during these tests and form the basis of specifications and control. The moisture content controls may not be specified and 98% of such densities as achieved in field trails are only specified.

Compaction of Cohesive Soils (Clays)

1. The main objectives of compacting predominantly clayey soils is to achieve a uniform mass of soil with no voids between the chunks of clays which are placed during the earthwork. Rollers will tend to sink into the soil if the moisture content is too high while chunks will not yield to rolling by rollers if the moisture content is too low. Maximum Dry Densities and Optimum Moisture Contents should be ascertained from laboratory tests for heavy compaction as specified in IS: 2720 (Pt. VIII)–1983. The laboratory results may only be used for determining those practically achievable values of densities and optimum moisture contents as obtained from the field trails as per IS: 10379–1982.
2. Sheep foot rollers are most effective in breaking the clods and filling large spaces. The layer thickness should be equal to the depth of the feet of roller plus 50 mm.

Compaction of Cohesionless Soils

1. An effective method of compacting cohesionless soil is to use vibratory compaction. Moisture content control being redundant is not necessary. However, the railway embankments may show small settlements during the initial stages of traffic after the line is opened. Moreover, introduction of new type of stock with different vibratory characteristics and axle loads etc. may also result in small settlements due to the embankment soil undergoing further compaction. These settlements would be small and may not present much problem. As such, there does not appear to be much gain in compacting the whole embankment formed of purely cohesionless soils except in the top 1 m layer.
2. Poorly graded sands and gravels with uniformity coefficient of less than 2.0 should not be used in earthwork for the banks to safeguard against liquefaction under moving loads or especially due to an earthquake tremor.
3. IS Code No. 2720 (Pt. XIV)–1983 should be followed for compaction in cohesionless soils. Minimum 70% relative density must be achieved during compaction which shall be done in layers of uniform thickness not exceeding 60 cm.

Placement of Back-fills on Bridge Approaches and Similar Location

1. The back-fills resting on natural ground may settle in spite of heavy compaction and may cause differential settlements vis-à-vis abutments which rest on comparatively much stiffer base. To avoid such settlements, it is essential to compact the back-fill in the properly laid layers of soil. The back-fill should also be designed carefully to keep:
   (a) Settlements within tolerable limits.
   (b) The dynamic response or the coefficient of sub-grade reaction on the approach of bridge and on the abutments should not have an abrupt change.

Cuttings

1. If the subgrade soil is not fit to absorb stresses of traffic, the cutting will be made deeper to

take a layer of blanket/sub-ballast of adequate thickness which shall be compacted at 70% of the relative density with vibratory rollers.

2. In cutting slope, softening of soil occurs with the passage of time: therefore, long term stability is vital for designing the cuttings.

General Points

1. Drainage of Non-cohesive Soil.

   The essential property of a non-cohesive soil is that the individual particles of material are entirely separate from one another and water passes freely through the medium in the interstices between the particles. Such materials normally make fairly good subgrades and can easily be drained so that the water level remains low in the ballast.
2. The Drainage of Cohesive Soils:

   A cohesive soil is one which contains at least 10–20% of clay particles. These particles are extremely small and have a plate-like structure (around 100 microns across and only a microns thick or less). It is this property which—in the presence of water—gives a cohesive soil its characteristics of mouldability.

   The pores between the particles are extremely small, and form a network of fine capillaries with a very low permeability. By virtue of the phenomenon known as capillary suction, the faces of a hole dug in a body of cohesive soil remains apparently stable for some time. If rainfall or some other external water supply permeates the soil, the capillary suction is eventually dissipated, the particles being oversaturated with water are no longer held together, and the face of the excavation collapses. The length of time taken for this to happen depends on the pre-existing conditions in the pores of the material.
3. Drainage of Other Materials:

   Peat is a special case, and has a variety of textures. It will shrink if drained or subjected to repeated or static loading—rarely otherwise. Fibrous peat has a high angle of friction which activates fully only after large strains have occurred. Drainage of peat may have a harmful effect as it results in large settlements which may affect the fixed installations near the track. The track itself would require regular lifting.
4. Adequate drainage must be ensured taking into account the worst in service conditions. The road bed should have cross slope of 1 in 30 from the centre toward the side drains on either side.
5. The side slopes of the embankments and cuttings may be protected by special measures, such as, turfing etc. to prevent erosion.
6. It will be necessary to keep the borrow pits sufficiently away from the toe of the embankments to prevent base failures which may occur due to lateral escapement of the soil.
7. In the case of embankments in highly cohesive clayey soils, special treatment may be necessary to ensure a stable formation. Such measures will have to be determined after a thorough investigation and study of the soil properties.
8. Special investigation will also be necessary vis-à-vis high-full construction on swampy ground, marshy lands and deep cuttings.

8.6 UNSTABLE FORMATIONS

The main problems caused by unstable formations are:

1. Variation in track levels particularly during extreme hot or wet season, causing the need for speed restriction or increased maintenance.
2. Loss of ballast which sinks into the formation.
3. Instability of bank slopes resulting in slips and consequent disruption of traffic.

8.6.1 Causes of Formation Troubles

If any formation is suspected of giving trouble, the first step should be to investigate the cause of the trouble. To do so, ballast penetration profiles and other relevant data along with the history of section and the trouble should be obtained and analysed keeping in view various features of the site and probable causes of failures in the area or stretch.

In most cases, the basic cause of trouble is found in deficient track structure, especially the inadequate and clogged ballast cushion. In such cases, the remedy lies in deep-screening the ballast to recoup the ballast cushion, preferably by raising the track instead of cutting into the formation on hardened layer of ballast-ash and soil.

In relation to instability, when formation too is a contributory factor in the chain of factor mentioned below, then instability entails remedial measures:

1. Instability problems due to railway cutting/embankment not being stable, resulting in excessive creep deformations.
2. Excessive swelling and shrinking of bank soil causing large volumetric changes and thus unequal settlement and heaving of the formation, disrupting the track levels and alignment.
3. Bearing capacity failures due to
   (a) Inadequate cess width and/or bank slopes.
   (b) Inadequate thickness of ballast and blanket.
4. Other causes such as loss of formation soil caused by porcupines, ants, rats, seepage, etc.

Whatever be the cause, the problem aggravates due to faulty drainage during monsoons. The rain water impairs the soil strength by wetting and higher pore water pressures. Hence the track foundations should be designed to be adequate.

In Fig. 8.7, typical cumulative settlements are shown for stable and unstable sites. The small exponentially linear settlements for stable sites have been observed at several sites. This pattern of behaviour is used for

1. Checking stability of a formation site.
2. Evaluating the efficacy of a treatment.
3. Predicting maintainability problems with heavier traffic or axle loads.
4. Checking the comparative behaviour of two subgrade, materials including the blanket material.

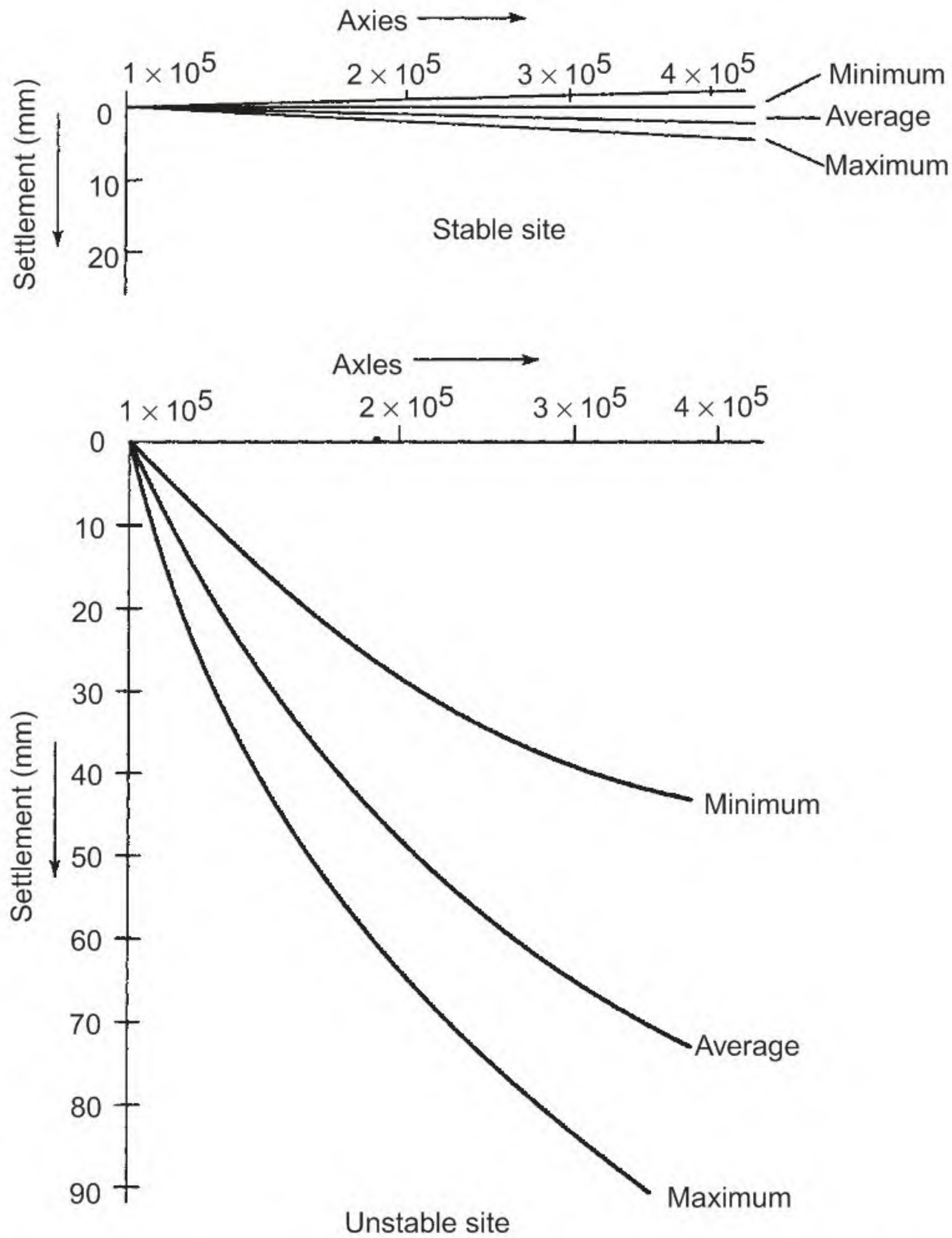


Fig. 8.7 Typical cumulative settlement of formation on stable and unstable sites

It is necessary to treat any unstable formation as early as possible due to the following:

1. To eliminate the probability of disruption in traffic due to blockade or speed restrictions.
2. To economize in track maintenance.
3. To maintain track quality.
4. To avail full life of track components and to avoid untimely renewals, replacements and recoupments.
5. Systematic track maintenance is possible only over stable formation.
6. Any modernization of track such as introduction of concrete sleepers, LWR/CWR, machine maintenance, high speed turnouts, etc. would succeed only on stable formation.
7. Due to the above reasons, requirements of blocks, speed restrictions, etc. reduce automatically.

8.7 FORMATION TREATMENT METHODS

One or more of the following methods are employed depending on the situation:

1. Provision of a 30–100 cm deep blanket of coarse grained material.
2. Grouting of formation and bank with—
   (a) Cement and sand slurry
   (b) Lime slurry pressure injection
3. Slope and cess repairs with subsurface drainage to provide a stable base for track foundation, i.e. ballast and blanket.

Grouting with cement or lime provides temporary relief for a few years only and would require repletion for restabilisation.

In the past, several other methods had been tried but did not give satisfactory results. To mention a few—

1. Lime piles
2. Vinyl drains
3. Sand drains
4. Moorum blanket
5. Cationic bitumen emulsion
6. Polyethylene sheet
7. Maxphalt crete
8. Pouring sand on ballast section
9. Geotextiles to check subgrade failures

It may be noted that vertical or surface sand drains, moorum blanket, geotextiles are useful civil engineering tools to tackle foundation and earthwork problems and their judicious employment should be done if warranted in a project or at a location.

Main causes of formation trouble and remedial measures found effective are tabulated in Table. 8.6.

8.8 SUBSTRUCTURE MAINTENANCE MANAGEMENT USING GROUND-PENETRATING RADAR

Track substructure is the term used to describe the different layers of rock and soil under the sleepers, including the ballast, sub-ballast—or formation protection layer—and the subgrade soil. Poorly performing substructure not only leads to high rates of track geometry degradation but also promotes higher rates of wear of the rail, sleepers, fastenings and other track components.

Substructure problems are typically associated with poor drainage, fouled ballast, subgrade failure or deformation, and longitudinal variation of conditions. Correction of chronic problems requires the root causes to be determined—typically one or more of the mentioned above. Ground-penetrating radar technology can be used to assess the condition of track substructure and produce quantitative indices for use in the management of track maintenance.

Table 8.6

Nature of defect	*Cause*	*Action/Treatment*	*Remarks*
1. Track level variation	(a) Track structure deficient	— Improve drainage — Recoup ballast, if necessary after deep-screening — Track components to be completed	— Even a good formation shall fail under deficient ballast cushion, etc.
	(b) Formation unstable	— Investigate the causes and formulate treatment plan	— Essential for successful treatment — In old bank, lack of compaction and subsoil settlements cannot be the cause of trouble
2. Unstable bank/ cutting	1. Inadequate factor of safety of slopes	— Proper slopes of bank/ cutting and drainage, etc. to be provided	— Old faileld earthwork requires design with residual strength parameters
	2. Inadequate cess width 3. Improper sub-surface drainage	— provision of sand layers	— New earthwork should be with sand layers, toe drains, etc. for proper subsurface seepage
3. Inadequate track founda-tions	Bearing capacity failures due to — inadequate ballast and blanket — inadequate cess	provide: — desired blanket thickness — proper cess width	— Partial blanket in case of deep ballast pockets can be considered. — Cess width can be up to .5 m in special loations/cases
4. Trouble during summers being acute	Swelling and shrinking soils	— 1 m blanket for full width of cess and if necessary on top of slopes also. — Wider cess to keep the zone of m/c changes away from track supporting earth mass.	— Only successful method of checking m/c variations in the body of the bank is to cover with a soil cover of sand or non-swelling soil.
5. Loss of soil	Termite, rat and porcupine	— Contact and find solution from local agricultural and forest authorities. — Grouting of holes with clay, etc.	— Premonsoon survey necessary to avoid sudden sinkage under traffic.

8.8.1 How it Works

The GPR method transmits pulses of radio energy into the subsurface, and then receives returning pulses that have reflected off layer boundaries below the track surface. GPR antenna pairs, consisting of transmitter and receiver pairs, are moved along the track with a continuous series of radar pulses, giving a profile of the subsurface. Reflections of the GPR pulse occur at boundaries in the subsurface where there is a change in material properties. Only a portion of the pulsed signal is reflected at a layer boundary, and the remaining part of the pulse travels across the interface to be reflected again back to the receiver from another interface boundary. The time the pulse takes to travel through the layer and back is controlled by the thickness and properties of the material.

The data produced by GPR helps in easy identification of the substructure problems such as poor drainage, fouled ballast, subgrade failure or deformation, or longitudinal variation of conditions. An optimum solution to the problem can then be found.

Chapter 9

Welding of Rails

9.1 GAP BETWEEN RAIL ENDS

Since inception, the existence of rail joint is the bugbear of every permanent wayman convinced that the gap between the rail ends should be proportional to the length of rails to allow for free expansion of rail metals during hot weather, i.e. for twice a given length, the amount of clearance between the rail ends should be double.

The presence of a gap between rail ends was generally thought to be the prime cause of impact at the joints. Although, the provision of long rail led to reduction in the number of joints, it was disfavoured due to increase in the intensity of impact, if proportionately wider gaps were to be provided at the ends. Therefore, welding of rails in long lengths was technically disinteresting.

Later, it was realised that the intensity of impact is not directly proportional to the width of the gap, and the gap itself need not be exactly proportional to the length of the rail because the rail could not really behave as a free rail when laid in track. With this realisation, any reduction in the number of joints was welcome, as it had the prospect of minimising, if not completely eliminating, the problems connected with the jointed track.

Given this background, welding of rails into 3 rails and 10 rails was started. These have been named as short welded rails (SWR) to distinguish from long welded rails (LWR).

Experience with short welded rails has been that joints with panels of length more than three rails cause more damage to track than the proportional advantages derived from the elimination of joints. Rails panels longer than three rails (39 m for BG and 36 m for MG) are, therefore, no longer in use in the Indian Railways.

Rails welded into long strings of 200 m or more—denominated as LWR/CWR—behave differently at the joints and are governed by their own inbuilt system, as discussed in Chapter 10.

9.2 METHODS OF WELDING OF RAIL JOINTS

Rails in India are produced in standard length of 13 m for BG and 12 m for MG, respectively. For making them into long lengths, two methods that are extensively used are:

1. Electric flash butt welding and
2. Alumino-thermic welding.

Besides, gas pressure welding and electric arc welding methods are also used but to a limited extent.

9.2.1 Electric Flash Butt Welding

This type of welding is generally done at a stationary plant, which, in addition to rail welding machine, is also equipped with many ancillary machines for ensuring good quality welds. A modern flash butt welding plant has the following arrangement.

The rails are brought in by train on BFR type of bogie stock on to sidings situated under the gantry cranes and are unloaded on the stacking platform or stillage. The rails are then passed forward on roller conveyors through the rail straightening machine. The standard of straightness required for rails meant for welding is much higher than that required for fishplated joints, and it is often found that the end of 2 feet or so of the rail is not straight enough to ensure good alignment of joint. The end of every rail is then tested for horizontal and vertical straightness, against a straight edge. Any rail that is not true, it is straightened by the application of hydraulic rams or jim crows. From here the rails either go straight to the welding shed or pass through the sawing and drilling machines for cropping of ends and drilling of holes in old rails. Hereafter, the rails move on the roller conveyor in the welding shed. Rail ends are then ground lightly to remove any rust or scale to give good contact with the copper electrodes in the welding machine.

To enable the work to proceed in all weathers further processes are carried out in a long shed, and these are:

(a) Electric welding
(b) Stripping-upset metal removed to within 0.75 mm of rail profile
(c) Shower cooling
(d) Foot grinding
(e) Profile grinding
(f) Post straightening

Presently, electric Flash Butt welding is done in Indian Railways by AI-APHF-30/APHF-60. It is a modern welding machine purchased from verson AI Ltd of Scotland. Its salient features are:

1. Automatic rail positioning, twist correction and close tolerance alignment of rail running surface at a pre-selected gauge face.
2. Built-in weld joint crown adjustment.
3. Programmable for a wide range of rail steels, including the wear resisting and chromium grades, and section up to a maximum of 78 kg/m.

4. Solid state electronic weld control unit, incorporating feedback systems and individual setting of velocity, pressure, energy and displacement.
5. Automatic monitoring of weld current, time, force, velocity and machine utilisation.
6. Automatic provision for planned preventive maintenance data.
7. AC or DC weld current options with post-heating facilities for wear resistant rail steels.
8. Automatic integral weld upset removal unit operating within overall cycle time.
9. Typical cycle time of 135 seconds, including rail-end positioning, rail alignment, welding and upset removal.
10. Average production capacity of 20 weld per hour.

There are five possible stages to the flash welding process: burn off, preheating, flashing, forging and post-weld heat treatment. Based on the extensive research, following points are kept in view, while welding.

(a) The welding voltage should be kept at the lowest value allowing continuous flashing.
(b) The rail ends should be burnt off as the first phase of welding to allow good contact over the full section.
(c) In pre-heating the out-of-contact period should be of similar duration to the in-contact time to facilitate uniform heat input.
(d) A short flashing period should occur between individual pre-heat cycles to maintain rail end squareness.
(e) Final flashing must be continuous with no evidence of breaks or short-circuiting of the work piece. The flashing velocity should be as high as possible.
(f) Weld forging should follow flashing with no break and should use the maximum forging load.

Important parameters evolved for flash butt welding rails on Indian Railways are as shown in Table 9.1.

Table 9.1 Important Parameters of Flash Butt Welding of Rails

Rail section	*Type of welding plant*	*Butting load Capacity (tons)*	*Flashing stroke (mm)*	*Butting stroke (mm)*	*No. of preheats*	*Burn off time (sec.)*	*Fnal flashing time (sec.)*
90 R (7 UTS)	AI-APHF-30	37	12	8	8	20	25–30
52 kg (72 UTS)	AI-APHF-30	37	12	10	10	10	35
52 kg (90 UTS)	ESAB	79	14	10	10	30–40	20–25
60 kg (72 UTS)	AI-APHF-30	37	12	10	12	10	40
60 kg (90 UTS)	ESAB	79	14	10	12	30–40	20–25
60 kg (110 UTS)	AI-APHF-60	60	5	5	8	5	19–24

Final Grinding and Straightening After stripping, the newly welded joint is passed under a shower to bring down the temperature. The joint is then finally ground to exact profile. It is checked for straightness and is brought within the desired tolerances with the help of the post-straightening machine. The rails are then moved outside the shed on the roller conveyor to the stacking area.

The stacking area is spanned by 40 (if 15 rails are being welded together in the plant) power operated overhead winches, all of which can be operated in unison to cross convey the rails from the conveyor to stack or stack to train. Some plants are provided with end loading arrangement for loading into special long welded rail loading rakes.

Mobile Flash Butt Welding Plant (*Fig. 9.1*): The plant is housed in a rolling stock-which is equipped with its own motive power capable of driving it at 80 kmph. The plant has the following equipment:

(a) Welding head mounted on a telescopic crane for its positioning on rail.
(b) Diesel engine with an output of 277 kW (375 HP).
(c) Alternator of 290 KVA capacity
(d) Hydraulic pump
(e) Control cabinet

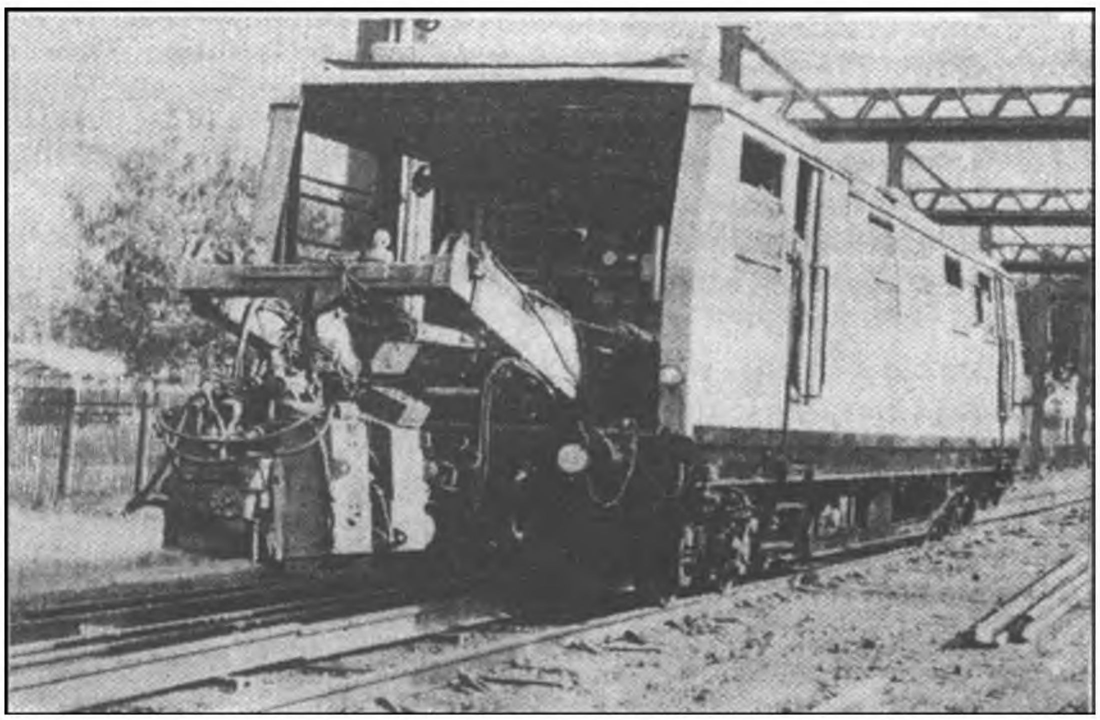


Fig. 9.1

Welding of a joint is completed in the following sequence:

(a) Clamping and centering of the rails
(b) Start order for automatic working
(c) Warming up
(d) Flash burn
(e) Compression
(f) Shearing off the upset metal
(g) Release of the rails

The time of welding a joint is 130–180 seconds. Output per hour is of 6–8 welds. The rail end grinding is done in advance to achieve the desired level of conductivity.

The plant can be usefully deployed on:

(a) New constructions, where single rails can be directly converted into LWR/CWR
(b) For converting short welded panel into LWR
(c) For *in situ* cutting and replacement of defective welds
(d) As a stationary welding unit in a depot

Judicious use of this plant can arrest the increasing trend in the population of thermic welds.

9.2.2 Gas Pressure Welding

1. *Principle of the process* Gas pressure welding is not a fusion process—it is solid phase bonding process. In this process, the rail ends are butted squarely against each other under pressure and the joint is accomplished at a temperature of about 1250–1300°C.

   This process utilises the mixture of oxygen and acetylene gases for heating the rail ends, and thereupon, the application of high pressure causes the bonding of rail ends. Since the butting faces do not reach the melting point of the rail steel, the mode of joining is different from that of the other fusion types of welding.
2. *Equipments* The Japanese Gas Pressure Welding Plant, Model TGP-5—used on Konkan Railway—comprised.

   (a) Pressure welding device
   (b) Hydraulic pump and its control unit
   (c) Gas cylinder and its accessories
   (d) Burner assembly
   (e) Gas flow control box
   (f) Automatic trimming device
   (g) Rail-end surface grinders
   (h) Disc and surface grinders
   (i) Flange correctors
   (j) Hot rail reform correctors (both vertical and horizontal)
   (k) Power generation set
   (l) Portal gantries and electric hoists
   (m) Rail lifting arrangements
   (n) Winch for pulling welded rail panels
   (o) Different type of rollers
   (p) Different type of working tools

3. *Procedure of Welding* The welding procedure entails the following operations:

   (a) *Rail end preparation prior to welding* In order to make a sound weld, the abutting faces should match squarely. There should not be any gap between the rail ends to be welded to avoid the formation of oxide film in between, which may lead to flat fracture of the joint. The rail ends, therefore, are ground and finished smooth and square. The embossed markings on the webs of the rails under the rail clamps are also required to be ground to avoid misclamping.

(b) *Alignment of rails* After the end preparations, the rails are placed on adjustable rollers for welding. The rail-end faces to be butted are cleaned by Carbon tetrachloride solution to remove traces of oil, grease, dust, rust, etc. The rail-ends are then aligned properly with the help of 1-m-long straight edge.

(c) *Clamping of rails and butting* After alignment, the welding machine is mounted on the rails. Both the rails are clamped with the help of hydraulic clamps, followed by the application of butting pressure. After butting, the 'upset' scale is adjusted to the 'upset' required—it is 26 mm for 52 kg rails—and the automatic trimmer is placed at its place.

(d) *Rail heating and upsetting* The burner assembly consisting of two halves is placed around the junction of rail-ends to be welded. Since uniform and concentrated heat is required to keep the core of the rail sections at the heating temperature without overheating the external surface, the burner is designed to have a contour similar to that of the rail section. Oxyacetylene is used for heating the rail-ends to a temperature of 1250–1300°C. This temperature renders easy plastic flow for the rail-ends to cause the desired upset due to the application of butting pressure applied initially.

(e) *Trimming of upset metal* As soon as the desired upset is formed, the flame is put off. The butting is stopped and immediately the automatic trimming operation is put on. After trimming of the upset metal, the burner is taken off the rails, the machine dismounted and taken out from the rails.

(f) *Dimensional check* Dimensional check for both vertical and horizontal tolerances is then carried out. If required, hydraulic Hot-Rail Reform correctors shall be used for corrections immediately.

(g) *Post-Weld finishing* After dimensional check, the rail joint is moved over the rollers. At the next stations, the excess of upset metal at the head portions is finished smooth by grinding. Since the trimmer does a neat job, the web and flange are not subjected to grinding.

(h) *Quality Control and Testing* The finished joint is subjected to Dye-penetrant tests for the detections of surface cracks. If any is detected, it is subjected to Ultrasonic tests.

To judge the quality of welding functions, one out of every 100 joints shall be subjected to transverse bend tests to find the static breaking load, deflection and the fracture characteristics of the joints. The Brinal Hardness tests shall also be carried out on the weld joints.

4. *Welding Parameters of gas welding* The following parameters have been used for welding of 52 kg rail joints on Konkan Railway. The heating time is 7–8 minutes per joint. The welding Pressure is 320 kg/cm^2 (also see Table 9.2).
5. *Output* On Konkan Railway an output of 3 weld per hour could be achieved.
6. *Acceptance Standards* Same as that of Flash butt welding.

Table 9.2

Gas	*Cylinder pressure* (kg/cm^2)	*Working pressure* (kg/cm^2)	*Volume* (*lit/min*)
Oxygen	7.0	0.30–0.40	90–95
Acetylene	1.4	0.70–0.80	90–95

9.2.3 Code of Practice for Flash Butt Welding

A code of practice for flash butt welding of rails has been evolved by RDSO. The important provision of the code are as follows:

1. *Types of Rails to be Welded* New or old but serviceable rails shall be welded. The heaviest section to be welded shall be determined according to the capacity of the individual plant. Only rails of the same poundage and cross-section shall be welded together. As far as possible, rails of the same specification rolled by the same manufacturer shall be welded together.
2. *Marking of Rails and Welded Rail Panels* Old rails to be welded shall be match-marked in the track before releasing to achieve maximum possible uniformity of head profiles in the welded panels.

   Rails to be welded are segregated into (a) old rails and (b) new rails.

   (a) *Defective rails* Rails having cracks or other defects, such as heavy corrosion pits or which are worn to more than 2 mm depth at rail seat, shall not be welded.
   (b) *Rails with holes* Ends of old rails with fishbolt holes/bored holes need to be cropped by a minimum lengths of 450 mm before welding, and the cropped end shall be free from roughness, burns and defects such as piping, etc.
   (c) *Permissible vertical wear* The vertical wear in old rails to be welded shall be within the limits specified in Table 9.3.

Table 9.3

Rail section	*Standard height of new rail* (mm)	*Minimum height of worn rail*
60 kg/m	172.00	<8 mm from the standard
52 kg/m	156.00	<6 mm from the standard
90R	142.88	<4 mm from the standard
75R	128.59	<3 mm from the standard

   (d) *Lateral wear* Old rails to be welded should preferably show similar pattern of side wear. The rail having more than 6 mm of lateral wear are not to be welded.

In the case of new rails, following entail welding:

(a) *New rails with fish bolt holes* It is to be ensured that the outer edge of the hole nearest to the end is at least 40 mm (17 mm allowed for upsetting of metal, 4 mm for shrinkage and 18 mm for the heat affected zone), from the end to be welded. This is necessary to avoid the heat affected zone of the weld extending up to the edge of the hole.

(b) *Difference in height between the ends to be welded* The individual welded ends may have a maximum difference in height of 1.2 mm at the welded joints at the time of welding. The top table of the rail should be kept in one level at the time of welding. The difference in height shall be transposed to the foot of the rail, which should be planed straight by grinding.

Difference in Width of Rail-Head between the Welded Joints

1. The difference in the lateral dimensions of the heads of two old rails to be welded shall not exceed 2 mm.
2. In case of old and new rails, if the difference between the width of rail head at the welded ends is less than 0.5 mm, the same should be adjusted by keeping equal offsets on either side, which shall later be ground down. Any difference in excess of 0.5 mm in case of both new and old rails shall be transposed to one side of the head, keeping the other side perfectly aligned. The aligned side of such welded panels shall be distinctly marked and shall form the gauge side when laid in track.

Pre-welding Inspection of Rails

A thorough inspection shall be carried out at the plant on the arrival of the rails to avoid welding of rails with the following defects: (a) End-bends in the vertical or horizontal plane greater than ± 0.75 mm on a 1.5 straight edge. (b) Deviation of the end from the square greater than ± 0.5 mm.

The rails rejected due to non-compliance with the above limits shall not be welded and may be used on unwelded track with fishplates after drilling the necessary holes.

9.2.4 Records of Welds

Records of all the welded joints shall be maintained in a register and shall include the information indicated in the proforma laid down by RDSO. This record will be useful in finding out the cause of fracture that may occur on the weld any time during its service.

The recorded parameters include:

1. Welding current
2. Upset force pressure
3. Displacement
4. Welding time

9.2.5 Acceptance Tests for Welds

1. *Transverse Test* The test weld samples, not less than 1.5 m long with the weld in the middle are to be placed on cylindrical/semi-cylindrical supports having 30–50 mm dia. Test span is 1.0 m, except otherwise shown, below. The test joint must withstand the specified minimum breaking load, with minimum deflection, without showing any sign of cracking or failure (Table 9.4).

Table 9.4 Flesh Butt Weld Joint

Rail type	*Span (m)*	*Min. breaking load (t)*	*Min. deflection at centre (mm)*
60 kg (UIC) Head hardened	1.25	115	30
60 kg (UIC) Chrome manganese alloy steel rail	1.25	110	12
60 kg (UIC) 90 UTS	1.0	150	20
52 kg (72 UTS)	1.0	120	15
60 kg (UIC) 72 UTS	1.0	135	30
52 kg (72 UTS)	1.0	100	30
90 R (72 UTS)	1.0	80	30
75 R (72 UTS)	1.0	70	30
60 R (72 UTS)	1.0	60	25

2. *Frequency of Transverse Test* In plants, where weld recorders are not provided, one test joint is made before the regular production starts for the day. In plants provided with weld recorders, one test joint per thousand joints is made and tested. Should the test joint fail to satisfy the test requirement, all the panels represented by the test joint shall be marked suitably and kept under observation in track or shall be tested ultrasonically, and then defective joints cutout and rewelded.
3. *Metallurgical Test* A macrograph of the joint shall be taken after every 5000 welds.
4. *Ultrasonic Test* It would be desirable to provide arrangements for ultrasonic testing of each welded joint. If capacity permits, the rails before welding should also be scanned ultrasonically to weed out any defective rail before welding.

9.2.6 Welding Tolerances

Each completed joint shall be checked for straightness, alignment and finishing by using a 1-m and 10-cm long straight edge. The permissible tolerances shall be as follows (Tables 9.5 and 9.6).

Table 9.5 Welds with New Rails

Parameter	*Permissible tolerance*	*Locaton*
1. Vertical misalignment	+0.3 mm –0 mm	at the centre of a 1m straight edge
2. Lateral misalignment	+0.3 mm	at the centre of a 1m straight edge
3. Head finishing (in width) Side of rail should be finished to:	+0.25 mm	on gauge side at the centre of 10 cm straight edge
4. Finishing of top table	+0.2 mm –0 mm	at the centre of 10 cm straight edge
5. Web zone (under side of head, web, top of base, both, fillet each side)	+3.0 –0 mm	of the parent contour
6. Underside of rail foot must be suitably finished without any minus tolerance to ensure proper seating on sleepers and unhindred movement of welded panels on end unloading rakes.		

Table 9.6 Welds with Old Rails

Parameter	*Permissible tolerance*	*Locaton*
1. Vertical misalignment	±0.5 mm	at the centre of a 1 m straight edge
2. Lateral misalignment	±0.5 mm	at the centre of a 1 m straight edge
3. Head finishing (on sides)	±0.3 mm	on the gauge side at the centre of a 10 cm straight edge
4. Head finishing (on top table surface)	±0.2 mm	at the centre of a 10 cm straight edge
5. Web zone (under side of head, web, top of base and both fillets on each side)	+3.0 mm ±0.0 mm	of parent contour

9.2.7 Alumino-Thermic Welding (Thermit Welding) (Fig. 9.2)

In the alumino-thermic process of welding, a mixture of iron oxide, aluminium, ferroalloys, etc. is ignited in a crucible to yield molten steel. This is poured into a mould enveloping the rail-ends. The rail ends are pre-heated before molten steel is poured. The molten steel on cooling solidifies in the mould, welding the two rail ends together. Extra metal around the rail ends is then chipped off.

The quantity of the mixture required for making one joint is called 'portion'. This is packed by the suppliers in one bag and marked with the poundage of rail for which it is meant. The mixture is blended to produce an alloy steel as close in composition and structure to the rail steel as possible.

The main chemical reaction which takes place when the mixture is ignited, is as follows:

$$Fe_2O_3 + 2A1 = A1_2O_3 + 2Fe + 848 \text{ Cal}$$

This means: Iron oxide + Aluminium = Fluid aluminium + Fluid iron + 848 calories of heat per gram of iron oxide.

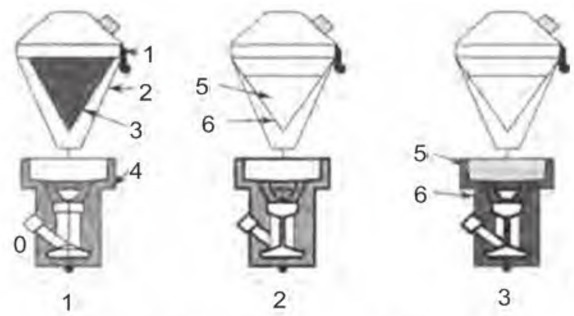


Fig 9.2 Schematic diagram of Thermic method

The reaction is strongly exothermic, i.e. there is liberation of heat. The mixture on ignition attains a temperature of about 2450°C in 20 $\pm$ 5 seconds. When the reaction is complete, the fluid iron released from the reaction is tapped in the mould for welding. Fluid aluminium, being lighter, rises up in the form of slag.

Types of Alumino-Thermic Welding On Indian Railways, conventional process of alumino-thermic welding has been in vogue for many years. In view of the better quality control that can be exercised with short preheat or SKV process, this method of welding is now being increasingly adopted.

The features distinguishing one process from the other are given in Table 9.7.

Table 9.7

Features	*Conventional method*	*Short preheat or SKV process*
1. Mode of preheating	Side heating	Top heating
2. Preheating time by a burner with mixture using hand air petrol fuel operated compressor*	45 $\pm$ 15 minutes	10 $\pm$ 5 minutes
3. Type of mould	Green sand mould prepared at welding site	Prefabricated mould
4. Source of energy to achieve full fusion	Mainly by prolonged heating	Partly by short preheat but mostly by the super-heated extra molten thermit steel

* Pre-heating time can be considerably reduced with gas heating, using oxygen-petrol, oxygen propane, oxygen LPG, etc.

Manual for Alumino-Thermic Welding The RDSO have issued a manual for welding of rail joints by the alumino-thermic process. In this manual, guidelines for welding by both the processes, viz. conventional and short preheat/SKV have been given. As the use of conventional process is being discontinued in the Indian Railways, important guidelines in relation to short-preheat process are given below.

First, the rails are segregated into new rails and old rails.

In the case of *new rails* the end-bends of the rails shall be within ±0.5 mm in vertical and lateral alignment, when checked with a 1 m straight edge.

For *second hand rails*, following points should be taken care of:

1. Rails should have a residual life of at least 10 years.
2. Maximum wear on the rail table should not exceed 8 mm for 60 kg, 6 mm for 52 kg, 4 mm for 90R, 3 mm for 75R and 2 mm for 60R rails. Lateral wear in the rail head should not exceed 6 mm.
3. Rails should be ultrasonically tested before welding to weed out defective rails.
4. End batter should not exceed 1 mm and end hogging, exclusive of battering should not exceed 1 mm. Rails with excessive battering and hogging may be used after end cropping.
5. Rails of the same quality should normally be welded together.

Preparation of Rail Ends Normally, no welded joint should be located closer than 4 m from any other welded or fishplated joint. The rail ends, including the end faces, shall be thoroughly cleaned by applying kerosene oil and vigorous brushing with wire brush to remove all dirt, grease or rust. Such cleaning shall be done on the entire portion to be covered by the mould box. Any burrs at the rail ends shall be removed. All bolt holes, within 130 mm of the rail ends to be welded, shall be thermally plugged temporarily with a metal plug to ensure proper conduction of heat in the hole region.

Preliminary Work Prior to Welding

1. The rail fastenings shall be loosened for at least five sleepers on either side of the proposed weld. The sleepers at the joint to be shifted to obtain a clear working space of 250 mm on either side to accommodate the moulds, clamps, preheating equipments etc. The rails shall be properly aligned both horizontally and vertically.
2. When welding on the cess, full rail length should be levelled by supporting on at least ten wooden blocks on either side. The rails shall be properly aligned, spiked and held in position.
3. Tensors must be used for any welding work done below the distressing temperature.

Alignment of Rail Ends

1. *Horizontal Alignment* The two rail ends after alignment shall be correct to ±0.5 mm when checked with a 1 m straight edge. Any difference in widths of rail heads shall always be fully kept on the non-gauge side, correctly aligning the rail ends on the gauge face.
2. *Vertical Alignment* The joint shall be kept higher by 1.5 to 2 mm (as compensation against sagging caused by differential shrinkage on cooling), when checked with 1 m straight edge. This should be achieved by wedges applied on the rail supporting blocks on both side of the joint.

Preparation of the Mould For welding by short-preheat/SKV process only prefabricated CO_2 sand mould shall be used. The mould should have adequate permeability for the escape of mould gases.

Fixing the Mould During fixing the moulds, it must be ensured that the entire line of the gap coincides with the centre line of the weld reinforcement gap provided in the mould to avoid cross joint.

After fixing up of the mould boxes, the luting strip should be packed firmly with luting sand to prevent misrun of the liquid weld metal. Moisture in the luting material must be controlled to avoid gas entrapment in the weld.

9.2.8 Portion for Welding

The suitability of the portion for the welding process in respect of the quality and section of the rail to be welded shall be ensured before commencing welding. The approximate weight of the portion for 52 and 60 kg rails is 13 and 15 kg, respectively.

9.2.9 Precautions During Execution of Welding

1. After the portion is ignited, the reaction should be allowed to continue for 20 + 5 sec. The reaction should not be vigorous or boiling.
2. After the reaction subsides, about 5 sec should be allowed for separation of slag from the metal, and the contents of crucible tapped into the mould after 5–7 sec from the time the reaction subsides.
3. The molten metal in the mould shall be allowed to cool and solidify for about 3–5 min. after pouring as timed by a stop watch and the mould shall then be taken off.

Some important parameters as evolved on Indian Railways for welding various types of rails with SKV process are given in Table 9.8.

Demoulding and Removal of Excess Metal After demoulding, the extra metal should be trimmed in red hot condition by a weld trimmer taking care not to cut the parent metal and forming cupping at the weld. The trimming operation should be confined to the rail table and the sides, leaving at least 1 mm excess metal over the rail table.

Post-weld Cooling The alloy steel rail joints (chrome manganese and chrome vanadium type) are required to be slowly cooled, immediately after trimming, by fixing an isolation hood, to control the cooling rate to avoid the formation of hard brittle structure, resulting in harmful cracks. The hood is kept around the joint for at least 20 minutes.

Post-weld Packing of Sleepers Before the passage of traffic, joint sleepers which were shifted to obtain the clear gap of 250 mm on either side are to be reshifted to the original location and re-packed.

Passing of Traffic Before allowing the first train on the welded joint, at least 30 min. time gap must be given after pouring the metal. Necessary speed restriction must be observed until the grinding operation is over.

Table 9.8

Rail type	*Gap between rail ends (mm)*	*Preheating time (minutes)*	*Reaction time (seconds)*	*Heating technique*
75 R (72 UTS)	24 – 26	6 – 8	20 ± 3	Top heating with air and petrol
75 R (90 UTS)	24 – 26	6 – 8	20 ± 3	-do-
90 R (72 UTS)	24 – 26	8 – 10	20 ± 3	-do-
90 R (90 UTS)	24 – 26	8 – 10	20 ± 3	-do-
52 kg (72 UTS)	24 – 26	10 – 12	20 ± 3	-do-
52 kg (90 UTS)	24 – 26	10 – 12	20 ± 3	-do-
60 kg (72 UTS)	24 – 26	10 – 12	20 ± 3	-do-
60 kg (90 UTS)	24 – 26	10 – 12	20 ± 3	-do-
60 kg (110 UTS)	24 – 26	15	20 ± 3	-do-
Chrome Managanese Alloy Steel Rail 60 kg (UIC) Head Hardened Rail	24 – 26	4.5	20 ± 3	Top heating with air and petrol with compressed air and post weld treatment.
52 kg (72 UTS)	24 – 26	2	20 ± 3	Top heating with Oxygen and LPG
52 kg (90 UTS)	24 – 26	2.5	20 ± 3	-do-
60 kg (90 UTS)	24 – 26	2.5	20 ± 3	-do-
Wide Gap				
52 kg (90 UTS)	74 – 75	10	25 ± 5	Top heating with air and petrol.
60 kg (90 UTS)	74 – 75	12	25 ± 5	-do-
Combination Joint				
52 kg (90 UTS)/ 90 R (72 UTS)	48 – 50	10	25 ± 5	-do-
60 kg (90 UTS)/ 52 kg (90 UTS)	46 – 48	12	25 ± 5	-do-

Grinding This should be done with portable grinders or hand files. The grinding operation should commence only after the sleeper fastenings are replaced, after the removal of wedges.

Marking The welded joint after finishing should be distinctly marked, numbered and the record maintained to enable the particulars of joints being traced in case of failure at a later date.

Acceptance Tests One joint for every 100 joints welded must be tested in accordance with Clause 17 of IRS T-1984 specification, by picking up representative samples for carrying out the acceptance test. Important items of the test are as follows:

1. *Hardness Test* The brinnel hardness survey should be carried out at the welded zone, heat affected zone and parent metal of the rail.

The average hardness should be

(a) Weld metal ±20
(b) Heat affected zone ±2

} of the parent rail hardness

The average hardness of IRS T-12 medium manganese rails is 230 and that of UIC 860 Grade A 90 UTS, is 280.

2. *Transverse Breaking Load Test* The test weld should be supported on cylindrical or semi-cylindrical supports having a diameter of 30–50 mm and a distance of one meter between them from centre to centre. The weld shall be at the centre of the span and loaded in such a manner that the foot of the rail is in tension. The mandrel diameter should be between 30–50 mm. The load should be gradually increased till rupture occurs.

The minimum values of the load in tonnes and deflection in mm at rupture are tabulated in Table 9.9.

Table 9.9 Load Deflection Values for Different Rails

Rail type	*Rail section*	*Min. transverse breaking load in tonnes*	*Min. deflection in mm at the centre at the load in col.3*
72 UTS to IRS T-12	60 R	50	15
-do-	75 R	60	15
-do-	90 R	70	15
-do-	52 kg	85	18
-do-	60 kg	95	18
90 UTS to IRS T-12/ UIC 860-0 or equivalent	75 R	65	15
-do-	90 R	85	15
-do-	52 kg	90	15
-do-	60 kg	115	15
Alloy Steel (Cr-Mn or Cr-V type 110 UTS)	52 kg	95	10
-do-	60	115	10
Head hardened rails	60 kg	115	15

Note:

1. If the fracture occurs far outside the weld, a slice should be cut transversely at the weld and etched in boiling 1 : 1 hydrochloric acid for about 20 minutes to determine the casting defects.
2. The fractured surface of the weld or in cases, where etching is done on transverse slices, should not show, blow holes, porosities or inclusions aggregating to more than 1% of the cross-sectional area of the rail section welded.

Dimensional Check and Tolerances The joint should be examined carefully to detect any visible defect like cracks, hot tears, inclusion of slag, blow holes in the weld etc. Any joint, which shows any of the defects should be rejected. Is case of *in situ* welding, the portion of the rail with the defective weld is cut and removed for length of about 4 m to carry out rewelding, duly introducing a rail piece of equivalent length to ensure that the consecutive welds are not closer than 4 m. In case of cess welding, a portion of minimum 8 m with the defective weld at the centre should be cut and removed. The cut ends are brought closer and welded.

The finished joints should be checked for dimensional tolerances after the welded joint has cooled down. The tolerance laid down for alumino-thermic welds of new rails are given in Table 9.10.

Table 9.10 A.T. Welding Joints Dimensional Tolerances

1. Vertical misalignment	+1.0 mm −0.0 mm	Measured at the end of 1 m straight edge
2. Lateral misalignment	±0.5 mm	Measured at the centre of 1 m straight edge
3. Head finishing on sides	±0.3 mm	On gauge side (Measured atthe centre of 10 cm straight edge)
4. Finishing top table surface	+0.4 mm −0 mm	Measured at the end of 10 cmstraight edge

Note: Dispensation for geometry in case of old rails may be permitted by Chief Engineer.

Atmosphere and Weather Condition Welding must not be carried out during rainfall. The portions and the crucible should be completely dry. On no account should the joint be exposed to moisture or rainfall during and immediately after demoulding.

9.2.10 Ultrasonic Testing and Alumino-Thermic Welds

Thermic welds tend to fracture early in service if proper precautions during their execution are not taken. Mainly the flaws are due to lack of fusion between the parent rail metal and the weld metal. Other flaws can be the existence of blow holes, inclusion of extraneous matter and impurities in the weld metal. It has been observed that in about 80 percent cases the flaws have their origin in the foot; and in 10 percent cases in the head. This is on account of the fact that rail foot due to insufficient traffic block time is not heated to the required temperature before the weld metal is poured in, leading to lack of fusion in the rail foot area.

To detect the defective thermit welds before they actually fracture under traffic, a method for ultrasonic testing of thermit welds has been evolved. For testing, double rail tester RT-201, and Single rail tester RT-101 are in use on Indian Railways. In this method normal and 70° probes are used for detection of flaws in the head portion and an 80° angle probe for hand probing in the foot portion.

A code of practice for ultrasonic testing of thermit welds has been issued by RDSO, which gives detailed guidelines for testing procedure and for the classification of defective weld joints.

The defective joints are classified into two categories namely IMR and OBS. The joints with major flaws are taken in IMR category and with comparatively minor flaws in OBS category.

For details refer to Section 2.33.

Wider Gap Alumino-Thermic Welding For the replacement of the defective welds, it is necessary to cut out a 4 metres rail piece, 2 metres long on either side of the weld. A new 4 metres rail piece is then introduced by having two new welds. Thus one defective weld has to be replaced by two AT welds. Apart from increasing the population of AT welds, this process is time consuming, needing more traffic blocks.

A 50 and 75-mm-wide gap welding has been developed, where only one weld is made in replacement of the defective weld. In this process, the existing defective weld is flame cut and a gap of 50 $\pm$ 2 mm or 75 $\pm$ 3 mm is created in its place. The rest of the procedure of welding is the same except, special portion and moulds are used for the job, which are formulated and tested for their specific requirement.

9.2.11 Single Use Crucible Alumino-Thermic Welding

1. General

There are three types of crucibles for use with thermit portions:

1. Long Life
2. Light Weight
3. Single Use

The Long Life and Light Weight Crucible are similar to each other, but differ in their service life. A range of equipment has been developed to adapt these crucibles for different uses.

The Single Use Crucible (Fig. 9.3) with a life of one thermit weld has been developed to give the following advantages:

1. It is supplied ready for welding
2. It is simple to use
3. It has a low weight
4. It requires minimal ancillary equipment
5. The spent crucible can be used to transport waste from site

The Single Use Crucible also provides ergonomic advantages for the welding crew.

2. Features

The crucible consists of a refractory lined steel container, which is provided with a carrying handle. The base incorporates a device for automatic tapping and the unit is completed by a ceramic crucible cap.

No other accessories are required. The cap is packed inside the crucible to form a very compact package for transport and storage.

It is not necessary to dry the crucible before use as it is supplied as an hermetically sealed unit. The 10–15% of oxygen and propane gas cylinder capacity that is saved can be used for pre-heating rail ends.

The thermit portions used with the single use crucible have quiet reactions and are labelled as SKV- 1 W.

Fig. 9.3 A Single Use Crucible (See also Color Plate 3)

The crucible charged with the thermit portion is located centrally over and close to the upper part of the mould by placing it onto specially designed mould shoes. A new simplified clamping device is made possible by the lighter weight of the single use crucible.

In particular the single use crucible can be favoured when thermit welding technology is applied with central pouring systems. In case of asymmetrical ingating (SmW- F) or with wide gap welds a modified universal clamping device is provided.

After the weld has been finished, the crucible can be used as a bucket to transport waste such as steel risers and slag to an approved point for disposal in accordance with environmental regulations.

9.2.12 Submerged ARC Welding

In this method, gap at the rail joints is filled with the weld metal, using the appropriate type of electrodes. The joint so produced has exhibited good structural integrity, much superior to alumino-thermic welding. The following methodology is adopted for welding:

1. Cleaning and removal of rust form the rail ends.
2. Creation of a gap of 12–13 mm at the rail ends.

3. Heating of the rail ends to about 250°C with oxyacetylene torch.
4. Deposit of weld metal with appropriate quality of electrodes. Top 6 mm gap is filled with a special wear resistant metal, matching the hardness of the parent rail.

A block of about one hour duration is usually used for making a weld joint. Welder's competence plays a crucial role in getting the proper quality welds. This technique can be usefully employed for *in situ* welding of flashbutt welded rail panels into LWR/CWR. High rate of failures in thermic welds has revived the interest in the use of enclosed ARC welding in Indian Railways.

9.3 WELD STRENGTH WITH VARIOUS WELDING TECHNIQUES

The weld strength of various welding techniques was evaluated by the Japanese National Railway and the results are summarised in Table 9.11.

Table 9.11 Weld Strengths of Different Techniques

Item	*Fatigue limit in kg/mm²*	*Percentage of fatigue life as compared to parent rail*
Parent rail	33–36	100
Gas pressure welding	34	95.8
Flash butt welding	30–34	90.1
Enclosed ARC welding	28–78	90.0
Alumino-thermic welding	18–22	56.4

9.4 METHODS TO REDUCE WELD FAILURE

The incidence of weld failure in Indian Railways has considerably increased in the last few years. Most of the weld failures are confined to thermit welds, although some failures of flash butt welds have also been reported.

The following measures are being taken to arrest the trend:

1. Avoid thermic welding to the extent possible by
   (a) Obtaining 26/39/78/120 metres rail from the steel plants.
   (b) All new rails to be welded into longer panels of 240/480 m lengths in integrated flash-butt welding plants.
   (c) Increased deployment of mobile flash butt welding plant.
   (d) Explore the possibility of deployment of gas pressure welding plants for site welding, particularly at the project sites.
   (e) Have a fresh look on the use of enclosed arc welding, as a possible alternative to thermic-welding for converting welded panel into LWR/CWR.

2. Improve the quality of thermic welding by:

(a) Complete switchover to SPW/SKV technique of welding.
(b) Preheating by LPG instead of using petrol–air mixture.
(c) Ensuring proper joint gaps during welding, with the use of tensors.
(d) Use of hydraulic weld trimmers and portable grinding machines.
(e) Ensuring adequate traffic blocks for welding.
(f) Employment of competent trained welders.
(g) Improving upon the specification of the thermit portions.
(h) Adoption of single use crucible technology.

9.5 THERMAL FORCES IN SHORT WELDED RAILS

Unlike LWR, SWR track is likely to creep. If on account of provision of insufficient gaps at the time of laying or due to creep, the gaps of SWR track close at a temperature lower than the mean annual rail temperature, the thermal force generated at the maximum rail temperature is likely to be greater than that in LWR track. Under such high compressive forces, the fishplated rail joints in SWR with their inherent weakness can trigger off the process of buckling. Further, at low temperatures the tensile forces developed in SWR at the minimum temperatures have to be withstood by fishplated joints, which is not the case with LWR. Thus the degree of uncertainty of the knowledge of forces and their effects in SWR is more than that in the case of fishplated or LWR track. It is for this reason that the laying and maintenance instructions for SWR have to be specially stipulated for.

9.6 MANUAL OF INSTRUCTIONS

The RDSO have brought out a manual of instructions for laying and maintenance of short welded rails (SWR). Important provision from the manual are reproduced in the following paragraphs. These instructions are applicable for 3 rail panels SWR, i.e. 39 m long rail for BG and 36 m long rail for MG.

Definitions

1. *SWR* is a welded rail which contracts and expands throughout its length.
2. *Rail temperature* is the temperature of the rail as recorded by an approved type of rail thermometer at the site. This differs from the ambient temperature which is the temperature of the air in shade at any place, as reported by the meteorological department.
3. *Mean annual rail temperature* (t_m) is the average of the maximum and minimum of rail temperatures during the year. It will be fixed locally wherever rail temperature records are available for a reasonable period, say, about 5 years. When local records are not available, t_m can be read from the rail temperature map.
4. *Installation temperature* (t_i) is the average rail temperature during the process of fastening the rails to the sleeper at the time of installation of SWR.
5. *Standard installation temperature* (t_s) is the installation temperature at which the standard gap of 6 mm at the fishplated joints is provided in SWR.

9.7 TRACK STRUCTURE FOR SWR

Formation: SWR shall be laid generally on stable and efficiently drained formation.

Rails: The minimum section of the rail shall be 90R for BG and 60R for MG. Only new rails or old rails conforming to the stipulations laid down in Sections 9.2.3 and 9.2.7 for flash butt weld and thermit weld, respectively, shall be welded into SWR.

Sleepers: The sleepers approved for use with SWR are; (a) wooden sleepers with anti-creep or elastic fastenings, (b) cast iron sleepers and steel trough sleepers, with key type or elastic fastenings, (c) concrete sleepers.

Wooden sleepers approved for use with MS bearing plates and rail free fastenings may preferably be used at all fishplated joints where SWR is laid on metal sleepers. On account of acute scarcity of wooden sleepers, special concrete sleepers for joints have been evolved.

Sleeper Density The sleeper spacings under welded joints of all type with or without holes in the rail web shall be the same as the intermediate sleeper spacings. Sleepers spacings to be adopted for M + 4 and M + 7 sleeper densities with 3 × 13 m rails on BG and 3 × 12 m rails on MG are indicated in Table 9.12.

With other sleeper densities and/or different lengths of SWR, the maximum sleeper spacings shall not exceed those given below in Table 9.12.

1. For catering to different lengths of rails, caused by difference in the basic length of rails or due to tolerances permitted in rail lengths, the actual sleepers spacings to be adopted should be worked out at the site, keeping in view the points mentioned in S. No. 2, 3 and 4 below.
2. To facilitate 'on-track' tamping, it is desirable to have continuous stretches with uniform sleeper spacing as far as possible.
3. The sleeper spacings shown are from centre to centre of sleepers. At the fishplated joints, the spacing shown is from the centre line of the joint to the centre line of the joint sleeper.
4. The following assumptions have been made while calculating sleeper spacings

   (i) Length of unwelded rail = 13000 mm/12000 mm.
   (ii) Total reduction in length of rail at each flash-butt or gas-pressure welded joint = 20 mm.
   (iii) Gap to be provided at joint prior to welding by ordinary alumino-thermic process = 12 mm.
   (iv) Minimum sleeper spacing at any location, except at fishplated joint = 560 mm.

5. All dimensions are in millimeters.

9.7.1 Ballast

Only stone ballast shall be used. The minimum ballast cushion below the bottom of sleeper shall be 200 mm on BG and MG. An extra width 100 mm of shoulder ballast over and above the standard ballast section of tangent tracks shall be provided outside of curves. The extra width shall be

Table 9.12 Sleeper Spacings under B.G. and M.G. Short Welded Panels (3-Rail)

Type of sleepers at fishplated joint	*Type of weld*	*X joint*	*Y shoulder*	*Z adjacent to shoulder*	*A intermediate*
		3 × 13 m Rail (BG) M + 4 sleeper density			
Wooden	FB	150	643	750	46 × 780
Wooden	AT	150	645	780	46 × 780
Metal/concrete	FB	190	620	730	46 × 780
Metal/concrete	AT	190	625	760	46 × 780
		3 × 13 m Rail (BG) M + 7 sleeper density			
Wooden	FB	150	573	610	55 × 660
Wooden	AT	150	595	620	55 × 660
Metal/concrete	FB	190	563	580	55 × 660
Metal/concrete	AT	190	575	600	55 × 600
		3 × 12 m Rail (MG) M + 4 Sleeper density			
Wooden	FB	120	600	708	43 × 770
Wooden	AT	120	600	740	43 × 770
Metal/concrete	FB	160	580	688	43 × 770
Metal/concrete	AT	160	600	700	43 × 770
		3 × 12 m Rail (MG) M + 7 Sleeper density			
Wooden	FB	120	603	620	52 × 640
Wooden	AT	120	615	640	52 × 640
Metal/concrete	FB	160	573	610	52 × 640
Metal/concrete	AT	160	595	620	52 × 640

increased to 150 mm on curves of 2° and sharper on BG and 3° and sharper on MG. For SWR laid with 60 kg rails, the ballast profile shall be as prescribed for LWR track.

9.7.2 Conditions of Laying

1. *Alignment* SWR shall not be laid on curves sharper than 500 m radius in both BG and MG.
2. *Level crossing* SWR may be continued through level crossings, avoiding fishplated joints in the level crossing portion and within 6 m from the end of the level crossing.
3. *Junction with insulated joints and points and crossings* SWR shall not butt against insulated joints, heel of crossings and stock rail joints. Two standard length rails (13 m/12 m) shall be interposed to isolate the SWR from such locations. These standard length rails shall be anchored effectively to arrest movement in either direction.

4. *Junction with standard length rails on wooden sleepers* When SWR track butt against track laid with standard length rails, on wooden sleepers, the later shall be adequately anchored for at least six rail lengths to check the creep of rails. These six rail lengths shall have a sleeper density of M + 7. Additional shoulder ballast should also be provided.
5. *SWR on girder bridges with unballasted decks* There is no restriction to laying of SWR on ballasted deck bridges. SWR may be continued over girder bridges with unballasted decks with clear distance between abutments up to 13.3 m if the length of SWR is symmetrical to the centre of the bridge. If SWR is unsymmetrical, the clear distance between abutments is not to exceed 6.1 m. It shall be ensured that no fishplated joint is located on the girder or within 6 m from either abutment. In all such cases rail free fastenings such as rail screw, dog spikes or rail free clips shall be used so that movement between rail and sleeper may take place.

9.7.3 Laying of SWR

The gaps to be provided for SWR at the time of laying shall be in accordance with Table 9.13.

Table 9.13 Initial Laying Gaps for SWR (2 ½ and 3-rail Panels) for Various Installation Temperatures

	t_s – 17.5°C to t_s – 12.6°C	t_s – 12.5°C to t_s – 7.6°C	t_s – 7.5°C to t_s – 2.6°C	t_s – 2.5°C to t_s + 2.5°C	t_s + 2.6°C to t_s + 7.5°C	t_s + 7.6°C to t_s + 12.5°C
Gap	12 mm	10 mm	8 mm	6 mm	4 mm	2 mm

The t_s shall be equal to t_m for rail temperature zones I and II and equal to (t_m – 5°C) for zones III and IV shown in the rail temperature map (Fig. 10.9 Chapter 10).

If the laying has to be done outside the temperature range given in Table 9.13 or wherever joint gaps could not be provided as per table, readjustment of gap shall be carried out within two days of laying and before the track consolidates. Along with the gap adjustment, any respacing of sleepers, if required, must be carried out.

9.7.4 Maintenance of SWR

1. Regular track maintenance, including all operations involving packing, lifting, aligning, local adjustment of curves, screening of ballast other than deep screening and scattered renewal of, rails/sleepers, may be carried out without restriction, when the rail temperature is below t_s + 25°C. However, on curves of less than 875 m, radius on BG and less than 600 m radius on MG or on yielding formations, the above temperature limit is restricted to t_s + 15°C.

2. If maintenance operations have to be undertaken at temperature higher than mentioned above, not more than 30 sleeper spaces in one continuous stretch shall be opened, leaving at least 30 fully boxed sleeper spaces between the adjacent lengths which are opened out. Before the end of the day it shall be ensured that the ballast is boxed up. These precautions shall be taken throughout summer even if at the time of opening of sleeper spaces the temperature is within the range mentioned above.
3. Adequate number of joggled fishplates with special clamps shall be provided to the gangs for use in emergencies.
4. In case of any fracture in the weld or in the rail, the portion of the rail with fracture is cut and removed for length of not less than 4 m to carry out the rewelding, duly introducing a rail piece of appropriate length, also ensuring that no weld lies closer than 4 m from the fishplated joint.
5. Major lifting, major realignment of track, deep screening and *renewal of sleepers in continuous length* shall be done with suitable precautions and normally, when the rail temperature is below t_s + 15°C, adequate speed restriction shall be imposed.
6. Measured shovel packing on SWR shall be carried out only when the temperature is below t_s + 15°, provided the rails are not butting and are not likely to butt during the course of the work.

   MSP of the wooden sleepers at joints may be undertaken even when the rail temperature is above t_s + 15°C, provided the gaps are not closed, and the temperature is falling as normally obtainable in late afternoons.

7. Gap survey and rectification of gap is to be carried out in stretches where track develops excessive creep, jammed joints, sunkinks, buckling, side gaps, battered and hogged joints, fracture at joints, bending of bolt, etc. The gap survey and adjustment should normally be done, before the end of February each year, (i.e. before the onset of summer). Not more than two consecutive jammed joints should be permitted in SWR. A detailed account of gap survey and rectification is as follows:
   (a) The gap survey on 3 rail panels should be conducted between 12 hours to 15 hours on a clear and sunny day when the rail temperature is between t_s + 10°C and t_s + 15°C. The length over which the gap survey is to be done should, wherever possible, be divided into suitable subsections each bounded by fixed points, such as level crossings points and crossings, etc. The gap survey on each subsection should be completed within a short time when the rail temperature is not likely to vary appreciably. For this, adequate number of survey parties should be engaged.
   (b) The joint gaps should be measured by taper gauge and the readings entered into the prescribed proforma.
   (c) The recommended range of values for the gaps, both individual and average for various ranges of rail temperature, are laid down in Table 9.14.
   (d) The average of the measured gaps is worked out. Comparison of the average values obtained from survey, with the joint gaps stipulated in Table 9.14 for particular range of temperature will lead to one of the following cases:

Table 9.14 Recommended Values of Gaps (in mm) during service for the Various Rail Temperature Ranges (in °C) (Gap survey being carried out when rail temperature is in rising trend only)

Temp. during Gap survey in °C	$t_s - 12.5$ to $t_s - 7.6$	$t_s - 7.5$ to $t_s - 2.6$	$t_s - 2.5$ to $t_s + 2.5$	$t_s + 2.6$ to $t_s + 7.5$	$t_s + 7.6$ to $t_s + 12.5$	$t_s + 12.6$ to $t_s + 17.5$
Permissible Value of gaps in mm	11 – 14	9 – 13	7 – 11	5 – 9	3 – 7	1 – 5

Note: The gaps given above are to be distinguished from the gaps given in Table 9.13, which are intended to be provided at the time of initial laying of SWR.

Case (*i*) Average gap is within the recommended range, but some of the individual gaps fall outside the range.

Case (*ii*) Average gap falls outside the recommended range.

(e) The action to be taken in each of the above two cases shall be as follows:

Case (*i*) Rectification work should be restricted to correct the individual gaps which fall outside the recommended range. Rectification should be done by pulling the minimum number of rail. Under no circumstances shall the adjustment be done by cutting a rail or introducing a larger rail.

Case (*ii*) The joint gaps should be systematically adjusted from one end to the other end of the subsection. The rails shall be unfastened over convenient lengths, the gaps adjusted to the initial gaps as per Table 9.12 and rails fastened. In this case introduction of a longer or a shorter rail will be involved. Effort should be made to see that only the minimum number of joint sleepers are disturbed.

10 Chapter

Long Welded Rails

10.1 LONG WELDED RAILS

A *long welded rail*, is the rail whose central part does not undergo any longitudinal movement with temperature variation (Fig.10.1).

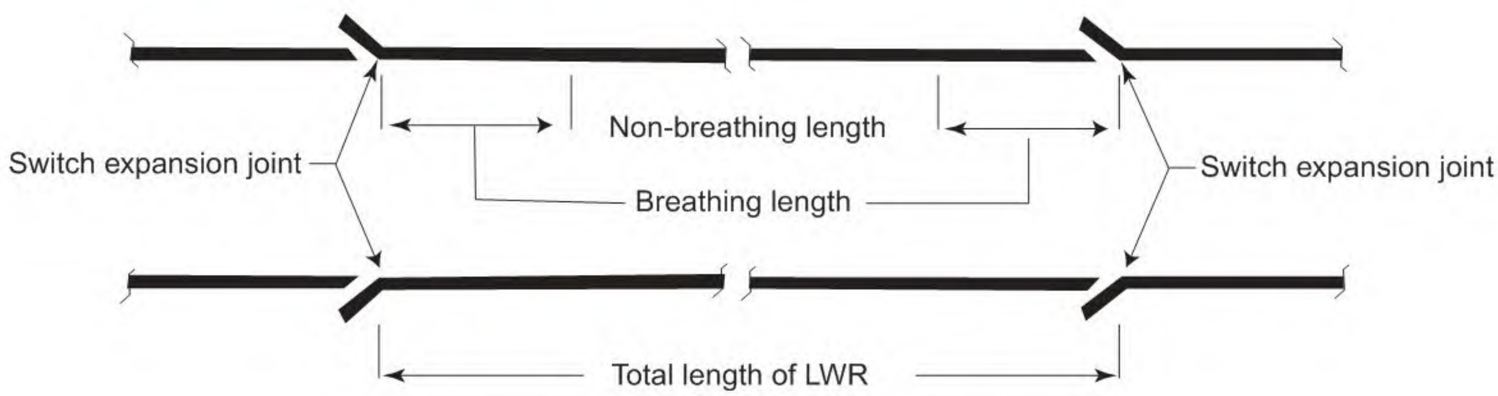


Fig. 10.1 Long welded rail

The minimum length of a rail to function as an LWR depends upon the range of temperature variations, the section of the rail, resistance offered by the rail-sleeper fastenings to the longitudinal movement of the rail, and the resistance offered by the ballast to the sleepers. Normally any length greater than 200 m on BG, and 300 m on MG will function as LWR. Thus, in a LWR of more than 200 m on BG, only a length of about 70–100 m at either end—depending on track structure—is subjected to movement on account of temperature variations. This length on either end is called 'breathing length'.

10.1.1 Theory of Long Welded Rails/Continuously Welded Rails

Temperature is the governing factor in the behaviour of long welded rails. Any change in temperature produces forces in the rail which must be controlled to achieve a stable track.

A lay observer may well ask 'How come that expansion gap has to be provided at the joints between relatively short rails, whereas continuously welded rail of a kilometer or more requires none? If a 13 m rail requires 8 mm of expansion gap, a 130 m rail should need 10 times as much'.

The fallacy in this approach lies in the fact, that it only applies to a completely unrestrained rail. In practice, the rail is secured by rail fastenings to the sleepers, which in turn are embedded in track ballast, and both these apply restraint to longitudinal movement. In fact, movement of a long rail due to temperature change continues until the sum of the individual restraint provided by the fastenings and sleepers equals the expanding or contracting force. With typically varying BG rail fastenings of sleepers and ballast, complete restraint is achieved in about 70 to 100 m of track or 100 to 150 sleepers.

Considering a fully restrained rail and neglecting creep effect of the metal, it is possible to say that the force P in a rail due to temperature change is

$$P = EA\alpha t$$

where

E = Modulus of elasticity of rail steel

= 2150 tonnes per sq cm

A = Cross-sectional area of rail in cm^2

α = Coefficient of liner expansion of steel

= 0.00001152/°C

t = temperature change in centigrade

That cross-sectional area of a standard 52 kg/m rail = 66.15 sq cm.

Thus the force exerted by each degree change of temperature is

$$= 2150 \times 66.15 \times 0.00001152$$

$$= 1.638 \text{ tonnes}$$

It will be noted that the length of the rail is not a factor in the value of the force exerted. When one considers that the minimum rail temperature encountered is about 0°C and the maximum about 70°C, it can be seen that considerable forces are generated in the LWR rails. One would therefore fix down rail at some temperature between the two such extremes that the forces generated by rise and fall of temperature are equally divided between compression and tension. Something of the order of 35°C seems ideal, and in fact the LWR rails in Northern India are distressed at this temperature or thereabout.

The maximum compression and tension forces generated in the rail are, therefore, of the order of 1.638 × 35 = 57.3 tonnes.

Investigations made by some railways have revealed that the sleeper embedded in ballast is able to resist the longitudinal force of one tonne, i.e. 1/2 tonne per rail seat. Thus, the total force generated in each rail will balanced by the resistance offered by about 104 end sleepers. That is shown in Fig. 10.2.

Once the locked up forces are fully balanced by about 104 sleepers of the end, the rest of LWR remains theoretically clamped, with hardly any movement under the varying temperature conditions.

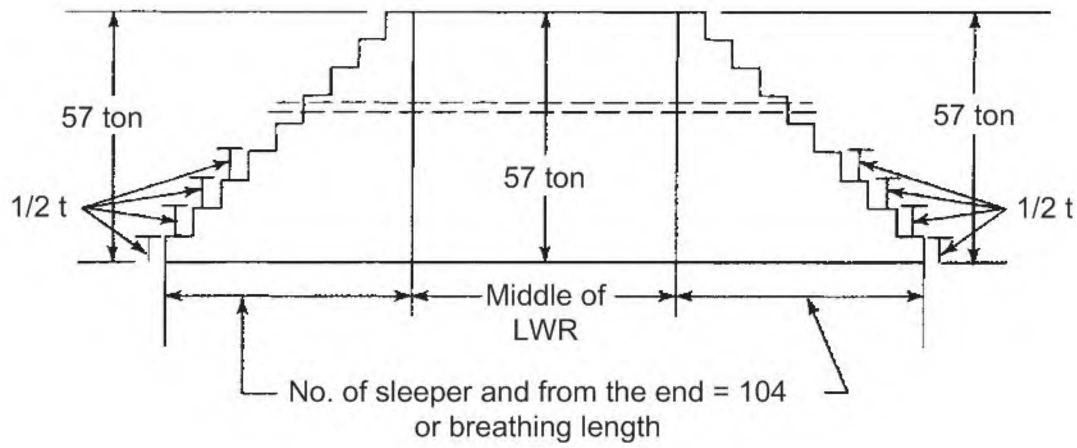


Fig. 10.2

The two short lengths at the end of the LWR in which there can be movement due to temperature variations are the 'breathing lengths'.

The behaviour of the LWR track over varying temperature ranges and particularly the effect of small misalignments in the track on buckling has been studied at various research centers with the following general conclusions.

1. Three components of track, namely the rails, the sleeper fastenings and the ballast each contribute to resistance to buckling.
2. The contribution of rails depends on the section of the rail and does not alter appreciably with age or wear. It represents about 15% of the total resisting force.
3. The contribution of the sleeper fastenings is influenced by the torsional resistance of the fastenings and consequently by the number of sleepers in any given length. This can represent 30% of the total resisting force.
4. The contribution made by the ballast at the end of the sleepers and the sides and underneath represent about 55% of the total resistance to buckling, the ballast underneath the sleeper being responsible for about half of this.

The value of the latter two can deteriorate considerably with age or poor maintenance so that the total resistance to buckling can vary considerably. Thus a very high standard of workmanship at the time of installation and of subsequent maintenance is essential to achieve a reasonable factor of safety.

10.2 SOME IMPORTANT DEFINITIONS

1. *Anchor length* (l_a) is the length of track required to resist the pull exerted on rails by the rail tensor at temperature t_p.

   For practical purpose, this may be taken as equal to 2.5 m per degree centigrade of $(t_0 - t_p)$ for BG, and 4.5 m per degree centigrade of $(t_0 - t_p)$ for MG. (These values are for 52 kg and 75R rail sections, respectively.)

2. *Breathing length* is that length at each end of LWR/CWR which is subjected to expansion/contraction on account of temperature variations. The usual breathing lengths in BG and MG for different types of sleepers-cum-fastening for different temperature zones are given in Table 10.1.

Table 10.1 Breathing Length in Metres

Zone	*Type of sleepers*	*Breathing length in metres*				
		Broad gauge			*Metre gauge*	
		60 kg (UIC) rails	*52 kg rails*	*90 R rails*	*90 R rails*	*75 R rails*
I	PRC	60	52	38	...	...
	ST	77	66	49	134	111
	CST-9	...	89	66	152	126
II	PRC	69	59	44	...	...
	ST	88	75	57	156	130
	CST-9	...	101	76	178	147
III	PRC	77	66	51	...	...
	ST	98	85	65	179	149
	CST-9	...	114	87	202	168
IV	PRC	82	70	55	...	...
	ST	105	90	70	192	160
	CST-9	...	122	94	217	181

Note:

(a) $t_d = t_m$ to $t_m + 5$ °C for all rail sections lighter than 52 kg and all rail temperature zones.
(b) $t_d = t_m + 5$ °C to $t_m + 10$ °C for 52 kg and heavier rails for all zones.
(c) Breathing lengths indicated above are for new sleepers freshly packed and are liable to vary. Also dependent on other site conditions.

3. *Buffer rails* are a set of rails provided at the ends of LWR/CWR to allow expansion/contraction of the breathing lengths due to temperature variations. These may be used as a temporary alternative to SEJs.
4. *Consolidation of Track* is the process of building up sleeper-to-ballast resistance either initially before laying LWR or making up the subsequent loss of resistance caused by some maintenance operation, using any of the following methods:

   (a) Passage of at least 3,00,000 gross tonnes of traffic on BG or at least 1,00,000 gross tonnes of traffic on MG, when compaction of ballast is done using hand operated compactors/consolidators or rammers.
   (b) Passage of at least 50,000 gross tonnes of traffic on BG or at least 20,000 gross tonnes of traffic on MG or a period of 2 days, whichever is later, when compaction is done by means of mechanised shoulder and crib compactor.
   (c) At least one round of stabilisation by Dynamic Track Stabiliser (DTS).

(d) For newly laid LWR/CWR, at least three rounds of packing are required, out of which the last two should be with on-track tamping machines.

5. *Continuously welded rail* (*CWR*) CWR is an LWR, destressing of which has to be carried out in stages. LWR longer than 1 km usually comes in this category.
6. *Destressing* is the operation undertaken with or without rail tensors to secure stress free condition in the LWR at a desired/specified rail temperature.
7. *Destressing temperature* (t_d) is the average rail temperature during the period of fastening of rails to the sleepers after destressing LWR without the use of rail tensor. If rail tensor is used t_d for all practical purposes is equal to t_0 as mentioned earlier, t_d/t_0 shall be within temperature range as given here:

Rail section	*Range*
(a) 52 kg and heavier	t_m + 5°C to t_m + 10°C
(b) all other rail section	t_m to t_m + 5°C

8. *Glued Insulated Joints* These are fiber/epoxy bonded fishplated insulated joints capable of withstanding high thermal forces in CWR and are provided for Track-circuiting as part of CWR, for signalling purpose.
9. *Hot weather patrol* is the patrol carried out when the rail temperature exceeds t_d + 20°C.
10. *Installation temperature* (t_i) is the average rail temperature during the process of fastening the rails to the sleepers at the time of installation of the LWR/CWR.
11. *Mean rail temperature* (t_m) for a section is the average of the maximum and minimum rail temperatures recorded for the section.
12. *Prevailing rail temperature* (t_p) is the rail temperature prevailing at the time when any operation connected with destressing is carried out.
13. *Rail temperature* is the temperature of the rail as recorded by an approved type of rail thermometer at the site. This is different from the ambient temperature, which is the temperature of air in shade at that place.
14. *Rail tensor* is a hydraulic or mechanical device used for stretching the rail physically.
15. *Stress free temperature* (t_0) is the rail temperature at which the rail is free of thermal stress. When tensors are utilised for the destressing operation, the work has to be carried out at t_p, which shall be lower than the stress free temperature.
16. *Switch expansion joint* (*SEJ*) is an expansion joint installed at each end of LWR/CWR to permit expansion/contraction of the adjoining breathing lengths due to temperature variations (Fig. 10.3).

10.3 MEASUREMENT OF RAIL TEMPERATURE

Rail temperature plays an important role in the installation and maintenance of LWR. It is, therefore, necessary to measure rail temperature with approved thermometers only. They are:

1. *Embedded thermometer* In this an ordinary thermometer is inserted in a cavity made in a separate rail piece, which is about 75 mm long and consists of rail head section only [Fig. 10.4 (a)].

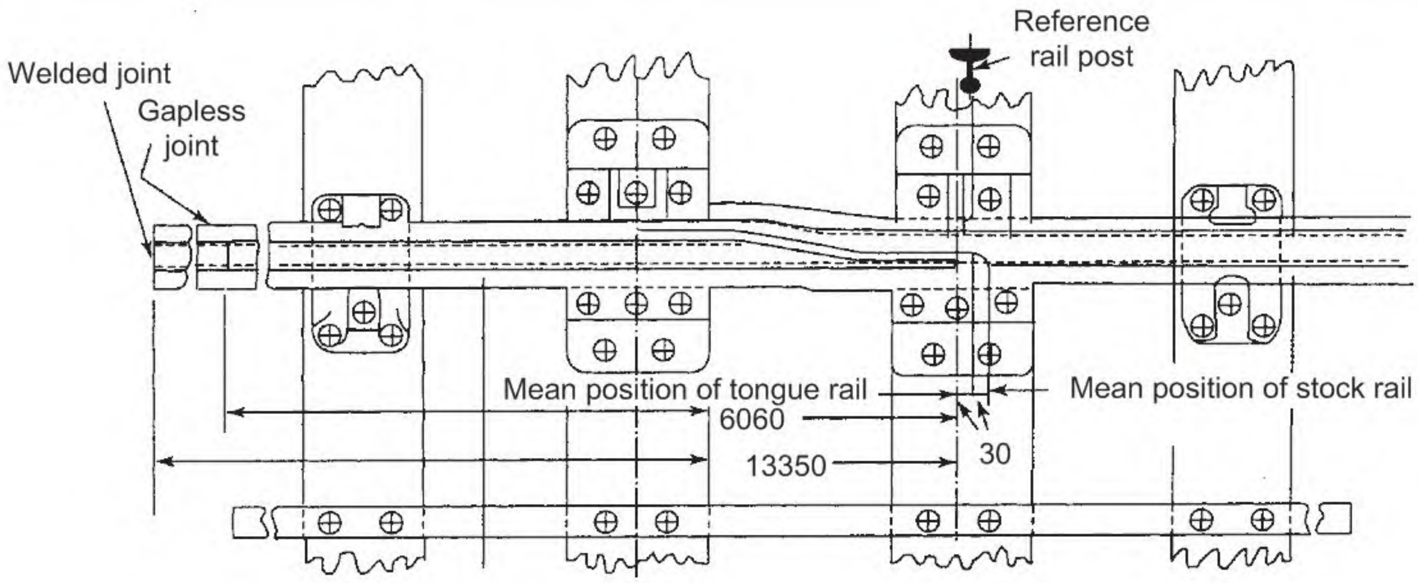


Fig. 10.3 Switch expansion joint

After placing the thermometer, the cavity is filled with mercury and sealed. When the rail piece embedded with thermometer is exposed to the same condition as the rail in the track, it takes 25 to 30 minutes for the thermometer to attain the temperature of the track rail.

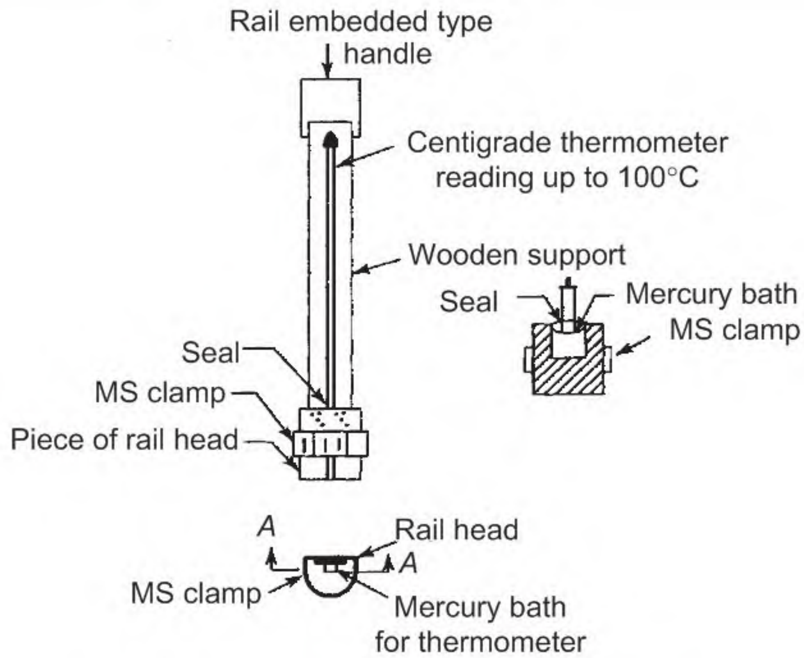
2. *Dial type* This thermometer is of bimetallic type and has a magnet for attaching it to the track rail [Fig. 10.4 (b)]. The thermometer is attached on the shady side of the web of the track rail and it takes about 8 minutes to reach a steady temperature.
3. *Continuous recording type* Basically, it is an embedded type thermometer with an attachment to furnish a continuous record of the temperature on a graph paper for a long period of time [Fig. 10.4 (c)]

It is desirable that rail temperature records are maintained for each PWI's section using a continuous recording type thermometer. The highest and lowest rail temperatures for over a continuous period of at least 5 years shall be ascertained and the mean rail temperature (t_m) for the section arrived at. The temperature record shall also be analysed to assess the probable availability of time during different parts of the year for attending to track maintenance, destressing operation, and to provide guidance for track patrolling requirements.

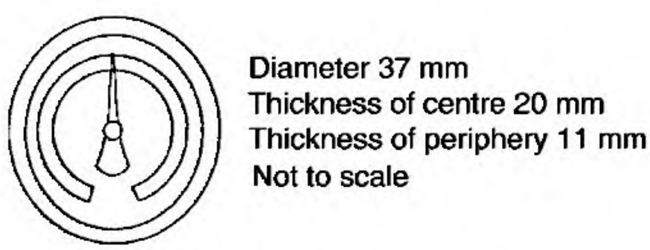
10.4 PERMITTED LOCATIONS OF LWR/CWR

10.4.1 General

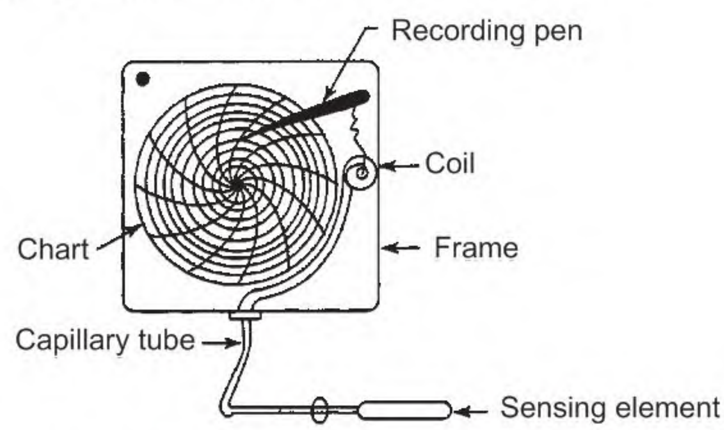
1. Wherever track conditions permit, complete track renewals shall be with LWR/CWR, priority to be given to group *A*, *B* and *C* routes on BG. Existing rails on these routes should also be progressively converted into LWR/CWR.
2. In the case of new construction and doublings, LWR is not to be laid till the formation and the track have stabilised.



(a) Rail embedded type thermometer



(b) Dial type thermometer



(c) Continuous rail temperature recorder

Fig. 10.4

3. LWR is not to be laid on locations where: (a) the rails are subject to heavy corrosion or need frequent renewals; (b) the formation is weak and track deformations are large enough to lead to buckling; and (c) formation soil is susceptible to pumping failure causing ballast contamination, which would require frequent opening out of track and ballast screening.
4. The track is vulnerable to frequent floodings, subsidence and breaches.
5. In goods running lines, goods yards, reception yards and classification yards, rail joints may be welded to form LWR if the condition of all the components of track is generally sound and without any deficiency, subject to such relaxation as may be approved by Chief Engineer in each specific case.

10.4.2 Alignment

1. LWR/CWR shall not be laid on curves sharper than 440 metre radius both for BG and MG.
2. LWR/CWR may be continued through reverse curves not sharper than 875 metre radius.

For reverse curves sharper than 1500 metre radius, shoulder ballast of 600 mm over a length of 100 metre on either side of the common point should be provided.

10.4.3 Gradients

The steepest permitted grade is 1 in 100. At change of gradient, where the algebraic difference between the grades is equal to or more than 4 mm per metre i.e. 0.4%, vertical curves of the following radii are recommended.

Classification of route	*Min. radius*
Group 'A' BG	4000 M
Group 'B' BG	3000 M
Other routes of BG and all routes of MG	2500 M

10.5 TRACK STRUCTURE FOR LWR/CWR

10.5.1 Formation

Formation should be stable. Stretches of bad formation should be stabilised before laying LWR.

10.5.2 Ballast

The minimum stone ballast cushion below the bottom of the sleeper should be 250 mm. On routes where speeds of more than 130 kmph for BG and 100 kmph for MG are contemplated, minimum ballast cushion should be 300 mm or preferably 200 mm ballast along with 150 mm of sub-ballast. Shoulder width should be 350 mm on straight and inside of curves, and 500 mm on outside of curves.

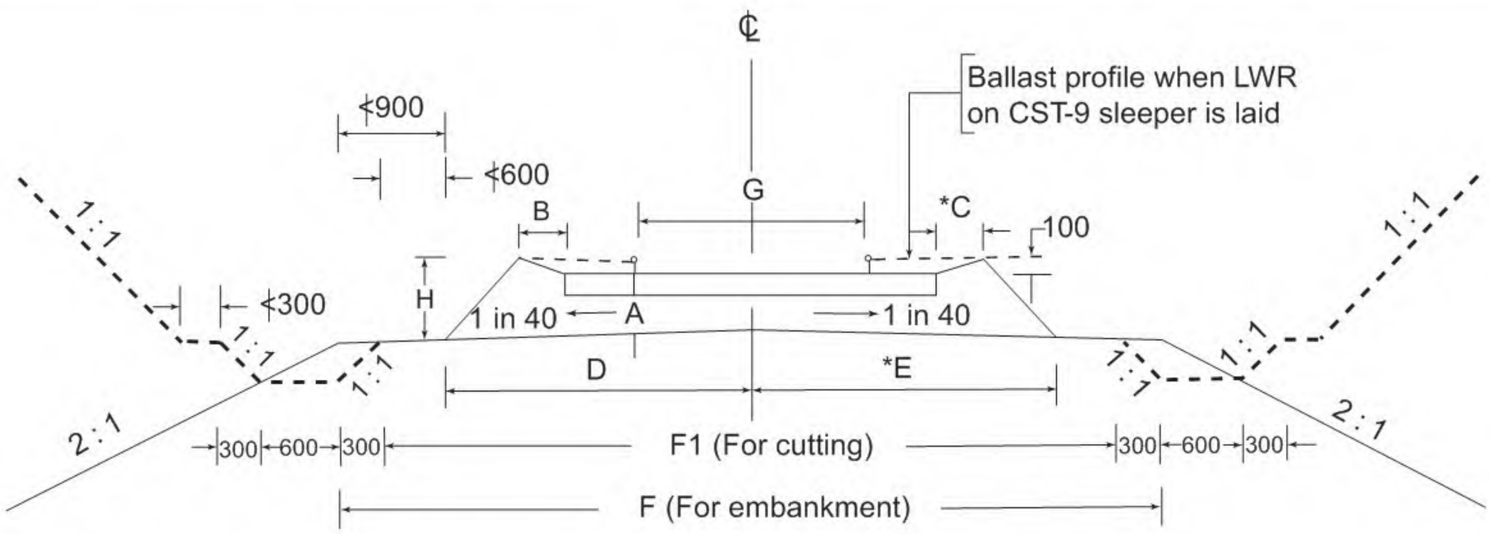
Shoulders on both sides should be humped to the extent of 100 mm.

Ballast profile for single line for BG and MG should be as shown in Figs 10.5 (a) and (b) and for double lines of BG and MG as shown in Figs 10.5 (c) and (d).

10.5.3 Sleepers

1. The sleepers approved for use in LWR (BG) should be as follows:
   - (i) Concrete sleepers with elastic fastenings.
   - (ii) Steel trough sleepers with elastic fastenings for speeds not exceeding 130 kmph (up to 160 kmph as an interim measure).

For LWR (MG) the specification of sleepers are:

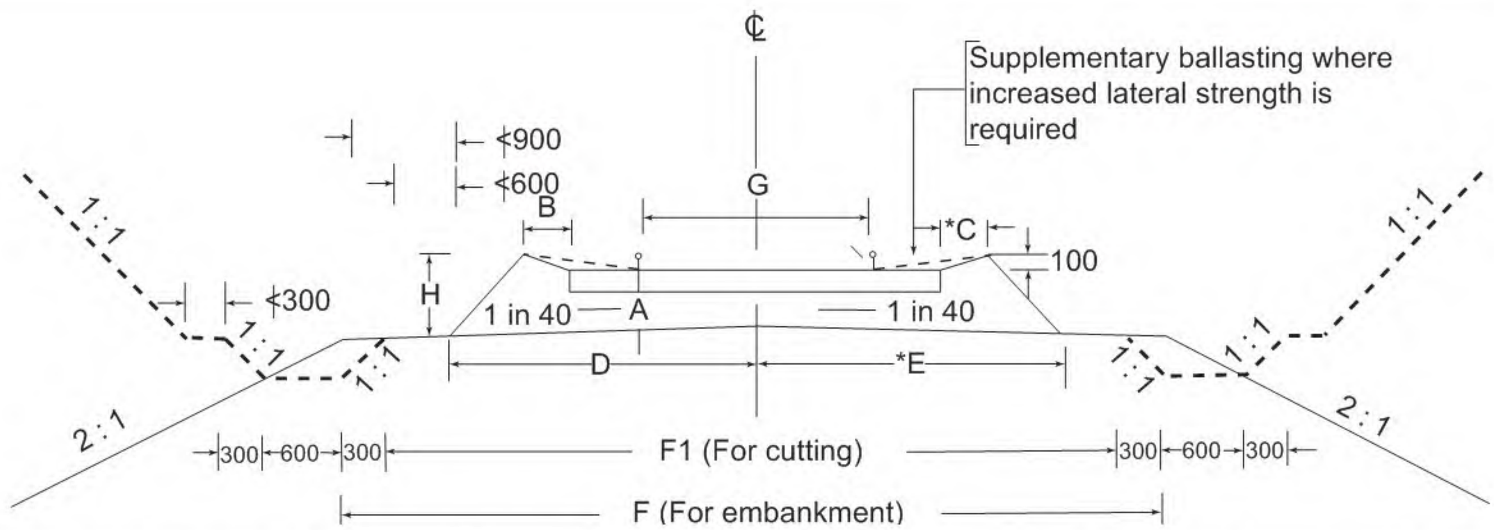


G Gauge	Type of Sleeper	A	B	*C	D	*E	F	F1	H
1676	Wooden	250	350	500	2270	2420	6850	6250	540
		300	350	500	2270	2420	6850	6250	590
		200 over 150 sub-ballast	350	500	2270	2420	6850	6250	640
	Steel Trough	250	350	500	2280	2430	6850	6250	550
		300	350	500	2280	2430	6850	6250	600
		200 over 150 sub-ballast	350	500	2280	2430	6850	6250	650
	PRC	250	350	500	2525	2675	6850	6250	640
		300	350	500	2525	2675	6850	6250	690
		200 over 150 sub-ballast	350	500	2525	2675	6850	6250	740

Note:

1. The minimum clean stone ballst cushion below the bottom of sleeper, i.e., A = 250 mm.
2. For routes where speeds are to be more than 130 kmph, A = 300 or 200 mm along with 150 mm of sub-ballast.
3. On outer side of curves only.*
4. Suitable slope shall be given for side slope of ballast profile.
5. Dimensions for formation width (F and F1) are given for straight portion only this should be suitably increased taking into account extra ballast shoulder on outside of curves and for super-elevation.
6. All dimensions are in millimetres.

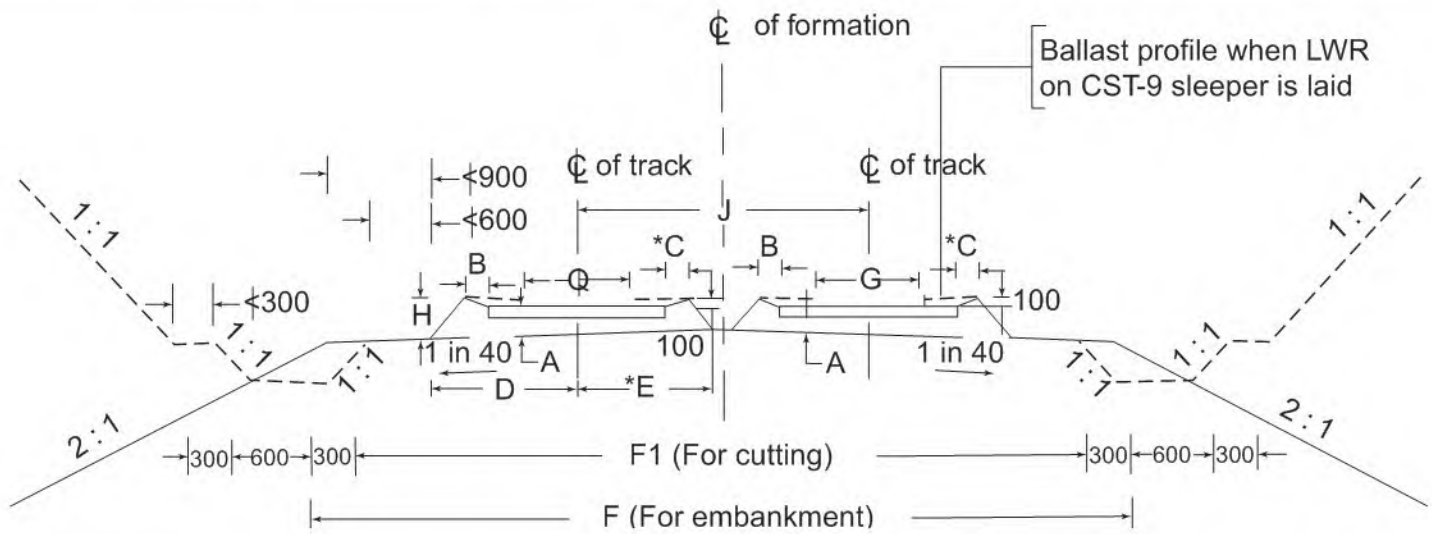
Fig. 10.5 (a) Ballast profile (Single line BG)



G Gauge	Type of Sleeper	A	B	*C	D	*E	F	F1	H
1000	Wooden	250	350	500	1760	1930	5850	5250	510
		300	350	500	1760	1930	5850	5250	560
		200 over 150 sub-ballast	350	500	1760	1930	5850	5250	610
	Steel Trough	250	350	500	1790	1940	5850	5250	520
		300	350	500	1790	1940	5850	5250	570
		200 over 150 sub-ballast	350	500	1790	1940	5850	5250	620
	PRC	250	350	500	2025	2175	5850	5250	510
		300	350	500	2025	2175	5850	5250	560
		200 over 150 sub-ballast	350	500	2025	2175	5850	5250	610
	CST-9	250	350	500	1730	1880	5850	5250	510
		300	350	500	1730	1880	5850	5250	560
		200 over 150 sub-ballast	350	500	1730	1880	5850	250	610

Note:
1. The minimum clean stone ballst cushion below the bottom of sleeper, i.e., A = 250 mm.
2. For routes where speeds are to be more than 100 kmph, A = 300 or 200 mm along with 150 mm of sub-ballast.
3. On outer side of curves only.*
4. Suitable slope shall be given for side slope of ballast profile.
5. Dimensions for formation width (F and F1) are given for straight portion only this should be suitably increased taking into account extra ballast shoulder on outside of curves and for super-elevation.
6. All dimensions are in millimetres.

Fig. 10.5 (b) Ballast profile (Single line MG)

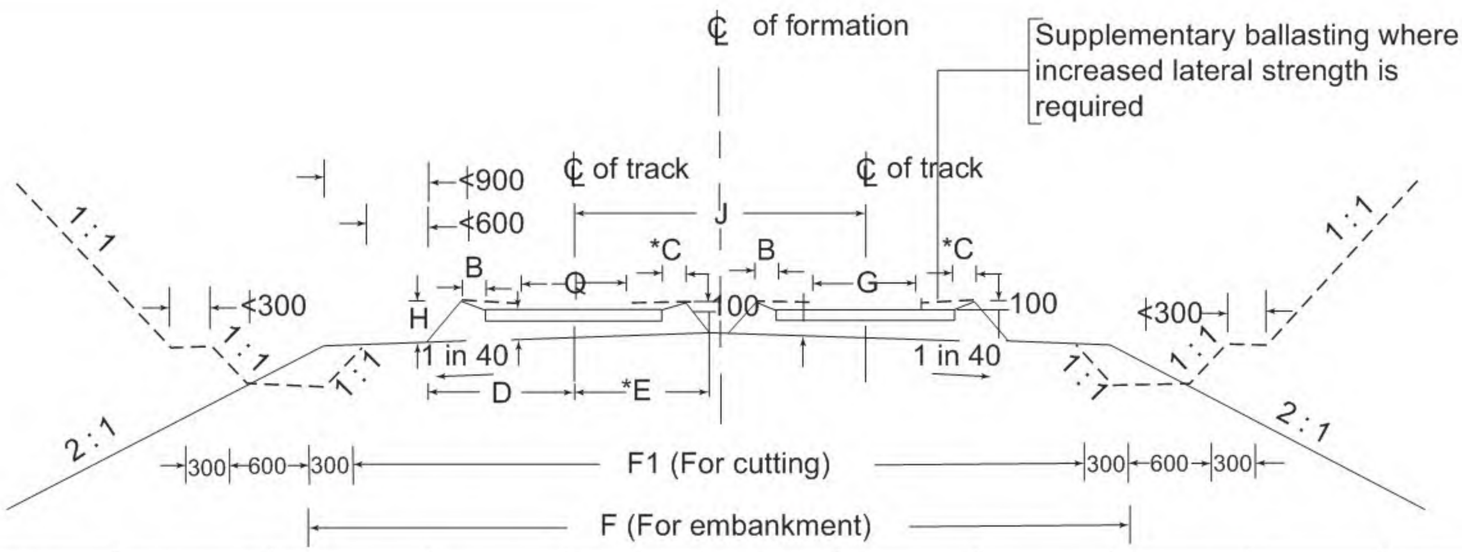


G Gauge	Type of Sleeper	A	B	*C	D	*E	F	F1	H	J
1676	Wooden	250	350	500	2300	2340	12155	11555	570	5300
		300	350	500	2300	2340	12155	11555	620	5300
		200 over 150 sub-ballast	350	500	2300	2340	12155	11555	670	5300
	Steel Trough	250	350	500	2310	2350	12155	11555	580	5300
		300	350	500	2310	2350	6850	11555	630	5300
		200 over 150 sub-ballast	350	500	2310	2350	12155	11555	680	5300
	PRC	250	350	500	2525	2460	12155	11555	700	5300
		300	350	500	2525	2460	12155	11555	750	5300
		200 over 150 sub-ballast	350	500	2525	2460	12155	11555	800	5300

Note:

1. The minimum clean stone ballst cushion below the bottom of sleeper, i.e., A = 250 mm.
2. For routes where speeds are to be more than 130 kmph, A = 300 or 200 mm along with 150 mm of sub-ballast.
3. On outer side of curves only.*
4. Suitable slope shall be given for side slope of ballast profile.
5. Dimensions for formation width (F and F1) are given for straight portion only this should be suitably increased taking into account extra ballast shoulder on outside of curves and for super-elevation.
6. All dimensions are in millimetres.

Fig. 10.5 (c) Ballast profile (Double line BG)



G Gauge	Type of Sleeper	A	B	*C	D	*E	F	F1	H	J
1676	Wooden	250	350	500	1790	1850	9810	9210	535	3960
		300	350	500	1790	1850	9810	9210	585	3960
		200 over 150 sub-ballast	350	500	1790	1850	9810	9210	635	3960
	Steel Trough	250	350	500	1810	1860	9810	9210	540	3960
		300	350	500	1810	1860	9810	9210	590	3960
		200 over 150 sub-ballast	350	500	1810	1860	9810	9210	640	3960
	PRC	250	350	500	2025	1970	9810	9210	595	3960
		300	350	500	2025	1970	9810	9210	645	3960
		200 over 150 sub-ballast	350	500	2025	1970	9810	9210	695	3960
	CST-9	250	350	500	1750	1810	9810	9210	695	3960
		300	350	500	1750	1810	9810	9210	535	3960
		200 over 150 sub-ballast	350	500	1750	1810	9810	9210	635	3960

Note:

1. The minimum clean stone ballast cushion below the bottom of sleeper, i.e., A = 250 mm.
2. For routes where speeds are to be more than 100 kmph, A = 300 or 200 mm along with 150 mm of sub-ballast.
3. On outer side of curves only.*
4. Suitable slope shall be given for side slope of ballast profile.
5. Dimensions for formation width (F and F1) are given for straight portion only this should be suitably increased taking into account extra ballast shoulder on outside of curves and for super-elevation.
6. All dimensions are in millimetres.

Fig. 10.5 (d) Ballast Profile (Double line MG)

(i)	Concrete sleepers with Elastic fastenings	Preferably for speeds above 75 kmph but a must for speeds above 100 kmph
(ii)	Steel trough sleepers with Elastic fastenings	–do–
(iii)	Steel-trough sleepers with keys	For speeds not exceeding 100 kmph
(iv)	CST-9 sleepers with keys	–do–

2. Existing LWRs/CWRs on wooden sleepers with anticreep bearing (ACB) plates and two way keys or elastic fastenings, if behaving satisfactorily, may be continued for maximum speed of 130 kmph on BG and 100 kmph on MG.

3. In case of CST-9 sleepers, undermentioned precautions shall be adhered to.

(a) LWRs/CWRs shall not preferably be provided on CST-9 sleepers in areas where the incidence of derailment or theft of fastenings is significant.

(b) Sleepers already in service in jointed track shall have negligible wear at rail seat and jaws, when converting this track into CWR.

(c) Ballast shall be heaped up in a rising slope from end of ballast-shoulder to the bottom of rail head on the outside of track for increasing lateral resistance to CWR.

(d) Crib and shoulder compaction shall invariably be carried out soon after sleeper-renewal/through-packing/overhauling-deep-screening or any other operation causing reduction of **ballast resistance**. Till such compaction is done, suitable speed restriction shall be observed.

(e) On single line, in LWR/CWR, both keys in a sleeper shall be driven in the same direction and the keys in the next sleeper shall be in reverse direction and so on.

(f) On double line 75 percent of keys shall be driven in the direction of traffic and 25 percent in the opposite direction in the central portion of LWR/CWR. In the breathing lengths, keys shall be driven alternately in both directions on successive sleepers.

(g) Attempt shall be made to keep both the keys of the same sleeper uniformly tight to avoid plates going out of square. When even, a fallen key is driven back, the opposite key on the same sleeper shall also be adequately driven to match with that on the opposite plate.

(h) Wherever possible, reverse jaw type plates shall be replaced with ordinary type plates, since the former afford hindrance while lifting LWR on rollers during destressing. If the replacement cannot be done while initially laying LWR, the same may be done on a programmed basis.

(i) On-track-tamping-machine shall preferably be used for maintaining LWR/CWR lengths. In case of manual maintenance, lifting of LWR/CWR track on CST-9 sleepers in excess of 20 mm shall be carried out under the supervision of an Inspector not below the rank of Permanent Way Inspector/Incharge of sub section.

(j) During destressing, before the rails is supported on rollers, the rail seat shall be covered by 3 mm thick MS plate of suitable size so that the rollers do not get stuck into the slits at the rail seats. The cover plates shall have both the opposite edges bent downwards to prevent their slipping off from the rail seats.

(k) If it is not possible to drive 100 percent keys within the block period after destressing, 33 percent keys in central portion and 100 percent of the keys in the breathing lengths shall be driven first and the traffic resumed at restricted speed. Full speed should be restored only after driving 100 percent keys and giving other required attentions.

(l) Creep shall be regularly measured at SEJs and at centre of each LWR panel and records seen by AEN and DEN for taking remedial measures, if required.

Sleeper Density: The minimum sleeper density (number of sleepers/km) in LWR/CWR shall be as follows.

Type of Sleeper	*Sleeper Density BG/MG*
1. PRC Sleeper	1310 in temperature zones I & II
2. PRC Sleeper	1540 in temperature zones III & IV
3. Other Sleepers	1540 in all temperature zones

10.5.4 Rails

1. LWR shall be laid with 90 R or heavier rails on BG and 75 R or heavier rails on MG. New rails should be as far as possible without fishbolt holes.
2. In case of conversion of existing fishplated track on SWR into LWR, the following additional precautions are to be observed; (a) the anticipated residual life of the rails shall be at least 10 years; (b) the rails shall be tested ultrasonically and defective rails removed; (c) defective rail-ends shall be cropped, and; (d) fishbolt holes if any, shall be chamfered.

10.5.5 Miscellaneous Provisions in Laying of LWR/CWR

1. *Continuity of Track Structure*: Wherever LWR/CWR is followed by fishplated track/SWR, the same track structure as that of LWR/CWR shall be continued for three rail lengths beyond SEJ.
2. *Level Crossings*: Level crossings situated in LWR/CWR territory shall not fall within the breathing lengths.
3. *Points and Crossings*: LWR/CWR shall not run through points and crossings. Three normal rail lengths shall be provided between stock rail (SRJ) and SEJ, as well as between the crossing and SEJ. These normal rail lengths shall be provided with elastic rail clips/anchors to arrest creep. However on concrete sleeper turnouts, one three rail panel shall be provided between SEJ and SRJ, as well as between heal of the crossing and SEJ.
4. *Glued Joints*: All insulations for track circuiting in LWR/CWR shall be done by providing glued joints G3 (L) type.
5. *Location of SEJ*: The exact locations of SEJ shall be fixed taking into account the location of various obligatory points such as level crossings, girder bridges, points and crossings gradients, curves and insulated joints. SEJ with straight tongue and stock shall not be located on curves sharper than 0.5° (3500 m radius) as far as possible. SEJ shall not be located on transition of curves.

6. *Bridges with Ballasted Deck* (*Without Bearing*): LWR/CWR can be continued over bridges without bearings such as slabs, box culverts and arches.
7. *Girder Bridges with/without Ballasted Deck*: They should qualify as follows:

   (a) LWR/CWR shall not be continued over bridges with overall length as specified in para 8 to 11 for BG and not more than 20 metres for MG.
   (b) Girder bridges on which LWR/CWR is not permitted/provided shall be isolated by a minimum length of 36 metre well anchored track on either sides.

8. *Girder Bridges provided with rail free fastenings* (*single span not exceeding 30.5 metre and having sliding bearing on both ends*): In such cases the overall length of the bridge should not exceed the maximum prescribed in Table 10.2 with following stipulations.

Table 10.2 Maximum Overall Length of Girder Bridges Permitted on LWR/CWR on B.G. (in metre) (Para 8 and 9)

Temperature zone	*Rail section*	*Rail free fastenings on bridges (Para 8)* *Type of sleepers used in approaches* *PRC/ST*	*Rail free fastenings on bridges partly box anchored (Para 9)* *Type of sleeper used in approaches* *PRC/ST*
(I)	60 kg	30	77
	52 kg/90 R	45	90
(II)	60 kg	11	42
	52 kg/90 R	27	58
(III)	60 kg	11	23
	52 kg/90 R	27	43
(IV)	60 kg	11	23
	52 kg/90 R	27	43

   (a) Rail free fastenings shall be provided through out the length of the bridge between abutments.
   (b) The approach track up to 50 m on both sides shall be well anchored by providing any one of the following:

      (i) ST sleepers with elastic fastenings.
      (ii) PRC sleepers with elastic rail clips with fair T or similar type creep anchors.

   (c) The ballast section of approach track up to 50 metre shall be heaped up to the foot of the rail on the shoulders and kept in well consolidated and compacted condition during the months of extreme summer and winter.

9. *Girder Bridges provided with rail free fastenings and partly box anchored* (*with single span not exceeding 30.5 metre and having sliding bearings at both ends entail*): An overall

length of the bridge not to exceed the maximum prescribed in Table 10.2 with following stipulations.

(a) On each span, four central sleepers shall be box-anchored with fair T or similar type creep anchors and the remaining sleepers shall be provided with rail-free fastenings.
(b) The bridge timbers laid on girders shall not be provided with through notch but shall be notched to accommodate individual rivet heads.
(c) The track structure in the approaches shall be laid and maintained to the standards as stated in Para 8 (b) and (c) above.
(d) The girders shall be centralized with reference to the location strips on the bearing, before laying LWR/CWR.
(e) The sliding bearing shall be inspected during the month of March and October each year and cleared of all foreign material. Lubrication of the bearings shall be done once in two years.

10. Welded rails may be provided from pier to pier with rail-free fastenings and with SEJ on each pier. The rail shall be box anchored on four sleepers at the fixed end of the girder if the girder is supported on rollers on one side and rockers on the other. In case of girders supported on sliding bearings on both sides, the central portion of the welded rails over each span shall be box anchored on four sleepers (Fig. 10.6).

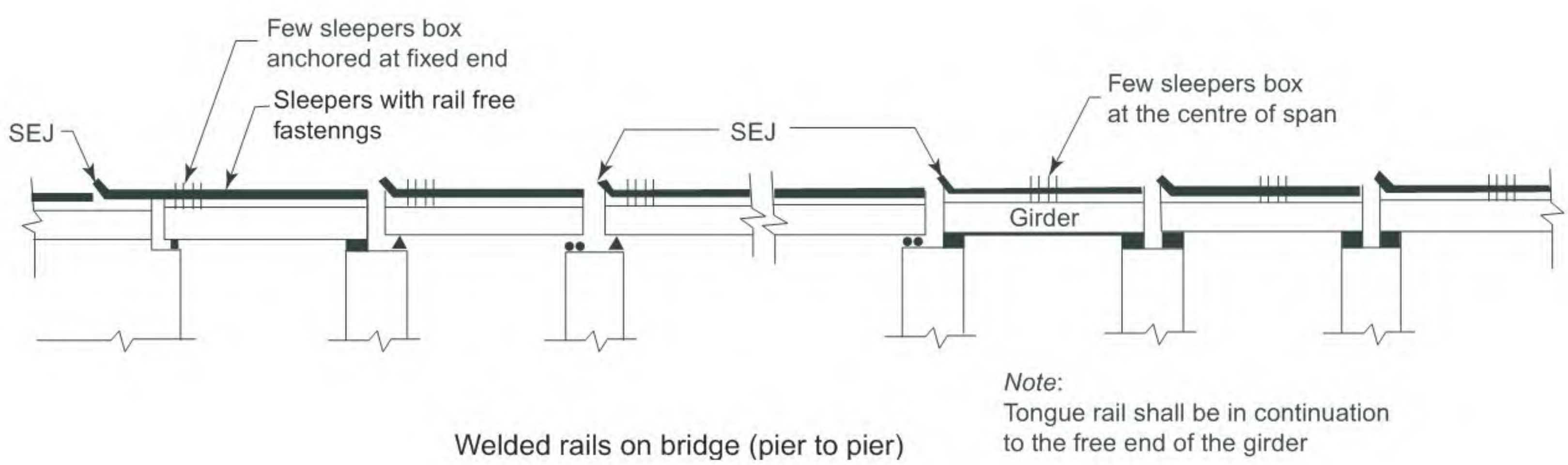


Fig. 10.6 Welded rails on bridge

11. LWR/CWR may also be continued over a girder bridge with the provision of SEJ at the far end approach of the bridge using rail-free fastenings over the girder bridge (Fig. 10.7). The length of the girder bridge in this case, however, will be restricted by the capacity of the SEJ to absorb expansion, contraction and creep, if any, of the rails.

The length of the girder bridges with the above arrangements that can be permitted in various rail temperature zones for LWR/CWR with SEJs having maximum movement of 120 mm and 190 mm are given in Table 10.3.

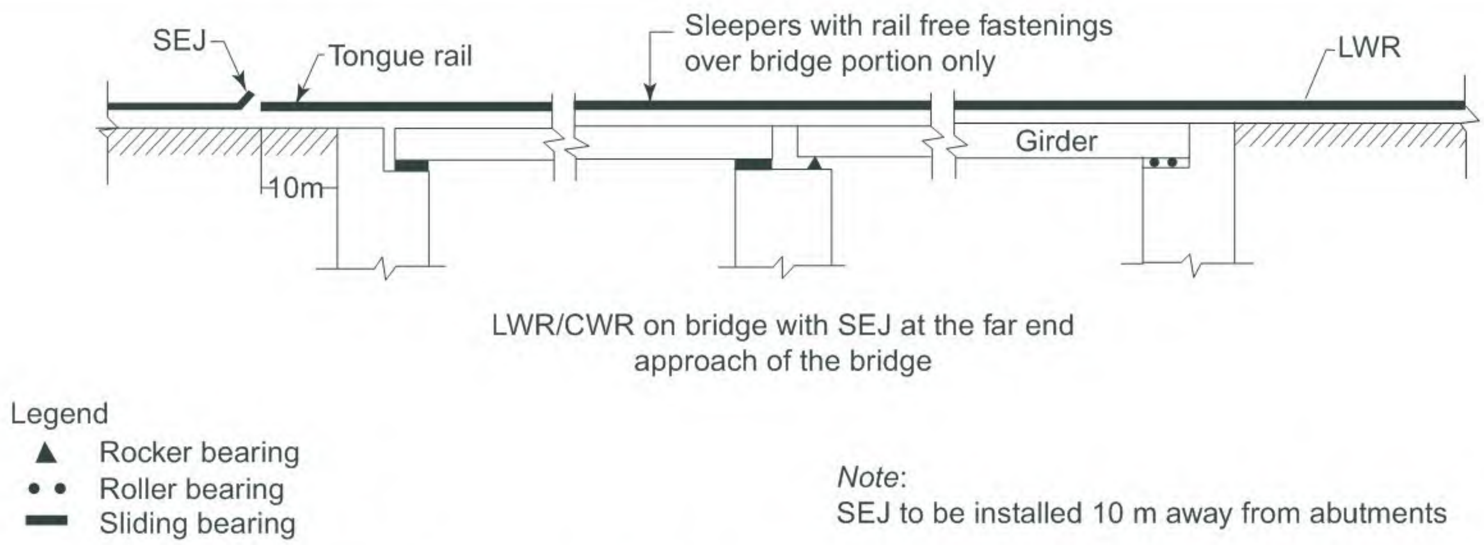


Fig. 10.7 LWR/CWR on girder bridge with SEJ at the far end-approach of the bridge.

Table 10.3

Rail temp zone	*Maximum movement of SEJ used*	*Max. length of bridge with SEJ*		*Initial gap to be provided at t_d*	
		With ST/PRC approach sleepers (m)	*With CST-9 approach sleepers (m)*	*WithST/PRC approach sleepers (cm)*	*With CST-9 approach sleepers (cm)*
IV	190	55	45	7.0	6.5
III	190	70	70	7.0	6.5
II	190	110	100	6.5	6.5
I	190	160	150	6.5	6.0
II	120	20	15	4.0	4.0
I	120	50	50	4.0	4.0

Note: SEJ is to be installed 10 metres away from the abutments.

10.6 LAYING OF LONG WELDED RAILS/CONTINUOUSLY WELDED RAILS

The rail-roading with LWR/CWR entails:

1. *Survey*: A foot by foot survey of the sections, where LWR/CWR is proposed to be laid, shall be carried out in regard to the following:

   (a) Locations where LWR/CWR cannot be executed due to such constraints as bridges having sub-structure/superstructure in a distressed condition, gradients; points and crossings, unstable formation etc. Such stretches of track shall be isolated from the remaining portion of LWR/CWR by providing SEJs at either end.

(b) Locations where following preliminary works are required to be carried out, shall be identified for completion before laying of LWR/CWR:

(i) Replacement of conventional insulated joints by glued insulated joints;
(ii) Realignment of curves;
(iii) Lifting or lowering of track to eliminate sags and humps;
(iv) Introduction and improvement of vertical curves;
(v) Stabilization of troublesome formation;
(vi) Rehabilitation of weak bridges involving removal or lifting of rails or introduction of temporary arrangements.

(c) A detailed plan shall be made showing the exact locations of SEJs and of various other features mentioned in sub-paras (a) and (b). A sample of the detailed plan can be seen in Fig. 10.8. The plans may be prepared to a horizontal scale of 1 : 5000.

2. *Temperature Records*: The maximum daily variation of rail temperature and the mean rail temperature (t_m) for the section shall be ascertained from the temperature records maintained by the PWI over the last five years.
If rail temperature records of preceding five years are not available, the mean and range of rail temperatures shown in the "Map of India showing Rail Temperature Zones" (Fig. 10.9), shall be adopted.

3. *Material Required*: Laying of an LWR entails the following materials [Fig.10.10 (a)–(c)]

(a) Four numbers of 6.5 metre or longer rail pieces of the same rail section as LWR;
(b) Two sets of SEJs with sleepers and fastenings;
(c) Adequate numbers of 1 metre long fishplates with special screw clamps/joggled fishplates with slotted grooves & bolted clamps as in Fig. 10.11. The slotted fishplates with fishbolts may be used in exceptional cases.
(d) Rail closures of suitable sizes;
(e) One metre and 10 cm straight edges;
(f) Calipers and feeler gauges (2 mm to 0.1 mm);
(g) Rail cutting equipment;
(h) Destressing equipment, i.e. rollers, mechanical/hydraulic rail tensor, mallets and side rollers for curves.
(i) Alumino-thermic/mobile gas pressure welding equipment and consumable materials;
(j) Equipment for protection of track;
(k) Equipment for night working.

4. *Preliminary Works*: The under mentioned preliminary works are prerequisites to the laying of an LWR.

(a) Deep screening of ballast along with lifting or lowering of track, if required, should precede laying of LWR/CWR. Standard ballast section as stated in Section 10.5 for LWR/CWR shall be provided.

All other preliminary works mentioned under survey [1(b)] shall also be completed before laying of LWR/CWR.

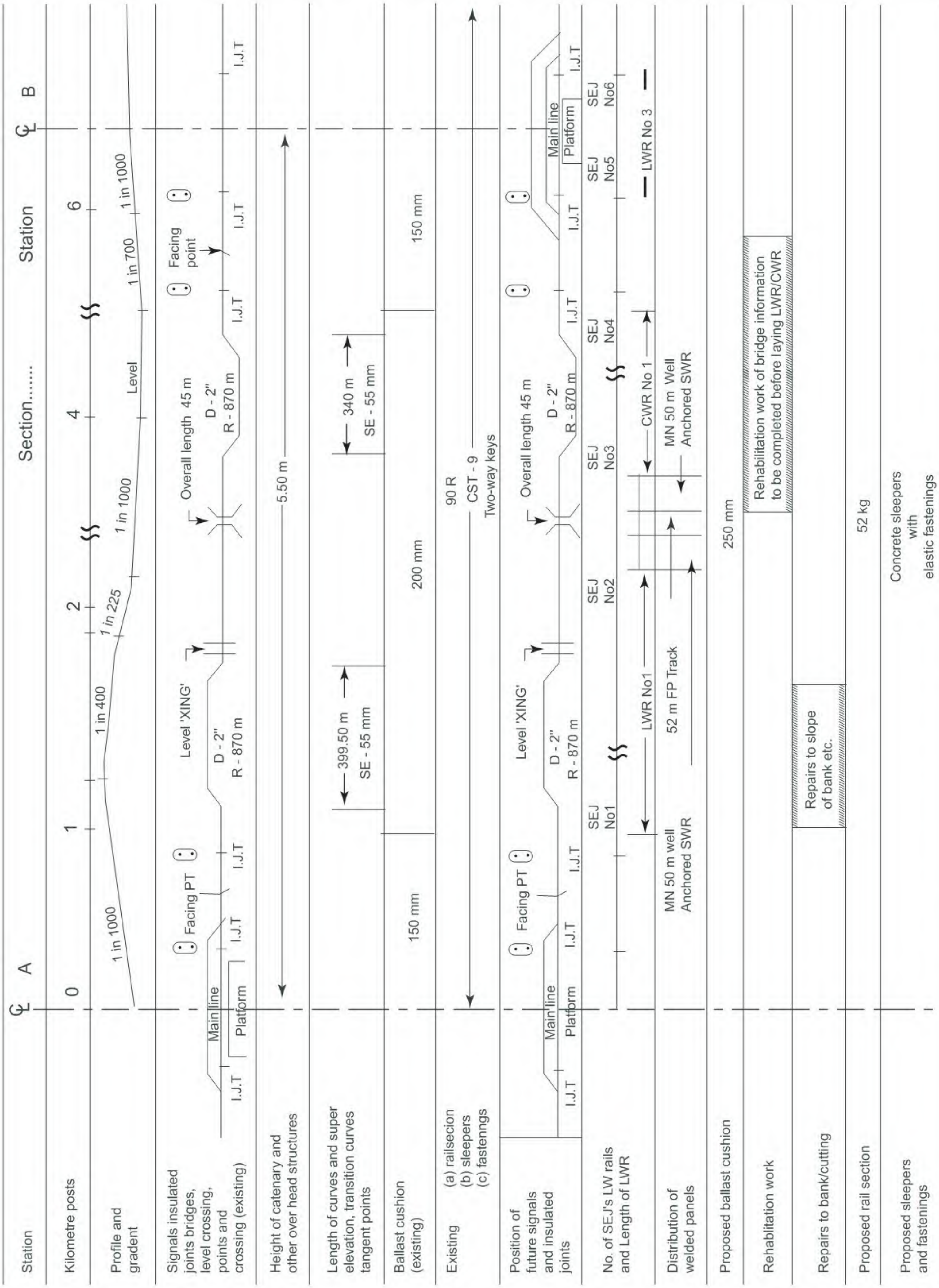


Fig. 10.8 Proposals for laying long and continuous welded rails

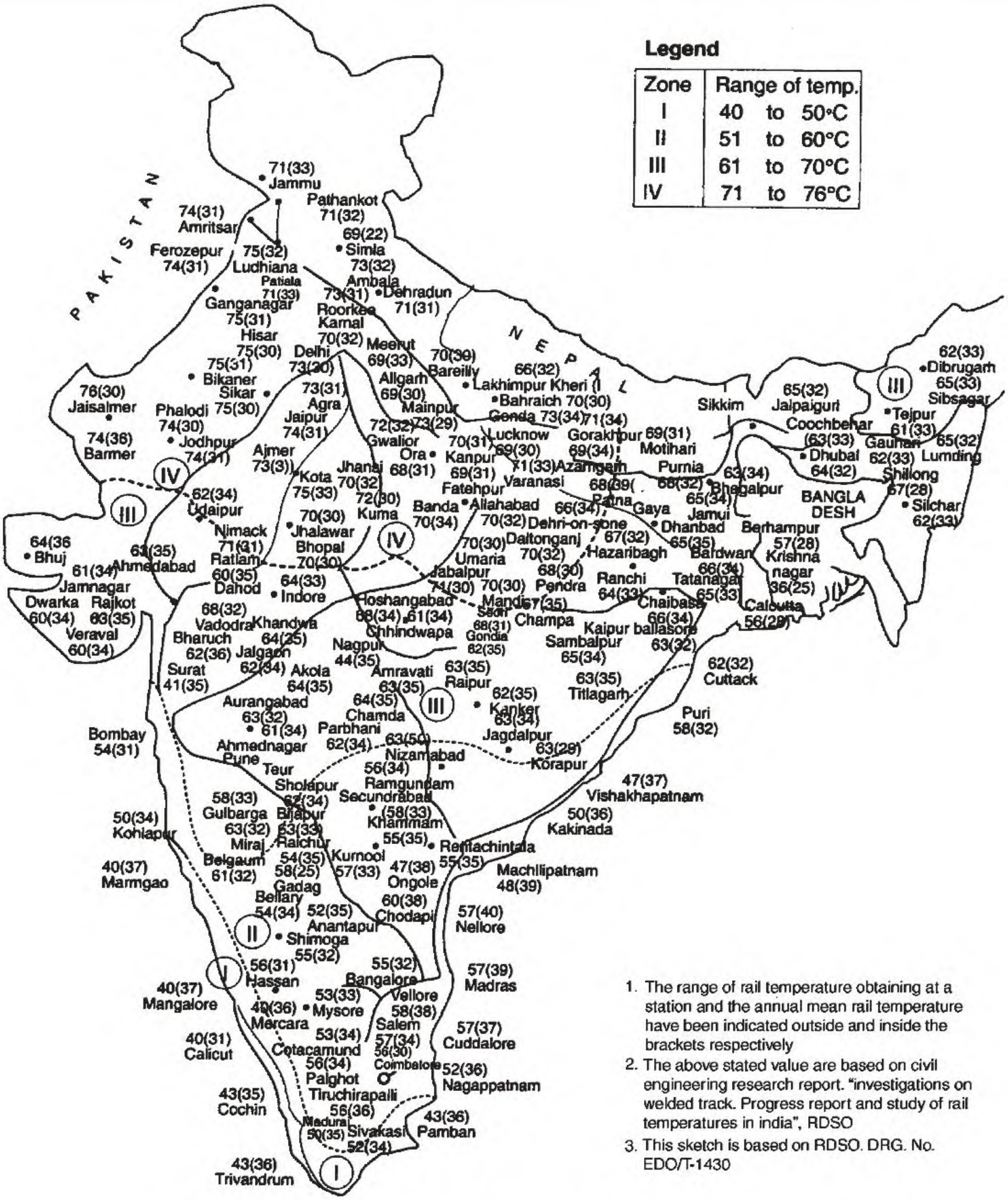


Fig. 10.9 Map of India showing rail temperature zones

(b) If any of the preliminary works cannot be completed before installation of LWR/CWR, such stretches should be isolated by providing SEJs. On completion of these works, such stretches may be welded, distressed and jointed with LWR/CWR in accordance with Sec. 10.7.8.

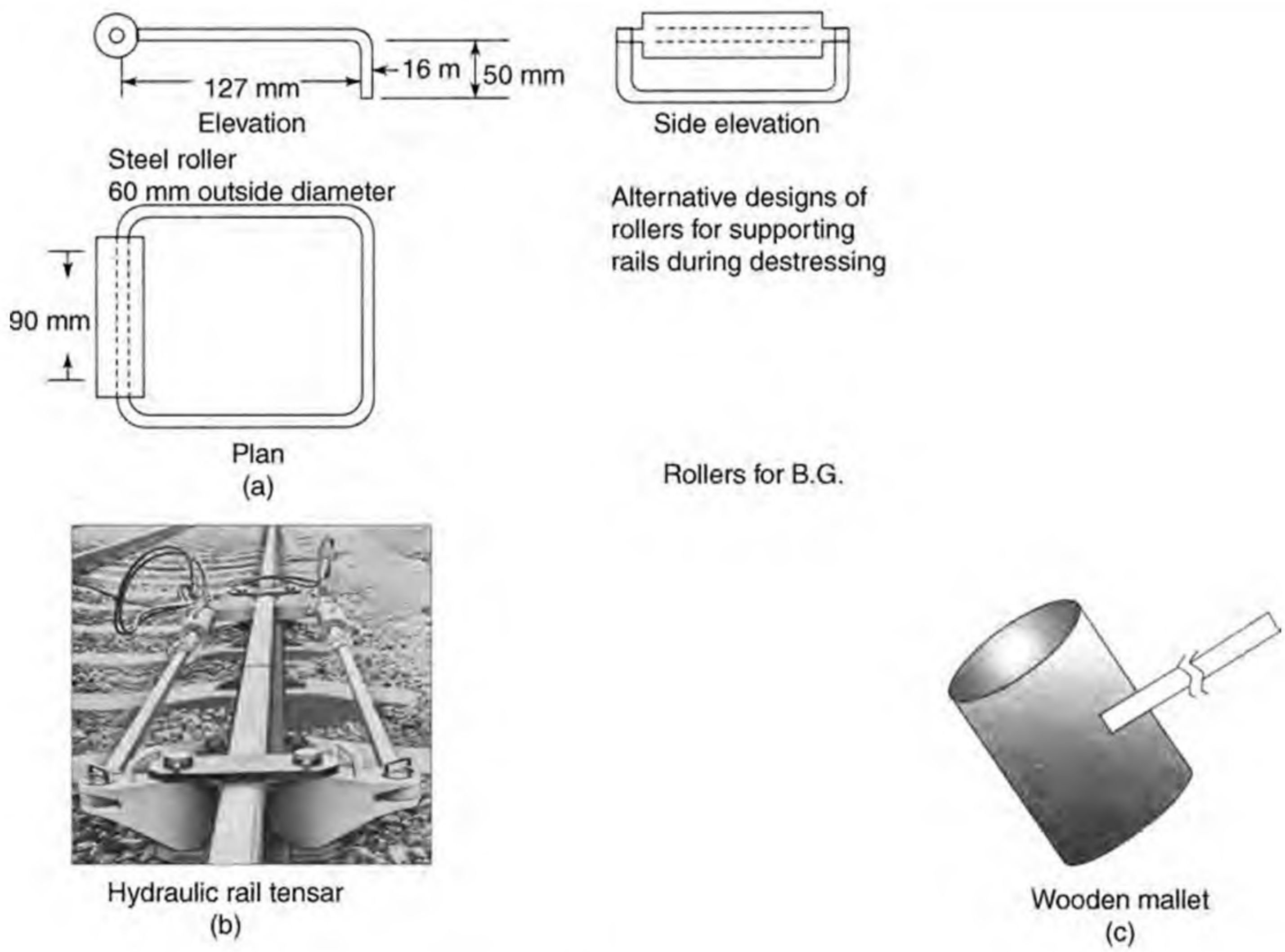


Fig. 10.10

5. *Welding of Rails to Form LWR*

(a) Rails shall normally be welded into sufficiently long panels of 10 to 20 rails lengths or more by flash butt welding/gas pressure welding, either in the welding depot or on cess or in situ. Only in between joints shall be welded by alumino-thermic welding (SKV Process).

(b) While unloading 880 grade (90 UTS) or higher grade rails, handling instructions as laid down should be followed.

(c) Before laying long welded panels and/or before welding of rails, two complete sets of SEJs, one at either end of the proposed LWR/CWR shall be inserted at predetermined locations with gaps in mean position as per Sec. 6. Closure rails of 6.5 metre or longer length shall be provided at LWR side/Sides of SEJs to facilitate adjustment of gaps during destressing operation.

(d) Laying of welded panels and/or welding of joints at site can be done at any time of the year. But after welding into sufficiently long panels of about 1 km or longer, destressing as per Sec 7 shall be undertaken as soon as possible. Under unavoidable circumstances where destressing can be done neither soon after nor within a reasonable period, a strict vigil shall be maintained on the prevailing rail temperatures, and if the rail temperature rises more than 20°C above the rail temperature at which welding of rails/laying of welded panels was done, temporary destressing shall be undertaken at a rail temperature of 10°C below the maximum rail temperature likely to be attained until final destressing. If the rail temperature falls appreciably, cold weather patrolling, as per instructions should be introduced. Final destressing shall be done after consolidation of track as suggested in item 4 under Sec. 10.2.

(e) Temporary speed restriction as indicated in Sec. 10.11 shall be imposed on the length of track where welded panels are joined by *1 m long fishplates with special screw clamps* or joggled fishplates with slotted grooves and bolted clamps as in Fig. 10.11.

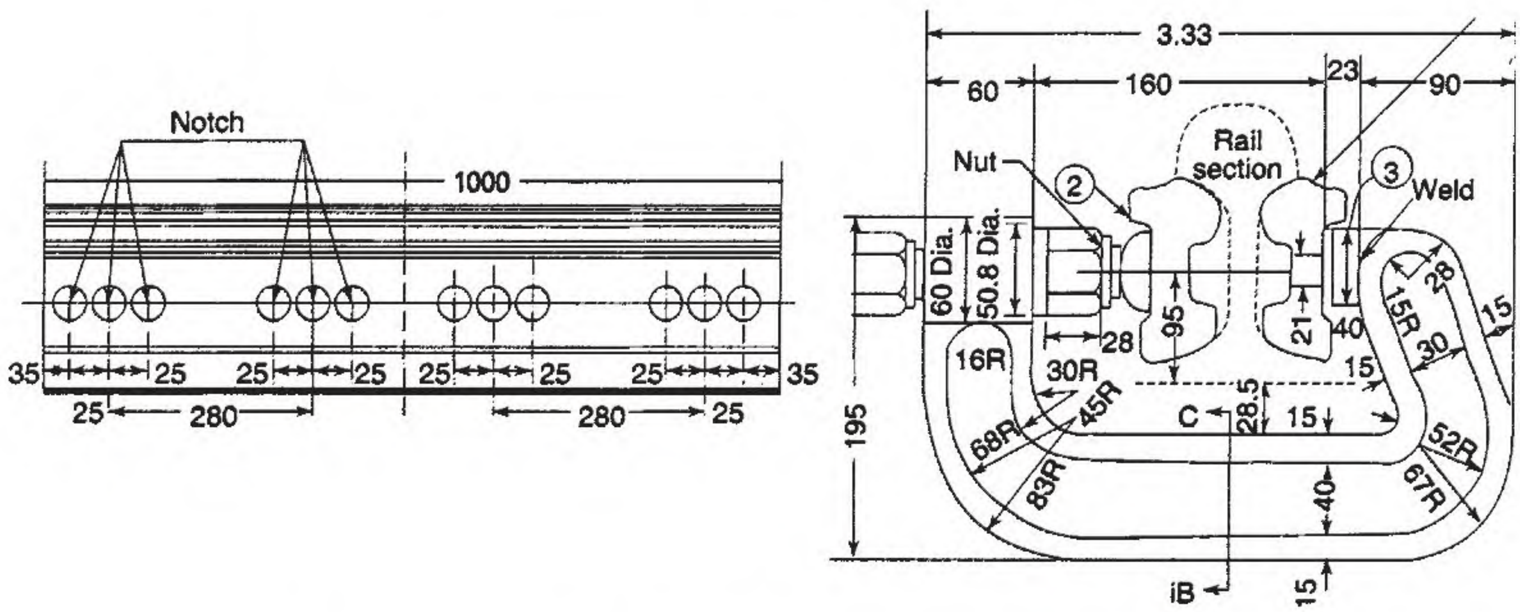


Fig 10.11 1000 mm long special fishplate for clamped joints

6. *Gaps at SEJ*

(a) Gaps at SEJ shall be adjusted at the time of laying/subsequent destressing of LWR/CWR, as illustrated in Fig. 10.3 and shall be as under:

Rail section laid	*Gap to be provided at t_d*
52 kg/60 kg	40 mm
Others	60 mm

(b) The gaps of SEJ at various rail temperatures shall not differ by more than ± 20 mm from the theoretical range as shown in Table 10.4 for 60 kg rails and PRC sleepers.

(c) Where fishplated or SWP track is jointed on one side of SEJ, the gap between the reference mark and tongue rail tip/stock rail corner on LWR/CWR side shall not differ by more than ± 10 mm half the theoretical range as shown in Table 10.4.

7. *Destressing of LWR*

(a) *General*

(i) The work of destressing shall be done during a traffic block under the personal supervision of PWI.

Table 10.4 Gaps between the reference mark and tongue rail tip/stock rail corner of SEJ for various temperatures in mm for BG, 60 kg, PRC sleeper, 1660 nos/km, value of R (Ballast resistance) assumed = 13.74 kg/cm/rail and t_d as per Sec. 10.2.

Temperature	*Zone I*	*Zone II*	*Zone III*	*Zone IV*
$t_d + 28$	–	–	–	14
$t_d + 25$	–	–	15	14–16
$t_d + 20$	–	17	15–18	14–18
$t_d + 15$	18	17–19	15–20	14–21
$t_d + 10$	18–20	17–21	16–23	15–23
$t_d + 05$	19–22	18–23	17–25	16–26
t_d	19–23	18–25	18–27	17–28
$t_d - 05$	20–25	19–26	19–28	18–29
$t_d - 10$	21–26	20–28	20–30	20–31
$t_d - 15$	22–27	22–29	21–31	21–32
$t_d - 20$	23–27	23–30	23–32	23–34
$t_d - 25$	25–28	25–30	25–33	25–35
$t_d - 30$	26–28	27–31	27–34	27–36
$t_d - 35$	28	29–31	29–34	29–36
$t_d - 40$	–	31	32–34	32–37
$t_d - 45$	–	–	35	35–37
$t_d - 48$	–	–	–	37

Note: The above values have been calculated with initial setting of gaps at SEJ as 40 mm. Where SEJs had initially been set with a gap of 60 mm, 10 mm should be added to each of above values for comparison of gaps at site.

(ii) It is preferable to impose a speed restriction of 30 kmph before actually obtaining the traffic block and to loosen/remove fastenings on alternate sleepers to reduce total duration of the traffic block.

(b) *Destressing Operation of LWRs/CWRs Panels without the use of Rail Tensor*

(i) A traffic block of adequate duration should be arranged at such a time that the rail temperature will be within the temperature range specified for t_d in Section 10.2 during the fastening down operations. The entire work shall be done under personal supervision of the PWI.

(ii) Before the block is actually taken, a speed restriction of 30 kmph should be imposed and fastenings on alternate sleepers loosened.

(iii) When the block is taken, the closure rails shall be removed, the SEJs adjusted as per item (6) under Sec. 10.6 and fastened.

(iv) The remaining sleepers fastenings on both running rails shall be loosened/removed starting from the proximal ends of the SEJs and proceeding towards the centre. The rails are lifted and placed on the rollers at about every 15^{th} sleeper to permit rails to move freely. While destressing on curved track, provision of side rollers may be adopted. The rails shall be struck horizontally with heavy wooden mallets to assist in their longitudinal movement.

(v) The rollers shall then be removed, the rails lowered to correct alignment and fastenings tightened, starting from the middle of LWR and proceeding toward both ends simultaneously. The tightening of fastening shall be completed within the temperature range for t_d as specified. The actual range of temperature during the period of tightening shall be recorded by PWI along with the time and date.

The tightening of fastening, and the arrangements for insertion of cut rails between the SEJ and LWR shall be simultaneous. The four gaps shall be measured individually and the rails of required length cut by saw keeping the required gaps for AT welding. The cut rails shall then be placed in position, fastened to the sleepers and welded at each end. Fastenings for 20 metre on each end of the LWR shall be removed before welding. Joints shall be clamped for 20 minutes after welding.

(c) *Destressing Operation of LWR with the use of Rail Tensors*

For destressing of LWR with the use of rail tensor, the following procedure shall be adopted:

(i) During the first traffic block, create a gap of 1 metre at location *B* i.e. centre of LWR (Fig. 10.12). Introduce rail closure as required and fasten with special fishplates and clamps. Allow traffic at restricted speed.

(ii) Mark the anchor length A_1, A_2 and C_1, C_2 each equal to L_a at either end of the length A_2, C_2 to be destressed (Fig. 10.12).

Note: The anchor length 'la' should be determined on the basic of the lowest value of tp at which the destressing is likely to be carried out.

(iii) Erect Marker pillars W_0, W_1 etc., on each of the length A_2B and C_2B. Transfer the marks W_0 into the rail foot [Fig. 10.12 (a)].

Note: The distance W_0 W_2, W_1 W_2 etc. shall be marked at intervals, 100 metre, or there about the distance from the previous pillars and the last pillar W_B may be less than 100 metre.

(iv) During the second traffic block, when t_p is less than the t_0 [(b) in Fig. 10.12], destressing operation shall be carried out for the lengths A_2B and C_2B as described as follows:

- Remove the closure rail from location *B*. Unfasten and mount on rollers the portion from A_2C_2.
- Fix the rail tensor across the gap at *B* and apply tension to obtain some movement at W_0 to remove any kinks or misalignment and to minimise the friction in the rollers etc. Release the tension and note the movement Y_0 at W_0.
- Transfer marks W_1, W_2, ……. onto the rail foot and the note temperature t_p.
- Calculate the required movement at W_1 as under:

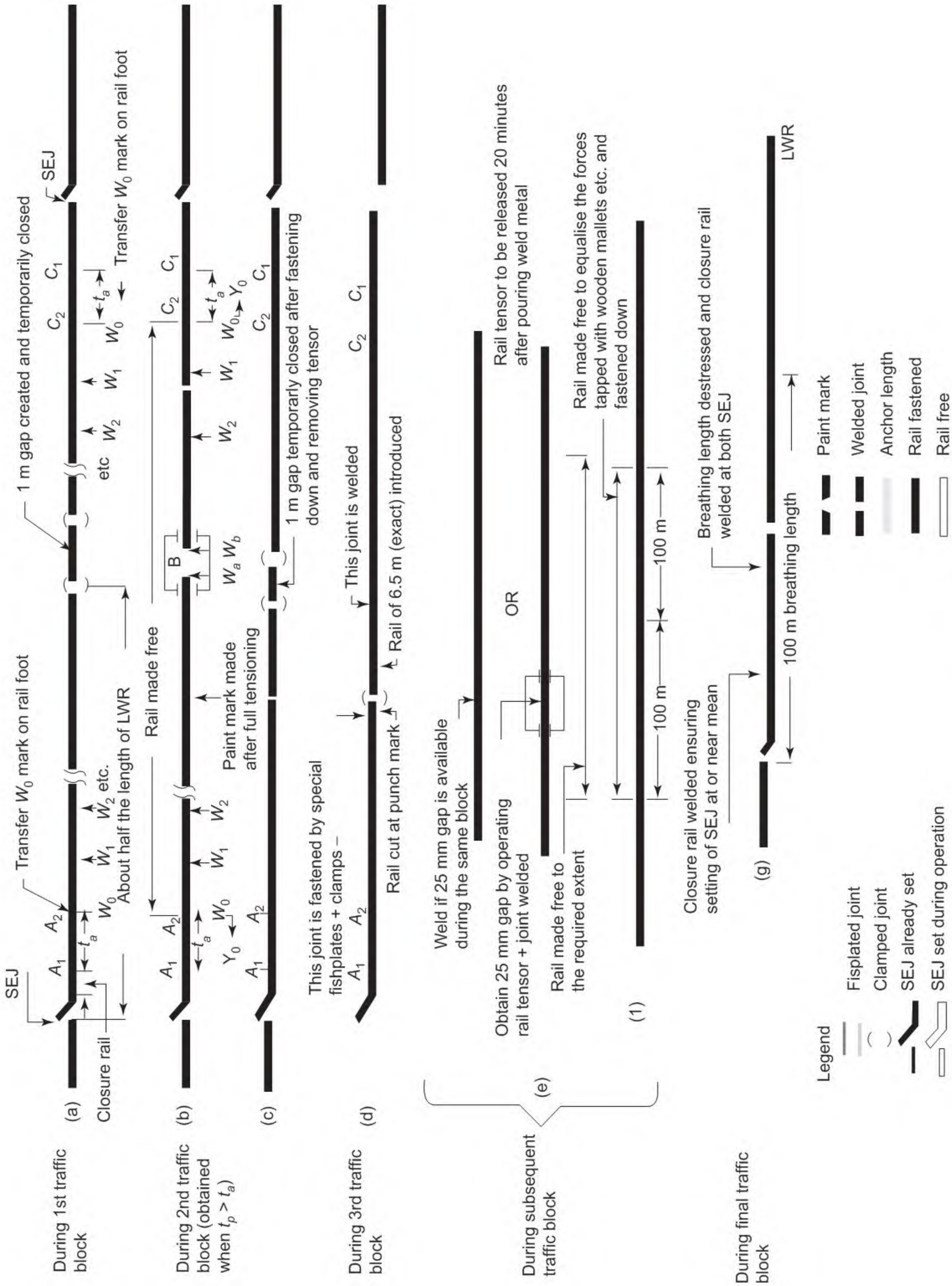


Fig 10.12 Distressing of LWR with the use of rail tensor

Movement at $W_1 = Y_0$ + elongation of length W_0W_1 (L) due to Temperature Difference $(t_0 - t_p) = Y_0 + a\,(t_0 - t_p)$

- Calculate the required movement at W_2 as under:

  Movement at W_2 = Movement at W_1 + elongation of length $W_1\,W_2$ (L) due to temperature difference $(t_0 - t_p)$.

Similarly, calculate the required movements successively at each of the remaining points.

Mark the above calculated extension with respect to the transferred marks referred above on the rail foot on the side away from the tensor.

Apply the tension by means of rail tensor till the mark of required extension comes opposite to the mark on the marker pillar W_1. Fasten down the segment $W_0\,W_1$. Then check at W_2, bring the mark of required extension at this location opposite to the mark on the marker pillar W_2, by adjusting the tensor either by reducing or increasing tension and fasten down the segment $W_1\,W_2$. Similarly, check the remaining marks, adjust the tension as required and fasten down each segment before proceeding to the next.

- After the fastening down of the last length A_2B and C_2B is completed, make a paint mark near the free end of one rail at a distance of (6.5 metre + 2 × 25 mm – 1 mm), measured from the end of the other rail across the gap spanned by the rail tensor.
- Remove the tensor, close the one metre gap temporarily and allow traffic at restricted speed (c) in Fig. 10.12.

(v) During another traffic block, cut the rail at the paint mark, insert a rail closure of length exactualy equal to 6.5 metre and weld one end thereof. If the gap at the other end is also 25 mm, it can be welded in the same block. Otherwise, fasten with special fishplates and clamps and allow traffic at restricted speed. In the latter case, during a subsequent block, when t_p is not greater than t_0, release rail fastenings on either side to the required extent and pull the rails with rail tensor to get the desired gap of 25 mm [(e) in Fig. 10.12), refasten the rail and weld the joint. Release the tensor after the lapse of a minimum of 20 minutes after pouring of the weld metal.

(vi) During a subsequent traffic block, when t_p is less than t_0 equalise the forces in the rail by releasing the fastenings over a length of 100 metre on either side of location B and tapping with wooden mallets etc. Fasten down the railend and allow traffic.

(vii) During another traffic block, when t_p is within the range of temperature specified for t_d in item (7) Sec. 10.2 destress the end of 100 metre from SEJ. Thereafter, weld the closure rail next to SEJ duly ensuring setting of the SEJ.

Note: Side rollers shall also be used while undertaking destressing on curved track. Side supports on the inside of curve should be spaced at every nth sleeper,

$$\text{where } n = \frac{\text{Radius of curve } (R) \times \text{No. of sleepers per rail length}}{50 \times (t_0 - t_p)}$$

Outside supports shall be used in addition at the rate of one for every three inside supports.

(d) In case rail temperature at the time of destressing is within the range specified in Para item (7) Section 10.2, detailed procedure as given in (b) without using rail tensor, may be adopted.

8. *Joining LWRs into CWR*

Detailed procedure for joining of LWRs into CWR is as follows:

(a) Replace the existing SEJ/buffer rails between the LWRs with ordinary rails, of which there should be two temporary rails about 6.5 metre long for each of left and right sides. Leaving the temporary rails fishplated, weld the other rails.

Note: Where fluctuations of temperatures during the period of joining are likely to be small, only one temporary rail instead of two, may suffice.

(b) Provide W_0 marker pillars for each of the LWRs at a distance of 100 metre from the centre of temporary rails to mark the ends of the breathing lengths.
(c) Keep ready two rails of standard length. Measure their lengths l correct to the nearest millimeter.
(d) Transfer the marks W_0 to the rail flange for both the LWRs.

During the first traffic block when t_p is less than desired t_0, remove the fishplates and fish-bolts connecting the temporary rails to the breathing lengths, release the fastenings of LWRs between the W_0 marks, mount the rails on rollers and note the movement Y_0 and Y_0 at the marker pillars W_0, for LWRs 1 and 2, respectively.

Note: The movement of Y_0 and Y_0 should be away from the ends of LWR, if the LWRs are in a state of correct destressing.

(e) Note t_p and mark the anchor length on either side as shown in Fig. 10.13.
(f) Make a paint mark near the end of the LWRs at a distance of $1 + L\alpha\,(t_p - t_0) + Y_0 + Y'_0 + 2 \times 25 - 1$ mm measured from the end of the other LWR. Here $L = 200$ metre, 25 mm is the allowance for each thermit weld and 1 mm is the allowance for a saw cut. The value of La $(t_{p0} - t_p)$ may be read from Table 10.5, e.g. for $(t_0 - t_p) = 10°$, $L \times a\,(t_0 - t_p) = 23$ mm.
(g) Remove the rollers, fasten down the length L, introducing closure pieces necessary, and allow traffic.
(h) During the second block [(d) in Fig. 10.13], cut the rail at the paint mark, remove the temporary rails, insert the rail of length l and weld one end of it. If the required 25 mm gap is not available, fasten the rails with fishplates and clamps and allow traffic at restricted speed.
(i) During the third block (e) in Fig. 10.13 weld the other joint if the gap is 25 mm. If the gap is more than 25 mm, release the rail fastenings on either side to the required extent and pull the rails with rail tensor to get the desired gap of 25 mm. Refasten and weld the rail. Release the tensor after the lapse of a minimum 20 minutes after pouring the weld metal.
(j) During the fourth and final block, (f) in Fig. 10.13 equalize the forces in the rail by releasing

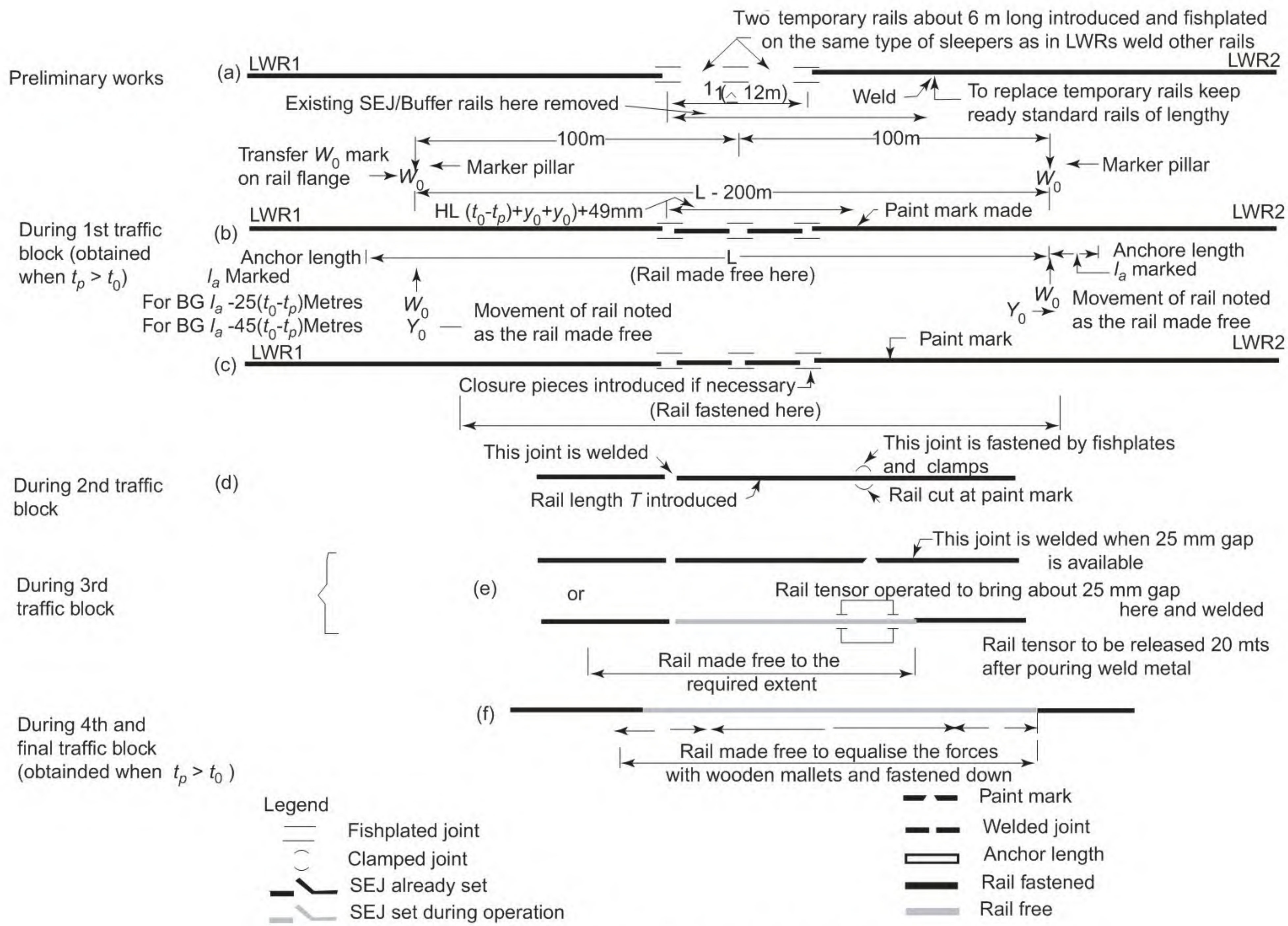


Fig. 10.13 Conversion of existing LWR and into CWR

Table 10.5 Extensions in mm Based on Formula $L\alpha(t_0 - t_p)$

(°C) $(t_0 - t_p)$	L (m) 10	20	30	40	50	60	70	80	90	100	200	300	400	500
1	…	…	…	…	1	1	1	1	1	1	2	3	5	6
2	…	…	1	1	1	1	2	2	2	2	5	7	9	11
3	…	1	1	1	2	2	2	3	3	3	7	10	14	17
4	…	1	1	2	2	3	3	4	4	5	9	14	18	23
5	1	2	1	2	3	3	4	5	5	6	11	17	23	29
6	1	1	2	3	3	4	5	6	6	7	13	21	28	34
7	1	2	2	3	4	5	6	6	7	13	20	24	32	40
8	1	2	3	4	5	6	6	7	8	9	18	28	37	46
9	1	2	3	4	5	6	7	8	9	10	21	31	41	52
10	1	2	3	4	6	7	8	9	10	11	23	35	48	57
11	1	3	4	5	6	7	9	10	11	13	25	38	50	63
12	1	3	4	5	7	8	9	11	12	14	28	41	55	69
13	1	3	4	6	7	9	10	12	13	15	30	45	60	75
14	2	3	5	6	8	10	11	13	14	16	32	48	64	80
15	2	3	5	7	9	10	12	14	16	17	34	52	69	86

Notes:

(i) Table 10.5 gives the value of $L\alpha(t_0 - t_p)$ for different values to L and $(t_0 - t_p)$

(ii) Only one value of t_p has to be taken at the time of marking W_1, W_2 etc. on the rail foot. The value of t_p is not required to be taken thereafter. The variation of temperature, if any, during the destressing operation shall automatically be taken care of by reducing or increasing the tensile force from the tensor, while coinciding the reference mark on rail with the corresponding mark on pillars.

(iii) If for any reason, both the lengths A_2B and C_2B can not be fastened down simultaneously, the final adjustment in the fastenings over the portion marked L and also over the anchor lengths on either side and tapping with wooden mallets, etc. Fasten down the rail and restore traffic.

9. *Reference Marks*

Reference marks shall be fixed at each SEJ and at the centre of LWR/CWR on the reference pillars erected for this purpose. While the reference marks, on the reference pillars shall be saw marks on the running rails they shall be paint marks, on the non-gauge face of the rail. In no case, a saw mark shall be made on the running rail. Reference marks are required to be fixed immediately after destressing of LWR/CWR and shall not be shifted or tampered with, thereafter. Additional reference marks in fixed portion and breathing length may be provided to know the behaviour of LWR/CWR.

10.7 MAINTENANCE OF LWR/CWR

An important prerequisite for proper functioning of LWR/CWR is its initial laying to a high standard and its subsequent maintenance by trained personnel. Regular track maintenance of LWR/CWR entails (a) General maintenance, (b) Mechanised maintenance, (c) Manual maintenance, (d) Casual renewal of sleeper, (e) Renewal of fastenings, (f) Maintenance of SEJ/buffer rails.

Regular track maintenance in LWR/CWR includes following operations:

(a) Tamping/packing
(b) Lifting
(c) Aligning including minor realignment of curves
(d) Shallow screening/shoulder cleaning
(e) Casual renewal of sleepers
(f) Renewal of fastenings
(g) Maintenance on SEJs/buffer rails

10.7.1 General Instructions

1. Regular track maintenance in LWR/CWR shall be confined to the hours when the rail temperature is between $t_d + 10°C$ and $t_d - 30°C$ and shall be completed well before onset of summer. If rail temperature after a maintenance operation exceeds $t_d + 20°C$, then during the period of consolidation a speed restriction of 50 kmph on BG and 40 kmph on MG shall be imposed when shoulder and crib compaction has been done and 30 kmph and 20 kmph, respectively when shoulder and crib compaction has not been done, in addition to posting of mobile watchman.
2. Ballast section shall be properly maintained, specially on pedestrian and cattle crossing, curves and approaches to level crossings and bridges. Cess level should be correctly maintained. Dwarf walls may be provided on pedestrian and cattle crossings to prevent loss of ballast. Replacement of ballast shall be completed before onset of summer. Shortage of ballast in the shoulder at isolated places shall be taken care of by the gang mate by taking out minimum quantity of ballast from the centre of the track between the two rails over a width not exceeding 600 mm/350 mm and a depth not exceeding 100 mm/75 mm for BG/MG, respectively.
3. Sufficient quantity of ballast shall be collected to provide full ballast section before commencing any maintenance operation, specially lifting.
4. When crow bars are used for slewing, care shall be take to apply these in a manner as to avoid lifting of track.
5. Special attention shall be paid to maintenance of track at following locations.

   (a) SEJs/breathing lengths
   (b) Approaches to level crossings, points and crossings and unballasted deck bridges

(c) Horizontal and vertical curves

6. Special attention shall be paid to maintenance of fastenings in LWR/CWR.
7. All fastenings shall be complete and well secured.

10.7.2 Mechanised Maintenance

1. *Maintenance tamping* Tamping in LWR/CWR with general lift not exceeding 50 mm in case of concrete sleepers and 25 mm in case of other sleeper including correction of alignment shall be carried out during the period when prevailing rail temperatures are as suggested in (1) under General instructions together with precautions laid down therein.
2. *Lifting of track* Lifting where needed, in excess of 50 mm in case of concrete sleepers/25 mm in case of other types of sleepers shall be carried out in stages with adequate time gap between successive stages to achieve full consolidation of the previous stage.
3. *Cleaning of shoulder ballast* Mechanized cleaning of shoulder ballast shall be undertaken when prevailing rail temperatures are within the limits prescribed in (1) under General instructions together with the precautions mentioned therein.

10.7.3 Manual Maintenance

1. At no time, not more than 30 sleepers spaces in a continuous stretch shall be opened for manual maintenance or shallow screening with at least 30 fully boxed sleeper spaces left in between adjacent openings. Maintenance operation in between lengths shall not be undertaken till passage of traffic for at least 24 hours in case of BG carrying more than 10 GMT or two days in case of other BG and MG routes.
2. For correction of *alignment*, the shoulder ballast shall be opened out to the minimum extent necessary and that too, just opposite the sleeper end. The ballast in shoulders shall then be put back before opening out crib ballast for packing.

10.7.4 Casual Renewal of Sleepers

Not more than one sleeper in 30 consecutive sleepers shall be replaced at a time. Should it be necessary to renew two or more consecutive sleepers in the same length, they may be renewed one at a time after packing the sleepers renewed earlier, duly observing the temperature vide (1) under general instructions together with precautions mentioned therein.

10.7.5 Renewal of Fastenings

The work of renewal of fastenings shall be carried out when rail temperature is within the limits specified in 1 under General instructions with following additional precautions.

(a) *Renewal of fastenings not requiring lifting* Fastenings not requiring lifting of rails, shall be renewed on not more than one sleeper at a time. In case fastenings of more than one sleeper are required to be renewed at a time, then at least 15 sleepers in between shall be kept intact. Work shall be done under supervision of keyman.

(b) *Renewal of fastenings requiring lifting* Fastenings requiring lifting of rails, i.e. grooved rubber pads, etc, shall be renewed on not more than one sleeper at a time. In case fastenings of more than one sleeper are required to be renewed at a time, then at least 30 sleepers in between shall be kept intact. Work shall be done under supervision of Gangmate.

10.7.6 Maintenance of SEJs/Buffer Rails

1. Once in a fortnight SEJs shall be checked, packed and aligned if necessary. Oiling and greasing of tongue and stock rails of SEJ and tightening of fastenings shall be done simultaneously. Movement of SEJs shall be checked and action taken for destressing, if necessary.
2. During daily patrolling, keyman shall keep special watch on the SEJs falling in his beat.
3. Buffer rails shall be maintained in accordance with Sec. 10.10.

10.7.7 Renewal of Defective Rails/Welds

The procedure laid down in Sec. 10.9, for repairs to track after rail fracture shall be followed.

10.7.8 Special Track Maintenance

1. Deep screening/mechanised cleaning of ballast.
2. Lowering/Lifting of track.
3. Major realignment of curves.
4. Sleeper renewal other than casual renewals.
5. Rehabilitation of bridges and formation causing disturbance to track.

Deep screening/mechanised cleaning of ballast The method as explained in Sec. 11.6 will generally be followed, with the special care as indicated below.

1. Ballast Cleaning Machine (BCM), tamping machine and Dynamic Track Stabilizer (DTS) shall, as far as possible, be deployed in one consist.
2. Temperature records of the sections where deep screening is to be undertaken, shall be studied for the previous and the current year. The maximum and minimum rail temperature attainable during the period of deep screening and during the period of consolidation shall be estimated. Any of the following three methods may be adopted for carrying out the work of deep screening/mechanised cleaning:

    (a) If range of rail temperature falls within t_d + 10°C, to t_d – 20°C, deep screening may be done without cutting or temporary destressing.

    (b) If range of rail temperature falls outside (a) above, temporary destressing shall be carried out 10°C below the maximum rail temperature likely to be attained during the period of work. CWR shall be cut into LWRs of about 1 km length with two temporary buffer rails of 6.5 metre long clamped with special 1.0 metre long fishplates.

(c) Wherever rail renewals are being carried out, LWR/CWR may be converted into three rail panels and deep screening done.

3. Constant monitoring of rail temperature shall be done during the progress of work. Should the temperature rise more than 10°C above t_d/temporary destressing temperature, adequate precautions shall be taken including another round of temporary destressing.

Note: Deep screening shall be undertaken within 15 days of temporary destressing failing which temporary destressing may become due again, if the range of rail temperature varies appreciably.

4. During the period of deep screening, if there is any possibility of minimum temperature falling 30°C below t_d/temporary destressing temperature, cold weather patrol as per prescribed instructions should be introduced to detect/guard against rail fractures.
5. Sequence of operation:

   (a) Deep screening of LWR may be done from one end of LWR to another end.
   (b) After deep screening and consolidation as per item, (4) under Section 10.2, destressing of LWR shall be undertaken as per item (7) under Section 10.6.

10.7.9 Other Special Maintenance

This includes the following:

1. Jobs like lowering of track, major realignment of curves, renewal of large number of sleepers or rehabilitation of formation/bridges causing disturbance to track. For carrying out such maintenance, the affected length of track may be isolated from LWR/CWR by introducing SEJs or buffer rails as needed.
2. Temperature records of the section shall be studied and action taken in accordance with item (2) and (3) under 'Deep Screening'.
3. After completion of work, the affected length of track shall be destressed at the required destressing temperature and jointed with the rest of the LWR/CWR in accordance with item 8 of Sec. 10.6.

10.7.10 Destressing during Maintenance

The above exercise is undertaken apropos of item (7) of Sec. 10.6 when an LWR/CWR behaves abnormally. Such a behaviour is characterised by the following circumstance:

1. When the gap observed at SEJ

   (a) Differs beyond limits specified in Para (6) under Sec. 10.6.
   (b) Exceeds the maximum designed gap of SEJ;
   (c) When stock/tongue rail crosses the mean position.

2. After special maintenance operations mentioned in Sec. 10.7.
3. Any unusual occurrence after restoration of track.
4. If number of locations where temporary repairs have been done exceed three per km.

Destressing of CWR shall be done by cutting if into LWRs of about 1 km length which shall be jointed after destressing in accordance with Para (8) under Section 10.6.

10.7.11 Special Equipment for Maintenance of LWR/CWR

Besides the trained personnel required for maintenance of LWR/CWR, following additional equipments are also necessary:

Additional equipments with the Gangs

(a) A pair of joggled fishplates with bolted clamps (Fig. 10.14).
(b) Rail thermometer with markings for temperature ranges for maintenance.
(c) Special one metre long fishplates with screw clamps (Fig. 10.11)
(d) Rail closure pieces.

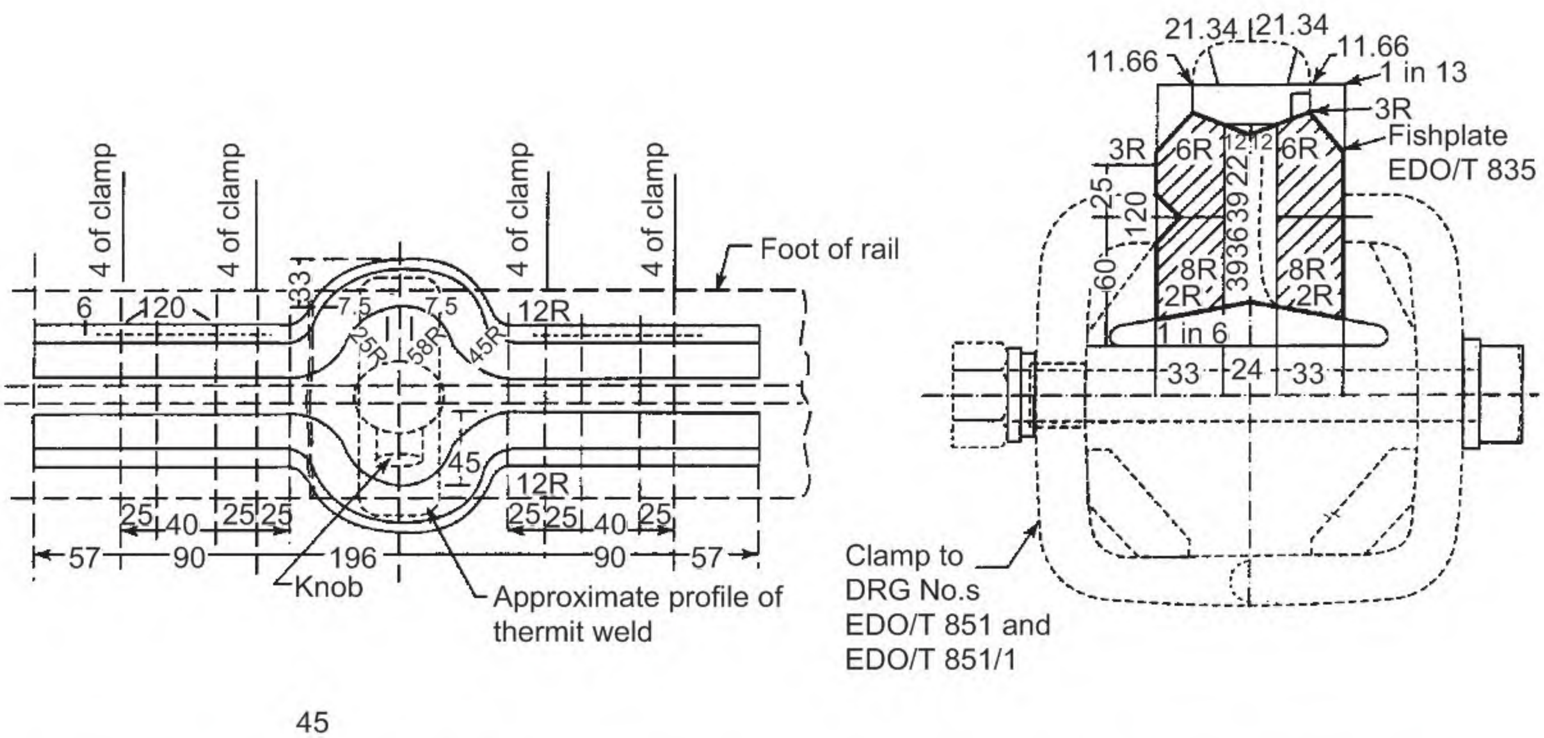


Fig. 10.14 Joggled fishplates with clamps for rail fractures BG for BS No. 90R

10.7.12 Rail Scan Equipment

LWR tracks are fixed in position at neutral temperature so that thermal stresses in the rail, both compressive and tensile, remain within acceptable limits. It has been noticed that during service rail often get subjected to very high thermal stresses, mainly on account of rail creep caused by ineffective fastenings or when work of rectification of rail/weld fractures is carried out in a careless manner (Fig. 10.15).

Fig. 10.15 The rail scan equipment (See also Color Plate 4)

At present, Indian Railways rely on the judgement of the permanent way staff in determining the criticality of thermal stresses. This is an unreliable system and often leads to buckling of rail or rail/weld fractures.

Many world railways particularly the Hungarian and Italian railways use rail scan equipment for determining thermal stresses in long welded rails. This equipment works in a non-destructive manner, similar to the working of ultrasonic rail flaw detection equipment. The thermal stresses by this equipment are determined by evaluating Barkhausen noise which has a direct correlation with the stresses in long welded rails. Other similar equipments have come in the world market, which can be usefully deployed to know about the thermal condition of LWR tracks.

10.8 MOVEMENT OF RAIL ENDS AT THE SEJ-HYSTERESIS EFFECT

In a rail, free from any constraint, say resting on frictionless rollers, the movement at the rail-ends are directly proportional to the rail length and the change in temperature. The relationship between the movement at the rail-ends and the temperature is, therefore, linear. This is not so in the case of rails fixed in track which are held by sleepers embedded in ballast. In this case, for the first few degree changes in the temperature, there is no movement at the rail-end as the thermal forces get fully balanced by the restrictive forces. As the temperature rises, thermal forces start overcoming the resistance offered by the sleepers at the rail-end. With further rise in temperature, additional length of the rails at the ends start moving. The relationship between the movement of the rail-ends and the change in the temperature in such a case is not linear but follows a parabolic path. The relationship is shown in Fig. 10.16.

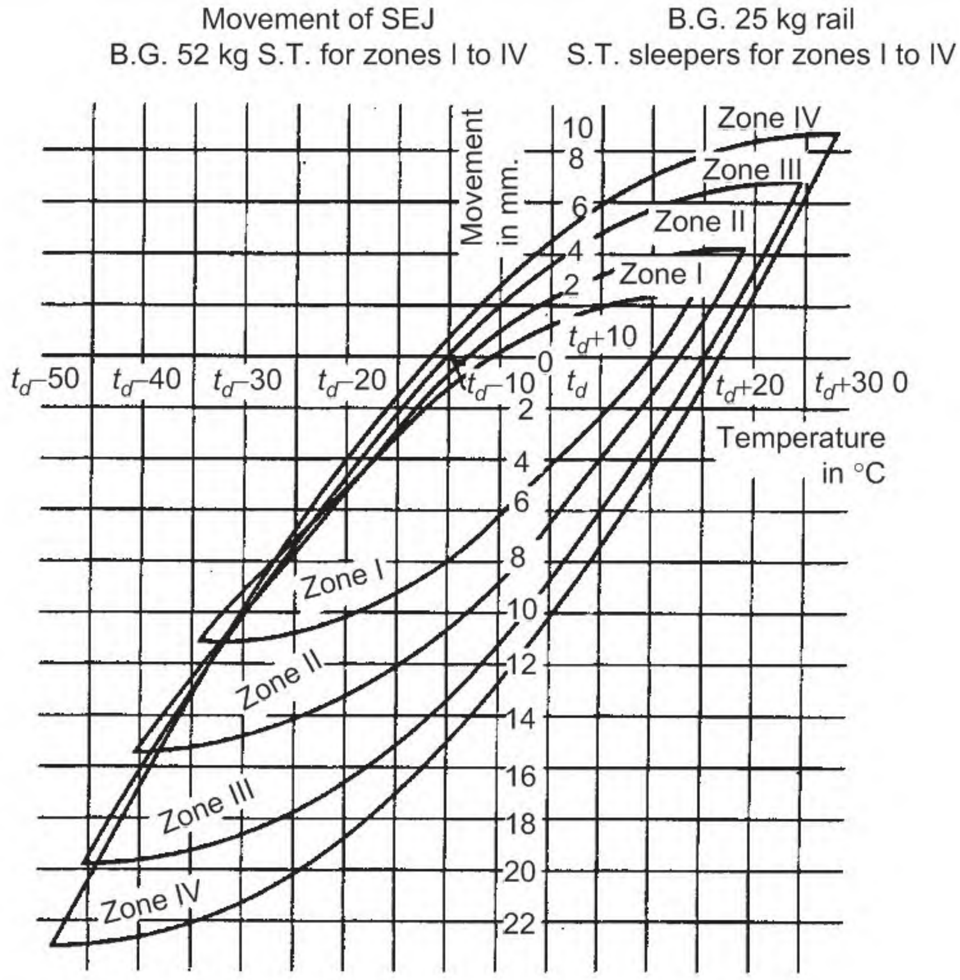


Fig. 10.16 Movement of SEJ

It may be seen from the figure that at any one temperature, rail-ends can have two positions and as long as the rail-ends at the SEJ are within the range indicated in the figure, the rails are in correct state of destressing. This non-linear relationship between the rail movement and temperature is also termed as 'Hystresis Effect' on the rail movement and the diagram is called a Hysteresis Diagram. Table 10.4 gives the gap at a SEJ in a specific Track combination of CWR, as derived from the hysteresis diagram and can be used in deciding the need for destressing of LWR. Different set of Hystresis Daigrams are formed with change of track structure, fittings and gauge (last one affecting sleeper length and so the ballast resistance).

10.9 RECTIFICATION OF RAIL FRACTURES

10.9.1 Equipment Required

1. Screw clamps, joggled fishplates for fractures at welded joints and special 1.0 m long fishplates. See Figs 10.11 and 10.14 apropos of item (1) under special equipment for maintenance of LWR/CWR.
2. Steel tape reading to 1 mm.
3. Thermit welding equipment.

4. Punch hammer.
5. Equipment for destressing.
6. 6.5 m long sawn rail cut pieces of the same section.
7. Rail closure of suitable lengths.
8. Equipment for protection of track.

10.9.2 Procedure for Repair

Emergency repairs The fractured rails shall be jointed by using suitable special fishplates and screw clamps. Rail closure may be used if the gap is extensive. Traffic may be resumed at 10 kmph.

Temporary repairs Two points on either side of the fracture shall be punched on the rail at a distance equal to the length of the available rail cut (not less than 4 m), plus two gaps required for welding (25 m × 2), plus the measured fracture gap minus 1 mm for each saw cut. In a traffic block, the rails are to be cut through these points by saw and the new rail piece to be inserted and jointed on both sides by special fishplates and screw clamps. Traffic can then be permitted at 30 kmph.

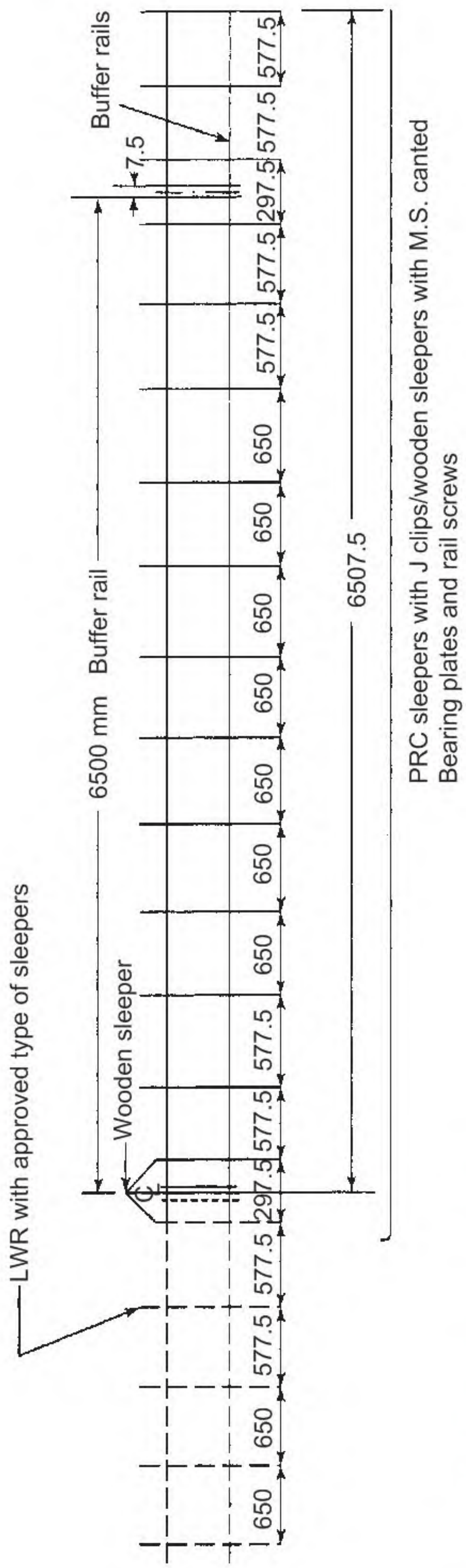
Permanent repairs with or without the use of rail tensor A welding party is arranged and the traffic block is taken at a time when rail temperature is less than t_d. One side weld is then made. The gap in the other side of the rail piece is then observed. If the gap is excessive, i.e. more than 25 mm, the rail will be allowed to be heated by sun rays. Second weld is made when the required gap is obtained. The fastenings are then loosened for a distance of 100 m on each side to equalize the locked up stresses.

Rail tensor can also be used for getting the required gap. In that case method used for pulling the rails is described already under 'Desbressing operation of LWR with the use of Rail Tensors'.

10.10 BUFFER RAILS

Instruction for Laying and Maintenance of Buffer Rails at the end of LWRs/CWRs.

1. Buffer Rails may be provided as a temporary substitute for SEJ.
2. In rail temperature zone I and II, 3 buffer rails, while in zone III and IV, 4 buffer rails shall be provided. On BG buffer rails would be 6.5 metre long and while for MG 6.0 metre long.
3. Buffer rails may be laid on PRC sleepers/wooden sleepers with standard fishplated joints. However for effective tightness of bolts, bolt to drawing No. T-11599 may be used in lieu of drawing No. RDSO/T-1899. The number, type and spacing of sleepers for buffer rail assembly shall be as indicated in Fig. 10.17 for BG.



Note: All dimensions are in millimetres

Fig. 10.17 Sleeper spacings under 6.5 m buffer rails (B.G.)

4. A gap of 7.5 mm shall be provided at each of fishplated joints of buffer rails assembly at the time of initial laying/destressing.
5. The fishplated joints of buffer rails shall be accurately fabricated. In case predrilled rails and standard fishplates are used, the dimensions and squareness of rail-ends shall conform to the tolerances stipulated in the specifications IRS T-12 for rails and IRS T-1 for fishplates. Holes drilled at site shall also conform to the above specifications. All holes in buffer rails shall be chamfered.
6. In the case of buffer rails laid between conventional track and LWR, the former shall be box anchored for three rail lengths.
7. Special and prompt attention shall be paid to the alignment and levels of track in the buffer rail portions. Buffer rails shall be free from kinks and hogs. The inspecting officials shall critically examine the buffer rails each time they pass over the same.
8. The fishbolts shall be kept tight at all times.
9. Joints in buffer rails shall be lubricated twice in a year when the rail temperature is between $t_d + 15°C$ and $t_d - 15°C$ and when the average gap value is between 3 mm and 12 mm. The rail-ends shall be examined at the time of lubrication for any crack around bolt holes. Bent fishbolts, if any, shall be replaced.
10. (a) The individual gaps in the buffer rail portion may vary and no attempt to equalise them need be made.

    (b) The gap of buffer rails shall be measured as per schedules laid down for SEJs. In addition to above schedule, the gaps shall also be carefully inspected during regular inspections. In Rail Temperature Zones III and IV, if all the gaps are found to close at a temperature lower than $t_d + 30°C$ and/or to fully open to 15 mm at a temperature higher than $t_d - 30°C$, it indicates one or more of the following.

    (i) Defective initial gaps.
    (ii) Inadequate packing in breathing length.
    (iii) Relative movement of rail over sleepers in breathing lengths.
    (iv) Creep of LWR.

    For Rail Temperature Zones I and II, the lower limit of temperature for gap closing and the upper limit of temperature for fully opening of gaps shall be taken as $t_d + 25°C$ and $t_d - 25°C$.

    (c) Rectification shall be done by destressing the LWRs/CWRs and by resorting to initial gaps at 7.5 mm. Breathing lengths shall be well packed. Other remedial measures for proper functioning of LWRs/CWRs will also be taken.
11. Details of buffer rails and gap measurement of fishplated joints shall be recorded at the time of initial laying/subsequent inspections as per given proforma.

10.11 SCHEDULE OF SPEED RESTRICTIONS OF VARIOUS WORKS

Schedule of speed restrictions of various works given in Table 10.6.

Table 10.6

S. No.	*Condition of track*	*Restriction imposed in kmph*
1.	When 1 metre long fishplated Fig. 10.11 with special clamps or joggled fishplates with bolted clamps (Fig. 10.4) are used at a temporary rail joint and there is 24 hrs watch (both BG and MG).	30
2.	When other clamps are used at a temporary rail join (both BG and MG).	20
3.	When sleeper fastenings on alternate sleepers are loosened before destressing (both BG and MG).	30
4.	At fracture after emergency repairs are completed	
	(a) First train	STOP DEAD and 10
	(b) Subsequent trains	20
5.	After emergency repairs of track after buckling	
	(a) First train	STOP DEAD and 10
	(b) Subsequent trains	20
6.	Speed restriction during consolidation period of track after regular track maintenance operations, when rail temperature exceeds $t_d + 20°C$	
	(a) When shoulder and crib compaction has been done	
	For BG	50
	For MG	40
	(b) When shoulder and crib compaction has not been done	
	For BG	30
	For MG	20

10.12 WORK CHART AND AUTHORISED LEVEL OF SUPERVISION

Work chart and authorised level of supervision is given in Table 10.7.

Table 10.7

S. No.	*Nature of work*	*Details of work*	*Lowest Level staff/supervisor in charge of work*
1.	Maintenance of Operation	(a) **Mechanised** Tamping Lifting (general lift) Alignment Minor alignment of curves Deep screening	PWI
		(b) **Manual** Packing	Gangemate

(*Contd.*)

S. No.	*Nature of work*	*Details of work*	*Lowest Level staff/supervisor in charge of work*
		Alignment	
		(c) Lifting/Lowering of track	PWM
		(d) Lifting, aligning, packing etc. in case of emergencies at temperatures higher than permitted	PWI
2.	Rail, sleeper and fastening	(a) Ensuring that all creep anchors butt against sleepers during daily rounds	Keyman
		(b) Packing or renewal of single isolated sleeper not requiring lifting or slewing of track	Gangmate
		(c) Renewal of fastenings not requiring lifting	Kayman
		(d) Renewal/recoupement of fastenings requiring lifting	Gangmate
		(e) Casual renewal of sleepers and fastening over long stretches	PWM
		(f) Renewal of defective rails	PWM
		(g) Carrying out welding of rail joint at site	PWI
3.	Ballast	(a) Making up shortage of ballast in shoulders at isolated places	Gangmate
		(b) Replacement of ballast and checking ballast section before the onset of summer	PWI
		(c) Screeing of ballast—other than deep screening	Gangmate
		(d) Deep screening	PWM
4.	Curve realignment	(a) Minor realignment of curves	PWM
		(b) Major realignment of curves under special instructions from AEN	PWI
5.	Hot weather work	(a) Imposing speed restriction if the temperature exceeds $t_d + 20°C$ after maintenance work is completed, manually or by machines	Gangmate
		(b) Organising hot weather patrolling during summer months	PWI
		(c) Ensuring that hot weather patrolman turn out promptly for duty during the required period of patrolling and during other periods when rail temperature exceeds $t_d + 20°$ C	Gangmate
		(d) Hot weather patrolling, watching stability of track, presence of large number of sleepers with defective	Hot weather patrolman

S. No.	*Nature of work*	*Details of work*	*Lowest Level staff/supervisor in charge of work*
		packing, alignment of track, checking if the profile of ballast is disturbed, tendency for lateral/vertical deformation of track	
		(e) Inspection in summer months and checking on the working of hot weather patrols	PWI
6.	Cold weather patrolman	Cold weather patrolling	Cold weather patrolman
7.	Destressing	All operations regarding destressing	PWI
8.	Rail fracture	(a) Emergency repairs	Keyman/Gangman
		(b) Temporary repairs	PWM
		(c) Permanent repairs	PWM
9.	Buckling	(a) Protection of track and secure safety of trains in case of buckling, rail fractures, or any abnormal behaviour of track	Patrolman/Gangman Gangmate
		(b) Emergency repairs	PWI
		(c) Permanent repairs	PWI
10.	Emergencies	in case of damage to track following derailments, breaches etc.	PWI
11.	Inspection and checking	(a) Checking of SEJ, oiling and greasing and retightening/ renewal of fittings once a fortnight	Keyman
		(b) Inspection of SEJ	PWI

Note: Hot and cold weather patrolmen should be aware of their duties and should be drawn, as far as possible, from gangs.

11 Chapter

Conventional—Manual Track Maintenance Practices

11.1 TRACK STRUCTURE AND ITS MAINTENANCE NEEDS

Most of the civil engineering structures such as buildings, bridges, dams and viaducts have solid foundations which do not get unduly strained with oncoming loads. As compared to this, railway track rests on a floating foundation of ballast.

In the general civil engineering field, the structures are massive and the live loads imposed on them are small while in the case of track, the structure is a tiny thing, compared with the heavy, high speed vehicles that run over it. This makes obvious the difference in the maintenance needs of the track, vis-à-vis other Civil Engineering structures.

In the conventional track, the impact force of running trains is absorbed by way of a change in the composite contact relationship along the ballast pieces. The change is cumulative in nature. The major work in the track maintenance, therefore, entails correcting the surface geometry by rebuilding the deformed ballast. In common parlance this is termed as "packing of track".

Then, the heavy moving loads cause attrition and loss of ballast, wear and tear of track components, which need attention. The elements of nature such as rains, floods, winds, temperature variation, etc. Compliment the maintenance needs of the track structure and its components.

11.2 ITEMS OF TRACK MAINTENANCE

Over the passage of time, the track requires maintenance apropos of:

1. Slopes of embankments and cuttings.
2. Catch water drains.
3. Cess Level.
4. Weed removal.
5. Recoupment of ballast.

6. Packing and overhauling of track.
7. Picking up of slacks and attention to joint sleepers.
8. Raising and lowering of track.
9. Deep screening of ballast.
10. Upkeep of track drainage.
11. Attention to sleeper and other fittings and fastenings.
12. Casual renewal of worn out and broken components.
13. Complete track renewal after it has outlived its life.

Complete track renewals have been dealt with separately in this book. The other items are discussed in this chapter.

11.3 PACKING AND OVERHAULING OF TRACK

11.3.1 Manual Methods of Packing of Track

Periodical correction of track geometry by packing of ballast under sleepers is the main task in any track maintenance schedule. Methods generally employed are given below.

Beater Packing The beater is basically a pick-axe with one of its end blunted into tee shape. The pick end is used for loosening the ballast core while the blunt end is used for driving the ballast under the sleeper. If carried out in a systematic manner by trained gangmen under guidance of a capable mate, it is capable of producing a good track top. For over a century, beater packing has been the only method used for the maintenance of track. However, it is beset by following disadvantages:

1. Beater packing is strenuous and is therefore not liked by the present day gangmen.
2. Beater packing as done by present day gangs does not sustain the track for long under heavy density fast traffic.
3. The results of beater packing are not consistent. The quality of packing differs from trackman to trackman and this is not desirable in a high speed track.
4. Labour output cannot be measured accurately. It is difficult to assess the labour required for maintaining track to particular standards.
5. Ballast life is shortened under beater packing as beater strokes break and pulverizes the ballast pieces. In the long run it affects track drainage.
6. Beater packing damages the concrete sleepers. Even wooden sleepers have less life with beater packing.

Measured Shovel Packing Measured shovel packing has been able to provide a solution to some of the problems faced with beater packing. In this method measured quantity of stone chips are spread over the ballast underneath the sleeper to correct track geometry. The disadvantages of MSP are enumerated below.

1. It can only be satisfactorily used with flat bottomed sleepers.

2. It cannot be used immediately after deep screening and relaying, when the track needs maximum consolidation.
3. On points and crossings and other complicated layouts, it is difficult to get good results from MSP.
4. Small size stone chips of appropriate quality as needed for MSP are not only expensive, but involve a lot of work in their procurement, transport and distribution at site.
5. MSP, when adopted for LWR track, has to be done under many working restrictions, which make the task difficult.
6. MSP affects track drainage in the long run.

Through Packing (*Conventional Maintenance of Beater Packing*) It is usually undertaken by a permanent way gang headed by a P Way mistry or mate. A minimum of 12 gangmen for BG and 6 gangmen for MG are required for an effective slewing operation which is an essential part of through packing. About 50 percent extra gangmen would be required if slewing of track is to be done at points and crossings. The gang equipment generally consists of the followings:

(a) Level cum gauge.
(b) Square.
(c) Hemp chord.
(d) Marking chalk.
(e) Rail thermometer.
(f) Wooden mallet or canne-a-boule.
(g) 30 cm long steel scale.
(h) 1 m long straight edge.
(i) Keying and spiking hammers.
(j) Sufficient numbers for beaters, *phowrahs*, crow bars, Ballast forks or rakes, mortar pans and baskets.
(k) One set of hand signal flags for the day and two hand signal lamps for the night.
(l) Two detonators.
(m) Spare keys, cotters, lines, nuts bolts, etc. as required.

Detailed guidelines have been laid down in the Indian Railway Permanent Way Manual for carrying out through packing work and they are given below.

The length of track opened out on any one day shall not be more than what can be efficiently repacked before the end of the day. Through packing is best done continuously from one end of a gang length toward the other. It consists of the following operations in sequence.

Opening of Road This is effected without disturbing the cores under the sleepers while opening the ballast on either side of the rail seats to a depth of 50 mm below the packing surfaces to the extent as follows:

1. Broad Gauge-end of sleepers to 450 mm inside of the rail seat.
2. Metre gauge-end of sleepers to 350 mm inside of the rail seat.
3. Narrow gauge (762 mm)-end of sleeper to 250 mm inside of the rail seat.

In case of cast iron plate or pot sleepers, the opening out should be to the extent of the plates or pots to enable convenient packing.

The ballast should be drawn by phowrahs/shovels outward and inward. The portion of the ballast on the outside of the rail should be drawn outward while the portions between the rails toward the centre. However, care should be taken to see that the ridge between the rails does not project more than 50 mm above rail level.

Examination of Rails, Sleepers and Fastenings

1. Rails should be examined: the underside for corrosion, the ends for cracks; the head for top and side wear: rail joints for wear on the fishing planes: and fishbolts for tightness. If rails on curves wear at an unusual rapid rate, lubrication of the gauge face should be done. Rust and dust must be removed from the corroded rails by using wire brushes and kinks in rails should be removed by jimcrowing.
2. Sleepers should be inspected for their condition and soundness particularly at the rail seats. In case of wooden sleepers, plate screws, spikes and fangbolts should be examined for their firm grip. Sleepers should be checked for split and decay.

In case of cast iron sleepers, the condition and firmness of cotters and keys should be examined. Loose keys should be tightened by providing liners or replaced by appropriate oversized keys. In the case of wear in the rail seat of CST-9 plates, suitable pad/saddle plates may be provided. Fastenings and fittings should be examined to ensure that they are in good order and appropriately tightened to hold the rails. The broken ones should be replaced.

Squaring of Rails Gauge variations and kinks inevitably result from sleepers getting out of square.

1. The spacing of sleepers on the sighting rail should first be checked and correctly chalk marked. Corresponding marks should then be made on the other rail using the square at every point. The cores of sleepers that are out of square should then be 'picked' with the pick ends of beaters, the fastenings loosened and the sleepers lowered and squared to correct position.
2. Squaring should be done by planting the crowbars firmly against the sleeper and pushing it. Under no circumstances should the sleepers be hammered. Sleepers that are squared should the regauged immediately, the fastenings tightened and sleeper repacked.

Slewing of Track to Correct Alignment

1. Heavy slewing will only be required during realignment of curves when it will be necessary to loosen the rail joints; and in case of steel sleepers and cast iron sleepers to loosen the fastenings, the packing cores being broken with the pick ends of beaters. Slewing for normal maintenance will be of a small order and should be done after opening out the road, loosening the cores at ends and removing sufficient ballast at the ends of the sleepers.
2. Slewing of track shall be directed by the mate who on straights should sight the rail from a distance of 30–60 m. He should sight the outer rail on curves. Slewing is best done in the morning unless it is cloudy, as visibility becomes poorer later on.

When slewing, the crowbars should be planted well into the ballast at an angle not more than 30 degrees from the vertical; otherwise it may result in the lifting of the track.

Gauging

1. Preservation of gauge is essential to track maintenance especially through points and crossings. For good riding, the basic requirement is uniform gauge over a continuous stretch of track and such gauge should be allowed to continue so long as it is within the permissible limits of tightness or slackness.
2. Gauging should only be done after ensuring that sleepers are truly square. Only standard keying hammers are to be used. Beaters and heavier hammers should not be used as they cause over driving of keys and strained lugs on metal sleepers.
3. The track gauge should be held firm with one lug against the base rail, and the other end being swivelled over the opposite rail. The tightest position obtained determines the correct points to test the gauge. The gauge should not be forced as that causes considerable wear on the gauge lug.
4. The track gauge should be adjusted to correct gauge on the rail opposite to the base rail. The required slackness on sharp curves should be attained by using liners of the requisite thickness against the lug of the gauge.
5. Essential as it is to maintain a correct gauge, it is not desirable to regauge the wooden sleepered road frequently because this will result in 'spike killing' of the rail seats. And neither on pot or plate sleepered road, as this will result in the packing getting distributed. Where, due to the age and condition of the sleepers, it is not possible to maintain the correct gauge, it is a good practice to work within the following tolerances provided uniform gauge can be maintained over long lengths.

BG on straight	3 mm tight to 6 mm slack
On curves with radius more than 400 m	3 mm tight to 10 mm slack
On curves with radius less than 400 m	up to 20 mm slack

Note: These are with reference to nominal gauge of 1676 mm.

MG on straight	3 mm tight to 6 mm slack
On curves with radius more than 275 m radius	3 mm tight to 15 mm slack
On curves with radius less than 275 m radius	up to 20 mm slack

Note: These are with reference to a nominal gauge of 1000 m.

NG (762 mm) on straight	3 mm tight to 6 mm slack
On curves with radius of more than 175 m	3 mm tight to 15 mm slack
On curves with radius less than 175 mm	up to 20 mm slack

All the above tolerances are from the point of riding comfort only.

11.3.2 Packing of Sleepers

1. The aim of packing is to have each sleeper firmly and uniformly packed to ensure that the rails are at their correct relatives level; i.e. level on the straight track and to the required cant on curves and that no sleeper has any void between it and its bed.

2. Before packing is commenced, it is necessary to ensure that the chairs/bearing plates are firmly fixed to the sleepers and the rails are bearing on the chairs/bearing plates. In case of rails resting directly on sleepers it should be ensured that there is no gap between the bottom of the rail and top of the sleeper.
3. The base rail shall be sighted by the Mate with eye along the lower edge of the head of rail and any dip or low joint lifted correctly. The adjacent sleepers should then be packed and the top checked. After two rail lengths have been attended to, the rail on the other side should be brought to the correct level by checking cross level with the straight edge and spirit level at every rail joint and at every fourth sleeper. The next two rail lengths should then be taken up and the process continued.
4. No joint or dip should be lifted higher than the proper level in the expectation that it will settle to the correct level. Instead, it will settle more under traffic as a result of being high and cause rough running.
5. Having aligned the track and adjusted the 'top', the gangmen should be in batches of two for packing all sleepers in a systematic manner, commencing from one end. Four men should deal with every sleeper successively, two at each rail seat. The ballast under the sleeper should be packed by the men standing back to back working their beaters diagonally under the rail seat at the same time to ensure firm packing.
6. It is important that men should thoroughly 'break' the cores with the pick-end and then use the blunt ends (head-ones) as otherwise uniform packing will not be achieved and elasticity of the road bed affected. After packing the rail seat, the packing should be continued outward and inward to the requisite extent on each side of the rail seat i.e., end of the sleeper to 450 mm inside on the BG and end of sleeper to 350 mm inside on the MG and end of the sleeper to 250 mm inside on the NG (762 mm). The beaters should not be lifted above the chest level, the strokes being kept as nearly horizontal as possible. Care must be taken to avoid forcing under the sleeper any stone large enough to cause uneven bearing and to avoid striking the edges of the sleepers and timbers. All men should aim to work the beater from the same height (chest level) so that the sleepers are uniformly packed. Higher or lower lifting or the beaters result in uneven compactness.
7. In case of steel-trough and wooden sleepers, packing under the rail seat causes the ballast to work toward the centre. Before final dressing is done, it should be ensured that no sleeper is centre bound by working the pick-ends over the central range. Centre bound sleepers cause vehicles to roll from side to side.
8. In the case of CST-9 sleepers, it should be ensured that the end pockets or bowls filled with ballast and the main packing should be done at ends and corners. The central flat portion of the plate should not be packed hard but only tamped lightly. On pot sleepers the ballast should be punned through the holes provided at the top of the pot and rammed in with crowbars.
9. Care must also be taken while packing to ensure that the work does not result in the sleepers adjoining those being packed lifted off their bed, thus creating artificial void under them.
10. The packing on the inside and outside of every rail seat should before boxing the track, be checked by the mate by tapping with a wooden mallet or canne-a-boule. A hollow sound would indicate defective packing which should be attended to again.

11. With the completion of packing, slight distortions in alignment and top should be checked and corrected by the mate; and the sleeper disturbed for this purpose be finally repacked.

Repacking of Joint Sleepers The 'joint' and 'shoulder' sleepers should be repacked before boxing is done and the cross-levels at joints checked. The rail joints being the weakest portion, firmness of its support is essential.

Boxing of Ballast Section and Tidying

1. After completing the preceding operations in sequence, clean ballast should be worked in with ballast forks or rakes. The ballast section should be dressed to the specified dimensions, a template being used for the purpose. Hemp chords of 6 mm dia with sufficient length should be used for lining the top and bottom edges of the ballast section. Where the quantity of ballast is inadequate, full section of ballast should be provided near the rail seat, the deficiency being reflected along the centre of the track and not under the rails or in the shoulders.
2. The cess should then be tided up. Where earth ridging exists at the edge of the bank, this should be removed. Cess should be maintained to the correct depth below rail level according to the ballast section and formation profile. Too high cess affects drainage and too low results in ballast spread and wastage.

11.3.3 Overhauling of Track

The overhauling of track entails sequence of operations as follows:

Shallow Screening and Making up of Ballast

1. In the case of manual maintenance, unlike deep screening, the crib ballast between sleepers is opened out to a depth of 50–75 mm below the bottom of sleepers, sloping from the centre toward sleepers end. For machine maintained section the crib ballast in the shoulders should be opened out to a depth of 75–100 mm below the bottom of sleepers, sloping from the centre toward the sleeper end. The ballast in the shoulders opposite to the crib and the sleepers is removed to the full depth. A slope is given at the bottom sloping outward from the sleeper end. The ballast is then screened and put back. Care should be taken to see that the packing under the sleepers is not disturbed and the muck removed is not allowed to raise the cess above the correct level.
2. Two continuous spaces between sleepers should not be worked at the same time.
3. Screening should be progressed in alternate panels of one rail length. Under no circumstance should several rail lengths of track be stripped of ballast.
4. Where drains across the track exist, they should be cleaned and filled with boulders or ballast to prevent packing from working out and forming slacks.
5. After screening, full ballast section should be provided extra ballast being run out previously for the purpose. Work should be commenced after making sure that the ballast will not be deficient. Any deficiency, if allowed in the central portion of sleeper, should be made up soon.

Through packing of Track It is done as described in Section 11.12 under methods of packing.

Making up of Cess Cess, when high, should be cut along with overhauling and made up wherever low. A template should be used for this purpose.

Overhauling in general should be completed before the onset of summer, i.e. before the end of March. In case of LWR and SWR, special precautions as laid down are to be taken.

11.4 PICKING UP SLACKS

'Slacks' are locations in track which require more frequent attention than that provided by systematic through packing or overhauling. Slacks generally occur at the following places:

1. Approaches to level crossings, girder bridges, portions of transition curves and approaches to curves, points and crossings and their approaches, approaches to ash pits and at water columns.
2. Rail joints with excessive gaps.
3. Places where drainage conditions are poor.
4. Poor ballast conditions and unstable formations.
5. At such places as platform lines, gauntlet tracks, etc. where packing to the desired standards cannot be carried out due to some inherent drawbacks.

Attention to 'slacks' is to be need based, the need being determined by inspections and results of track recording. The output of a gang, during the day, will depend on the number of sleepers requiring packing and the extent of travel that the gang has to do.

In all cases sighting is done, the defects assessed and marks made with chalk on the sleepers to be dealt with. The marked sleepers are then dealt with as in 'through packing': where a large number of sleepers need attention in a rail length, the entire rail length is attended to. It is necessary that when joints are picked up, at least three sleepers on either side of the joints are packed.

In the case of low joint, the fishplate should be slightly loosened and the joint tapped so that the rail ends are rendered free and are capable of being lifted. After the joint is thoroughly packed, the fishplate should be tightened again.

11.5 OBSERVANCE OF SLEEPERS UNDER PASSAGE OF TRAFFIC

During the passage of the first and last trains within working hours, the mate and gangmen at the work site should stand on the cess, about one rail length apart on either side of the position of track they are attending to—whether through packing or picking up slacks—and observe the movement of sleepers under load. Immediately after the passing of train, loose sleepers should be marked, packed uniformly and the packing tested. Apropos of other trains, the mate and the gangmen should observe the sleepers from a nearer range and take similar action. Firm and uniform packing is primarily essential of good track maintenance.

11.6 DEEP SCREENING OF BALLAST

General

1. Drainage is a basic requirement for the success of any track maintenance programme. For this purpose periodic overhauling of track is carried out as described in Sec. 11.7. In the course of time the ballast gets crushed by the moving loads and the tools used for packing of track. Cinder, brake dust, dirt and dust particles also get mixed with ballast. On untreated poor formation ballast gets coated with soil particles. The whole structure gradually turns into a compact mass thereby, losing its valuable property of elasticity and drainage so essential for the maintenance of proper track geometry. In such a situation it becomes necessary to screen the entire ballast right up to the formation level/sub-ballast level. Such screening is called deep screening as distinguished from shallow screening, which is done during overhauling.
2. Deep screening is usually carried out in the following situations by providing full ballast cushion.

   (a) Prior to complete track renewal.
   (b) Prior to through sleeper renewal.
   (c) Where the caking of ballast makes difficult to maintain the track geometry.
   (d) Before the introduction of machine maintenance, unless the ballast was screened in the recent past.
   (e) Before converting existing fish plated or SWR track into LWR.

3. In the case of bad formation, formation treatment should as far as possible be carried out along with deep screening.

11.6.1 Procedure for Systematic Deep Screening

Survey Before deep screening of a section is undertaken, it is necessary to survey the section. This consists of the following operations:

1. A longitudinal section of the track should be taken indicating the rail levels at every 30 m as also at changes of grades and obligatory points like culverts, bridges, overline structures, tunnels, level crossings, signal gantries, ash pits, points and crossings etc.
2. In station yards, on run through lines, cross-sections at every 50 m should be taken and plotted including platform levels, rail-levels, clearance to underside of overline structures.
3. On the basis of the longitudinal and cross-sections, the final levels will be decided keeping in view (a) the depth of ballast cushion to be provided; (b) the relative implications of lifting or lowering of track and (c) the possibility of eliminating humps, sags and unevenness in the existing longitudinal section.

It is not necessarily intended to restore the original longitudinal section of the line.

Preliminary Works

1. Additional ballast, if necessary, should be unloaded and spread out opposite to the place

where it is required. As ballast is collected along the track, care should be taken to see that the new ballast is not mixed with the unscreened ballast.

2. Cess should be brought up to correct level vis-à-vis the final rail level.
3. Pegs should be provided at intervals of 30 m to indicate the final rail level.
4. Slewing of curves should be done in advance.
5. Sleeper renewal as necessary should be carried out in advance.

11.6.2 Screening Operations

General

1. The work will be done under the supervision of a competent official.
2. The daily output should be predetermined, depending on the time allowance, availability of labour, extent of ballasting/screening to be done, etc.
3. The length to be screened on a given day should be preceded by (a) a notice to all concerned, (b) planning of speed restrictions and (c) setting up of speed restriction boards.
4. It is always desirable to commence deep screening in a direction opposite to the traffic on double line.

Detailed Procedure A day's length will be deep screened as per procedure detailed below and illustrated in Fig. 11.1.

Stage I: The ballast should be removed from space 'A' and 'B' on either side of sleeper '1' down to final formation level and wooden blocks provided to support the rail for passing trains.

Stage II: The ballast is removed from under sleeper 'I', down to final formation level/sub-ballast level.

Stage III: The ballast should then be screened and placed back under sleeper '1', which should then be packed.

Stage IV: The wooden blocks from space 'A' should be removed.

Stage V: The ballast from space 'C' down to formation level should be removed and after screening be placed in space 'A' up to bottom of sleeper. The balance may be taken outside the track and screened. The rail in space 'C' should be supported with wooden blocks.

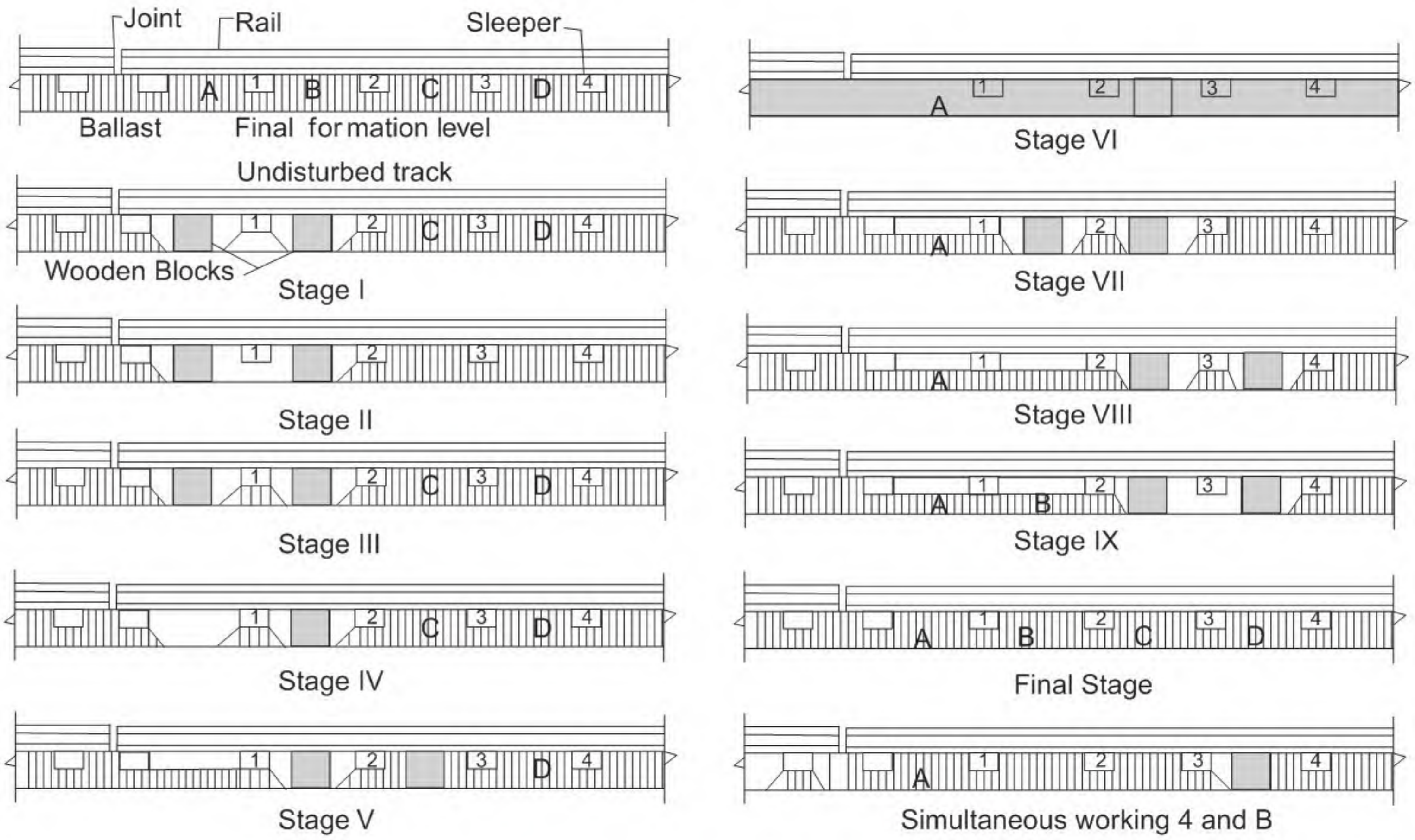
Stage VI: The ballast should be removed from under sleeper '2' down to formation level.

Stage VII: Screened ballast should be provided under sleeper '2' and the sleeper well packed.

Stage VIII: The ballast from space 'D' down to formation level should be removed and after screening be placed in space 'B' up to bottom of sleeper the balance may be taken outside the track and screened. The wooden blocks should be removed from space 'B' and placed to support the rail in space 'D'.

Stage IX: The ballast from under sleeper '3' should be removed and so on till the whole rail length is provided with screened ballast up to bottom level of sleepers.

Final Stage: The track should be provide additional cushion where required packed in the final position, and then boxed.



Note: Four Sleepers in between are supported

Fig. 11.1 Sketch showing the sequence of operations of deep screening

Precautions

1. No unscreened length should be left between screened lengths of track.
2. It should be ensured, that when ballast is being removed from any sleeper, there are at least four fully supported sleepers between it and the next sleeper worked upon.
3. Lifting should be limited to 50 mm at a time.
4. It should be ensured that packing, cross-levels and grade run-off are satisfactory before closing the day's work.
5. The work should be done under a speed restriction of 15 kmph.
6. The speed should be gradually increased as given in Tables 11.1 and 11.2. This will vary with the nature of maintenance in the section.

11.6.3 Schedule for Working and Speed Restrictions

Manual Packing: The details of work to be carried out in stages on various days after commencement of the screening operation and the speed restrictions recommended to be imposed are shown in Table 11.1. According to this schedule, normal sectional speed can be restored on the 21st day.

Table 11.1 Proposed Schedule for Deep Screening (Manual Packing)

Details of work in sequence	*Days for each work*	*Various speed restrictions and their duration*	
		Broad gauge	*Metre gauge*
Deep screening and initial packing	1st	15 kmph	15 kmph
First through packing	2nd	do	do
Second through packing	3rd	do	do
Picking up slacks	4th to 9th	45 kmph	30 kmph
Third through packing	10th	do	do
Picking slacks	11th to 19th	75 kmph	60 kmph
Fourth through packing	20th	do	do
After slack packing	21st	Normal section speed	Normal section speed

Machine Packing: The details of work to be executed in stages on various days after the start of the screening operations and the speed restrictions recommended to be imposed are shown in schematic representation in Table 11.2. According to this schedule, normal sectional speed can be resumed on the 10th day.

Table 11.2 Proposed Schedules for Deep Screening (Machine Packing/BG)

Details of work in sequence	*Days for each work*	*Various speed restrictions and their duration* (kmph)
Deep screening with manual filling/packing	1st day	15
First machine packing	2nd day	do
Slack packing	3rd day	do
Picking up slacks	4th–5th day	45
Second machine packing	6th day	do
Picking up slacks	7th day	do
Picking slacks	8th day	75
Third machine packing	9th day	do
After slack picking	10th day onwards	Normal sectional speed above 75 kmph

The period mentioned in schedules above in very much dependent upon the type of sleepers, the depth of deep screening, and the efficiency of the track machines. This may be suitably modified by the Chief Engineer—wherever considered necessary.

11.7 SYSTEM OF TRACK MAINTENANCE

The track is maintained either by conventional system maintenance or by systematic directed track maintenance. In both the systems, certain length of the gang beat is overhauled so that complete track is overhauled within a specified period (normally three to five years). Directed track maintenance has been with later in this book (Table 11.3).

Table 11.3 Annual Programme in Conventional System of Track Maintenance

Period	*Work*
1. Postmonsoon attention: Six month or thereabout after the monsoon.	1. Attention to run-down length in the entire gang beat to restore the section to good shape. 2. One cycle of systematic through packing/systematic directed track maintenance from one end of the gang length to the other including overhauling of the nominated sections, as mentioned above in this section. 3. Normally, four to five days per week should be allotted for through packing/overhauling and the remaining days for picking up of slacks, attention to bridge approaches, level crossings and points and crossings over the entire gang beat. Works such as lubrication of rail joints, joint gap adjustment as required and realignment of curves should be done during this period.
2. Premonsoon attention for about 2 months prior to the break of monsoon.	Normally, two to four days in a week should be devoted to clearing of side and catch water drains, earthwork repairs to cess clearing water-ways and picking up slacks. In the remainder days normal systematic maintenance will be carried out.
3. Attention during monsoon	Attention to track as required. This will consist primarily of picking up slacks and attention to side and catch water drains and waterways. During abnormally heavy rains, patrolling of the line by gangs should be carried out in addition to regular monsoon patrolling. *Note*: 1. Scattered or casual renewals creep adjustment and earth work repairs are done as necessary. 2. For maintenance schedule on LWR/ CWR special instructions for LWR/ CWR are in addition be followed.

11.8 MAINTENANCE PLANNING

Every Permanent Way Inspector must prepare a maintenance plan of his section one month in advance. Besides the normal inspections, it should include inspection of points and crossing, curves, adjustment of creep, deep screening, casual renewals, renewal of points and crossings, welding of joints, destressing of long welded rails, etc., so that optimum utilization of his time and labour resources is possible. He should also ensure that arrangements are made for adequate material, tool, labour, manpower and necessary caution orders/books, as many be necessary.

11.9 RECORD OF GANG WORK

1. Each mate should be supplied with a gang chart and a gang diary. In the gang chart, details of track maintenance work done over the gang length on a day to day basis should be recorded by the Permanent Way Inspector according to extent instructions. The work assigned to the gang should also be indicated in a gang chart by suitable notations. A typical gang chart is

given in Fig. 11.2. In the gang diary supplied to each gang, weekly programme of work should be entered by the Permanent Way Inspector. At the end of the week, the Inspector should carry out a qualitative and quantitative assessment of the work done during the week after a thorough inspection and make suitable observations in the gang diary.

Each gang chart/diary should be adequate for recording the work during the complete year. Temporary gangs employed in work related to track maintenance should be supplied with gang diary, wherein the details of the work set and the work carried out should be entered by the Permanent Way Inspector. Details of maintenance work carried out by these gangs should be entered in the gang chart of the respective permanent gang.

2. On withdrawal of gang chart/diary and supply of fresh ones, the Permanent Way Inspector should carefully analyse the work done and take note of running kilometres as those gave frequently trouble during the previous year, with a view to formulating such special measures as may be necessary. Action may be taken to preserve the gang charts for a period of three years.

11.10 PERMANENT WAY INSPECTOR'S SECTION REGISTER

Each Permanent Way Inspector shall maintain a section register containing all important informations including a brief history of the section. Entries shall be brief and categorized under various section as indicated below.

11.10.1 Administration

1. Change in Permanent Way Inspectors, mistry and clerks.
2. Change in jurisdiction.

11.10.2 Permanent Way

1. Formation: Sections giving frequent trouble with brief history and remedial measures adopted if any.
2. Track structure, method of maintenance, details of particular locations giving frequent trouble and remedial measures, adopted if any.
3. Details of kilometres of track laid as short welded panels, long welded rails, continuous welded rails, etc; incidence of buckling, maximum and minimum rail temperature, welded rails, etc; observed behaviour of SEJ and buffer rails.
4. Grades—regrading done, with brief details of lifting or lowering of track.
5. Curves realignment and/or transitioning of curves.
6. Kilometres of track where there is deficiency of ballast and details of recoupment done, particulars of deep screening carried out yearwise.
7. Details of creep adjustment done and action taken to reduce creep, details of gap survey carried out and adjustment done.
8. Major renewals carried out—such as a relaying, rerailing and resleepering; besides, large scale renewal of track components at a station should also be shown.

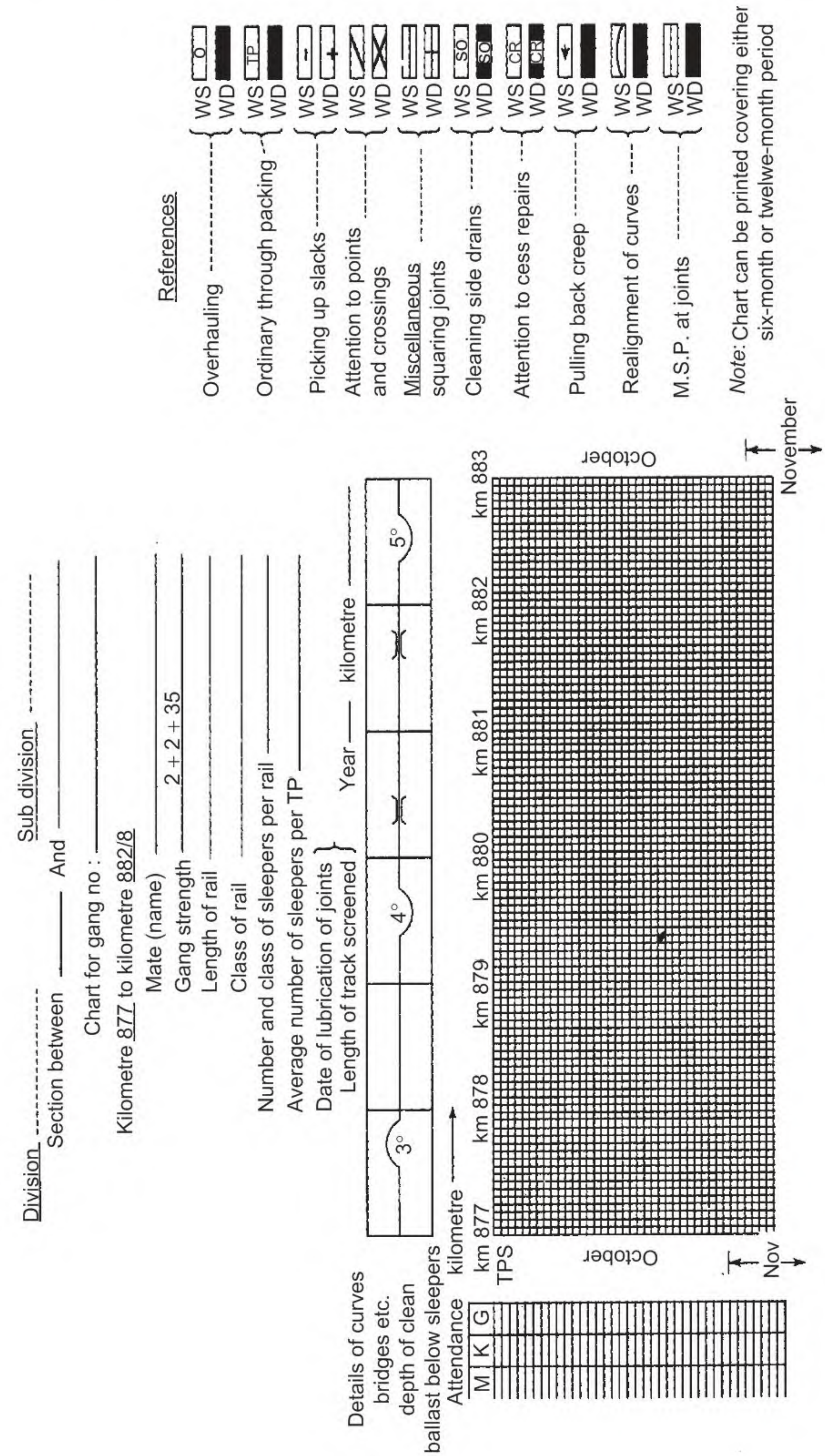

Division
Sub division
Section between
And
Chart for gang no :
Kilometre 877 to kilometre 882/8
Mate (name)
Gang strength
2 + 2 + 35
Length of rail
Class of rail
Number and class of sleepers per rail
Average number of sleepers per TP
Date of lubrication of joints
Length of track screened
Year
kilometre
3°
4°
5°
Details of curves
bridges etc.
depth of clean
ballast below sleepers
Attendance
M
K
G
kilometre
km TPS
km 877
km 878
km 879
km 880
km 881
km 882
km 883
October
Nov
November
References
Overhauling
Ordinary through packing
Picking up slacks
Attention to points
and crossings
Miscellaneous
squaring joints
Cleaning side drains
Attention to cess repairs
Pulling back creep
Realignment of curves
M.S.P. at joints
WS
WD
O
TP
SO
CR
Note: Chart can be printed covering either
six-month or twelwe-month period

Fig. 11.2

9. Station yards and sidings—extension or alterations to sidings, platforms and renewals of points and crossings.
10. Brief particulars of all types of rail failures, including weld failures, should be noted in the section register connecting references to the failures reports.
11. Records of rail testing by ultrasonic testing method; brief details of all rails with reasons for removal. This will form the basis of justification for through/casual renewals.
12. Brief particulars of fishplates failures with details of fishplates and reasons for failure.
13. Particulars of work done in lubrication of rail joints with dates of each year.
14. Connect reference to note in the 'materials-under-trial' register with brief particulars.
15. Summary of the results of the various track recording car.

11.11 PHENOMENON OF CREEP IN RAILWAY TRACK

11.11.1 General

Rails have a tendency to move gradually in the direction of the dominant traffic. It is believed to be caused by the 'ironing out' of yielding track by the moving load, augmented by braking loads, and by the impact of the wheels on the running-on ends of the rails, particularly at times when they are in a state of expansion or contraction. Among the trouble caused by 'creep' are:

1. Sleepers getting out of square.
2. Distortion of gauge.
3. Loosening of joints.
4. Shearing and breaking of spikes, bolts and fishplates.
5. Buckling—in extreme cases.

11.11.2 Causes

The following are some of the avoidable causes to which creep is attributed.

1. Inadequate toe load of the rail to sleeper fastening and rails not secured properly to sleepers.
2. Inadequate ballast resistance to the movement of sleepers due to poor or insufficient ballast or other causes.
3. Inefficiency or badly maintained rail joints.
4. Light rails vis-à-vis the traffic load.
5. Improper expansion gaps.
6. Decaying sleepers, uneven spacing of sleepers.
7. Lack of proper drainage.
8. Yielding formation resulting in uneven cross-levels.
9. Loose/uneven packing.
10. Rail seat wear in metal sleeper road.

11.11.3 Precautions

1. To reduce creep, it must be ensured that the rails are held firmly to the sleepers and adequate ballast resistance is available. All spikes, screws and keys should be driven home, the sleepers properly packed, and crib and shoulder ballast compacted. Rail anchors be provided wherever necessary.
2. With steel trough and cast iron plate sleepers and in the case of sleepers where elastic fastenings and other fastenings with adequate toe-load are used, no trouble is normally experienced. A vigil should be kept for a series of jammed joints, which should not exceed six jammed joints in a row in the case of single rail joints. In case of SWP not more than two consecutive jammed joints should be permitted at rail temperature lower than t_m in the case of Zone I and II, $t_m - 5$ in the case of Zone III and IV. On girder bridges, adjustment may be necessitated at regular intervals. Anti-creep devices should be provided on the approaches of girder bridges for adequate length.

11.11.4 Creep Register

Creep registers should be maintained in the prescribed proforma. Entries should be completed as regards running kilometres of section and length of rail, sleeper density, type and number of anchors per rail length used.

11.11.5 Creep Indication Posts

Creep indication posts square to the track should be created on either side of the track on the cess at intervals of about 1 km. These may be unserviceable rail posts with chisel mark square to the joints. The top of the posts should be about 25 mm above the rail level and the amount of creep, one way or the other, measured with a fishing chord stretched over the chisel marks.

The maximum permissible limit of creep is 150 mm.

11.11.6 Adjustment

Adjustments of creep should be carried out in the following manner.

1. Careful measurement of expansion gaps, as existing, should be carried out and appropriate length that can be dealt with in one operation should be chosen. The total amount of gap in the length should be equal to the standard expansion gap required for the temperature at the time, multiplied by the number of joints in the length.
2. Work should start simultaneously at the running-on end of the length just beyond the points and crossings or level crossings. The work of creep adjustments should be carried out under the protection of engineering signals by the Permanent Way Inspector. Before pulling-back is commenced the keys are knocked out and fishplates removed or eased. Correct expansion liners should be used and the rail should be pulled back with bars. If the fishplates are removed, the bars can pull against a tommy bar thrust through a bolt hole. Next, the rail is

keyed up, the bolts of the joints correctly tightened up, and the expansion liner moved to the next joint, whereupon the process is repeated.

3. It is a good practice to adjust creep before the commencement of summer. It is desirable to pull back the rails during the cool hours of the day.
4. Mechanical and hydraulic devices are available for adjustment of creep. Such a device can be set with the wide joints behind it and the tight joints ahead of it. Expansion liners corresponding to the prevailing rail temperature are put in all the keys, spikes and fishbolts are loosened.

   The adjuster then closes up the rails behind it by pushing, leaving a gap of some centimeters between the rail ends at the machine. The corrected rails are then fastened up.

   The machine is next attached to the rail ahead of it; keys, spikes and fishbolts loosened for that rail and those beyond it. These rails are then pulled until only the normal expansion gap is left at the machine. The operation leaves some of the gaps wide and it is then necessary to fix the machines further ahead in order to close them up to normal by pulling against expansion liners.
5. When the value of total gap existing is more than the standard expansion gap required for the temperature at the time of adjustment multiplied by the number of joints, it is necessary to provide closure rails. When closure rails are put in, a speed restriction of 30 kmph should be imposed, which should be removed when closure rails is changed.
6. During the adjustment of creep, the sleeper spacing should be adjusted, if necessary; with special attention to the joint and shoulder sleeper spacing.

11.11.7 Provision of Anchors to Arrest Creep

To arrest excessive creep on wooden sleepered road—not provided with anti-creep fastening—adequate number of anchors of approved design should be provided, no anchors being provided at the joint sleepers. Both rail seats at the sleepers should be anchored on the same side. In addition to sufficient directional anchors being provided, back-up anchors may be provided—if considered necessary.

11.11.8 Prevention of Creep of Metal Sleepers Road

Creep on cast iron plate sleepers should be counteracted as follows.

1. On CI plate sleepers all keys should be driven in the direction of traffic on the double track and alternately in the opposite direction on single track.
2. On steel trough road on double track, all the four keys may be driven in the direction of creep (generally in the direction of traffic). On single track, keys may be driven in the opposite direction on alternative sleepers.

11.12 BUCKLING OF TRACK

Buckling of track occurs when high compressive forces are created in the rails associated with inadequacy of lateral resistance in the track at that place. A special watch should be kept on the junction of two stretches of track, one liable to creep and the other held against creep; such as when track on wooden sleepers with inadequate anchors and scantly ballast or track on metal sleepers with loose keys butts against track laid on new sleepers with tight fastenings. As one side of such a junction point is held firmly against creep, the movement of rails due to creep from the other side is resisted resulting in heavy compressive force being exerted which will tend to buckle the track. Jammed rail joints at such junctions are therefore an indication of the track being subjected to undue strains.

11.12.1 Conditions which Induce Buckling

The following conditions create high compressive forces in the rail (a) inadequate expansion gaps (b) failure to counteract creep in time (c) non-lubrication of rail joints and (d) failure to remove rail closures from track.

The lateral resistance gets impaired due to inadequacy of ballast and carrying out of such operations as deep screening, lifting of track and slewing of track, without adequate precautions.

11.12.2 Precautions

1. Operations which impair the lateral resistance of track are not carried out when rail temperatures are high.
2. The greasing of fishplates is done before hot weather sets in.
3. The joint gap survey is effected in the case of SWP and adjusted before the hot weather. Similarly in case of single rail panel, joint gaps should be adjusted wherever necessary.
4. Adequate precautions are taken to reduce creep as detailed in the preceding section.
5. Overtightening of fishbolts is avoided though they should be reasonably tight.
6. Particular attention is also paid to stretches of track, one liable to creep and the other held against creep. Jammed joints at such junctions call for remedial measures. Extra shoulder ballast should be provided at such places.

11.12.3 Action on Buckling of Track

If buckling does occur or appears imminent the track should be protected immediately with hand signal and detonators as per the protection rules laid down. The track should be slewed to a flat reverse curves. On curves, the track should be slewed outwards. On double line, the track centers should first be increased. Clearance to structures and signals should be checked carefully. After verifying that none of the rails or joints is crippled by buckling, traffic can be resumed at reduced speed over the affected portion. It may not be possible to do any more until the temperature drops, when the joints must be adjusted and the track restored to proper alignment. Particular care must be taken to see that the factors which contributed to buckling, i.e. jammed joints, seized fishplates or shortage of ballast receive appropriate attention without delay.

11.13 MAINTENANCE OF RAIL JOINTS

11.13.1 High Joints

The incidence of high joints usually occurs in through metal sleeper track provided with wooden sleepers at the joints. Wooden sleepers settle much less under traffic as compared to metal sleepers, thus leading to high joints. Remedy lies in lifting and packing of metal sleepers, without attending to the wooden sleepers.

11.13.2 Blowing Joints

This means a joint covered with a fine layer of dust and indicates that the joint sleepers are loose and indeed the ballast underneath is not clean. The situation is aggravated by battered rail ends, unserviceable joint sleepers and wide expansion gaps.

Remedy lies in cleaning the dirty ballast, through packing of joint sleepers and tightening of joint fittings. Improvement of battered rail ends, replacement of unserviceable sleepers and reduction of expansion gaps may also be necessary.

11.13.3 Pumping Joints

In rainy season blowing joints get converted into pumping joints. Improvement in drainage, besides the remedies mentioned in blowing joints is necessary for satisfactory results.

11.14 RAISING AND LOWERING OF TRACK

11.14.1 Lifting of Track

1. To keep a good top, lifting of the track often becomes necessary during regrading and for elimination of minor sags which develop because of improper maintenance or yielding soil.
2. Correct level pegs should be fixed at suitable intervals, before lifting is commenced.
3. Heavy lifting should always be carried out under suitable speed restriction and under the protection of corresponding engineering signals. Lifting should not exceed 75 mm at a time to allow proper consolidation. The easement gradient for the passage of trains should not be steeper than 25 mm in one rail length of 13 m. The operation should be repeated until the required level is attained when the track should be finally ballasted, through packed and boxed, the cess being made up to proper level.
4. Lifting should commence from the downhill end and carried out in the direction of rising grade in case of single line. It should be proceeded in the opposite direction of traffic; in-case of double line, care being taken not to exceed the easement grade.
5. When lifting the track under bridges and overhead structure and in tunnels, it should be ensured that there is no infringement of standard dimensions.

6. In case of curves, it is usual to set the inner rail to the correct level and grade and to raise the outer rail to give the required superelevation, care being taken to see that the cant gradient is within the permissible limit.

11.14.2 Lowering of Track

1. Lowering of the track should be resorted to under inevitable circumstances when so it should be effected under suitable speed restriction and protection of engineering signals.
2. When lowering is to be done, trenches should be made across the track at every 30 m to the final level to give a clear indication that the work is in progress. The ballast should be removed sufficiently away from the track to prevent its mixing with excavated material.
3. The procedure is to clear the spaces between the sleepers, then slightly lift the track, break the core beneath and level it into the space between sleepers. The material is then removed and the operation repeated until the final level is reached. The road should then be ballasted, through packed and boxed, the cess being cut down to proper level.
4. Lowering as in the case of lifting should be restricted to a maximum of 75 mm at a time and the grade for passage of trains should not exceed 25 mm in a rail length of 13 m. As opposed to lifting, lowering should be carried out in the direction of the falling grade. Work of lifting or lowering of track should be carried out in the presence of a Permanent Way Inspector.

11.15 LEVEL CROSSING

Track Structure in Level Crossing

1. In level crossing 'U' category sleepers (durable) or concrete sleepers should preferably be used.
2. All wooden sleepers used in level crossings should be provided with suitable bearing plates.
3. Rail joints should be avoided in check rails and on the running rails—within the level crossings and three metres on either side.
4. On wooden sleepers in each rail seat, four spikes per sleeper seat should be provided.
5. In the case of SWP, the short welded panel may be continued through the level crossing avoiding fishplate joints on level crossing and within 6 m from the end of the level crossing.
6. The level crossing should not fall within the breathing lengths of LWR.

11.15.1 Inspection and Maintenance

Each level crossing must be opened out and the condition of sleepers and fittings, rails and fastenings inspected at least once a year or more frequently as warranted by the condition. In all cases rails and fastenings in contact with the road shall be thoroughly cleaned with wire brush and coat of coal-tar/anticorrosive paint applied. Flange-way clearances, cross levels, gauge and alignment should be checked and corrected as necessary and the track packed thoroughly before reopening the level crossing for road traffic.

11.16 MAINTENANCE OF TRACK CIRCUITED AREAS

To promote safety in train operation, at some specific location track circuited areas are provided. In these areas, the two rails of the track are electrically insulated from each other with the use of sleepers made of non-conductive material. These lengths of track are also electrically insulated from the adjoining lengths with the use of insulated joints. When any vehicle comes over the track circuited areas, the electrical circuit gets completed through the vehicle and the presence of the vehicle gets relayed to the station cabin. Through a system of mechanical or electronic gadgetry, it is ensured that once a vehicle/train occupies a track circuited area no other vehicle/train can enter the area.

Permanent Way staff is required to take the following precaution while maintaining track in track circuited areas.

1. No P. Way tool or metal object should be placed across or touching two rails. This may cause short circuiting.
2. All gauges, level, trolleys and lorries on track circuited lengths should be insulated.
3. While carrying out track maintenance operation care should be taken to see that no track circuit fittings, i.e. rail bonding wires, lead wires, jumper wires, etc., are damaged. Signalling staff should be associated with the maintenance work when considered necessary.
4. Proper drainage should be ensured as the accumulation of water touching the two rails can cause failure of track circuit.
5. Ballast top should be at least 50 mm below the rail foot. In rainy season, wet ballast can cause track circuit failure if touching the rails or rail fastenings.

Various types of insulated joints in use in the Indian Railways have been described in Chapter 3.

11.17 TRACK MAINTENANCE IN ELECTRIFIED AREAS

In electrified routes, while overhead conductors carry high voltage electric currents for feeding the traction motors of the electric locos or EMUs, the return current flows through the track rail fully or partially. To ensure reliable continuity in the electrical circuit, and proper earthing in case of leakage of current, various types of traction bonds such as longitudinal rail bonds, cross bonds (in DC area), etc., are attached to the rails. To avoid any disruption in rail traffic and ensure personal safety, the following precautions need to be taken by track maintenance staff while carrying out track maintenance work in electrified routes.

1. No damage should be caused to any of the traction bond. For maintaining the continuity of track during renewal of track, rail fractures, removal of fishplates, etc. temporary metallic jumpers of approved design should be provided.

2. The distance between the track components and the electric masts, and the OHE wires should be maintained within the prescribed tolerances. Special care thus need be exercised in realigning of curves, changing of superelevation, deep screening of ballast, relaying of track etc.
3. No work should be carried out within a distance of 2 m from the live parts unless a power block is taken.
4. Sometimes, owing to the phenomenon of induction, there is a build-up dangerous voltage potential in long metallic bodies laying along the track. Such structures should be earthed. For similar reasons, new or released rails lying along the track should have a gap of about 300 mm. To avoid electric shocks from high induced voltages, permanent way staff are advised not to have contract with the track when an electrically hauled train is within 250 m of the place of work.
5. Permanent Way Tools (Insulated and Uninsulated) along with gloves shall be used in the manner as approved by the Chief Engineer of the Railway.

11.18 ENGINEERING SIGNALS FOR PROTECTION OF TRAINS

11.18.1 Categories of Engineering Works

Engineering works are broadly divided into three categories as follows:

Category I Works of routine maintenance—requiring no speed restriction, not necessitating exhibition of hand signals and evolving no danger to trains or traffic—include routine maintenance such as through packing up slacks and overhauling of track etc.

Category II Works of short duration, viz casual renewal of rails and sleepers, adjustment of creep and lubrication of rail joints, that are completed by sunset and require no speed restriction thereafter.

Hand signals, banner flags and fog signals shall be used at specified distances to afford protection to trains.

Category III Works such as relaying, bridge construction, diversions which extend over a few days or weeks during which period continuous restriction of speed is to be in force are termed as *works of long duration.*

Temporary engineering signals in the form of caution, stop, speed and termination indicators are used at specified distances to afford protection to trains (Fig. 11.3).

These works will be carried out to a programme, about which all concerned will be advised in advance.

11.18.2 Positioning of Signals/Indicators

The type of signals/indicators used and their placement have been indicated with the help of diagrams for the various situations that are met with in Figs 11.4–11.7.

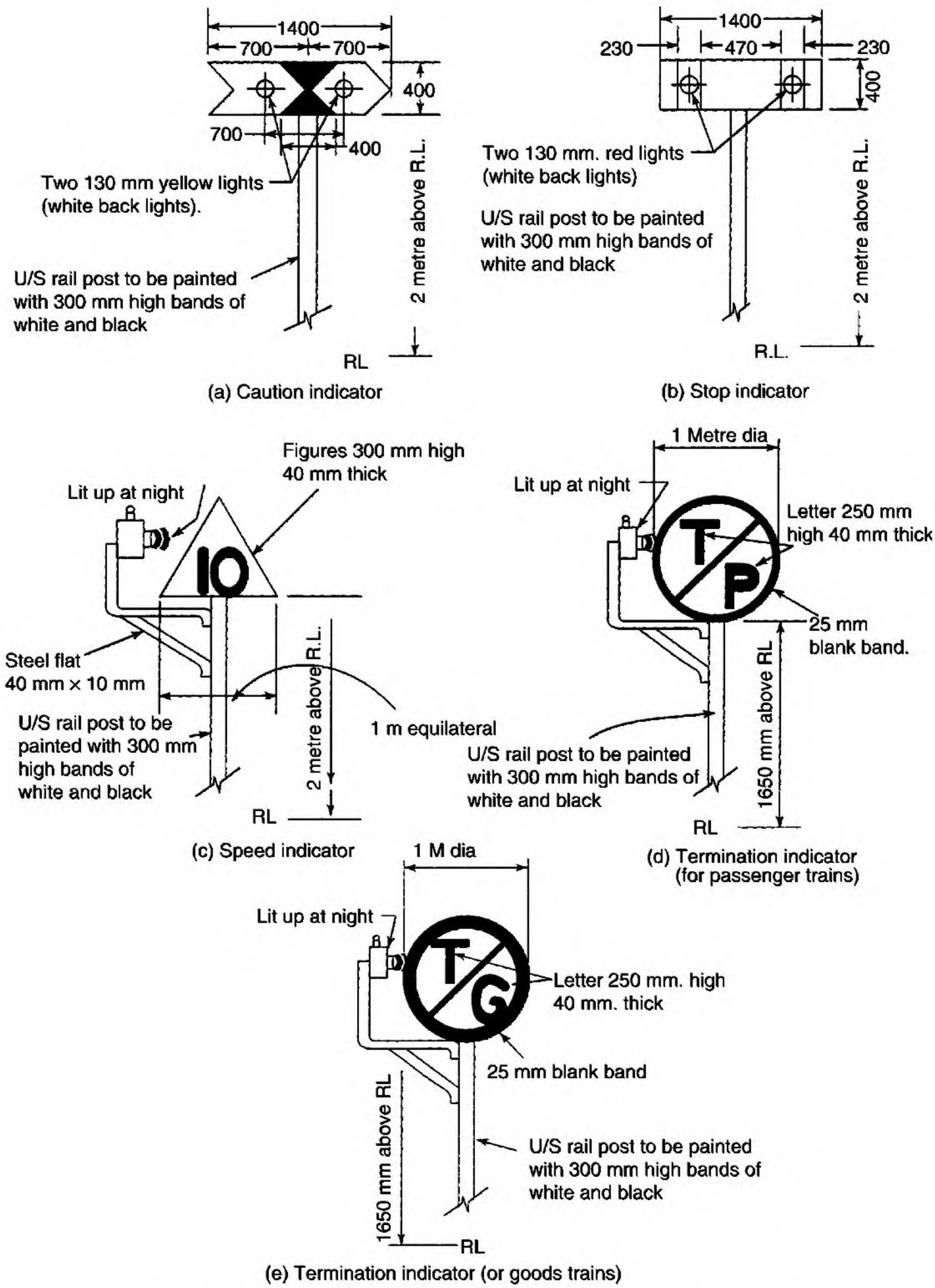
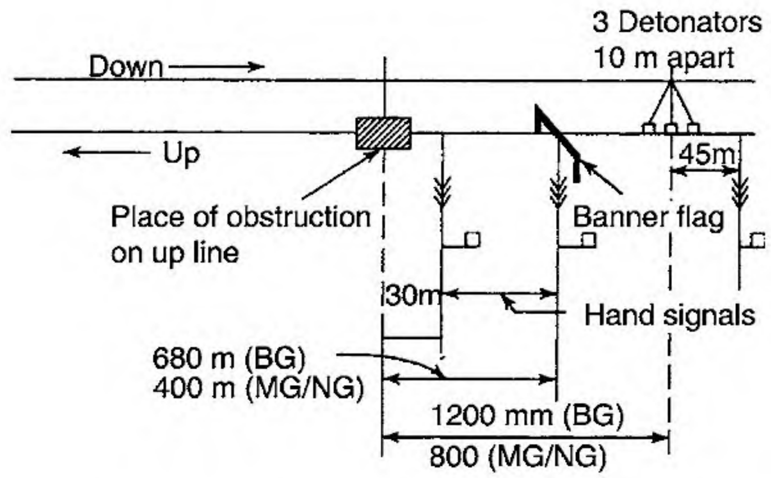


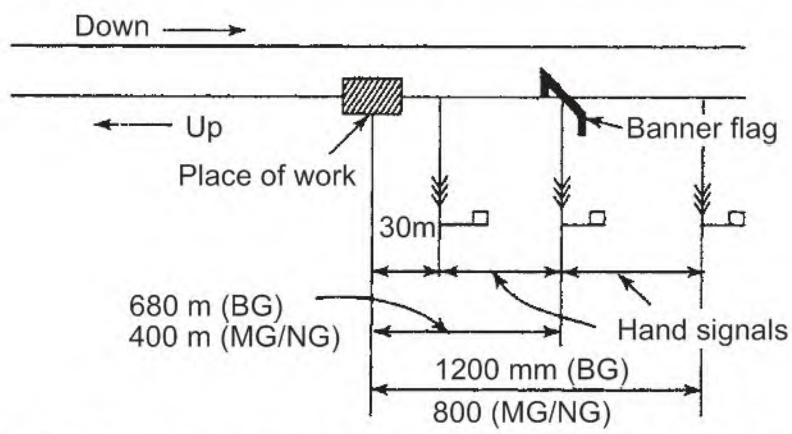
Fig. 11.3 Engineering indicators for temporary restrictions



Notes:

1. In the case of MG sections, whre the trains run at a speed more than 75 kmph, the distance of hand signals and detonators shall be increased suitably as per approved special instructions.
2. In the case of single line sections, both sides will be protected.

Fig. 11.4 Works of short duration requiring stop dead restrictions



Notes: The intermediate flag man will keep the Banner flag until the speed of the train has been reduced, after which the Banner flag will be removed and train hand signalled to move ahead.

Fig. 11.5 Works of short duration providing protection by reduced speed

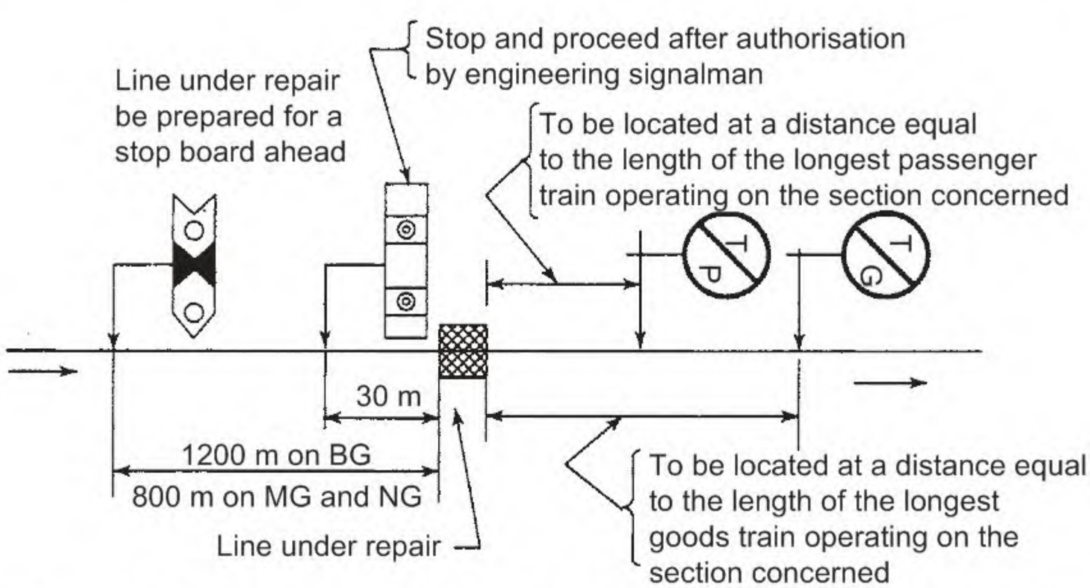


Fig. 11.6 Fixture of engineering indicators for dead stop restrictions outside station limits

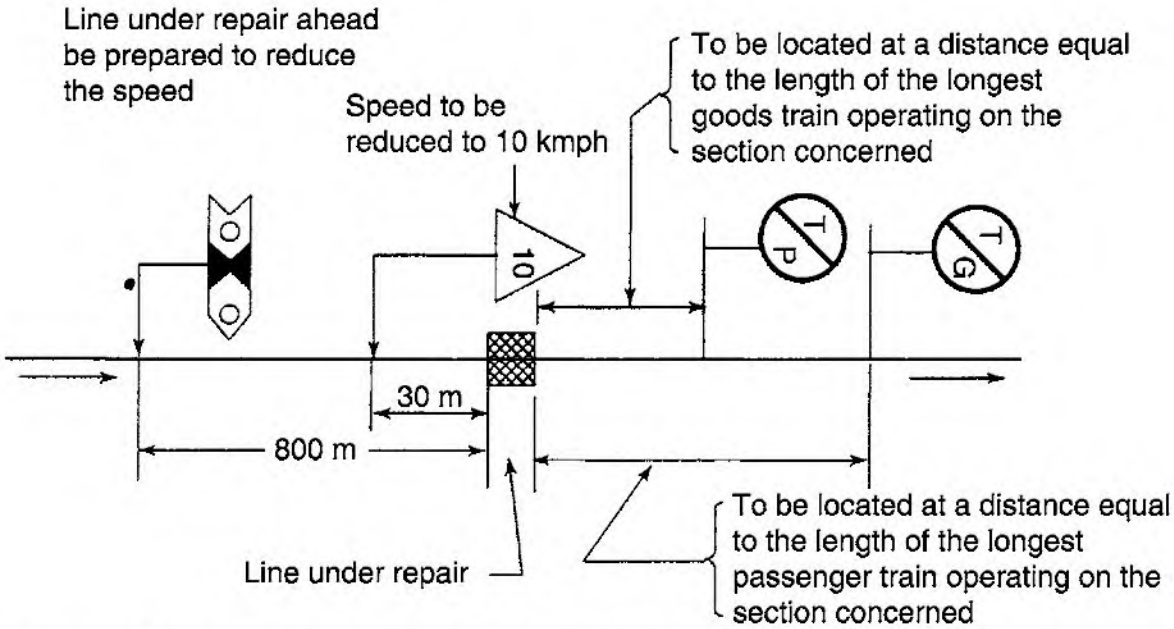


Fig. 11.7 Works of long duration providing protection by reduced speed outside station limits

11.18.3 Temporary Signals in Emergency

1. Due to any obstruction on a line or for any other reason, when a Railway servant deems necessary to stop an approaching train, he shall plant a danger signal at the spot and proceed with all the haste in the direction of the approaching train with a danger signal (red flag by day and red light by night) to a point 680 m for BG and 400 m for MG and NG from the obstruction and place one detonator on the line; after which he shall proceed further for not less than 1200 m for BG and 800 m for MG and NG from the obstruction, and place three detonators on the line 10 m apart. He should then taken a stand at a place not less than 45 m from where he can have a good view of the approaching train and continue to show the danger signal until recalled. If recalled, he shall leave down the three detonators and on his way back, pick up the intermediate detonator, showing the danger signal all the while. In case of those MG sections where the maximum speed is more than 75 kmph, these distances will be as per approved special instructions.
2. On a single line, the line must be protected on either side of the obstruction.
3. Where there are adjacent lines and it is necessary to protect such lines, action should be taken on each such line in a similar manner.

11.19 DIVERSIONS

Shifting of track alignment laterally, for a limited period of time, is called diversion. These are often required to bypass traffic from a certain portion of track which is not usable on account of an obstruction caused by an accident or some construction work such as building of a new bridge or rebuilding of an old bridge.

11.19.1 Types of Diversions

Diversions are of two kinds discussed below.

Temporary diversions Such diversion as are not likely to be in use for more than 10 days. All trains must 'stop dead' before entering a temporary diversion and proceed at a speed of 10 kmph. These are usually laid when line is obstructed due to a train accident.

Semi-permanent diversions It is laid for a special purpose of carrying out some construction activity and is likely to be in use for a period of more than 10 days. On a semi-permanent diversion, trains may proceed at a nonstop reduced speed after adequate period of consolidation.

11.19.2 Curvature and Gradients

As far as possible, the radius of curvature on the diversion should not be less than 450 m, 300 m and 45 m for BG, MG and NG, respectively. Gradient should not be steeper than 1 in 100, 1 in 80 and 1 in 40 on BG, MG and NG respectively, compensated for curvature. No superelevation is provided on a temporary diversion. Semi-permanent diversion may be provided with superelevation for the permitted speed.

11.19.3 Calculation for Setting out Diversion

The following formula is adopted while setting out diversion. See Fig. 11.8.

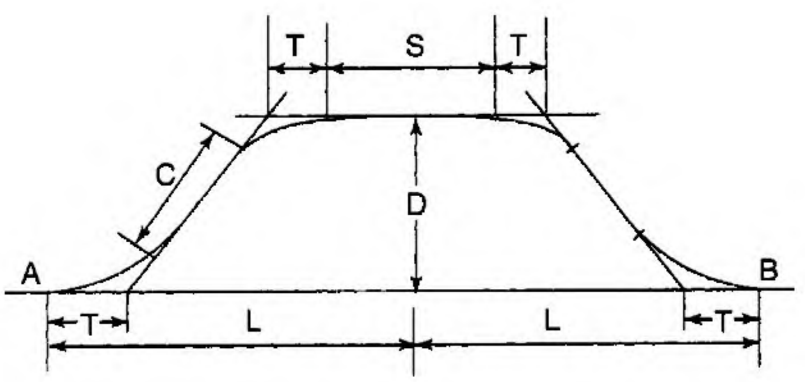


Fig. 11.8

$$L = \sqrt{C^2 + 4RD - D^2} + S/2$$

$$T = \frac{RD}{L - S/2 + C}$$

All measurements to be taken in the same units,

where AB = Portion of existing line to be diverted
L = length of half the diversion, measured along the original alignment
D = maximum distance of diversion from original alignment
S = straight portion of diversion
C = length of straight between reverse curves, usually kept as 30.5 m
R = radius of curves
T = length of tangent

11.19.4 Opening for Traffic

The diversion track should be adequately consolidated and tested by locomotives/wagons before opening to traffic. The most vulnerable portion of the diversion is the junction of the old bank with the new bank. To avoid slippage, benching of slopes on the old bank should be done at the junction while putting earth for the diversion track. Cross-levels should be checked after passage of every train and rectified till the track gets stabilised.

11.19.5 Examples

Example 1. *A BG mainline is required to be diverted for carrying out long duration repair works. Design an economical semi-permanent diversion 15 m away from the main track. The diversion should be laid with a radius of 450 m and a gradient of 1 in 100.*

Solution

Data

$$
\begin{aligned}
D &= 15 \text{ m} \\
R &= 450 \text{ m (about } 4^\circ \text{ curve)} \\
C &= 30.5 \text{ m} \\
S &= 30.0 \text{ m} \\
\text{Gradient} &= 1\ \% \\
L &= \text{half length of diversion along the straight} \\
L &= \sqrt{4\,RD + C^2 - D^2} + S/2 \\
&= \sqrt{(4 \times 450 \times 15) + (30.5)^2 - (15)^2} + 30/2 \\
&= 181.5 \text{ m} \\
2L &= 363 \text{ m} \\
T &= \frac{RD}{L - \frac{S}{2} + C} \\
&= \frac{450 \times 15}{1815 - \frac{30}{2} + 30.5}
\end{aligned}
$$

$= 34.26$ m

Total diversion length along curve

$= (8T + 2C + S)$

$= (8 \times 34.26 + 2 \times 30.5 + 30)$

$= 365.08$ m

Offset where existing main track ends on diversion

$$O = \frac{\text{Formation width + Track Gauge}}{2}$$

$$= \frac{6.10 + 1.676}{2}$$

$= 3.888$ m

Hence, distance from take-off of diversion to the point where main track ends on diversion,

$$X = \sqrt{2 \times 0 \times R}$$

$$= \sqrt{2 \times 3.888 \times 450}$$

$= 59.15$ m

Length of diversion where grade is to be provided on either side

$= (4T + C - X)$

$= (4 \times 34.26 + 30.5 - 59.15)$

$= 108.39$ m

Compensating gradient on curve @ 0.04 percent per degree of curvature;

Compensated gradient $=$ I percent $- (4 \times 0.04)$ percent

$= 0.84$ percent

Hence, maximum lowering of bank of diversion that can be permitted

$$= \frac{108.39 \times 0.84}{100}$$

$= 0.91$ m, say 0.9 m

Example 2. *Design the layout of a 1.5 m high BG semi-permanent diversion for rebuilding a destressed 3 × 6.1 m bridge on 4 m high main line bank. Adopt economical values. See Fig. 11.9.*

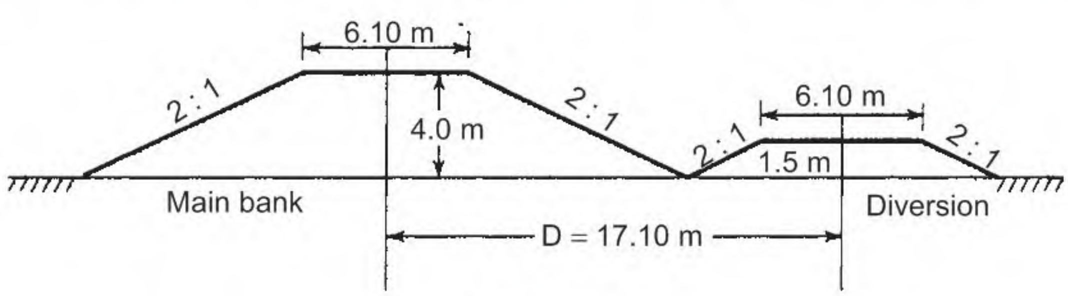


Fig. 11.9

Solution

Data

Let R = 450 m (about 4° curve)

C = 30.5 m

Gradient = 1 percent

Grade compensation = 0.04 percent per degree of curvature

Height of main bank = 4 m

Height of diversion bank = 1.5 m

Hence, difference in height of bank = 2.5 m

Minimum S = (30.5 + 3 × 6.1 + 30.5) m

= 79.3 m, say 80.0 m

Minimum D = (2 × 4 + 2 × 1.5 + 6.10) m

= 17.1 m

$$L = \sqrt{4\,RD + C^2 - D^2} + S/2$$

$$= \sqrt{(4 \times 450 \times 17.1) + (30.5)^2 - (17.1)^2} + 80/2$$

= 217.25 m

$2L$ = 434.5 m

$$T = \frac{RD}{L - S/2 + C}$$

$$= \frac{450 \times 17.1}{217.25 - 80/2 + 30.5}$$

= 37.04 m

As worked out in Example 1,

O = 3.888 m

And X = 59.15 m

Hence, length of diversion where grade to be provided on either side

= $(4T + C - X)$

= (4 × 37.04 + 30.5 – 59.15)

= 119.51 m

Compensated gradient = 1%

Hence, permissible lowering of bank of diversion

= 119.51 × 0.84/100

= 1.004 or 1.0 m

Therefore, (2.5 – 1.0) = 1.5 m height will have to be adjusted in the portion of diversion length running straight and parallel to the mainline. Hence, length required to cover 1.5 m height at 1 percent gradient

= 1.5 × 150 m

Therefore, total diversion length along the curve,

$$= 8T + 2C + S + (2 \times 150)$$
$$= (8 \times 37.04) + (2 \times 30.5) + 80 + (2 \times 150)$$
$$= 737.32 \text{ m}$$

Hence, revised total diversion length along the straight,

$$2L' = 2L + (2 \times 150)$$
$$= 434.5 + 300$$
$$= 734.5 \text{ m}$$

11.20 GANG STRENGTH

To provide manpower for the maintenance of track on a national basis, the following gang strength formula has been evolved in the Indian Railways.

$$N = MKE,$$

where,
N = number of men per km
M = manpower factor;
K = correction factor due to modernization of track maintenance, etc,
E = equated track kilometre (ETKM).

11.20.1 Manpower Factor M (Basic Requirement of Gangmen/km)

This is the manpower factor of standard fishplated track with conventional manual maintenance. This is worked out by finding out the total manpower needed in one calendar year for carrying out all normal maintenance operations (say X). The actual number of workingman-days available in a year are found by subtracting the number of Sundays, holidays, etc. from the total man-days in year (say Y). M, the manpower factor is taken as

$$M = \frac{\text{Man-days required}}{\text{Man-days available}} = \frac{x}{y}$$

There are certain operations of track, such as overhauling and through packing which cannot be done during monsoon. The factor M is modified to take into account the man-days needed in the dry working season for carrying out these essential operations and those available in that period. Working on the above basis, the following values of M have been obtained for adoption.

$$M \text{ for BG} = 1.47$$
$$M \text{ for MG} = 1.21$$

Correction Factor *K*

This factor depends on the track section and the type of maintenance. Values of K adopted in the formula are as given in Table 11.4.

It may be noted that manpower requirement for MSP and DTM has been considered the same as that for conventional manual maintenance.

Table 11.4

S. No.	Type of track	Method of maintenance	
		Conventional/ MSP/DTP	*Mechanical with on-track tampers*
1.	Fishplated, track, including track layout, running loops and sidings	1.00	0.80
2.	SWP	0.95	0.75
3.	LWR on metal and wooden sleepers	0.85	0.60
4.	LWR on concrete sleepers	—	0.50

11.20.2 Equated Track Kilometre—ETKM

To work out the manpower requirement for the maintenance of various types of tracks of different gauges under different traffic densities, variable formation alignment and rainfall condition, a formula has been evolved in which all type of tracks are converted into equivalent standard track, called equated track kilometre (ETKM). The formula is:

$$E = L \times U\,(1 + A + B + C)$$

where

E = equated track kilometre
L = running track kilometre
U = traffic density factor
A = formation factor
B = alignment factor
C = rainfall factor

Values to be adopted for the above factor are:

U = Traffic Density Factor

11.20.3 Broad Gauge

1. Heavy worked suburban section or ghat sections with gradients of 1 in 60 and steeper (1.4)
2. Sections where the annual traffic density is 20 million GTKs per kilometre and over. (1.4)
3. Sections where the annual traffic density is 15 million GTKs and over per kilometre but less than 20 million GTKs per kilometre. (1.3)
4. Sections having a daily train density of 30 and over or where the annual traffic density is 10 million GTKs per kilometre and over but less that 15 million GTKs per kilometre. (1.2)

5. Sections having a daily train density of 20 and over but less than 30 or where the annual traffic density is 6 million GTKs per kilometre and over but less than 10 million GTKs. (1.1)
6. Other primary sections where the annual traffic density is less than 6 million GTKs per kilometre. (1.0)
7. Secondary or tertiary lines. (0.8)

11.20.4 Metre Gauge

1. Suburban and ghat sections with gradients of 1 in 60 and steeper. (1.2)
2. Primary lines where annual traffic density is more than 5 million GTKs per kilometre. (1.1)
3. Primary lines having a daily train density of 20 and over where the annual traffic density is over 2.5 million GTKs per kilometre. (1.0)
4. Secondary lines or other lines with a train density of 10–20 per day. (0.8)
5. Tertiary lines. (0.6)

Note:

In double or multiple lines, the traffic density factor may be assessed for the average traffic density of the lines and applied to all the lines.

For working out equated track kilometres, wherever track is maintained to permit running of trains at a speed of over 105 kilometres per hour, the above value of 'U' should be increased by 0.1.

A = Formation factor

This factor covers the nature of soil in bank and will have the following values:

	Nature of soil	Factor
(a)	Stable soil	0
(b)	Ordinary unstable soil	0.1
(c)	Shrinkable soil and viscous blank cotton soil	0.2

B = Alignment factor

This factor is applicable to curve of

(b) 1.5° and more on BG
(c) 3° and more on MG

Note: The formation factor *A* and alignment factor *B* above should be assessed prorata for the length falling under bad soil conditions or curves compared to the total length.

C = Rainfall factor

The factor *C* is dependent rainfall. The value of zero should be applied when the rainfall is less than 200 cm. An annual rainfall of 200 cm would attract a value of 0.1 with an increase of 0.01 for every additional 10 cm increase in the annual rainfall subject to the maximum of 0.2 for the factor.

11.20.5 For Marshalling Yards and other Sidings

The formula for working out the equated track kilometres will be:

$$E = L \times U^1$$

Where E and L have the same value as given above and the value of U^1 is:

	BG	MG	NG
Marshalling and other busy sidings	0.7	0.5	0.3
All other sidings	0.4	0.3	0.3

Note: The sidings/lines in a yard may be classified as busy and non-busy and equated track kilometres worked out separately.

Track Connections and Layouts should be treated as 'sets' on the following scale, and ten such sets should be treated as equal to one kilometre length of track:

Turnout	1 set
Diamond	1 set
Diamond crossing with single slip	1 ½ set
Diamond crossing with double slips	2 sets
Cross-over	2 sets
Three-throw	2 sets
Scissors cross-over	5 sets
Trap	1/5th set
Double trap	2/5th set

The running kilometres thus arrived at should be converted into equated track kilometres by applying the formulae mentioned in either of the first two formulae as the case may be. These formulae and the value of factors U, U^1, A, B and C used for working out equated track kilometres would be with respect to the more important line connected by the track connection/layout.

For turnouts, cross-overs (ordinary and scissors), three-throw, etc., the through kilometrage will be measured along the main track and the length of the track in sidings and loop will be measured from the heel of the crossing and not from the toe of the switch. Similarly, in diamond crossings with single or double slips, the curved lead of the slip/slips will not be included in the length of the track.

Note: The equated track kilometres shall be worked out kilometre-wise for each section on each gauge separately and added to sum total of gauge. Further, these shall be based on the mean of running kilometres of track open for each section for the whole year and not on the basis of running kilometres open at the end of the year.

11.20.6 Items of Normal Track Maintenance

Items of normal track maintenance work in standard fishplated track for which gang strength is provided in the formulae are the following.

1. Through packing.
2. Through packing including overhauling or shallow screening.
3. Picking up slacks.
4. Lubrication of rail joint.
5. Minor attention to cess.
6. Clearance of drain.
7. Casual renewal of rails and sleepers.
8. Adjustment of creep over short lengths.
9. Overhauling of level crossings.
10. Special attention to points and crossings.
11. Other miscellaneous items like renewal of bridge timbers etc.

The gauge strength formula do not provide for occasional or miscellaneous items of work such as:

1. Loading and unloading of materials.
2. Lorrying out of the materials other than for causal renewals of rails and sleepers.
3. Monsoon patrolling.
4. Security or special patrolling.
5. Repairs to bridges.
6. Cleaning of good sheds or platform surfaces.
7. Stock verification.
8. Attention to ash pits, water columns, CC aprons, etc.
9. Painting of rails in station yards.
10. Deep screening of ballast.
11. Resurfacing of points and crossings.
12. Watching of materials.
13. Painting of bridges.
14. Heavy repairs to track including lifting.
15. Complete renewal of points and crossings.
16. Complete realignment of curves.

Then there may be isolated stretches of track which need special attention due to exceptional formation problems not covered by the condition laid down in working out ETKMs, thus needing extra labour. Such extra labour can be allowed at the discretion of the engineer incharge. Similarly, extra labour may be needed in the removal of sand dunes in the desert areas.

11.20.7 Determination of Gang Strength

For determining the gang strength for a particular km of track, one should find out the *ETKM* of that running *km* of track taking all the relevant factors apropos of Sec. 11.20. Then, appropriate values of M and K are found out. The gang strength requirement for that particular km will then be found from the formula $N = MKE$. Similar exercise is done km for km and the total gang strength for a particular section is determined.

11.20.8 Normal Strength of a P Way Gang

The above formula gives the number of gangmen required for carrying out track maintenance operation without including keyman, mate, gateman, and the element of leave reserve.

In conventional system the gang length does not normally exceed 6 km for mainlines and 8 km for branch line section.

The total number of gangmen in gangs are limited to about 18, exclusive of mate and keymen. Two keymen are usually provided per gang for double line section. The gang is headed by a mate.

11.21 JURISDICTION OF PERMANENT WAY INSPECTOR AND ASSISTANT INSPECTOR

1. The following broad criteria have been laid down for fixing the jurisdiction of PWIs.
   (a) On BG and MG main and trunk lines the route length should not exceed 60–70 km.
   (b) On BG main and trunk lines, equated track kilometres should be limited to:
      (i) 110–125 single line section which gives the route length of 60–70 km approximately.
      (ii) 150 for double line section which gives a route length of 50 km approximately.
      (iii) 170 for multiple line section which gives a route length of 40 km approximately.
   (c) On MG main and trunk lines, equated track kilometres should be limited to:
      (i) 95–105 for single line.
      (ii) 115–130 for double line.
   (d) On BG and MG branch lines, the route length should not exceed 80–90 km.
2. Jurisdiction of Assistant Inspectors/Additional PWI.
   (a) On trunk route and main lines:
      (i) Single line
         - Route length of 30–40 km.
         - Maximum equated track kilometres: 40 for MG and 50 for BG.
      (ii) Double line
         - Route length of 20–30 km.
         - Maximum equated track kilometres: 60 for MG and 80 for BG.
   (b) On branch lines: A PWI may be assisted by one APWI and a few permanent way mistries.

APWI is generally assisted by a minimum of two APWI. PWIs and APWIs are generally provided with push trolleys and trolley men for the inspection of their sections.

12 Chapter

Mechanised Track Maintenance

12.1 MECHANISED TRACK MAINTENANCE

Mechanised track maintenance, particularly with on-track tamping machines, has been able to overcome most of the limitations enumerated in the other two methods, i.e. beater packing and measured shovel packing. Its particular superiority lies in:

1. Its capability to maintain longitudinal and lateral alignment of modern LWR track laid with concrete sleepers to close tolerances, as required for high speed traffic.
2. The track maintenance operation being automatic, the chances of human fatigue are significantly fewer.
3. Its high speed of operations, are particularly beneficial for the restoration of track geometry after deep screening or relaying in the short time.

In the Indian Railways, mechanised track maintenance is being increasingly adopted for the maintenance of high speed routes and for quicker restoration of track after relaying. Its present fleet of machines consists of more than 400 on-track tamping machines. In addition, there are crib and shoulder compactors, dynamic track stabilisers, ballast regulators, ballast cleaning machines and multi purpose tamping machines working on the Indian Railways.

12.2 TRACK TAMPING MACHINES

Track tamping machines fall into two broad categories, viz off-track tamping machines and on-track tamping machines they are discussed below.

12.2.1 Off-Track Tamping Machines

These tamping machines are a type of hand tools driven by compressed air, electricity or patrol engine. Pneumatic tools require a compressor to provide compressed air, and electric tools require a generator. Petrol tools are usually self contained with the engine, i.e. engine and the tools are in the machine. These machines generally work in between the train intervals, thus requiring no traffic block. They do not lift the track and therefore require the assistance of jacks for lifting and levelling.

12.2.2 Off-track Tamping Machines in Indian Railways

Off-track tampers, to be successful, need to meet the following criteria.

1. For the safety of the operation, light tampers are preferable to heavy tampers.
2. Any electric tool must be free of the possibility of giving a lethal shock to the operator.
3. The quieter the tool, the better is the safety and comfort of the operator.
4. The tools and the ancillary equipment must be reliable and should not require frequent servicing.
5. The output of the tamper should be good on a long term rating and should produce track which is stable over a long period.

Following types of off-track tamping machines are under trials on Indian Railways.

Kango Tampers Kango tamper, is an electric tool, which by a combination of electric motor drive and pneumatic piston through coupling, gives a high frequency impact to the ballast. The stroke combines the respective advantages of the impact and vibratory principles to give a high consolidating energy without raising impact value high enough to break the ballast.

'Kango' tamping tools are generally used in sets of four or eight tools driven from generators supplying power to two or four tools. The two-tool generator is considerably lighter than the four-tool generator and is thus convenient to handle. Further, to increase the mobility of 'kango' equipment, single tool generator sets are also used, where this aspect is of paramount importance. Each tamping tool weighs about 18 kg. Four tamping tools with two generators form a set, and can an output give an output of 64 sleepers per day.

Bosch Tampers Bosch tampers set consists of four tampers capable of variable compaction. Each tamping tool weighs about 10 kg. Each set of four tampers is provided with two 5 kVa generating sets. The special features of Bosch tampers are:

(a) Least vibration to the operator
(b) Easy to operate
(c) Fully dampened strokes
(d) Variable compaction facility

With each set of four tamping tool it is possible to achieve an output of 120 sleepers, per day. HILTI off track tampers also come into this category.

Pionjar Tampers The tamping tools have an inbuilt petrol engine to provide the desired stroke to the tamping tool. Each tool weighs about 27 kg. Its heavy weight coupled with a high power stroke helps in better penetration into ballast. With a set of two tampering tools, an output of 100 sleepers as per day can be achieved. ATLAS off track tampers also come into this category.

Out of the three types of off-track-tampers described above, 'Bosch' tampers show a good promise for use on Indian Railways.

12.2.3 Problems with the Use of Off-track Tampers

Before tamping, it is necessary to lift and level the track with the help of track jacks and open up the ballast to the bottom of the sleepers. In the use of off-track tampers considerable amount of work has to be done manually, besides the operation of the tamping tools is also fatiguing.

Another main hurdle in their deployment is the difficulty of their transport to the site of work. This problem is being successfully solved on Konkan Railway by providing self propelled gangers lorry to the track maintenance gang. It must however be understood that given the present heavy track structure consisting of concrete sleepers and long welded rails, off-track tampers can best be used only for limited work of packing of isolated sleepers, the main tamping work entails on-track tamping machines.

12.2.4 On-Tack Tamping Machines

These are self propelled machines. The tamping is done automatically through controls provided near the operator's seat. On-track tamping machines are of two types:

1. *Light On-track Tamping Machines* These usually consist of two tamping units mounted on a common motorized trolley. These machines are not very heavy (1–1.2 tonne) and can be taken off the track without much difficulty. They can tamp about 150 sleepers per hour, all lifting and levelling of the track has to be done manually in advance. Their travelling speed is about 10 kmph. Various designs of light on-track tamping machine are available in the world market. Chinese tie tampers fall into this category. Light on-track tampers have not been found much useful on Indian Railways and thus their further use has been discontinued.

2. *Heavy On-Track Tamping Machines* These are heavy machines weighing 30 tonne and above. The earlier machines were able to do tamping alone, but the latest models can do lifting, levelling, tamping and lining of track automatically. They cannot be easily removed from the track. Although some of them are provided with off-tracking equipment. They need long traffic block for economic working.

12.2.5 Heavy On-track Tamping Machines in Indian Railways

Past Machines The first on-track tamping machine was used in the Indian Railways in 1963, when one Matisa B-60 model was put into operation. This was only a tamping machine, all lifting, levelling and aligning of track was required to be done manually in advance of tamping.

This was followed by the development of the Matisa BN-60 tamping machines in the years 1963–66. They were improved versions of Matisa B-60. They could lift, level and tamp the track automatically.

Present Machines Plasser and Theurer, an Austrian firm, supplied their first on-track-tamping machine, VKR-05, to Indian Railways in 1966. Later, this firm set up a factory in India at Faridabad, and started supplying machines from there with progressive indigenisation of machine components. The first batch of twelve Plassermatic 06-16 SLC on-track tamping machines were supplied from Faridabad factory in 1968–69. These machines could lift, level, tamp and align the track automatically. Later models of tamping machines supplied from this factory basically perform the same functions and generally have the same *modes operandi* in the smoothening or complete correction of track geometry. The Plassermatic 06-16 SLC machine is discussed in detail in the subsequent paragraphs. The changes adopted in later models have been discussed under separate headings.

12.3 PLASSERMATIC 06–16 SLC ON-TRACK TAMPING MACHINE

Nomenclature The first group of digits, 06, identifies the 6th in the series of Plasser and Theurer track taming machines; the second group of digits, 16, indicates the total number of tamping tools (or tamping tines) in that particular model, eight for each rail seat. The tamping tools are arranged in pairs with one pair in each of the four quadrants at the rail seat. SLC stands for 'Super Lining Control'. These machines can do lifting, levelling, tamping and lining of track automatically. (See Fig. 12.1.)

Fig. 12.1

Tamping Units Two independent tamping units (banks) are mounted on the machine by means of vertical guide columns. A total of 16 tamping tools (or tamping lines) are provided and placed in pairs to cover all the eight tamping sides of the sleeper. The tamping is carried out by the Plasser non-synchronous vibratory squeeze tamping system. Lifting and lowering of the tamping unit is done with a servo controlled hydraulic cylinder. Vibration is caused by an eccentric shaft driven by a V-belt drive, with mechanical transmission from the engine. There is one eccentric shaft for each tamping unit. The closing and opening of the tamping tools for squeezing action is done hydraulically. Each pair of tools has its own individual hydraulic squeezing cylinder and therefore moves individually, as circumstances dictate. This results in non-synchronous tamping of sleepers.

This non-synchronous system of vibratory squeezing of ballast under the sleeper has the following advantages:

1. The sleeper is tamped from all sides with equal pressure.
2. The sleeper can have effective tamping even when it is not perfectly square.
3. The sleeper can get reasonably good tamping, even if one pair of tamping tools gets stuck against some obstruction.

The tamping pressure can be adjusted according to the track conditions. The opening width of the tamping tools can be increased so that double sleepers at the joints can also be tamped.

Track Lifting Equipment For each rail, a roller lifting device is mounted on a vertical guide column. The roller clamps can be swivelled to allow exact centering above the rail. A lifting cylinder mounted on the protruding frame, whose position-rod is connected with the frame on the lifting lamp, causes the lifting of the track.

The lifting and levelling process gets initiated simultaneously and automatically, and has also the option of the operation for extra feed to meet some extra local requirements. Lifting and levelling stop automatically when preset lifts and levels have been reached and feelers cut off the circuit.

Levelling Equipment The Plassermatic 06-16 SLC is required with an infrared levelling device. This consists of a front tower which carries three infrared transmitters: one, above each rail and one, above the centre of track. On the machine are two receivers (photo cells) mounted on two rods and two shadow boards—one for each rail. The shadow boards control the lifting of the sleepers to be tamped. The power to the front tower is fed from the machine through electric cables. The transmitters emit modulated infrared rays toward the machine. The beams are invisible; hence, not dangerous. The modulated infrared rays act on the photoelectric cell in the receiver and actuate the track lifting device via an amplifier and a relay. Together, with the lifting of the track the shadow boards are also lifted. When the correct level is reached, the shadow boards interrupt the infrabeam from the front tower and thus cut off the lifting. The track remains lifted until the tamping operation finishes. To check the cross-levels, a precision pendulum is mounted on the shadow board feeler rods and transmits the actual cross-level value electrically to an indicator.

An existing error in longitudinal level is reduced to 1/ 5th.

L-17, 000 mm distance between transmitter and receiver.

I-3,500 mm distance between sleeper to be lifted and tamped and receiver.

Remaining longitudinal error is in the following proportion I/L-3500/17500-1/5.

If the centre beam method is used and the longitudinal error is mainly due to cross-level error of the track, the remaining error is reduced to 1/10th.

The outside transmitters are manually adjustable and to be used when the track has to be lifted to fixed points (specified track level), where the lifts are marked on the sleepers (pre-levelled with an optical instrument). When several cross-level errors occurs, which are read from the cross-level gauge on the front tower frame, the outside transmitters are also used for correction. The method of track levelling with outside transmitters are called double or outside beam method.

When the track geometry is not too bad and the track requires consolidation and improvement, the centre line method is used. In this method no pre-levelling is required and the centre transmitter is only used. It is very efficient method and renders high working speed.

Lining Unit The lining unit is mounted between the two axles. It consists of double flanged rollers, two on each rail. While travelling these rollers remain in the lifted position for the lining operation the rollers are placed on the rails. The force for lining the track is exerted through hydraulic cylinders. The actual amount of slew is determined by the two chord measuring system. With this system, the versines are automatically registered on a long and short chord. Whenever the versine ratio is not correct, it actuates certain relays, which in turn operate the slewing mechanism. As the track comes to proper alignment, the slewing is stopped. The slewing can be done automatically or by manual operation. The defect is reduced to at least 1/6th of the original fault in the track. The two chord system has been further discussed below (Fig. 12.2).

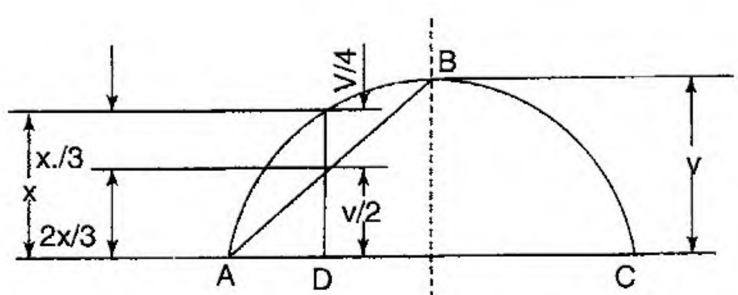


Fig. 12.2

In a true circle, with a chord *AB*, half the chord *AC*, the versine on the short chord *AB* is equal to 1/3rd the value of the ordinate measured at quarter point on the long chord *AC*.

This principle is applied in the Plasser's two chord system. Two cords are stretched parallel to one of the rails, which is taken as the reference rail for lining purposes. One chord is double the length of the other. The versine of the short chord and the ordinate of the long chord are compared at the same point *D* (measuring bogie). If the ration between the two is 1 : 3, the track alignment is correct. If not, the adjustment in alignment is made by slewing the track at the end *B* of the short chord. The movement at end *B* is affected by special rollers which move on the rails and the rollers push the rails with the help of aligning pistons.

Output SLC machines, when in good condition, were able to give a progress of 600–700 sleepers—properly tamped and aligned—per hour with single insertion.
The machines provide great flexibility of operation since they can be used as:

1. Purely as a tamping machine, which can be either set to bring the track to a particular level or smoothen the existing irregularities.
2. Tamping and lining machine. The lining can be through manual or automatic control.
3. As a lining machine only.

Lifting, levelling, tamping and lining of track with this type of machine results in:

(a) Correction of errors in cross-levels.
(b) Correction of errors in longitudinal levels.
(c) Correction of errors in alignment.
(d) Uniform compaction of ballast under each sleeper. The pyramid of ballast under the sleeper is uniformly compacted which is not possible in any other method of packing. The machine compacted ballast gives a better elastic bed for the track as a whole.
(e) The clean ballast is forced up against the sleeper bottom giving it good lateral and longitudinal resistance.
(f) The dirt from the ballast will drop down due to vibratory squeeze action.
(g) Improvement in drainage results as a consequence of (f).

Tamping Results Tamping results with these machines get effected due to the following causes:

1. *Wrong tool depth adjustment* The top of the shoulder of the tamping-tine should be set by the limit switches 10–20 mm below the bottom of the sleeper. A greater depth setting will result in poor consolidation of the top of the sleeper bed and on shallow ballast may drive the ballast into the subsoil bringing the subsoil up into the ballast. Too high a setting results in ineffective tamping and damage to sleepers.
2. *Wrong tamping pressure* The hydraulic tamping pressure is adjustable and is regulated by a hydraulic switch. The pressure required depends on the bottom width of the sleeper, the track weight and stiffness and nature of the ballast and formation. Wide sleepers and softer ballast need less tamping pressure.
3. *Insufficient and/or dirty ballast* Tamping should not be done unless there is adequate clean ballast under and around the sleepers and on the shoulders; otherwise, tamping will leave the track in a weak condition with respect to both the rate of settlement under traffic and lateral strength.
4. *Loose or missing fittings* Loose fishbolts and fastenings should always be tightened and missing ones replaced before tamping: otherwise, the consolidation of ballast and even the longitudinal levels will vary from one sleeper to another.
5. *Bad drainage.*
6. *Weak formation.*
7. *Old track with worn track components.*

Requirement of Traffic Blocks For the machines to become an economical proposition, they must work at least 4 hours per day. As the machines can work only in complete traffic block, a block of 4 to 5 hours duration has to be arranged. This block can be in two spells of 2–3 hours duration and on double line sections one spell can be arranged on each of the UP and DN lines, at different hours of the day, in the same or adjacent block sections. A block of less than one hour is not of much use, as most of the time would be spent in travel to and fro, setting up the machine and finally winding up.

SLC type of machines supplied to Indian Railways have mostly been phased put, after working for 25 to 30 years.

Fig. 12.3 Universal main liner 06-16 on-track tamper

12.4 UNIVERSAL MAIN LINER 06-16, UNIVERSAL TAMPER (UT)

The basic principles of tamping, lifting and lining used in these machines are the same as those in Plassermatic 06-16 SLC machines. Many parts are also interchangeable. Some of the special features of these machines are given below.

1. *Quicker Setting* Universal machine can be set more quickly into operation as the front tower needs only to be lowered and does not require to be drawn out as in the case of SLC type machines. This allows a more effective use of traffic blocks.
2. *Simultaneous lifting and lining* The lifting, levelling, tamping and lining units are all located at one place and work simultaneously. Superior quality output is achieved with this arrangement. Track gets lined quicker, while lifted for tamping on each sleeper (In SLC machines lining was done much behind the sleeper under tamping, taking time, which affected the working speed).
3. *Shoulder Compactors* Universal machines supplied to the Indian Railways were provided with shoulder compactors. These compactors, wherever maintained in good health, were found to be quite effective in improving the retentivity of packing and lining.
4. *Sturdy and Simple* The machine has sturdy and simple construction which makes it less costly than those with cantilever frames. A larger wheel base of 8 m provides greater travel safety.
5. *Recording unit* Three of the UT machines procured by Indian Railways were fitted with track recorder. This is two channel recorder in which one channel is utilized for cross-level and the other for alignment. Cross-level instrument is placed on the leading bogie of the 10

m chord and the measurements are electrically transmitted to a recording pen working on a moving graph paper in the operator's cabin. On the graph the cross-levels are indicated in the scale 1 : 2, i.e. 1 mm cross-level difference is recorded as 2 mm on the graph.

Alignment is measured as a versine at the centre of the 10 m chord on a special measuring bogie. The alignment recording is done to a scale of 1 : 1 (See Fig. 12.4).

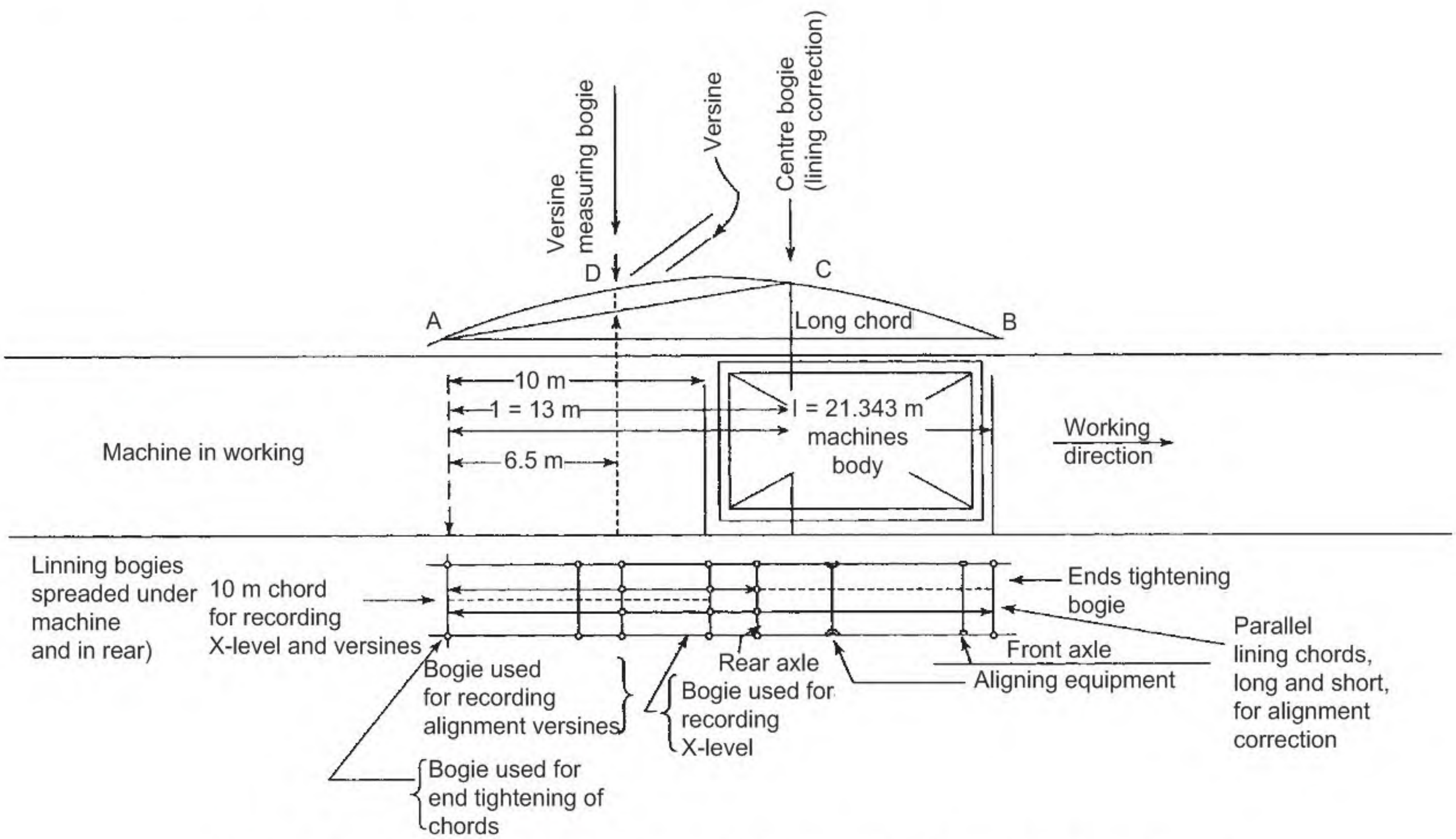


Fig. 12.4 Schematic Illustration of Lining and Recording Systems of Universal Main Liner 06-16 Tamper

The graph paper movement is linked with the speed of the machine through a gear arrangement which can be set to any of the following three gear ratios (a) 1 in 500, (b) 1 in 1000 and (c) 1in 2000.

Arrangement for Track Recording in Universal Machines As the recording instruments for both cross-level and alignment are mounted on light bogies, the recorded results represent the track measurement under floating conditions. The recording is done after the machine has completed its job and thus it depicts the maintenance tolerances that the machine is capable of achieving.

As UT machines too have become quite old, they are being phased out.

12.5 DUO-MATIC 08-32 ON-TRACK TAMPING MACHINE

Duo-matic 08-32 is a tamping machine (Fig. 12.5) belonging to the 8th series of M/s. Plasser & Theurer Co. It has a double set of Tamping Tools for packing two sleepers at a time. Total number of tamping times are 32 compared with 16 in 06-16 SLC machines. The machine is equipped with Kirloskar Cummins diesel engine (water cooled) rated to produce 243 BHP at 2000 RPM.

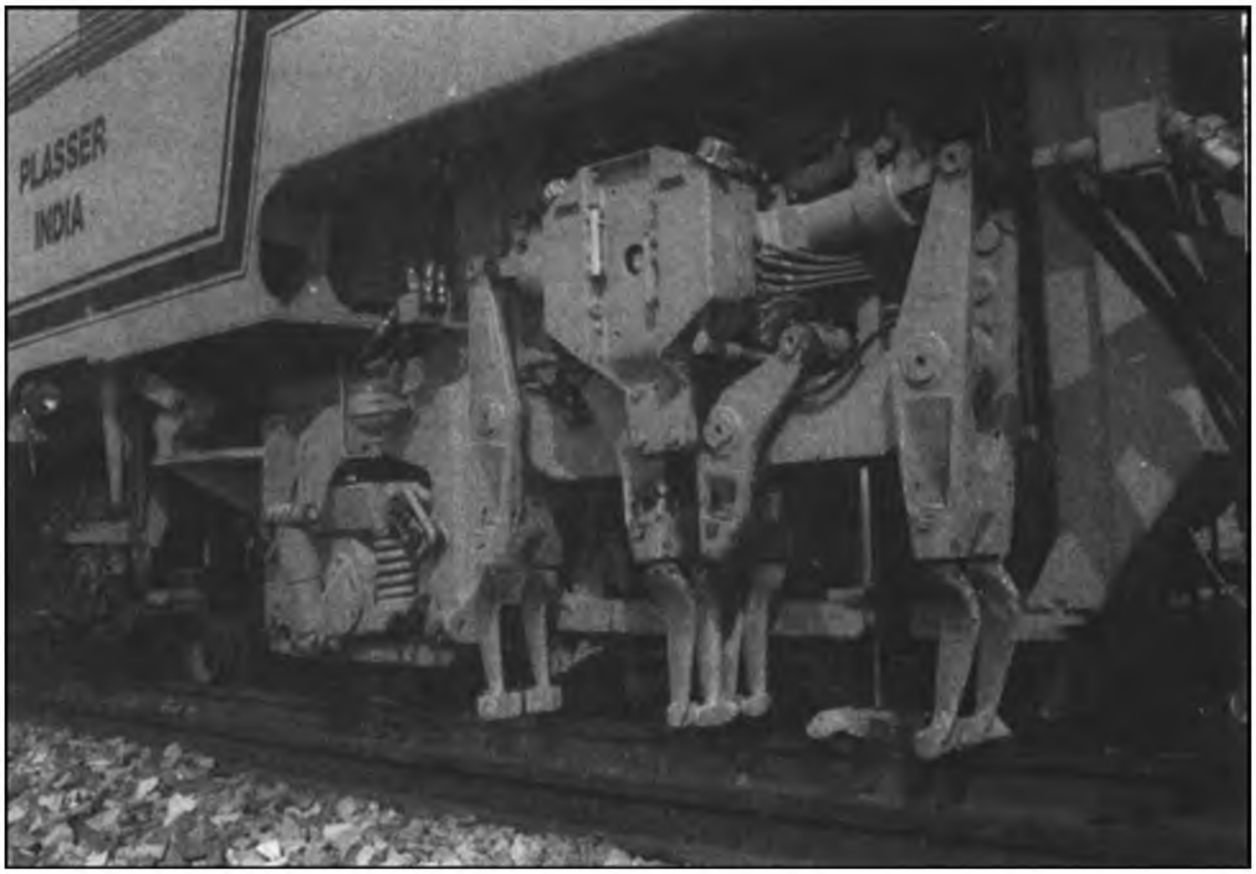


Fig. 12.5 Duo-matic tamping machine

Salient Features

Length over buffers	18710 mm
Height over rail top	3285 mm
Width	3050 mm
Wheels	Two axle bogies (8 wheels) with rigid axles
Wheel diametre	710 mm
Weight	40 tonnes
Speed under own power while travelling	80 kmph
Speed in train formation	100 kmph
Output	1500 sleeper per hours

Functions The machine can perform the following five functions automatically (a) lifting (b) levelling (c) tamping (d) aligning and (e) shoulder consolidation of ballast.

Basically the systems/units provided in the machine to perform the above mentioned functions are the same, as in other Plasser & Theurer machines described in the earlier paragraphs. Some new features incorporated in lifting, levelling and lining systems have been discussed in the following paragraph.

12.6 NEW FEATURES IN THE LIFTING, LEVELLING AND LINING SYSTEMS OF 08 AND 09 SERIES OF PLASSER TRACK TAMPING MACHINES

Lifting and Levelling System (*Fig. 12.6*) The level of each rail is sensed separately with the help of rollers at three points:

1. In front of the leading bogie.
2. In the tamped area.
3. Infront of the rear bogie.

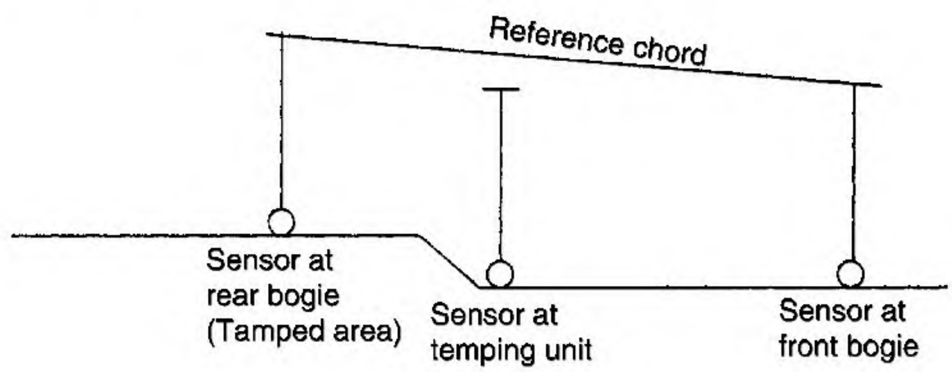


Fig. 12.6

The reference line for longitudinal levelling is a steel chord stretched over each rail, from the rear reference point to the front one.

The equipment rolling over the tamping area carries sensors which scan the height of the reference chords with respect to each rail. The signals from the sensing device get amplified and act on a servo system, which controls the lifting cylinders.

Cross-level is also controlled by the two steel chords. The front reference point carries an electronic precision pendulum, which automatically controls the cross-level of the two reference steel chords. In this way, cross-level is always set to the desired value. The proportional levelling system allows working to smoothening system or to achieve absolute profile.

In the smoothening system, a prescribed general lift is decided. During tamping, the track gets the desired lift along with the reduction in irregularities in longitudinal levels. In the second method, a premarked, correct longitudinal level is achieved.

In both the cases, cross-level faults are completely corrected.

Lining System The new generation of Plasser Track Tamping machines make use of the single chord measurement system for alignment corrections. The lining system is suitable for adoption in the following ways:

1. *The compensating (smoothening) method taking the 4-point measurement* The track in this method is measured at four points and two versines are compared to control the lining system. The existing errors are reduced and the continuous real time interaction between the two versine values through electronical circuitery brings out the much improved align-

ment. The measuring and lining system operates fully automatically at straight and circular curves. For transitions, predetermined values are required to be fed in the system.

The 4-point system is mainly used when

- the track alignment is to be smoothened and brought with in the accepted norms. (Similar to versine surveys.) In this method, it is also possible to slew the track to the specified slewing values.

2. *Precision method and the 3-point system*: The track in this method is measured at three points, and lined accordingly to achieve specific theoretical versines.

   The three-point precision method is mainly used, if

   - the track is to be lined according to fixed points or specified radii or versines;
   - the lining system is used in connection with a sighting device and a remote control equipment or a laser.

4-Point System—Its Geometrical Principles (*Figs. 12.7 and 12.8*) In a circular curve, two versines of a chord are related in a ratio, depending upon the measuring point distance. This vesine ratio '*i*' is independent of the radius of the circular curve and is always constant. It is also valid for straights, which are circles, with infinite radii.

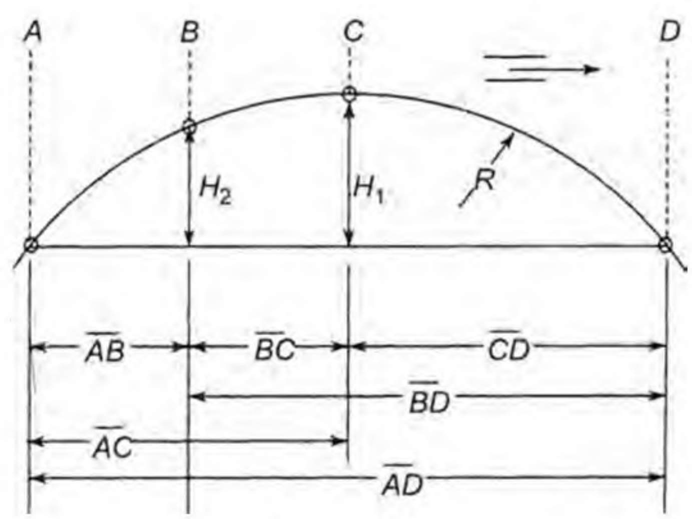


Fig. 12.7

The track is measured at four points. The versine H_2 at point *B* represents the measuring base. At point *C*, the lining slew is made till the vesine H_1 is in correct ratio to H_2 ($H_1 = H_2 \times i$).

It may be seen that the ratio (*i*) is independent of the radius of the circle.

12.6.1 Error Reduction according to the 4-Point System (Fig. 12.8)

The points *A* and *B* are on the already lined track, behind the machine. The front-end of the chord, point *D* is at the lining error *F*, resulting in a new versine H_2 at *B*. The point *C* is now moved laterally until H_1 is in correct ratio to H_2.

Depending upon the measuring point distances, the remaining error *FR at C* is equal to *F/n,* where *n* is the error reduction ratio.

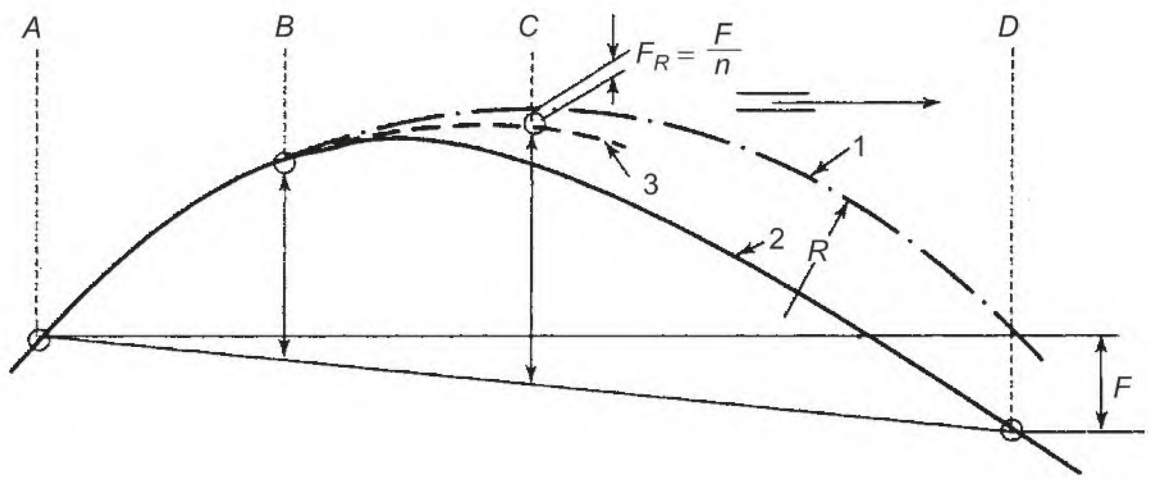


Fig. 12.8

$$n = \frac{AD \times BD}{AC \times BC} \text{ (From Fig. 12.7)}$$

The constant versine ratio is only for tracks with constant curvature, e.g. circular curve, straight. Changes in the curvature, e.g. in transition, the versine ratio is adapted to the curvature by the input of correction values. The correction values and their sequence can be obtained from the tables. On the standard machine, the correction values are introduced manually. With the additional 'GVA' (Track Geometry Value Adjustment Automatic), the correction values are calculated automatically by the computer on board and fed into the lining system.

3-Point System—Its Geometrical Principles (*Fig. 12.9*) The versine H_2 at point *B* is not measured. The track is measured at three points. The lining versine H_1 at point *C* is specified according to the radius of the curve. The lining mechanism continues to work until the theoretical versine, as per the degree of curvature, is achieved. Using the 3-point system, the chord is generally fixed at point *B*, which results in a reduction of the length of the measuring chord. The versine is, thus, measured on *BD*, as shown in Fig. 12.9.

In the three-point measuring system, the lining equipment can be set to either of the working mode of error reduction or error elimination.

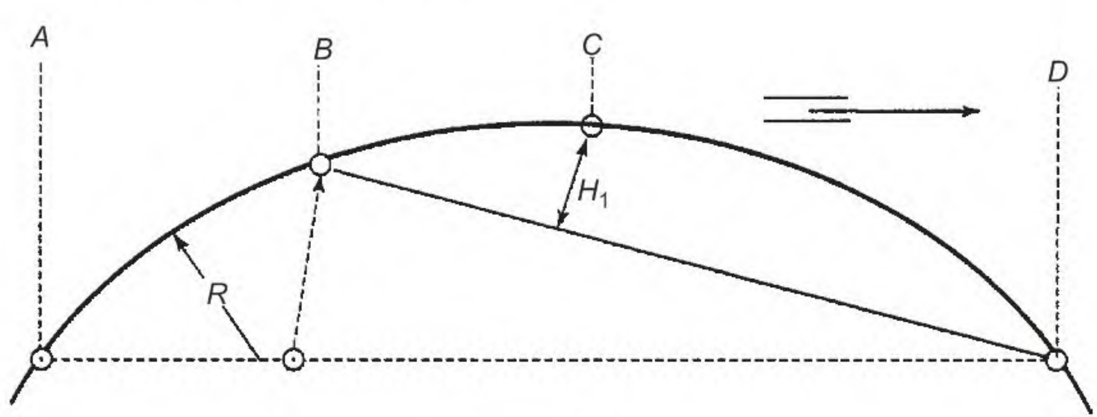


Fig. 12.9

Lining with Sighting Device and Remote Control In this case, a sighting device is fixed on the track in front of the machine. A sighting board is fitted at the front end of the machine, in which is incorporated a device capable of manipulating the front end of the measuring chord. The front end of the measuring chord is this case does not represent the position of the track at the front end of the machine, but an adjusted position, as per the signals received from the sighting device through the sighting board. This system represents a theoretical extension of the measuring chord—between the machine and the position of the sighting device. The resulting error reduction ratio is, thus improved considerably.

The distance between the sighting device (a telescope) and the machine is dependent on the visibility conditions at the time of the working of the machine.

Lining with Laser Beam The difference between the Laser system and the system with the sighting device is that the sighting device and the sighting board are replaced by the Laser receiver and a laser transmitter. The laser system operates fully automatically and is able to cope with distance up to 300 metres.

12.6.2 Compensating Correction in the Lining System of 09 Series of Track Machines

In case of 09 series of tamping machines, there is relative motion between the satellite and the rest of the machine. When lining correction is taking place, the position of lining bogie keeps on changing. This change is taken care of through an electronic circuitry which transmits signals, corresponding to the position of the satellite at a particular moment, as that when the final lining signal is fed to the lining circuit, it is not vitiated by the satellite movement.

12.7 SLEEPER CRIB SHOULDER CONSOLIDATING MACHINE-VDM-800 V (Fig. 12.10)

With the introduction of LWR, emphasis has shifted to ensure adequate longitudinal and lateral resistance of the track. Tests conducted have shown that with the sleeper crib and shoulder consolidation machines, lateral and longitudinal resistance of the track can be considerably increased. In addition, with such consolidation the following benefits can also be derived.

1. *Greater durability of tamping* The tamping cycles are increased by 20 to 30 percent.
2. *Prevention of loose sleepers* If crib consolidating machine follows the tamping machine, there will be a marked reduction in the number of loose sleepers after tamping.
3. *Quick restoration of track stability after the renewals* Full sectional speed can be restored after first round of tamping and crib consolidation.

Main Features The main features of VDM 800 U consolidating machine manufactured by Plasser and Theurer in use in the Indian Railways are as follows:

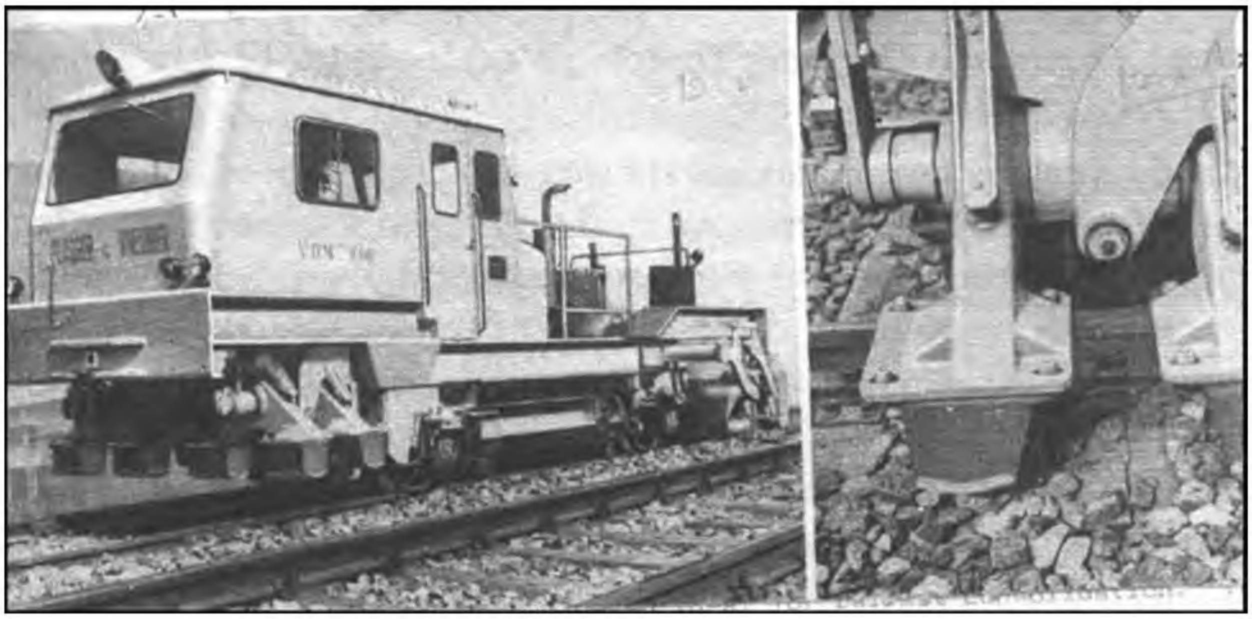


Fig. 12.10 Sleeper crib and shoulder consolidating machine

1. Each consolidating machine is equipped with two sleeper crib consolidating units. On each unit, two consolidating shoes consolidate the cribs on the left and two on the right of the rail, that is to say that a total of eight consolidating shoes are in operation. The distance between the consolidating tool can be adjusted to suit sleeper spacing.
2. The consolidating tools work exactly in the same area as the tamping tools of the tamping machine and crib consolidation is therefore a direct follow-up operation of tamping. Each tool consolidates an area of 740 cm^2 or almost 0.6 m^2 for all tools together.
3. The vibration frequency of crib consolidation is fixed at 38.5 cycles per second with an amplitude of vibration of 2.5 mm, which is considered ideal for ballast consolidation. The consolidating action consists of two components (a) dynamic impact force and (b) additional surface load. These two acting together result in better compaction of ballast.
4. To consolidate sleeper ends and ballast shoulders it can be fitted with shoulder end consolidators on each side of the machine. Each consolidator covers an area of 130 cm × 20 cm at the sleeper ends and applies a surface load of 1000 kg.
5. In the output they match the performance of universal tamping machines and thus following them complete the work within the same traffic block.

12.8 POINTS AND CROSSING TAMPING MACHINE [FIG. 12.11 (a)]

Points and crossings assemblies are subjected to high level of lateral forces when the moving vehicles take the turnout tracks. Break in the continuity of rails at the crossing, constraining forces at the check rails, and the difference in cross-levels at the points, all cause faster deterioration of track geometry at the points and crossings. Heavy track structure and closer sleeper spacing makes it difficult to lift, align and pack the tracks at points and crossings. Points and crossings tamping machine can maintain the assembly automatically bringing the track to much superior condition than can be achieved manually. The following paragraphs give a brief description of PLM-275 S, Points and Crossings Tamper working in the Indian Railways.

Fig. 12.11 (a) Points and crossing tamping machine (See also Color Plate 5)

Broad Features It is a two-axled self propelled vehicle and its maximum driving speed is 50 kmph in either direction. The main source of power is a diesel engine of 150 BHP at 2000 RPM. The important dimensions and the weight of the machine are as follows:

Overall length	13635 mm
Overall width	3000 mm
Height over rail top	3300 mm
Wheel diameter	710 mm
Wheel base	8000 mm
Total weight	24 t
Front axle load	11.5 t
Rear axle load	15.5 t

12.8.1 Tamping System

It has 2 tamping units mounted independent of one another on two vertical guide columns immediately in front of the rear axle. The tamping units are laterally displaceable and can be centred above the rail when working in the curves or points and crossings. It has got 8 tamping tools (compared to 16 on other machines in use), which are placed outside and inside the rail on either side of the sleeper. Each tamping tool has the provision of tilting and can be adjusted up to an angle of 15° towards inside and 85° towards outside from their normal vertical position. The tilting of the tamping tools is controlled hydraulically from the operator's seat. Tilting of outside tamping tools can also be controlled from an outside panel by an operator standing on the cess. This is generally required as the operator's view in the cabin is restricted.

This machine has the latest facility of adjusting the tamping depth from within the cabin, which is required to meet the needs of different types of sleeper with different depths.

12.8.2 Levelling System

The levelling system adopted for this machine is the normal centre line chord levelling system.

12.8.3 Lifting and Lining Unit

In front of the tamping unit between the axles, the combined lifting and lining unit is mounted. This unit is composed of a separate frame holding two inner flanged rollers and one lifting hook per rail. The lifting tools undergrip the rail head or the base from the outside. They are automatically brought toward the rail head or the rail base for each tamping.

This machine has one chord lining measuring system. This system has been adopted for all 08 series machine supplied by Plasser (India) Ltd.

12.9 UNIMAT 08-275 3S SWITCHES AND CROSSING TAMPING MACHINES [Fig. 12.11 (b)]

Heavier designs of switches and crossings due to the use of concrete sleepers and heavy rail profiles demand additional measures for their treatment.

With the development of the Unimat 08-275 3S an innovative step has been made for the treatment of modern high performance switches and crossings.

The Unimat 08-275 3S has the following features which guarantee a careful and effective treatment of modern types of permanent way:

- Synchronous three-rail lifting for the careful treatment of sleepers and fastenings in switches and crossings with concrete sleepers and in heavy types of switches and crossings
- Pivoting suspension of the tamping units for optimum treatment of slanting sleepers
- Longer spacing between bogie pivots

Fig. 12.11 (b) Unimat 08-275 3S switches and crossing tamping machine (See also Color Plate 5)

12.9.1 Unimat 08-475 4S

Essentially the Unimat 4S has adopted all the features of its predecessors, but brings additional advantages which offer a further dimension in the treatment of switches and crossings:

- In addition to the three-rail lifting the four-rail tamping

Prominent features are four tamping units each with four tilting tamping tines. The two outer units can be slewed out so that the branching line of the switch is also tamped. The pivoting suspension of all units permits adjustment to slanting sleepers in the entire area of the switch.

12.10 BALLAST CLEANING MACHINES (Fig. 12.12)

1. To improve track drainage, retain elasticity of track and to prolong the life of the track materials, periodical ballast cleaning is necessary. On the Indian Railways all trunk routes and main lines are to be deep screened once in 12–15 years. Track tampers cannot work effectively in dirty ballast and the sections which are put under mechanical maintenance, much have complete deep screening.

   Manual deep screening besides being costly is of poor quality. In spite of the best supervision, conglomerate of mud and ballast are often left by the labour in the track. Many a times the screened ballast put back into the track has still enough dirt and dust in it. With manual deep screening it is seldom possible to cut the formation to proper slope so necessary for effective drainage.
2. The main advantages of the ballast cleaning machine are:
   (a) The quality of ballast cleaning is extraordinarily good, too difficult to get from manual work.

Fig. 12.12 Ballast cleaning machine

(b) The required slopes can be given to the formation.
(c) The loss of ballast is negligible. There is a saving of 10–15% of the ballast, which normally goes waste with manual screening.

3. Ballast cleaning machines perform the following operations:
   (a) Screen the excavated material and return to the track all the good ballast immediately behind the excavating mechanism.
   (b) Grade mark ballast into various sizes and distribute them as per requirement.
   (c) Discharge the spoil from the front of the machine to keep the track free behind the machine for re-ballasting and tamping operations.
   (d) Can excavate all the materials in the ballast bed without screening, if required.
   (e) Can provide a sand blanketing between subgrade and ballast, if required.
4. Broad features of a modern ballast cleaning machine—RM 80 manufactured by Plasser & Theurer of Austria for broad gauge tracks of Indian Railways are as follows:

Length (ready for work)	32,800 mm
Length over buffers	30,600 mm
Height above rail top	4,250 mm
Width (for transit)	3,150 mm
Wheel diameter	900 mm
Total weight	91 t
Maximum working speed	1,000 m/hour
Maximum speed when self-propelled	80 kmph

Excavation width	3,960 mm
Maximum excavation depth	1,000 mm below rail wheel
Engine: air-cooled diesel (two number)	333 kw (446 HP) each engine
Screens: mesh-size upper screen	80 mm
Middle screen	50 mm
Lower screen	25 to 30 mm
Superelevation equalisation	up to 150 mm
Lifting and slewing unit lift	up to 250 mm
Output	650 cubic metre of ballast per hour

5. *Traffic Block Requirement* The machine can work only in complete traffic block. Minimum block of 4 to 5 hours duration is necessary to have an effective working period of 3 to 4 hours approximately. The machine can effectively work at night as well. Ballast cleaning operation should generally be followed by unloading of fresh ballast, tamping by 'on tack tamping machines' and a track stabiliser.

12.10.1 Other Ballast Cleaning Machines and Associated Equipments

RM 76—Ballast Cleaning Machine for Switches, Crossings and Plain Track While RM-80 is a machine designed to work on plain track, RM 76 is meant for cleaning the ballast on the main line and the turnout track simultaneously. In this machine the excavation width is extended up to about 7.7 m by inserting additional links in the cutter bar.

FRM 80 Shoulder Cleaning Machines The shoulder cleaning machine FRM 80 is a specially designed machine for cleaning of ballast on the two shoulders of the sleepers in the track. On Indian Railways, shoulder cleaning forms an integral part of the Track Overhauling. In the concrete sleeper long welded rail track, manual shoulder cleaning becomes a very fatiguing exercise for the trackman on account of the large volume of ballast to be screened. Shoulder cleaning machine carries out this work very efficiently and effectively.

While working with FRM-80 on the double line track, it is necessary that cross drainage is also assured for the discharge of the water collected in the shoulder drain cut out between the two lines. The output for FRM 80 may vary from 500 m to 3 km per hour depending upon the site conditions.

MFS 40 MFS units (material conveyor and hopper unit) are deployed to transport the spoil released during ballast cleaning. At many locations it is no longer possible to dump the spoil along the track and has to be transported to defined places.

MFS units are open high sided wagons in standard Railway Vehicle design provided with conveyor Belts: a floor conveyor and a transfer conveyor belt at the front of each unit. The conveyor belts are powered hydraulically. Power is supplied by a diesel engine installed in the unit itself. MFS 40 purchased by the Indian Railways have a capacity of 40 cubic metre per wagon.

12.11 09-CSM CONTINUOUS ACTION TAMPING MACHINE (Fig. 12.13)

In 09-CSM continuous tamping machine, only 20% of the total mass of the machine is accelerated and braked while in conventional tamping machine the entire mass of the machine has to be accelerated and braked at every cycle. This advantage in 09-CSM has been possible by positioning the tamping, lifting and lining units on a separate underframe. With this arrangement only the actual work units are moved in work cycle from sleeper to sleeper. The main frame of the machine moves forward continuously. The machine is available in the options of 16–32 tamping tines. With the use of 09-CSM continuous action tamping machine, a tamping output of 30% higher than the conventional tamping machine has been achieved on Indian Railways.

Broad features of Du-matic 09-32 CSM in use on BG are as under:

Length	19,400 mm
Width	2,960 mm

Fig. 12.13 09-CSM continuous action tamping machine (See also Color Plate 6)

Height	3,300 mm
Wheel diametre	730 mm
Total weight	57 t
Axle load	14 t
Power pack	Diesel engine of 348 kV (437 HP)
Maximum speed (Self-propelled)	90 kmph
Maximum speed (hauled)	100 kmph

The lifting, levelling and lining system adopted in the machine have been explained in Sec. 12.6.

12.11.1 Tamping Express–09–3X [Fig. 12.14 (a) and Fig. 12.14 (b)]

The latest development in improving the output of tamping machines is in the form of tamping express. The tamping express has the basic design features of 09-CSM series, but is provided with the tamping system which can tamp three sleepers simultaneously. This increases its output by 30–40% compared with the continuous action 2 sleeper tamping machines of CSM series. Indian Railways are procuring a few of these machines to obtain the maximum output with in the limited working time available for track maintenance in the heavy density routes. Tamping express can be utilised:

(a) For track maintenance work and tamping newly laid track
(b) As a continuous action 3 sleeper tamping machine
(c) As a continuous action one sleeper tamping machine and
(d) If required for cyclic tamping

Tamping Express 09-4X, which can tamp four sleepers at a time have also come in the world market.

Fig. 12.14 (a) (See also Color Plate 6)

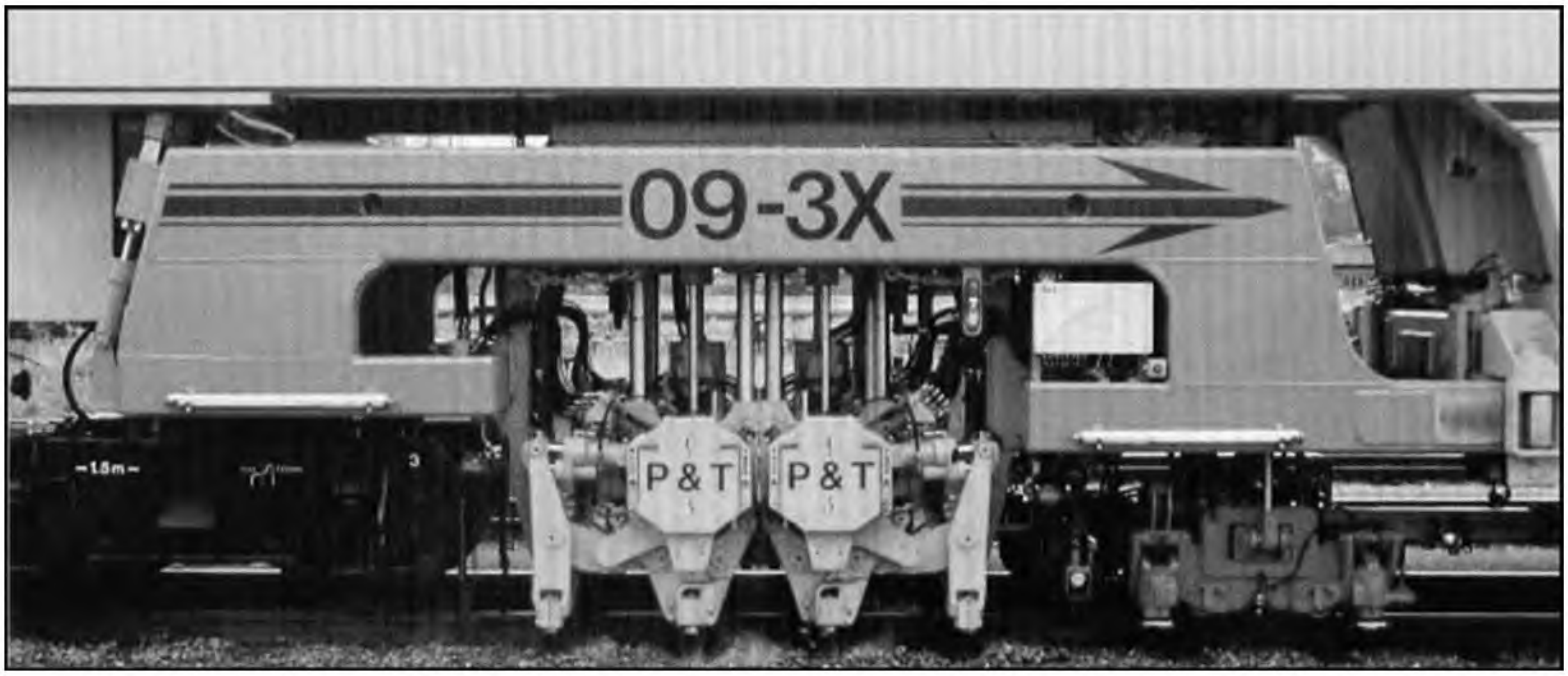


Fig. 12.14 (b) (See also Color Plate 7)

12.12 UNIVERSAL BALLAST DISTRIBUTION AND GRADING MACHINE—USP 303 (Fig. 12.15)

USP–303 machine is capable of ballast grading and distribution on the track with the hydraulic plough blades adjustable at suitable angles. A sweeper unit is provided with the machine for picking up the excess ballast and storing that in the hopper provided with the machine. Considerable economy can be achieved with the use of this machine by picking up the excess ballast and distribute the same in deficient area.

Fig. 12.15 (See also Color Plate 7)

12.13 DYNAMIC TRACK STABILISER (DTS) [Figs 12.16(a)–(b)]

The machine was developed by Plasser of Austria. It produces fast, accurate and controlled settlement of the track, following levelling, tamping and lining work, ballast cleaning or track laying.

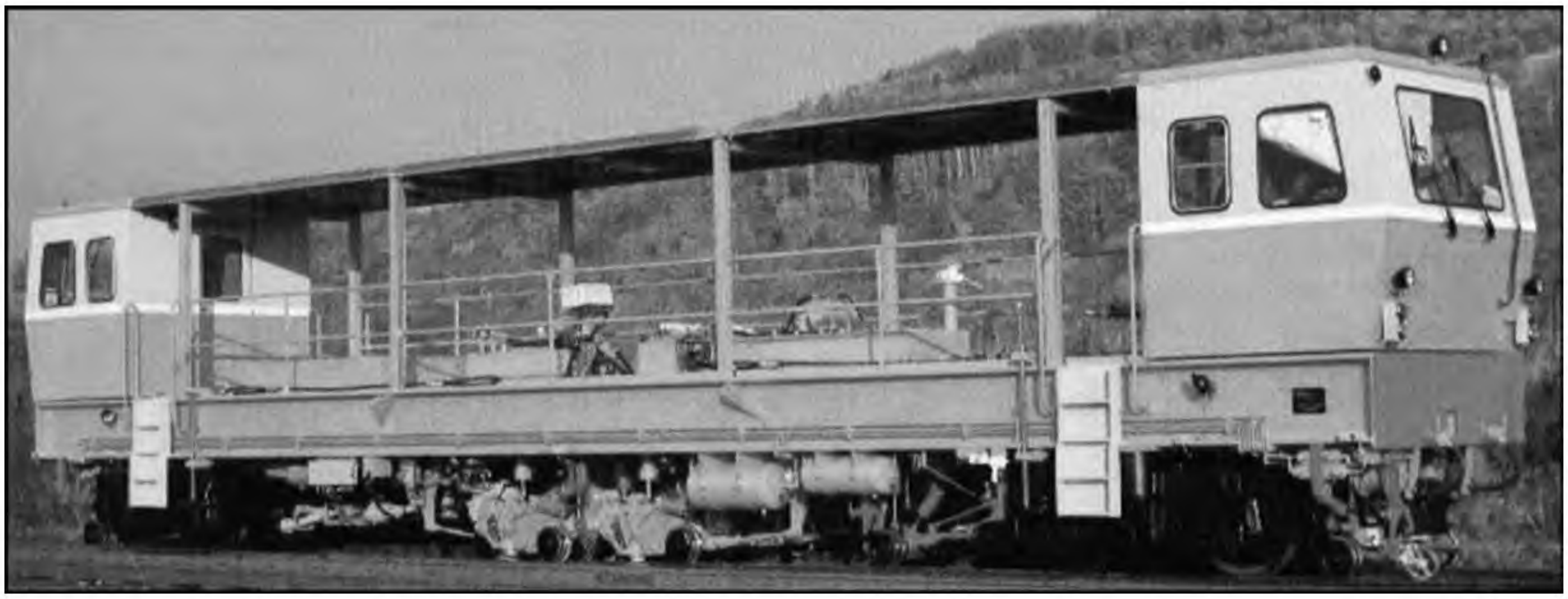


Fig. 12.16 (a) (See also Color Plate 8)

Fig. 12.16 (b) (See also Color Plate 8)

For stable track geometry, the stability of sleepers in the ballast bed is of great importance. This drops down to about half when the track is packed by track tamping machines (lifting, tamping and lining). As the trains move, on the tamped portion, it reaches about 70% of its original value after

1,00,000 tonnes of traffic load, and full original value after a load of around 3 million tonnes. The settlement of track under trains loads is not uniform, and this induces irregularities in track geometry, soon after they are rectified during the tamping operation. With DTS, using a combination of horizontal vibration with a static vertical load, the unavoidable initial settlements can be achieved by dynamic stabilisation in controlled manner, directly in the course of the track maintenance work itself. The track is lowered uniformly and the integrity of the improved track geometry is well preserved. The ballast particles are packed together more closely with broader contact surfaces. The consolidation of the ballast bed raises the lateral resistance considerably and has been found to be equal to about 1,00,000 tonnes of traffic loads.

The dynamic stabiliser DGS 62 N has two 2-axle bogies and cabin at both ends of the machine (distance between bogie pivots 12 m, weight 60 t). Underneath the main frame between the bogies, guided on the track, the two stabilising units grip the rail head with 8 flange rollers and on the outside with four roller discs. The two synchronised oscillation units put the track into horizontal oscillation. The vibration frequency varies from 0–45 Hz. At 35 Hz, the size of the dynamic force is about 14 t. The most favourable frequency to stabilise a track after deep screening is 33 Hz. The track is loaded automatically with the pressure necessary for the required settlement (max. 36 t) by four vertical hydraulic cylinders which are jointed on to and supported against the vertical frame.

The speed of DTS in the working mode is 1–1.5 kmph.

In order to lower the track structure in a controlled way, the DTS is steered by a proportional chord levelling device. A steel chord is spanned over each rail between feeler rods, which are jointed to the inner axles of the two bogies of the machines. These chords from the reference base for the measuring system of the longitudinal level. The lowering is controlled and monitored by a feeler rod between the stabilising units.

The measuring equipment needed to monitor the quality of work and the track geometry is located in the measuring trailer. The following parameters are recorded using a 6-chanel recording unit.

1. Longitudinal level of the left rail.
2. Longitudinal level of the right rail.
3. Superelevation before DTS.
4. Superelevation after DTS.
5. Track twist.
6. Track alignment

Tests made with the use of DTS have shown that its deployment immediately after maintenance tamping with one pass only brings about the desired degree of compaction. But on new track, it is most effective if used in the following manner.

After the penultimate tamping operation, the ballast bed is compacted by applying a UNIFORM LOAD, without controlled lowering. Then, after the last tamping pass, the controlled lowering is carried out with VARIABLE LOADING. With this method of work the areas with varying thickness of ballast are eliminated during the first dynamic stabilisation. This contributes greater durability of track geometry.

By this process the track lowering by DTS is

— approximately 15 mm, with UNIFORM LOAD without control.
— approximately 10 mm, with VARIABLE LOAD and controlled application.

On bridges and in tunnels, DTS should be worked with half the load pressure on the stabilising units compared to tracks on earth formation.

12.13.1 Measurements of Lateral Track Strength

DTS stabilises track by applying horizontal oscillations with a constant amplitude of about 2 mm. The energy expended by the hydraulic oscillation unit of the DTS is proportional to the lateral track resistance. Lateral track strength attained during stabilisation can thus be derived from the measured working pressure of the hydraulic drive motor. The system provides an effective method of determining the quality of stabilisation achieved by DTS. Taking the lateral resistance of track before, tamping, as 100%, the following values were obtained during a test carried out by Swedish Railways.

After tamping – 75%
After stabilisation – 84%

European Railways have now begun to measure the lateral resistance of the track during stabilisation work to quantify the machine output.

Fig. 12.17 (See also Color Plate 9)

12.14 MULTIPURPOSE TAMPING MACHINE (Fig. 12.17)

While heavy on-track tamping machine of 0–9 series are being deployed on Indian Railways for periodical attention to concrete sleeper track, a need is felt for a multipurpose tamping machine which can attend to isolated patches of rundown track. The track maintenance gangs are also facing problem in the transport of men and material for carrying out urgent track repair works. To fulfill these demands, Indian Railways have purchased a few of the multipurpose tamping machines as a trial measure. If found advantageous, more such machines may be provided to lend necessary support in the track maintenance operations, at the divisional level.

Following are the important features of the unimat compact machines.

1. Capability to attend the bad spots both on plain track and on switches and crossings.
2. High transfer speed for prompt attention to the troubled areas and for minimum line occupation.
3. Equipped for loading and transport of rails, small permanent way materials and tools.
4. Transport facilities for a group of permanent way workmen.

12.15 AHM–800 R FORMATION REHABILITATION MACHINE (Fig. 12.18)

On Indian Railways about 700 km of track is under permanent speed restrictions due to weak formation. In addition, several temporary speed restrictions are imposed during monsoon on a considerable length, for the same reason.

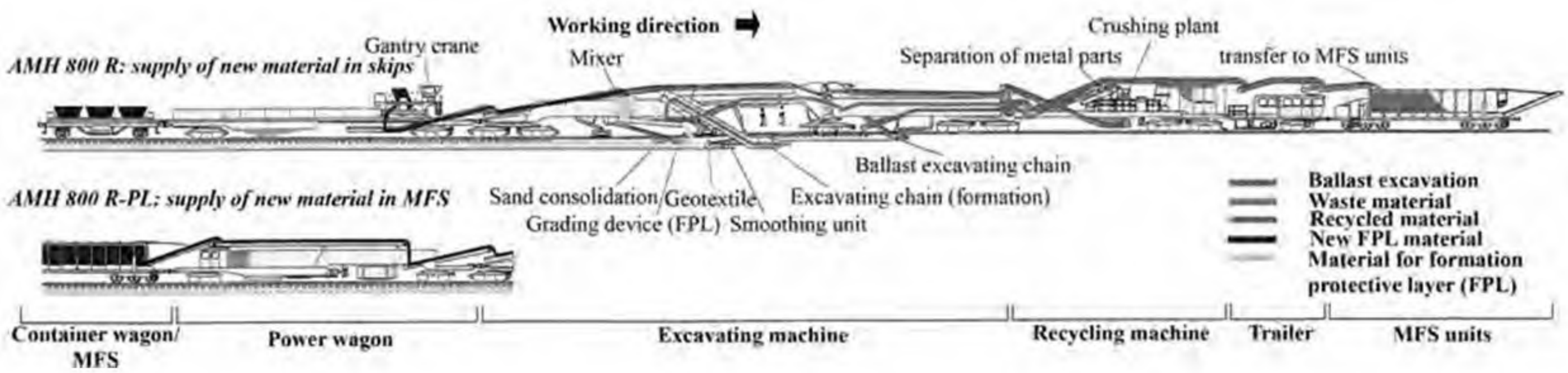


Fig. 12.18 Formation rehabilitation machine (See also Color Plate 9)

It has been found that 95% of formation problems are due to sub-grade failure, which can be overcome by introducing a layer of blanket of appropriate thickness and composition under the ballast. Presently, there is a limited progress in the formation rehabilitation work on account of the difficulties being experienced in carrying out the work manually.

Indian Railways are planning to procure one AHM – 800 R formation rehabilitation machine for carrying out the work more efficiently and effectively. The machine performs the following main functions.

1. Remove upper layer, say 150–200 mm, of ballast, crushes this ballast and transfers it to sand/gravel mixture.
2. Produces the finished sand gravel mixture while checking the moisture content.
3. Excavates of the remaining ballast material and the upper layer of sub-soil.
4. Levels new earth formation.

5. Instals protective materials such as geotextiles, styrofoam, plastic sheeting or geomeshing.
6. Instals substructure layer.

The basic working principle of the machine is shown in Fig. 12.18. The machines has two chains. The smaller chain at the front picks up the top layer, which is mainly old ballast, over a width of four metre. This material is transported to crushing unit through conveyor belts where it is crushed to grain size of 0 to 33 mm. This crushed stone is transferred to mixing plant where it is mixed with fresh material and water to form sand/gravel mixture conforming to prescribed specification for the sub-structure layer. The moisture content of the mixture is controlled continuously to ensure a good quality. The second larger excavating chain excavates the remaining ballast bed material and the upper layer of the sub-soil. The width can be adjusted from four metres to six metres. The new formation is levelled with proper cant. The prepared sand-gravel mixture is laid on the dressed subgrade using the slewing conveyor belt. If required, geotextile and geogrid can be laid below the subgrade material. This belt distributes the sand-gravel mixture under the track over the entire width. The regulating unit distributes the material evenly and the six vibrating plates compact it to form the finished formation protective layer.

The maximum thickness of protective layer inserted in one operation is 500 mm.

The average progress achieved with this machine is 3.5 km per week working in two shifts.

In addition to AHM-800 R, M/s. Plasser & Theurer offers two more types of formation rehabilitation machines. The RPMW 2002-2 cleans the used ballast with a star screen and a high pressure water plant, sharpens the ballast in a crushing plant and screens it before putting it back into the track. The PM 200-2 R uses an initial grid screen for pre-cleaning, before the ballast is sharpened, screened again and finally washed. It also includes a clarification plant to treat the waste water. The washing of used ballast ensures the removal of almost all fine particles attached to the stones, especially when the excavated material is damp. The cleaning efficiency is almost 100%.

12.16 TIME ECONOMY AND MECHANISED TRACK MAINTENANCE

Economy in time and mechanical track maintenance can be concomitants only with regular traffic blocks.

Railway Corporate Plan envisages considerable increase of traffic in the coming years. This entails new tracks laid with concrete sleepers, sturdier turnouts and replacement of present rails with LWR/CWR. These changes necessitate mechanised maintenance.

The number of track machines presently working on Indian Railways are given below in Table 12.1.

To meet the growing need for machines for track laying and renewals, maintenance and monitoring, indigenous manufacture of track machines shall have to be stepped up with foreign technical collaboration to remain at par with world standard.

To ensure maximum productivity from costly track machines, action already initiated on the following lined need to be augmented.

1. Provision of time slots in the working time table and ensure their availability.

Table 12.1 Track Machines on Indian Railways*

S. No.	*Track Machines*	*Numbers*
1.	Tamping machines	190
2.	Ballast cleaners	64
3.	Shoulder cleaners	29
4.	DTS	62
5.	Track laying trains	9
6.	T- 28 turnout relaying equipment	25
7.	Another odd machines such as portal crane, Old UT machines etc.	100 (Approx.)

(*) Position as in the year 2008.

2. An effective organisation for operation and maintenance of machines. Suitable incentives for motivation of track-machine-organisation staff.
3. Proper training courses for the staff dealing with the track machines to ensure competence in taking adequate care of the machines.
4. Adequate availability of spare parts.

12.17 SMALL TRACK MACHINES

A large number of small track machines have been deployed on Indian Railways for carrying out track maintenance operations. They are useful for speeding up the track work and for reducing fatigue. A list of these machines is as follows.

1. Rail Drilling Machine
2. Rail Cutting Machines (Saw Type) and Abrasive Rail Cutter
3. Hydraulic Rail Bender (Jim Crow)
4. Hydraulic Extractor for Jammed Pandrol Clips
5. Power Rail Hauling System
6. Portable Ballast Cleaner (Semi-Mechanised)
7. Double Action Weld Trimmer
8. Rail Profile Weld Grinder
9. Rail Tensor (mech.)/Rail Tensor (Hyd.)
10. Portable Shoulder Ballast Compactor
11. Toe Load Measuring Device
12. Hydraulic Track Jack
13. Hydraulic Sleeper Spacer
14. Rail Creep Adjuster
15. Concrete Sleeper Drilling Machine
16. Portable Track Lifting & Slewing Device (TRAILS)
17. Jib Crane Attachable to BFR/BRH for handling Concrete Sleepers & PSC Turnout Sleepers
18. Hydraulic Rail Joint Straightener

Indian Railway Board have constituted a special committee for identifying the types of small track machines useful for the trackmen and for standardizing such equipment. Unfortunately, the progress made in the utilization of small track machine has not been very encouraging. The main causes for poor acceptance by trackmen are:

1. Lack of proper transport facilities for the movement of machines.
2. Lack of proper facilities for repair and maintenance of machines.
3. Lack of properly trained man power for handling the machine.

These problems have been overcome to a large extent in the new fully mechanised track maintenance system in operation on Konkan Railway.

13 Chapter

Directed Maintenance of Track: Track Management System

13.1 INTRODUCTION

The system of conventional through packing is based on the concept that loosening and repacking of ballast under each and every sleeper according to a fixed schedule rectifies the track irregularities and indeed improves track elasticity and thereby the riding quality of track. Since each and every sleeper is required to be attended to irrespective of its packing condition and track geometry and the record maintained being minimal, the gang mate in this system can be any semi-literate person with requisite experience. It is realised that conventional through packing involves certain amount of unproductive work, but as the track produced is of reasonably good standard, the system continues to have wide acceptance with permanent way engineers, particularly under situations where other maintenance systems are not considered viable.

There have been some major developments in the field of track technology and social environments in the last two or three decades, which have influenced the system of track maintenance. These are:

1. Large scale introduction of SWR and LWR/CWR. Any loosening of ballast in welded track lends instability to track structure and thus the system of maintenance, which causes least disturbance to the consolidated track condition, is welcome.
2. Better understanding of vehicle-track interaction resulting in the laying down of track tolerances for riding comfort.
3. Improved systems of track monitoring which provides an objective assessment of track condition.
4. Sharp increase in labour cost which makes any reduction in unproductive work a worthwhile proposition.
5. Increase in literary standards which has made educated young men available for working as track supervisors.

Given these developments, directed maintenance of track is being increasingly adopted where only that portion of track is generally attended to where the track irregularity conditions so demand; the rest of the sleepers are left untouched. This identification of run-down track requiring attention is done with the help of track monitoring aids and/or by physical verification of the track by a competent supervisor at the work-site.

The directed maintenance of track essentially consists of increased and improved supervision of track maintenance work with emphasis on proper identification of defects in the track, before undertaking any work and to ensure the removal of these defects. The overall effect is an improved standard of maintenance of track achieved at less labour cost. Apart from direct benefits, improvement in track maintenance standard leads to a reduction in labour and machine inputs required for the continued maintenance of track to the same standard. It also indirectly results in less wear and tear of track components and rolling stock resulting in further economy.

Indian Railways have issued a detailed manual for DTM. It gives a system of methods, principles and rules for regulating Directed Track Maintenance, which is stated in the following sections.

13.2 TRACK MAINTENANCE UNDER DTM

13.2.1 Definition of DTM

Directed Track Maintenance (*DTM*) is similar to conventional maintenance except that in this system the emphasis is on 'needed based maintenance' rather than on routine cycle of maintenance from one end to another.

13.2.2 Use of DTM

Use of DTM should preferably be limited to the following locations.

1. Track on double lines and multiple lines.
2. Track maintained by machines.
3. Track being systematically and continuously monitored by special track recording devices at fairly frequent intervals.

DTM is not recommended or introduction on single lines, unless proper transport facilities are provided for the movement of a viable gang unit.

13.2.3 Pre-requisites for adopting DTM

These are broadly:

1. Reasonably good track geometry with adequate retention of packing
2. Effective track components
3. Reasonably adequate ballast resistance
4. Stable formation in major portion of the length

13.2.4 Maintenance

This is classified into the following categories:

1. Systematic maintenance
2. Periodical inspection and need based maintenance
3. Occasional maintenance

13.3 SYSTEMATIC MAINTENANCE

The following items of maintenance fall under systematic maintenance:

1. Systematic through packing
2. Systematic overhauling
3. Systematic attention to points and crossings, level crossings and other items of track

Under DTM, above operations will be carried out at regular intervals prescribed by the Chief Engineer or otherwise stipulated. Single rail/SWR CST-9 track would require through packing every year to ensure proper examination of fittings and fastenings. Other tracks, particularly LWR track with concrete sleepers, may not need through packing for several years. The schedule for overhauling will also differ from one track structure to another.

13.4 PERIODICAL INSPECTION AND NEED BASED MAINTENANCE

The periodical inspection and need based maintenance necessitate the items mentioned below, as is the case in conventional system of track maintenance.

1. Gap survey and its adjustment
2. Destressing of LWR/CWR
3. Adjustment of creep
4. Realignment of curves
5. Cleaning of drains

Besides, rectification of track geometry is given effect to after identification of defects instead of giving routine attention from one end to other. This is discussed in details in the following paragraphs.

DTM Operations: The operations involved are:

1. Location of defects by recording track geometry and inspection of track.
2. Analysis of recorded observations during inspection, identifying the spots needing immediate attention and stretches to be programmed for attention.
3. Identification and recording of defects in the unit inspection book after ground measurement by a trained supervisor with precise instruments.

4. Rectification of defects.
5. Post-checking and recording by the DTM-Supervisor for quality and output of work done.

Location of defects can be located manually or with Track Recording Instruments. It is desirable to have a continuous record of track geometry and riding characteristics in all parameters such as twist, cross-level, gauge, unevenness and alignment as well as of riding characteristics.

The equipment for recording these parameters in the Indian Railways are:

1. Track recording-cum-research car (TRRC)
2. Track recording-cum-curve corrector (TRCC)
3. Track recording car, with or without microprocessor (TRC)
4. Oscillograph car
5. Portable accelerometer
6. Inspection by foot plate of the locomotive
7. Inspection by last vehicle of fast train
8. Inspection by push or motor trolley
9. Detailed ground measurement during inspection by foot.

Analysis of Inspections and Recordings By using various means of identifying the defects, analysis is done by the inspector to decide:

1. Stretches of track needing immediate attention in order of priority
2. Stretches which require to be programmed for regular attention
3. Stretches which do not need any attention

The inspector then draw a programme of work. Where the defects are located with the help of TRRC results, a minimum stretch of 200 m length may be earmarked for attention.

Record of Observations The PWM of each unit will systematically check on foot the defective portion given in the programme of work in the order of priority. He will cover a sufficient length every day to ensure that the work to be assigned to the unit for the next 2–3 days can be decided upon. The examination will normally be completed in 2–3 hours in the forenoon after which the PWM will return to the gang to supervise its work. During the inspection, he will take detailed measurements and mark the defects noticed as given in Table 13.1.

13.4.1 Recording of Defects in Unit Inspection Book (UIB)

The track geometry and other observations will be recorded in the Unit Inspection Book. One page being allotted for one TP/one electric mast interval and successive pages of UIB will cover the track length continuously. An extract from a unit inspection book is shown in Table 13.2.

Index Tolerances for Identification of Defects In the absence of any other indicator of track defect, northern Railway has laid down index values of track parameters propose of their trunk routes and mainlines for the benefit of their P. Way supervisors to decide the spots requiring attention. These values are as follows:

1.	Cross-level	3 mm
2.	Alignment (Versine on 7.5 m base)	3 mm
3.	Gauge	Tightness and slackness as permitted in traditional system of maintenance. Sleeper to sleeper variation not to exceed 2 mm. For this purpose, gauge at the joint sleepers, shoulder sleepers, the sleeper at the centre of the rail, and on the sleepers adjoining the rail centre should be checked. If gauge at these sleepers or gauge variation exceeds the tolerance limits, the other sleepers should also be checked.
4.	Loose packing	All sleepers must be checked for looseness with a canne-a-boule or beater handle. Any joint sleeper found loose must be packed. Intermediate sleepers should be tackled if two or more consecutive sleepers are found loose.
5.	Unevenness (sags and humps)	Humps and sags (unevenness) which are distinctly visible to the eye when sighting along the inner lower edge of the rail head is done, should be attended to.

Table 13.1

S. No.	*Defect*	*Location of measurement*	*Symbol of defect*	*Place of indication*	*Remarks*
1.	Cross-level	Every fifth sleeper and at joints	C	On the sleepers inside gauge face	
2.	Alignment	Complete track	↓ →	On foot of rail inside the gauge face	Located by eyesight and measured by nylon chord. The horizontal arrows indicate the length needing attention and the arrows at the right angles to the track indicate direction of slew required.
3.	Uneveness	Complete track	→←	Rail web on the gauge face side	Located by sighting outer lower edge of the rail head and measured by a nylon chord over a 3.6 m base length.
4.	Loose packing	Every sleeper	H	On the sleeper outside the gauge surface	Canne-a-boule to be used for assessing packing voids

S. No.	Defect	Location of measurement	Symbol of defect	Place of indication	Remarks
5.	Gauge	Four sleeper at the fishplated welded joints. Alternative sleepers on the remaining portion	O	On the sleeper inside gauge face	—
6.	Loose broken and missing fittings		Dab of paint or chalk marks	On or near the component	—

Table 13.2 Record of Ground Measurements and Rectification; km. 249 TP 5-6. Total Number of Sleepers 150

Ground measurements							
Defect revealed by	*Date of ground measurement*	*Loose packed sleepers*		*Gauge variations (mm)*	*Cross-level variations (mm)*	*Maximum unevenness over 3.6 m chord*	
		Numbers	*Percentage*			*Left rail (mm)*	*Right rail (mm)*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
*TRC/	1/2 days After TRC	24	16%	–4 to + 3	6LR to 4 RR	3	4

Rectification					
Maximum misalignment over 10 m chord		*Condition of rail sleepers and track fittings including missing fittings, if any*	*Remarks and signature of supervisor*	*Date*	*Remarks and signature of supervisor*
Left rail (mm)	*Right rail (mm)*				
9	*10*				
3	5	Loose Some screw spikes loose		31.1.74	

* Indicates whether the defect was noticed by TRRC/TRC/OSG/Accelerometer car run on date_______ or by engine rear vehicle/trolley inspection by APWI or PWI, etc. on date_______.

13.4.2 Rectification of Defects

Based on the track recording and/or results of ground measurements, the type of attention to be given to the track will be determined. Through packing or picking up of slacks or through—Measured

Shovel Packing of MSP at joints or other attention of track is given only as warranted. The procedure to be followed for through packing, MSP, etc. is the same as for conventional system.

13.4.3 Post Checking and Recording of Track Geometry

Prior to boxing of ballast, the DTM supervisor will check the work done and ensure that right track geometry has been achieved and record the results of his appraisal in the Unit Inspection Book.

13.5 OCCASIONAL MAINTENANCE WORKS

In occasional maintenance, there are certain items which are done occasionally. Important among them are:

1. Repair to formation and cess
2. Scattered renewal of rails, sleepers and other track components
3. Restoration of correct spacing of sleepers
4. Building of damaged rail ends.
5. Reconditioning of switches and crossings.
6. Making good the deficiency of ballast
7. Works to improve track drainage

In DTM these items continue to be carried out as per the conventional system.

13.6 GANG CHARTS AND ANNUAL REVIEW

Gang charts on the prescribed proforma will be maintained to cover all the categories of works carried out under DTM. The gang charts will be scrutinized periodically to locate stretches which require frequent attention. DTM supervisor will bring these stretches to the notice of the higher authorities for taking suitable measures. Furthermore, an annual review will be conducted so that stretches of track requiring increased or reduced frequency of attention are identified to guide future inspection and maintenance schedule. Besides, it will cover the features of such stretches as needing excessive maintenance efforts and steps of improvement of track structure to bring down the track maintenance need.

13.7 ORGANISATION OF DTM

13.7.1 Beat of DTM Unit

The beat of the DTM unit is normally fixed at 6–8 route kilometres. The tool boxes are so located at manned level crossings, stations and gang huts, that gangmen with tools can reach the site of programmed work without undue loss of time and much effort. However, for efficient communication and quick deployment in case of emergency, the ultimate aim should be to locate headquarter of DTM units at stations, with beats from midsection to midsection on either side of their headquarter.

13.7.2 Supervision

The concept of DTM requires higher degree of skill in recording of measurements and assessing the maintenance requirements. It is, therefore, desirable that the units work under the supervision of an official not lower in rank than a permanent way supervisor (PWS). When the PWS is in charge of a unit, it is economical to combine two gangs into one and place them under the charge of the PWS. Such manning of gangs can be conveniently done in double line and multiple line sections where the total length of the unit will not be more than 8 km. The unit shall consist of one P. Way supervisor, one or two mates, one or two keymen and a viable number of gangmen. Out of the two mates, one will accompany the PWS for taking detailed measurements of track, marking and recording and the other will be in charge of the supervision of the gang. The duties of two mates shall be interchanged periodically. If the DTM unit has only one mate, he will be in charge of supervision of the gang and the PWS will take the assistance of the suitable gangman for taking measurements of track geometry.

13.7.3 Training for DTM Supervisor/Permanent Way Supervisor (PWS)

PWS as in charge of DTM units will be given detailed training in track structure, conventional methods of maintenance, MSP, DTM, maintenance of SWR/LWR/ CWR, track renewals, safety rules, etc. On satisfactory completion of training, the PWMs should be awarded a competency certificate, before being given the charge of DTM unit.

13.8 INSTRUMENTS AND EQUIPMENT OF DTM UNIT

Each DTM unit shall have the following measuring equipments in addition to normal maintenance and safety equipment.

	Instruments	*Number*
1.	Nylon chord—25 m long tested for 16 kg, to be used for checking the alignment and unevenness	1
2.	Stepped gauge (capable of reading in steps of 1 mm)	1
3.	Gauge-cum-level	1
4.	Canne-a-boule (with rubber cap for concrete sleepers)	1
5.	Steel Scale 15 cm long and graduated in mm	1
6.	A straight edge, 1 m long	1

If MSP is adopted as a normal method of maintenance, the gang will be provided with a complete set of tools required for MSP work. Track Recording cum curve corrector (TRCC) may be used to record the track geometry where available.

13.9 MODERN TRACK MANAGEMENT SYSTEM

In the conventional system of track maintenance, track is attended to systematically from one end to another. Track renewals are carried out on age-cum-condition basis. For rail renewals, aggregate GMT carried by the rail is also an important consideration.

In the system of 'Directed maintenance of track' only that portion of track is attended to, where track irregularities exceed certain index values, the rest of the sleepers are left untouched. Most of the decision making process in this system is subjective, though the results of the track recording/oscillograph cars are made use of. To the extent DTM system optimizes the track maintenance inputs, it can be called a forerunner of the "Track Management System".

Modern Track Management system deals with the track structure in totality. Inputs in all track operations such as track construction, maintenance, monitoring and renewals are to be analysed to arrive at the most cost-effective solution to provide the desired level of service. Track renewal in this system is an extension of track maintenance and has to be justified as an economic alternative. Appropriate price tags are to be attached to passenger discomforts, transit delays, safety hazards and such other factors, besides direct costs to work out the cost-benefit analysis.

13.9.1 Basic Requirements of a Track Management System

1. *Reasonably sound track structure* A track which needs constant attention even to keep it in safe condition would not qualify for the adoption of the Track Management System. The track should, therefore, be free from weak formation, inefficient drainage, poor ballast condition high percentage of unserviceable sleepers, weak turnouts, over-fatigued rails, etc. Old and impaired track will obviously need a complete renewal, before any Track Management System, worth the name, can be contemplated.
2. *Complete data base* All updated formation about track structure in track maintenance unit (usually 200 m length for plain track and additional formation about other features such as turnouts, curves, transitions, bridges, etc.) should be available and easily accessible to the central computer. This will include:
   (a) Formation conditions
   (b) Depth of ballast cushion, type of ballast, when last deep screened
   (c) Drainage condition
   (d) Type of sleepers, date of laying
   (e) Type of rail to sleeper fastenings
   (f) Type of rubber pads, if any, when last changed
   (g) Type of rail, make, date of laying
   (h) Straight, curve transition, degree of curvature
   (i) Jointed or LWR/CWR, joint sleepers
   (j) Traffic miscellaneous, passenger, freight, axle load, bogie design
   (k) Speed spectrum
   (l) Annual GMT, accumulated GMT

3. *An objective track evaluation system* This consists of a track recording car and ultrasonic rail testing car. Some of the track recording cars used on advanced railway systems for track management system have the following features:

   (a) They can record the track geometry, vehicle acceleration and ride index values at the maximum permissible speed of the section.
   (b) All the recording is on inertial profile; irregularities on any wavelength relevant for the operation of a particular rolling stock can be obtained.
   (c) Contactless sensors are used so that there are no wearing components to be looked after.
   (d) They pick up the track location with great accuracy with the help of track transponders. Track irregularities can, thus, be easily pinpointed.
   (e) They can be attached to any fast train for recording. More frequent recording are, therefore, possible without encroaching upon the line capacity of the section.
   (f) They are equipped with powerful on-board computers, capable of analyzing all the input data on real time basis. The current recordings can be compared with the earlier recordings and stored in the computer memory. The data can be transferred to the central computer through tapes or discs for further use in the Track Management System.

4. Threshold values for track parameters have been fixed by each of the Railway Administration for different category of lines.
5. The track maintenance planning cell is provided with necessary computer hardware and software support where the inputs obtained from the data base, track recording car and other track monitoring system, threshold values for track geometry and track components, interact to indicate (a) nature of track maintenance work to be carried out (b) the location of faults (c) methodology for rectification.
6. *Track degradation models* It has been possible to develop track geometry degradation models, track components wear and replacement models in the track management system. These are useful for future planning of track maintenance and renewal works. It is also possible to generate cost modules for upgrading of track structure and for upgrading of track geometry.

13.9.2 Track Maintenance Planning and Control Under Track Management System

The track maintenance planning and control under track management system is carried out at three levels.

1. *Zonal Level* (*Chief Track Engineer's Level*) The TRC data, ultrasonic rail car data and the data obtained from field inspections is processed here in close interaction with the threshold values of track maintenance, track standards, degradation modes, cost models and traffic projections. The planning for track maintenance, track renewal, deployment of heavy

duty track machines; allotment of track materials, ballast procurement, etc. is made on the basis of the reports obtained from the computer.

2. *Divisional Level* (*or Regional Level*) Planning of all track works such as casual renewals, welding, destressing, attention to switches and crossings, special attention to vulnerable spots.
3. *Chief PWI Level* Patrolling of tracks and only emergent repairs with the help of small mobile gangs. All planned repair and maintenance work is executed by the divisional or zonal controlled units.

13.10 TRACK MANAGEMENT SYSTEM ON INDIAN RAILWAYS

In view of the great potential of the system of utilising scarce resources in the most optimal manner, it has been decided to adopt this system on Indian Railway in a phased manner. For developing the system a cell was created in CRIS (Centre for Railway Information System) assisted by a core group of officers from RDSO and Zonal Railways.

The track management system entails the following.

1. *Database* A database which contains information about track structure, track geometry, track condition and operating environment, is created. TFMS (Track Features Measuring System) has been evolved for creating this database. In this system a motor trolley is equipped with a route measuring device and the data is manually fed and stored on a tape during the run.
2. *Track Monitoring System* The existing track recording cars have been upgraded by providing contactless sensors. Some of the cars can be attached to fast trains and can record track parameters, with a considerable degree of accuracy, at high speed. OMS (Oscillation Monitoring System) is being deployed on a fixed schedule to get the desired information about the riding quality of the track.
3. *Threshold Values* In the initial stages it was decided to follow the threshold values presently prescribed for high speed routes for carrying out track maintenance operations. They include threshold values in respect to track geometry and accelerations. In addition, the inspection notes regarding running quality of track and other track faults can also be incorporated into the system.
4. *A Computer Hardware and Software* system has been developed which runs on an interactive programme for printing out the locations requiring attention. In the programme, interaction is provided among (a) database, (b) track monitoring results and (c) threshold values. The output comes in the form of work programme sheets, indicating the track faults and their locations. Detailed guide lines have been issued to the Permanent Way Officers for dealing with these work sheets and for feeding back the information about the repair and maintenance works carried out.

13.10.1 Track Maintenance Units

The maintenance work is carried out through the following three modules.

1. Mechanised units consisting of on-track machines for carrying out programmed maintenance works, generally from one end to another.

2. Semi-mechanised mobile units for isolated attention to track including casual renewal, welding, rail and weld fractures, etc.
3. Sectional Manual Gangs for routine upkeep of fittings and fastenings and for patrolling.

13.10.2 Advantages of TMS

Although the implementation of TMS is still in initial stages and the system is facing teething troubles, the following advantages are becoming increasingly visible.

1. Optimisation of labour and material inputs in track
2. Optimum deployment of heavy on track machines
3. Timely planning for replacement of track components and complete track renewals

13.11 MECHANISED TRACK MAINTENANCE SYSTEM FOR KONKAN RAILWAY

Konkan Railway is 760 km long, with a speed potential of 160 km per hour. It was recently opened to traffic on the western coast of India. A modern cost effective fully mechanised track maintenance system has been evolved for this new railway line. The system is in various stages of implementation and is showing the promise of being a forerunner of the system to be adopted on Indian Railways as a whole. This system, which consists of three tier of track maintenance units, has been adopted as the construction carried out on Konkan Railway is of a high standard.

13.11.1 Standard of Construction on Konkan Railway

Formation

— Treated (reduced chances of settlement)
— Blanket of granular material provided where considered necessary

Ballast

— Good quality ballast made out of Deccan trap
— Ballast rolled and compacted before laying of concrete sleepers

Rails

— Welded into long lengths with Flash Butt welding/Gas Pressure welding and without holes

Sleepers

— Concrete Sleepers, for Plain track as well as for switches and crossing
— Ballastless track for tunnels

Level and line

— Accuracy ensured by precision instruments

Bridges

— Mostly with ballasted deck

13.11.2 Mandatory Provisions in General Rules (GR)

While developing the system following mandatory provisions of GR have been kept in view. They are listed in Table 13.3.

Table 13.3 Mandatory Provisions of GR

Para in GR	*Brief particulars*
15.04	Every portion of Permanent Way to be inspected daily on foot by a Railway servant
15.11	Every gang to have a competent gangmate
15.06	No work affecting traffic to commence without permission of competent Railway servant, who shall himself be present to supervise.
15.06	In emergency, gangmate may commence work before arrival of competent Railway servant
15.05	Patrolling to be done on any portion likely to be endangered by rains, storm or civil disturbances
15.14	Gangmate to keep his length all time safe for passage of trains
15.14	Gangmate to be present at spot while performing operations Involving cautions driving of trains

13.11.3 Broad Framework of the System

Top Tier

A group of machines consisting of:

1. Ballast regulator
2. 09 type continuous tamping machine
3. Ballast reprofiler
4. Dynamic track stabilizer and
5. Switch and crossing tamper

Middle Tier

These consist of two units:

1. On-track tampers for isolated spots
2. Mobile Multi-purpose Gangs (MMG) with an On-track Multi-purpose gang lorry

The MMG will carry out the following jobs:

(a) Repair to rail/weld fracture

(b) Reconditioning of switches and crossing
(c) Adjustment of SEJs
(d) Replacement of switches and crossings components
(e) Spot renewals of rails and sleepers
(f) Destressing of LWR
(g) Tamping of a few sleepers with off-track tampers
(h) Any other work incidental to track maintenance, which cannot be carried out by the sectional gangs (TMMG).

13.11.4 Gang Lorry and its Equipment (MMG)

Gang lorry is to be provided for the mobility of the unit. Equipment to include:

1. Portable generator
2. Rail cutter
3. Rail driller
4. Jacks
5. Thermit welding equipment
6. Off-track tampers (BOSCH)
7. Switches and Crossings resurfacing equipment
8. Trolleys
9. Destressing equipment
10. Hoist 1 tonne capacity

13.11.5 Strength of the MMG and its Composition

Each MMG will have a crew of 5 persons excluding the PWI (M), who will be overall in charge of the unit. The crew will consist of:

1.	Motorman-cum-track man	1
2.	Motor mechanic	1
3.	Welder-cum-blacksmith	1
4.	Electrical fitter	1
5.	Mechanical fitter	1

All the crew members as a group will be trained to carry out the track jobs jointly. For example, while carrying out welding of rails, the welder will be assisted by the other four crew members in carrying out welding operation.

PWI (M) in charge of the gang will be trained to work as motor man to drive the gang lorry, if required.

Base Tier

Track Monitoring and maintenance Gangs (TMMG)

Each TMMG unit will consist of:

1. TMMG Mate
2. Key man
3. Track man
4. Level Crossing gatemen and RG Gateman

Note: There will be reserve trackmen with each sectional PWI at the rate of one man per TMMG, which can form a multipurpose gang.

13.11.6 Duties and Responsibilities

1. Patrolling of the gang length
2. Ensuring safety
3. Inspection duties
4. Measurement of track geometry
5. Maintenance of fitting and fastenings of the track
6. Assistance to other maintenance unit
7. Attention to level crossings
8. Action during emergencies

Jurisdiction

Jurisdiction:	7–10 km
Headquarters:	At stations (present and future)

Strength and Composition All the persons will have technical qualification. The level crossing gatemen should be technically qualified like trackmen.

Detailed guidelines have been issued for the working of the various Track Maintenance Units.

The system shows a great promise for achieving a high standard of track maintenance at a considerably less cost.

Chapter 14

Measured Shovel Packing

14.1 GENERAL

Till the year 1910, track in most of the world railways was maintained by "beater packing". It was in this historic year, that an idea dawned upon a gangmate of the British Railways to lift a loose sleeper and spread a small quantity of stone chips on the consolidated bed under the sleeper and bring it to the correct level. This was the beginning of shovel packing of track. Measured shovel packing in the present form was developed in France around 1927. Thereafter, it became quite popular for maintenance of track in many advanced countries.

Measured shovel packing is an improved form of manual packing and aims at a scientific method of maintenance without the use of sophisticated mechanical aids. The basic principles of the shovel packing method is to leave the sleeper bed of ballast which has been well compacted by traffic undisturbed as far as possible and eliminate the unevenness caused in course of time by filling chips of prescribed sizes under the sleeper. The better the general condition of track, the smaller is the lift required and correspondingly, the smaller the size of the chips used.

Track is to be maintained needs a well settled ballast cushion and a stable formation to obtain the best and durable results. For this reason, this method of packing should neither be used immediately after track renewal and deep screening nor during renewal of large numbers of sleepers or when the lift required is more than 30 mm. This method can be successfully utilized for packing points and crossings, with wooden concrete, or steel sleepers layouts and also for dehogging of joints.

Measured shovel packing can also be used for the maintenance of welded track with necessary precautions to mitigate the disadvantages of smaller resistance to lateral deformation obtained for a short period immediately after the packing.

The number of rounds of through MSP required to be undertaken per year would depend upon the site conditions. A judicious combination of the principle of DTM and MSP may yield the desired results.

In the Indian Railways, this method has been recommended for adoption in the following cases.

1. Through packing of wooden sleeper track
2. Packing of wooden sleepers at the joints, in a metal sleeper track
3. Dehogging of rails
4. Through packing of points and crossings with wooden concrete and steel sleepers
5. Measured shovel packing of long welded rail sections with wooden or concrete sleepers

Mechanized maintenance with on-track tampers (wherever available) should however be given preference for LWR maintenance.

Advantages

1. The track can be maintained to finer tolerances than that can be achieved by ordinary beater packing.
2. Life of measured shovel packing is longer than beater packing.
3. While beater causes damage to the underside of the wooden sleepers, shovel packing does not, and thus the life of the sleeper is prolonged.
4. With shovel packing, the centre binding of the sleeper is avoided.
5. MSP is less strenuous and more scientific, with the result that present day labour prefers this method to beater packing.
6. It is economical apropos of the labour required for the maintenance of track.

Disadvantages

1. This method can only be employed for the maintenance of flat bottom sleepers.
2. It needs a high degree of skill. Any carelessness, especially with LWR, can endanger the safety of the track.
3. Special size stone chips are required which create the problem of their procurement, storage and transport. They are costlier also.
4. Some of the instruments used are quite delicate and need careful handling.
5. It can only be done on a considerable ballast bed.

14.2 EQUIPMENT REQUIRED FOR MEASURED SHOVEL PACKING

MSP essentially consists of filing stone chips of sizes from 8 to 15 mm under the sleeper to eliminate track irregularities caused due to the traffic. The filling of stone chips is done by raising the track with the help of jacks or with simple crowbars. For the maintenance of track, it is essential that the various track parameters such as cross-level, unevenness, alignment and twist are kept within the limits laid down for a particular category of track. Small sophisticated measuring instruments form an essential equipment for MSP. These help in measuring these track parameters and in finding the quality of stone chips to be fed for any correction in these parameters.

The essential equipments required for MSP are as follows.

Canne-a-Boule This is used for determining the extent of hallowness or voids under the sleepers (Fig. 14.1). It is an iron ball of 10 cm dia having a mild steel rod handle of 20 mm dia and 1.20 m length.

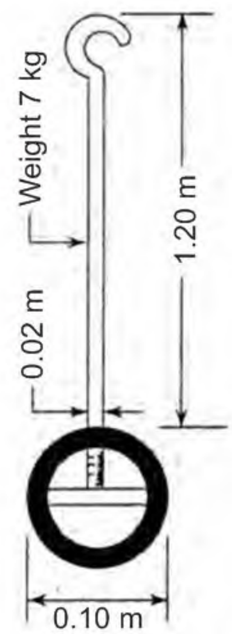


Fig. 14.1 Canne-a-Boule

Dansometer This measures the depression of sleeper under a passing train. The three tripod legs rest on the ballast with the dancing rod resting on the sleeper (Fig. 14.2). The extent to which the friction sleeve shifts from its original position determines the voids under the sleeper under dynamic conditions.

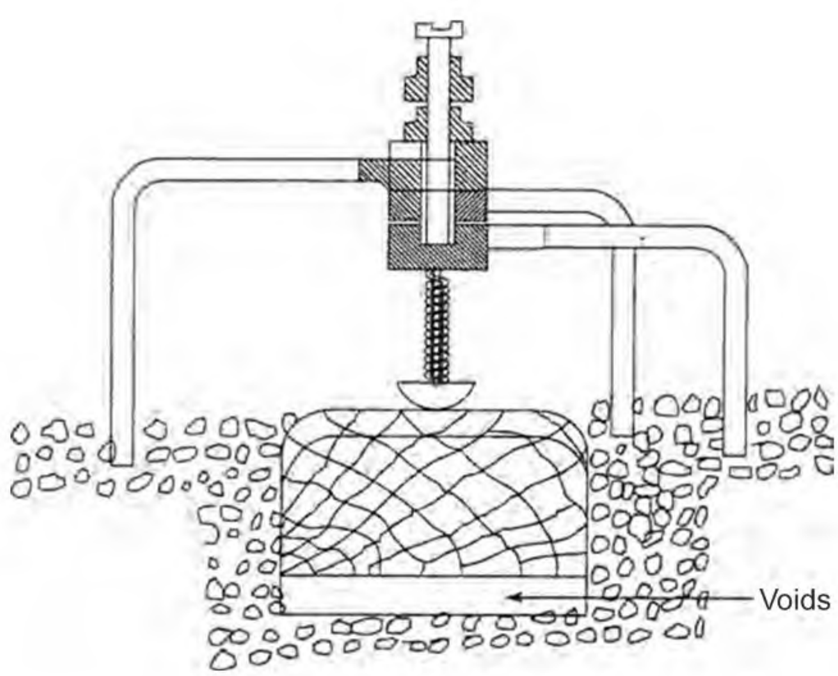


Fig. 14.2 Dansometer

Fleximeter This measures the total depression of rail under load. If the rail to sleeper fastenings are tight, the fleximeter and dansometer readings should be the same; otherwise, their difference will show the extent of loose fastenings (Fig. 14.3).

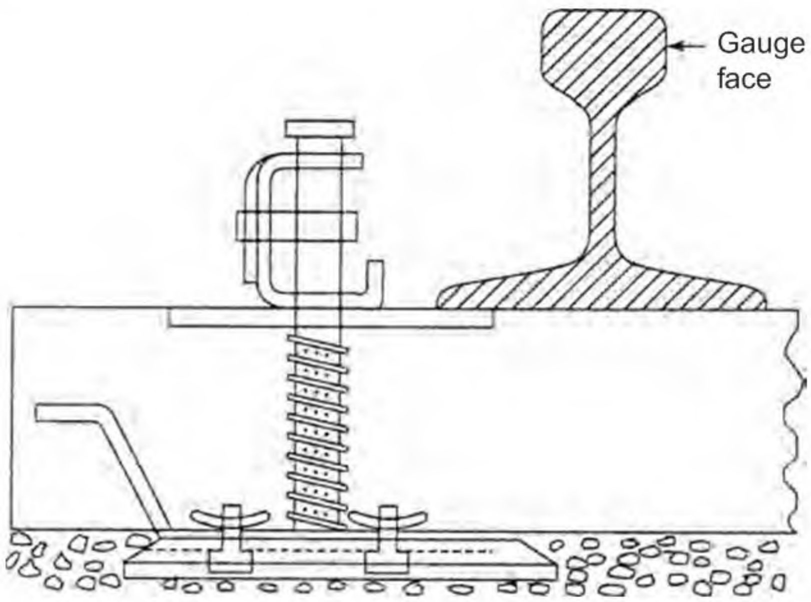


Fig. 14.3 Fleximeter

Gauge-cum-Level This measures gauge and cross-levels to an accuracy of 1 mm. The cross-level is measured with the help of a sensitive spirit level about 200 mm long and having a sensitively of 2 minutes 30 seconds (Fig. 14.4).

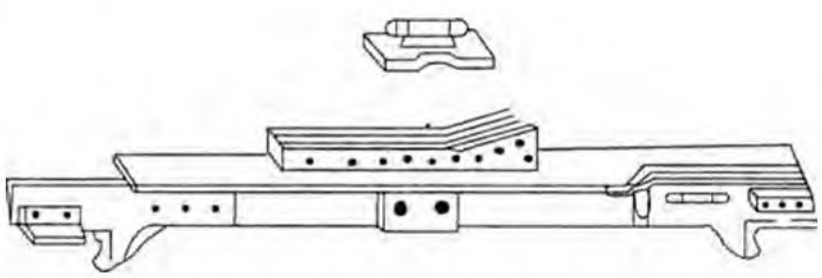


Fig. 14.4 Gauge-cum-level and spirit level

Viseur and Mire These instruments are comparable to Surveyor's level and staff and can measure the unevenness of rail top. By fixing a collimation line and by moving the 'mire' from sleeper to sleeper, the lift required in an individual sleeper to make an even rail top can be determined. Two sets of packing plates are used to raise the viseur and mire to the required level.

The viseur and mire are fixed to the rail head with the spring clips which form an integral part of the instruments (Figs 14.5 and 14.6).

Non-infringing Track Jack This is used for lifting the track so that stone ships can be spread over the bed of the sleeper. Even in its fully lifted position, the jack does not infringe any part of the running train; it is thus called non-infringing jack. The jack, however must be released before the arrival of the train, as it will get damaged otherwise and a lifted track can lead to unsafe conditions.

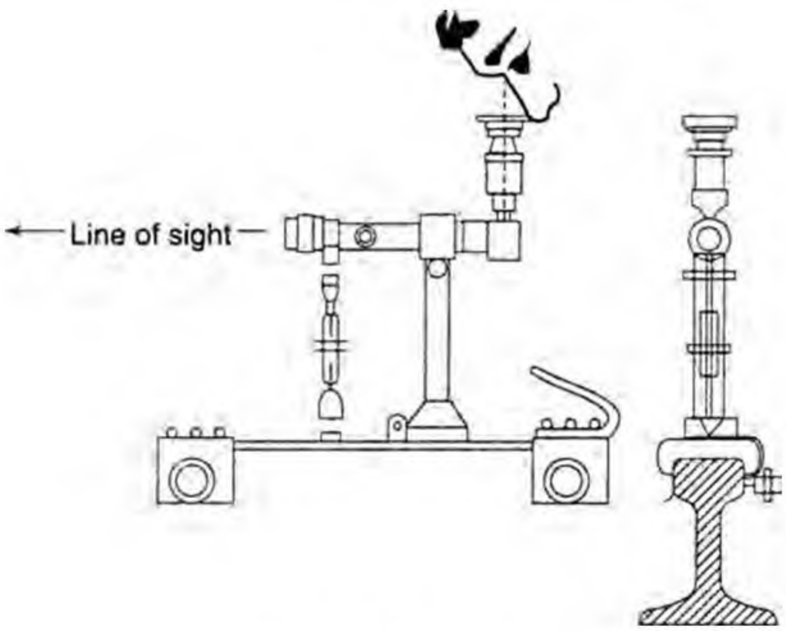


Fig. 14.5 Viseur

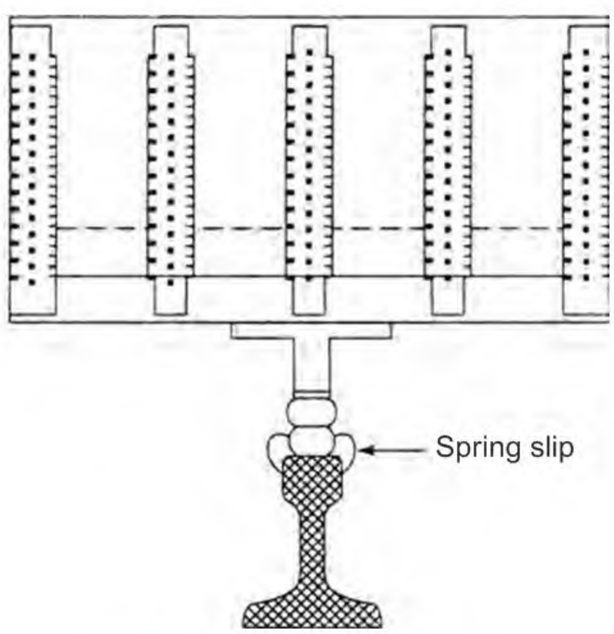


Fig. 14.6 Staff (Mire)

The jack is provided with a quick release mechanism with which it can be lowered instantaneously (Fig. 14.7).

Both mechanical and hydraulic non-infringing jacks are now available in the market. Their load carrying capacity varies from 5 to 10 tonne, with a lift of 75–100 mm.

Packing Shovels This is used for the distribution of stone chips on the sleeper bed. The throw of blade is 100 mm for BG and 85 mm for MG (Fig. 14.8).

Dozing Shovels and Measuring Can These are used for measuring and feeding the required quantity of stone chips in the packing shovels [Figs 14.9 (a) and (b)].

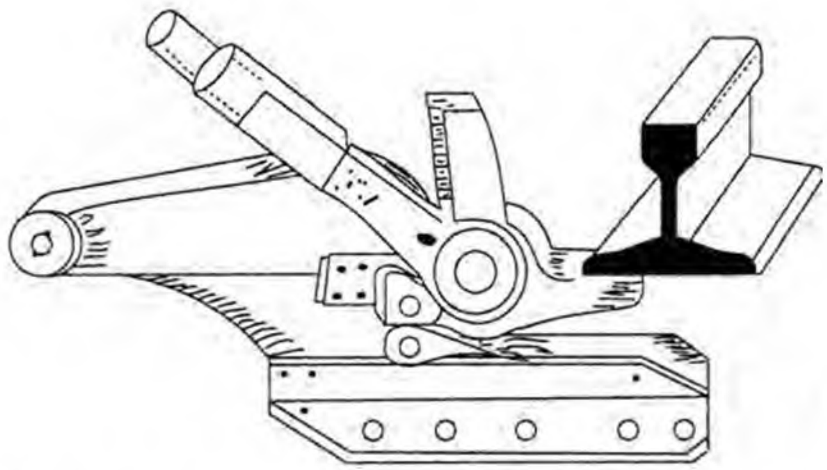


Fig. 14.7 Non-infringing type of mechanical jack

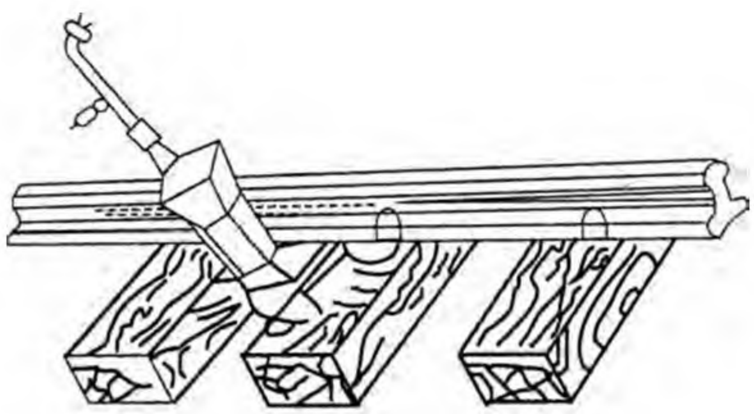


Fig. 14.8 Packing shovel

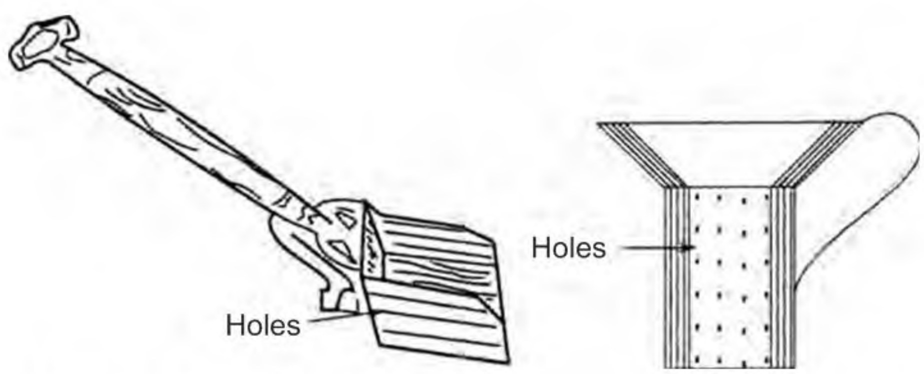


Fig. 14.9 (a) Dozing shovel (b) Measuring can

Plain Shovel This is used for spreading stone chips over the bed of the sleepers at places where packing shovels cannot be used for want of space (Fig. 14.10).

Other equipments like stepped feeler gauge, special beater, tamping bars, wheel-barrow, etc., can be used to step up the progress of work. All this equipment is now being locally manufactures by various firms and railway workshops.

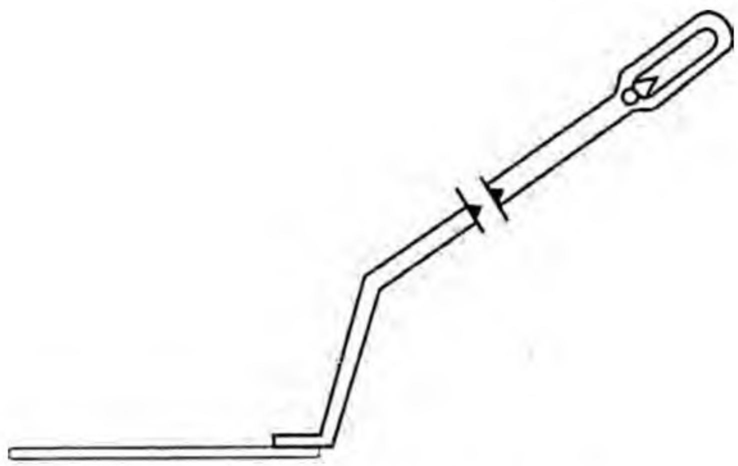


Fig. 14.10 Plain shovel

14.3 THROUGH MEASURED SHOVEL PACKING OF FLAT BOTTOM SLEEPER TRACK

14.3.1 Preliminary Works

The following preliminary works should be carried out 10 to 15 days in advanced of measured shovel packing work.

1. Renewal of worn out sleepers and fittings
2. Tightening of rail-sleeper fastenings to eliminate any play.
3. Squaring of sleepers
4. Gauging
5. Rectification of major alignment defect and removing kinks
6. Adjustment of creep and expansion gaps
7. Track should be well ballasted

14.3.2 Sequence of Operations

MSP of flat bottom track entails several operations in the sequence as follows:

Measurement of Packing Voids The canne-a-boule is dropped at each end of the sleepers from a height of about 400 mm and the looseness of the sleeper is judged by the sound and the rebound of the ball. For a good rebound and a healthy sound, zero value is given, which is increased depending upon the rebound and dullness of sound. These values are written with chalk at the end of the sleepers. At a few places of dansometers are fixed and their readings are taken after the passage of train. The dansometer readings are compared with the canne-a-boule readings and if there is a difference, necessary correction is applied to canne-a-boule readings.

Fixation of High Points (*PH*) By bending and sighting along the inside lower edge of the rail head, high points are located on both the rails. The distance between high points located on either of the rail should not exceed 25 m.

Transference of High Points (*PH*) *to Good Points* (*PB*) The cross-levels at all the high points are checked and the lift required to be given to lower rail to bring it in level with the higher rail noted. In addition, a general lift is given even to the highest point and this value is usually 10 mm in the first round of MSP, on subsequent rounds this may be reduced to 5 mm. The sum of the general rise values and cross-level correction value is called PB value (good point value), for each rail for each high point. For example, if cross-level difference at one high point is 4 mm and the general rise is 10 mm, the PB value for the higher rail will be 10 and that of lower rail 14.

Longitudinal Levelling The longitudinal levels are then taken between two high points on every alternate sleeper with the help of viseur and mire (Fig. 14.11). The readings on the intermediate sleepers are obtained by interpolation.

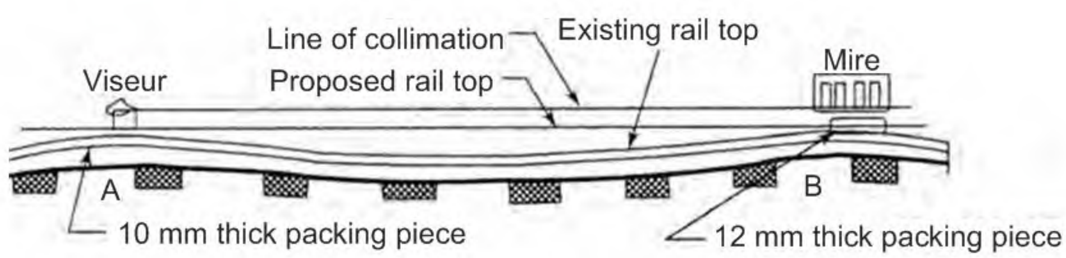


Fig. 14.11

Total Feed—MD (*Mark Definitive*) The total feed is the sum of longitudinal level correction and the packing void. This is also called 'Mark definitive' and this figure is written on the foot of the rail on the inside (Fig. 14.12).

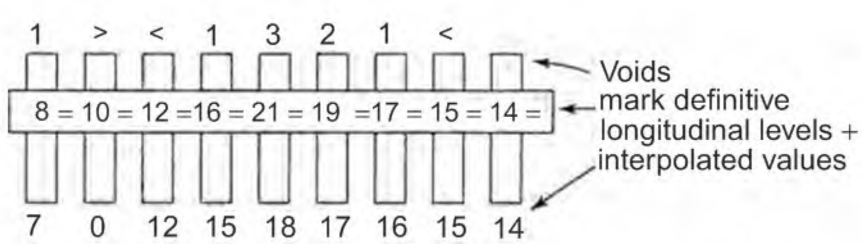


Fig. 14.12 Interpolation of values of mark definitive

Removal of Ballast Special beaters or wire claws are used for removing the ballast for shovel packing. Ballast for 250 mm on either side of the centre of rail for 150–200 mm width and up to bottom of sleeper is removed as shown in Fig. 14.13. The section *XX* shows the position of sleepers after lifting.

In all cases, only one side of the sleeper is opened out. On double line, opening is done in the direction of the approaching trains. On single line, direction of opening is changed at every 25 m.

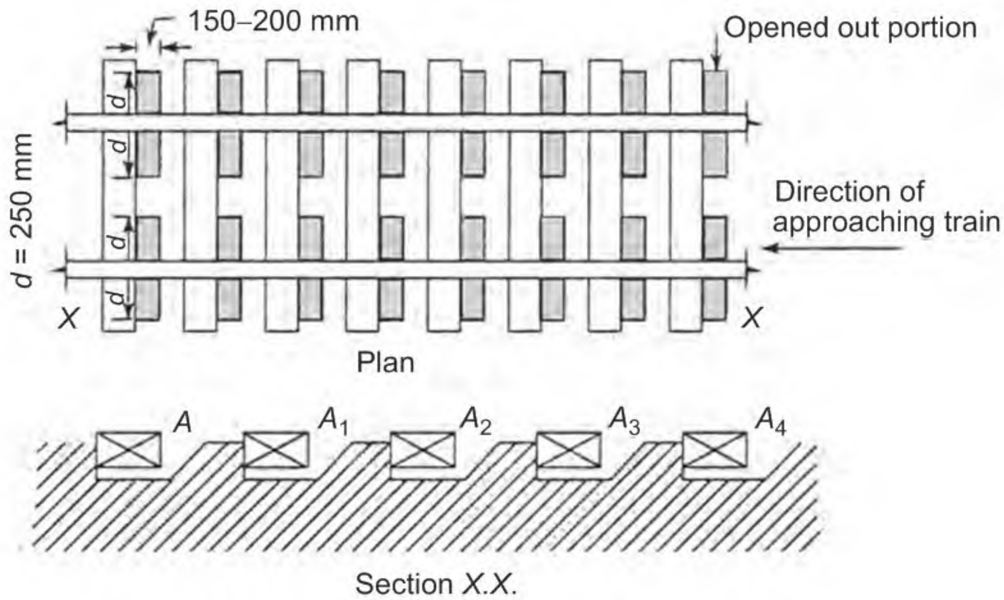


Fig. 14.13 Track lifted by jacks

Lifting by Jacks Non-infringing jacks are used for lifting. The lift is restricted to 40 mm for packing. For lifting the track, the jacks in pairs of two, one for each rail, are packed nine sleepers apart. After finishing the packing up to the 6th sleeper, the first pair of jacks is shifted to the 6th sleeper and the second pair of jacks to a position six sleepers in advance, thus keeping the gap of nine sleeper spacings. The packing is thus continued uninterrupted.

Shovel Packing Dozing shovels are used for feeding chips to packing shovels. The quantity of stone chips taken in dozing shovels is as per the total feed marked on the rails and is for one side of the rail seat only. Similar quantity is taken for the other side of the rail seat. When feeding the stone chips, the packing shovel is kept close to the rail foot in an inclined position toward the rail centre line. The shovel is shaken and the handle is operated briskly twice or thrice. The quantity of chips dozed at a time should not be more than required for a 20 mm lift. When one rail length is complete, six men should tamp rail flange three times by using blunt end crowbars at every rail seat.

Providing Ramps At the end of the day's work, a ramp or run out of 1 mm per sleeper is given to the track. The balance quantity is fed in continuation at the beginning of next day's work (Fig. 14.14).

Aligning Track alignment can also be checked and rectified by using viseur and mire. The rear side of the mire which has a vertical central line is used as a target for this purpose.

Putting Back the Ballast After passage of at least one train, the ballast should be drawn in and boxed to the proper section by ballast rakes.

Checking After passage of two trains over the treated reach, check the cross-levels by gauge-cum-level and the longitudinal level by eye. Cross-levels shall not have an error more than 3 mm at any sleeper and the variation from sleeper to sleeper shall not exceed 1 mm.

Majoration of Joints On the following day the joints are again examined visually. If they appear low the joint and shoulder sleepers are lifted to the required amount by MSP.

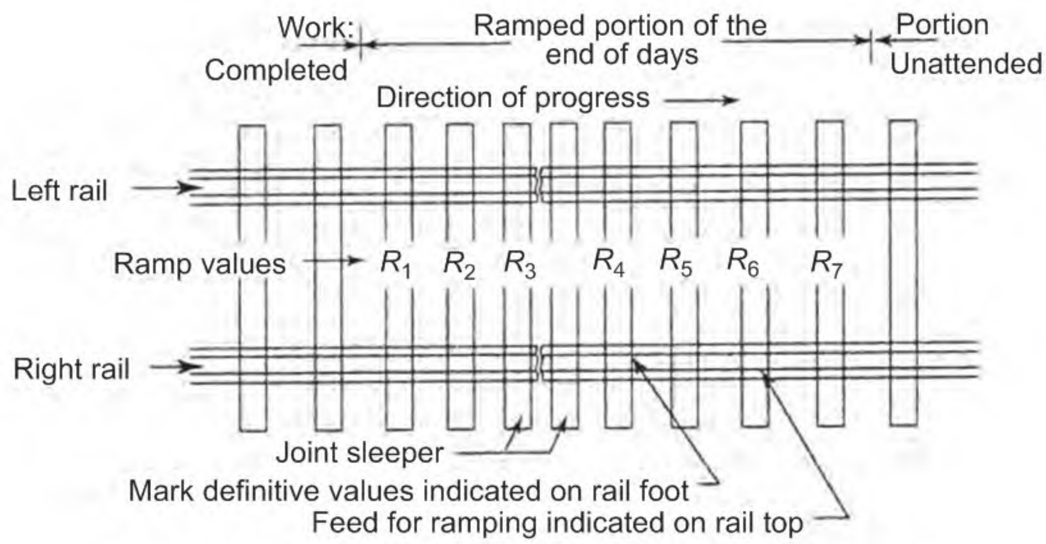


Fig. 14.14 Ramp definitive at the end of day's work

14.3.3 Distribution of MSP Gang and its Output

For efficient working, an MSP unit should consist of a minimum of nine men headed by an Asst. Permanent Way Inspector to give an output of 150–160 m/day. The distribution of their work will be as follows:

1. One APWI and two men for measurements. This work should take about 2½ hours and should be done one day in advance. After measurements are finished, these two men will bring stone chips from the stack to the site of packing
2. Two men for operating track jacks
3. Two men on packing shovels
4. Two men on dozing shovels
5. One man to work as look-out man

Gang Equipment Table 14.1 gives a list of equipment required for this work. A list of the bare minimum items is also given with which the work can be carried on for some time, till full equipment is available. When jacks are not available, crowbars may be used for lifting the track.

14.4 MEASURED SHOVEL PACKING OF JOINT WOODEN SLEEPERS

One APWI, eight gangmen and one look-out man can achieve a progress of 50 joints per day. The distribution of these men will be on the same pattern as for through MSP.

Gang Equipment Table 14.1 gives a full list of equipment required for this work. In addition a list of the bare minimum items is also given, to carry on the work till full equipment is available.

For 50 joints, i.e. packing 100 sleepers, 0.57 cum stone ships would be sufficient.

Measured shovel packing of joint wooden sleepers in a through metal sleeper road is done in two ways. In one case, the joint sleepers are only attended to by the MSP and the metal sleepers are not touched. In the second case, the MSP of the joint sleepers is done along with beater packing of intermediate metal sleepers.

Table 14.1

S. No.	*Item*	*Full equipment*	*Bare minimum equipment*
1.	Viseur and mire	1 set	1 set
2.	Packing plates	2 sets	1 set
3.	Gauge-cum-level	1 no.	—
4.	Spirit level	1 no.	1 no.
5.	Canne-a-boule	1 no.	1 no.
6.	Dansometers	2 nos.	1 no.
7.	Fleximeter	2 nos.	1 no.
8.	Special beaters	8 nos.	—
9.	Track jacks 5 tons	4 nos.	2 nos.
10.	Packing shovels	2 nos.	2 nos.
11.	Dozing shovels	2 nos.	2 nos.
12.	Plain shovels	2 nos.	2 nos.
13.	Measuring can	1 no.	—
14.	Tamping bars	6 nos.	—
15.	Stepped feeler gauge	1 no.	—
16.	Wheel-barrow	1 no.	—
17.	Nylon chord 10 m long	1 no.	—
18.	Stone chips (8–15 mm)	3 cubic metre or about 100 cft for 500 sleepers	

14.4.1 MSP of Joint Wooden Sleepers without Attention to Adjacent Sleepers

In this case it is most important to ensure that the cross-levels at the joints are not brought to level, but an attempt is made to bring them equal to an average of the cross-levels taken at 3.5 m distance on either side of the joint. In this way twist of the track is kept to the bare minimum. The details of the operations are as follows:

1. Assessing voids of joint sleepers and checking with dansometers.
2. Measurement of existing cross-level at the joint and at two places, 3.5 m on either side of the joint.
3. Measurement of dip or lowness at the joint of both the rails by stretching a 3.5 m chord laced centrally at the joint.
4. Calculation of the total feed, which will be equal to packing voids plus cross-level correction. Cross-level correction is to be determined as follows:
   (a) Find out the average of the cross-levels taken at a distance of 3.5 m on either side of the joint.
   (b) Compare this average cross-level with the actual cross-level at the joint and find out which rail is to be lifted and how much to get the average cross-level.
   (c) Find out the difference in the dip at the two rail seats. This difference again tends to upset the cross-levels. The value of lift obtained in (b) is further corrected for the difference in dip to ensure that the new cross-level at the joint is an average as found in (a) above.

It is however, to be ensured that minimum feed is dip plus void and the adjustment to get the average cross-level is to be made by lifting one of the rails slightly higher than indicated by the dip. The following two examples will make the method more clear.

Example 1 *Let the dip for* R_1 *and* R_2 *be 2 and 4 mm respectively. Let the cross-levels at A (3.5 m from B) be 2 – 0, at B 0 – 3, and C (3.5 m from B) 0 – 4. Let dance or void values be* d_1, d_2, d_3, d_4 *at the respective rail seats (Fig. 14.15). Average of cross-levels = (– 2 + 4)/2 = 1, i.e. 0, 1 at B. Cross-level correction will be 3 – 1 = 2, i.e. 2 mm lift of* R_2.

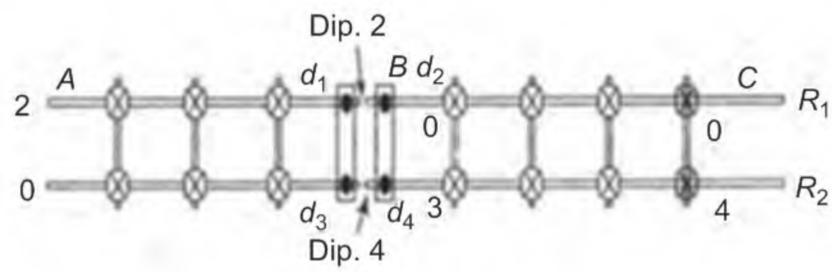


Fig. 14.15

Difference in dips = 4 – 2 = 2, which when corrected tends to raise R_2 by 2 mm.

So, final cross-level correction = 2 – 2 = 0, the correction of dip itself will provide the new cross-levels equal to an average of *A* and *C*. Final will be

For R_1, d_1 + 2 and d_2 + 2
For R_2, d_3 + 4 and d_4 + 4

Table 14.2

S. No.	*Item*	*Full equipment*	*Bare minimum equipment*
1.	Gauge-cum-level	1 no.	—
2.	Spirit level	1 no.	1 no.
3.	Canne-a-boule	1 no.	1 no.
4.	Dansometer	2 nos.	—
5.	Fleximeter	2 nos.	2 nos.
6.	Special beater	2 nos.	—
7.	Track jacks 5 tons	2 nos.	2 nos.
8.	Packing shovel	2 nos.	2 nos.
9.	Dozing shovel	2 nos.	2 nos.
10.	Plain shovel	2 nos.	—
11.	Measuring can	1 no.	—
12.	Tamping bars	4 nos.	—
13.	Stepped feeler gauge	1 no.	1 no.
14.	Wheel barrow	1 no.	—
15.	Nylon chord	10 metres	10 metres

Example 2 *Let the dip for* R_1 *and* R_2 *be 3 and 4 mm respectively. Let the cross-levels at A (3.5 m from B) be 0, – 4; at B 0, – 2; at C (3.5 m from B 0, – 2).*

Let dance or voids value be d_1, d_2, d_3 and d_4 at the respective rail seat (Fig. 14.16).

$$\text{Average of cross-levels} = \frac{4+2}{2} = 3, \text{ i.e. } 0 - 3 \text{ at } B$$

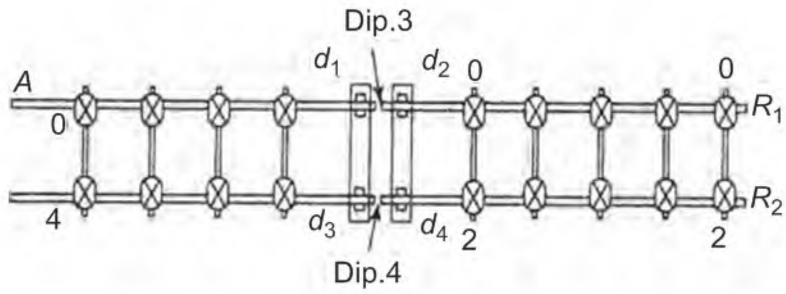


Fig. 14.16

Cross-level correction will be 2 – 3 = – 1, i.e.1 mm lowering of R_2
Difference in dips = 4 – 3 = 1, which when corrected tends to raise R_1 by 1 mm.
So, final cross-level correction = – 1 – 1 = – 2, i.e.,
Lowering rail R_2 be 2 mm or since we do not lower the rails, lift the rail R_1 by 2 mm.
Final feeds will be

For R_1, $3 + 2 + d_1$ and $3 + 2 + d_2$
For R_2, $4 + d_3$ and $3 + d_4$

After the feeds are calculated, the joint sleepers are opened to the same extent as for through MSP. The track is lifted with jacks or crowbars, and the required quantity of stone chips are spread on the sleeper beds. After the passage of a train, the metal sleepers adjoining the joint sleepers are checked and if found loose are beater packed without any lifting.

A simplification of the above method of packing of joint sleepers has been tried and found quite successful. In this method, no cross-levels are measured. The dip at the rail tops at the joint is measured by stretching a 3.5 m chord for both the rails. Canne-a-boul readings are also taken for both the joint sleepers on both sides at the rail seats. The feed for each sleeper is given equal to dip plus void.

It has been noticed that the feed calculated this way is not much different from that calculated by the earlier method. The method is quite simple. It may, however, be noted that the new cross-level at the joint will be an average of cross-levels of two places 1.75 m from the rail joint, which should give reasonably good results.

14.4.2 MSP of Wooden Sleepers at the Joints along with the Through Beater Packing of Intermediate Metal Sleepers

The details of the operating are as follows:

1. Measurement of void at the joint sleepers.
2. The measurement of longitudinal dip can be done with the help of fleximeters. For this purpose, the fleximeters are fixed in compressed position under the two rails near the joint

sleepers. The intermediate sleepers are then packed as in through beater packing, by first lifting the sighting rail and then transferring the levels to the other rail. The joint sleepers are left untouched. When all the intermediate sleepers are packed, the readings of the two fleximeters are taken. This will give the dips to be compensated for each rail. No cross-level measurement is needed to be taken at the joint.

The total feed at the joint will be dip plus void for each rail seat.

The fixing of fleximeter under one of the rails can be dispensed with, by lifting the sighting rail to the correct height and then applying cross-level correction to the dip value obtained from the fleximeter fixed under the sighting rail.

3. The joint can then be lifted with the help of track jacks or with four crowbars and the chips are spread with packing shovels.
4. Rails at the joints are tamped with four crowbars, so that the sleepers are seated evenly before the arrival of any train.

14.5 DEHOGGING OF RAILS ENDS (Fig. 14.17)

Dehogging of rail ends can be accomplished with the help of MSP. The procedure adopted for this purpose is as follows:

1. The dip is measured at the joint with a 1.5 m chord, say a.
2. The dance or voids of the joint sleepers are found with canne-a-boule or the dansometer, say d.
3. Total feed for the joint sleeper is worked out as

$$a + d + a'$$

   when $a' = a$ (subject to maximum of 5 mm)

4. The joint sleepers are shovel packed to the value given above; the adjacent sleepers are not touched for two days.
5. After two days of traffic, the adjacent sleepers are also beater or shovel packed without causing any lifting to joint sleepers.
6. The dip is measured again and the dehogging operation repeated if necessary.

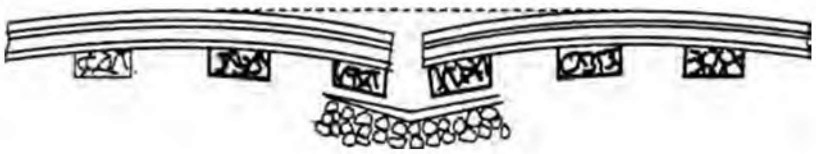


Fig. 14.17

14.6 MEASURED SHOVEL PACKING OF POINTS AND CROSSINGS

Excellent results have been achieved by MSP of wooden sleeper layout of points and crossings. The results achieved with steel sleepers have also been reasonably satisfactory, but as their sleeper beds are found quite hallow, MSP is required to be repeated two or three times to get really satisfactory results.

14.6.1 Number of Gangmen Required and their Distribution

For efficient working, an MSP unit for this work should consist of one APWI and 15 gangmen. Measurement and calculation of feed is to be done in advance. The distribution of work should be as follows; 4 men of jacks, 4 men on grating shovels, 4 men on dozing shovels, 2 men for supplying stone chips, and 1 man as a look-out man.

14.6.2 Equipment Required

1.	Viseur and mire	1 set
2.	Packing plates	2 sets
3.	Gauge-cum-level	1 no.
4.	Spirit level	1 no.
5.	Canne-a-boule	1 no.
6.	Dansometer	4 nos.
7.	Fleximeter	2 nos.
8.	Track jack 5 tonnes	4 nos. (preferably of 15 tonnes capacity)
9.	Grating shovel	4 nos.
10.	Plain shovel	2 nos.
11.	Measuring can	1 no.
12.	Tamping bar	6 nos.
13.	Stepped feeler gauge	1 no.
14.	Nylon chord	10 metres
15.	Ballast rake or special beater	1 no.
16.	Dozing shovel	8 nos.
	Stone chips (8–15 mm), 0.85 per turnout	

14.6.3 Details of Operation

1. *Measurement of looseness or dance of sleepers* The dance is measured for the mainline and turnout side, including the lead curve, separately. However, on the switch portion, up to the place the track divergence is less than 40 cm; the dance need not to be measured separately. Similarly, near the crossing the dance may be measured on both sides of the crossing and an average value taken.
2. *Location of high points* The points are located in the usual manner on the mainline, but if any point is located on the switch portion, it should be located on stock rail.
3. *Cross-level correction at high points* This is done in the same way as in through MSP. After cross-level correction, these points are called good points. This term is also used for

through MSP. On switch portion, the good points are located on stock rail.

4. *Measurement of longitudinal dips by viseur and mire* The same method as for through MSP.
5. *Total feed or mark definitive* The total of the packing voids and the longitudinal dips gives the total feed. In the switch and crossing portions when the two rails are close to each other and when a combined feed has to be given, additional dosage are worked out for the space between the two rails proportionately. Such a combined packing is required for the sleepers where the distance between the two rails is less than 40 cm. On the turnout side, the feed for the lead portion is worked out in the following manner:

   The sleeper is considered as a rigid body. When the mainline rails are lifted by (a) and (b), the tilt given to the sleeper on account of this lift gives a corresponding lift of (c) and (d) on the middle and the outer rail.

   These values can be calculated as:

$$c = a + \frac{(b-a)x}{G}$$

$$d = b + \frac{(b-a)x}{G}$$

   When G is the gauge and x is the distance of turnout rail from the mainline rails. These values of c and d when added to dance values will give the total feed.
6. *Shovel packing* Ballast between the sleepers is completely removed up to the sleeper bed and the track is lifted on jacks. Four grating shovels are used for packing, two each on the outside and inside of rails. The shovels on inner side are used for additional feeds up to a width of spread of rails of 40 cm. Thereafter, all the four shovels feed the four rails independently.
7. The *ballast* is put back after the passage of one or two trains. The MSP of joints is done again, if need arises.
8. *Alignment correction* The alignment is likely to get disturbed, which must be corrected.
9. *Approaches* The approaches of turnout will also have to be attended to along with the MSP of turnout, eight by MSP or beater packing.
10. All the measurements taken for MSP of turnout are properly recorded on special proformas and the total feed for each sleeper calculated before starting the work.
11. *Need for traffic block* A traffic block of about 1½ hour duration is necessary for MSP of a turnout.

14.7 DISCONTINUOUS MEASURED SHOVEL PACKING WITH ABATEMENT (AMSP)

14.7.1 General

Discontinuous MSP with Abatement (AMSP) in effect can be called directed track maintenance by MSP, since this method is adopted where the track irregularities go beyond certain tolerances, but the track has not deteriorated to need through MSP. It aims at improving run down tracks while economizing on labour by minimizing the number of sleepers to be packed and on the cost of the chips by minimizing the lifts to be given.

AMSP aims at eliminating packing voids (dance) completely and reducing unevenness to within 2 mm. The track is not given any general lift and the cross-level or twist is also not corrected. The longitudinal corrections are reduced by 2 mm (1 mm at the fishplated joint sleepers), thereby leaving an unevenness of 2 mm at high points. High points are selected on both the rails and each rail is treated independently. No cross-level corrections are made as stated above. This method can be adopted, once the track has stabilized after sufficient attention with through MSP.

The application of this method is subject to the observance of certain conditions and safeguards mentioned below.

1. Error in cross-level at any high points should not exceed 10 mm.
2. Rate of variation of cross-levels, i.e. twist should not exceed, 2.08 mm/m (7.5 mm on 3.6 m base), i.e. the track should be within the 'B' category, as per the TRC results. If the above mentioned limits are exceeded. Through MSP should be carried out.

14.7.2 Procedure

The following detailed procedure should be adopted, other items remaining the same as indicated in 'Measured Shovel Packing'.

1. Select suitable stretches, satisfying the conditions laid down in Section 14.7.
2. Assess packing-voids (dance) under each rail seat of a sleeper by canne-a-boule.
3. Locate high points, as usual, on either rail.
4. Measure the longitudinal levels between the high points with the help of viseur and mire.
5. Deduct 2 mm from the longitudinal level values measured in (4) above. In the case of fishplated joints, deduct 1 mm from the longitudinal level at the joint sleepers against 2 mm for the remaining sleepers.
6. Add dance to the reduced longitudinal values to get final feed values.
7. Further procedure is the same as brought out in Section 14.3.

14.8 MEASURED TUBE PACKING (MTP)

14.8.1 General

Measured tube packing is a method of packing of steel-trough sleepers by introducing stone chips over the consolidated sleepers bed, through the holes of the loose jaws, with the help of a steel tube.

14.8.2 Specialised Equipment

The feeding tube is a simple steel tube of about 25 mm inner diameter for BG and 20 mm inner diameter for MG, made out of 2.5 mm thick steel sheet (Fig. 14.18). It is provided with a funnel at the top and a collar at the bottom. The bottom end is half cut and provided with a slightly bent tip to guide the falling chips on to the ballast core. The height is about 1 m which gives the falling chips necessary momentum to get themselves spread under the sleeper. The holes provided for loose jaws are made use of to give the feed. The standard measuring-can (MG) and dozing-shovel (MG) are used for Broad Gauge track. The dozing-shovel and measuring-can of MG are used on BG, because the packing area of chips to be fed by packing-tube in steel-trough sleepers is about 700 sq cm, which is equivalent to the packing area of the MG wooden sleepers. For packing of MG steel sleeper, a modified dozing-shovel and measuring-can is required to be designed.

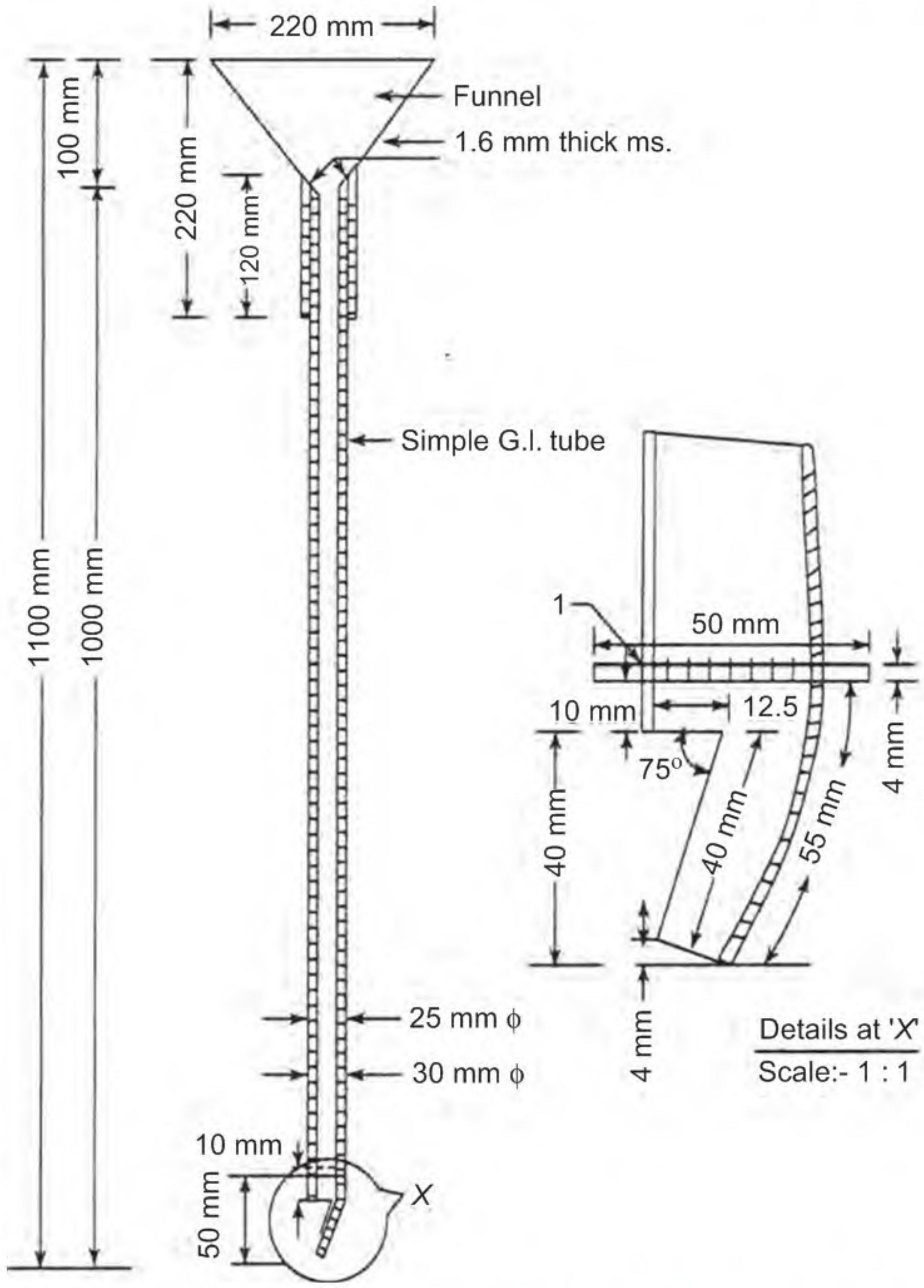


Fig. 14.18 Packing tube for measured tube packing of ST sleepers BG

14.8.3 Packing Procedure

The method for determining the packing voids and the total feed, 'mark definitive' in measured tube packing is the same as for normal measured shovel packing of wooden sleepers. The track is lifted with the help of two track jaws—one under each rail—by about 50 mm high, or with the help of two crowbars as in the case of normal measured shovel packing. Inside keys and loose jaws for four sleepers on either side of the track jacks are removed first and the required quantity of stone chips as per mark definitive taken with the help of dozing-shovel (MG) and fed through the tube to the sleeper. The tube is rotated while feeding the chips. After feeding the chips through the holes of the sleepers, the jaws and keys are refixed in position.

After packing sleepers on the inner side, the outer side keys and jaws of the same sleepers are opened and the chips are fed through the holes.

Then the jaws and keys are refixed in position and the track is lowered to its normal position.

When the chips are poured from the top, the tube is continuously rotated all round shaking the same vertically, with the collar provided at bottom, touching the rail foot.

For correcting the residual unevenness in surface at isolated spots, additional feed to the desired extent is given with the help of tube.

14.9 MEASURED SHOVEL PACKING VERSUS ON-TRACK TAMPING

Measurements made by British Railway on tracks tamped by on-track tamping machines revealed that the vertical track geometry deteriorated rapidly after the passage of traffic; sometimes half the geometric improvement is lost after the first week's traffic. They further observed that the geometry to which the track deteriorated was almost identical to that which existed prior to the tamping operations. This led them to the conclusion that the track has an inherent shape (can be called "ballast memory") that it tends to revert. Track maintenance by Tamping machines fails to erase the "ballast memory" with the small lifts that it gives to the track.

Track maintained by "Measured Shovel Packing" has been able to retain the track geometry much better, with a general lift of 40 mm. A back to back comparison with the results obtained from conventional tamping machines has shown that MSP could lengthen the time interval between maintenance cycles by up to a factor of four, mainly because the method has a greater potential of erasing the old 'ballast memory' of track. These findings have revived the interest of track engineers in the maintenance of track by MSP which was almost given up after the appearance of on-track tamping machines on the world scene.

However, there is another school of thought on British Railways which favours tamping, and they hold that the pea gravel below the sleepers would (a) soon get crushed, leading to loss of track resilience and caking up of ballast; (b) would fill up the voids and may result in centre-binding in some cases and (c) will affect the track drainage in the long run.

14.10 MACHINES FOR MSP

One of the major drawback of MSP is that the method is labour intensive. All the work of track measurement, opening and closing of ballast, feeding of chips, is usually done manually.

British Railway has been making efforts to mechanise the system. The following two methods have been evolved:

1. *Semi-Mechanised method* In this method, a portable compressor is used to blow the stone chips underneath the sleeper through a hallow metal tube. The tube is driven down between the ballast and the face of sleeper in a way that the end opening of the tube faces the void under the sleeper. No opening of the ballast is needed for feeding the chips. However, rest of the work which includes the measurement of track geometry, calculation of feeds, transportation and feeding of stone chips in the metal tube is done manually. The compressor is also required to be moved from one place to another.
2. *Fully mechanised method* P.B.I-84 stone bower by British Railway, is a fully mechanised system for MSP. PBI stands for Pneumatic Ballast Injection. PBI-84 is s three-bogie articulated vehicle weighing about 80 tonnes, with an overall length of 29.4 m. Equipped with its own ballast hopper and grab, it can load and carry 10 tonnes of stone, which is sufficient for a normal working shift. The machine can pack 400 m of track per hour. It measures the geometry, calculates the feed for each sleeper with the help of an on-board microprocessor, lifts and aligns the track and blows the requisite quantity of stone chips—all automatically.

   On Indian Railways, a stone blower may provide a good techno-economic solution for the maintenance of long length of branch lines deficient in ballast which are laid with steel/CST-9 sleepers, where tamping machines cannot be deployed efficiently.

Chapter 15

Track Renewal

15.1 PREAMBLE

Track renewals are carried out either due to wear and tear of existing rails or when the latter are unable to cope with the increasing quantum of traffic. The term track renewal implies replacement of existing rails or sleepers, either separately or together by new or second hand serviceable material. The material used for replacement is vis-à-vis the importance of the line.

15.2 CLASSIFICATION OF RENEWALS

1. All track renewals can be classified into one of the following categories.
   (a) Complete track renewal (Primary) abbreviated as CTR (P)
   (b) Complete track renewal (Secondary) abbreviated as CTR (S)
   (c) Through rail renewal (Primary) abbreviated as TRR (P)
   (d) Through rail renewal (Secondary) abbreviated as TRR (S)
   (e) Through sleeper renewal (Primary abbreviated as TSR (P)
   (f) Through sleeper renewal (Secondary) abbreviated as TSR (S)
   (g) Casual renewals
2. Primary renewals are those where only new materials are used while secondary renewals are those where released serviceable materials are used.
3. In the case of casual renewals, unserviceable rails, sleepers and fastenings are replaced by identical sections of serviceable or new track components. These are carried out in isolated locations and not in continuous stretches. Such renewals are a part of normal maintenance operations.

15.3 CRITERIA FOR TRACK RENEWAL

15.3.1 Criteria for Rail Renewal

Rails are renewed in the track on service life-cum-condition basis. The majority of rail failures have their origin in fatigue. Fatigue is a cumulative process by compounded corrosion and wear, so that the longer the rail remains in track, the more fatigue damages it accumulates. If not detected in line, the situation can aggravate with further development of fatigue cracks or fractures.

Rails are therefore often removed from the track as an insurance against fatigue failures long before they are worn out to a section too weak to carry the maximum permitted axle loads. In the absence of any reliable measure of cumulative fatigue damage prior to the formation of a crack, rails are proposed for renewals after they have carried a certain GMT of traffic or have got worn out to some predetermined amount.

The following items are considered in connection with the criteria for rail renewal.

Primary Rail Renewal

1. *Incidence of rail fractures/failures* A spate of rail fractures on a particular length showing an abnormally upward trend will have priority when deciding rail renewals. In such cases, ultrasonic testing of rails shall be carried out in the section and the results of such testing taken into consideration before formulating the proposal. In case the rail failures at joints are predominant, end-cropping with or without welding could be considered.
2. *Wear on rail—It includes the following four factors*:
   (a) *Limiting loss of section* The limiting loss in rail section, as a criterion for recommending rail renewals shall be as given in Table 15.1. Rail wear may be determined by actual weighment, or taking rail profiles at ends after unfishing joint or taking rail profiles with special profile measuring gadgets. Computer aided rail measuring devices are presently coming into the market.

Table 15.1

Gauge	*Rail section (kg/m)*	*Loss in section in percentage*
BG	52 kg	6
	90 R	5
MG	75 R	4.2
	60 R	3.25

   (b) *Wear due to corrosion* Corrosion beyond 1.5 mm in the web and foot may be taken as the criterion for wear due to corrosion. Existence of localized corrosion such as corrosion pits, specially on the underside of the foot, acting as stress raisers, form the origin of fatigue cracks and would necessitate renewals.
   (c) *Vertical wear* When the reduction of depth of the rail head reaches a point beyond which there is a risk of wheel flanges grazing the fishplates, the rails should be renewed. The

limits of vertical wear at which renewals are to be planned are given in Table 15.2.

A typical profile showing the measure of vertical wear of the rail is given in Fig. 15.1. Vertical wear is to be measured at the centre of the rail either by measuring the height of the worn out rail by calipers or by plotting the profile. In the first case, the wear is a difference between the height of the new rail and the height of the worn out rails.

Table 15.2

Gauge	*Rail section*	*Vertical wear* (mm)
BG	60 kg/m	13.00
	52 kg/m	8.00
	90 R	5.00
MG	75 R	4.50
	60 R	3.00

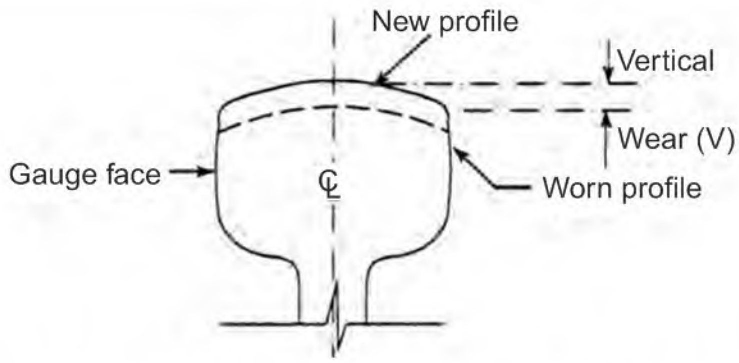


Fig. 15.1 A typical profile showing the measure of vertical wear of the rail

(d) *Lateral wear* Limits of lateral wear from relaying consideration are given in Table 15.3.

A typical profile of the worn rail showing the measures of lateral wear is shown in Fig. 15.2.

Table 15.3

Section	*Gauge*	*Category of track*	*Lateral wear* (mm)
Curves	BG	Group A and B routes	8
		Group C and D routes	10
	MG	Q and R routes	9
Straight	BG	Group A and B routes	6
		Group C and D routes	8
	MG	'Q' routes	6
		'R' routes	8

Lateral wear is to be measured at 13–15 mm below the rail top table. Worn rail profile should be recorded and superimposed over new profile to find out the lateral wear.

3. *Maintainability of track to prescribed standards* This is of importance in view of the following:

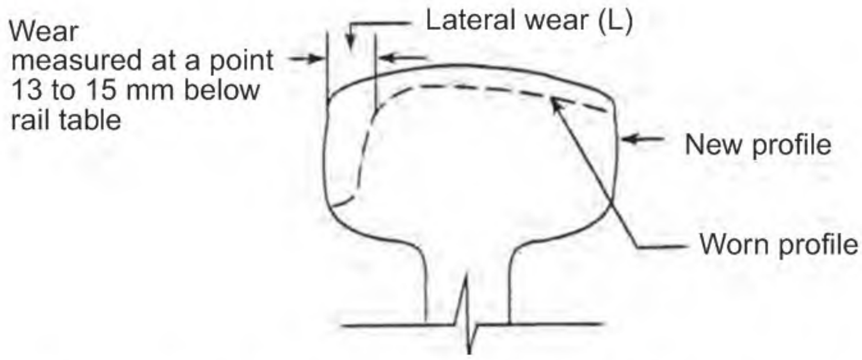


Fig. 15.2 A typical profile of the worn rail showing the measures of lateral wear

(a) There may be cases, where renewals may be necessary either due to poor running quality of track in spite of extra maintenance labour engaged for maintaining the same or disproportionate cost of maintaining the portion of track in a safe condition.

(b) The condition of rails apropos of hogging/battering, scabbing and wheel burns and other conditions such as excessive corrugation of rail, as can be ascertained by visual inspections, which affects the running quality of track, and make the track maintenance difficult and uneconomical. This should be taken into account when proposing renewals.

(c) Renewal of rails due to hogged and battered rail ends should be considered only if other remedies have not been found to be effective.

4. *Renewals vis-à-vis service life* The rail shall be planned for through renewal after it has carried the minimum total traffic as given in Table 15.4.

Table 15.4

Gauge	*Rail section*	*Total GMT* carried (for t-12 med. manganese, 72 UTS rails)*
BG	60 kg/m	550
	52 kg/m	350
	90 R	250
MG	75 R	150
	60 R	125

Note: For 90 UTS rails, life is generally 1.5 times the 72 UTS rails

5. *Plan based renewals*: Renewals to predetermined plans with the objective of modernizing the track structure on selected routes in the shortest possible time may be planned even if it involves premature renewals.

Secondary Rail Renewal

1. In the case of secondary renewals, if the condition of rail is satisfactory, it will be a good practice to crop the rail ends and weld them into SWR and use them in less important lines. The rail should be ultrasonically tested before use.
2. Welding of chipped rail ends will also improve the service life.

3. The rails released from primary relaying and not fit for use in secondary relaying should be used in sidings.

15.3.2 Criteria for Sleeper Renewal

Generally a sleeper is considered serviceable if it can hold gauge, provide a satisfactory rail seat, permit a tight grip for the fastenings, and retain the packing underneath the sleeper. Sleepers that are not likely to fulfill the above functions even after reconditioning, are renewed. When only sleeper renewal is justified, this should be carried out in continuous stretches; the released serviceable sleepers being utilized for casual renewals elsewhere. The average life of various types of sleepers and the factors which affect their serviceability have been discussed in Chapter 4.

The presence of about 30 to 35 percent unserviceable sleepers in the track will justify through sleeper renewal.

15.3.3 Thorough Track Renewals

Keeping the above mentioned criteria in view, planning for renewal of track is to be made in such a way that complete track renewals are done as far as possible on the important routes, instead of separate rail and sleeper renewals.

Renewals should be planned in as long and continuous lengths as practicable. Short isolated stretches of 10 km and less, not due for renewal, may be programmed along with the adjoining lengths, if these stretches do not conform to the required standards. Apropos of track renewals, a proforma is given in Appendix 15.1, of the Indian Railways, which provides the justification for a particular stretch for track renewals kilometre wise.

15.4 SPEED RESTRICTIONS DURING TRACK RENEWAL

The speed restrictions to be imposed during various sequences of work are given in Tables 15.5 and 15.6.

15.5 MANUAL TRACK RENEWAL

15.5.1 Preliminary Works

1. Ballast required for making good possible deficiency in cushion due to deep screening should be unloaded on both sides of the track opposite to the place where it is required. It should be pulled back on the cess so as not to permit its admixture with unscreened ballast, where complete track renewal or through sleeper renewal is to be done with deep

Table 15.5 B.G. and M.G.—Manual Packing

Day	*Sequence of work*	*Broad gauge speed in kmph*	*Metre gauge speed in kmph*
1st	Opening, relaying and initial packing	15	15
2nd	1st through packing	15	15
3rd	2nd through packing	15	15
4th–9th	Picking up of slacks as required	45 (after 2nd through packing)	30 (after 2nd packing)
10th	3rd through packing	45	30
11th–19th	Picking up of slacks 3rd as required	75 (after 3rd through packing)	60 (after packing)
20th	4th and final through packing	75	60
21st	Normal sectional speed restored after 4th through packing	—	—

Table 15.6 B.G. Machine Packing

Day	*Sequence of work*	*Speed in kmph*
1st	Opening, relaying and packing	15
2nd	1st tamping	15
3rd–5th	Attention to track as required	45 after completion of 1st tamping
6th	2nd tamping	45
7th and 8th	Attention to track as required	75 after completion of 2nd tamping
9th	3rd tamping	
10th	Normal sectional speed restored after completion of 3rd tamping	

Note: The work of track renewals on double lines should normally proceed in the direction opposite to traffic.

screening. Deep screening should match with the progress of renewals and should precede complete track renewal or through sleeper renewal by a couple of days. In the case of LWR track the additional requirement of ballast for the extra profile should also be ensured.

2. Treatment of bad formation should be carried out in advance of the relaying.
3. Centre line and level pegs made out of scrap bars as also the pegs for realignment of curves should be fixed beforehand. Where necessary, curves should be realigned and transitioned. Longer transitions should be provided to cater for future increase in speed wherever possible. In case heavy slewing is necessary for providing longer transitions, centre line pegs indicating revised alignments should be fixed and new track laid accordingly. The formation should be suitably widened.

4. On sections where creep is noticeable, joints should be squared and gaps rectified for short length at the point of commencement.
5. Where wooden sleepers are used, adzing, auguring, end binding, etc. should be done sufficiently in advance of the daily requirements. In the case of CST-9 sleepers and two block concrete sleepers, tie bars should be given a coat of coal tar before laying. The underside of bearing plates should be treated with black oil before reuse. A few extra bolts, nuts, keys spikes, rail screws, etc, should be arranged.
6. As a preliminary measure the Permanent Way Inspector should actually mark out the position of the new rail joints with a tape. The lengths marked out should be the length of the new rail together with one expansion space. On a curve, the rail lengths should be set out along each rail, starting from a point on the straight where the sites of the two joints have been set out opposite one another by means of a square. The square should be used at each joint on the curve to determine the amount by which equal to half the distance between the fishbolts holes, a length shall be sawn off at the end of the rail equal to the full distance and a new fishbolt hole drilled. The length of cut-rails in the curve varies according to the degree of each curve.
7. Sufficient track gauges, gauge-cum-levels, spanners, keying hammers, augers, crowbars; tommy bars, claw bars, grip gauges; coater splitters, beaters, ballast rakes; wire claws, forks, wire brushes; ballast screens, mortar pans, screening baskets; shovels, phowrahs, rail thermometers, expansion liners, slotted fishplates, rail closures; combination fishplates, wooden blocks and wedges and all tools and equipment necessary for efficient execution of work including that for rail cutting and rail drilling should be arranged by the Permanent Way Inspector in advance. Before starting and during the course of work, the track gauge and the gauge-cum-levels should be checked periodically for their accuracy.
8. Labour should be properly organized and suitably distributed to ensure maximum efficiency.
9. Before carrying out track renewal work in electrified areas, sufficient notice should be given to the Electrical Traction Distribution Department to arrange for adjustment of overhead wires to conform to the new alignment and level. They will also arrange for bonding the new track. In track circuited sections and in yards where change in yard layout is contemplated, notice shall be given to the signalling department for getting assistance in executing joint works. Advance notice as laid down by the respective railway should be given to the Operating Department of the actual commencement of work by the Permanent Way Inspector, for sending advice to all concerned. The safety of traffic is of paramount consideration.

15.5.2 Unloading of Rail, Sleepers and Fastenings

1. It should be ensured that materials are unloaded fairly opposite to the position where they are to be laid. Care should be taken to avoid unloading of materials in excess of the actual requirement to avoid double handling.
2. Utmost care should be exercised in unloading rails. Ramps made of unserviceable rails should be used for unloading. Short welded panels as well as rail panels for laying welded rails may be unloaded by “end-off-loading” method, wherever possible.

3. The unloaded panel should be carefully stacked on a level base, care being taken to prevent formation of kinks. Flat footed rails, as a rule, should rest on the foot. Any carelessness in unloading and staking is liable to cause irreparable damage resulting in bad running. While carrying rails they should be supported at several places by rail tongs or rail slings. Carrying of rails and heavy articles on the head or shoulder should be avoided. Kinked rail must be jim-crowned and straightened. Punch marks on rails or marking by chisel should be prohibited as these cause incipient failures.
4. New rails should be unloaded on one side of the track preferably on the cess, leaving the other side free for stacking released rails. Care should be taken not to unload rails and CI sleepers one over the other, as this practice causes bending of rails and breakage of CI sleepers.
5. New rails and sleepers for the next day's work should be hauled from the place of unloading to opposite the place, where they are to be laid.
6. Material new or old, lying alongside the track is always a potential source of danger; thus, efforts should be made to keep them as low as possible.

15.5.3 Method of Carrying Out Track Renewal Manually

Manually, complete track renewal is carried out by one of the following two methods:

1. Complete dismantling of old track and relaying with new track
2. Piecemeal method in which resleepering and rerailing are carried out separately.

Complete Relaying Method (*Manual*)

1. *Preparatory Work Before Block Period*

   (a) Track should be deep screened one or two days in advance of the relaying. The ballast section should be prepared up to the bottom of the sleeper to facilitate relaying. The balance quantity of screened ballast should be stacked on the section for use after relaying.
   (b) Work is carried out under block protection.
   (c) A speed restriction of 15 kmph is imposed at the site of the work. Temporary fixed engineering signals are erected at appropriate places.
   (d) Fishbolts are oiled and eased one day in advance of the actual block day.
   (e) A couple of hours before the actual operation of the block, fishbolts at the end of each joint, and, fastenings of alternate sleepers are removed.

2. *Work During Block Period*

   (a) *Dismantling of Old Track* Immediately after the commencement of the block, the remaining fishbolts and fastenings are removed. To prevent loss, care should be taken to screw the nuts of released fishbolts onto these bolts immediately after bolts are removed from the fishplates. The old track is dismantled and released materials are moved onto opposite side of the line where new materials have been unloaded, due care being taken not to disturb the centre line and level pegs. The ballast in the sleeper bed is then levelled.

(b) *Linking New Track*

(i) New sleepers are spread out to correct spacing with the help of spacing-rods on which the sleeper spacing is marked. The new rails are then linked over the sleepers, using expansion liners giving correct expansion gaps.

(ii) Only two bolts in each joint are put in and tightened lightly. The rails are then straightened up and roughly aligned and the sleepers adjusted to the correct spacing as per marking on the new rails. The keys and spikes are then fixed to the rails. It is essential that the base rail is aligned first and fixed in position before the other rail is linked to correct gauge.

(iii) Having reached the predetermined length of track in the above manner, rail closures should be inserted to connect to new track with the old track. Combination fishplates should be used where necessary. The track is then lifted and packed. The traffic block is cleared and the traffic passed at a restricted speed of 15 kmph, after ensuring that all sleepers are supported by initial packing.

(iv) While renewals are being carried out, advantage may be taken of the block period for loading new materials as also for picking up the released materials.

3. *Work During Post Block Period*

(a) During this period the new track is attended by different packing parties at suitable intervals. These parties generally attend to the track in all respects with special attention to:

(i) Squaring of sleepers
(ii) Tightening of fittings
(iii) Gauging
(iv) Fixing of cotters
(v) Packing of the sleepers
(vi) Correction of cross-levels
(vii) Providing correct superelevation, and providing curve boards and pillars for each curve
(viii) Aligning and surfacing
(ix) Boxing and providing full ballast section
(x) Making up cess to correct depth
(xi) And clearing of side drains

(b) The speed restriction should be relaxed progressively after attending to the track as per the schedules laid down in Sec. 15.4. The track will always require attention for some time and additional labour should be provided to help the sectional gangs. Arrangements should be made to remove released materials.

Piece Meal Method of Relaying (*Manual*)

1. *General* In this method through sleeper renewal (TSR) is carried out first. Rail renewal is carried out after the track gets consolidated by three rounds of through packing and also on account of passage of trains. This method can be carried out when the section of the new rail is the same as the existing rail or where 90 R rails are renewed by 52 kg rails in BG.
2. *Preparatory Work Before Relaying involves*:
   - (a) The exact position of rail joints after allowing for one expansion gap each is marked accurately with steel tape on the base rail.
   - (b) Position of new sleepers is then marked on the base rail with white paint and transferred to the opposite rail by means of T-square.
   - (c) A speed restriction of 15 kmph is imposed and temporary engineering restriction boards are fixed at appropriate places.
3. *Work During Block Period*
   - (a) Deep screening is carried out under speed restriction. While carrying out the deep screening work, renewal of sleepers is also carried out simultaneously. The work is so programmed that at the end of a day's work, both deep screening and resleepering is completed in a continuous stretch without leaving any gap.
   - (b) At the end of the day's work, the track is lifted and packed to the final level and suitable ramp provided to meet with the levels of the existing track.
   - (c) After three rounds of through packing, through rail renewal is carried out under suitable short block.
   - (d) The final round of through packing is undertaken and the speed relaxed to normal in accordance with the laid down time schedule.

Note: If adequate blocks are available for carrying out the work of deep screening, both the deep screening and sleeper renewal works are carried out in a continuous stretch. If however, the work is carried out under speed restriction as described above, every fifth sleeper will be renewed leaving at least four inter sleeper spaces in-tact.

4. *Post Relaying Works* During this period, special attention is given to the following items.
   - (a) Attending to the alignment, surfacing, gauging, packing, cross-levels and tightening of fittings.
   - (b) Boxing and providing full ballast section
   - (c) Making up cess to the required depth
   - (d) Providing curve boards over each curve, providing correct superelevation on curves
   - (e) Cleaning of side drains
   - (f) Removal of all released materials and cleaning the site

15.5.4 Essential Points to be Observed During Linking of Rails

1. Correct expansion gap should be provided according to the temperature at the time of laying, in accordance with the existing instructions in the case of SWP. In the case of free

rails (single rails), the recommended initial laying gap for 12/13 m rails length for various temperature ranges for temperature zone no. IV is given in Table 15.7.

Table 15.7

Rail temperature range (°C)	*Recommended initial laying gap for 12/13 m rail length* (mm)
0–10	10
10–25	8
25–40	6
40–55	4
55–70	2
Above 70	0

The liners shall be made of steel and so shaped that the wheels of a train can pass over them. Each liner must have the corresponding expansion space in millimeters stamped on it. Details of a suitable pattern are given in Fig. 15.3. The expansion liners should be kept in position at the joints for at least six rail lengths at a time and the rails butting against expansion pieces.

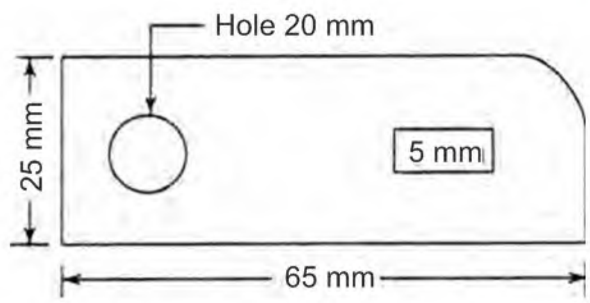


Fig. 15.3 Sketch showing a liner

2. Fishing surfaces of rail and fishplates should be greased before putting the fishplates in position.
3. Bent rails shall on no account be put into the track. These should be straightened with a jimcrow before laying.
4. The rails used at level crossings and station yards should be given a coat of coal tar before laying.
5. Rail should be laid with a cant of 1 to 20 toward the centre of the track.
6. The shortest length of rails to be used in track shall not be less than 5.5 m except as a temporary measure when cut pieces can be used with suitable speed restrictions. Short rail should be laid in yards except where required for approaches of bridges and level crossings.
7. Rail of the same length should be used in pairs.

15.5.5 Track Laying Standards

1. Utmost care should be taken during linking to ensure good quality of work, which on no account should be allowed to suffer.

2. As a good practice, the following laying standards of track geometry measured in floating conditions during primary renewals for broad gauge and metre gauge should be achieved (track laid with new materials). The track geometry will be recorded three months after the speed is raised to normal.

(a)	Gauge	Sleeper to sleeper variation	±2 mm
(b)	Expansion gap	Average gap worked out by Recording 20 successive gaps	±2 mm
(c)	Joints	(i) Low joints not permitted.	
		(ii) High joints not more than	2 mm
		(iii) Squareness of joints on straight	±10 mm
(d)	Spacing of Sleepers	With respect to theoretical spacing	±20 mm
(e)	Cross-level	To be recorded on every 4th Sleeper	±3 mm
(f)	Alignment	(i) On straight on 10 m chord	
		(ii) On curves of radius more than 600 m on 20 m chord variation over theoretical versines	5 mm
		(iii) On curves of radius less than 600 m on 20 m chord Variation over theoretical versines	10 mm
(g)	Longitudinal level	Variation in longitudinal level with reference to approved longitudinal sections	±50 mm

15.6 MECHANISED TRACK RENEWAL

For modern track structure, renewal with heavy concrete sleepers, each weighing one quarter of a ton, would create a difficult problem if mechanical means for their handling and laying are not adopted. It was also realised that a fully mechanised relaying system, in which all the old track is lifted and new track is laid automatically, is not only very costly but also needs long continuous traffic blocks. Such traffic blocks are difficult to obtain on the busy trunk routes of Indian Railways, where the track modernisation work is now in progress. In the early seventies, it was therefore decided to go in for Plasser Quick Relaying System (PQRS) which is partially mechanised relaying system for track relaying.

The equipment in one set of PQRS comprises:

Portal cranes	4 nos.
Sleeper layer	1 no.
Hand operated rail gantries	10 nos.
Track jacks	40 nos.

Over the years, it was experienced that except for the portal cranes, other equipment was not found to be much use. At present, considerable length of mechanised relaying on Indian Railways is done by portal cranes, which helps in lifting the old track panels and lay the new panels in position.

In the earlier design two portal cranes were needed to handle one 13 m panel of rails holding the concrete sleepers. Stronger portal cranes have now been developed which can handle a 13 m concrete sleeper panel individually. With their introduction, it is possible to achieve faster progress in track renewal works, with the same set of equipment.

In the following paragraph, the broad features of portal cranes and method of relaying with them heve been discussed.

15.6.1 Portal Cranes

Each cranes is a self driven four wheeled machine. The wheels are double flanged and move on a track gauge of 3400 mm. For the movement of portal cranes while working, temporary auxiliary rails on both sides of the track to be renewed are laid, well clear of the track sleepers. The bridge of the portal cranes is provided with rails and sleeper pick up mechanism. Each of the portal crane can lift a 13 metre panel complete with CST-9 sleepers and load it on a BFR four to five tier high. As the concrete sleepers are heavier, it needed two portal cranes to lift a 13 metre concrete sleeper panel in the earlier design of portal cranes [Figs. 15.4 (a) and (b)].

Fig. 15.4 (a) Portal cranes laying concrete sleeper

Portal cranes developed to new design can lift such panels individually.

Its sleeper pick up and release mechanism can lift 10 concrete sleepers at a time, which can be employed for unloading of concrete sleepers from the wagons/BFRS at the panel fabrication depots.

The portal crane has retractable legs, which enable it to load and unload from specially modified flat BFR's, without any outside assistance. It is also provided with turnable arrangement so that

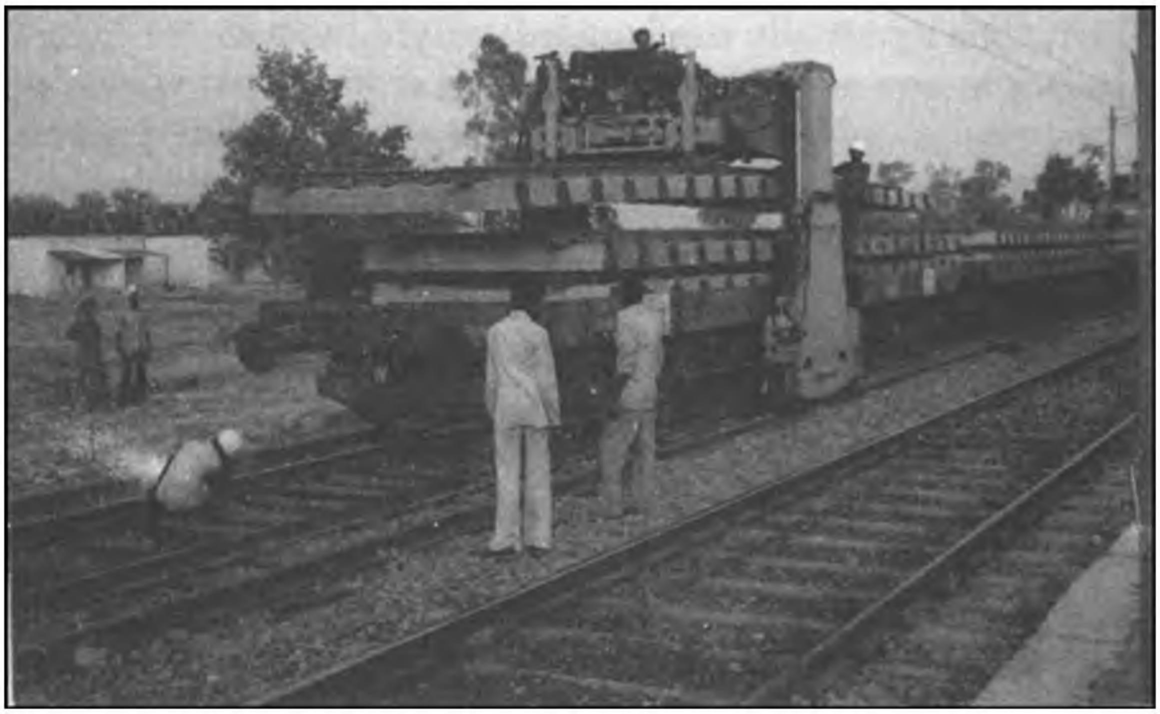


Fig. 15.4 (b) Portal crane licking up concrete sleeper panel

after seating on the special BFR, it can turn over at right angles to secure itself properly for travel within moving dimensions at normal speed.

Other important particulars of the portal cranes are given in Table 15.8.

Table 15.8

S. No.	*Quantifications*	*Older design portal cranes*	*New Portal cranes-model 201*
1.	Overall length	2,914 mm	3,050 mm
2.	Overall width	3,860 mm	3,860 mm
3.	Maximum height above the top of the rail	4,400 mm	4,390 mm
4.	Track gauge	3,400 mm	3,400 mm
5.	Weight	10 tonnes	12 tonnes
6.	Travelling speed	10 kmph	14 kmph
7.	Lifting capacity	5 tonnes	9 tonnes

15.6.2 Operations Connected with Mechanical Relaying

Preparatory Work at Site of Relaying

1. Since concrete sleepers are laid with LWR/CWR, all preparatory works as required for LWR/CWR relaying should be carried out before laying concrete sleepers. In addition, longitudinal section showing the existing rail levels should be plotted and proposed rail level determined, taking into consideration the following points:
   (a) 300 mm ballast cushion is available below the concrete sleepers.

(b) Clearances to structures are maintained within the accepted limits.
(c) The track and the road surface are suitably raised and approaches regraded.
(d) Where lifting of track is not possible at places like below overline structures, on girder bridges and in yards, etc., suitable ramping out should be done.

2. The proposed predetermined rail level should be indicated at suitable intervals along the tracks.
3. Auxiliary track should be laid at 3.4 m gauge keeping its centre line same as that of the existing track.
4. The existing welded rails should be converted into single rail panels of such suitable lengths that the capacity of the portal crane is not exceeded while handling the old panel. If rails are to be reused in track elsewhere, single rail/panels shall be made by cutting at welds for rewelding possibility.

15.6.3 Pre-assembly of Panels

Sleepers received from the concrete sleeper plants are unloaded and stacked at the base depot. Handling of concrete sleepers is done by portal cranes or separate cranes provided for the purpose. These sleepers are assembled into panels making use of service rails. When assembling the panels, elastic fastenings, complete in all respects, should be provided and correct uniform spacings of sleepers should be ensured.

The assembled panels are stacked and are later loaded in BFRs in three to four tiers. Typical layout of a pre-assembly yard is shown in Fig. 15.5.

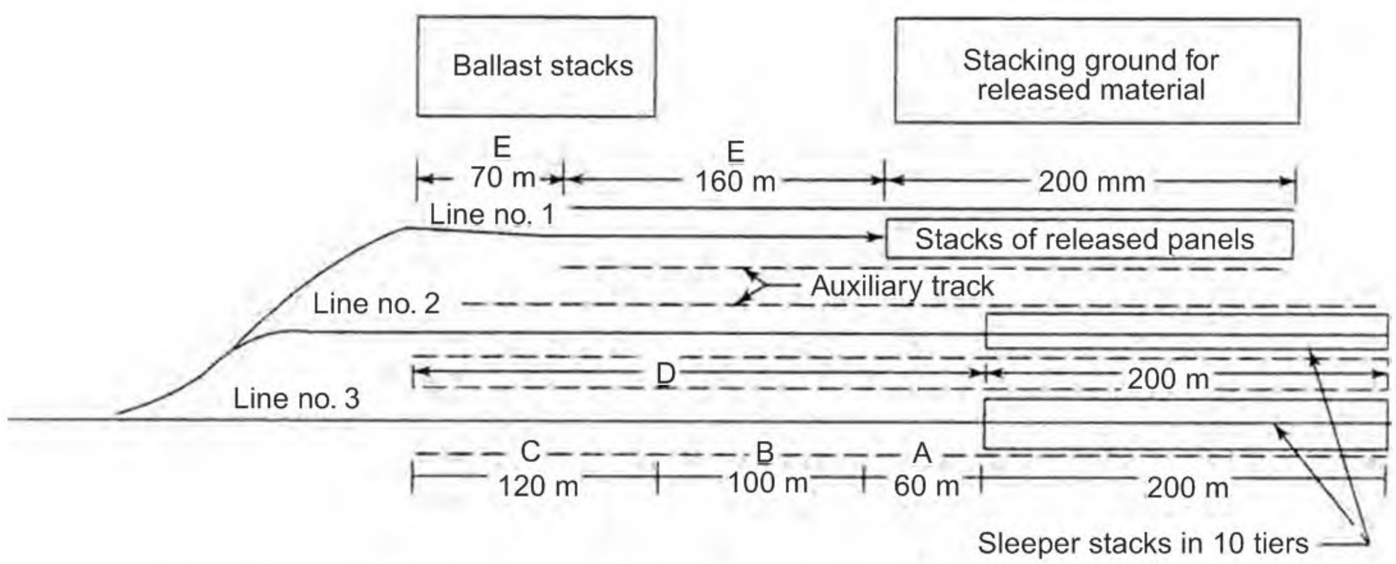


Fig. 15.5 Typical layout of a pre-assembly yard of relaying train

15.6.4 Formation of Relaying Train

The relaying train shall consist of two empty BFRs for loading released track panels, adequate number of BFRs loaded with pre-assembled panels, BFRs loaded with portal cranes; an equipment and tool van, one crew rest van, one brake van and an engine. A typical marshalling order of the relaying train is indicated in Fig. 15.6.

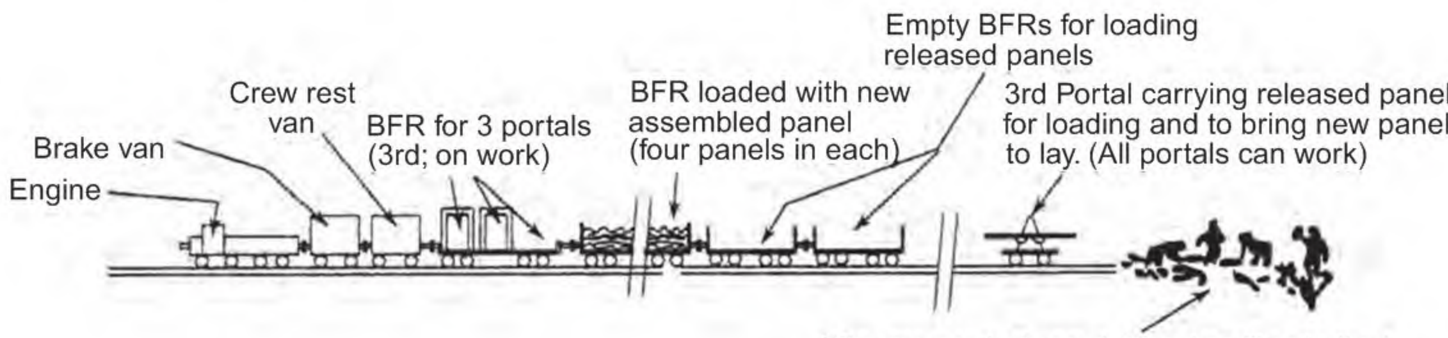


Fig. 15.6 A typical marshalling order of the relaying train for site working

15.6.5 Actual Relaying

A speed restriction of 15 kmph is imposed at the place of relaying and preliminary works such as loosening of fastenings, removal of ballast, etc., carried out in advance. On the day of relaying, traffic block is imposed and the relaying train enters the block section. After the relaying train is positioned, the portal cranes unload by themselves on the auxiliary track. The old track is removed in panels and loaded by the portal cranes on the empty BFRs. The ballast is then levelled and the preassembled concrete sleeper panels are laid in position. The new and existing tracks are jointed by closure rails and sleepers of existing old track. After the last panel is laid, a ramp is made in two rail lengths between the existing track and the new track, running out the difference in longitudinal levels by grading the old track. The relaying train returns to the base depot where the old track panels are unloaded. Figure 15.6 shows the working of the relaying train at the relaying site.

15.6.6 Changing of Service-Rails with End Unloading Rakes and Other Post-Relaying Works

In subsequent blocks, the service rails are replaced by welded panels. This replacement should be done with the help of end loading rakes as far as possible, if kinks in the welded panels and other damage to the new rails are to be avoided.

To minimize the number of Thermit Welding joints the new rails are welded into 15/20 rail panels at red Flash-But Welding Plants. Transport and unloading of these panels can be best done with the help of end-loading rakes. The rails on these rakes rest on rollers, 3/4 tier high, each tier having about 14 rails. For unloading purpose, two rails at a time are threaded through a special end unloading threader and tied to the track. The rake is slowly pulled forward by the engine and rails are unloaded on both sides of the track. With proper gadgetry, the rails can also be directly placed on the sleepers. Figure 15.7 shows the end unloading rake and how the rail panels are unloaded from these rakes on to the track.

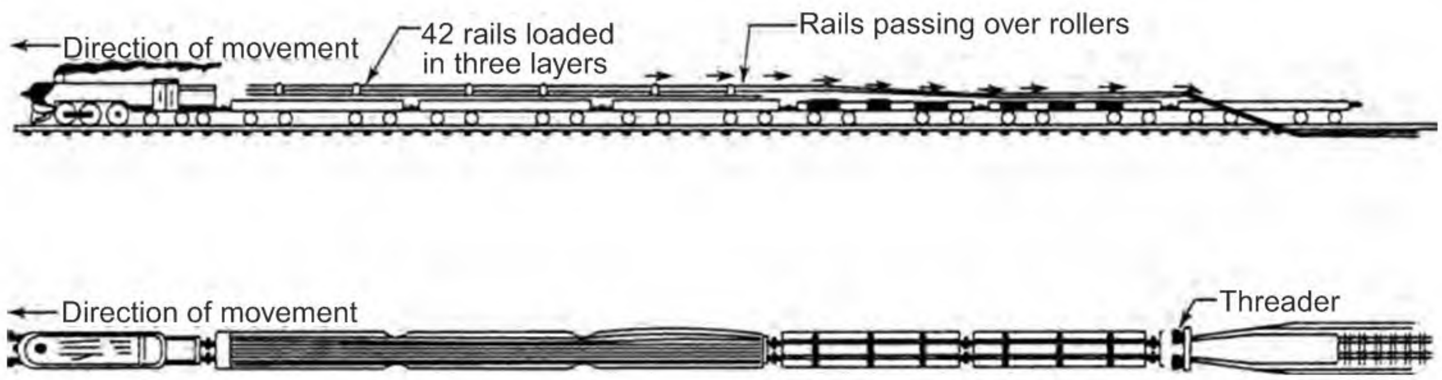


Fig. 15.7

The newly laid track is tamped and speed restriction removed as per the schedule mentioned in Sec. 15.4. Before resuming the speed to normal, provision of proper LWR ballast profile should be ensured.

15.7 TRACK RELAYING TRAIN: PQRS AND ITS LIMITATIONS

Track renewal using PQRS is being extensively carried out on Indian Railways for the laying of concrete sleeper tracks. With the picking up of the production of MG concrete sleepers, PQRS is being used for MG track relaying as well. The equipment is being manufactured totally indigenously, which has helped in organizing proper repair and maintenance facilities for the equipment.

The system, however, is beset by the following shortcutting and limitations.

1. Auxiliary track needed for the movement of portal cranes increases the work load significantly. Labour requirement for its handling, shifting and linking is considerable.
2. Service rails are required for laying panels, which further add to the manpower requirement during the track relaying operation.
3. In the limited time interval when the old tracks are picked up and the new track panels are placed in position, the ballast bed has to be levelled manually. This is a very fatiguing and hazardous job.
4. Sleeper renewal cannot be done independently with PQRS.
5. During track renewal operation, strict speed restriction of the order of 15 kmph has to be imposed. Long lengths of track remain under speed restriction, which affects the mobility of the section adversely.
6. The productivity per hour of traffic block is low, particularly considering the busy routes where traffic blocks cause considerable dislocation of traffic and are therefore difficult to get.

In an effort to overcome the limitations of PQRS, Indian Railways have procured track relaying trains. These are deployed on busy routes so that the progress of track renewal per hour of traffic block can be maximised.

15.8 TRACK RELAYING TRAIN–P-811S

Track Relaying Train (TRT)–P-811s is supplied by tamper corporation of USA in collaboration with Phooltas Tamper of India. It is a high output relaying machine and a step towards complete mechanisation of track renewal process. It does not require any service track and there is no need of fabricating panels in the base depot as required in case of relaying by portal cranes. Concrete sleepers to be laid in track are loaded in modified BRH wagons and laid at site one by one, after picking each old sleeper following removal of old rails. New rails unloaded at site in advance are inducted in track after sleeper renewal.

Distributed over its length in sequence of renewal operations TRT performs the following functions in crawling motion.

1. Threads out old rails (after unfastening from sleepers)
2. Picks up old sleepers
3. Levels and compacts ballast bed
4. Laying new sleepers
5. Threads in new rails
6. Places sleeper fittings on sleepers (to fasten the rail)

TRT can be used in one of the following modes:

1. Complete track renewal
2. Replacement of sleepers only
3. Replacement of rails only

Composition of TRT and placement of Renewal Mechanism in it is shown in Fig. 15.8.

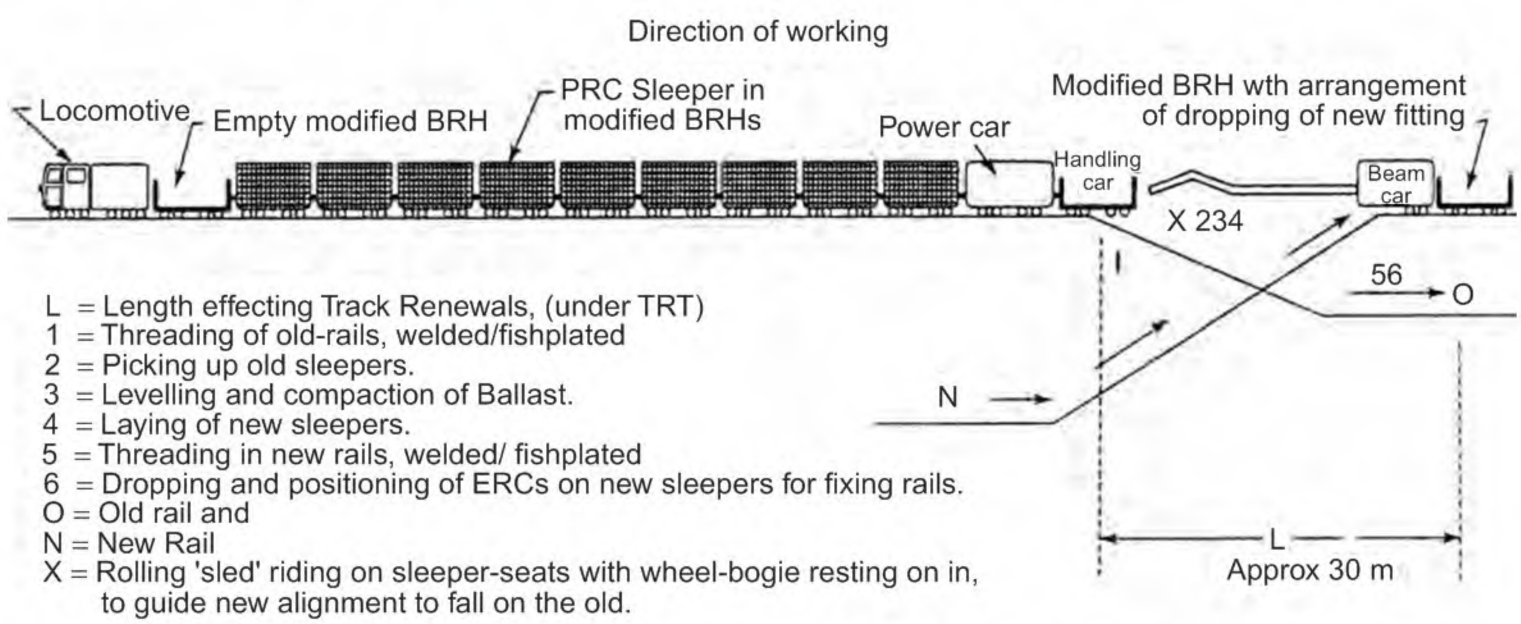


Fig. 15.8 Composition of ART with modified BRHs and track renewal mechanism

The mechanism of sleeper renewal is shown in Figs 15.9–15.11.

15.8.1 Other Allied Machines and Special Rolling Stock

In addition to main machine (TRT), following other equipments have also been procured.

1. Two gantry cranes
2. Lip cutter

Fig. 15.9 Picking of old sleepers and laying of new sleepers

Fig. 15.10 Changing of rails (See also Color Plate 10)

3. Clip applicator
4. Rail pick up unit (UTV)
5. Modified BRHs

Gantry Crane Gantry cranes are portal cranes, which run over BRHs on a track of 3 m gauge. The rails for the track are fastened on the outer sides of the BRHs, which are specially modified to hold the rails in position. Gantry cranes which run on the BRHs feed new sleeper to the TRT machine and on return carry old released sleepers. In one trip, a gantry crane can carry about 20 concrete sleepers.

Lip Cutter To cut reverse jaws of CST-9 sleepers, lip cutter is used. It has two abrasive discs and can cut the lip of reverse jaw CST/9 sleepers. Lip cutter is a self propelled machine.

Clip Applicator Clip applicator is a self propelled machine capable of driving in position all the four Pandrol Clips of a sleeper simultaneously.

Rail Pick Up Unit (*UTV*) Rail pick up unit is an auxiliary unit for picking up released 13 m long rails. It is a road crane mounted on the floor of a BFR wagon and hauled by a dedicated locomotive having capacity to pull a load of 300 t at a speed of 45 kmph. The crane has been designed to lift single rails from cess and load the same in adjoining empty BFR wagon attached with the unit. It can load 50 rails per hour.

Modified BRHs Concrete sleepers for working of TRT are loaded on modified BRHs having auxiliary track of 3 m gauge on the side of BRHs. In each BRH, concrete sleepers are loaded in two stacks of four layers each. Each layer of sleepers is separated by wooden battens of 75 mm × 75 mm size. Proper gap between two layers of sleepers is necessary so that jaws of gantry crane can reach between the two layers for picking up of the sleepers. About 160 sleepers can be loaded on each BRH.

To have continuous path between two BRHs for the movement of gantry cranes, one detachable bridge is provided. This bridge is fixed at one end and has sliding arrangement at the other end so that it takes care of movement of BRHs on curves.

Base Depot Similar to PQRS depot, one depot is also required for working of TRT. The base depot required for TRT work should have two lines of about 600 m length and one line of about 300 m length. In addition, there should be a shunting neck so that for any shunting work in base depot, no running line is required to be blocked. On two lines of 600 m length, concrete sleepers for about one week's work are stacked and on third line, loading of released sleepers is done. One base depot can easily be used for renewal of 60–80 km of track on either side.

Advance Preparations for Working of TRT Sleepers are loaded in modified BRHs in the base depot which are attached to TRT machine. In addition, in one BFR/brakevan, fittings (ERCs, liners and rubber pads) are loaded. TRT rake so formed is taken to site of work by a locomotive.

New rail panels unloaded in advance at site of work are pulled so as to close the gap between two panels. Panels are fishplated in the length of day's work. These rail panels are placed parallel to existing track with rail foot down. Rail panels are placed near the shoulders of sleepers.

Before the arrival of TRT rake at site of work, about 50 percent of the fastenings of the sleepers are removed and remaining inside fittings are removed after the arrival of TRT rake at site. Balance outside fittings are removed at the time of working, just before arrival of power car of TRT machine.

A cut is made in both the rails at a distance of about 9 m from the point of start of relaying. Also, crib and shoulder ballast of first eight sleepers from the starting point is removed to create the necessary conditions for laying new sleepers after picking up the old sleepers.

In case, a level crossing is falling in the day's work, the road surface is dug up in between the rails and up to one metre on either side of rails. Road surface material is removed in this portion up to top of the sleepers. Also check rails are removed.

In case, there exists any Switch Expansion Joint in old track, it should be replaced by ordinary rails.

In summers, the old rails are destressed at higher temperature so that track rails do not buckle when fitting are removed for TRT working.

Requirement of Block Out of the total traffic block permitted for working of TRT, about 90 minutes of block period is utilized for following non productive operations:

1.	Running time for TRT rake to the site of work from the nearest stabling station.	:	20 minutes
2.	Setting of machine in working mode at the start of work	:	25 minutes
3.	Winding up of machine and restoration of track at the close of work	:	25 minutes
4.	Clearing the block section	:	20 minutes
	Total	:	90 minutes

Staff Requirement In addition to the staff required for the operation of various TRT equipment, Permanent Way Supervisors and gangmen are required for following operations of working of TRT:

1. For removing eight sleepers manually at the start of work, supporting rails on rollers, restoration of track at the close of work, etc.
2. Removing sleeper fastenings for working of TRT, etc.
3. Fixing of liners and ERCs in position on concrete sleepers, dropping of fittings form BFR, correcting spacing and squaring of sleepers, etc.
4. Placing rubber pads on rail seats of sleepers.
5. Connecting rails with fishplates.
6. Gas cutting of rails.

Sequence of Machines Along with TRT, various other self propelled machines also go to site of work. Prior to this all these machines are marshalled in following sequence on the loop line of the nearest station wherefrom these machines enter in the block section.

1. Lip cutter, if working on CST 9 sleepers track.
2. TRT rake with locomotive in the direction of work.
3. Clip applicator.
4. Ballast regulator.
5. Rail pick up unit (UTV).
6. Tie tamping machine.
7. Dynamic track stabiliser.

Progress of Relaying by TRT TRT system has been designed to lay sleepers at a rate of 10 sleepers per minute on an average with peak performance of 16 sleepers per minute. If there is no interruption during working of TRT, about 1,500 sleepers can be laid in a gross block of four hours.

Speed Restriction at Work Site Soon after relaying at TRT work site, trains are permitted to run at 40 kmph even without tamping of relaid sleepers. The speed is increased to 75 kmph on following day after one round of tamping. Trains are permitted to run at normal speed (100 to 120 kmph) after training out of ballast followed by second round of tamping.

Special Features of TRT

1. No auxiliary track is required for working of TRT.
2. No power block is required for working in electrified sections.
3. It reproduces existing track geometry. No adjustment/setting is required for working on curves, etc.
4. New sleepers can be laid at desired spacings.
5. Track adjoining high level platform can be renewed without any special efforts.
6. Track centres can be reduced/increased by 100 mm.

In view of the high output per effective traffic block hour and superior geometry of track soon after relaying works, TRT provides a superior method for relaying of track. Given its high initial cost, economic benefits from TRT can only be obtained by obtaining regular traffic blocks for its working.

The average progress per month from these machines so far has been of the order of only 6 to 7 km per month, thus requiring considerable additional attention from the management to maximise its output.

15.9 SLEEPER CHANGER

For replacement of sleepers in the track, Indian Railways have purchased a few Tie Replacers from Kershaw. Tie Replacer can remove or insert wooden or concrete sleepers up to 5.49 m long. Important features of tie replacer are as follows:

1. Tie Replacer can retrieve and insert ties placed beyond the toe of the shoulder slope.
2. Rail clamping, lifting and tie kicking sequence is automatic when operator presses one pedal.
3. Single operator control of inserting and extracting ties.
4. With optional flipper feature, the inserter/extractor head can work at almost any angle from the track to allow tie insertion/removal over third rails and against steep banks.
5. Excellent visibility of work area.
6. Automatic hydraulically applied brakes in work mode provide easier and quicker indexing for tie insertion/removal.
7. Optional turntable allows turning machine without using crane.

For bringing the sleepers from the stacking area to the track sleeper, handling crane is often required. Indian Railways have therefore purchased tie cranes also to work along with the tie replacers. The tie crane has a lifting capacity of about 400 kg at 7.5 m from the track centre.

The tie replacer and tie crane are best used for quick replacement of sleepers damaged by a train derailment. They can be usefully employed for isolated replacement of sleepers as well. Sleeper changer is shown in Fig. 15.11 and Tie crane in Fig. 15.12.

APPENDIX 15.1

Justification for Complete Track Renewal

Division ____________ Section ____________ From km ____________ to km

1. Railway ____________
2. Total service traffic carried so far (GMT) ____________

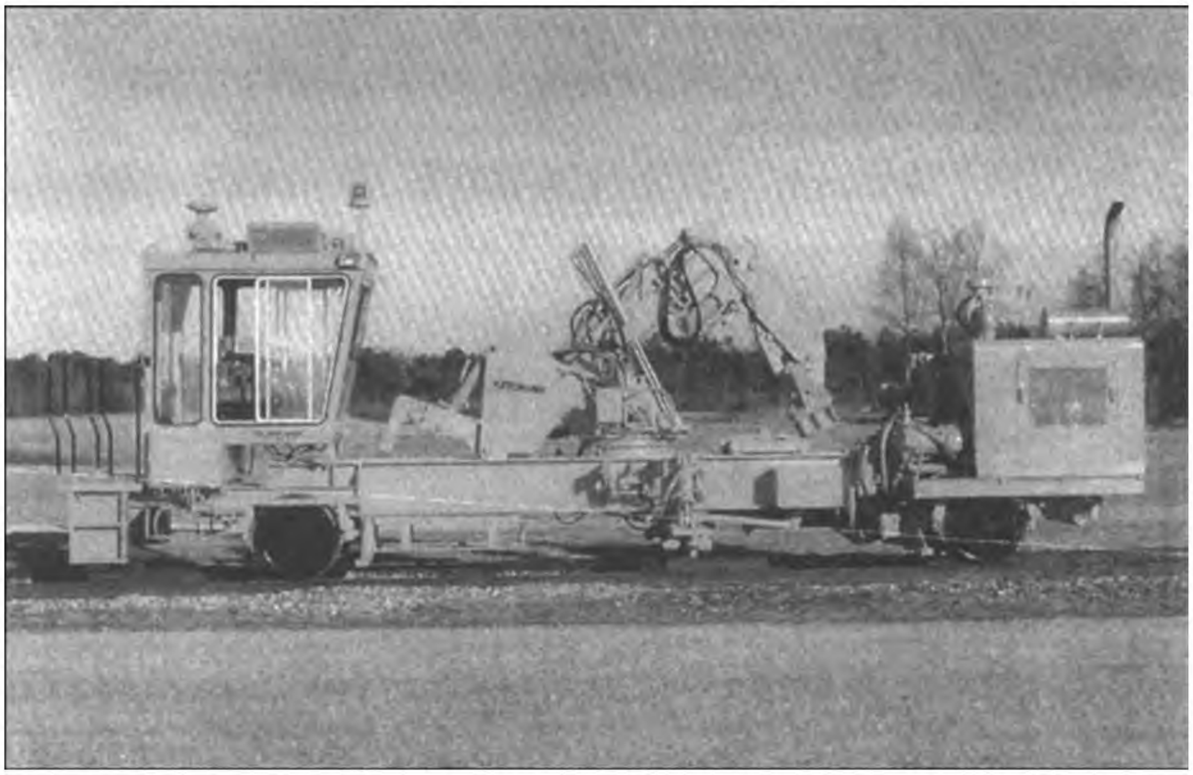


Fig. 15.11 Sleeper changer

Fig. 15.12 Sleeper crane

3. Present Annual Traffic Density (GMT): Single Line ____________
4. Present Nature of Traffic:
   (i) Average No. of trains per day ____________
   (ii) Max. permissible speed: ____________

(iii) Heaviest locomotive in use: Type ____________ Axle load ____________

5. Present track structure: Rail ___________ Sleepers __________ Density ___________

OBSERVATION

S. No.	*Item*	*Running kilometers from The beginning of the Proposed renewal (excluding loops and sidings in yards)* 0-1 1-2 2-3 3-4	*Designation of the Official recording observation*

1. *Rails*
   - (a) Type
   - (b) Age
   - (c) Percentage wear of rails
   - (d) Corrosion (mm) (also gives condition regarding pitting etc)
   - (e) Rail failures (during Last 5 years)
     - (i) Rail ends (nos)
     - (ii) Manufacturing (nos)
   - (f) Rail ends
     - (i) Hogged % age/km
     - (ii) Battered % age/km
   - (g) Scabbed rails: % age/km
   - (h) Other defects (corrugation etc):
2. *Sleepers*
   - (a) Type
   - (b) Age
   - (c) Condition
   - (d) Unserviceable (% age)
3. *Ballast cushion* (*cm*)
4. *Formation*
   - (i) Soil
   - (ii) Condition
   - (iii) Treatment proposed, if any
5. *Casual renewals:* (*during last 3 years*)
   - (i) Rails (nos)
   - (ii) Sleeper (nos)

Chapter 16

Modern Track Construction

16.1 MODERN TRACK CONSTRUCTION

Modern track construction is characterised with the employment of sophisticated techniques of surveying, increased use of modern geo technology for the preparation of sub grade and the deployment of computer controlled construction machinery in obtaining a highly accurate railway alignment and a long lasting track structure.

16.2 CONVENTIONAL RAILWAY LOCATION SURVEY

This consists of:

(a) Marking of the railway alignment on topographical sheets taking into account the obligatory points such as connectivity to important places and crossing of major rivers and other natural obstructions. The track design parameters in respect to grades and curves are duly taken into consideration for marking of the new alignment.

(b) Field survey parties are organised to mark out the centre line of the alignment using conventional survey instruments.

(c) Final location survey is carried out for picking up the details of all the construction work that would be required to be carried out for the new railway line.

The method is very labour intensive. At times, a number of alternate routes are surveyed to arrive at the optimal alignment.

16.3 MODERN SURVEY TECHNIQUES

Modern survey technology employs satellite imageries, aerial photographs and digital terrain modeling in arriving at the final location for the new railway line.

Satellite imageries with very high resolution are available for almost all places around the globe. These imageries are very useful in marking out any new alignment of railway line. Satellite imageries can also help in generating topographical data of the route. Once a rough alignment is obtained, aerial photographs can be used for further improvement to the alignment. With the help of topographical sheets and the inputs obtained from satellite imageries, and aerial photographs, digital terrain models can be generated. These models help in further refining the alignment to arrive at the most optimal solution satisfying all the design criteria and bringing down the construction costs.

In unchartered areas, customized aerial survey can be arranged for evolving the contour plan of the area.

Most of this work can be done from the office desk without undertaking hazardous journeys to the site of work. Field visits will of course be necessary once the decision to construct the new railway line has been taken and hydrological and geological data has to be collected for carrying out the structural designed work.

16.4 GEO TECHNOLOGY IN AID OF SUB GRADE PREPARATION

Considerable advancements have been made in the field of geo technology. It is extensively used in the design of sub grade for railway lines and helps in obtaining a trouble free sub-grade.

Quite often, the natural soil is not good enough to provide stable foundation for the railway track. Following are some of the techniques employed in strengthening the formation.

(i) *Vibratory surface and deep vibro-compaction* surface vibratory compaction is used for densification of loose cohesion-less soils using vibratory roller. Deep vibro-compaction can be done for the loose sandy deposits having less than 15% of fines for depths up to 10m. Compaction is carried out by inserting the probe up to the design depth of improvement and allowing the soil around the probe to get compacted for a certain time interval.

(ii) *Removal and replacement* For localized areas with soft soils of limited depth and thickness, removal of unsuitable material and replacement with suitable fill may be carried out.

(iii) *Preloading* Preloading of soft soils is based on the consolidation concepts, whereby pore water is squeezed from the voids until the water content and the volume of the soil are in equilibrium under the loading stresses imposed by the surcharge.

(iv) *Prefabricated vertical drains and pre-loading* with increased thickness of the soft clay where the consolidation period is too long for full consolidation of primary settlements, vertical drainage may be incorporated in conjunction with preloading in order to accelerate the settlement.

(v) *Dynamic replacement* Dynamic replacement utilizes a heavy pounder, usually lifted by crane to a designed height and then dropped onto the soil in a grid pattern such that the site is adequately covered.

(vi) *Stone columns* Stones columns may be provided in areas where subsoil consists of more than about 5 m thick soft cohesive soil and where stability and stringent considerations cannot be satisfied with conventional removal/replacement of soft material.

(vii) *Piled embankment and viaduct* In soft soil areas, embankment height exceeding the pre-consolidation pressure will give rise to excessive settlement. This can be avoided by means of structural solutions such as viaduct or piled embankment. Structural solution is recommended in soft ground conditions with depths exceeding 15 m.

16.5 MAJOR CONSTITUENTS OF TRACK WORK

Once the sub-grade has been prepared to the desired standard, further track work constitutes of the following elements.

(i) Procurement and placement of stone ballast in layers of appropriate thickness. The provision of sub-ballast/blanket forms a part of substructure.
(ii) Transport, handling and placement of concrete sleepers at appropriate places.
(iii) Transport, handling, laying and fastening of rails in a coordinated manner.
(iv) Lifting, leveling, lining and tamping of track (first round).
(v) Spreading additional ballast in track in appropriate manner.
(vi) Lifting, leveling, and lining and tamping of track (second round).
(vii) Further distribution of ballast to form the correct ballast profile.
(viii) Welding of rails into long/continuous welded rails, followed by de-stressing of rails.
(ix) Final round of tamping.

16.6 MECHANISED TRACK CONSTRUCTION

Various methods of mechanised track construction have been adopted by track construction organisations around the world depending upon the local construction environment, such as:

(a) Volume of work
(b) Availability of skilled man power
(c) Desired quality standards
(d) Available track laying equipment

In India, most of the track construction work has so far been carried out by using simple road based equipment. Only after the track is manually laid, on-track tamping machines, borrowed from the open line track organization are deployed for giving final rounds of tamping. In this method, inspite of the deployment of tamping machines there is a considerable degree of compromise on the quality of track produced.

Manual handling of heavy track materials is not only hazardous for the labour but track components also get damaged, particularly the concrete sleepers and high UTS long rails. In the following paragraphs, two methods of mechanized track construction have been described. In the first method, simple track machines which can be transported by road from one construction site to another are used. IRCON (International), a public sector company has been progressively using this method in their railway construction works. The second method makes use of complete track laying trains which carry out track laying operations, all automatically.

16.6.1 Mechanised Track Construction Using Simple Portable Track Laying Equipment

The procedure adopted in this method is as follows:

- First, a layer of 100 mm of ballast is placed on the prepared sub-grade. For this purpose, road based equipment is used for the transport, loading and distribution of ballast. Concrete paver type of equipment has been successfully used for the spreading of the ballast. The road dumpers are used for the transportation of ballast from the ballast stacks to the distributing equipment.
- New rails brought on road trailers, in single rail lengths or 2/3 rail panels, are brought to the site and placed gently on the ballast at 3400 mm gauge, with the help of road cranes. The rails are without holes, joined together using fishplates and bolted clamps.
- Robel's sleeper laying unit PA 1-20 ES (Fig. 16.1) can be used for the transport and placement of concrete sleepers in position. The sleeper layer moves on auxiliary rails earlier laid at 3400 mm gauge. The sleeper layer is supplied with concrete sleepers from the sleepers stacks with a road crane. Earlier, the sleepers are stacked at suitable locations along the line, after transporting them from the concrete sleeper manufacturing plant in road/rail vehicles – Weight of sleeper layer 15 t—Progress 140–160 m/hour.

Fig. 16.1 (See also Color Plate 10)

- After sleeper laying in a certain portion of track is completed, rails are placed on the sleepers, with the help of Robel's Rail threader—43.32 0 (weight 1.5 t) Fig. 16.2 or Robel's rail movers 43.02 Fig. 16.3 (weight 115 kg).

Next operation is to lift, level and align the track. This is carried out with the help of Robel's equipment no. HGR 47. 230 (Weight 1.5t) (Fig. 16.4). This is followed by first round of tamping.

Fig. 16.2 (See also Color Plate 10)

Fig. 16.3 (See also Color Plate 11)

Fig. 16.4 (See also Color Plate 11)

- For initial lifting, leveling, aligning and tamping of track, Plasser tamping machine-Minima 2 (Weight 7.5 t) (Fig. 16.5) can be deployed—Progress 100–120 m/hour. This is followed by spreading of additional ballast using self-propelled rail mounted dumpers. Further lifting, leveling and slewing of track is again carried out using Robel's equipment no. HGR 47. 230. Second round of tamping of track is then carried out with Plasser tamping machine- Minima 2.

Fig. 16.5 (See also Color Plate 11)

- Once the sleepers are well consolidated, welding of rails into long rail lengths can be done using Mobile Flash Butt welding plants/Alumino Thermit Welding. This is followed by destressing of rails. At this stage, a third round of tamping with Minima 2 can be given if required.
- For obtaining the correct ballast profile, a ballast-profiling machine can be used.
- For final round of tamping, self-loading tamping machine Plasser 08-275zw (weight 30 tonne) (Fig. 16.6) can be deployed. This machine can be transported on a road trailer from one construction site to another. After this tamping operation, the track should be fit enough for regular operation.

16.6.2 Mechanised Track Construction Using Continuous Action Track Laying Machine

M/s Plasser & Theurer SVM 1000 S (Fig. 16.7) is one of the high capacity track laying machine. The important features of this machine are as follows:

(1) It can place the sleepers automatically at a specified spacing.
(2) It carries the rails and can unload them on the track-less area ahead of the machine.
(3) During travel from one work site to another, the equipment is conveniently placed on standard railway flat-bed wagons.

Main Components of the Machine

(a) Laying Machine
During work the front of the laying machine runs on the crawler track and the rear end is supported on the transport wagon.

Fig. 16.6 (See also Color Plate 12)

Fig. 16.7 (See also Color Plate 12)

Conveyor belts take the sleepers brought by the gantry crane to the laying unit. The sleepers are aligned exactly before being laid in the pre-selected spacing.

Rail guide clamps thread the new rails onto the base plates. Guiding rollers and rail conveyor units are mounted on the laying machine for transporting the new rails in front of the laying machine- coming from the rail transport wagon.

Lifting rams and auxiliary undercarriages enable the laying machine to be unloaded and loaded quickly and simply at the start and end of work.

A reference wire spanned at the side serves as a geometrical reference base to control the machine.

In front of the laying unit there is an enclosed, soundproofed operator cabin, which houses the control units. Another cabin is located in the area where the rails are positioned on the base plates.

The laying machine operates fully hydraulically and is powered by a diesel engine. Apart from the sleeper laying unit, details of the other individual elements of the laying machine are as under:

I. Gantry Crane

The gantry crane is used to transport the sleepers from the sleeper transport wagon to the laying machine. It transports up to 20- sleepers at a time, running on crane rails which are fixed on the sides of the wagons and on the rear section of the laying machine.

There are also rail holding devices mounted on the crane. These are used at the start of work to thread the front ends of the rails into the rail guiding rollers mounted close to the crane rails.

II. Drive Unit

To be able to perform the necessary manoeuvring runs on the worksite without the need for a work locomotive, it is possible to integrate a drive unit into the SVM 1000S. This consists of a bridge-shaped frame with a power supply unit and two 2-axled bogies. Both axles of a bogie are powered hydrostatically. Due to the special frame design it also offers the possibility to store rail fastenings and to insert them in this area.

III. Rail Pulling and Conveying Device

With the help of two cable pulleys, a rail support roller and rail guide rollers, two rails at a time are transported from the rail carrying wagons to the rail conveyor units, which push the rails to the laying machine. Two pairs of rail clamps are positioned to deflect the rails from the rail conveyor units to the rail guiding rollers mounted on the sides of the wagons.

All drives and movements are powered hydraulically. A separate diesel engine with hydraulic plant is installed for the power supply. Just before the rail conveyor units, the individual rail lengths are joined together using special clamping fishplates.

At the start of work the front ends of the first rails are threaded into the rail guiding rollers with the help of the gantry crane.

IV. Tractor for Pulling Long Rails

In the trackless area the long rails are pulled forward by a tractor equipped with rail clamps.

Sequence of track laying operations with SVM 1000 S Following will be the sequence of operations for carrying of track with SVM 1000 S track laying machine.

- A ballast layer of about 15 cm thickness is created over the sub grade by using road based ballast distribution equipment.
- The track laying train with integrated rail supply unit is moved to the construction site. The Crawler unit of the track laying train unloads itself from the transport wagon. The rail pulling and conveying unit pulls the rail from the rail wagons and moves the rails across the track laying machine to the front of the machine. The rails are pulled forward by a tractor and laid on the ballast. The machine then starts its work and lays the concrete sleeper at regular spacing. As the machine progresses with the laying of sleepers, the rails are brought in position on the concrete sleepers. The track laying machine is continuously fed with concrete sleepers by the portal crane, which picks up the sleeper from the sleeper wagons and places them on the conveying belt.
- After the rails are placed in position, elastic fastenings are tightened using simple track tools.
- The laying of track is followed by tamping with on-track tamping machines.
- More ballast is then brought to the laying site and is placed in layers of 10 cm's each followed by further tamping and consolidation.
- The rails are converted into continuously welded rails and destressed once the track is properly consolidated.
- For obtaining good progress, it is desirable to set up track laying depots at regular intervals, from where the machine will be brought to site for carrying out its operations. The concrete sleepers can be stacked in these depots and arrangement for mechanical loading of sleeper is made in these depots. The rails can be brought from the rolling mills adopting "*Just in time*" concept of supply of rails.

Advantages of the SVM 1000 S

- Flexible range of application as units can operate separately
- New track is laid in continuous working action
- Laying of long rails
- Simple unloading of long rails in the trackless area
- Exact radial laying of sleepers
- Automatic laying of sleepers at the pre-selected sleeper spacing
- High tractive force thanks to crawler track
- No work locomotive needed during working operation
- The SVM 1000 S is mounted and transported on standard flat-bed wagons
- Careful handling of the rails and sleepers being laid
- Short time needed for setting up and closing down
- High performance and high quality standards.

17 Chapter

Track Tolerances, Track Inspection and Track Recordings

17.1 TRACK TOLERANCES

For the safe, smooth and comfortable running of the vehicles over the track, it is necessary that the track irregularities are kept to the bare minimum. The track parameters which have significant contribution in this respect are alignment, cross-levels, twist unevenness and gauge.

Even with the best system of track construction and maintenance, it is practically impossible to ensure that all track parameters remain absolutely true to their requirements at all times. The variations which can be permitted to these parameters have, therefore, been laid down by various railway systems, and they are termed as 'Track Tolerances'.

Track tolerances are of various types, depending upon the objectives they are required to fulfill. Important among these are given below. Their graphic illustrations representing their interrelationship is at Fig. 17.1.

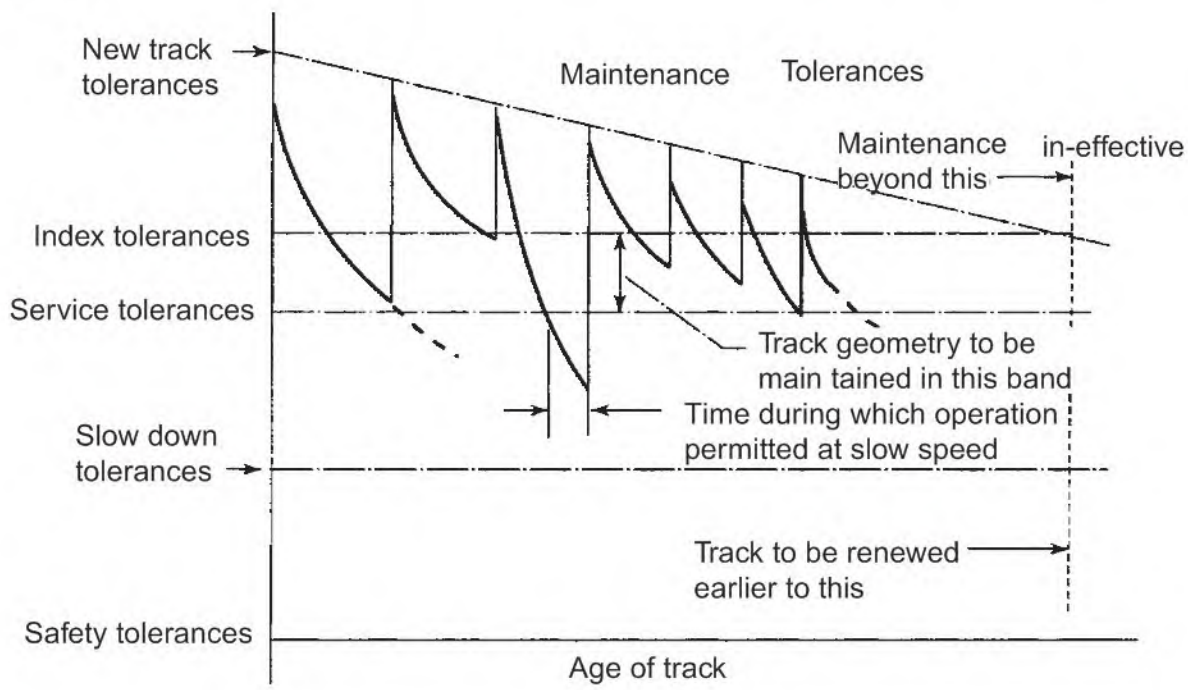


Fig. 17.1

17.1.1 Safety Tolerances

These would furnish the limits of variations in track geometry, which when exceeded can lead to unsafe conditions for vehicle which in turn depend upon so many complex and indeterminate factors that it has not been possible for any railway system, so far, to lay down these tolerances.

17.1.2 New Track Tolerances

These give the limits of variations in track parameters which could be permitted in newly laid track. These have been discussed in Sec. 15.5.

17.1.3 Maintenance Tolerances

Whenever a track maintenance unit works on a particular portion of track, it is expected to be brought to a reasonably good standard. The achievable standard of track, will depend upon the condition of track materials, the type of tools used, the effort of the labour or the operator in case of mechanical maintenance and the quality control exercised by the supervisor. Maintenance tolerances would indicate the limits of variations permitted, just after the track is attended to.

No such tolerances have been laid down in the Indian Railways for manual maintenance of track. For mechanized maintenance with on-track tampers, maintenance tolerance of $\pm$ 2 mm for alignment, cross-level and unevenness has been laid down when measured in floating condition.

17.1.4 Service Tolerances and Slow Down Tolerances

Service tolerances would express the extent of irregularities that can be permitted in the track geometry at any time during its service. These limits are generally fixed for riding comfort and on economic considerations, and are much closer than what could be permitted purely for safety considerations. Track maintained to better standards, provides a comfortable ride and indeed is cheaper to maintain, causes less damage to the rolling stock and has a longer life. After detailed studies conducted in connection with the running of the *Rajdhani Express*, service tolerances have been laid down in the Indian Railways for the maintenance of track for general operation of the WDM 4 Diesel electric locomotives and Indian built ICF all-coil coaching stock, at a maximum permissible speed of 130 kmph. These tolerances are now taken as guidelines for the maintenance of all BG trunk routes and mainlines, which have a potential of high speed trains.

Similarly, service tolerances have been laid down for MG 100 kmph routes.

If due to some reasons it is not possible to maintain track according to the service tolerances laid down for the maximum permissible speed of the section, the trains are required to be slowed down. Some of the railway systems have laid down track tolerances for various stages of slow speeds. Such tolerances are named as *Slow down tolerances*. Indian Railways have not laid down any such tolerances so far.

17.1.5 Index Tolerances

To ensure that the track irregularities in service do not exceed the limit laid down for service tolerances, it is necessary that the track is attended to sometime before service tolerances are reached. In directed system of track maintenance, such tolerances have been laid down and are called Index Tolerances. Only the portion of track where the index tolerances are exceeded is attended to.

17.2 SERVICE TOLERANCES LAID DOWN IN INDIAN RAILWAYS

17.2.1 Broad Gauge

As mentioned earlier, service tolerances have been laid down in the Indian Railways for the maintenance of track on Rajdhani routes, and these tolerances are now taken as guidelines for other BG trunk routes and mainlines.

Tolerances for the following track parameters, measured in the manner described below, have been laid down.

Alignment For alignment, the limits have been laid down for the versines measured on 7.5 m base. When taking ground measurements, a cord 7.5 m in length is stretched along the running face to the rail and versine at the centre of the chord is measured. Separate tolerances have been laid down for straight and curved track. These variations can be either on floating (unloaded) track or on loaded track.

Cross-levels The relative difference in the level of the two rail tops at the same location across is measured with the help of a level board and a sensitive spirit level. Cross-levels are also measured with the gauge-cum-level instruments supplied to MSP gangs. To get realistic picture, cross-level is supposed to be measured under load, which is difficult for ordinary gangs.

Twist While the rolling stock can absorb wide variations in cross-levels, they are sensitive to the sudden changes in cross-levels. This change of cross-levels in a certain length of track is called *Twist of track*. Twist measurements are made on loaded track, by determining cross-level variation over an interval of 3.5 m. If, for example, the difference in cross-levels measured at two places on track –3.5 m apart is –7 mm, the track has a twist of 2 mm per metre.

Unevenness The vertical depression of a rail at the centre of a given base is termed as unevenness. The unevenness is measured separately for each rail on loaded track in a base of 3.5 m. For measuring unevenness of rail joint, the relative depression of the joint with respect to the line joining two points at a distance of 1.75 m on either side of the joint, under loaded condition, is to be found out. This is automatically done in the track recording cars, and can also be determined with the help of fleximeters.

Gauge This is measured as the minimum distance between the running or the gauge faces of the two rails.

Service tolerances laid down in Indian Railways for sanctioned speed above 100 kmph and up to 140 kmph on BG, are as follows:

	Parameter	*Generally*	*In isolated locations*
1.	Alignment (Versine measured on 7.5 m chord)		
	(a) Straight track	±5 mm	±10 mm
	(b) Curved track	±5 mm	±7 mm
	(Total change of versine from chord to chord should not exceed 10 mm)		
2.	Cross-level	No special tolerances. The track should be maintained to standards generally superior to that at present available on mainline track on which unrestricted speeds up to 100 kmph are permitted.	
3.	Twist Loaded track (Measured on 3.5 m base)		
	(a) On straight and curved track	2 mm/m	3.5 mm/m
	(b) On transition curves	1 mm/m	2.1 mm/m
4.	Unevenness (Measured on 3.5 m base) (Rail joint depression)	10 mm: at a few isolated spots up to 15 mm	
5.	Track gauge Same as normal track limits, which are:		
	(a) Straight track	+6 mm –3 mm	
	(b) Curved track with more than 400 m radius	+15 mm –3 mm	
	(c) Curved track with less than 400 m radius	+20 mm	
		(nominal gauge 1676 mm)	

Note: Isolated locations has been taken as not exceeding ten per km.

Metre Gauge Service tolerances laid down for 100 kmph MG routes are as follows:

Parameter			*Generally*	*In isolated locations*
1.	Alignment (Versine measured on 10 m chord)			
	(a)	Straight track	±5 mm	±8 mm
	(b)	Curved track	±5 mm	±8 mm
		(Total change of versine from chord to chord at stations 5 m apart should not exceed 10 mm on a 10 m chord)		
2.	Twist (Loaded track, 2.75 m base)			
	(a)	Straight and curved track	2 mm/m	3 mm/m
	(b)	Transition curves	1.5 mm/m	2 mm/m
3.	Unevenness (loaded track 2.74 m base)		5 mm	8 mm
4.	Cross-levels		no special tolerances	
5 .	Gauge same as normal Track limits, which are:			
	(a)	Straight track	–3 mm +6 mm	
	(b)	On curves with radius more than 275 m	–3 mm +15 mm	
	(c)	On curves with radius less than 275 m	+20 mm	
		(These limits are apropos of a nominal gauge of 1000 m.)		

17.3 TRACK INSPECTIONS

17.3.1 Types of Track Inspection

Permanent way men responsible for track maintenance have been adopting various methods of inspections to exercise control on the standards of track maintenance and to ensure the safe running of the rolling stock.

Among the common types of track inspections prevalent in the Indian Railways are:

Inspection by Foot The entire gang length is inspected by the keymen of the gang everyday on foot. Once a week, the gangmate makes the inspection, and the keyman supervises the work of the gang in his place. This is a safety oriented inspection and the main job is to see that all track fittings and fastenings are in position and are well tightened. If at any location, track is found unsafe due to some reason, prompt action is required to be taken to stop or regulate the traffic.

Inspection by Push Trolley/Motor Trolley These trolleys are equipped with instruments to measure track parameters in floating condition. Besides visual observation, the inspecting official makes a random check of track geometry and issues necessary directions for the rectification of defects noticed.

While push trolley inspection helps in making more close and detailed observations, inspection by motor trolley enables long sections being covered. As running of motor trolley requires traffic block, it is becoming increasingly difficult to conduct motor trolley inspections on busy routes.

All important aspects of safety, track structure, track geometry, and implementation of important track policy directions are expected to be covered during these inspections.

Inspection by Last Vehicle or Locomotive of a Fast Train Both these inspections are to observe the riding qualities of track. Although the rolling stock defects also influence the riding quality, but by experience one can indicate the type of track defect which had led to the poor riding. The field staff are expected to make a detailed physical check at site before taking up the rectification of defects pointed out in these inspections.

Schedule of Inspection The minimum schedule of inspection laid down for the permanent way inspectors and engineers in the Indian Railways for covering the entire length of section under their charge is given in Table 17.1.

Table 17.1

S. No.	*Types of inspection*	*APWI*	*PWI*	*AEN*	*DEN*
1.	Push trolley (Motor trolley)	Twice a week	Once a week	Once a month except that unimportant branch lines may be covered once in two months	Trunk routes, main lines and important branch lines- once in three months : other lines at discretion
2.	Last Vehicle	Once a week	Once a week	Trunk routes and main line- once a month, other lines once in two months	Trunk routes main lines important branch lines once in 6 months; other lines at discretion
3.	Footplate of the engine	Twice a month	Twice a month	Same as for last vehicle	

Notes:

(a) Inspections should be done every week for some time.

(b) Motor trolley inspections, in place of push trolley inspections, may be done by AEN only for unimportant branch lines. In that case, alternate inspection should be with push trolley.

(c) On double/multiple lines each line should be inspected separately.

Some of the railway have laid down schedule for inspection during night hours. These are supposed to be surprise inspections by footplate of an engine to check the lighting conditions of gate lamps, gate signal lamps, engineering restriction board lamps, and alertness of gate keepers and engineering staff manning the engineering restriction signals.

For efficient track maintenance system, it is not only necessary that all inspections are carried out as per laid down schedules but necessary follow-up action is taken to rectify the defects noticed or the improvements suggested during the inspection.

Detailed guidelines have been issued by the railway for this purpose in the form of maintenance of inspection diaries/registers and for reviewing the progress through them.

The above mentioned inspection are besides the inspection of specific type of track structure such as points and crossings, bridges, level crossings, curves, etc. for which separate schedules of inspection at various levels have been laid down.

17.4 TRACK RECORDINGS

Since the inspection of the railway system, inspection by foot, by trolley, on the foot plate of the locomotive of a fast moving train and by trailing window have been used, and these continue to be important methods of exercising check on the quality of track maintenance even to this day. The drawback of these methods is that they are purely subjective and do not provide a uniform yardstick which can be applied over the entire system and by which the results obtained at different times can be compared. There was general awareness of the shortcomings of these methods and the use of track recording machine was a development in this direction.

17.5 TRACK RECORDING CARS

There are two types of track recording cars currently in use in the Indian Railways: one mechanical and the other electronic. With these track recording cars, it is possible to have a continuous record of the track geometry under loaded conditions, by running the cars at nominated intervals.

17.5.1 Mechanical Track Recording Cars (BG)

1. It has two bogies: one of two axles and the other of three axles. The measuring bogie has a base of 3.6 m and is three axled with an axle load of 7.0 tonnes. It gives a continuous record of:
   (a) Unevenness—left rail
   (b) Unevenness—right rail
   (c) Gauge
   (d) Twist
   (e) Curvature/alignment—left rail
   (f) Curvature/alignment—right rail
   (g) Speed

2. The manner of recording of each parameter is indicated as follows:

(a) *Unevenness* The longitudinal unevenness of rail is measured as deviation in the vertical plane (depression or rise) of the middle axle of the measuring bogies with reference to the average position of the two outer axles. The outer axles are spaced 3.6 m for left and right rail separately.

(b) *Gauge* The changes in gauge are picked up by spring loaded gauge feelers which are in contact with the gauge faces at about 17 mm below the rail table. The recording is done to a scale of 1:1. The feelers are so made that they can pass over the points and crossings and through check rails at level crossings without difficulty.

(c) *Twist* Twist is measured as the relative out plane position of one of the four wheels with respect to the plane formed by the other three wheels, of the outer axles of the measuring bogie. If, a, b are the movements of the axle boxes of the leading axle and c, d are the relative movements of the axle boxes of the rear axle then, $(a + d) - (b + c)$ gives the twist over a base of 3.6 m. The point from where these movements are picked up from the frame connected to the outer axles are so located as to compensate for the frame spacing being wider then the gauge. The twist is also recorded to a full scale of 1:1.

(d) *Curvature/alignment* Curvature is deduced from the angle between two tangents and a chord of known length at any point of the rail assumed to be circular. Two spring loaded feelers press against the rails form the tangents. The line joining the centers of the pivots of the two bogies forms the chord. By arrangement of cables attached to these feelers, the differential movement of the feelers with respect to the chord is transmitted to the recording table. The curvature is recorded as versines in mm on a 7.2 m chord. This measurement, however, is some what vitiated due to transverse play existing between the various parts of the vehicle such as between wheels and rails, between axles and bogie and between bogie and the vehicle. The magnitude of inaccuracy on this account is of a small order and the recording gives general guidance regarding the condition of alignment.

17.5.2 Electronic Track Recording Car

Broad Gauge

1. The construction features of this car are the same as those of the mechanical car except that the sensing elements of various track parameters transmit impulses electrically. Electrical track recorder gives the various track parameters in analogical form on a graph paper.
2. With the indigenously modified electronic track recording cars, it is possible to get a continuous record of alignment of each rail on a 7.2 m chord besides the parameters described in the above Section.
3. In the electronic car, alignment is measured by versines on a chord length of 3.6 m. The mid-chord processor facilitates the conversion of the versines measured on 3.6 m base to 7.2 m base, electronically. This is according to formula $V = V_1 + 2V_2 + V_3$ where V_1; V_2; V_3 are the versines on 3.6 m chord. V = versine on 7.2 m chord.

Note: It is to be noted that while service tolerances have been laid down for 3.5 m and 7.5 m chord for unevenness and alignment respectively, the measurement by broad gauge track recording cars are made at 3.6 and 7.2 m chords. This anomaly is expected to be eliminated in the new design of track recording cars. Similar anomaly does exist in metre gauge track recording cars as well.

Metre Gauge

1. *Construction features* The MG track recording car is equipped with a measuring frame similar to the one provided in BG track recording car. The transmission is electronic and the recording is done on a six channel BNL recorder. The vertical and lateral acceleration are measured by an accelerometer fitted on the floor of the coach.
2. *Items of measurement* For MG an indigenous track recording car is in use for recording the following parameters. (a) gauge, (b) twist, (c) unevenness-left rail, (d) unevenness-right rail, and (e) speed.
   (a) The gauge is recorded at 14 mm below the rail surface to a scale of 1 : 1. Feelers are pressed against the rail surface by spring loaded arrangement. The relative movements of the feelers are picked up by LVDTs (Liner Variable Differential Transformer) and transferred to the recording table electrically.
   (b) *Twist* is recorded to a base of 2.74 m, the distance between the two outer axles of a three axle bogie. The relative movements of the outer wheels apropos of carriage frames is picked up by LVDTs. When recording the twist, it is amplified to give an appreciable record on the chart. A record of 5 mm on chart is equivalent to 1 mm/m.
   (c) *Unevenness* is recorded over a base of 2.74 m. The relative movements of central axle with respect to the outer axles connected by a longitudinal beam is picked up with the help of suitable LVDTs.

17.5.3 Frequency of Track Recording

Track recording cars are run regularly according to the following frequencies:

Broad Gauge

1.	Routes with existing speeds above 130 kmph	Once in two months
2.	Routes with existing speeds above 110 kmph and up to 130 kmph	Once in three months
3.	Other *A* and *B* Group routes	Once in four months
4.	*C* and *D* group routes	Once in six months
5.	*E* routes	Once in 12 months

Metre Gauge Extensive conversion of MG to BG, has left only unimportant routes on MG. The monitoring of track geometry of MG routes at regular intervals has thus been discontinued.

17.5.4 Analysis of Track Recording Charts

The charts produced by the track recording cars analysed for the following reasons.

1. Finding out locations where the track needs immediate attention; such places are usually noted by the Permanent Way staff during the track recording run itself.
2. For finding stretches of track which have rundown and need early picking up.
3. For classifying the track to find out the trends of track improvement or deterioration.

Analysis of track recordings is done by counting the number of peaks in each kilometer, going beyond a particular limit for each parameter. To facilitate this, lines parallel to the base line are drawn.

From these studies, the RDSO has evolved the system of track classification based on track recording charts. The extent of irregularities in unevenness, twist, gauge and alignment for the classification of track under different categories *A, B, C* and *D* has been laid down.

Sample charts of readings of track recording cars BG (mechanical and electronic) and that of MG (electronic) are shown in Fig. 17.2 (a)–(c).

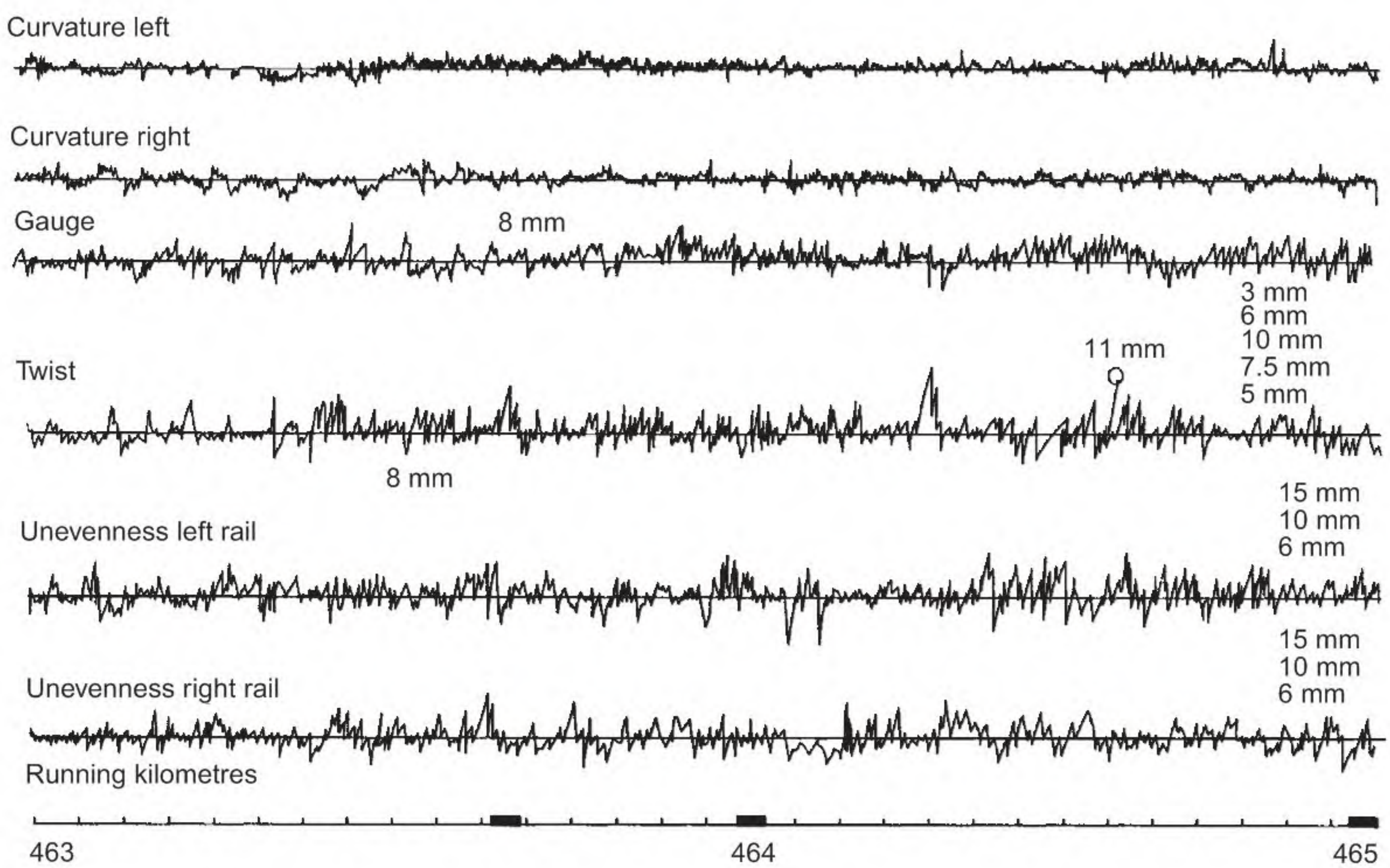


Fig. 17.2 (a) Sample chart of TRC (Mechanical) broad gauge

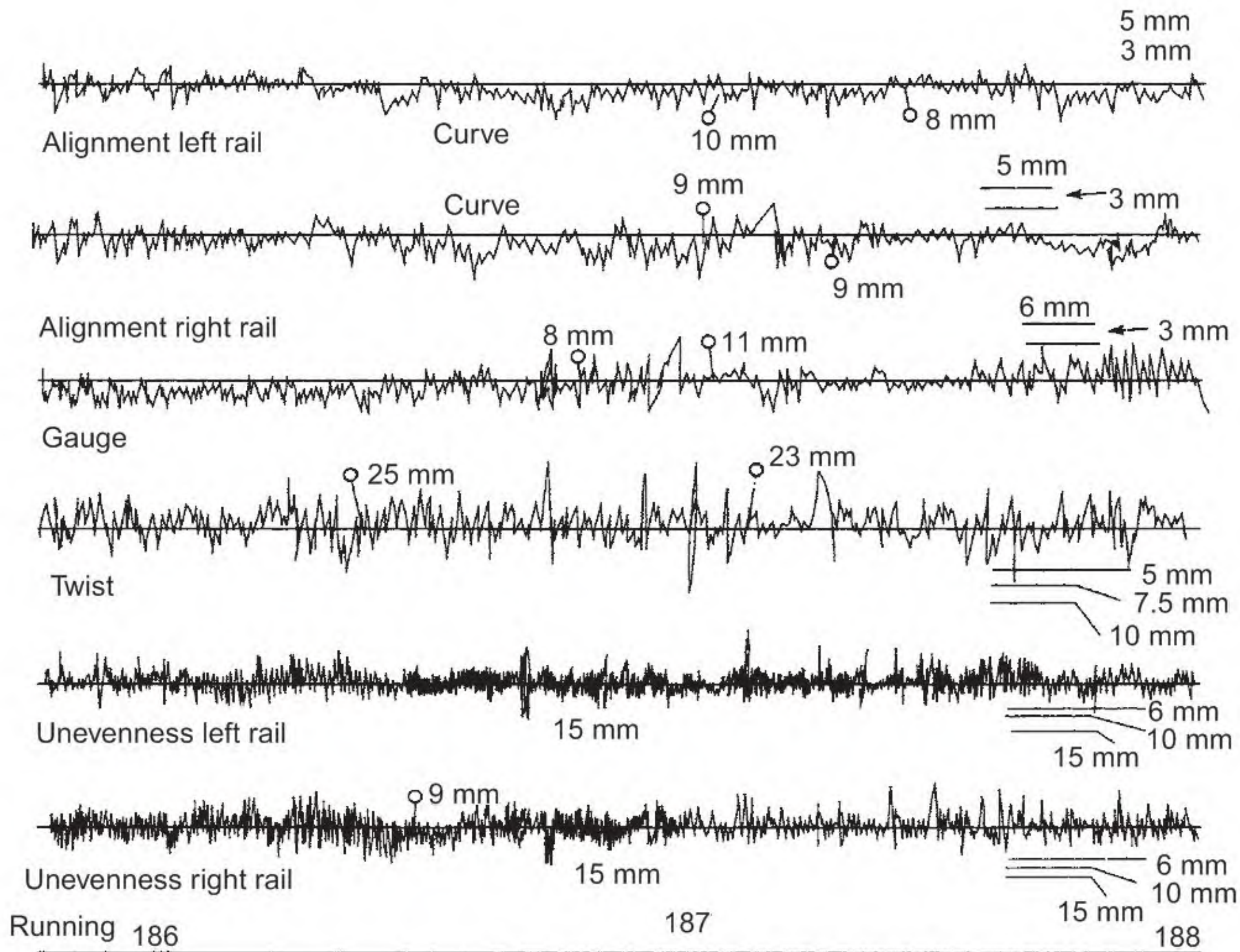


Fig. 17.2 (b) Sample chart of TRC (Electric) broad gauge

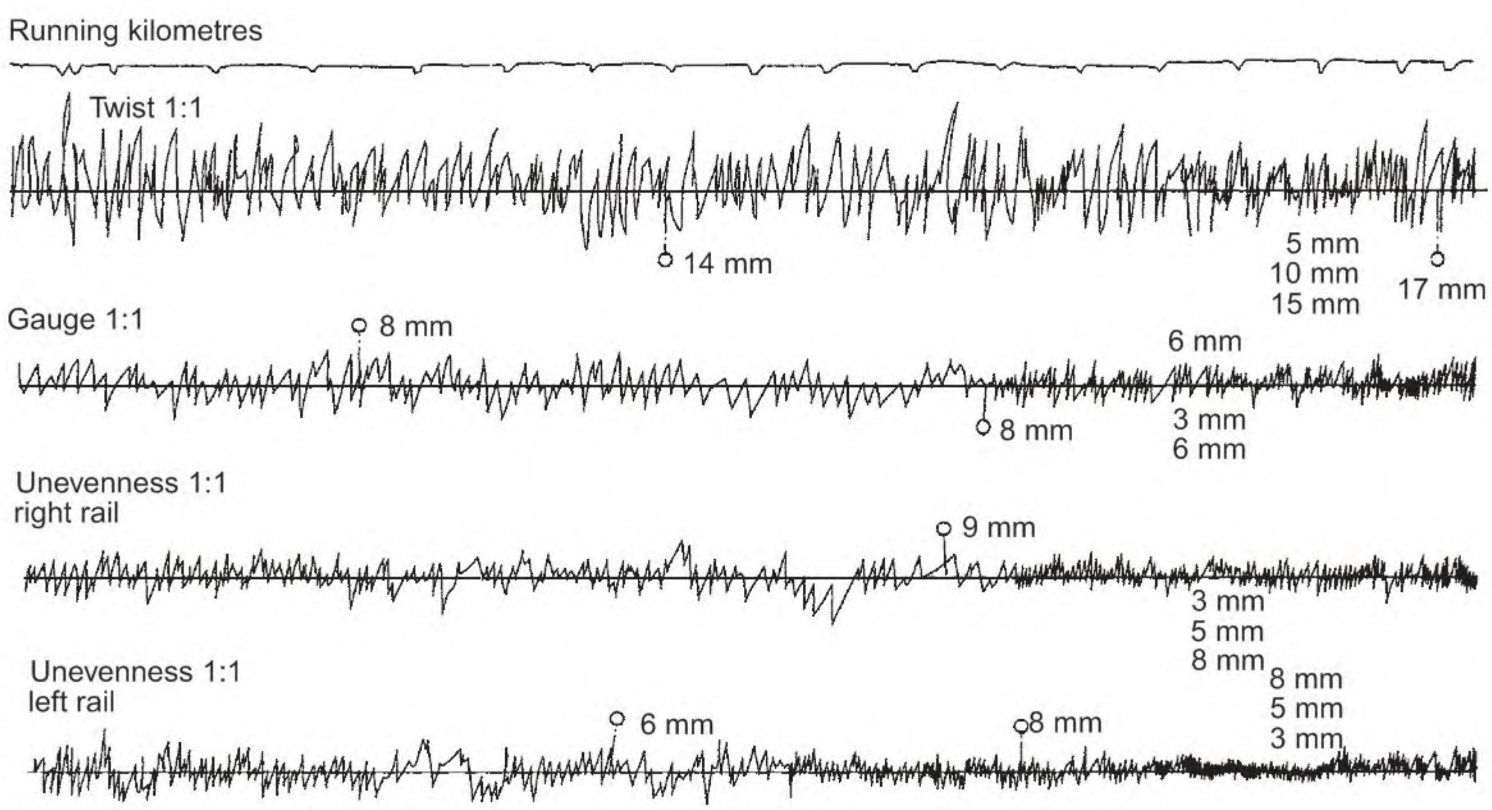


Fig. 17.2 (c) Sample chart of TRC (Electric) metre gauge

17.5.5 Classification of BG Track

Table 17.2

	Broad gauge	*Category*	*Extent of irregularities*
1.	Unevenness (3.6 m chord)	A	0–6 mm (inclusive)
		B	6 mm (exclusive) to 10 mm (inclusive)
		C	10 mm (exclusive) to 15 mm (inclusive)
		D	Above 15 mm
2.	Twist (3.6 m base)	A	0–5.0 mm on chart (up to and inclusive of 1.39 mm/m)
	Note: 1 mm/m = 3.6 mm on chart	B	5–7.5 mm on chart (1.39 mm/m to 2.08 mm/m inclusive)
		C	7.5–10.0 mm on chart (2.08 mm/m to 2.78 mm/m inclusive)
		D	Above 10.0 mm on chart (above 2.78 mm/m)
3.	Gauge	A	Up to and ± 3 mm (inclusive)
		B	± 3 mm to 6 mm (inclusive)
		C	Above ± 6 mm
4.	Alignment (7.2 m chord)	A	Up to 3 mm versine (inclusive)
		B	More than 3 mm and less than 5 mm versine
		C	5 mm and above versine

17.5.6 Classification of MG Track

Table 17.3

	Broad gauge	*Category*	*Extent irregularities*
1.	Unevenness (2.74 m chord)	A	0 to 3 mm (inclusive)
		B	3 to 5 mm (inclusive)
		C	5 to 8 mm (inclusive)
		D	Above 8 mm
2.	Twist (2.74 m base)	A	0 to 5 mm (inclusive) on chart up to and 1 mm/m (inclusive)
	Note: 1 mm/m = 5 mm on chart	B	5 to 10 mm (inclusive) in chart 1 mm to 2 mm/m (inclusive)
		C	10 to 15 mm (inclusive) in Chart (2 to mm/m inclusive)
		D	Above 15 mm on chart (above 3 mm/m)
3.	Gauge	A	Up to and + 3 mm (inclusive)
		B	+ (3 to 6 mm)
		C	Above + 6 mm

(Contd.)

	Broad gauge	*Category*	*Extent irregularities*
4.	Alignment (10.0 m base)	A B C	0–3 mm (inclusive) 3–5 mm (inclusive) Above 5 mm

Note:

(a) Ten points exceeding the outer limit of an irregularity under each category is allowed in one km length of track. If more than ten peaks in one km, cross the outer limits of A category, the kilometre is classified B and so on. Based on the number of peaks and extent of irregularity, the track is classified into A, B, C, D categories separately for each parameter, gauge, twist, unevenness and alignment.

(b) The number of peaks in each kilometre exceeding the outer limit for the B category is indicated as suffix.

(c) The peaks on points and crossings are not counted in the number of peaks for categorization. However, quality of maintenance of points and crossings is judged on the basis of peaks recorded over them.

17.5.7 Performance Review Charts

Along with the classification of track in A, B, C and D categories, numerous other analyses of the track recording results are done to review the performance of an individual P Way Inspector in bringing up the track geometry. These are in the form of preparation of histograms and plotting of graphs.

Kilometrewise, histograms are plotted for each of the recorded parameter, from which the results of the various recordings can be compared.

Another method adopted to find out the number of peaks exceeding *A* category (i.e., 6 mm for unevenness for BG, and similar value for other tack parameters), for a PWI's section and find out the average number of such peaks per km.

These values when plotted for successive recordings give a good indication of the trends in track improvement or deterioration.

17.5.8 Track Recoding Index of Performance

As the riding quality of the track depends upon the combined value of various track parameters recorded, Northern Railways has evolved the following empirical formula for determining the combined track recording index value (CTR value) of a particular BG section.

$$\text{CTR value} = 100 - (u + G + T + A)$$

Where u = No. of peaks exceeding 6 mm unevenness per km. For this purpose peaks on both the rails are counted, including the peaks on points and crossings and divided by the length of both the rails.

G = No. of peaks exceeding 3 mm in gauge per km.

T = No. of peaks exceeding 5 mm in twist per km.

A = No. of peaks exceeding 5 mm in alignment per km. Peaks of both the rails are to be counted as in u above.

Track is classified as per CTR value in the following categories:

CTR Value	*Classification of track*
Above 80	outstanding
Between 70 and 80	very good
Between 60 and 70	good
Between 50 and 60	average
Below 50	poor

As in the formula, threshold value of *A* category has been taken, the CTR value obtained generally reflects the percentage of track in *A* category in the length analysed.

17.6 OSCILLOGRAPH CAR

Oscillograph car is equipped with a mobile laboratory-cum-instrument compartment located at the end of the car in which pen-recording type oscillographs have been installed. These oscillograph cars record parameters such as vertical and transverse body accelerations, spring deflections, bolster swing, bogie rotation, etc. Separate recording is done for the oscillograph coach and the loco used during the tests. For controlling track irregularities and for comparing general track conditions in successive runs, only vertical and lateral accelerations, as experienced on the foot plate of the loco, are considered. These accelerations are recorded by accelerometers placed in the loco cab floor. The accelerations recorded in them are transmitted through electrical circuit to the recording pen in the oscillograph car.

Accelerometer in the Oscillograph Car, to record vertical or lateral accelerations, consists of a mass *M* mounted at the free end of a cantilever *AB* (Fig. 17.3).

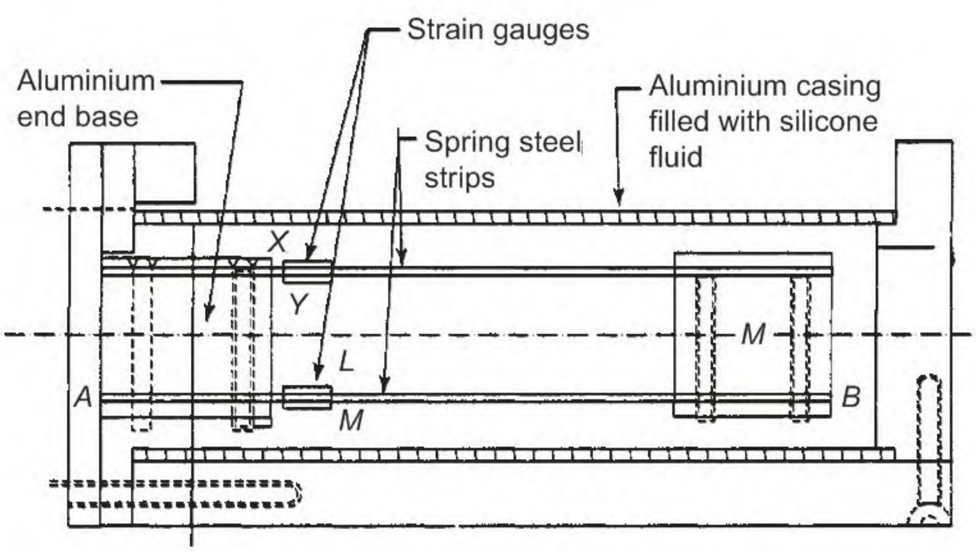


Fig. 17.3

The mass *M* and the cantilever *AB* are enclosed in aluminium casing filled with silicon fluid. The accelerometer is placed on the floor of the loco cab and any acceleration experienced at the loco floor is registered by the mass *M* which deflects the cantilever. The deflection is electrically transmitted to the recording pens in the oscillograph car. Two accelerometers, one for recording vertical and the other for lateral acceleration, are used. Both these accelerometers are attached to a heavy angle iron weight which is placed at the floor of the loco cab and with that heavy weight the accelerometer behaves as a part of the loco body and experiences the same acceleration as experienced by the loco floor at that place. The record of the lateral and vertical accelerations is made on a moving graph paper with the help of the recording pens.

Similar accelerometers are placed for recording acceleration of the floor of the oscillograph car bogie, and similar recordings are made for them. But, for track monitoring purposes, only the accelerations recorded at the loco cab floor are made use of.

The physical features of the track, i.e. km and TPs, level-crossings, bridges, station-yards, etc., are marked on the recording graph paper manually to facilitate in finding out the exact location of a particular peak on the ground.

Analysis of Data All peaks exceeding 0.2 g are marked both for lateral and vertical accelerations. The number of peaks exceeding 0.2 g in a particular section or a particular run are counted and by dividing them with the number of kilometres recorded, one can find out the number of peaks per kilometre of track recorded. Any stretch of track having more than 10 peaks per kilometre is taken as a bad stretch and is indicated separately in the record. The peaks experienced in the yards are also given separately. Isolated peaks exceeding 0.3 g are specially marked for immediate attention.

Riding Index An index of riding comfort termed as "Ride Index" is also computed from the oscillograph car records to obtain an overall picture of the riding performance of the coach or the locomotive.

Investigations made have revealed that the human body is most sensitive to vibrations in the frequency range of 4 to 6 cycles per second, and the body remains sensitive to the frequencies of up to 30 cycles/second. Dr. Sperling of Germany found that depending upon the frequency range, the sensitiveness of the human body is related to acceleration to which it is subjected to. He, therefore, expressed the ride index V for any vehicle as

$$V = 0.869\sqrt[10]{\frac{b^3}{f} \times Q(f)}$$

where b is the acceleration in cm/s^2

f is the frequency per second

and $Q(f)$ is a correction factor allowing for the effect of different frequencies on the human body.

This formula is now widely known as the Sperling formula for 'Ride Index'.

After extensive experiment, Dr. Sperling has standardised the following numerical values for various degree of riding comforts, which have been approved by UIC (International Union of Railways). It would be seen from the table that for Delhi–Mumbai and Delhi–Howrah routes, on which Rajdhani Expresses run; the 'Ride Index' value should be between 2.0 and 2.5 with about 16 hours of journey time.

Table 17.4 Numerical Values for Various Degree of Riding Comfort

Ride	*General appreciation of the Vehicle riding characteristics*	*Time limit for body fatigue*
1	2	3
1.0	Very good	Over 24 hours
1.5	Almost good	
2.0	Good	
2.5	Nearly good	10.0 hours
3.0	Passable	5.0 hours
3.5	Still passable	2.8 hours
4.0	Able to run	1.5 hours
4.5	Not able to run	45 minutes
5.0	Dangerous	15 minutes

It is evident that ride index, as an evaluation criterion is exclusively based on the comfort consideration of the passengers travelling in the coach. To apply this criterion for the assessment of the safety of operation of general rolling stock would be too rigid a standard.

Taking on overall view, the following ride index values have been laid for BG system on Indian Railways.

	Maximum	*Preferable*
Diesel and electric engines	4.0	3.75
Coaches	3.5	3.25

The values of accelerations for vertical and lateral direction, both for engines and coaches are also limited to 0.3 g. The peak value up to 0.35 g can be permitted, if the records do not indicate a resonance tendency in the region of peak value.

Sample Charts A copy of the sample chart obtained from an oscillograph car is placed in Fig. 17.4. Table 17.5 is a ready reckoner for determining ride index values as brought out in the following example.

Example *Suppose a km is recorded at a speed of 132 kmph and has 8 peaks in the ranges of 0.15 to 0.20 g and 4 peaks in the range of above 0.20 g. Total no. of equivalent peaks in the range of 0.15 g – 0.20 g = 8 × 1 + (2.1 + 4) = 8 + 8.4 = 16.4 say 16 no.*

The speed of 132 kmph is in the range of 126 – 135 kmph and thus figures under column 4 are to read. Thus RIDE INDEX VALUE = 3.88 (marked in bold in Table 17.5) read from the chart.

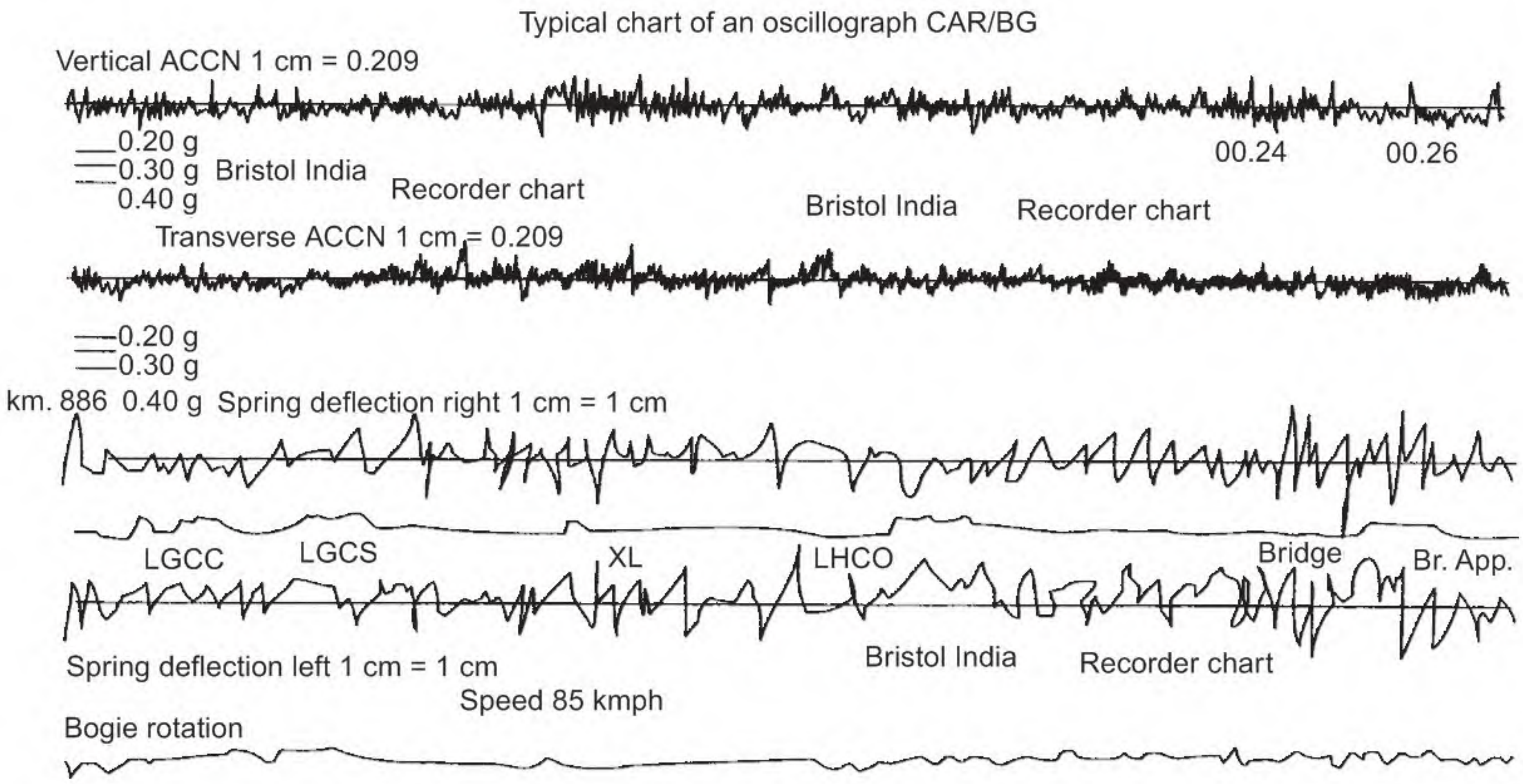


Fig. 17.4 A copy of sample chart obtained from an oscillograph car

17.6.1 Portable Accelerometers

Portable accelerometers are convenient and handy to record the vertical and lateral accelerations. These can also be used for measuring the vertical and lateral ride indices, thereby checking the riding quality of track. This is more or less similar to Hallade Track Recorder, with added features that its records are precalibrated to give vertical and lateral accelerations and time measurement, very accurately.

Description The device consists of two pendulums supported in such a way that one of them is sensitive only to vertical acceleration and the other to lateral acceleration. The movement of the pendulum is conveyed through a connecting rod and a magnifying rod to the recording pen. The recording pen records on oil paper the accelerations experienced by the pendulums. The paper can be moved at 5,10 or 20 mm per second. The vertical and lateral accelerations are recorded on two channels with a recording sensitivity of 5.0 mm per g (acceleration due to gravity). In addition to the vertical and lateral accelerations, the distance and time marks are also available on recorder chart. The distance marks are obtained by manual press button system of one flick for telegraph posts and two flicks for km posts.

Operation The device is kept on the cabin floor of a locomotive or on the coach floor as close to the bogie pivot as possible. It is preferable that the same accelerometer and the same vehicular position is used in successive runs. The portable accelerometer should be calibrated before use. Figure 17.5 gives a typical oscillogram of a portable accelerometer.

Analysis of Recordings The records obtained from the accelerometer are analysed in the same way as that obtained from a oscillograph. Since the speed of recording is important, records obtained only

Table 17.5 Table for Reading Lateral Ride Indices for WDM 4 Diesel Locomotives

Conversion factors to be applied for the two ranges of accelerations noted from the oscillograph are as follows:

Ist range—0.15 to 0.20 g . . . . Conversion factor = 1

IInd range—0.20 g and above . . . . Conversion factor = 2.1

No. of peaks	*Ride indices*				*No. of peaks*	*Ride indices*			
between 0.15 g to 0.20 g	*105–115 kmph*	*116–125 kmph*	*126–135 kmph*	*136–145 kmph*	*between 0.15 g to 0.20 g*	*105–115 kmph*	*116–125 kmph*	*126–135 kmph*	*135–145 kmph*
1	2	3	4	5	1	2	3	4	5
0	3.62	3.65	3.69	3.72	26	3.90	3.93	3.96	4.01
1	3.64	3.67	3.71	3.76	27	3.91	3.93	3.96	4.01
2	3.66	3.69	3.72	3.77	28	3.92	3.94	3.97	4.02
3	3.67	3.70	3.73	3.78	29	3.92	3.95	3.98	4.03
4	3.68	3.71	3.75	3.80	30	3.93	3.96	3.98	4.03
5	3.70	3.73	3.76	3.81	31	3.94	3.96	3.99	4.04
6	3.71	3.74	3.77	3.82	32	3.95	3.97	4.99	4.04
7	3.72	3.75	3.79	3.84	33	3.95	3.97	4.00	4.05
8	3.73	3.76	3.80	3.85	34	3.96	3.98	4.01	4.06
9	3.74	3.77	3.81	3.86	35	3.97	3.99	4.01	4.06
10	3.76	3.79	3.82	3.87	36	3.97	3.99	4.01	4.06
11	3.77	3.80	3.83	3.88	37	3.98	4.00	4.03	4.08
12	3.78	3.81	3.84	3.89	38	3.99	4.01	4.03	4.08
13	3.78	3.82	3.85	3.90	39	.3.99	4.01	4.04	4.09
14	3.79	3.82	3.86	3.91	40	4.00	4.02	4.04	4.09
15	3.81	3.84	3.87	3.92	41	4.00	4.02	4.04	4.09”
16	3.82	3.85	**3.88**	3.93	42	4.01	4.03	4.05	4.10
17	3.83	3.86	3.89	3.94	43	4.02	4.04	4.06	4.11
18	3.84	3.87	3.90	3.95	44	4.02	4.04	4.06	4.11
19	3.84	3.87	3.90	3.95	45	4.03	4.04	4.06	4.11
20	3.85	3.88	3.91	3.96	46	4.04	4.05	4.07	4.12
21	3.86	3.89	3.92	3.97	47	4.04	4.06	4.08	4.13
22	3.87	3.90	3.93	3.98	48	4.05	4.06	4.08	4.13
23	3.88	3.91	3.94	3.99	49	4.05	4.07	4.09	4.14
24	3.88	3.91	3.95	3.99	50	4.06	4.07	.4.09	4.14
25	3.89	3.92	3.95	4.00	51	4.07	—	—	—

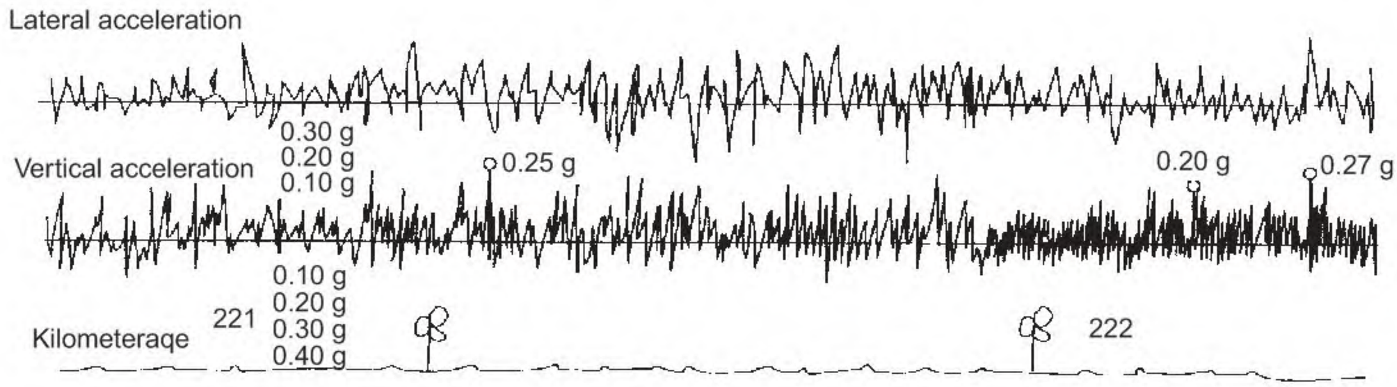


Fig. 17.5 Sample chart of portable accelerometer

at a particular speed are comparable. When the instrument is placed in the loco, peaks above 0.2 g are counted and compared. For bogie floor, the threshold value is taken as 0.15 g. In addition to the comparing with previous results—which indicate the trend of track improvement/deterioration—location of high peaks are examined for track defects and they are attended to as early as possible.

17.7 PORTABLE OSCILLATIONS MONITORING SYSTEM OMS-2000

The portable Oscillations Monitoring System OMS-2000 (Fig. 17.6) is a microprocessor based system for track monitoring by measurement of the following parameters:

1. Speed
2. Vertical and lateral accelerations on the loco/coach floor
3. Sperling ride index

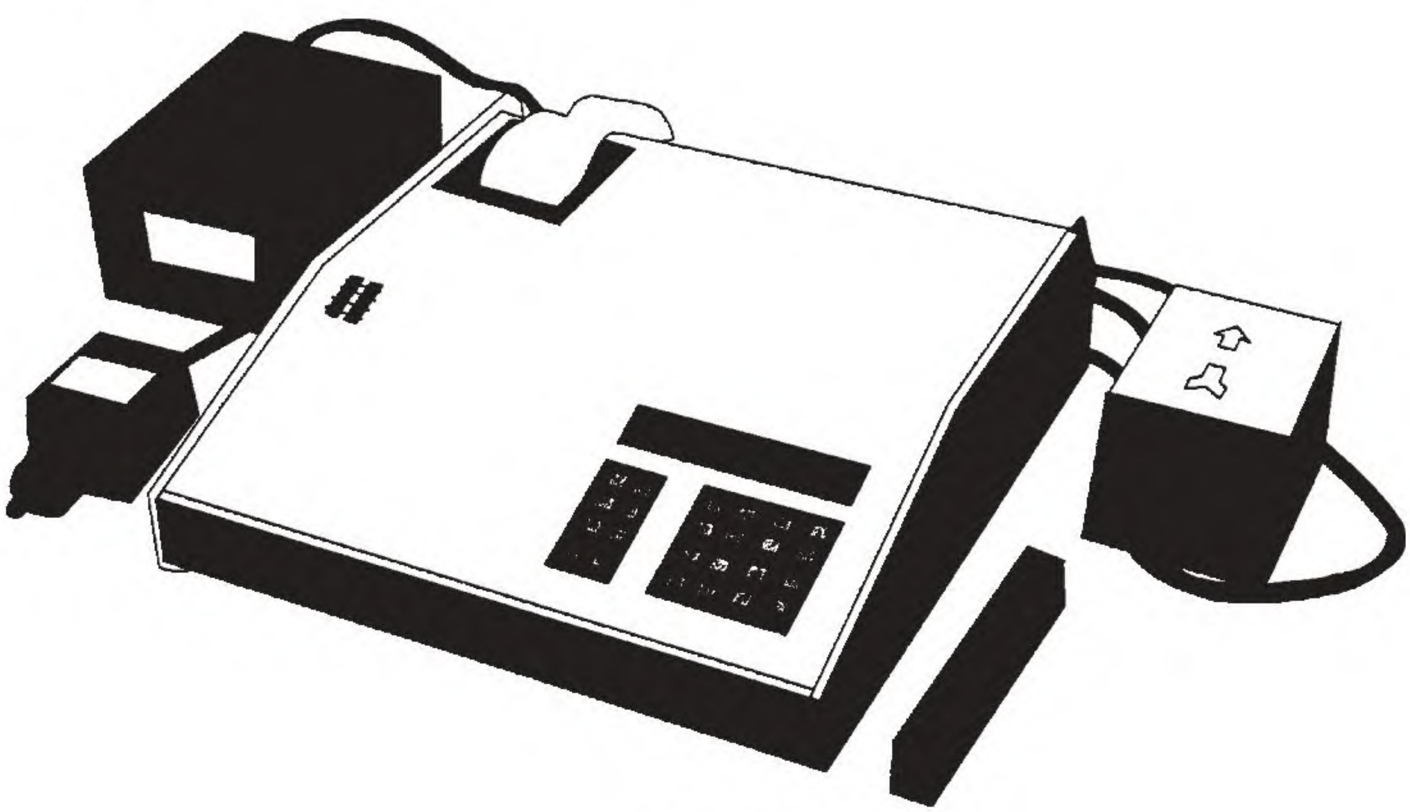


Fig. 17.6

The above three parameters are monitored in real time, and results are produced in the form of a printout on a numerical printer. Whenever any of the above parameters exceed a preset limit, an exception report of the excess is printed out. Besides this, the data collected during the run is stored in battery backed memory and may be transferred to an IBM PC compatible computer at the end of the run. OMSLINK software package for transferring and analyzing the data is available as an option.

The speed of the train is measured using a tachometer which is driven by a flexible shaft connected to the wheel. The tachometer generates pulses which are fed to OMS-2000. The gear ratio of the driving arrangement of the tachometer should be such that the shaft makes one full rotation on travelling 24.6 metres. This will generate one pulse every 0.41 metres on a 60 slot tachometer.

The vertical and lateral acceleration levels on the coach floor are monitored using two accelerometers mounted in a transducer assembly. There is a built-in instrumentation amplifier in OMS-2000 to condition the accelerometer signals. The same acceleration signals are used to detect large acceleration peaks and for collecting acceleration peak data for ride index calculations. The ride index is calculated according to the Sperling formula.

In case a tachometer is connected, the precise location of the excess in terms of the KM and the distance in metres from the last KM post will be printed in the excess report. If it is not possible to connect a tachometer, the KM and the Telegraph Post from the last KM post and the time of occurrence of peak in seconds (from the last KM) will be printed in the excess report. The time of occurrence of each peak (in seconds, up to 2 decimal places) is also printed. This helps in precisely locating the faults on the ground. There is a switch assembly with KM and TP switches for entering the KM post and the TP information in OMS-2000 during the run.

The equipment is portable: total weight is about 18 kg including battery and transducer assembly, which is supplied in two plastic moulded cases for ease of transportation. Thus existing loco or coaches can be used for the monitoring purpose. The entire equipment runs on a 12 volts rechargeable battery.

The reports generated by OMS-2000 can be used for directing the track maintenance efforts to the exact spots where high dynamic activity has been noticed.

Monitoring of riding quality by OMS

1. *Frequency of recording*
   (a) Broad gauge
      (i) Routes having speed of 100 kmph and above : once every month
      (ii) Other routes : once in 2 months
   (b) Metre gauge
      (i) Routes having speed of 75 kmph and above : once every month
      (ii) Other routs : once in 2 months
2. *Recording of defects* Peak values exceeding the following preset limits for both lateral and vertical modes shall be recorded for various routes

(a) Broad gauge

(i) Shatabdi and Rajdhani routes : 0.15 g
(ii) Rest of the routes : 0.20 g

3. Classification/acceptable standards in terms of peaks/km

	Very good	*Good*	*Average*
High speed	1.0	1–2	2
Rest of routes	1.5	1.5–3	3

17.8 CORRELATION BETWEEN AMSLER TRACK RECORDING CAR AND OSCILLOGRAPH CAR RESULTS

Permanent way men responsible for track maintenance often get baffled at poor correlation between the Amsler car and Oscillograph car results. This can be explained as follows.

17.8.1 Natural Frequency of Vibration of a Rolling Stock

Depending upon its suspension characteristics, such as spring stiffness, damping system and mass distribution, every rolling stock has its own natural frequency of vibration, which will be different for vertical and lateral modes. For example, the coaching stock on Indian Railways has a natural frequency of around two cycles per second (2 Hz) in the vertical mode. This implies that if a vertical jerk is given to the coach body, it will start going up and down completing one cycle of movement every half second and will continue to do so till this movement is damped by its damping system. If at the end of a cycle, i.e. after 1/2 second, another vertical jerk is given to the vehicle, the vehicle will get excited further causing discomfort to the passenger travelling in the coach. In an extreme case, when such jerks are repeated successively a number of times, the vehicle suspension system can itself get damaged.

17.8.2 Track Irregularity

Track is never smooth. The track irregularities consist of wavelengths and their associated amplitudes. Figure 17.7 shows track irregularity in a vertical mode. The actual track irregularity comprises a large number of defects on different wavelengths and corresponding amplitudes of track, rail length, track structure, etc. These irregularities will exist both in vertical and lateral planes affecting track geometry parameters, i.e. unevenness, cross levels, alignment, gauge and twist.

17.8.3 Vehicle-Track-Interaction

When a coach moves on the track at a speed of 100 kmph, it travels 27.8 metres per second. In 1/2 second, which is the natural cycle of its vibration, the coach would move to 13.9 metres. If track

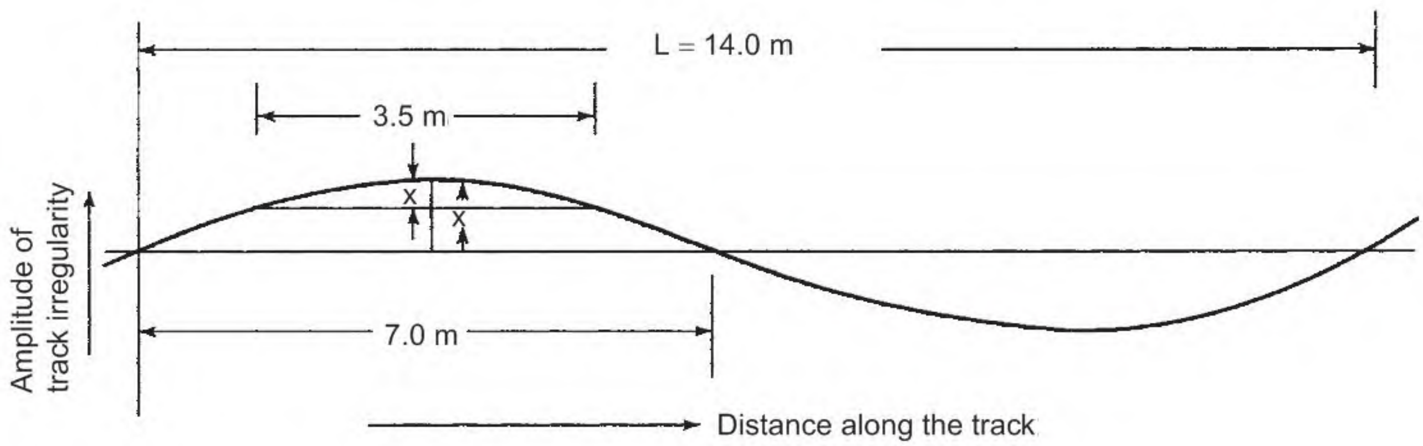


Fig. 17.7

conditions are such that at every 13.9 metres the track irregularity is going to generate a vertical push to the vehicle, the vehicle response will be abnormal and the acceleration experienced by the passengers will be quite high. Thus the coach when travelling at 100 kmph is very sensitive to those track irregularities, which have a wavelength of 13.9 metres. The track irregularities of other wavelengths would not matter to the coach at that speed. To have a correct assessment of track condition relevant to the movement of the coach, the track magnitude irregularities must therefore be measured to the base length of 13.9/2, i.e. 6.95 m (say 7 m). If the magnitude of irregularities in track, when measured at 7.0 m base, are high and are often repeated, the coach will have rough riding in the vertical mode at 100 kmph. To improve the track conditions, therefore, it is necessary that the measuring system should produce information about the track irregularities with a base length of 7.0 m. If recording data of measurement is produced at different base lengths, that will not be much relevance.

17.8.4 Transfer Function of the Recording System

Track irregularity of a wavelength of 14.0 m has an amplitude X mm which will be obtained when measured on 7.0 m base. If the same irregularity is measured on a 3.5 m base it will indicate an amplitude of x which would be 30% of X. The ratio $F\ X/x$ is termed as a transfer function of a recording system. It is to be noted that a track recording system with a fixed base of measurement will have different transfer functions for different rolling stocks and even different for the same stock running at different speeds. Table 17.6 gives the transfer functions of mid-chord measurement of three base lengths, viz, 3.6 m, 9.6 m and 12.0 m for various wavelengths of track irregularities.

17.8.5 Output from Amsler Track Recording Car and Oscillograph Car

On Indian Railways oscillograph car runs are made on high-speed routes to evaluate the riding comfort. Track locations where high values of acceleration and ride index are observed, are noted for immediate attention. These runs are made at the maximum permissible speed of about 130/140 kmph.

Table 17.6

Wavelength of track irregularity	*Transfer function of mid-chord measurement of the base length*		
	*3.6 m**	*9.6 m*	*12.0*
1	0.69	0.21	0
2	0.19	1.81	0
3	1.81	1.81	0
4	1.95	0.69	2.0
5	1.64	0.0	0.69
6	1.21	0.69	0.0
7	1.05	1.39	0.37
8	0.84	1.80	1.00
9	0.69	1.98	1.50
10	0.57	1.99	1.81
15	0.27	1.43	1.81
20	0.16	0.94	1.35
30	0.02	0.46	0.69

* Recording base of Amsler track recording car.

At 130 kmph (36.1 m/sec) coaching stock of Indian Railways with a natural frequency of around 2 Hz (2 cycles per sec.) will be sensitive to track irregularities of wavelength of 36.1/2 = 18.05 m.

It may be seen from Table 17.6 that for a wavelength of 18.5 the Amsler car with a base length of 3.6 m will have a transfer function of 0.19 only. A series of unevenness defects of 10 mm, occurring on a wavelength of 18.05 m will give rise to very high acceleration and uncomfortable ride and will be indicated as such by the oscillograph car. The same defects will be shown as 2 mm unevenness defects by the Amsler car, as measured on a 3.5 m base, and thus would get ignored. Similar can be the situation with other track irregularities occurring in the lateral or transverse mode. Low transfer function of the present Amsler track recording car is therefore the main reason for poor correlation between the results produced by the oscillograph car and the Amsler car.

Microprocessor based track monitoring system which record the track profile on inertial principles and from where track irregularities at any desired wavelength can be obtained, provides the right solution. With this system, the measurement of track irregularities at the desired base, which is relevant to a particular type of rolling stock and its operating speed, can be computed. This can help in identifying clearly the location and magnitude of track defects which have contributed to rough riding and need to be attended to.

17.9 STANDARD DEVIATION AS A MEASURE OF TRACK IRREGULARITY

It is not always possible to properly comprehend the analogous records of track geometry produced in the form of track recording charts. Similar difficulties are experienced in digesting the digital data presented in the form of number of peaks of different values of the track parameters. For maintenance requirements the data should be presented in such a manner that it can meaningfully describe track geometry vis-à-vis the vehicle riding characteristics.

The analysis of the track vehicle system indicates that Power Spectral Density (PSD) description is most ideal for correlating track geometry with vehicle response. Power Spectral Density (PSD) brings out the sum total of all defects, big or small, in a given stretch of track. Since PSD description is complex and not easily amenable to field adoption, the Standard Deviation (SD) provides the second best alternative to represent the track irregularities.

It has been observed that track irregularities belong to stationary random process and have Gaussian (normal) Distribution System. Standard Deviation can, therefore, be used to describe the track geometry to a considerable accuracy. SD brings out the spread or scatter of the individual values about the mean value. Since mean value is of no significance in effecting riding quality, the same can be removed by averaging.

17.9.1 Concept of Standard Deviation

If X, ($i = 1, \ldots, N$) be the N samples of data then

$$\bar{X}(\text{means}) = \frac{1}{N}\sum_{i=1}^{N} x_i$$

and

$$\text{SD} = \left[\sum_{i=1}^{N}(Xi - \bar{X})^2/N\right]^{1/2}$$

were SD = Standard Deviation, also known as Route Mean Square Deviation.

As already mentioned, it has been observed that distribution of track irregularities about mean value fits into normal distribution. Normal distribution is described in Fig. 17.8. In Normal Distribution 64 to 65% of the samples lie within one SD from mean value, 95% of the samples lie within 2 SD away and only about 2% samples are 3 SD away from the mean. There can be a few samples which lie more than 3 SD away, but they are not of much significance to affect the running quality of track. Individually, high peaks of irregularities can be picked up by the Track Monitoring Unit separately for immediate attention.

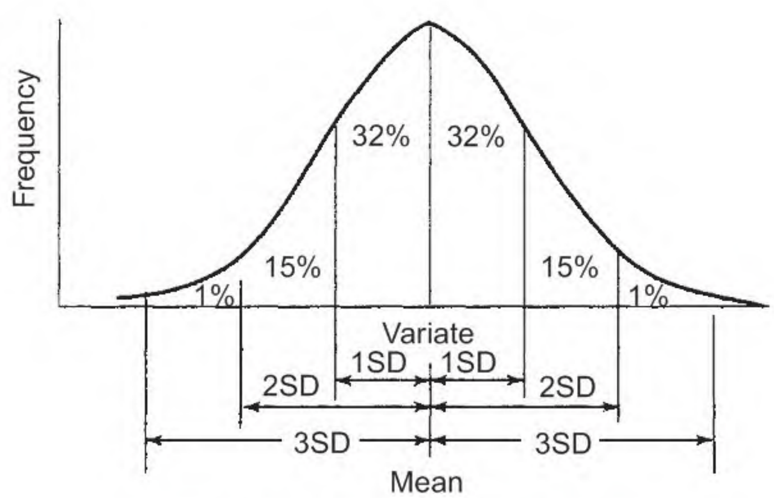


Fig. 17.8 Normal distribution

A sample calculation of standard deviation for a typical track geometry record is brought out in Table 17.7.

Table 17.7 Sample Calculation of SD

S. No.	x_i	$x - \bar{X}_i$	$(x - \bar{X}_i)^2$
1	2.5	−1.04	1.0816
2	3.2	−1.74	3.0276
3	2.2	−0.74	0.5476
4	1.0	0.46	0.2116
5	−0.8	2.26	5.1076
6	−2.4	3.86	14.8996
7	−1.1	2.56	6.5536
8	0.4	1.06	1.1236
9	2.1	−0.64	0.4096
10	3.8	−2.34	5.4756
11	4.2	−2.74	7.5076
12	2.4	−9.04	0.8836
$N = 12$	$\Sigma x_i = 17.5$		$\Sigma[(x - x_i)]^2 = 46.8292$

$$x = \frac{\sum x_i}{N} = \frac{17.5}{12}$$
$$= 1.46$$

$$\sigma = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{N}} = \sqrt{\frac{46.829^2}{12}}$$
$$= \sqrt{3.90}$$
$$= 1.97$$

17.9.2 Track Maintenance Standards Based on SD

Figure 17.9 shows the normal distribution curves for track twist (TW) in three broad assessments of track quality, i.e. good, average and bad, indicating the 65% band representing 1 SD away from the mean value of zero. Figure 17.10 indicates sample analogus records of 1 km of various track parameters along with the Standard Deviation values. The record amply establishes the visual correlation between track geometry roughness and standard deviation.

For the calculation of SD, the length of track for which SD value is to be obtained has to be decided. SD on too short a stretch does not give enough statistical confidence in the estimation of parameters. A stretch too long has the following drawbacks:

1. The isolated bad patches of track are masked in good patches and vice versa.
2. It results in larger maintenance requirements as the whole stretch where the threshold SD is exceeded is required to be attended to.

Presently, a length of 200 metres has been adopted for Indian Railways. The estimation of SD on this length is both economical and has the required level of reliability. Extensive monitoring has indicated that SD value of 2.0 can be considered good, value of 4.0 as bad and value above this indicates a poor track geometry.

Tentative track geometry standards is the form of standard deviation laid down on Indian Railway are given in Table 17.8.

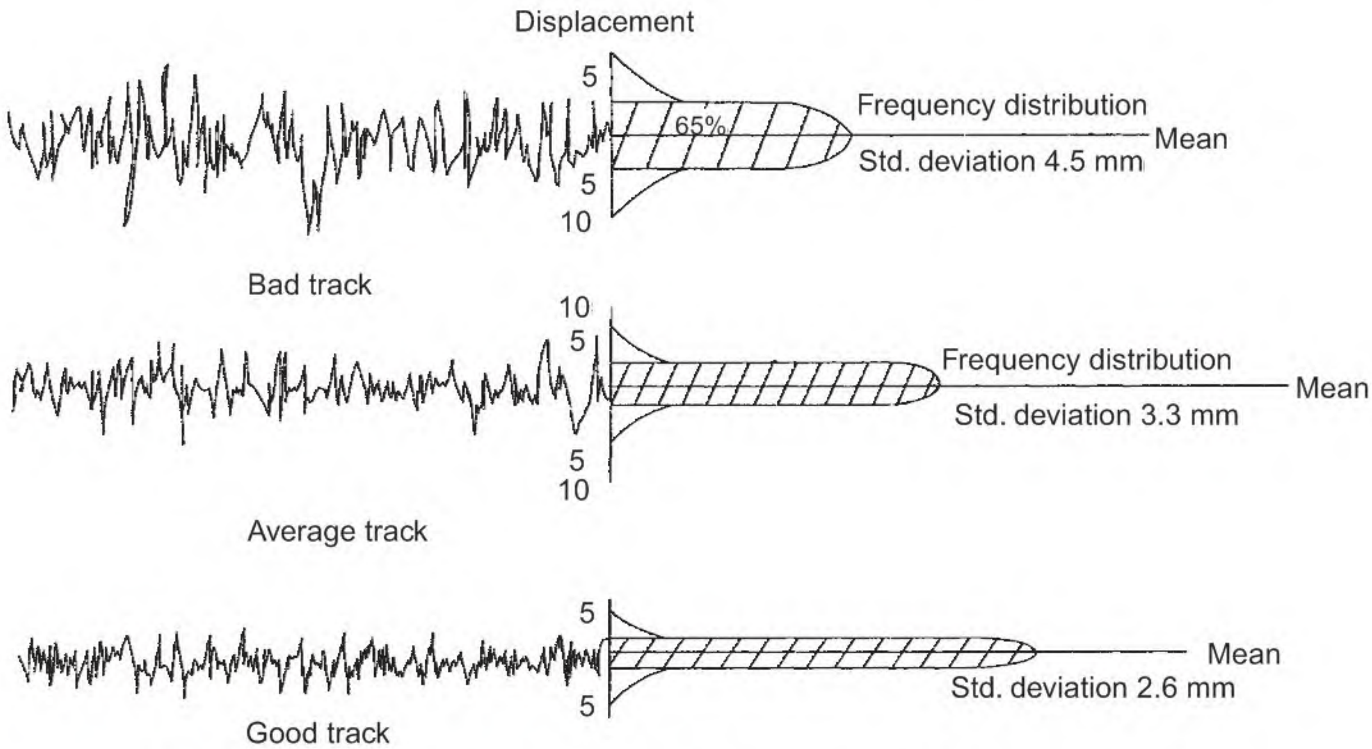


Fig. 17.9 Standard deviation as a measure of track quality (TW)

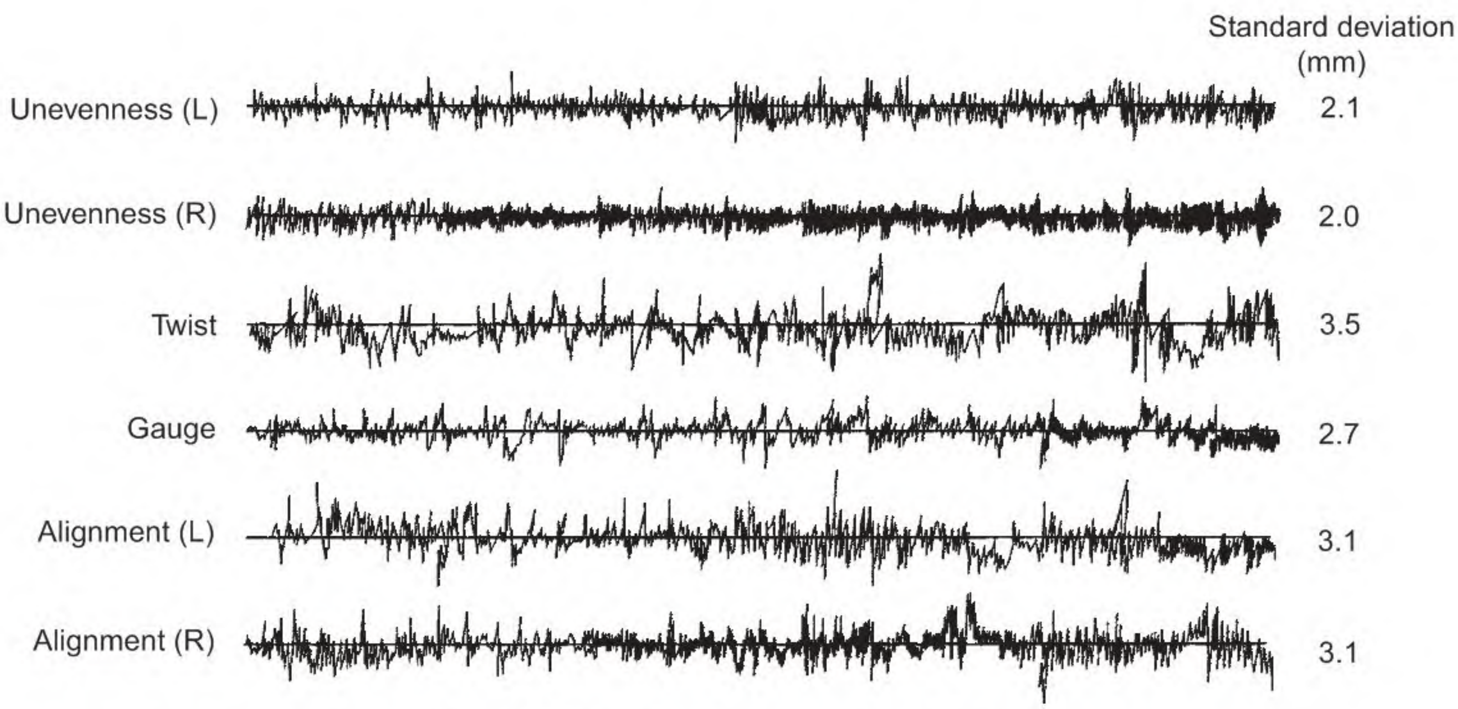


Fig. 17.10 Sample records with SD

17.10 MICROPROCESSOR BASED TRACK MONITORING SYSTEM

The Track Recording Cars (both mechanical and electronic) used on Indian Railways work on the principle of "mid-chord" measuring technique using a chord of 3.6 metres for broad gauge and 2.74 metres for metre gauge. The existing mid-chord measurement system has serious limitations, as track geometry records do not exhibit proper correlation with the vehicle response. The track recording-cum-research car of RDSO has been provided with an inertial track recording

Table 17.8

Extensive Analysis of existing track vehicle systems on Indian Railways have led to the specification of the following tentative track geometry standards in the form of standard deviation:

(Standard deviation in mm)

Stock	*Speed*	*Short chord*		*Gauge*	*Align-ment*	*UN*	
		UN 3.6	*TW 3.6*		*7.2*	*9.6*	
Passenger	110 and up to 130	3.6	3.8	3.6	3.0	6.2	Track requiring urgent maintenance
		3.0	3.4	2.9	2.8	5.5	Track requiring maintenance
		2.4	3.0	2.3	2.5	4.8	Track to be planned for maintenance
Passenger	100	3.6	4.2	3.6	3.0	7.4	Track requiring urgent maintenance
		3.0	3.8	2.9	2.8	6.5	Track requiring maintenance
		2.4	3.3	2.3	2.5	5.5	Track to be planned for maintenance
Freight		4.5	4.5	Track requiring urgent maintenance			
		3.4	3.4	Track requiring maintenance			
		2.3	2.3	Track to be planned for maintenance			

system for measurement of vertical track profile. In this system vertical accelerations recorded with the help of an Accelerometer placed at the floor of the car are converted into vertical displacements or unevenness by double integration. Applying suitable corrections, which cater for the relative movement of the various components of the car, these displacements are converted into vertical unevenness of track. A vertical profile of the track can thus be obtained. Similar method using inertial principle has also been developed and validated to measure lateral profile of the track. Inertial measurement techniques can, therefore, be successfully used for measuring track geometry, thereby dispensing with the cumbersome method of measuring track geometry as used in the present track recording cars.

The operation of mixed traffic on Indian Railways puts extraordinary demands on track maintenance. Track irregularities occur in the form of waves which are of short and long lengths. Both short wave and long wave length defects are important for carrying out track geometry corrections under mixed traffic conditions; the former for goods stock and latter for passenger coaches. The monitoring system which can measure track irregularities, both on short and long wavelength, can only provide a feasible solution. Track monitoring system based on inertial measurement offers the right solution as from this system track irregularities at any wavelength can be computed which can further be easily converted into mid-chord measurements. Another important requirement of the track measuring system is that it should be possible to mount it on any of the existing track inspection coach or an existing TRC.

The microprocessor based track monitoring system as developed by RDSO has been able to meet the above mentioned basic requirements. In its final form it is capable of operation up to a speed of 150 kmph capable of further updating for higher speeds.

17.10.1 Principle of the System

Figure 17.11 is the block diagram indicating the overall function of the microprocessor based track monitoring system. The track geometry records are produced by manipulations of seven signals obtained from transducers mounted inside coach or on the bogie. The output from these seven transducers are processed by a special purpose analogue card to yield following track geometry parameters in analogue.

1. Central line unevenness (UN)
2. Cross level (XL)
3. Centre line alignment AL)
4. Gauge (G)

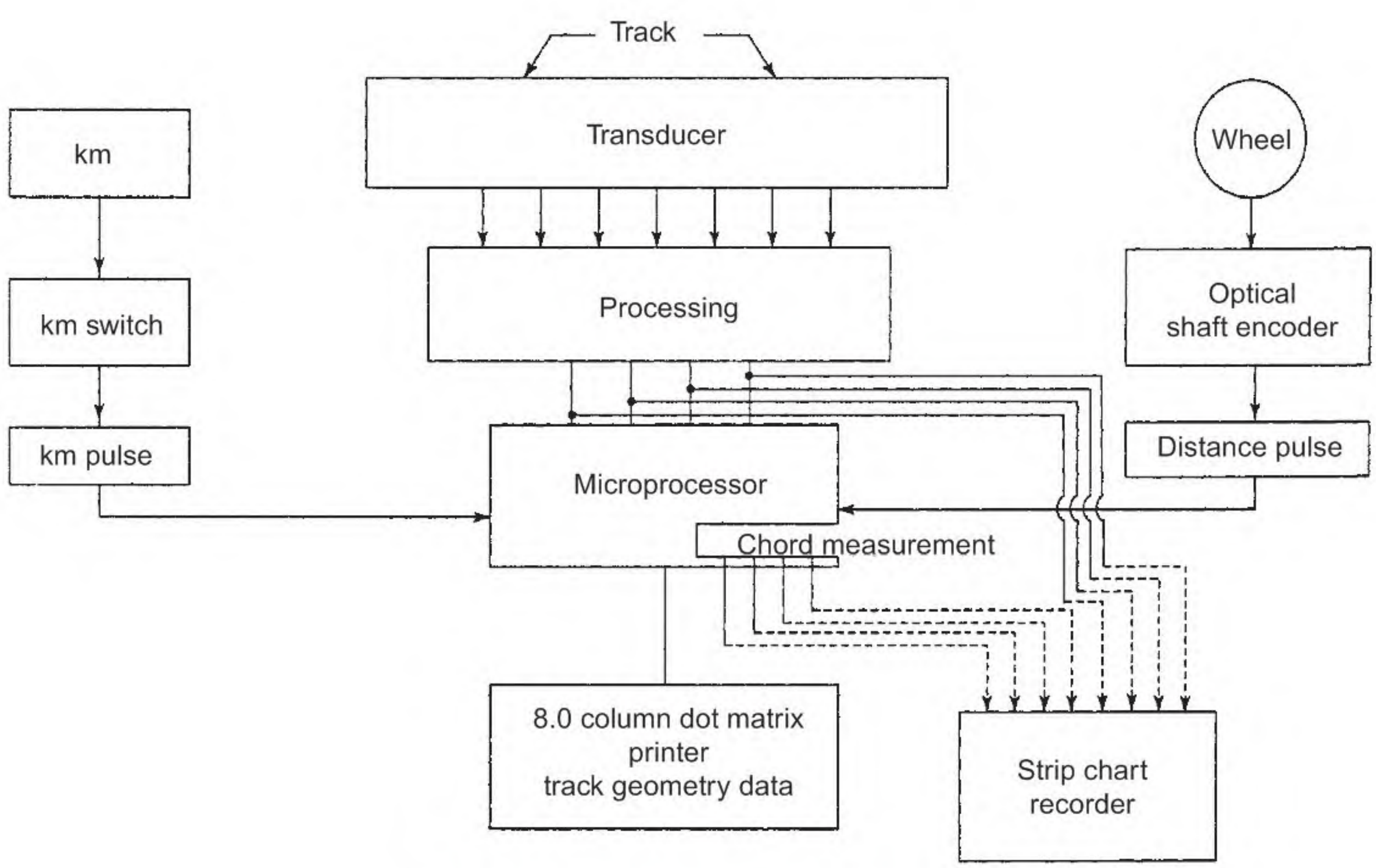


Fig. 17.11 System block diagram

The data can be recorded on strip-chart recorder when necessary. The data is digitized by a fast A/d converter and taken to microprocessor for evaluating mid-chord off-sets by running an electric chord. Two chord options are available:

Parameter	*Option-1*	*Option-2*
UN	3.6 M	9.6 M
XL	3.6 M	3.6 M
AL	7.2 M	9.6 M
G	Direct	Direct

The digital data of of-sets on a chord is further processed for:

1. Evaluating Standard Deviation (SD) on 200 M stretch.
2. Large peak information.
3. Categorization of track in A, B, C, D, category.

The mid-chord off-sets can be converted again into analogue signals for visual observation on strip-chart recorder when required. The final results are presented on a dot matrix printer.

17.10.2 Measuring Transducers

Figure 17.12 shows the location of the measurement transducers on the vehicle. Those are as follows:

1. *Accelerometer* For measuring motion of coach body in vertical plane (2 nos.) and of bogie in lateral plane (1 no.).

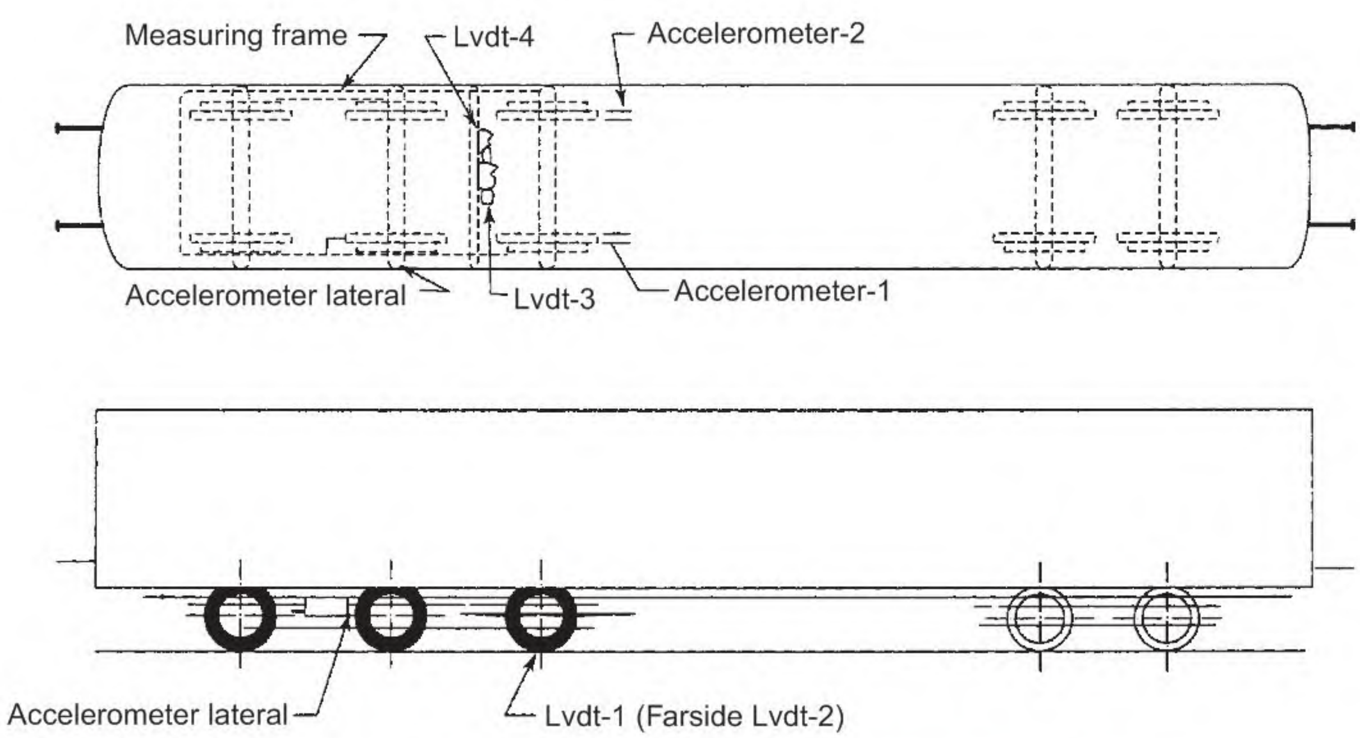


Fig. 17.12 Location of transducers in measuring vehicle

2. *Liner Voltage Differential Transducers* To measure displacement between axle box and coach floor (2 nos.) and between rail face and bogie.
3. *Optical Shaft Encoder* For distance measurement it can be mounted either direct on axle or through flexible coupling inside the coach.
4. *KM Marker* A switch to transfer KM arrival information to microprocessor through an interrupt control.

17.10.3 Track Geometry Description and Parameters Measured

The track geometry in space can be completely described by following four parameters (Fig. 17.13).

1. Centre line unevenness (UN)
2. Centre line alignment (AL)
3. Cross level (XL)
4. Gauge (G)

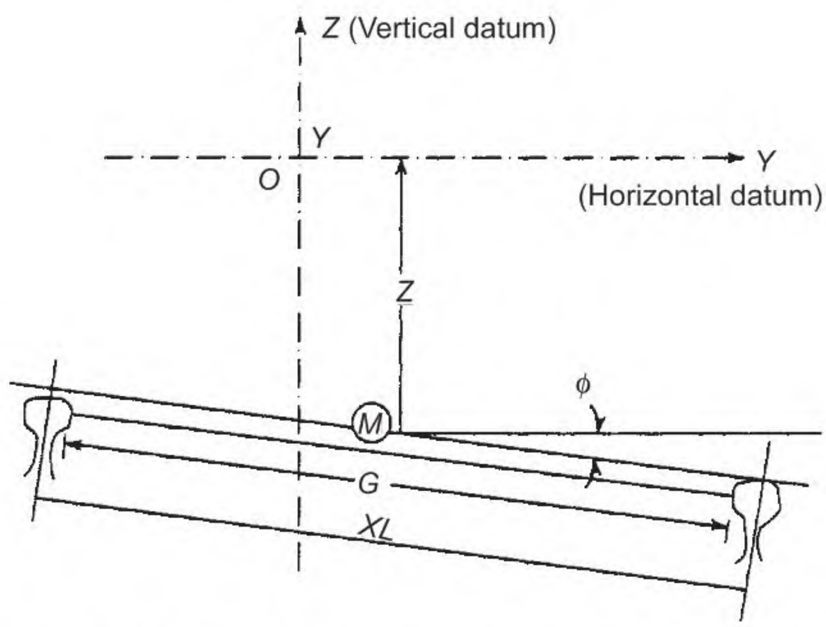


Fig. 17.13 Description of track irregularities

Indian Railways have used mid-chord measurement system since 1965, and field staff is familiar with its description. The irregularities can therefore be passed through mid-chord measurement system to get the desired off-sets on an appropriate chord.

Vertical Profile The schematic vertical profile system is shown in Fig. 17.14. The centre line vertical profile is obtained from vertical profile of left and right rail. The profile of left and right rail is obtained by tracing the movement of axle box in vertical plane. With the assumption that wheel remains in contact with rail, this profile is same as rail profile. To obtain vertical profile of left rail an accelerometer is mounted in coach above the axle box. The output of this accelerometer

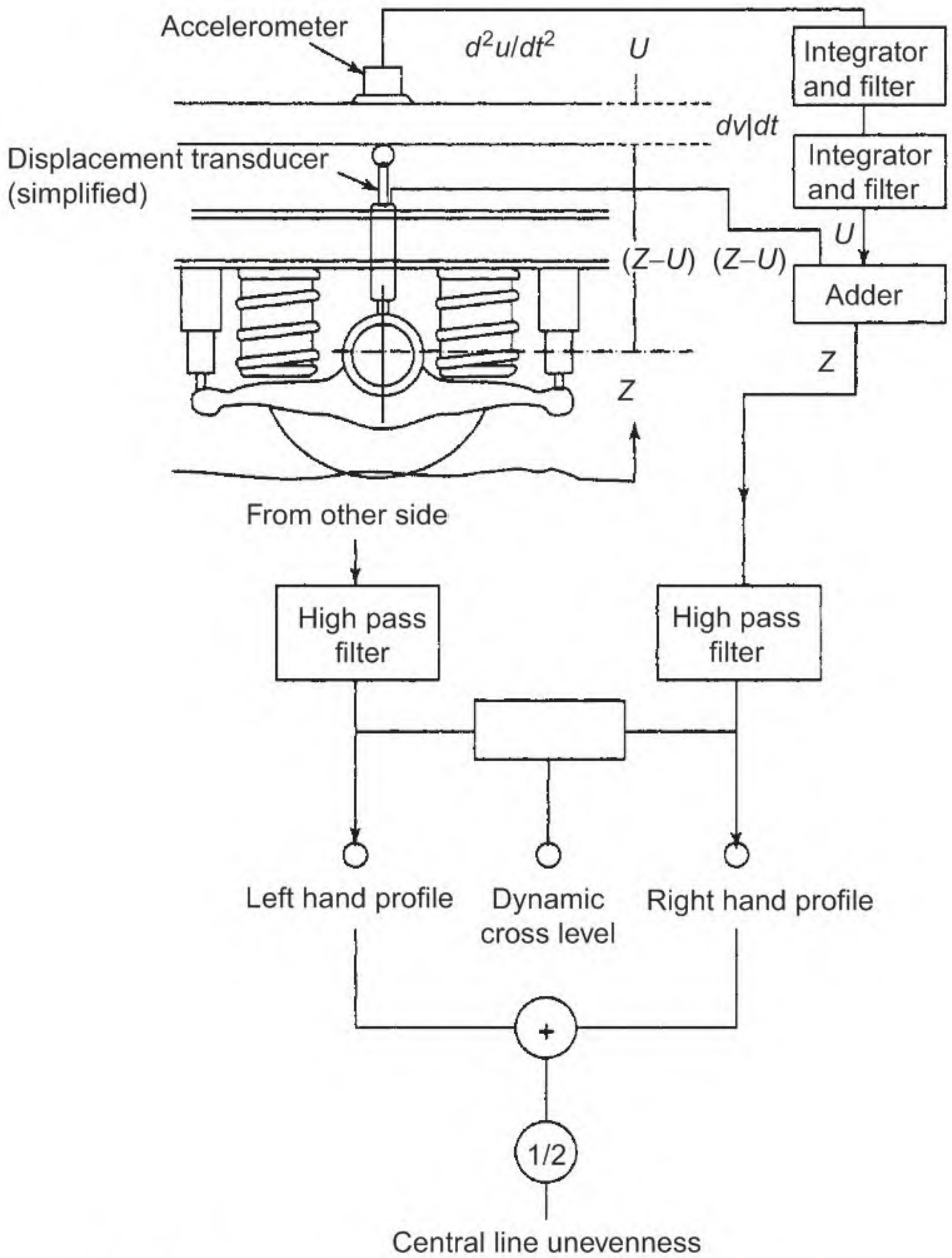
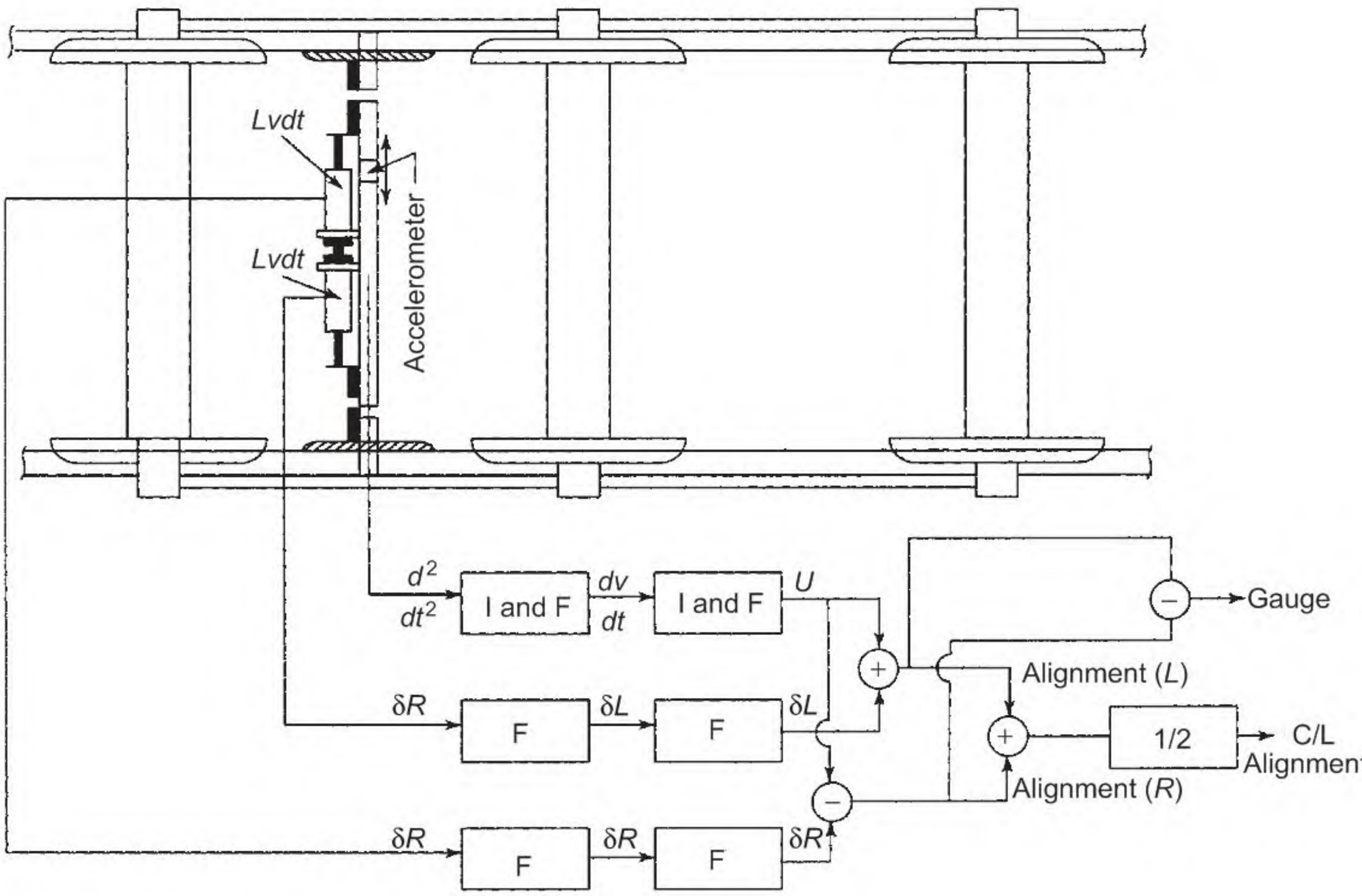


Fig. 17.14 Vertical profile system (schematic)

is integrated twice and suitably high pass filtered and corrected with the variation in the distances between accelerometer base and axle box. Thus by combining the double integration of accelerometer with suspension movement, it is possible to obtain the vertical profile of one rail. The other set of transducer gives the vertical profile of second rail. The two profiles are averaged to get the centre line vertical profile. When this profile is passed through a chord, the unevenness on desired base is obtained.

Dynamic Cross Level The difference in left and right vertical profiles result in a parameter which is known as dynamic cross level. This is of course independent of any design superelevation and may be considered to be the cross level with the design cant filtered out. When this parameter is suitably manipulated, twist of track on desired base is obtained.

Centre Line Alignment The measurement of centre line alignment is done as per the schematic diagram shown in Fig. 17.15. The principle of measurement is to locate the measuring frame movement in space by double integration of acceleration signals and thus measure the distance of left and right rail from the measuring frame with the help of transducers. The manipulation of double integration of accelerometer signals and the transducers signals give the profile of left and right rail. The average of the two yields the centre line alignment. The signal when passed through a mid-chord filter yields the measurement on the chord length.



I and F = Integrator cum filter

F = Filter

Fig. 17.15

Gauge The gauge is measured as difference of the lateral profile of left and right rail.

Analysis and Output The data is analysed digitally and presented on line printer. However, analogue recording on strip-chart recorder is also feasible.

Analogue Data It has been the experience with Amsler Track Recording Car that analogue data has very limited utility. Accordingly, this system has been conceived without any analogue data recorder. This was also essential to keep the system portable. However, following analogue output are available and can be recorded on a suitable strip-chart recorder whenever required.

Inertial Profile

Centre line unevenness
Centre line alignment
Dynamic cross level
Gauge

Mid-Chord Measurements

UN on 3.6 or 9.6 M chord
AL on 7.2 or 9.6 M chord
TW on 3.6 M base

Gauge

It is proposed not to be provide a strip-chart recorder in a routine manner and user can tap these signals when necessary.

Digital Output The processed results of track geometry data are presented on a 80 column dot matrix printer. A sample printout is shown (Table 17.9). The following information is made available to user.

Standard Deviation of Irregularities (*SD*) The standard deviation of track for the four track geometry parameters is evaluated over a length of 200 M.

Table 17.9 AAPL/RDSO DATES-02-84 (S) 1235 Standard Deviation

	UN	*TWT*	*A/L*	*GAG*	*TIV*	*TIL*	*TI*	*MI*
1	00.9	02.5	01.7	03.6	29	38	55	***
2	01.1	02.4	01.5	02.8	25	33	50	***
3	01.0	02.2	01.5	03.6	27	36	52	***
4	01.0	02.5	01.3	03.0	30	33	51	***
	A 00	C 22	C 10	D 38	Track classification			

Large peaks					
U/N	06/658	06/152	06/237	06/331	06/85
TWT	13/284	12/440	12/760	11/182	11/568
A/L	08/23	07/276	07/311	07/617	07/848
GAG	18.628	16/48	15/652	15/334	15/212

Maintenance of Instruction (*MI*) Depending upon the limits of track irregularity a maintenance instruction for each block is evaluated and printed with following connotations:

*** Urgent Maintenance
** Regular Maintenance
* To be planned for maintenance

The tolerances built in are for a maximum speed of 130 kmph for existing rolling stocks and can be altered when new limits are evaluated or are desired. The information of SD, TI and MI is presented for all the five blocks. The minimum number of blocks are four and maximum six per km.

Track Classification (*TI*) Indian Railways presently classify their track geometry in A, B, C, D category using peak counting system. Even though this classification is not considered rational with the new monitoring system, the same has been retained for providing gradual transition to new system. The classification consists of category (A, B, C, D) and suffix which is indicated by number of peaks crossing the 'B' category limits.

Large Peak Information (*LPI*) The information of isolated track irregularities is considered essential to undertake repair of isolated track faults. Five worst peaks is a km for each parameter are displayed with distance from the start of a km in metre. The information of first five worst peaks that occur in a km is given. It has been observed that normally number of peaks that can be effectively called isolated will not be more than five (5).

17.11 TRACK GEOMETRY INDEX (TGI) FOR STANDARD DEVIATION BASED ASSESSMENT OF TRACK GEOMETRY

Traditionally, the assessment of track geometry of Track on Indian Railways was being done through Composite Track Record (CTR)

$$\text{CTR} = 100 - (U_A + T_A + G_A + A_B)$$

The CTR formula has the following limitations:

1. No direct correlation with Riding Quality.
2. Very sensitive to minor changes in track geometry.
3. It being a measure of total peaks beyond *A* limits (*B* in alignment), it in no way is correlated to the limiting values of the parameters. Thus a fairly good track, in *B* category may show very low CTR value though it is well within the safe limits.
4. It considers only the excess values at isolated locations rather than assessing the continuous quality of the track.
5. This has equal weightage for all the parameters irrespective of their contribution in RI.

To overcome the above hazards, a standard deviation based Track Geometry Index has been evolved. This takes into account the index for different parameters, assessing the condition with respect to the range defined by best maintained track on one side and track needing urgent maintenance on the other side.

The index for individual parameter (e.g. Twist) is worked out as:

$$\text{TI}_{(\text{Twist index})} = 100 \times e^{-\frac{(\text{SD}_{\text{Measured}} - \text{SD}_{\text{New track standards}})}{(\text{SD}_{\text{Urgent Maint}} - \text{SD}_{\text{New track standard}})}}$$

Thus, when the track is as good as Newly Laid Track Standard, the TI will be 100. When the track is at the stage of urgent maintenance limit, the TI will be $100/e = 36$.

Thus for each parameter, index going below 36, the SD exceeding the SD value worked out for urgent attention for the sectional speed.

Considering the effect of each parameter on the Ride Index, different weightages have been assigned to different parameters (Unevenness, Twist, Alignment and Gauge) and the composite TGI is worked out as below:

$$\text{TGI} = \frac{2\text{UI} + \text{TI} + 6\text{AI} + \text{GI}}{10}$$

Assigning 60% weightage to AI, 20% to unevenness and 10% each to Twist and Gauge.

The SD value (mm) adopted for newly laid track and track needing urgent attention is as follows:

Table 17.10

		Index tolerance for urgent maintenance	
	Newly laid track	*Speed > 105 kmph*	*Speed < 105 kmph*
U (9.6 mts.)	2.50	6.20	7.20
T (3.6 mts.)	1.75	3.80	4.20
G ———	1.00	3.60	3.60
A1 (7.2 mts.)	1.50	3.00	3.00

The TGI will normally vary from 120 for very good track to 20 for very poorly maintained track.

The index for individual parameter and TGI is calculated in blocks of 200 mts. each. In the digital printout generated during the TRC run, the blocks, where SD value exceeds that laid down for urgent maintenance, as identified with three star marking (***) and the block where limit for planned maintenance is exceeded are identified with two stars (**).

The limiting values for these indexes are:

Above 80	No maintenance required
80–50	Need based maintenance required
50–36	Planned through maintenance required
below 36	Urgent maintenance required

For attention to isolated defects in stretches of track otherwise maintained well, the report generated on real time during TRC run gives digital printout of the size and location of eight largest peaks in each km.

The advantages of TGI are:

1. It gives an idea of health of continuous length rather than highlighting isolated bad locations.
2. It gives due weightage to different parameters as per their effect on the Ride Index.
3. The range over which it varies is much smaller and it does not get affected by minor changes

from run to run. A variation of 10 in TGI shows a significant improvement/deterioration in the track quality.

17.12 PLASSER AND THEURER'S MODERN TRACK RECORDING CARS

Plasser and Theurer's modern track recording cars are equipped with a non-contacting track geometry measuring system with integrated GPS navigation and Dual OGM Optical Gauge Measurement to measure, record and analyse the track geometry.

The system measures the following parameters: longitudinal profile of left and right rail, alignment of left and right rail, track gauge (dual measurement), cross level, twist, curvature and curve radius, gradient and position using GPS.

Also measured and recorded are measuring speed (traveling speed of recording car), distance (line mileage), events (e.g. level crossings, bridges, turnouts, etc.) and the ambient temperature.

17.12.1 The Hardware Components

The track geometry measuring system consists of the following units: the inertial measuring unit (IMU), two optical gauge measuring systems (Dual OGMS) and the navigation system (navigation computer with integrated GPS receiver, GPS antenna).

The recording car itself is equipped with a measuring frame which is fixed to the four axle boxes of a bogie. The IMU and the four measuring sensors of the dual track gauge measurement are mounted on the measuring frame. The entire construction is an extremely rugged design. This arrangement ensures that the measuring frame, the IMU and the sensors are always guided parallel to the rail surfaces, therefore the measuring frame can be used as a reference plane for the track geometry measurement. As the bogie applies a load to the track during the measuring run, the track geometry is measured under realistic loading conditions.

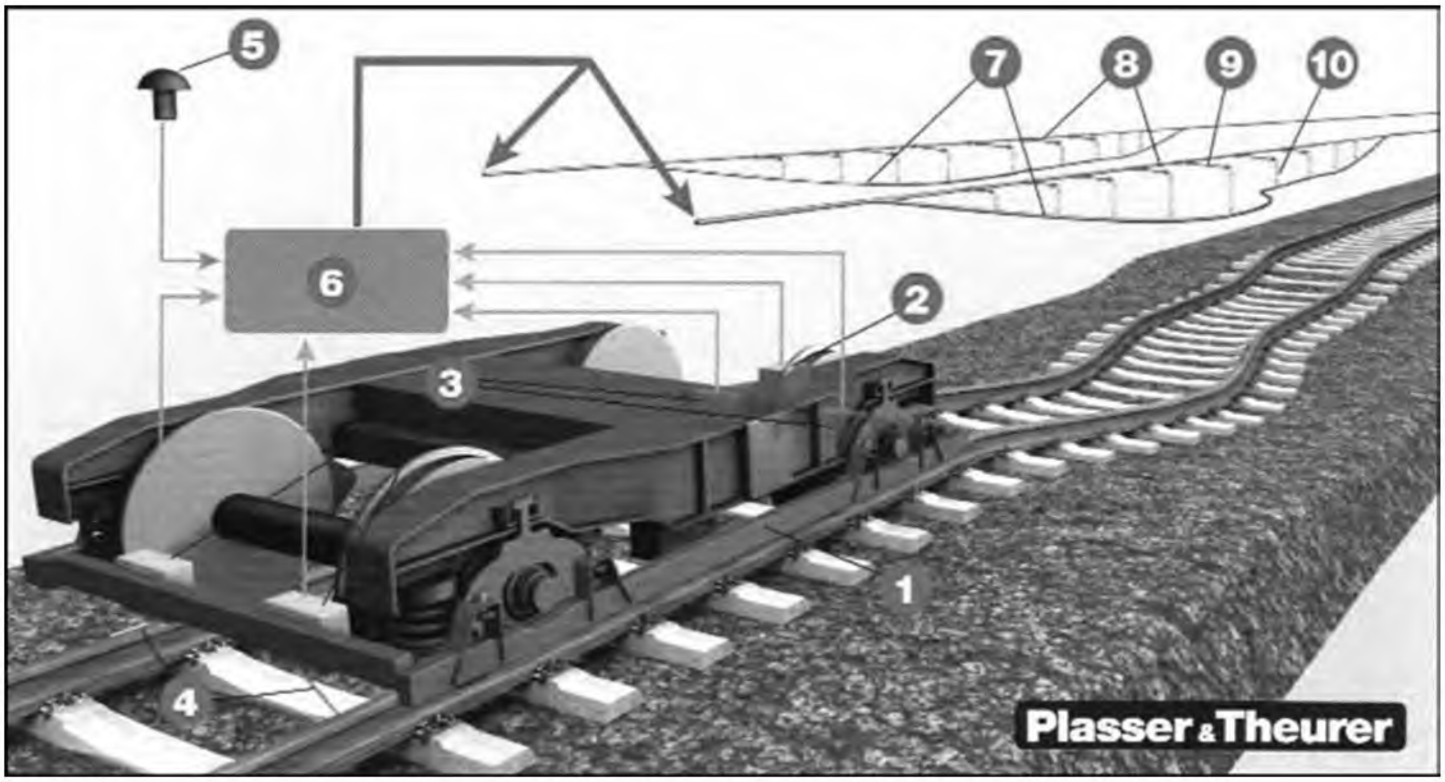
The track recording cars are also able to measure the rail profile and the wear conditions of the rails with the help of lasers and video cameras.

The non-contacting corrugation measuring system identifies defects on the rail surfaces in a wavelength range of 10 to 900 mm at measuring speeds of up to 300 km/h.

The axle box acceleration measuring system measures vertical accelerations of both axle boxes.

A measuring system is also designed for checking track clearances and the ballast profile.

Figure 17.16 shows the working principle of Plasser and Theurer's track geometry measuring system.



1. Measuring frame with fixed vertical distance to the rail surfaces
2. Inertial measuring unit (IMU)
3. Sensors of the track gauge measurement
4. Laser beams to scan the track gauge
5. GPS antenna
6. Navigation computer
7. Blue curves: space curves of both rails derived from the measurements along the track, synchronised with GPS data
8. Green line: track design line
9. Red arrows (horizontal): alignment defects, calculated from the space curve
10. Orange arrows (vertical): longitudinal level defects, calculated from the space curve

Fig. 17.16 Working principle of the Plasser & Theurer track geometry measuring system. (See also Color Plate 13)

Chapter 18

High-Speed Track

18.1 CONCEPT OF HIGH-SPEED TRAIN

The council of the European Union in their directive no. 96/48/EC has defined the term "High-Speed" covering all railway express services operated at speeds in the 200 to 300 kmph range. This includes railway lines:

(i) Built specially for high-speed generally equal to or greater than 250 kmph.
(ii) Specially upgraded for high-speed travels of the order of 200 kmph.

The provision of a high-speed service is not restricted to reducing journey times. Its undoubted success is also due to the quality associated with high-speed travel, viz:

- The frequency of service,
- Regular-interval timetables,
- A high level of comfort,
- A pricing structure adapted to the needs of customers,
- Complementarity with other forms of transport,
- More on-board and station services.

A high-speed system is designed to incorporate the whole range of services which the customer has come to expect when travelling on high-speed trains, including both pre-travel services (information, ticket purchasing, seat reservations, etc.) and post-travel ones (after-sales service).

High-speed railways in addition to providing a high level of mobility of people are greatly advantageous as environmentally friendly means of transport.

Transport is responsible for 25% of the world's carbon dioxide (CO_2) emissions, with 80 to 90% coming from cars and highway trucks, and only 2% from rail. Moreover, emission levels are increasing faster than technological progress due to the total dependence of road and air transport on oil, and the continuing growth of traffic. On high-speed railways the energy consumption per passenger-kilometre is three and half times less than for a bus, five times less than for an air and ten times less than for a private car.

The social cost of noise, dust, carbon dioxide, nitric oxide and sulfur oxide emission, for high-speed rail is one fourth of road transport and one-sixth for air. It requires the construction of an eight-lane highway to provide the same capacity as a double track high-speed railway line.

Fig. 18.1 High-speed track on Korean railway system (See also Color Plate 13)

Noise and vibrations have been a matter of concern in high-speed rail operations. Measures such as, damped wheels, structures around the bogies, line side noise barriers, special structures at the tunnel portals etc., have been able to contain the noise within the acceptable limits of 75 dB (A).

Table 18.1 gives a list of high-speed lines as in the year 2005 operating at a maximum speed of 200 kmph and above with a start-to-stop average speed exceeding 150 kmph.

Table 18.1 Start-to-stop Runs Exceeding 150 kmph

Country and speed limit in kmph	*Train*	*From*	*To*	*Distance km*	*Average speed kmph*
France 320	TGV	Lyon-St Exupery	Aix-en-Provence	289.6	263.3
Japan 300	Nozomi	Hiroshima	Kokura	192.0	261.8
Belgium 300	Thalys	Brussels Midi	Valence TGV	831.7	242.2
Germany 300	ICE	Frankfurt Flughafen	Siegburg/Bonn	144.0	233.5
Spain 300	AVE	Madrid Atocha	Ciudad Real	170.7	204.8
Sweden 200	X2000	Falkoping	Katrineholm	209.7	190.6
South Korea 300	KTX	Seoul	Taejeon	155.0	189.8
United Kingdom 200	IC225	Stevenage	Grantham	125.3	181.1
Italy 250	Eurostar	Roma Termini	Firenze SWN	261.0	166.6
USA 240	Acela Express	Wilmington	Baltimore	110.1	165.1
Finland 200	Pendolino	Salo	Karjaa	53.1	151.7
China 200	Expresses T805/6	Shenzhen	Guangzhou Dong	139.0	151.6

The best performance of the average speed attained in other countries, although below the high speed range, are given in Table 18.2 for a proper appreciation of the status of high-speed technology in that country.

Table 18.2 Fastest Station-to-Station Timetables Journeys in Other Countries

Country	*From*	*To*	*Distance*	*Speed (kmph)*
Norway 180	Lillestrom	Gardermoen	30.2	151.2
Portugal	Coimbra	Aveiro	55.0	143.5
Russia	St. Petersburg	Moscow	649.9	143.4
Denmark	Odense	Hoje Tastrup	145.0	142.6
Austria	Linz Hbf	St Polten	127.9	142.1
Saudi Arabia	Abqaiq	Ad Dammam	74.0	134.5
Hungary	Hegyeshalom	Gyor	47.0	143.3
Canada	Cornwall	Kingston	174.1	133.9
Israel	Hof Ha-Carmel	Tel Aviv University	81.7	132.5
Poland	Warszawa Centralna	Zawierce	253.2	128.7
Morocco	Rabat Agdal	Mohammedia	63.0	126.0
Turkey	Eskisehir	Ankara	253.0	122.4
Switzerland	Sion	Montreux	66.0	116.5
Greece	Inoi	Lianokiadi	151.1	116.2
Czech Republic	Ostrava Svinov	Prerov	79.0	115.6
Taiwan	I'ian	Taipei	97.0	114.1
Ireland	Dublin	Thurles	139.2	113.6
Chile	Rancagua	San Fernado	53.0	109.7
Kazakhstan	Qaraghandu	Sari Shagan	462.0	109.6
Netherlands	Utrecht	Arnhem	57.0	106.9
Egypt	Sidi Gaber	Cairo	203.0	106.8
India	Mathura Junction	Sawai Madhopur	210.0	105.9

18.2 TECHNOLOGIES FOR HIGH-SPEED OPERATIONS

Following two distinct technologies have been adopted for high-speed operation, these are:

(i) Improvement of the conventional railway operational system.
The modest increase of speed on Indian Railways on some selected roots come under this category. Measures adopted by Indian Railways are discussed in subsequent paragraphs.

(ii) Construction of dedicated high-speed corridors.

18.2.1 Improvement of the Conventional Railway Operational System

In adopting this technology the hindrances existing in the operation of high-speed are removed to the extent possible. These hindrances are in the form of

(a) *Tight Horizontal Curves* The centrifugal forces generated on the curves, vary with the square of the speed. The curves are therefore required to be eased out to keep the centrifugal forces with in a manageable limit.

(b) *Vertical Curves* The desirable values of radii of vertical curves for high-speed operation is much higher.

(c) *Level Crossing/Grade Separations* For high-speed operation, all level crossings are required to be replaced by suitable grade separation works.
(d) *Fencing* On high-speed lines trespassing on tracks cannot be permitted. Thus the entire high-speed line has to be fenced.
(e) *Track Geometry* Very close tolerances in track geometry are required to be maintained requiring sturdy track layouts and sophisticated track maintenance and monitoring system.

The problem in respect to tight curves has to some extent been solved by adopting tilting train technology.

18.2.2 Tilting Train Technology

All along, since the advent of the railway transportation system, the maximum permissible speed on the railway lines has been governed by the cant (superelevation) and cant deficiency values. The development of bogie tilting technology, in which vehicles are tilted depending upon the degree of curvature, has opened a new era of high-speed operation. The tilting of the bogies is achieved by utilising hydraulic or pneumatic power, while lately electric power is also being utilised. Currently, vehicles are being manufactured by adopting any one of the following tilt technologies. As per the latest available information the percentage of vehicles incorporating different tilt technologies is given in Table 18.3.

Table 18.3

Tilt technology	*Percentage (%) of vehicles*
Fiat tilt technology Fs	45 %
Adtranz tilt technology (ABB/AEG)	17 %
Bombardier tilt technology	11 %
Hitachi tilt technology	22 %
Siemens tilt technology	5 %
Total	100 %

18.2.3 What Tilt Achieves

Tilting trains exploit the fact that speed through curves is principally limited by passenger comfort, and not by either lateral forces on the track or the risk of overturning. The principals and basic equations related to tilting are well known.

Two primary decisions need to be made. The first is the maximum tilt angle to be provided (θ_{tilt}); this is based upon the mechanical design of the vehicle. The second decision is what cant deficiency, the passengers should experience on a constant radius curve ($\theta_{\text{CD tilt}}$), which is of primary importance to comfort.

Given these two decisions, and the value of cant deficiency that applies for the non-tilting case ($\theta_{\text{CD non-tilt}}$), it is possible to derive an equation for the increase in curving speed, or speed-up, offered by tilt:

Fig. 18.2 Tilting train (See also Color Plate 14)

$$\frac{V_{\text{tilt}}}{V_{\text{non-tilt}}} = \sqrt{\frac{\sin(\theta_{\text{cant}} + \theta_{\text{tilt}} + \theta_{\text{CD tilt}})}{\sin(\theta_{\text{cant}} + \theta_{\text{CD non-tilt}})}}$$

Maximum track cant is usually 6°, and typically 6° of cant deficiency is specified for a non-tilting train. Applying 9° of tilt and with a cant deficiency of 6° for the tilting train, the calculation indicates a speed-up of 32%.

In the light of the above facts tilting trains speed up the trains by about 30%. It is however important to design the transition curves properly, so as to ensure the comfort level to be within the acceptable limit.

18.2.4 Dedicated High-Speed Corridors and their Construction Parameters

For high-speed operation exclusive corridors have been designed and constructed. On these corridors construction parameters have been appropriately selected for smooth, efficient and safe operation at the designated speed. The construction parameters, which need special attention on these corridors, are:

(a) *Horizontal Curves* Their radius, cant, cant-deficiency etc. easiest possible curves are provided on high-speed corridors.

(b) *Ruling Gradient* As the high-speed trains are lighter in load and are provided with high tractive power, steeper gradients can be allowed on high-speed lines.

(c) *Vertical curves* For better passenger comfort, gentler vertical curves are provided on high-speed lines as compared to that adopted on conventional lines.

(d) *Spacing of tracks* On high-speed tracks, provision of wider centre to centre spacing for double lines is important in view of the higher air pressure generated during the crossing of the trains.

(e) *Track Structure* For ballasted tracks, track structure as adopted on conventional lines is considered good enough except that the sub-grade should be more stable and unyielding. Suitably graded granular material is generally used in the construction of embankments. Even in cuttings, poor soils should be replaced by good material. Track drainage has to be given paramount importance.

Ballastless tracks are now being increasingly adopted on high-speed lines. While Shin-Kan-Sen in Japan are adopting ballastless tracks on all their new lines, ballastless tracks have also been provided on high-speed lines in Taiwan, Korea and Germany. France and Spain, so far have preferred to continue with ballasted tracks.

Comparative merits and demerits of providing ballast less track structure on high-speed lines are discussed, in a subsequent paragraph.

18.3 BALLASTLESS TRACK, PREFERRED TRACK STRUCTURE FOR HIGH-SPEED OPERATION

While the first high-speed line, the new Tokaido line of Shin-Kan-Sen, Japan, was constructed with ballasted track, followed by TGV of France, also a ballasted track, most of the new high-speed lines are adopting ballastless track structure. After new Takaido line all Shin-Kan-Sen lines have ballastless track. Ballastless tracks have also been adopted in Germany and Italy. Recently constructed high-speed lines in South Korea and Taiwan have long lengths of ballastless tracks. China on their new Beijing-Shanghai high-speed lines will have all ballastless tracks indigenously developed by them.

For high-speed line, the advantages that accrue with the adoption of ballastless tracks are:

(a) Little or no maintenance requirement and thus higher operational availability and low maintenance expenditure.
(b) Economy in construction, when adopted in tunnels and on viaducts, on account of reduced structural height and less static load.
(c) Long service life.
(d) High lateral track resistance, which will permit higher speeds with the introduction of tilting technology.
(e) No ballast turbulence, a major drawback in ballasted tracks on high-speed trains.
(f) Better rheological properties.

In India, in addition to the above-mentioned advantages of the adoption of ballastless tracks, there will be other significant benefits, which are:

(i) With the heavy rainfall during monsoon months, it will be difficult to maintain the desired track tolerance on ballasted tracks. Extensive tamping operations will be needed during monsoons and after, to restore normalcy.
(ii) Ballasted tracks at high-speeds are great environmental hazard by raising a huge cloud of dust following the movement of high-speed train. Such tracks will be a nuisance for the habitants residing in the villages/towns located adjacent to the high-speed lines.

(iii) Ballast contamination by dust and its churning, will need more frequent ballast cleaning operations.

In the light of above-mentioned facts, high-speed lines in India will necessary have to opt for ballastless track structure.

18.4 CONSTRUCTION PARAMETERS AS ADOPTED ON EXCLUSIVE HIGH-SPEED CORRIDORS

The geometric parameters as adopted by various world railways on their high-speed corridors are as follows:

18.4.1 Horizontal and Vertical Curves

Horizontal curves are in the range of 7000 m to 10000 m. For standard gauge track, radius and other curve parameters as adopted in various countries are tabulated in Table 18.4.

Table 18.4 Curve Parameters

			Country		
Parameters	*France*	*Germany*	*Spain*	*Korea*	*Japan*
Speeds kmph	300/350	300	350	300/350	350
Radius of horizontal curves (m)	10000	7000	7000	7000	4000
Maximum cant in (mm)	180	170	150	130	180
Cant deficiency	85	150	100	65	50
Maximum grade (mm/m)	35	40	12.5	25	15
Cant gradient (mm/s)	50	34.7	32	NA	NA
Minimum vertical radius (m)	16000	14000	24000	NA	10 000

(NA = Not available)

18.4.2 Spacing of Tracks

Minimum distance between tracks centers adopted by some of the high-speed networks using standard gauge are given in Table 18.5.

Table 18.5 Minimum Distance between Tracks

Country	*Minimum distance between tracks (m) at the following speed*	
	300 kmph	*350 kmph*
France	4.2	4.5
Germany	4.5	4.5
Italy	5.0	5.0
Spain	4.3	4.7
Japan	4.3	4.3

Indian Railways provide a c/c spacing of 5.35 m between tracks on broad gauge for new construction projects, which is sufficient for high-speed corridor.

18.4.3 Ballast

Generally the depth of ballast cushion varies from 30 to 35 cm on high-speed lines. Ballast is laid on a sub-ballast layer of 20 to 30 cm thickness. The characteristics of ballast and sub-ballast on some of the high-speed networks are given in Table 18.6.

Table 18.6 Characteristics of Ballast and Sub-ballast

Parameters	*Country (Speed: kmph)*			
	France 300/350	*Germany* 300	*Japan* 300	*Italy* 300
Minimum/Maximum size of ballast (mm)	25/50	22/63	30/60	30/60
Minimum thickness of the ballast (cm)	30	35	30	35
Minimum thickness of the sub-ballast (cm)	20	30	25	30

18.4.4 Rails and Sleepers

Rails and concrete sleepers for high-speed tracks are not much different from the standards adopted on conventional tracks. Most of the high-speed network use 60 kg/h, UIC, 90 UTS rails. Standard concrete sleepers at a centre-to-centre spacing of 60 cm are used. While fastening systems are generally the same, the technical specification in respect to the dynamic rigidity of the rail pads is kept with in 600 MN/m. This helps in better attenuation of impact forces.

18.4.5 Sub-grade Improvement for Ballastless Tracks

Ballastless tracks when adopted on viaducts and in tunnels have the advantage of hard unyielding bed and are thus free from any subsidence or settlement, an important requirement of ballastless track. They need considerable degree of sub-grade improvements works, when laid on normal soils. This is to ensure zero/no settlement or very little settlement, after the ballastless track is laid in position. For that purpose, following types of ground treatments are generally adopted depending upon the types of soils encountered.

(a) *Vibratory Surface and Deep Vibro-compaction*

Surface vibratory compaction is used for densification of loose cohesion-less soils using vibratory roller.

Deep vibro-compaction can be done for the loose sandy deposits having less than 15% of fines for depths up to 10 m. Compaction is carried out by inserting the probe up to the design depth of improvement and allowing the soil around the probe to get compacted for a certain time interval.

(b) *Removal and Replacement*
For localized areas with soft soils of limited depth and thickness, removal of unsuitable material and replacement with suitable fill may be carried out.

(c) *Preloading*
Preloading of soft soils is based on the consolidation concepts, whereby; pore water is squeezed from the voids until the water content and the volume of the soil are in equilibrium under the loading stresses imposed by the surcharge.

(d) *Prefabricated Vertical Drains and Pre-loading*
With increased thickness of the soft clay where the consolidation period is too long for full consolidation of primary settlements, vertical drainage may be incorporated in conjunction with preloading in order to accelerate the settlement.

(e) *Dynamic Replacement*
Dynamic replacement utilises a heavy pounder, usually lifted by crane to designed height and then dropped onto the soil, in a grid pattern such that the site is adequately covered.

(f) *Stone Columns*
Stones columns may be provided in areas where subsoil consists of more than about 5 m thick soft cohesive soil and where stability and stringent considerations cannot be satisfied with conventional removal/replacement of soft material.

(g) *Piled Embankment and Viaduct*
In soft soil areas, embankment height exceeding the pre-consolidation pressure will give rise to excessive settlement. This can be avoided by means of structural solutions such as viaduct or piled embankment. Structural solution is recommended in soft ground conditions with depths exceeding 15 m.

18.5 BALLASTLESS TRACK TECHNOLOGIES OF HIGH-SPEED RAILWAY LINES

Following types of ballastless tracks have been adopted, by various world railway systems, on their high-speed tracks.

18.5.1 Slab Track-based on the Design Adopted on Shin-Kan-Sen (Japan) (Fig. 18.3)

In this system a base of reinforced cement concrete is created over a properly consolidated soil. Pre-cast cement concrete panels about 5 m long and 2.34 m wide and 160 mm thick support the rails at their precise locations. Specially designed mixture of cement and maxphalt about 50 mm thick is introduced between the two concrete surfaces of base concrete and the top concrete panel. This mix provides a medium for vertical adjustment and helps in reducing track vibrations. Rails are fixed on the top slab with standard KAWA type fastening system, having a rail-pad and also an elastomeric pad under the base plate. The rail fastening system allows considerable scope for vertical and latter adjustment. The cement maxphalt mix layer can be suitably adjusted to accommodate any settlement of formation.

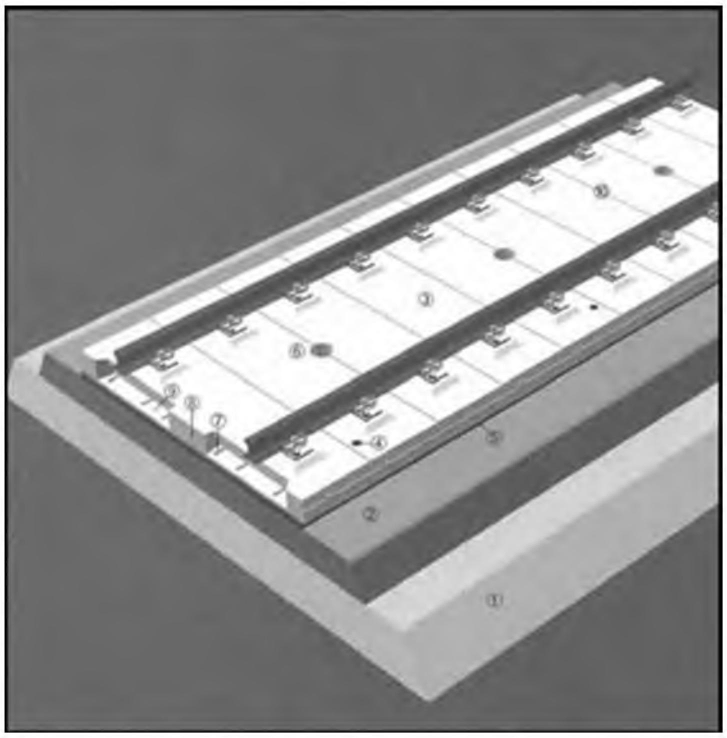


Fig. 18.3 Max Bogl slab track system (See also Color Plate 14)

Similar system with certain modifications has been evolved by M/s Max Bogl called "slab track system FF-Bogl". Italian and Chinese railways have also evolved a similar system for their high-speed lines.

18.5.2 REHDA Ballastless Track System (Fig. 18.4)

In this system, the sleeper with ordinary reinforcement (without pre-stressing) together with the concrete bed that encloses it, constitutes a homogenous ballastless track structure. Various versions of REHDA system have been developed. The latest among them is REHDA 2000. The REHDA 2000 is installed as a top-down system, with the help of service rails. The sleepers are assembled together with the rails to form a track framework, which is installed at proper position with the use of a special adjustment system. The track-supporting layer of concrete is poured only after final alignment and levelling. This system has been used on a number of new high-speed lines in Germany. Recently, it has also been used in the station areas for turnouts installation on Taiwan's high-speed line.

18.5.3 The Low Vibration Track (LVT) System (Fig. 18.5)

LVT System developed by Mr. Roger Sonneville, comprises concrete blocks, resilient pads placed under the blocks and rubber boots encased in a second pour concrete. The rails are fixed in position with the concrete blocks adopting the standard French Nabla elastic clips. Pandrol, Vossloh or

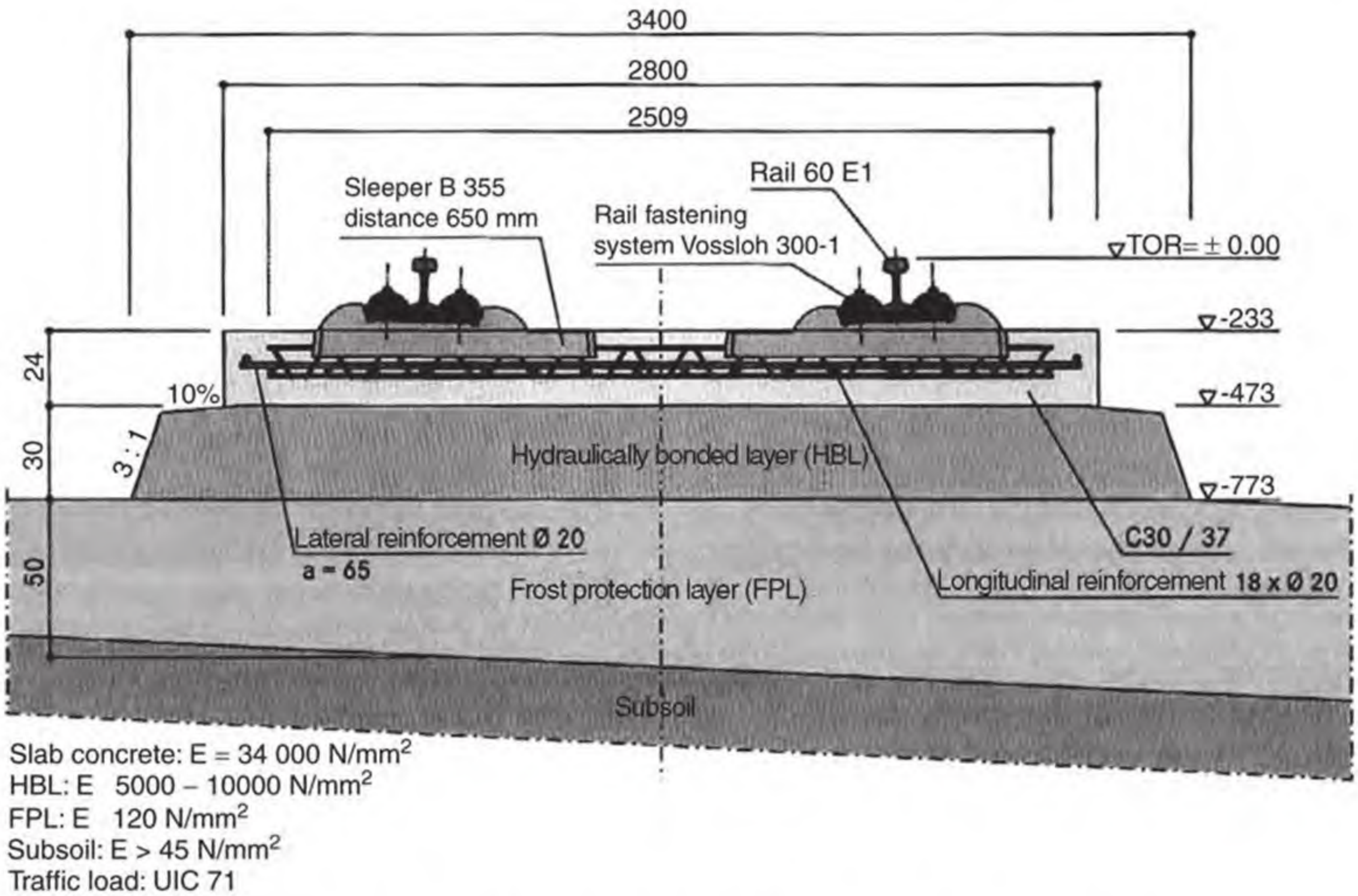


Fig. 18.4 REHDA ballastless track (See also Color Plate 15)

Fig. 18.5 Low vibration track (See also Color Plate 15)

other similar elastic fastening system can also be used. No adjustment is possible in the position of concrete blocks after the second pour concrete. This system has been found true to its reputation of allowing very low vibrations from the railway tracks to adjoining structures. The system has therefore been extensively used on railway tracks in tunnel including the channel tunnel and also the tunnels on the Taiwan high-speed lines.

18.5.4 Solid Slab Track-system NBO (Fig. 18.6)

The solid slab "track-system NBO" is similar to the paved concrete track evolved sometime in 1970's, where a specially designed concrete paver was used to lay the concrete slab to close tolerances. In the NBO system concrete paver leaves a groove in which rails with their elastic fastening system are accurately placed, adopting top-bottom construction technology. This system does not use sleepers and is claimed to have the following characteristics:

- Rails resting on single fastenings
- Concrete as a long lasting slab having tight tolerances
- Laying the rails complete with fastenings
- High degree of precision when laying the track
- Leveling plates to maintain tight tolerances
- High technology surveying instruments for precision in track laying
- Use of rapid hardening grout (jointing compound)
- Environmental impact is considered in the planning and construction

Fig. 18.6 NBO track system (See also Color Plate 15)

This system, which is patented by M/s ThyssenKrupp, has been approved by technical university of Munich, Germany and has been laid on some high-speed lines in Germany and in South Korea. Needless to mention that formation under the pavement has to be properly designed and constructed to achieve zero settlement criteria, as the scope for vertical and lateral adjustment for soils only exists in the fastening system alone.

18.5.5 Edilon Embedded Rail System (Fig. 18.7)

In this system rails are embedded in position with a suitable formulated elastomeric compound, which provide the necessary degree of elasticity. This system is similar to the "NBU" system, where a concrete pavement is constructed leaving grooves for the installation of rails. This system although free from fastening component, has little scope for rail adjustment. This system has been adopted by Taiwan on their high-speed lines at Taipei station.

Fig. 18.7 Edilon embedded rail system (See also Color Plate 16)

18.5.6 Pandrol Vipa System, Logwell India Ballastless Track System [Figs 18.8 (a) and (b)]

M/s Pandrol of UK has evolved Vipa ballastless track system, which has been adopted on tracks in tunnels and on viaducts. M/s Logwell of India has also evolved a similar ballastless track system, which can be adopted on high-speed lines. In both the designs, an elastomeric pad of 10 to 12 mm thickness, is sandwiched between the two steel base plates, providing adequate elasticity to the track. The assembly has been suitably strengthened to counteract the increased lateral forces, generated in high-speed operation. For construction, the methodology as adopted by the Indian technicians in the laying of ballastless track for Delhi metro, can be successfully adopted on high-speed lines in India.

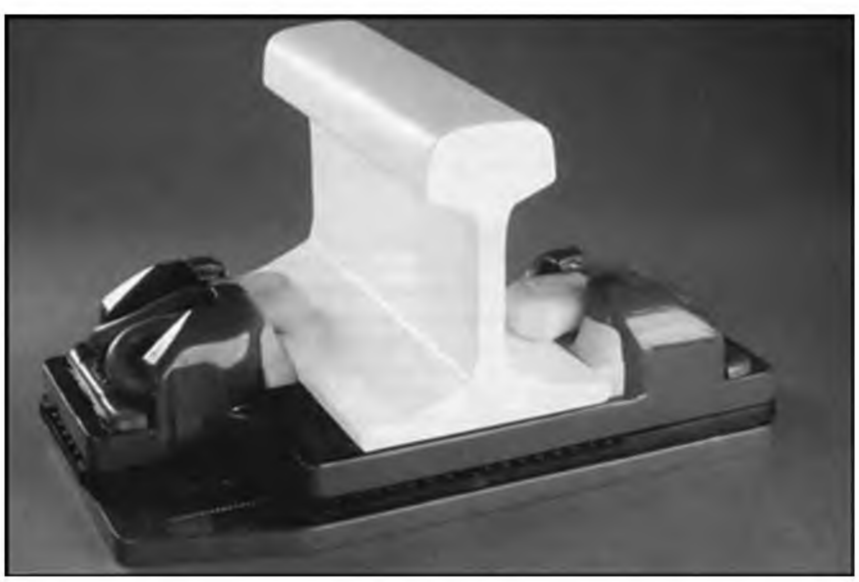


Fig. 18.8 (a) Pandrol Vipa ballastless track system (See also Color Plate 16)

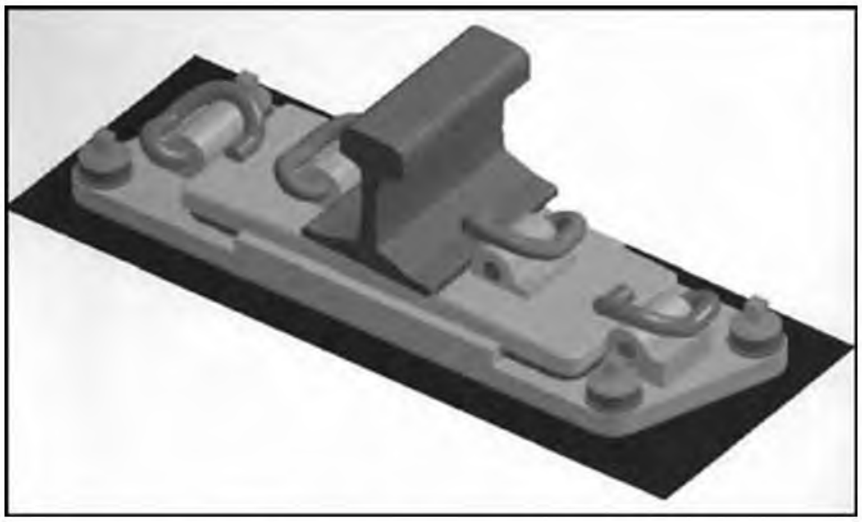


Fig. 18.8 (b) Logwell (India) ballastless track system (See also Color Plate 16)

From the above given descriptions of the various types of ballastless tracks, it may be seen that every technology has it's own plus and minus points. While Japanese slab system is among the costlier one, it provides the maximum safeguard against formation settlements.

The choice of track structure for a high-speed railway line will depend on many factors, such as: ground conditions, construction and maintenance machinery available and the operation environments. On Taiwan high-speed line four types of ballastless track systems has been used to meet the specific operational requirements, although mainly they have depended upon Japanese slab system.

18.6 TRACK STRUCTURE BEST SUITED FOR HIGH-SPEED LINES IN INDIA

18.6.1 Construction Parameters

India, particularly the northern India, consists of indo-gangetic plain. In this region, easy curves and grades are available in locating the high-speed alignment. Construction parameters as given in Table 18.7, can therefore be followed for the new high-speed line.

Table 18.7

Item No.	*Parameters*	*Magnitude*
I	Speed	300–350 kmph
II	Radius of horizontal curves	10,000 m
III	Maximum cant	180 mm
IV	Maximum grade	1 in 1000
V	Minimum vertical radius	24,000 m
VI	Cant deficiency	100 mm
VII	Spacing of the tracks	5.35 m

18.6.2 Viaducts—The Better Option

India is a densely populated country. Any new high-speed line will necessarily pass through the centers of habitation and the agriculture land. In such an environment, the construction of the new high-speed line on viaducts will provide a better option, as:

(a) The new line will not create any obstruction to the movement of men and materials across the railway line.
(b) The land needed for the construction of new line will be minimal.
(c) Noise and vibration generated with high-speed operation can be better controlled on viaducts.
(d) With the availability of hard concrete bed an economical ballastless track system can be adopted. Thus the overall cost of construction of new line on viaducts, may only be marginally higher than the tracks laid on formation.

18.6.3 Track Structures

In paragraph 3, it has been brought out that ballastless track structure is being increasingly adopted by world railways on their high-speed lines on account of the advantages that accrue with its adoption. In India, adoption of ballastless tracks for new high-speed lines is almost inescapable in view of the environmental problems, likely to be faced, with the ballasted tracks.

Important constituents of ballastless track structure will be:

(a) *60 kg UIC 90 UTS rails*, in continuously welded lengths. Jindal Steel and Power Limited (JSPL) has setup a new modern rail rolling mill at Raigarh, India, where 120 m long rails are being rolled. They have setup an integrated flash-butt rail welding plant, where the rolled rails are further welded into 480 m lengths. These rails when laid on high-speed lines can be converted into continuous length using mobile flash butt-welding plant. These long rails will provide the maximum safeguard in ensuring durable and safe track structure.
(b) *Sturdy high-speed turnouts with swing nose crossings.*
(c) *Modern glued insulated joints* having service life equal to the life of the rail.
(d) *Discrete support* at 60 cm c/c.

Regarding construction technology, the systems adopted by advanced countries require deployment of heavy machinery for their construction and maintenance. Pandrol Vipa System and Logwell Forge (India) System however can be constructed by trained skilled labor force without the use of heavy machinery.

It will be desirable to workout the life cycle costs for various systems and adopt the best, taking into account all the relevant factors, including construction cost, maintenance cost, availability of heavy construction machinery etc. May be, more than one ballastless track system shall have to be adopted on a line, as has been done on Taiwan's high-speed line.

18.7 MONITORING OF HIGH-SPEED LINES

Various types of track monitoring systems are used to obtain timely information about the condition of track structure, so that maintenance work is taken well in time for ensuring comfort and safety of the traveling public. Advances in technology are pushing the boundaries of what high-speed infrastructure measuring and diagnostic trains are able to achieve. One of the most modern monitoring trains being deployed will have systems to measure the functions and parameters tabulated in Table 18.8.

Table 18.8 Functions and Parameters Monitored by Diagnostic Train

Permanent way	*Overhead line*	*Ride quality*	*Signaling and telecom*	*Video inspection*	*Video recognition*	*Positioning system*
Track geometry	Geometry and wear	Body accelerations	Carrier intensity, frequency	Track, sideways driver view	Automatic detection of rail/track defects	Encoder-based positioning
Rail profile	Pantograph dynamic interaction	Axle box accelerations	Return current	Videos/frames recording	Detection of tunnel profile	Radar Doppler sensor
Equivalent conicity	Arc detection	Wheel/rail interaction	Induced magnetic field	Critical frames forwarding by wireless connection	Detection ballast profile and distance of side works	Data tag and transponder sensor
Rail corrugations	Termography		Vehicle magnetic transducers voltage			Laser passive milestone
	Electric parameters		GSM and GSM-R quality monitoring			DGPS

These monitoring cars will bring out exception reports, which will enable the maintenance staff to carry out their work in more efficient and affective manner.

18.8 TRACK MAINTENANCE ON JAPAN'S TOKAIDO-SHIN-KAN-SEN LINE

On Tokaido-Shin-Kan-Sen line, regular track leveling, lining and tamping is being carried out by heavy-duty on-track-tamping machines. Plasser & Theurer high performance machine are mainly used for this purpose. The machines are fitted with a 40 m long measuring chord, which gives good geometric track quality of work achieved. In conjunction with the tamping machines, a multifunctional ballast profiling and compacting machine us generally used to form a fully mechanised maintenance train. In addition, the track compaction is carried out with dynamic track stabilisers, supplied by M/s. Plasser & Theurer, producing a stable ballast bed, by controlled mechanical settlement.

Spot maintenance, which was earlier being carried out by mechanized hand tampers is now being done with small on-track-tamping machines, with better quality results. With the regular deployment of mechanised maintenance trains, the requirement of such spot maintenance is getting reduced. For maintenance of turnouts, Plasser & Theurer Unimat turnout tampers are being used.

Rail grinding Rails are usually ground on Shin-Kan-Sen to combat rolling noise and to extend the service life of rails. Speno grinding trains are used for this purpose. The whole system is ground once a year.

Rail renewal and welding 60 kg/m rails have replaced all earlier rails of 53 kg/m. For rail renewal, 200 m long rails are carried to the site on rail transport trains. Site welding, which was earlier carried out by the electric arc method, is now being done with thermit welding, incorporating the latest technology in this field.

Track maintenance tolerances as laid down on Tokaido-Shin-Kan-Sen are given in Table 18.9.

Table 18.9

Item		*Unit*	*Desired value*	*Nominal value*	*Riding comfort value*	*Limit value*
Faults	Longitudinal level	mm/10 m	≤ 4	6	7	10
	Alignment	mm/10 m	≤ 3	4	4	6
	Gauge	mm	$\leq \pm 2$	$+6 \sim -4$	$+6 \sim -4$	$+6 \sim -4$
	Cross level	mm	≤ 3	5	5	7
	Twist	mm/2.5 m	≤ 3	4	5	6
Acceleration	Vertical	g	—	0.25	0.25	0.35
	Horizontal	g	—	0.20	0.20	0.30

18.9 MAGLEV GUIDEWAY TRAINS—HIGH-SPEED TRAINS OF THE 21ST CENTURY

The trials are presently going on at the 42 km Maglev test track in Japan, which would form part of the first Maglev train to enter into commercial service for the transport of passengers between Tokyo and Osaka. These trains which will be supported and guided by concrete guide ways, both in the vertical and lateral direction, will not be running on rails, but over the concrete surface, separated by about 100 mm, by magnetic levitation. Figure 18.9 shows a typical vehicle moving over a Maglev guide way.

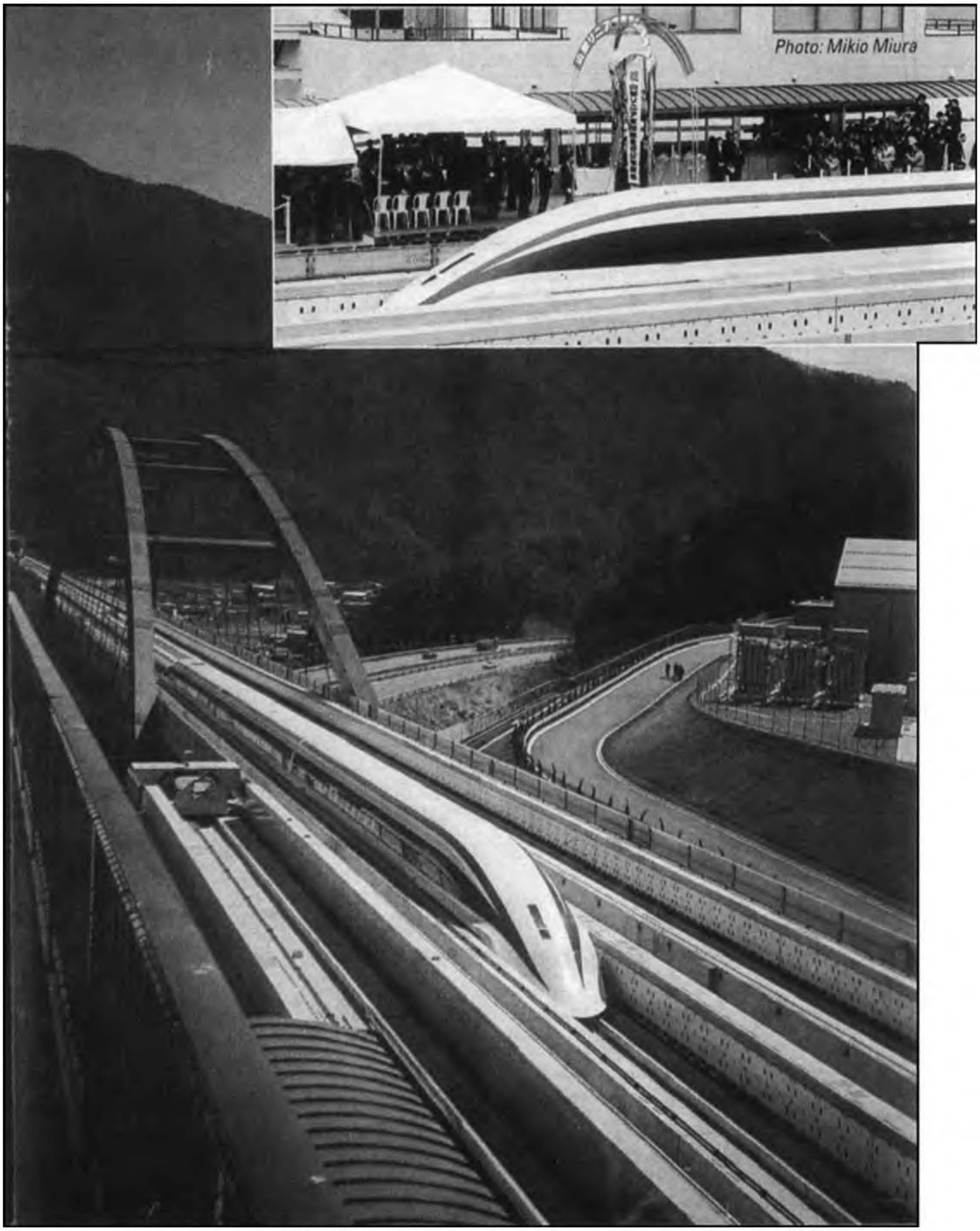


Fig. 18.9 Maglev guideway train (See also Color Plate 17)

In their movement at a speed of 550 kmph, the trains will be more akin in operation to the aeroplanes, than to the conventional railways. They are provided with retractable landing wheels and horizontal guide wheels, which will come into operation whenever the speed comes down below 200 kmph, the minimum to achieve levitation. The trains will be propelled using linear motor power; the 3 phase coils forming the starter of the linear motor shall be installed in the sidewalls of the guideway. The speed is controlled by varying the frequency of the power passing through the coils.

Various types of braking systems are being tried out to ensure that the trains can stop reliably from the speed of 550 kmph. Aerodynamic brakes similar to the vertical laps used in aeroplanes, have been installed over the roof of the train. Other forms of brakes include (a) a regenerative brake, that reverse the current in the guideway coils and returns power to the power house (b) a rheostatic guideway brake which makes the linear motor act as a generator and (c) disc brakes fitted to the undercarriage of wheels.

The entry to the carriages will be from the top. Thus overhead platforms will be built for the passengers to board the train.

The numbers of passengers, who have experienced Maglev trial ride, exceeded 80,000 persons by the year 2004. Test has also been successfully carried out of two trains passing each other at a maximum relative speed of 1,026 kmph. However, the results obtained so far from the trials in Japan have not been conclusive enough to favour the adoption of Maglev technology on a wider scale.

Concept plan of Maglev-guideway-trains and their energisation system has been given in Figs. 18.10 and 18.11.

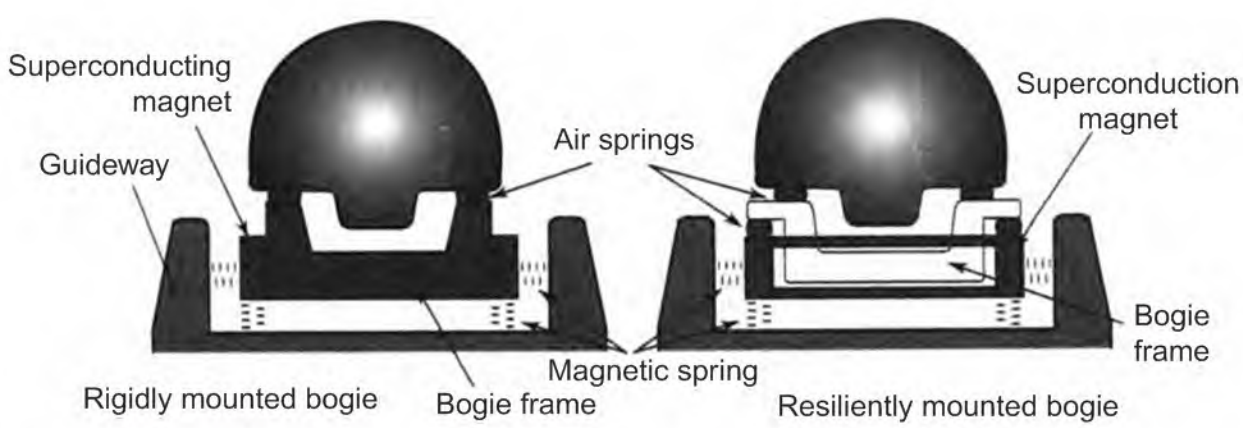


Fig. 18.10 The second test train will have resiliently mounted bogie (right); the rigidly mounted bogie (left) is lifted on the first train

18.9.1 Transrapid Maglev Trains (Fig. 18.12)

Transrapid is a German monorail system using magnetic levitation. There are two primary types of Maglev technology:

- *Electromagnetic suspension* (EMS) uses the attractive magnetic force of a magnet beneath a rail to lift the train up.

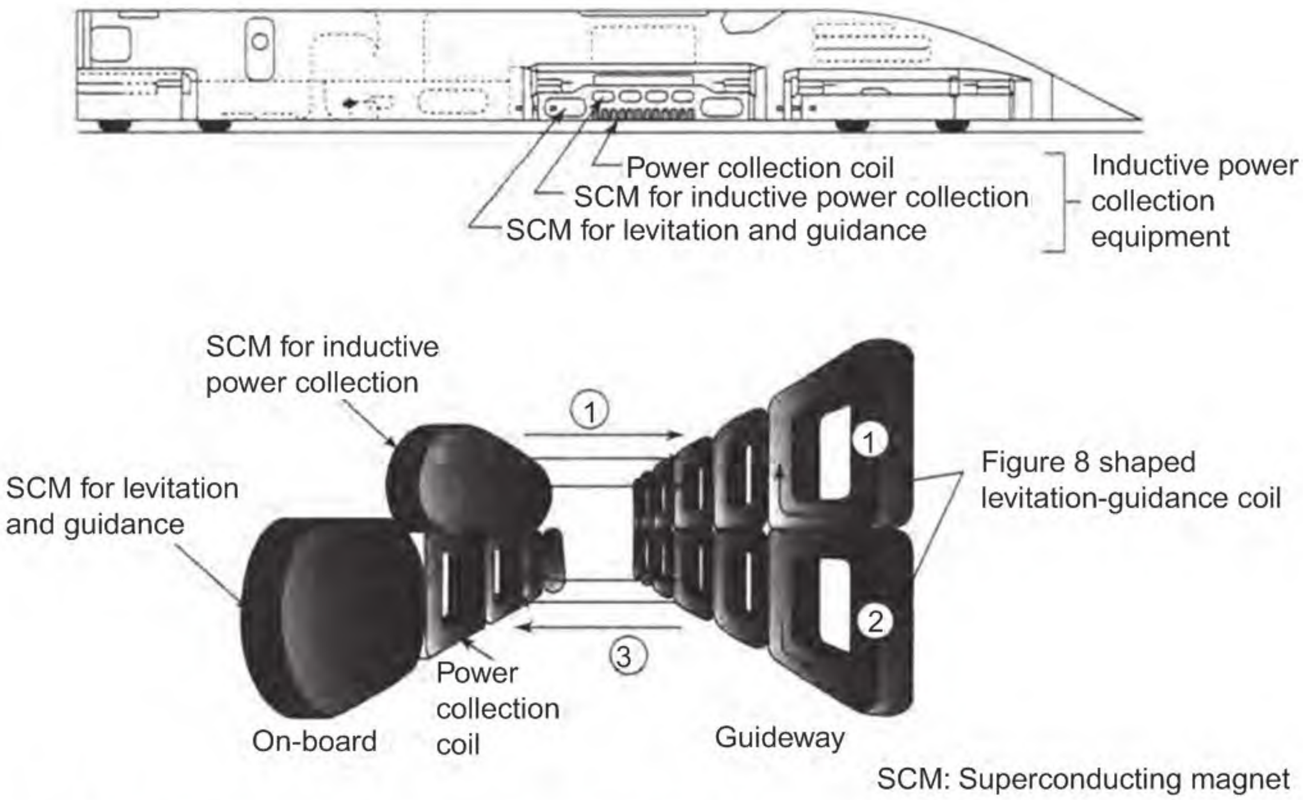


Fig. 18.11 Inductive power collection on the second train. Current is induced in the upper part of the levitation guidance coil (1), and then passes to the lower portion (2). This produces a magnetic field in the on-board power collection coil

- *Electrodynamic suspension* (EDS) uses a repulsive force between two magnetic fields to push the train away from the rail.

While Japanese system uses EDS technology, German transrapid has adopted EMS technology. One of the important difference between the two technologies is that in the EMS system, no wheels are necessary, whereas in the EDS system, the vehicles must be wheeled for travel at low speeds, up to 200 kmph.

Fig. 18.12 Transrapid magnetic levitation train in Shanghai (See also Color Plate 18)

Transrapid magnetic levitation trains are regularly running on a transrapid track, built to connect Shanghai metropolitan city to its Pudong International Airport. This 30 km distance is covered in just 7 min 20 sec at an average speed of 250 kmph and a top speed of 431 kmph. The cost of building 30 km Shanghai Maglev is US$ 1.2 billion.

In view of the high costs involved in Maglev train operation, this system of transport still remains at the developmental stage, world over.

18.10 MODERATE INCREASE OF SPEED ON INDIAN RAILWAYS

For many years the maximum permissible speed on broad gauge system of Indian Railways was limited to about 100 kmph. It was all along thought that increase of speed would necessarily result in corresponding increase of stresses in the track components and thus heavier structure would be required for the introduction of high speed. In the Indian Railways, within limited available resources, it was not found possible to provide heavier track structure necessary for high speed, as track rehabilitation and laying of new lines got an overriding priority. Not much of headway could, therefore, be made toward increasing of speeds.

From the investigations made by RDSO, it was found, that the effect of moving wheel load on straight track is practically independent of speed, provided the track maintenance standards are correspondingly improved with the increase in speed. Heavier track structure was, therefore, considered not a basic requirement, and thus initial outlay could be avoided provided ways and means could be found to maintain the existing track structure to better standards. This opened a new horizon for achieving high speed at low cost.

Safety and comfort at high speed is dependent upon the interaction of the track and the vehicles. Rolling stock having well designed suspension system can run at an acceptable level of comfort and stability on a comparatively inferior quality of track. Investigations made by RDSO revealed that of the existing rolling stock operating in the Indian Railways, some types of engines and coaching stock had the potential of attaining high speed even on the existing track maintained to usual standards.

The introduction of Rajdhani Express at a maximum permissible speed of 130 kmph is the direct result of these two new concepts, i.e. the selection of better type of rolling stock and the improved track maintenance standards of the existing track.

The conclusions drawn on the basis of the investigations made by RDSO on the various items concerning high-speed operation and the action taken on these items, for running the new high speed train are given in the succeeding paragraphs.

18.11 TRACK STRUCTURE AND ITS MAINTENANCE

It was found that the predominant factor influencing loads, deformation and stresses in track components is the parasitic movements (pitching, rolling, bouncing etc.), of the vehicle on the track. On a given track structure, it is possible to operate the same vehicle at higher speeds without imposing any additional loads and stresses on the track provided the standards of maintenance of track and the vehicles are sufficiently improved to ensure that the extent of parasitic movements of the vehicles at higher speeds are not more than those of the same vehicles at the lower speeds.

For exercising a control on the standards of track maintenance, service tolerances for the tracks on Rajdhani routes were laid down and the tracks are not allowed to deteriorate beyond these tolerances. The service tolerances prescribed, except in the case of alignment, are very much on the conservative side from the point of view of safety, stability and riding characteristics for a speed of 130 kmph with locomotives with WDM_4 loco type bogie or modified WDM_2 type bogie and ICF all coil coaching stock. In the case of alignment, it was found that where alignment defects occurred alone or in combination with other, defects, the lateral accelerations had a tendency to reach values, which were unacceptable in relation to ride indices, and/or local peak values.

18.11.1 Measures for Improving Track Structure and its Maintenance

For bringing the track structure within the prescribed tolerances for its maintenance at that level, the following measures have been adopted by the Railways.

1. *Frequent Track Recording* Frequent runs of track recording cars and portable accelerometers were made to find out the location of faults in track geometry or where high accelerations peaks were recorded. Detailed investigations were made to ascertain the causes of the trouble and measures to rectify the faults were taken to avoid their recurrence.
2. *Realignment of Curves* As the maximum track geometry irregularities were noticed on curves, a special operation of curves realignment was launched. For deciding the track need for realignment, a cumulative frequency diagram of the curve showing the versine differences between the theoretical and actual versine is plotted and the curves not satisfying the laid down criteria were realigned (see Sec. 6.9).
3. *Improvement at Points and Crossings* Points and crossings, if not maintained properly, usually figure quite prominently in the high acceleration peaks of the oscillograph car. These high peaks are mainly due to the following reasons.

   (a) Misalignment specially at the toe of the switch and the heel of toe crossing.
   (b) Due to the increased wear at the crossing and wing rails.
   (c) Unevenness due to ineffective packing in the crossing area.
   (d) Incomplete track components in the assembly.
   (e) Less retentivity of packing due to proper drainage.

Special gangs were formed to rectify the packing and alignment defects at points and crossings. Welding of crossings to ensure that the wear at the crossing does not exceed the prescribed limit was undertaken in a big-way. Depot electric welding of points and crossings is also being done.

4. *Welding of Rails* Wherever possible existing jointed track was converted into LWR to improve its maintainability. All new tracks are being laid as LWR tracks to the extent possible, with a track structure consisting of 60 kg 90 UTS rails, concrete sleepers, elastic fastenings and full depth of ballast cushion. The joints at the approaches of level crossings and bridges have been welded by thermit welding. The welding of straight lead rails of points and crossings has been done to improve their maintainability.

The joints at the approaches of level crossings and bridges are being welded by thermit welding as these locations usually deteriorate faster than the normal track.

5. *Mechanised Maintenance of Tracks* Almost all the track on high speed routes are being maintained with on-track tamping machines. Other small and bigger track machines are utilized to carryout track maintenance operations. Indian Railways have yet to find an effective solution for isolated attention to track.
6. *Directed Track Maintenance/Track Management System* For bringing the track within the prescribed tolerances and for its maintenance within these limits, the directed system of track maintenance has been introduced. It has been possible to have more frequent runs of maintenance with this method to control the track irregularities within acceptable limits. Presently, a computerised track management system is being introduced for optimum utilisation of resources.
7. *Provision of Adequate Ballast Cushion* Ballast provides the main anchor on which the whole stability and maintainability of the track rests. Provision of full depth of ballast cushion is being given the topmost priority on Rajdhani routes. Deep screening of ballast is being taken in a big way to improve drainage, track elasticity and for making the track fit for machine maintenance.

18.12 OTHER REQUISITES VIS-À-VIS HIGH-SPEED TRACKS

18.12.1 Brakes and Braking Distances

At the time of introduction of high-speed trains in the Indian Railways, almost all the trains were having vacuum brake system. This system did not provide sufficient safeguards during braking in emergency. Compressed airbrakes are now being universally adoped on all high-speed trains.

18.12.2 Signaling System for High Speed

The Indian Railways have adopted numerous types of signaling systems on the trunk routes and main lines. A large-scale change in the signaling system was physically and economically not possible as a prerequisite for the introduction of moderately high speed. During high speed trials, it was established that braking distance of high speed train running at 130 kmph provided with improved type of breaking system will be the same as that of conventional trains running at the speed of 100 kmph. No change in the signaling system was therefore considered necessary.

18.12.3 Strength of Bridges

The increase of speed of a passenger train hauled by a single locomotive from 100 to 130 kmph was not considered very significant, as the bridges are usually designed to cater for heavy double headed goods trains. On a study of the research made by other countries for similar projects, it was concluded that bridges, over which main line traffic is permitted without speed restriction would be quite suitable for Rajdhani Express at 130 kmph. No special bridge rehabilitation work was, therefore, considered necessary for the introduction of high-speed trains.

18.12.4 Curves

The curves and their transitions provided in the Indian Railways are designed for operation at speeds, which have been prevailing for the last so many years. On a track which has to carry both passenger and goods traffic, the superelevation provided is for equilibrium conditions being reached at 3/4th of the maximum speed. A cant deficiency of up to 75 mm is permitted. The length of the transition is sufficient to permit a cant gradient not exceeding 1 : 720. The rate of change of cant and that of cant deficiency is not allowed to exceed 38 mm per second.

Any increase of speed on curves would necessarily need increased superelevation, longer transition lengths, if designing criteria remain unchanged. Many advanced countries have been running high-speed trains for the past so many years. On the basis of designing criteria adopted by other countries for high-speed operation, the following new parameters given in Table 18.10 have been prescribed on Indian Railways for curves on high-speed tracks.

Table 18.10

Item	*For speeds of*		
	120 kmph	*160 kmph*	*200 kmph*
1. Maximum cant (mm)	165	185	185
2. Maximum cant deficiency (mm)	100	100	100
3. Length of transition	The length of transition shall be the maximum as obtained from the provisions given below		
(a) Maximum cant gradient	1 in 720	Preferred 1 in 1200 Limiting 1 in 1000	Preferred 1 in 1500 Limiting 1 in 1200
(b) Maximum rate of change of cant (mm per second)	55	55	55
(c) Maximum rate of change of cant Deficiency (mm per second)	55	55	55

On the basis of the provisions indicated above, the maximum speed over curves would be given by the formula $V = 4.58\sqrt{R}$ where V is speed in kmph and R is radius in metres

18.13 'SHATABDI' TRAINS ON INDIAN RAILWAYS

Indian Railways have introduced high-speed intercity trains named as Shatabdi Express, in memory of Late Jawaharlal Nehru, the first Prime Minister of independent India, whose birth ceremony was celebrated in the year 1988. Shatabdies run at a speed of 140 kmph. The Shatabdi Train has the following main features.

Train

1. Maximum permissible speed of 140 kmph, booked speed 130 kmph.
2. Vestibuled air-conditioned train with mainly chair cars.
3. Hauled by electric locomotive fitted with MK II bogies and twin pipe air brake system.

Track

1. Track structure is of Rajdhani standard except that 90 lb rails and CST-9 sleepers are not permitted, to achieve better maintainability.
2. Service tolerances for track maintenance are the same as those for Rajdhani routes.
3. Values of lateral and vertical accelerations and that of Ride indices, both for loco and coaching stock, shall be the same as those for Rajdhani Trains, even at higher speed of 140 kmph. Suitable improvement in the bogies of the rolling stock has been made for that purpose.

Signaling and Telecommunications

1. Distant signals are visible from a distance of at least 800 metres. Where this visibility is not available, the distance signal are shifted to such a locations, that the sum of its visibility distance plus the distance between the shifted distant signal and corresponding Home signal is, 1,800 metres or more. Where this distance is not available, a speed restriction of 120 kmph is imposed.
2. Track magnets of the Automatic Warning Signal (AWS) equipment are located 800 metres ahead of all the distant signals.
3. All level crossings are manned and provided with telecommunication.

19 Chapter

Track Stresses

19.1 INTRODUCTION

The term 'track' is used for the composite structure consisting of rails, rail joints with fishplates, fishbolts, sleepers, sleeper fastenings and ballast. The formation, particularly its top portion may also be included as part of the structure.

The basic problem of designing a railway track is to transfer the forces produced by rolling wheel loads on the rail head, in a safe manner, successively through rail, fittings and fastenings, sleeper, ballast and finally to the formation. The track, unlike normal civil engineering structures, is not firmly embedded in the ground, but may be regarded to some extent floating on the foundation. For this reason permanent way must be considered as a structure governed by its own inbuilt system. It is not surprising therefore that many engineers feel that the theoretical analysis of track stresses is at the most approximate, and practice without waiting for theory has determined the dimensions of track components. No calculation of track stresses or deformation as such, can therefore, be regarded as exact. The variables involved are numerous and a large number of assumptions are required to be made to obtain some concrete results. But a usable analytical treatment is of great value in the comparison of experimental data and for the determination of probable track stresses introduced by any new design of vehicle.

In the Indian Railways, the following parameters are considered for assessing the strength of track for speed clearance of the new design of locomotives and rolling stock. The method is also used when any increase of axle load or increase in speed in any of the existing design of locomotives and rolling stock is contemplated.

1. Bending stress on the head and foot of rail.
2. Rail wheel contact stresses.
3. Combined stresses in the rail head.
4. Formation pressure.
5. Fishplate and bolt hole stresses.
6. Dynamic overload at joints due to unsuspended masses.
7. Track deterioration and maintainability of track.

19.2 BENDING STRESSES IN THE RAIL

19.2.1 Elastic Theory

The fundamental basis of the elastic theory of track is that the track support is elastic, i.e. the depression of a sleeper is proportional to the load on the sleeper and the recovery is complete after the load is removed. There are, of course, slight failures in recovering completely due to crushing or displacement of ballast or formation. These failures, in course of time, accumulate to amounts which must be corrected by resurfacing the track. This however has marginal effect and is not accounted in the theoretical considerations.

Assuming that the wheels are uniformly loaded, the path of the wheels will be horizontal and the track will be depressed on the approach of the wheel and recover after the wheel has passed. Rail under such a condition bends in a continuous curve between the wheels and not between the sleepers. Due to continuity of the track, there will be both downward and upward bending, and between concave and convex will be a point of contraflexure.

The flexural or bending effects of adjoining wheels overlap. When the concave portion of the bending curve of one wheel overlaps the convex portion of the bending curve of another wheel, the net bending moment in the rail at a particular point is the difference between the bending moments at that point caused by the two wheels. The result is that the bending moment caused by one wheel at any particular point in the rail is reduced by the reverse bending moment of wheels on either side. Reduction in bending moment reduces the longitudinal bending stress on the rail. This is known as relief of stress Fig. 19.1.

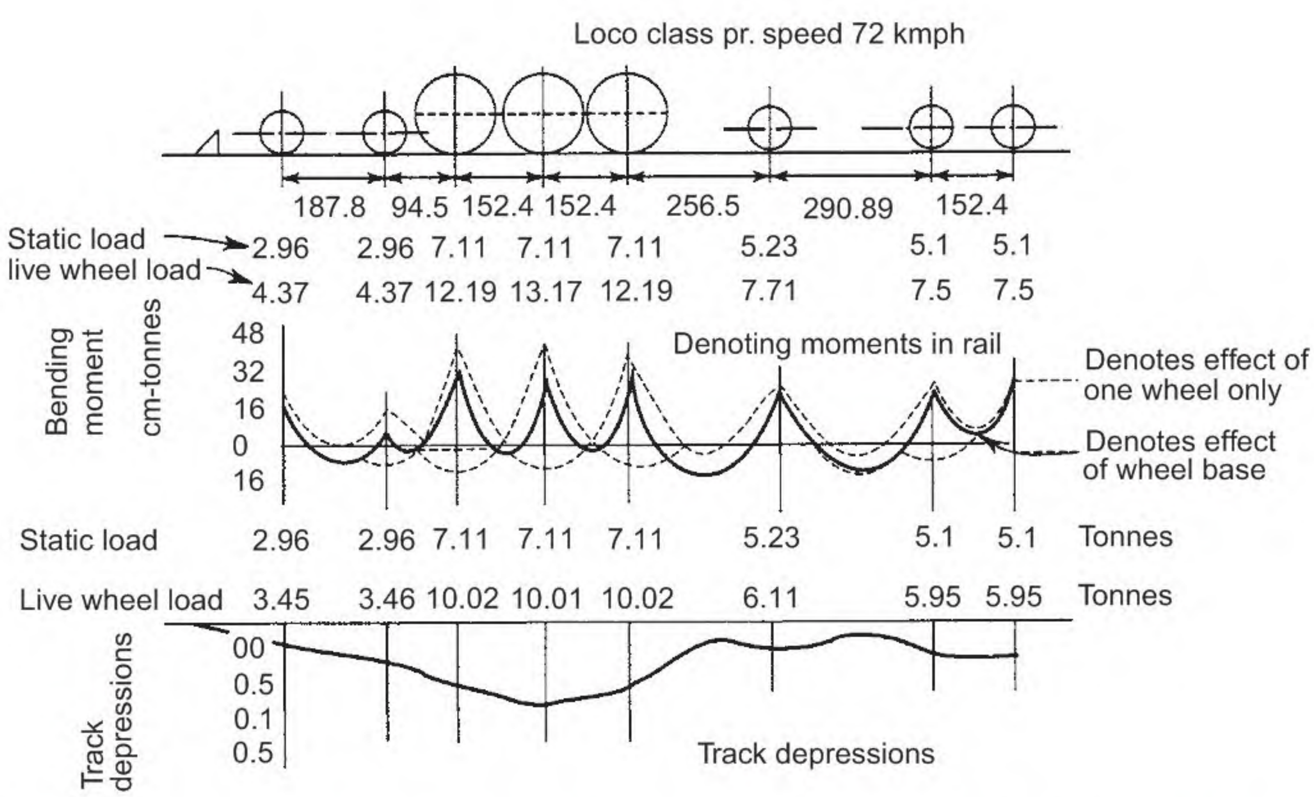


Fig. 19.1 Rail bending moments and depression curves for 4-6-2 locomotive

19.2.2 Virtual Wheel Load or Talbot Load (TIV)

The actual load per wheel or the static wheel load has to be modified to allow for a dynamic augment or impact effect which is caused by (a) speed (b) excess bending moment caused by the loading wheel (c) hammer blow, steam effect, and inertia of the reciprocating parts in the case of steam engines and the effect of adjoining wheel loads. The net wheel loads obtained after modifications are known as virtual wheel loads and the longitudinal stress in rails are obtained from these virtual wheel loads. These are also called Talbot loads after the name of the famous American Prof. A.N. Talbot, who did pioneering work in the field of track stresses.

19.2.3 Dynamic Augment (Speed Effect)

Railway vehicles when moving on the track, are subjected to parasitic movements like pitching, bouncing, rolling, hunting, etc. These are caused by track irregularities like faults in longitudinal levels, alignment, surface and twist, hanging sleepers, badly maintained rail joints, etc. and vehicle suspension characteristics and defects. The parasitic movements, in turn, cause variations in the instantaneous wheel loads imposed on the track. Until recently, the dynamic augments on wheel loads were calculated from the empirical formula.

$$\text{Dynamic augment} = \frac{V}{3\sqrt{u}}$$

where V is the speed in miles per hour and

u is the track modulus in pounds/inch/unit

This formula is still used for narrow gauge track.

For BG and MG track, speed factor was calculated as:

$$\frac{4.5V^2}{100,000} - \frac{15V^2}{10,000,00(} \qquad (V \text{ speed in kmph})$$

Recently, based on the extensive research work done in India, graphs showing the relationship between speed and dynamic augment (speed factors), have been plotted, for different types of rolling stock and these are used for calculation of track stresses both for BG and MG tracks. A typical graph giving the speed factor for BG loco and coaches is reproduced as Graph ‘A’ at the end of the chapter.

19.2.4 Lift of Rail

Additional bending stress caused by the leading wheel of the locomotives needs special consideration. Due to wave like effect in the rail with the passage of a train, the rail tends to bend upwards at some distance ahead of the leading wheel. An analysis of rail stresses is based on the assumptions that the rail supports are capable of developing negative reactions. In practice, there is often play between the rail foot and the dog spikes permitting certain lift of the rail and this causes an increase in the bending stresses in the rail by about 10 percent. When the condition of the sleepers is poor, the increase in rail stresses might even exceed this value. Experimental recordings confirm a proportionally high rail stress due to leading wheels. Similar conditions apply in general to all axles spaced at a distance greater than $6x - x$ is defined later in this section.

19.2.5 Track Modulus

The elasticity of the track system is denoted by a factor called track modulus (u). This is defined as the load per unit length of the rail required to produce a unit depression in the track. The factor is used in various equations for finding track stresses. From the recent track research it is seen that an initial load of about 4 tonnes gives greater initial deflection, which accounts for the gap between the rail and sleeper, between sleeper and the ballast and voids in the ballast depending upon the state of maintenance. Track modulus in this initial range is called initial track modulus U_i.

Track modulus beyond 4 tonnes load is in truly elastic range and is called elastic modulus U_e. It is seen that the stresses calculated by this double moduli method give more realistic value. This method is therefore used in calculating track stresses in the Indian Railways.

The track modulus varies with the track gauge, the type and spacing of sleepers, weight of rail section, ballast cushion, etc. The following values are adopted in the Indian Railways for calculation of tracks stresses.

Broad Gauge (*Initial Load* P_i = *4 tonnes*)

1. 90 R rails, N + 3 sleeper density and 200 mm ballast cushion

   Initial modulus (U_i) 75 kg/cm/cm
   Elastic modulus (U_e) 300 kg/cm/cm

2. 52 kg rails, $N + 6$ sleeper density and 250 mm ballast cushion

   Initial modulus (U_i) 120 kg/cm/cm
   Elastic modulus (U_e) 380 kg/cm/cm

Metre Gauge (*Initial Load* P_i = *3 tonnes*)

50 R, 60 R, 75 R Rails $N + 3$ sleeper density and 200 mm ballast cushion

Initial modulus (U_i) 50 kg/cm/cm
Elastic modulus (U_e) 250 kg/cm/cm

For other sleeper densities, the track modulus values are taken in inverse proportion to the intermediate sleeper spacing. For modern LWR track, consisting of 52 kg/60 kg rails, laid on a concrete sleeper, the track modulus values have been computed and they are:

Initial track modulus (U_i) 183.7 kg/cm/cm
Elastic modulus (U_e) 419.1 kg/cm/cm

19.2.6 Method of Calculating Longitudinal Bending Stress in Rails

The elastic theory shows how the following can be calculated.

X_i = the distance from the load to the point of contraflexure of the rail in cm.

M_o = the bending moment in the cm tonne immediately under an isolated load P tonne on one rail.

$f_{compression}$ = the consequent compressive stress in the rail head, under the load P, in tonne per square cm.

$f_{tension}$ = the consequent tensile stress in the rail foot, under the load P, in tonne per square cm.

d = deflection of track in cm.

The above are given by the formula

$$X_i = 42.33\sqrt[4]{\frac{I}{U}}\text{cm}$$

$$M_o = 0.319P \times X_i \text{ cm-tonne}$$

$$F_{camp} = \frac{M_o}{Z_{comp}} \text{ tonnes/cm}^2$$

$$f_{tension} = \frac{M_o}{Z_{tension}} \text{ tonnes/cm}^2$$

$$d = \frac{9.25P}{\sqrt[4]{IU^3}} \text{ cm}$$

where p = Load on one rail in tonnes

I = Vertical moment of inertia of rail section in cm^4

U = Track modulus in kg/cm/cm

Z_{comp} = Section modulus of rail in compression cm^3

$Z_{tension}$ = Section modulus of rail in tension cm^3

I, the moment of inertia of rail reduced by 10 percent to cater for the loss of section of rail in service.

Example *Bending stresses caused by WDM2. Broad gauge diesel electric locomotive, going at 105 kmph on 90 R rails, M + 4 sleeper density, 200 mm ballast cushion.*

U_i, initial track modulus (for initial 4 tonne live wheel load)

= 75 kg/cm/cm

U_e, elastic track modulus (beyond 4 tonne live wheel load)

= 300 kg/cm/cm

Assumed that I and Z of 5 percent worn rail are reduced by 10 percent.

I_{xx} (worn) = 1440 cm^4

Z_c (worn) = 192.46 cm^3

Z_t (worn) = 212.08 cm^3

$$X_i = 42.33 \times \sqrt[4]{\frac{I_{xx}(\text{worn})}{U}}$$

$$X_i\,(i) \text{ for initial load of 4t} = 42.33 \times \sqrt[4]{\frac{1440}{75}}$$

$$= 88.61 \text{ cm}$$

X_i (e) for rest of the load = $42.33 \times \sqrt[4]{\frac{1440}{300}}$

= 62.66 cm

Wheel arrangement

Axle load = 18.8 tonnes
Wheel load = 9.4 tonnes

Speed effect at 105 kmph = 41.5 percent (From graph *A*)

Live wheel load = 9.4 × 1.41
= 13.254 tonnes (say 13.25 t)

Bending moment coefficient from master diagram (Graph B)

With X_i (i) = 88.61 cm
for 170.2 cm = – 0.2
for 210.8 cm = – 0.19
for 381.0 cm = – 0.02
for 521.4 cm = 0

with X_i (e) = 62.66 cm
for 170.2 cm = – 0.15
for 210.8 cm = – 0.08
for 381.0 cm = 0
for 521.4 cm = 0

Effect of adjacent wheels

for initial load of 4 t

4 × (– 0.2) = – 0.8 t
4 × (– 0.19) = – 0.76 t
4 × (– 0.02) = – 0.08 t

for elastic load of, i.e. balance of live wheel load (13.25 – 4.00) = 9.25 t

– 9.25 × (– 0.15) = – 1.39 t
9.25 × (– 0.08) = – 0.74 t
9.25 × 0 = 0

Rail stresses

(a) *Stress due to vertical bending*
TIV (virtual wheel load) considering initial load of 4 t ..... *A*

Effect of wheel load No. 1	4.00	–.80	0.08			
Effect of wheel load No. 2	–.80	4.00	–.76			
Effect of wheel load No. 3	–.08	–.76	4.00			
Effect of wheel load No. 4				4.00	–.76	–.08
Effect of wheel load No. 5				–.76	4.00	–.80
Effect of wheel load No. 6				–.08	–.80	4.00
Virtual wheel load in tonnes	3.12	2.44	3.16	3.16	2.44	3.12

Note: Effect of leading wheel to be taken if the distance between adjacent axles is more than $6 \times X_i$ (Sec. 18.2.4)
Value of $6 \times X_i(i) = 6 \times 88.61 = 531.66$ cm

∴ No wheel except No. 1 and 6 have the effect of leading axle, as distance between all adjacent wheels is less than 531.66 cm.

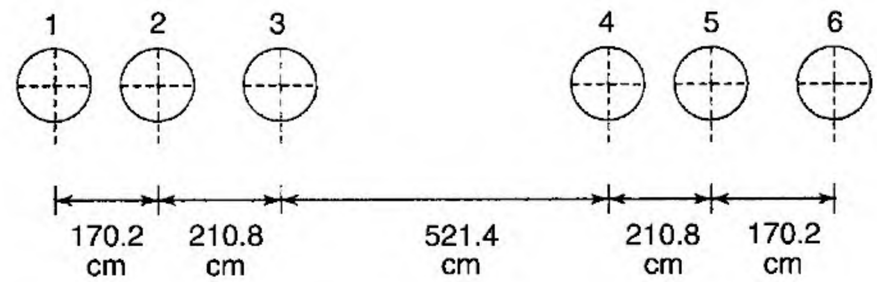


Fig. 19.2

Adding 10 percent for the effect of leading wheel
TIV for wheels 1 and 6 = 3.12 + 0.312 = 3.432 tonnes
TIV: considering elastic loading of 9.25 tons B
Value of $6 \times X_i(e) = 6 \times 62.66 = 375.96$ cm

Effect of wheel No. 1	9.25	– 1.39	—			
Effect of wheel No. 2	– 1.39	9.25	–.74			
Effect of wheel No. 3	—	–.74	9.25			
Effect of wheel No. 4				9.25	–.74	—
Effect of wheel No. 5				–.74	9.25	– 1.39
Effect of wheel No. 6				—	– 1.39	9.25
Virtual wheel load in tonnes	7.86	7.12	8.51	8.51	7.12	7.86

Spacing between wheels 3 and 4 = 521.4 cm which is greater than 375.96 cm. Hence, wheels 3 and 4 will also have the effect of leading wheel.

TIV for wheel 1 and 6 = 7.86 + .786 = 8.646 tonnes
TIV for wheels 3 and 4 = 8.51 + .851 = 9.361 tonnes

For maximum value of TIV, TIVs due to initial and elastic loading will be added.

TIV due to initial loading	3.432	2.44	3.160	3.160	2.44	3.432
TIV for elastic loading	8.646	7.12	9.361	9.361	7.12	8.646
Total TIV in t	12.078	9.56	12.521	12.521	9.56	12.078

Max TIV = 12.521 tonnes = (3.16 t + 9.361 t)
BM in rail $= 0.381 \times \text{TIV} \times X_i$
$= 0.318 \times 3.16 \times 88.61 + .318 \times 9.361 \times 62.66$
$= 89.042 + 186.526$
$= 275.568$ cm-tonnes

(i) Stress in the head (comp) $= \dfrac{275.568}{192.46} = 1.432\ \text{t/cm}^2$ (14.32 kg/mm^2)

(ii) Stress in the foot (tensile) $= \dfrac{275.568}{212.08} = 1.229\ \text{t/cm}^2$

= (12.99 kg/mm^2)

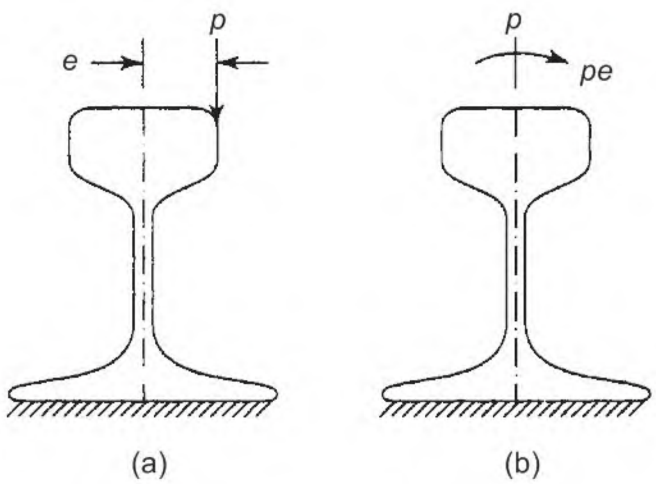


Fig. 19.3 Eccentric vertical load

Permissible value is 23.5 kg/mm^2 for rail steel (fixed empirically) Max. Ultimate tensile strength of rail steel varies from 70 kg/mm^2 to 85 kg/mm^2 (average value 77.5 kg/mm^2).

(b) *Stress due to electricity of vertical load*

A vertical load (P) applied eccentrically (e) on the head of the rail, produces bending in the vertical plane and twisting of the rail (Fig. 19.3). The twist of the rail has an effect equivalent to that of the rail subjected to a torque at the middle when held at the ends. This causes additional bending of head and foot of rail. These bending stresses are calculated using the following notations and equations.

$$M_t = \frac{\text{Torque}}{2}$$

E = Elasticity modulus of rail

A = Area of cross-section of rail

G = Modulus of rigidity of rail

I_p = Polar moment of inertia

$$C = \text{Torsional rigidity} = \frac{A^4 G}{40 I_p}$$

h = Distance between centroids of head and foot portion of rail

I_1 = Moment of inertia of head portion about the vertical centre line of rail

I_2 = Moment of inertia of the foot portion about the vertical centre line of rail

h_1 = Distance of centroid of head portion from the centre of twist

h_2 = Distance of centroid of foot portion from the centre of twist

then $$h_1 + h_2 = h$$

$$h_2 = \frac{hI_2}{I_1 + I_2}$$

$$h_1 = \frac{hI_1}{I_1 + I_2}$$

Let $$D_1 = \frac{EI_1 I_2}{I_1 + I_2}$$

and let $$r = \sqrt{\frac{C}{Dh^2}}$$

Then, bending moment in the head of the rail $= EI_2 h_2 \times \dfrac{M_t r}{C}$

Bending moment in the head of the rail $= EI_1 h_1 \times \dfrac{M_t r}{C}$

The eccentricity of the vertical load is taken as 1.5 cm for calculating bending stresses.

Torque $= 2M_t = \text{TIV} \times e$
$= 12.521 \times 1.5$

$$M_t = \frac{12.521 \times 1.5}{2} = 9.39075 \text{ cm } t$$

(i) Bending stress in the head due to eccentricity of load

$$= \mp M_t \frac{EI_1 h_1 \times r}{CZ_1}$$

$= 9.39075 \times 0.04353$*
$= 0.409 \text{ t/cm}^2$
$= (4.09 \text{ kg/mm}^2)$

(ii) Bending stress in the foot

$$= \mp M_t \times \frac{EI_2 h_2 \times r}{CZ_2}$$

$= 9.39075 \times .03105$*
$= 0.292 \text{ t/cm}^2$
$= (2.92 \text{ kg/mm}^2)$

The bending stresses in head and foot of rail due to eccentricity of vertical live wheel load have been plotted in Graph C (see Annexure).

(c) *For calculating bending stresses in the head and foot of the rail due to twisting of rail or due to lateral load* (R)

The total lateral force exerted by the rolling stock is the algebraic sum of the flange force and the friction between the wheel and rail. When the wheel flange is pressing against one rail, the friction on the other rail is resisting the lateral movement of the axle. Only 50 percent of the total lateral force is thus taken to be acting on the rail.

In the Indian Railways the lateral load is taken as 40 percent of the static wheel load unless otherwise, known by trials. (Lately the value of maximum lateral load is being taken from Prodhomme's formula, i.e. 0.85 $(1 + P/3)$ tonnes, when P is the axle load in tonnes.)

Lateral load on one rail $= \dfrac{0.40 \times 18.8}{2}$

$= 3.76$ t

Distance from the centre of twist to the point of application of lateral force

$$h_f = h - h_2 + \frac{\text{depth of rail head}}{2} - 5 \text{ mm}$$

$= 9.909$ (see Fig. 19.4)

Torque due to lateral force $= M_t$

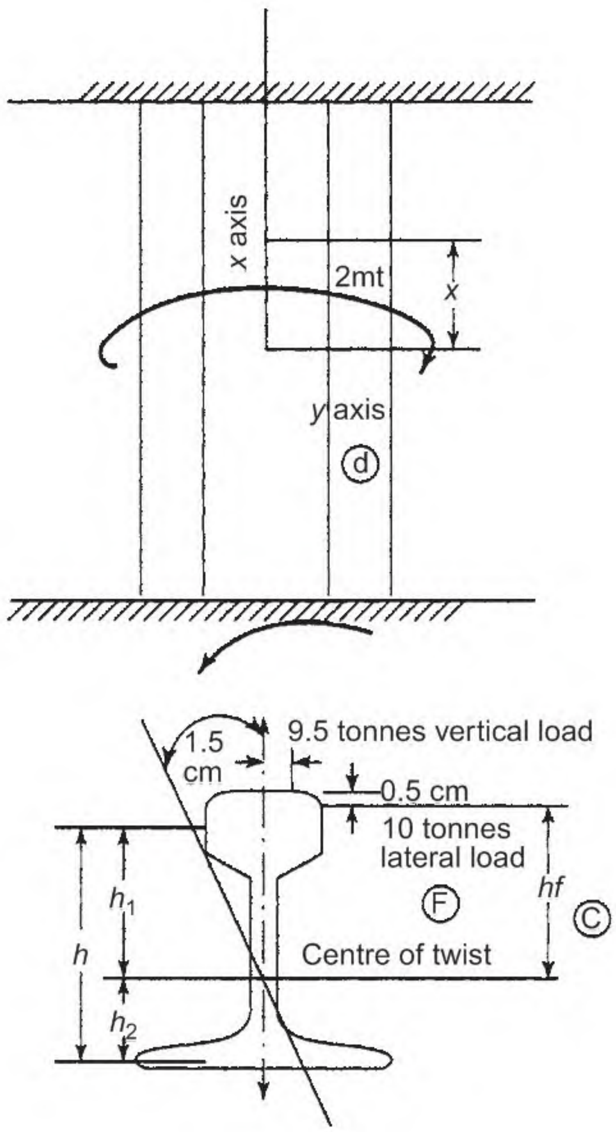


Fig. 19.4

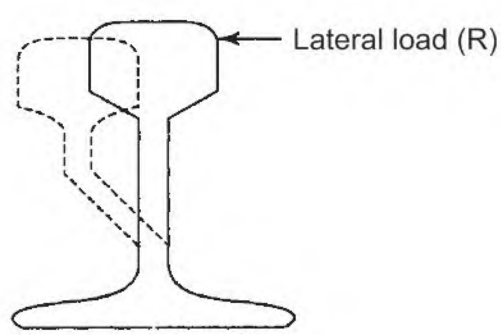


Fig. 19.5

or $$M_t = \frac{3.76 \times 9.909}{2} = 18.62882 \text{ cm-ton}$$

(i) Bending stress in the rail head due to torque M_t

$$= \frac{M_t \times EI_1 h_1 r}{CZ_1}$$
$$= 18.62892 \times 0.04353^*$$
$$= 0.811 \text{ t/cm}^2$$
$$= (8.11 \text{ kg/mm}^2)$$

(ii) Bending stress in the rail foot due to torque

$$= \frac{M_t \times EI_2 h_2 r}{CZ_2}$$
$$= 18.62892 \times .03105^*$$
$$= 0.578 \text{ t/cm}^2$$
$$= (5.78 \text{ kg/mm}^2)$$

The bending stress in head and foot of rail due to twisting effect under flange force has been plotted in Graph D (see Annexure).

(d) *Bending stress due to lateral deflection of rail under lateral load* (S) caused by the flange force.

It is assumed that the rail deflects horizontally between two adjacent sleepers only, under the lateral load. For an average sleeper spacing of 83 cm the lateral bending moment.

$$= \frac{SL}{4} = \frac{3.76 \times 83}{4}$$
$$= 78.02 \text{ cm ton}$$

Lateral modulus of section of rail for head

$$Z_3 = 96.323 \text{ cm}^3 *$$

Lateral modulus of section of rail for foot

$$Z_4 = 47.031 \text{ cm}^3 *$$

(i) Bending stress in head due to lateral bending

$$= \frac{BM}{Z_3} = \frac{78.02}{96.323} = 0.813 \text{ t/cm}^2$$
$$= (8.13 \text{ kg/mm}^2)$$

(ii) Bending stress in foot $$= \frac{BM}{Z_4} = \frac{78.02}{47.031} = 1.659 \text{ t/cm}^2$$
$$= (16.59 \text{ kg/mm}^2)$$

* See Appendix 19.2

The bending stress in head and foot of rail due to lateral deflection under flange force has been plotted in Graph E (see Annexure).

19.2.7 Combined Effects

1. Bending stress due to vertical load and its eccentricity only

   (i) $(P + Q)$ for head = 14.32 + 4.09 = 18.41 kg/mm^2
   (ii) $(P + Q)$ for foot = 12.99 + 2.92 = 15.91 kg/mm^2

   Permissible limit is 23.5 kg/mm^2 for 72 UTS rails
   Bending stress due to vertical load, its eccentricity and lateral load

   (iii) $(P + R + S - Q)$ for head
   = 14.32 + 8.11 + 8.13 – 4.09
   = 26.47 kg/mm^2

   (iv) $(P + Q + S - R)$ for foot
   = 12.99 + 2.92 + 16.59 – 5.78
   = 26.72 kg/mm^2

Permissible limit = 36.0 kg/mm^2 for fishplated track for 72 UTS rails.

19.3 THERMAL STRESSES

With the variation of temperature from the destressing temperature a long welded rail is subjected to thermal stresses. Considering a maximum temperature range of 76°C in India, the maximum variation can be 43°C in winter, and 38°C in summer, the destressing temperature being between t_m and t_m + 5°C.

(t_m = annual mean rail temperature)

This variation can introduce a maximum longitudinal stress of 10.75 kg/mm^2 in extreme winter and a compressive stress of 9.5 kg/mm^2 in extreme summer.

Tentatively, it has been decided that combined longitudinal stress due to vertical load, its eccentricity, flange force and thermal stress should not exceed 36 kg/mm^2 for fishplated track. This is to allow certain margin for some type of stresses whose value it is difficult to assess. These are residual stresses introduced in the rail during the process of manufacture, stresses due to flexed laying on curves, sun's radiation on one side of the rail, wheel flats, loose or hanging sleepers, etc. A 10 percent margin out of the yield limit of steel is kept for these unknown stresses. Lately, it has been decided to increase this margin to 25%.

Yield limit of rail steel is taken as 52 percent of UTS $= \dfrac{52}{100} \times 77.5 = 40.3$ kg/mm^2

Permissible stress is 10 percent less than 40.3 kg = 40.3 – 4.03 = 36 kg/mm^2 (i)

For LWR, the values have to be further reduced for thermal stress as indicated above.

Permissible limit for SWR track = 30.25 kg/mm^2 (ii)

Permissible limit for LWR track = (36.0 – 10.75) = 25.25 kg/mm^2 (iii)

With 25% of margin for unknown stress these figures for (i), (ii), (iii) are taken as 30, 24, 25 and 19.25 kg/mm^2 respectively.

19.4 RAIL WHEEL CONTACT STRESSES

With the increase in axle loads and reduction in wheel diameters, the rail wheel contact stresses have assumed considerable importance. Very high contact stresses develop in the immediate vicinity of the rail wheel contact zone which at times lead to plastic flow of metal in the rail head.

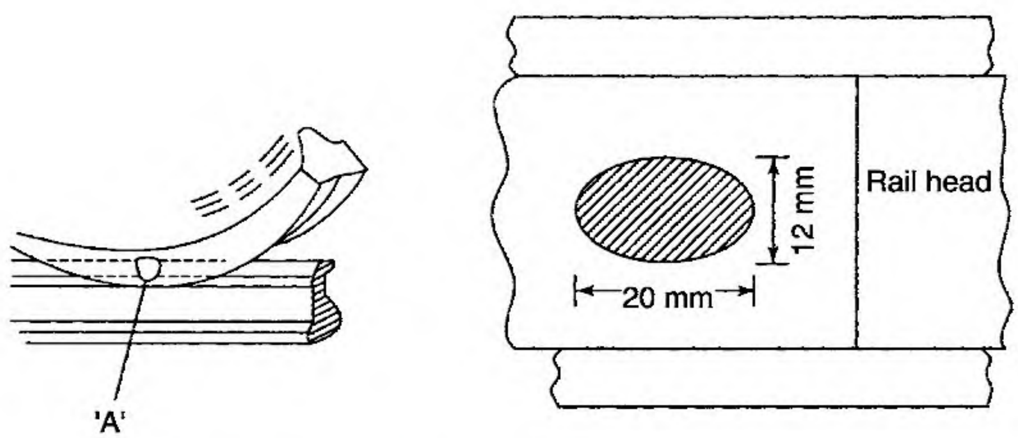


Fig. 19.6 Contact area between wheel and rail

Maximum contact shear stress which occur in the transverse direction at right angles to the rail is calculated by the formula given by UIC/ORE.

$$T_{max} = 4.13\sqrt{\frac{Q}{R}}$$

T_{max} = maximum shear stress in kg/mm^2

Q = static wheel load in kg increased for on-loading on curves.
This on-loading is taken as 1 ton (1000 kg)

R = wheel radius in mm (fully worn condition)

In case of WDM_2,

Q = 9.4 tonne (9400 kg) + 1 tonne (1000 kg)

Total = 10,400 kg

$$R = \frac{1092}{2} = 546 \text{ mm (new condition)}$$

$$\text{Wear} = 76 \text{ mm on diameter}$$

$$= \frac{76}{2} = 38 \text{ mm on radius}$$

or worn wheel radius = 546 – 38 = 508 mm

$$T_{max} = 4.13 \times \sqrt{\frac{10,400}{508}} = 18.69 \text{ kg/mm}^2$$

Contact shear stresses are limited to 21.6 kg/mm^2 which is 30 percent of UTS or rail steel.

19.5 COMBINED STRESSES IN THE RAIL HEAD

Due to rail wheel contact loading and the bending stresses, the rail head is subjected to a three-dimensional complex stress field. This three dimensional stress state can be reduced to an equivalent unidirectional "significant" stress. Maximum permissible limit of "significant stress" is kept as the fatigue limit of rail steel, which is taken as 45 percent of UTS, i.e. 34.7 kg/mm^2 for 77 UTS rail steel.

Dr. Hanna of W. Germany has evolved Graph F which gives the value of "significant" stress directly for various dynamic wheel loads and wheel diameters. Since the value of significant stress does not vary appreciably with the rail section, it has been decided to use this graph for Indian Railways.

For an example we may consider

Dynamic wheel load = 13.25 tonnes (Sec. 19.2)

Wheel dia = 1016 mm

Significant stress from the graph = 31.2 kg/mm^2 (Annexure; Graph F) which is still within the limit of 34.7 kg/mm^2.

19.6 FORMATION PRESSURE

The maximum formation pressure is calculated from the following formula:

$$P_{max} = \frac{2\,PS}{\pi DL} \times \sqrt[4]{\frac{U}{64\,EI}}$$

where P = live wheel load = 13.25 tonnes, in our case

S = sleeper spacing = 83 cm

D = depth of ballast under sleeper = 20 cm

L = effective length of sleeper under one rail seat

= 76.0 cm for BG and 63 cm for MG

U = track modulus = 300 kg/cm/cm

(Only track modulus in elastic range is considered)

I = moment of inertia of worn rail along horizontal axis
= 1440 cm^4
E = modulus of elasticity of rail steel
= 2.11×10^6 kg/cm^2

$$P_{max} = \frac{2 \times 13.25 \times 1000 \times 83}{\pi \times 20 \times 76} \times \sqrt[4]{\frac{300}{64 \times 2.11 \times 10^6 \times 1440}}$$

For permitting new rolling stock, formation pressure exerted by WP locomotives at 100 kmph and box wagon at 75 kmph on BG YP locomotives at 75 kmph and bogie wagons at 50 kmph on MG have been taken as the permissible limits.

A slightly higher value of pressure is permitted in the case of motive power units because of their smaller population.

Thus the permissible value of formation pressure adopted in the Indian Railways are:

		Unit	kg/cm^2
1.	For motive power		
		BG	3.5
		MG	2.5
2.	For freight wagons		
		BG	3.0
		MG	2.3

The maximum intensity of soil pressure has been plotted in Graph G (see Annexure).

19.7 FISHPLATE AND BOLT HOLE STRESSES

Based on empirical formula, graphs have been drawn which give directly the dynamic stress range and the total stresses for fishplate (Graph H).

For the example under consideration, dynamic wheel load = 13.25 tonnes

From the graph,

Dynamic stress range = 1.806 t/cm^2 = 18.06 kg/mm^2
Total stress = 2.299 t/cm^2 = 22.99 kg/mm^2

Maximum permissible value for dynamic stress range and for total stress are taken as 25 kg/mm^2 and 30 kg/mm^2 respectively.

As in the case of fishplate stresses, a graph has been drawn from where stresses in bolt holes can be read directly.

From Graph I, as the dynamic wheel load = 13.25 tonnes

Bolt hole stress range = 1.951 t/cm^2 = 19.51 kg/mm^2

Maximum permissible value is 27 kg/mm^2

19.8 DYNAMIC OVERLOADS AT JOINTS DUE TO UNSUSPENDED MASSES

The introduction of diesel and electric locomotives with smaller diameter wheels and higher unsprung masses lead to dynamic overloading of joints, causing faster deterioration of track near the joint.

The following empirical formula is used for finding the value of dynamic overload at a dipped rail joint (dip assumed as 12 mm) on mainline tracks.

$$F = F_0 + 0.1188 \times V \times \sqrt{W}$$

Where F = Dynamic overload at dipped joint in tonnes

F_0 = Static wheel load in tonnes
V = Speed in kmph
W = Unsprung masses per wheel in tonnes
(For WDM_2 locomotive it is = 1.985 tonnes)

Now applying the formula,

$$F = 9.4 + 0.1188 \times 105 \times \sqrt{1.985}$$
$$= 9.4 + 17.57$$
$$= 26.97 \text{ tonnes}$$

The permissible values in the Indian Railways are

BG – Locomotive	27 tonnes
EMU stock	23 tonnes
Wagons or coaches	19 tonnes
MG – Locomotive	17 tonnes
EMU stock	14 tonnes
Wagons or coaches	11 tonnes

Comparison of dynamic wheel loads showing the relative effects of higher speeds, static axle load and unsprung masses has been plotted Graph J (see Annexure).

19.9 TRACK DETERIORATION AND MAINTAINABILITY OF TRACK

Maintainability of track assumes considerable importance in the context of operation of high speed trains and high axle load freight stock. UIC/ORE have evolved the following formula for determining track deterioration factor for comparing track deterioration under different axle loads and speeds.

$$TD = W^3 (1 + 3S^2)$$

TD = Track deterioration factor
W = Nominal wheel load

$$S = \frac{\text{Standard deviation of wheel load}}{\text{Nominal wheel load}}$$

It may be seen that track deterioration is proportional to the third power of wheel load and any increase of wheel load has considerable adverse effect on the track maintainability.

Based on the above formula, TD factors calculated for various speed factors are given in the table at Appendix 19.1.

On Indian Railways, following freight stock, which are commonly running are taken as standard comparators for use in table of TD factors.

1. BG-Box wagons at 75 kmph.
2. MG-Four wheeler wagons at 50 kmph.

The axle loads and the permissible speeds of all new rolling stocks are controlled to have the TD factor less than the standard comparator.

19.10 MAXIMUM PERMISSIBLE SPEED OF A ROLLING STOCK

For determining the maximum permissible speed of a rolling stock the various factors discussed in the foregoing paragraphs are given due consideration. Normally, the lowest speed arrived at is permitted. In addition, the following aspects are also kept in view:

1. Experience gained from similar rolling stock already in service.
2. For vehicles which are not required for frequent runs, slightly higher speeds could be allowed.
3. Freight with higher axle loads can be cleared for close circuit operation on routes where high speed trains do not normally run.
4. Trains with higher speed can be permitted provided the increments above the current speed are in steps of 5 kmph and after each such increment the general behaviour is found to be satisfactory.

19.11 PERMISSIBLE SPEED OF WDM_4 LOCOMOTIVE ON 90R, M + 4, 20 CM BALLAST CUSHION TRACK

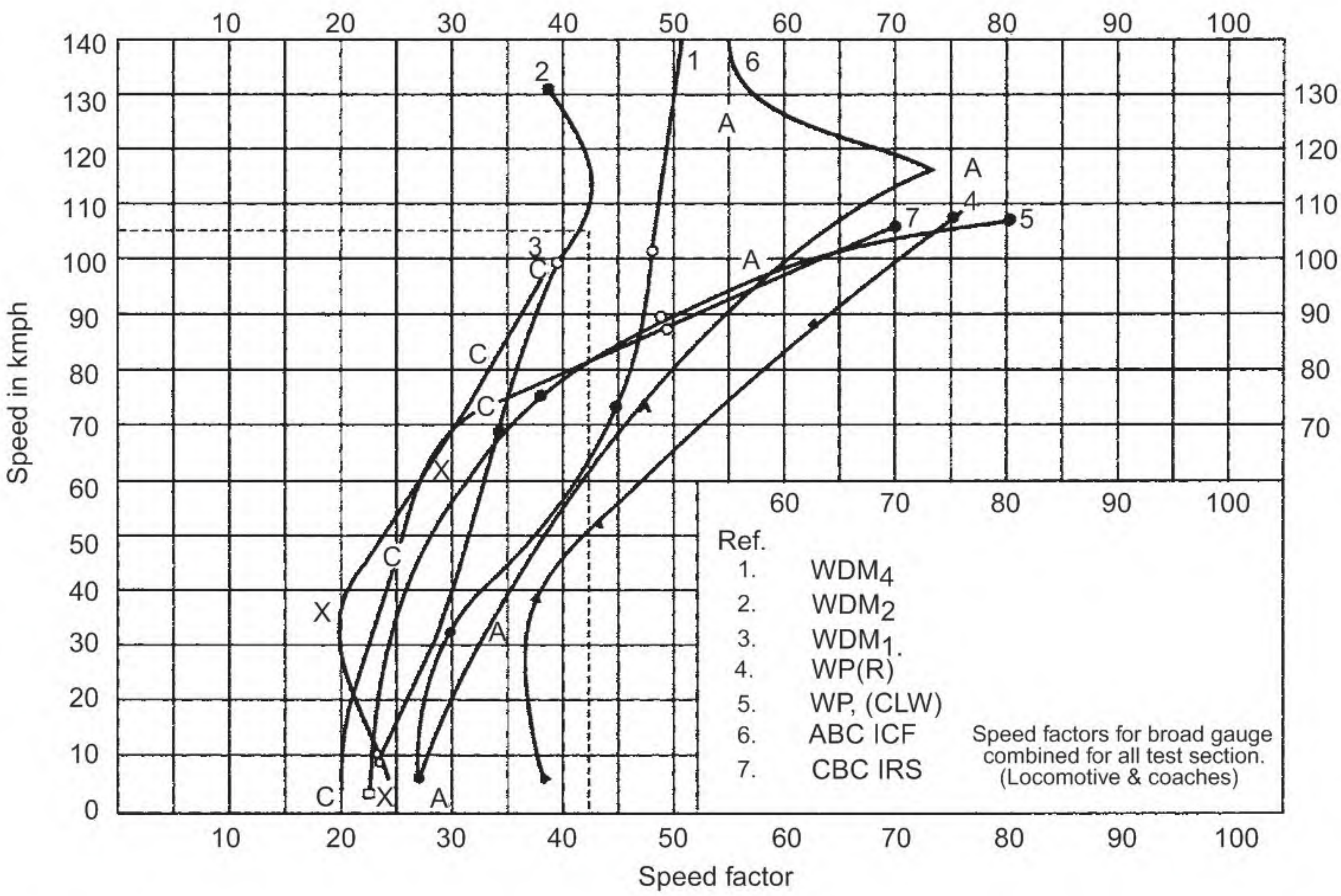
Keeping in view the guidelines indicated in Sec. 19.10 above, the permissible speed of WDM_4 loco on 90 R, M + 4, 20 cm ballast cushion track is fixed as follows:

	From consideration of	*Max. permissible speed*
1.	Combined stresses from Dr. Hannah's graph	Not more than 160 kmph
2.	Joint loading	112 kmph on fishplated track 132 kmph on welded track
3.	Rail wheel contact stresses	No limitation
4.	Max. formation pressure	Not more than 160 kmph
5.	Fishplate stresses	Not more than 160 kmph
6.	Bolthole stresses	Not more than 160 kmph
7.	Rail stresses	
	(a) Vertical bending stress + eccentricity	Safe at 160 kmph

(b) Vertical bending stress +
Eccentricity + flange force effects Safe at 160 kmph

From the above, WDM_4 locomotive can be permitted up to 110 kmph on fishplated track. Since only a few such locomotives are expected to run on Rajdhani Express at 130 kmph and as the track is being progressively welded, a speed of 130 kmph can be allowed. This speed has already been permitted for operation on Rajdhani routes.

A statement showing the results of calculation of stresses is given in Appendix 19.3.



Graph A Track calculations master diagram for bending moment and depression

Appendix 19.1 Track Deterioration Factors Cubic Formula W^3 $(1 + 3\ S^2)$

S. No.	*Speed factor as % of static wheel load*	*Axle loads tons*								
		16	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
		Track deterioration factors								
1	20%	527	632	750	885	1030	1,191	1,310	1,565	2,010
2	25%	536	642	762	897	1,047	1,210	1,392	1,590	2,042
3	30%	516	655	777	915	1,068	1,235	1,420	1,620	2,082
4	35%	559	670	796	935	1,092	1,262	1,433	1,660	2,136
5	40%	574	688	816	959	1,120	1,295	1,490	1,702	2,185
6	45%	590	706	840	987	1,152	1,332	1,532	1,750	2,250
7	50%	607	727	865	1,016	1,188	1,372	1,579	1,804	2,320
8	55%	628	752	894	1,052	1,227	1,420	1,632	1,862	2,395
9	60%	655	780	925	1,088	1,270	1,470	1,690	1,930	2,480
10	65%	674	810	960	1,130	1,318	1,523	1,753	2,000	2,575
11	70%	699	838	995	1,170	1,366	1,580	1,818	2,068	2,664
12	75%	729	873	1,035	1,218	1,422	1,644	1,892	2,130	2,780

Appendix 19.2 Properties/Factors for Rail Stress Calculations

Rail Section	Moment of inertia I_{xs}(worn)	For (a) Section modulus about XX axis Z_e(Worn)	For (a) Section modulus about XX axis Z_t(worn)	Factors for (b) and (c) $\frac{EI_1h_1r}{CZ_1}$ or $\frac{EI_2h_1r}{CZ_1}$	Factors for (b) and (c) $\frac{EI_1h_1r}{CZ_2}$ or $\frac{EI_2h_2r}{CZ_2}$	For(c) hf	For (d) Section modulus about YY axis Z_3(Head)	For (d) Section modulus about YY axis Z_t(Foot)
	cm^4	cm^2	cm^3	cm^{-3}	cm^{-3}	cm	cm^3	cm^3
50R	428 55	80.02	83.77	0.10447	0.07146	7.183	40.837	21.385
60R	609.11	103.82	109.73	0.08391	0.05318	7.988	50.980	26.613
75R	950.0	143.35	152.50	0.06045	0.03619	9.256	74.332	37.657
90R	1,440.0	192.46	212.08	**0.04353**	**0.03105**	9.909	96.323	47.031
52 kg	1,942 2	241.65	256.95	0.03511	0.02470	10.958	108.253	53.324
60 kg (UIC)	2,749.5	301.95	339.66	0.02986	0.019129	12.362	141.63	68.39

$E = 2.11 \times 10^6$ kg/cm² assumed

1.5 cm × vertical load = Torque

For case (b) Torque = $2M_t$

$hf \times$ Horizontal load = Torque for case (c) = $2M_t$

For (b) or (c) $\frac{EI_1h_1r}{CZ_1} \times M$ = Stress in head

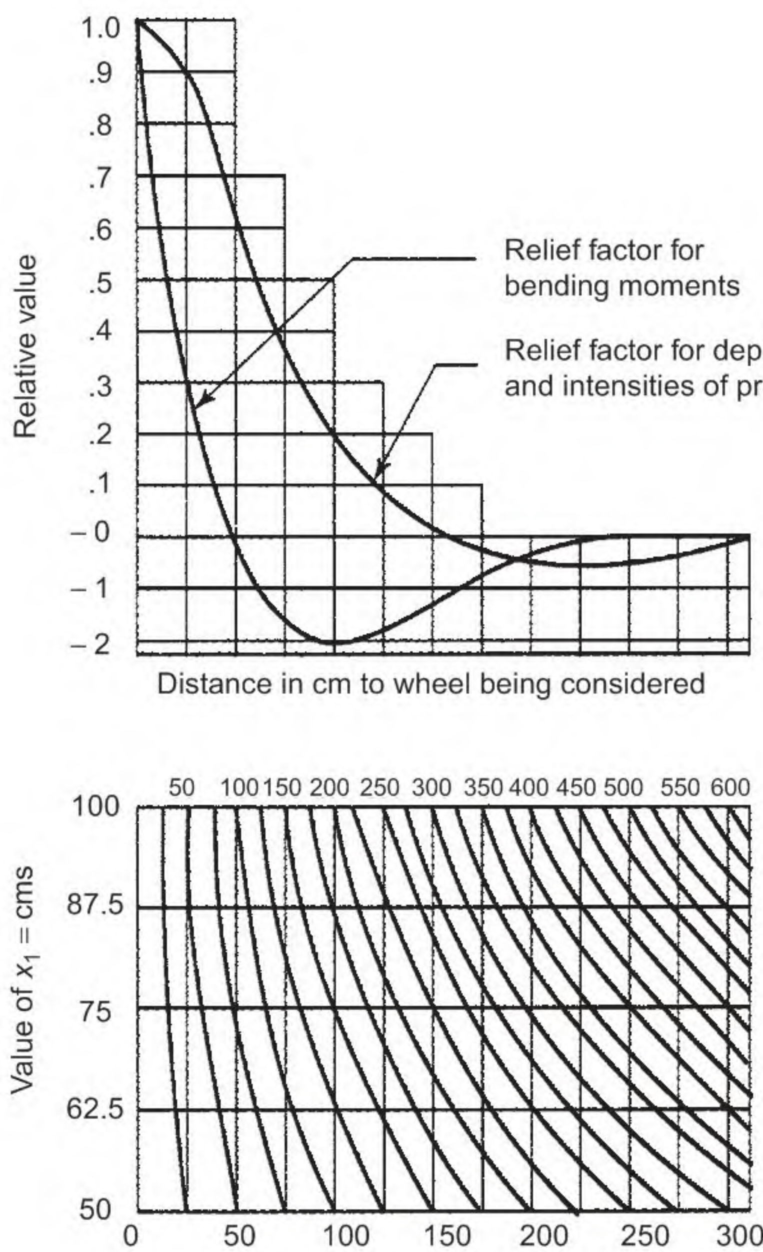
For (b) or (c) $\frac{EI_1h_1r}{CZ_1} \times M$ = Stress in foot

Appendix 19.3 Statement Showing the Results of Calculation of Stress

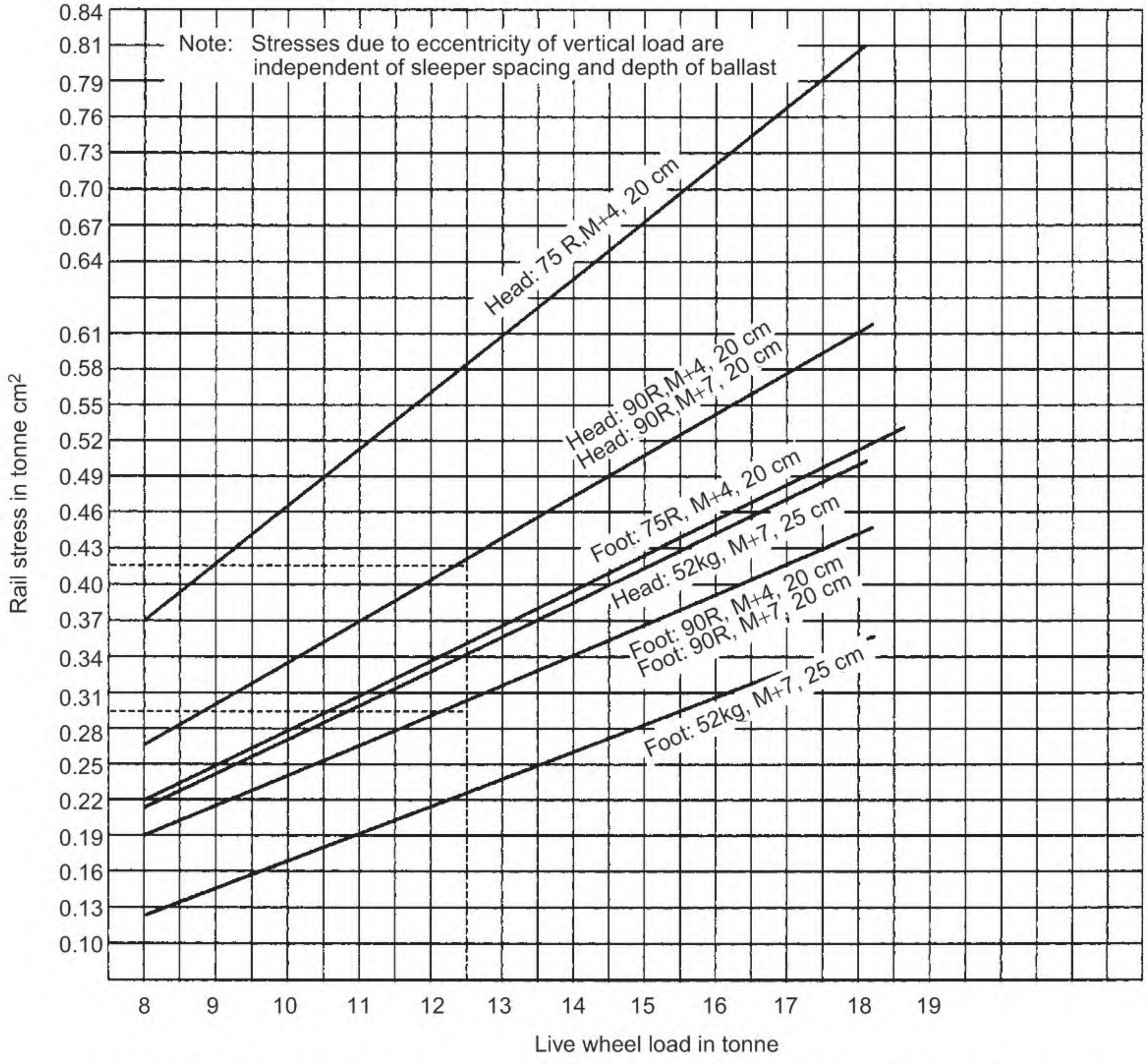
Track structure	*Axle load*	*Speed and speed factor*	*Rail stresses due to*			*Fishplate stresses*			*Bolt hole stress range*	*Maximum intensity of soil pressure*	*Joint loading*	*Combind stresses from Hannah's graph*	*Rail wheel contact stresses*
			Head or foot	*Vertical bending*	*Vertical bending and eccentricity effect*	*Vertical bending and eccentricity effect and flange forces effect*	*Dynamic stress range*	*Total stresses*					
Units →	*Tonnes*	*kmph*		*kg/mm²*	*kg/mm²*	*kg/mm²*	*kg/mm²*	*kg/mm²*	*kg/mm²*	*kg/mm²*	*Tonnes B.G./ M.G.*	*kg/mm²*	*kg/mm²*
Permissible limits →				23.5	FP36.00	SWP 30.25 LWR 25.25	25.0	30.0	27.0	Loco	Loco 27/17 EMU 23/14 C&W 19/11	34.7	21.6
90R M + 4 200 m.m	18.8	105 kmph 41.5% as per curve of WDM_2	Head Foot	14.32 12.99	18.41 15.91	26.47 26.72	18.06	22.99	19.51	2.89	26.97	31.2	18.69

General details:
- Name of stock WDM_2
- Lateral flange force 40% Tonnes/axle (assumed)
- Unsprung weight 3.97 Tonnes/axle
- Wheel dia new 1092 mm; Worn 1,016 mm
- Dynamic wheel load = 13.25 at 105 kmph.

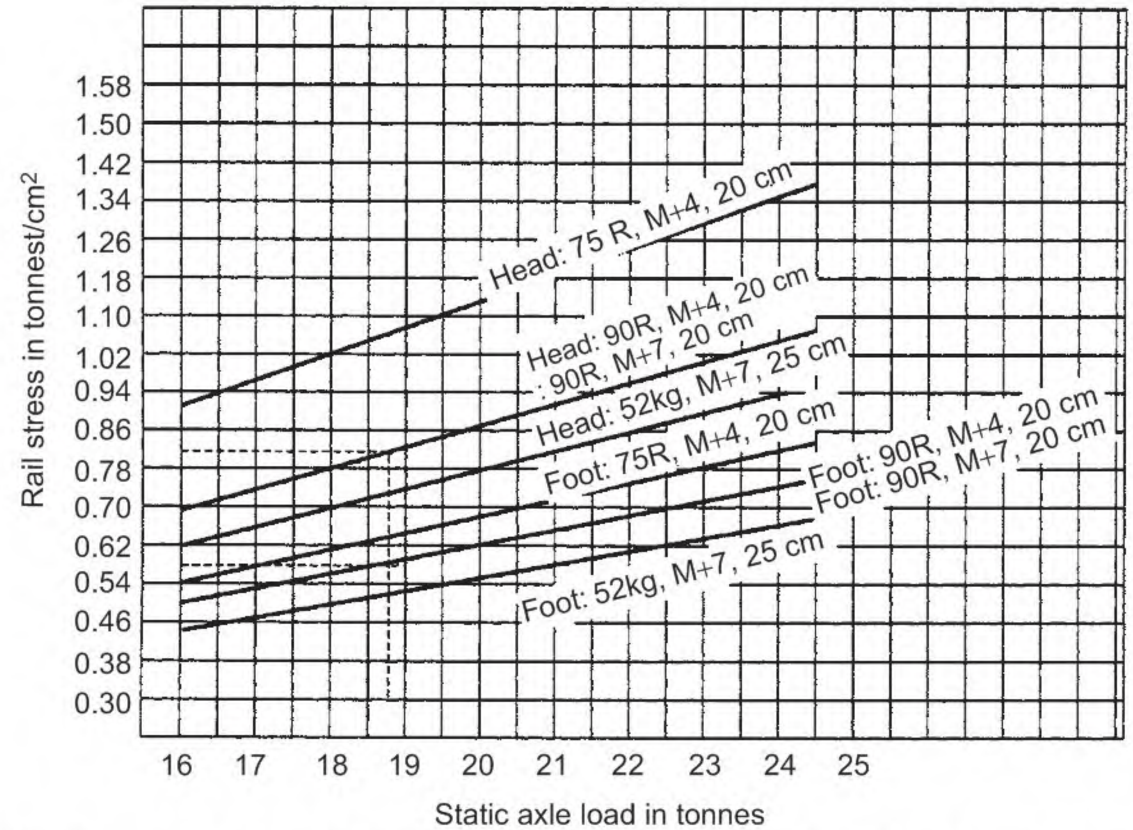
Start a distance = 150 cm and run down diagonal line to horizontal through X_1 = 85 cm then proceed
Vertically up to master diagram and read off
relative effect on BM = – .2 × 10 = 2.0 t
relative effect on depression = + .28 × 10 = 2.8 t



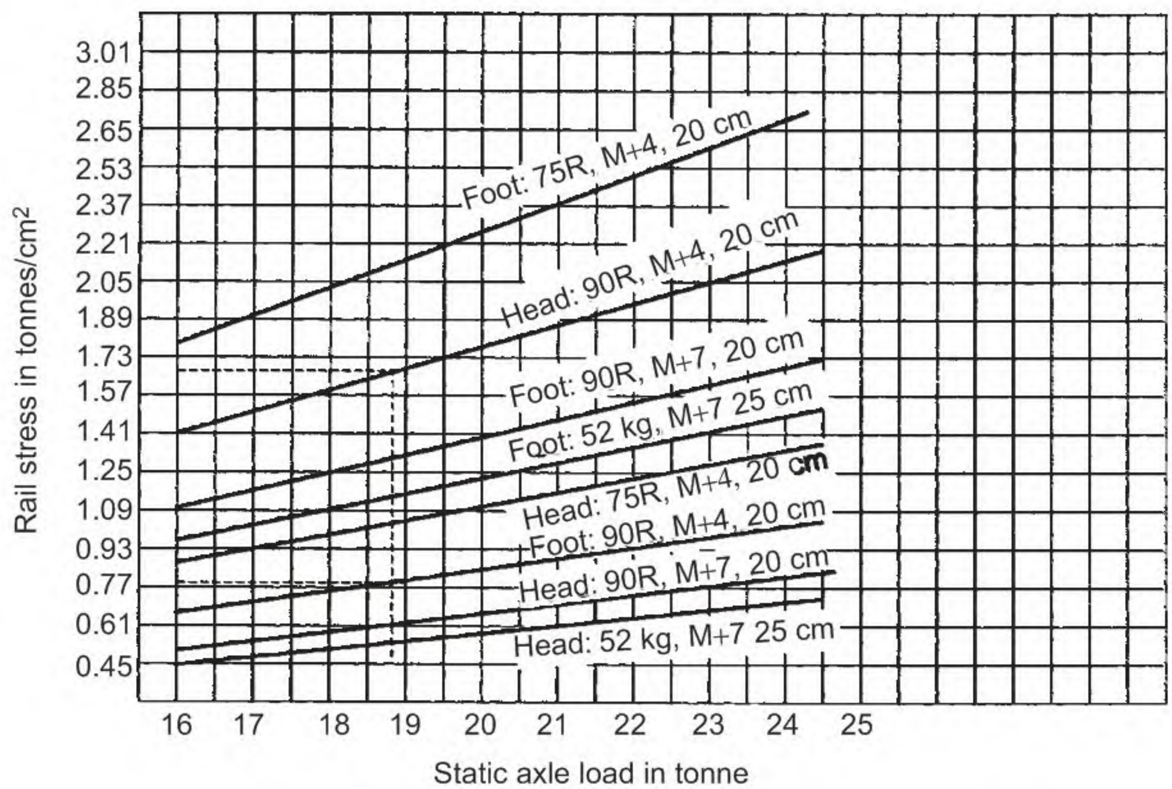
Graph B



Graph C Stresses due to eccentricity of vertical load (for broad gauge track)



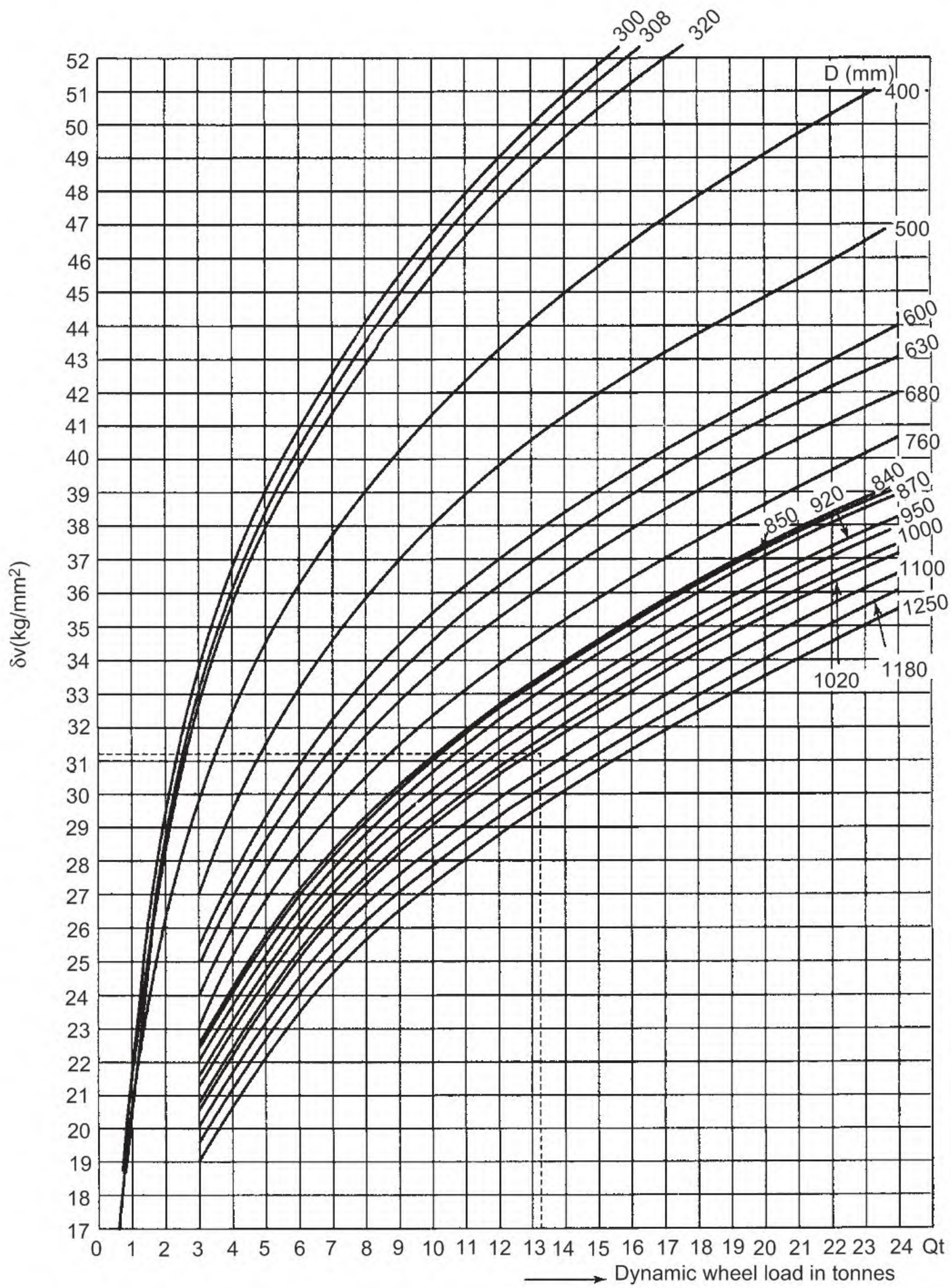
Graph D Stresses due to twisting effect under flange force (for broad gauge track)



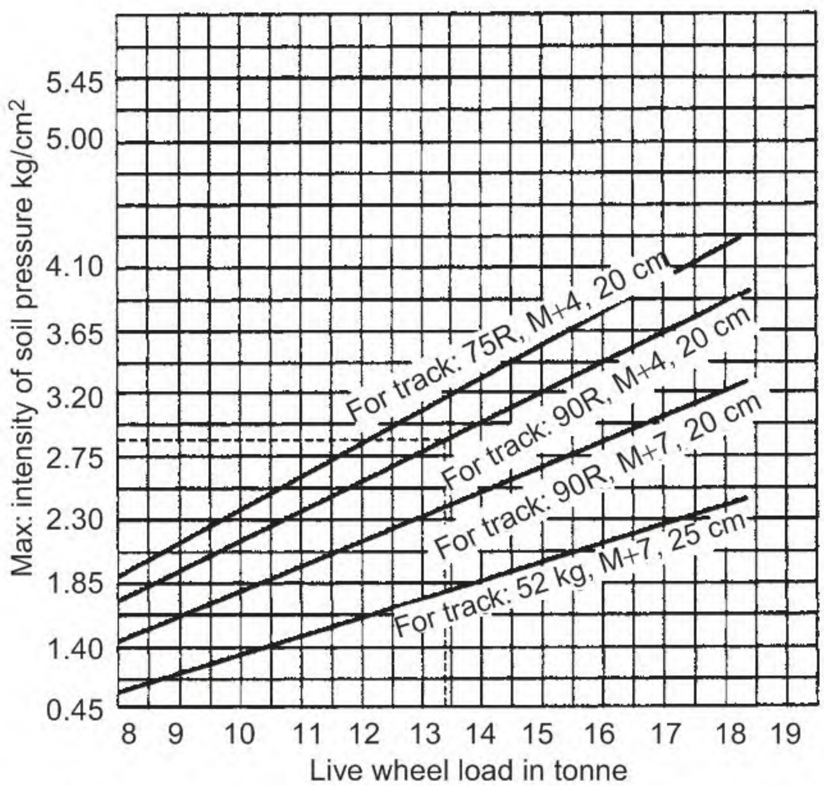
Notes:

1. Stress due to lateral deflection under flange force are independent of depth of ballast
2. Flange force is assumed to be 49% of the static axle

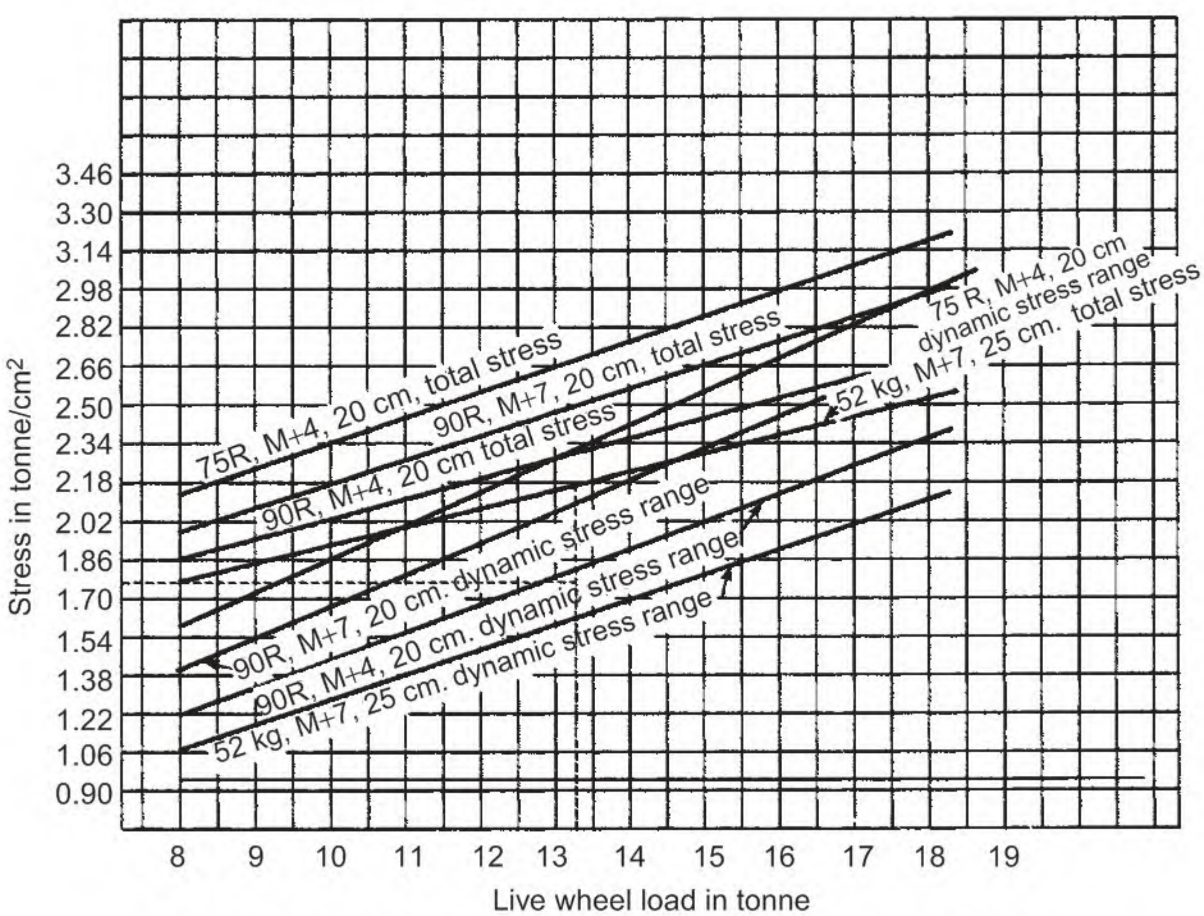
Graph E Stresses due to lateral deflection under flange force (for broad gauge track)



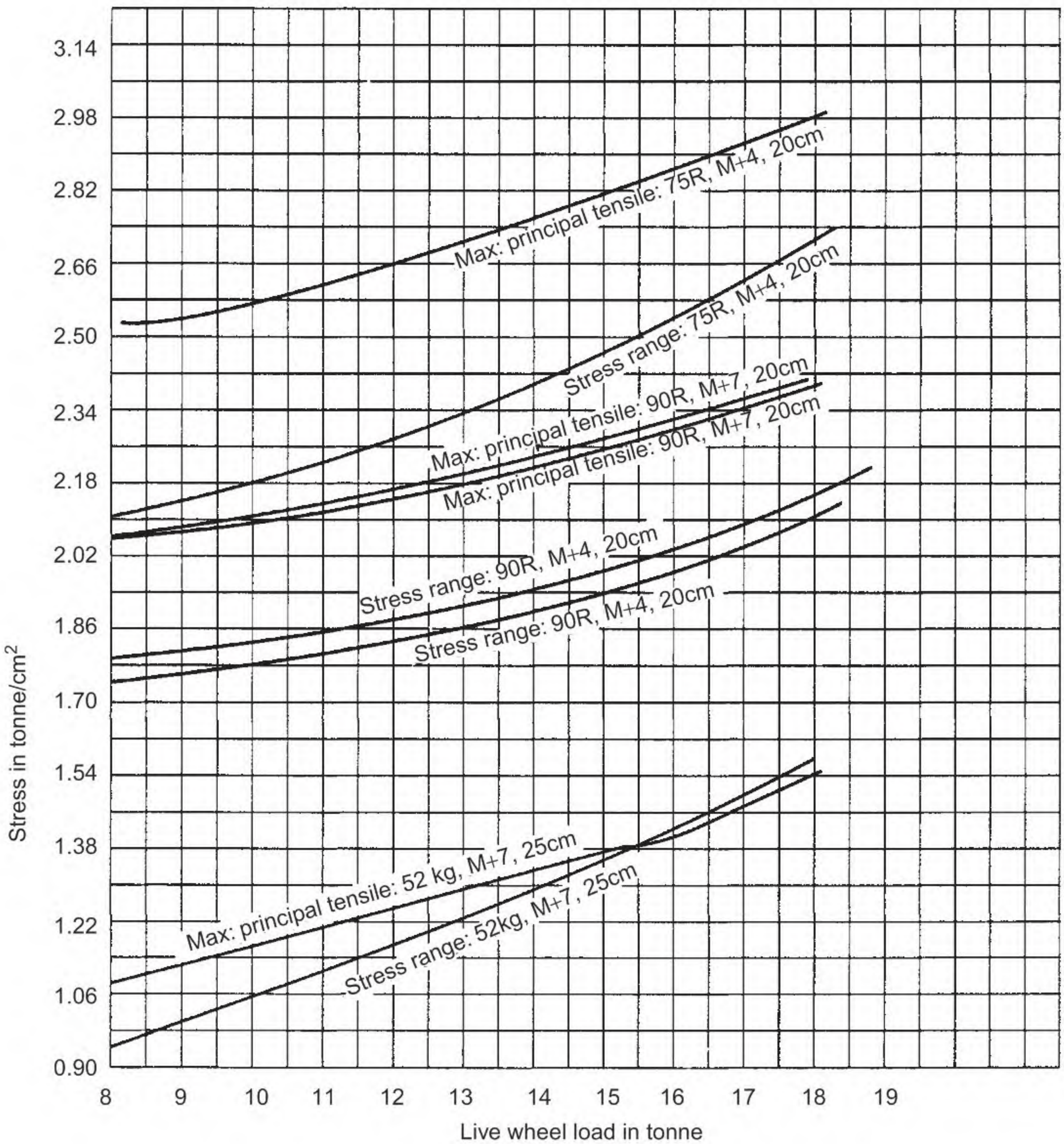
Graph F Hannah graph



Graph G Maximum intensity soil pressure (for broad gauge track)



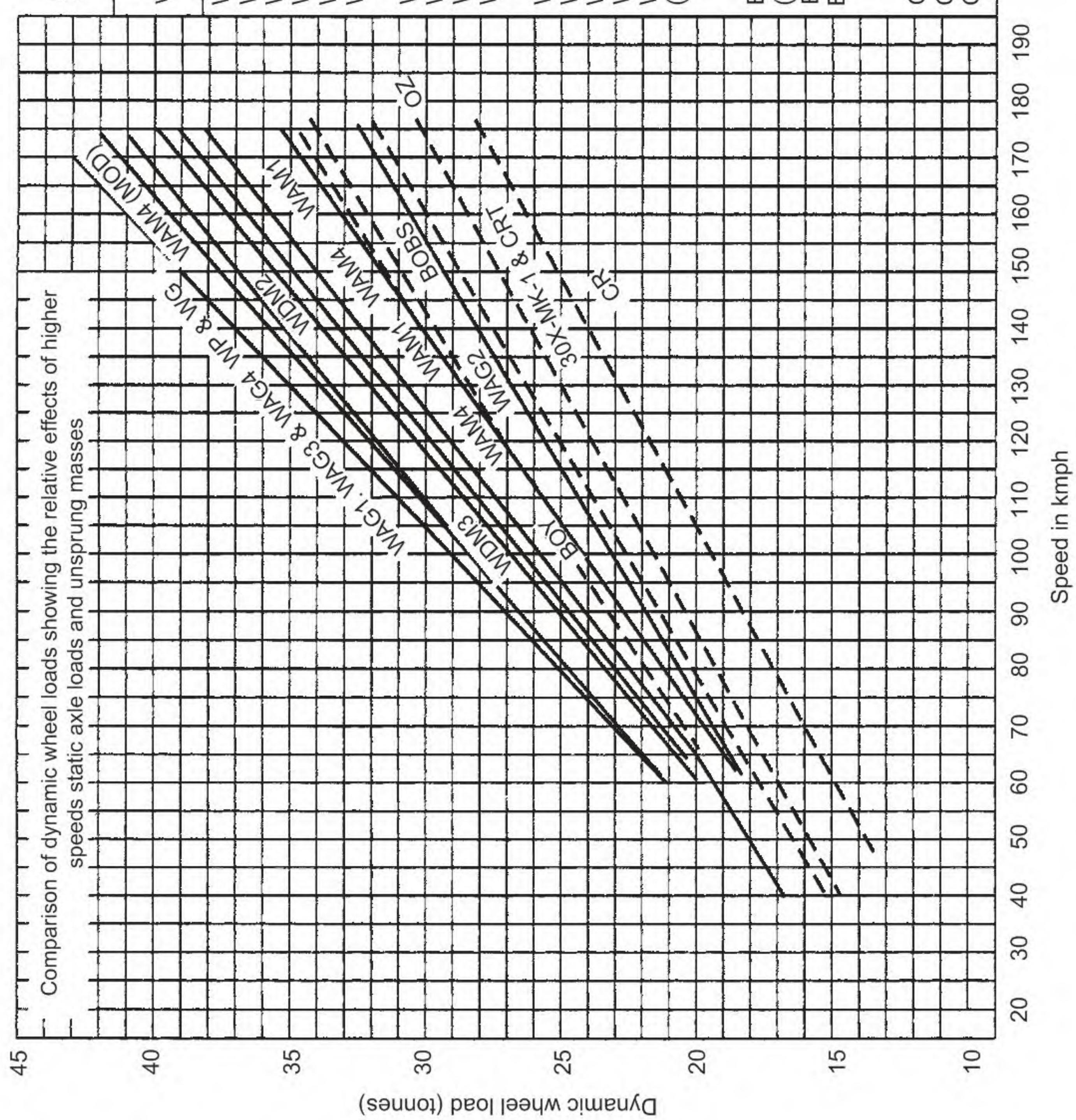
Graph H Fishplate stresses (for broad gauge track)



Graph I Stresses in bolt holes of 52 kg 90R, and 75 R rails (for broad gauge track)

References
Locomotive ———
Wagons - - - -

Loco/wagon	Axle load in tonnes	Unsprung mass per axle in tonnes
WP	18.78	5.164
WG	18.8	5.182
WDM1	18.6	3.54
WDM2	18.8	3.97
WDM3	19.57	3.68
WDM4	18.8	3.52
WAG1	21.8	3.9
WAG2	21.3	2.0
WAG3	21.8	3.9
WAG4	21.8	3.9
WAM1	18.5	2.9
WAM2	18.05	2.8
WAM3	18.05	2.8
WAM4	18.8	3.8
WAM4 (MOD)	20.0	4.34
BOX-(MK-I)	20.32	1.999
BOY	22.86	2.275
BOBS	22.86	2.16
CR	16.257	1.683
CRT	20.32	1.977
OZ	20.32	1.705



Graph J

20 Chapter

Track Standard and Track Rehabilitation

20.1 GENERAL

A railway network of any country consists of railway lines with wide variations in traffic density and the speed of the trains. For achieving overall economy in the construction and maintenance of these lines, it is necessary that the standards of their construction should be commensurate with their needs. Basic elements of track structure are rails, sleepers, rail to sleeper fastenings, turnouts and ballast. Laying of track standards thus constitutes laying of guidelines for the type, strength and quality of these elements for various levels of speed and traffic density.

20.2 FACTORS INFLUENCING CHOICE OF TRACK STRUCTURE

The track structure entails the following factors.

1. *Traffic Density* On routes with higher traffic density stronger track structure will be required for obtaining reasonably long life from track components.
2. *Axle Loads* Higher axle loads, apart from causing higher stresses in track components lead to faster deterioration of track geometry.
3. *Wheel Diameters* Smaller diameter wheels cause higher rail-wheel contact stresses requiring higher surface hardness of rails.
4. *Permissible Speed of Passenger and Goods Train* Higher speeds require the track to be maintained to closer tolerances, which can best be achieved with comparatively heavier track structure.
5. *Traffic Mix Pattern* The predominance of heavy haul trains in the traffic mix would require heavy track structure to be able to withstand higher stresses.
6. *Level of Comfort of Travelling Public* For comfortable travel the track geometry irregularities will be required to be controlled with in well defined limit, possible only with a strong and durable track components.

7. *Method of Track Maintenance* Mechanised track maintenance, to be efficient and effective would require, among other things, jointless track with uniform sleepers spacing and an adequate clean ballast cushion.

20.3 CHOICE OF RAILS

For rails, the choice has to be made about:

1. Type of rail
2. Weight of rail
3. UTS of rail
4. Rail hardness
5. Head hardened, End hardened, Volume hardened
6. Length of the rail from rail rolling mill
7. Weldability and method of welding

The factors influencing the decision about rail would be:

1. Traffic density
2. Speed
3. Axle load
4. Wheel diameter
5. Possible wear on curves

20.3.1 Quantification of Advantages of Heavier and Stronger Rails

Studies have been carried out by the various railway research organisations on the service life of rails under varying traffic environment. Some of the important conclusion drawn by them are as under:

1. Life time GMT carried by rails is proportional to:
   (i) $(\text{UTS})^2$
   (ii) $(\text{Section Weight})^3$
   (iii) $\dfrac{1}{[\text{Axle load}]^3}$
2. Track geometry deterioration should be proportional to $(\text{Axle Load})^2$
3. *Weight of Rail* Each additional kg in the weight of rail, saves 3% maintenance cost of track.
4. *Hardness Ratio* Ideal rail/wheel hardness ratio is 1
5. *LWR/CWR* Reduces fuel cost by more than 5%
6. *Heavier Track structure* Reduces soil pressure, thereby saving track maintenance cost.

20.4 CHOICE OF SLEEPERS

Railway sleepers are generally made of wood, concrete, steel and cast iron, plastic sleepers are also being tried out. The choice will depend upon:

1. *Technical considerations* Long welded rail track will have better maintainability with heavy concrete sleepers.
2. *Easy maintainability* Flat bottom sleepers are easier to maintain.
3. *System of track maintenance* Concrete sleepers can be better maintained with mechanised system of maintenance.
4. *Traffic density*
5. *Quality of subgrade*
6. *Environmental consideration* The use of wooden sleepers can lead to denudation of forest and is thus considered environmentally unfriendly.

On Indian Railways, on account of various technical and other considerations, concrete sleepers are used in all new tracks and relaying except for bridge timbers.

20.4.1 Sleeper Density

In designing the track structure, sleeper density has to be given a careful consideration. The sleeper density will depend upon

1. Axle loads, speed and traffic density
2. Strength of rail
3. Type of sleepers
4. Depth of ballast cushion/sub-ballast
5. Formation behaviour.

20.5 SWITCHES AND CROSSINGS

In choosing the right type of switches and crossings due consideration has to be given to:

1. *Speed on the straight and turnout track* This will determine the entry angle at the switch and the angle of crossings.
2. *Volume and tonnage of traffic* This will decide the structural strength of the turnout.

Following type of crossing assemblies are generally used on Indian Railways.

1. Fabricated bolted
2. Fabricated welded
3. Cast steel manganese crossings.

On Indian Railways fabricated crossings are being phased out from busy intersections. Welded crossing were proposed to be used for traffic density up to 10 GMT, and CMS crossings for higher traffic density. Fabricated bolted crossings may continue to be used on unimportant lines and yards. The trails conducted with welded crossings have not met with the desired degree of success. CMS crossings may therefore find a universal use on Indian Railways. On important routes, CMS crossings with weldable legs and thick web rail switches have been prescribed.

On all turnouts, concrete sleepers are generally replacing the other type of sleepers, hitherto being used on Indian Railways.

20.6 TRACK STRUCTURE VERSUS SUB-GRADE STRESSES

The bearing capacity of formation is varying between 2 to 4 kg/cm^2 on Indian Railways with certain stretches having a bearing capacity ranging between 2 and 2.5 kg/cm^2 only. With the conventional track structure of 90 lb rails, $N + 3$ sleeper density and 20 cm of ballast cushion, existing rolling stocks generate a formation pressure of up to 3.5 kg/cm^2 for loco and 3.0 kg/cm^2 for wagon. There is, therefore, need for improved track structure on this account. Studies made on American Railways have shown that sub-grade stresses get reduced on account of (a) increasing rail weight from 100 to 132 lb reduces sub-grade stresses by 6%; (b) reducing sleeper spacing from 26 to 22 inches reduces sub-grade stresses by 10%; (c) increasing sleeper length from 8 to 9 feet reduces sub-grade stresses by 12%; (d) increasing ballast cushion from 12 to 16 inches reduces sub-grade stresses by 20%.

Studies made by RDSO on Indian Railways have shown the following results:

Ballast cushion	*Sleeper*	*Density*
	$N + 3$	$N + 6$
8″	X	0.88 X
10″	0.79 X	0.70 X
12″	0.68 X	0.62 X

where X is the maximum pressure onto the formation having 8″ ballast cushion with $N + 3$ sleeper density. Thus by greater ballast cushion and increased sleeper density, the formation pressure is reduced to 0.62 X, indicating their important contribution in the design of Track Structure.

20.7 CLASSIFICATION OF LINES

In the foregoing paragraphs, the factors contributing in deciding the track structure have been brought out. Among them, the important influencing factors are speed and traffic density. The maximum speed present/future on a particular railway line is determined by the importance of the line in the national network and also on the traffic demands. The traffic density reflects the volume of goods and passenger traffic and is often a barometer of the economic development of the region in which the line is located. On Indian Railways quadrangle and diagonal routes connecting the four metropolises of Delhi, Kolkata, Mumbai and Chennai, carry more than 70% of the goods traffic. The demand of passenger is also the maximum on these routes. Similarly, there are other routes having different national priorities and varying economic needs.

To ensure the availability of a minimum track structure on a particular route for satisfying its traffic needs, it is desirable to classify the railway network into different categories and lay down minimum track standards for each of the category.

20.7.1 Broad Gauge

The BG lines have been classified into seven groups A to E on the basis of the future maximum permissible speeds, which are as under:

Group A – Speeds up to 160 kmph

(i) New Delhi to Howrah – Rajdhani Route (via the Grand Chord and Howrah – Burdhwan Chord).
(ii) New Delhi to Mumbai Central (Frontier Mail Route)
(iii) New Delhi to Chennai Central (Grand Trunk Route)
(iv) Howrah – Nagpur – Mumbai CST

Group B – Speeds up to 130 kmph

(i) Allahabad – Kanti – Jabalpur – Itarsi – Bhusaval
(ii) Kalyan – Pune – Daund – Wadi – Secunderabad – Kazipet
(iii) Kharagpur – Waltair – Vijayawada
(iv) Wadi – Raichur – Arakkonam – Chennai Central
(v) Howrah – Bandel – Barddhaman
(vi) Khanna – Barharwa – Farakka Bridge – Malda Town
(vii) Sitarampur – Madhupur – Kiul – Patna – Mughal Sarai
(viii) Kiul – Bhagalpur – Sahibganj – Barharwa
(ix) Delhi – Panipat – Ambala Cantt. – Kalka
(x) Ambala Cantt. – Ludhiana – Pathankot
(xi) Ambala Cantt. –Moradabad – Lucknow – Pratapgarh – Mughal sarai
(xii) Arakkonam – Jolarpettai – Salem – Erode – Coimbatore – Ernakulam
(xiii) Vadodara – Ahmedabad
(xiv) Jalarpettai – Bangalore
(xv) Ahmedabad – Ajmer – Jaipur – Bandikui – Rewari – Delhi
(xvi) Malda Town – Barsoi – New Jalpaiguri
(xvii) Chennai Beach – Dindigul
(xviii) Bangalore – Dharmavaram – Gooty
(xix) Ghaziabad – Saharanpur
(xx) Chennai Beach – Chennai Egmore 3rd line

Figure 20.1 shows Groups A and B routes.

Group C – Suburban sections of Mumbai, Delhi, Chennai and Kolkata as listed below:

Fig. 20.1 Indian Railways map

(i) CSTM – Kalyan – Kasara
(ii) CSTM – Kalyan – Karjat
(iii) CSTM – Kurla – Panvel
(iv) CSTM – Ravali – Mahim – Andheri
(v) CSTM – Ravali – Kurla
(vi) Churchgatge – Mumbai Central – Borivali – Virar
(vii) Chennai Central – Basin Bridge – Veysarpadi – Arakkonam
(viii) Chennai Central – Basin Bridge – Washermanpet – Chennai Beach – Tambaram
(ix) Chennai Central – Basin Bridge – Korukkupet – Tondiarpet – Tiruvottiyar – Gummidipundi
(x) Chennai Beach – Thirumayilai
(xi) Sealdah – Dumdum – Naihati – Kalyani – Ranaghat – Krishnanagar
(xii) Sealdah – Sonarpur – Baruipur
(xiii) Ballygunj – Budge Budge
(xiv) Howrah – Dankuni – Saktigarh – Bardhaman
(xv) Howrah – Bandel – Saktigarh
(xvi) Seoraphuli – Tarakeshwar
(xvii) Dumdum – Barasat
(xviii) Howrah – Panskura – Kharagpur

Group D special – Sections where the traffic density is very high or likely to grow substantially in future and the sanctioned speed is 100 kmph at present. The following routes will fall under this category:

(i) Kharagpur – Midnapur – Adra
(ii) Barkakana – Barwadih – Garwa road
(iii) Tundla – Yamuna Bridge
(iv) Bolangir – Titlagarh
(v) Gudur – Renigunta
(vi) Anara – Chandil – Kandra – Sini
(vii) Anuppur – Shahdol – Kanti – Bina
(viii) Ahmedabad – Viramgam
(ix) Nagda – Ujjain – Maksi – Bhopal
(x) Lucknow – Sultanpur – Zaffarabad – Banaras
(xi) Delhi – Ghaziabad – Hapur – Moradabad
(xii) Lucknow – Kanpur
(xiii) Chapra – Hajipur – Barauni
(xiv) Raipur – Titlagarh – Vizianagaram
(xv) Guntakal – Tornagallu – Hospet
(xvi) Udhna – Nandurbar – Jalgaon
(xvii) Gomoh – Chandrapura
(xviii) Garva Road – Chopn
(xix) Garva Road – Sone Nagar

(xx) Barauni – Katihar
(xxi) Sambalpur – Talcher – Nergundi
(xxii) Jharsuguda – Bolangir
(xxiii) Brabanki – Gonda – Gorakhpur – Chhapra
(xxiv) Champa – Gewra Road
(xxv) Bilaspur – Anuppur

Group D – Sections where the sanctioned speed is 100 kmph at present.

(i) Salem – Byappanhalli
(ii) Guntur – Donakonda – Guntakal
(iii) Vikarabad – Parli – Parbhani
(iv) Vijayawada – Bhimavaram – Nidadavolu
(v) Secunderabad – Dronachalam
(vi) Jodhpur – Marwar
(vii) Diva – Vasai Road
(viii) Pen – Roha
(ix) Kumedpur – Katihar Jn
(x) Rewari – Hissar
(xi) Kalumna – Nagpur (via Itwari)
(xii) Kota – Ruthiyai
(xiii) Bina – Guna – Ruthiyai

Group E special – Sections where traffic density is very high or likely to grow substantially in future and present sanctioned speed is less than 100 kmph, the following routes will fall under this category:

(i) Panskura – Haldia
(ii) Talcher – Rajatgarh – Salegaon – Nergundi
(iii) Cuttack – Paradeep
(iv) Radhakishorepur – Rajathgarh – Barang
(v) Kapilas Road – Salegaon
(vi) Radhakishorepur – Machapur
(vii) Kirandul – Koraput
(viii) Rajakharshwan – Dongaposi – Padapahar Barajamda – Gua
(ix) Bondamunda – Bimlargarh – Barsuan – Kiriburu
(x) Kandra – Gamharria
(xi) Marauda – Dallirajhara
(xii) Urkura – Sarona
(xiii) Bhojudih – Mohuda G-C
(xiv) Chandil – Muri – Bokaro – Rajbera
(xv) Padapahar – Banspani
(xvi) Barajamda – Bolanikhandan
(xvii) Muri – Barkakana
(xviii) Talgoria – Bokaro City
(xix) Andal – Sainthia

(xx) Hatia – Muri
(xxi) Mohuda – Gomoh
(xxii) Koraput – Kottavalasa
(xxiii) Koraput – Singapuram Road
(xxiv) Sambalpur – Angul
(xxv) Anuppur – Bijuri – Boridand
(xxvi) Boridand – Bisrampur
(xxvii) Durg – Marauda
(xxviii) Londa – Vasco
(xxix) Dewas – Maksi
(xxx) Gandhidham – Bhuj
(xxxi) Dornakal – Bhadrachalam Road – Manuguni and Kerapalli – Singereni Collieries
(xxxii) Sanathnagar – Maul Ali (by pass line)

Group E – All other sections and branch lines where the present sanctioned speed shall be less than 100 kmph.

20.7.2 Metre Gauge

The MG lines have been classified into three categories based on the speed potential and traffic density in the section, which are as under:

(a) ***Q-Routes*** – The *Q* routes consist of the routes where the maximum permissible speed will be more than 75 km.p.h. The traffic density is generally more than 2.5 GMT. The following routes will fall under category *Q*: -

(i) Delhi – Sarairohilla – Rewari – Ratangarh
(ii) Rewari – Ringus – Phulera
(iii) Ratangarh – Degana
(iv) Ajmer – Ratlam – Khandwa
(v) Jaipur – Phulera – Ajmer
(vi) Bandukui – Agra Fort
(vii) Ahmedabad – Bhavnagar
(viii) Agra – Mathura – Bhojipura – Lalkuan
(ix) Bhojipura – Lucknow
(x) Villupuram – Thanjavur – Tiruchchirappalli
(xi) Chennai Beach – Villupuram
(xii) Dindigul – Madurai

(b) ***R-Routes*** – These routes will have a speed potential of 75 kmph. And the traffic density is more than 1.5 GMT. R routes are further classified into three categories as follows, depending upon the volume of traffic carried: -

(i) R-1: when the traffic density is more than 5 GMT.
(ii) R-2: when traffic density is between 2.5 to 5 GMT.
(iii) R-3: when traffic density is between 1.5 to 2.5 GMT.

R1 Route

(i) Gandhidham – Palanpur

R2 Route

(i) Secunderabad – Mudkhed
(ii) Guntakal – Bellary
(iii) Guntakal – Villupuram
(iv) Tiruchchirappalli – Manamadurai – Virudunagar

R3 Route

(i) Madurai – Rameswaram
(ii) Virudunagar – Tenkasi
(iii) Dindigul – Pollachi
(iv) Ratangarh – Bikaner

Note: The following two routes also carry a traffic density of more than 5 GMT.

(i) Katihar – New Bongai Gaon
(ii) Guwahati – Tinsukia

These have not been included in R1 routes as they are slated for conversion.

(c) ***S-Routes*** – These will be the routes where the speed potential is less than 75 kmph and the traffic density is less than 1.5 GMT.

20.8 TRACK STRUCTURE FOR BROAD GAUGE ROUTES

The following track structure has been prescribed for the various categories of BG lines.

20.8.1 Rails

The minimum rail section for the various groups of lines are shown in Table 20.1.

Table 20.1

	Routes						
Traffic density in GMT	*A*	*B*	*C*	*D Spl*	*D*	*E Spl*	*E*
More than 20	60 kg	60 kg	60 kg	60 kg	60 kg	60 kg	60 kg
10 – 20	60 kg	60 kg	60 kg	60 kg	52/90	60 kg	52/90
5 – 10	60 kg	52/90	52/90	52/90	52/90	52/90	52/90

(*Contd.*)

	Routes						
Traffic density in GMT	*A*	*B*	*C*	*D Spl*	*D*	*E Spl*	*E*
Under 5	52/90	52/90	52/90	52/90 or 60 kg	52/90 or 60 kg (SH)	52/90 or 60 kg (SH)	*52/90 (SH) or 60 kg (SH)
Loop line	52 kg IRS-T-12 second quality rails or 52 kg (SH)						
Pvt siding	For sidings with operating speed more than 80 kmph and up to 100 kmph			Track structure specified for D routes			
	For sidings with operating speed more than 50 kmph and up to 80 kmph			Track structure specified for E routes			
	Where BOX 'N' or 22.1 Tonne axle wagons ply or operating speeds on sidings exceed 30 and are going up to 50 kmph			52 kg IRS-T-12 Second quality rails or 52 kg (SH)			
	For other sidings with operating speed up to 30 kmph			52 kg IRS-T-12 third quality rails also called 'Industrial use rails' or 52 kg (SH)			

Notes:

(i) All 60 kg rails are of 90 UTS.

(ii) 52/90 represents 52 kg/90 UTS rail section.

(iii) Existing 90-R rails may be allowed to remain for speeds not exceeding 110 kmph.

(iv) On routes identified for running of 22.1 tonne axle wagons, 60 kg rails shall be used on all routes.

(v) Head hardened rails should be used on (a) Local lines where dedicated EMU stock is running. (b) Ghat section with gradients steeper than 1 in 150 and/or curves sharper than 2 degree, (c) Locations where due to grades, curves, traffic density and type of stock, the rate of wear of rails is such as to necessitate rail renewal, on wear considerations, at a frequency of 10 years or so, (d) Routes where predominantly captive rolling stock is moving in close circuit movement, particularly with heavy mineral traffic, (e) The HH rails should be laid on continuous and long stretches.

(vi) Second hand 52 kg rails may be used on case-to-case basis, with the prior approval of Railway Board; depending upon quality of released rails available.*

Metre gauge: The following rail sections are recommended on MG routes:

Route	*Rail section recommended*
'Q' and 'R1'	52 kg (SH)/90 R (New)*
'R2' and 'R3'	52 kg (SH)/90 R (SH)
'S'	52 kg (SH)/90 R (SH)/75 R (SH)

* 90 R (New to be only used with specific approval of Railway Board, in case no suitable 52 kg (SH) rails are available for use on MG during renewal.

Narrow gauge (762 mm)—Suitable new or second hand rails 50 lbs and above.

20.8.2 Sleepers, Rail to Sleeper Fastenings and Sleeper Density

Sleepers and the rail to sleeper fastenings for various groups are prescribed in Table 20.2.

Table 20.2

Item	*A*	*B*	*C*	*D and E*
1. Sleeper	Concrete and steel	Concrete and steel	Concrete and steel	Concrete, steel and CST-9
2. Fastenings	Elastic fastenings	Elastic fastenings	Elastic fastenings and conventional fastenings	Elastic and conventional fastenings

Notes:
1. As an interim measure, steel sleepers with conventional fastenings may be used on groups A and B routes having traffic density up to 20 GMT.
2. Speeds higher than 130 kmph are not permitted on CST-9 sleepers.
3. Metal sleepers wherever used should have wooden/concrete sleepers at the joints. Such sleepers should be provided with rail free fastenings. Screw spike for that purpose may be treated as rail-free fastening.
4. Concrete sleepers fitted with special J clips can be used as joint sleepers.

20.8.3 Sleeper Density

Broad Gauge The minimum sleeper density for all future track renewals (complete track renewals and through sleeper renewals) is recommended and given as Table 20.3 (a).

Table 20.3 (a)

	Routes						
Traffic density in GMT	*A*	*B*	*C*	*D-Spl*	*D*	*E-Spl*	*E*
More than 20	1660	1660	1660	1660	1660	1660	1660
10 – 20	1660	1660	1660	1660	1540	1660	1540
Under 10	1660	1540	1540	1540	1540	1540	1540
Loop lines	1340	1340	1340	1340	1340	1340	1340
Pvt. Siding	1340	1340	1340	1340	1340	1340	1340

Note: Number of sleepers per km

(i) For routes for running 22.1 t axle load wagons, Sleeper density of 1660 nos/km should be adopted.

Metre Gauge In the case of MG track renewals, the sleeper densities are recommended for the various MG routes as given in Table 20.3 (b).

Table 20.3 (b) Sleeper Density for MG

Route	Q	R1	R2	R3	S
Sleeper density	M + 7	M + 7	M + 7	M + 7	M + 3

Notes:
(i) Higher sleeper density may be provided with the approval of the Chief Engineer
(ii) For LWR/CWR minimum sleeper density shall be 1540 sleeper/km
(iii) In case of SWR, the minimum sleeper density in the case of BG and MG is fixed as (M + 4)

20.8.4 Ballast Cushion and Ballast Profile

Table 20.4

	A	*B*	*C*	*D*	*E*
Ballast cushion	30 cm	25 cm	25 cm	20 cm	15 cm
Ballast profile	LWR ballast profile	Conventional profile except on LWR, where LWR ballast profile will be adopted			

Notes:
1. Increase in ballast cushion, where called for, will be carried out during complete track renewals of programmed deep screenings.
2. Wherever jointed track is converted into LWR, LWR ballast profile must be adopted.
3. On specific locations, additional ballast cushion or sub-ballast may be provided over and above the prescribed cushion to improve maintainability.
4. A minimum ballast cushion of 30 cm will be provided on routes where box 'N' wagons are going to ply.
5. When primary renewals are carried out on Group E routes, the ballast cushion should be 20 cm.

20.8.5 Points and Crossings

For Groups A and B routes, the following standards have been prescribed for strengthening the conventional layouts.

1. The stock rail joint ahead of the toe of the switch may be shifted away from the point by at least half rail length by welding the conventional stock joint.
2. Provision of additional sleepers on the lead portion of the turnouts, to reduce spacing and increase lateral stability to be considered.
3. All the lead rails, on straight as well as on curved track, should be welded together to eliminate joints. Whenever welding of joints is not possible, jammed joints with moon shaped liners may be adopted as an alternative.
4. Cast manganese steel crossings should be used on these routes.
5. Given the tendency of the sleepers in the crossing to bend in the centre with consequent difficulty to retain packing, deeper sleepers should be provided in the wooden sleeper layouts for the portion under crossing.

   Out of 6 numbers of sleepers involved, 5 should be of 25 cm × 20 cm size and the one bearing the gauge tie plate should be 28 cm × 20 cm size.
6. All wooden sleepers for points and crossings should be treated to increase their service life, even if they are made of durable variety of timber.

20.8.6 Switches and Turnouts

Apropos of switches and turnouts, it is advised as follows:

1. Curved switches should be invariably be provided on all Group A, B and C routes. On other routes, curved switches should be provided wherever replacement of straight switches becomes due.
2. All future designs of turnouts should be with a nominal gauge of 1,673 mm, i.e. 3 mm tight. On existing turnouts, whenever possible, the track should be maintained to 3 mm tight gauge, particularly on straight, for improving the running over such turnouts.
3. In all new turnouts and on replacement of the existing turnouts only concrete sleeper will be used for economy and better maintainability.

20.8.7 Curves

Standards for curves have been prescribed as follows:

1. The speed potential of the curve will be determined purely on theoretical consideration by the formula.

$$E = \frac{GV_2}{127R} \qquad \text{(see Sec. 6.8.5)}$$

where E = Superelevation
V = Speed in kmph
R = Radius of curves in metres

2. Equilibrium speed of the section should be determined on the basis of the attainable speeds by the trains in various sub sections.
3. For group A, B and C routes, the limiting value of maximum permissible cant will be 165 mm. A limiting value of cant of 185 mm may be assumed for the purpose of determining lateral clearance for locating permanent structures by the side of the curves.
4. Cant excess on BG shall not be allowed to exceed 75 mm.
5. Cant deficiency on group A and B routes may be limited to 100 mm.
6. For speeds up to 160 kmph, it will be preferable to aim at a rate of change of cant/cant deficiency not exceeding 38.1 mm/s. In difficult locations, it shall however be ensured that the same does not exceed 55 mm per second. For designing of future layout of curves, a cant gradient 1 in 1200 shall be aimed at.
7. Minimum radius of vertical curves shall be kept as follows:

Groups	*Minimum radius*
A	4,000 m
B	3,000 m
C and D	2,500 m

The vertical curves shall be laid out on the points of change of grade when the algebraic difference between grades is equal to or more than 5 mm/m (see Sec. 6.13).

20.8.8 Policy of Unigauge

In 1992, Indian Railways decided to have a unigauge system of broad gauge only. Presently, all the meter gauge railway lines are, under conversion into broad gauge. The residual track on metre gauge is being maintained with released materials only and the investment on track account on meter gauge system is kept down to the bare minimum.

20.9 DEDICATED FREIGHT CORRIDORS—CONSTRUCTION PARAMETERS AND TRACK STRUCTURE

With the accelerated growth of Indian economy it has become necessary to enhance the railways' transport capacity to meet the increased traffic demands. Most of the trunk routes on Indian Railways are already running to a saturated traffic condition. It has, therefore, been decided to have dedicated freight corridors for the speedy movement of goods. Dedicated freight corridors have the advantage that they can be designed to meet the specific requirements of specialised rolling stock for their movement at the designated speeds. The throughput of traffic on such corridors can be quite high, without any interference from the running of high/low speed passenger trains.

The main objectives of dedicated freight corridors (DFC) are summarised below:

- Designing a system for carrying bulk freight traffic at high-speed with higher capacity and higher axle load wagons and longer trains which in turn results in reduction in unit cost of transportation, better utilisation of assets and greater customer's satisfaction.
- Creating an infrastructure, which is capable to move high volumes of traffic and having capacity, adequate enough to meet the requirement of next 50 years or so.
- Relieving the existing Indian Railway network of a substantial part of present freight traffic, in turn resulting into increased capacity for augmenting passenger services, decongesting busy terminals and junctions and improved safety and satisfaction of passengers.
- Introduction of high-end technology in freight operation, which will permit the higher axle loads, higher Maximum Moving Dimension (MMD), higher Track Loading Density (TLD), improved pay load/tare weight ratio, reduced terminal detention and improved traffic throughput.
- Introduction of time tabled freight services and assured transit time.
- Introduction of a system requiring least maintenance efforts.
- Getting the final results in the form of increased railways share in the total freight transportation of the country.

20.9.1 Construction and Track Structure Parameters for DFC

DFC is being designed for an axle load of 32.5 tonnes, trailing loads of 15,000 tonnes and maximum permissible speed of 100 kmph. Following construction parameters have been proposed for DFC (Table 20.5).

Table 20.5 Construction Parameters

S. No.	*Description*	*Details*
1.	Gauge	1676 mm
2.	Maximum degree of curvature	2.5 degree (700 m radius)
3.	Curve compensation	At the rate of 0.04% per degree of curvature
4.	Ruling gradient	1 in 200 (compensated)
5.	Steepest gradient in yards	1 in 1200, 1 in 400 in exceptional cases
6.	Bank width for double line	12.85 m
7.	Cutting width for double line	14.9 m (11.9 + 2 × 1.5 m for side drains)
8.	Vertical maximum moving dimension	7.1 m
9.	Track centres between two DFC tracks	5.5 m
10.	Track centres between existing and DFC track	6.0 m

Track structure parameters are as follows

Table 20.6 Track Structure Parameters

S. No.	*Description*	*Details*
1.	Rails	60 kg UIC/68 kg, 90 UTS, HH on curves
2.	Sleeper	PSC, 1660 Nos./km for main line and 1540 Nos. per km for loop line and sidings
3.	Ballast	300 mm cushion
4.	Points and crossings	60 kg rail, 1 in 12 curved switches and CMS

Heavy Haul Association of the World Railways has defined heavy haul operation in the following terms: “Heavy haul railway operation is defined as a system with: 25 tonnes or greater axle loads, a minimum of 20 million gross tonnes annual traffic and/or the operation of unit trains, in excess of 5000 tonnes load.” DFC with their axle load of 32.5 tonnes and the trailing load of the 15,000 tonnes will come in the category of heavy haul operation. Heavy Haul Association (HAA) have made certain recommendations about track structure and track maintenance issues of heavy haul railway lines. Their recommendations for axle load of 30–34 tonnes are given as Annexure 1, at the end of this chapter for general guidance in deciding the track structure and the track maintenance system.

20.10 TRACK REHABILITATION

In developing countries, resource constraint often lead to situations, when track overdue for renewal, has to be kept going, even at a restricted speed. Proper understanding and application of the basic concepts of track technology help in the correct appreciation of such real life problems and in finding optimal solutions.

Safety has to be the paramount consideration in the rail movement. For safe running on track at any speed, the following three objectives are to be fulfilled.

1. Continuity of track or to be more precise, continuity of the two rail surfaces.
2. Rails should be held together to a fixed gauge within acceptable tolerances.
3. A support system where the rails should be held reasonably well in vertical, lateral and longitudinal planes.

The speed that can be permitted on track will depend on the above mentioned three basic requirements. In the following paragraphs the problems that generally arise and their possible solutions are given.

20.10.1 General Run-down of the Section

This is reflected in the poor track geometry. There is a marked deterioration in cross and longitudinal levels with the passage of only a few trains after the track irregularities are rectified. The remedy often lies in ensuring proper track drainage and providing full clean ballast cushion. Ballast is the cheapest of all track materials, but it lends maximum strength to the track.

Poor Condition of Rails

This is exhibited in the form of

1. Epidemic of rail/weld failures.
2. Excessive wear on curves.
3. Excessive loss of section causing fatigue failure of rails under heavy axle loads.
4. Battering and hogging.
5. Scales and wheel burns.
6. Corrugation.

Remedial Measures

1. If the rails are having end fractures, the remedy lies in cropping of the rails-ends by about 30 cm and welding them into 2/3 rail panels. If mid rail fractures are occurring, it is advisable to have thorough scanning by ultrasonic rail flaw detector and remove the defective rails or the defective portion of the rail. Periodic ultrasonic scanning shall have to be done to avoid rail failures under passing loads.
2. Changing of rails, either (a) end to end, so that gauge face becomes the outer face or (b) interchanging left and right rails or (c) changing rails to locations away from curve should be able to solve the problem of excessive wear on curves.
3. Excessive loss of section or lower poundage of rails can to some extent be compensated by increasing the sleeper density and depth of ballast cushion. A reduction in the speed of the

section will help in reducing the dynamic augment on these rails and thus reduce the rail stresses.

4. Dehogging of the rail ends can be done with dehogging machines. MSP can also be effectively used for dehogging. Ultimate remedy for battering and hogging lies in end cropping and welding of rails.
5. Scales and wheel burns can be rid off with the help of rail grinding machines. In their absence, it is advisable to change the rails to new locations, when further damage to rails can be avoided. The possibility of changing traffic conditions to avoid out of course stoppage of trains and consequent difficulty in starting, causing wheel burns should be also investigated.
6. At slow speeds, corrugations do not cause much problems except little addition to maintenance efforts, increasing sleeper density and deep screening of ballast have at times helped in removing rail corrugations.

20.10.2 Problems and Remedies of Overaged and Worn-out Sleepers

Wooden Sleepers

1. The sleepers of a worn down rail seat should be laterally shifted to new position to get a fresh rail seat.
2. Spike killed holes can be reconditioned with the help of (a) wooden plugs and (b) filling the holes with chemical compounds.
3. Sleepers unable to hold gauge can be remedied by providing separate gauge fixers at regular intervals. These fixers, which are made of scarp tie bars or angle iron, hold the rail at the rail foot at fixed distance apart. Drawings of rail fixers, with or without insulating arrangements, are available with RDSO.
4. Sleepers with two wooden blocks at either end held with scrap tie bars can be made out of old wooden sleepers having damaged rail seats. The blocks can be cut out of the central portion of the worn out sleepers. Such two block wooden sleepers are known to have given good service at restricted speeds.

Steel Trough Sleepers

1. Wear and depression at rail seat: These two problems can be overcome by providing a rubber pad, ply wood pad or a bakelite pad of appropriate thickness. Steel sheet with holes for the jaw has also been successively tried by some of the Railways.
2. Elongation of holes: This problem can be solved by the use of (a) oversize jaws (b) thicker keys and wooden (c) metal liners at the holes.
3. Development of cracks emanating from the holes, Corrosion and Widening of presses up lugs. These problems can be overcome, to a limited extent, by repair welding. But the effective solution lies in reconditioning of sleepers by (a) welding a new steel plate at the rail seat or (b) welding a saddle plate, cut out of the central portion of the rejected steel sleepers. Sleepers after such reconditioning are capable of giving as good a service as new ones.

Cast Iron Sleepers

1. Excessive wear at the rail seat.
2. Wear at the jaw.
3. Elongation of slots in tie bars housing cotters.

Problem (1) can be solved by using pad plates of steel or with the use of ply wood pads of appropriate thickness.

Problems (2) and (3) can be tackled by using oversize keys and cotters. Steel linears can also be provided at both the places to fill in the extra gap. Coal-tarring and sanding of keys have been found effective in reducing the incidence of falling keys in some railways. Adhesives have been developed which when coated on key reduce the incidence of falling keys.

Concrete Sleepers

1. Loose pandrol shoulders: The defect may have its origin at the manufacturing plant but gets exaggerated during service, particularly under corrugated rails. The defect can be remedied by injecting epoxy resin into Pandrol shoulders (see Fig. 20.2).

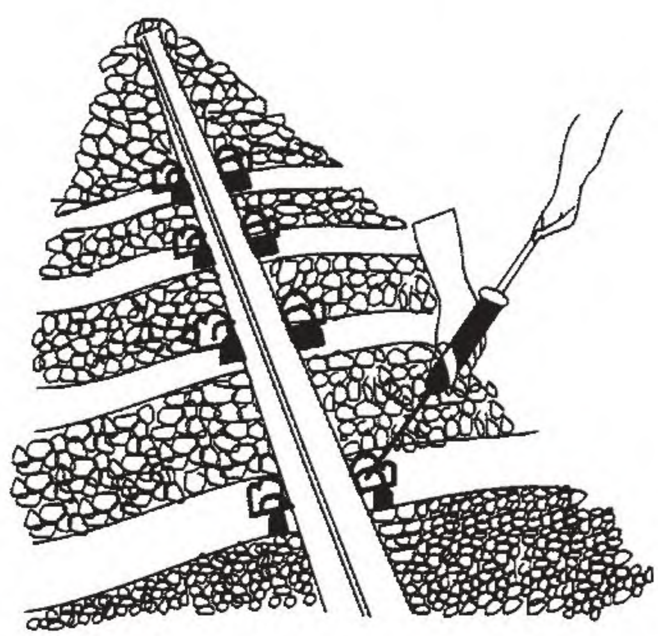


Fig. 20.2 Injecting epoxy resin into 'Pandrol' shoulders

2. Deterioration and cracking of underside of sleeper: This is caused by poor quality ballast, which puluvesizes under heavy traffic. In rainy season, this powder turns into slurry, and during summer, the slurry hardens into solid mass. Remedy lies in deep screening and provision of full ballast cushion of hard stone. Cracks in concrete sleepers could also occur on account of manufacturing defects, bad handling and improper laying in tracks. The cracks in concrete sleepers can be treated with water proofing polymer compounds. They avoid the ingress of moisture into the body of the sleepers. Such concrete sleepers can continue to provide many years of satisfactory service in tracks.

20.10.3 Other Problems

The problem of gauge holding steel or SCT-9 sleepers, if exists, can be solved by providing gauge ties at suitable intervals, as indicated in the case of wooden sleepers. The problem of poor longitudinal hold on rails on steel and CST-9 sleepers can be overcome by rail anchors at suitable intervals. On single rail section, box anchoring can be resorted to.

20.11 RAIL REPROFILING PLANT

Track standard for MG prescribe the use of second hand released rails on all the routes except those falling under Q and R categories. BG 90 R released rails are considered strong enough to bear the MG loads. The rails under long usage with varying traffic conditions do however have surface and subsurface defects. The removal of these defects would enhance service life of these rails on MG tracks and also contribute to better riding quality. Indian Railways procured two rail reprofiling plants, to carry out the following operation on the released rails.

1. Removal of alumino thermic welds by rail sawing machine.
2. Straightening of rails.
3. Ultrasonic testing of rails.
4. Cutting of portion found defective ultrasonically.
5. Reprofiling of head and gauge face.

The plants were installed at Arkonam (SP. Rly) and Sabarmati (SPW. Rly). These railways have flash butt welding plants at these locations and therefore reprofiled rails could be welded into long lengths before they are dispatched to the track relaying sites.

The main machine of the plant is the reprofiling equipment using milling tools.

The reprofiling machine Model PRV 250 is equipped with two milling units; one of which is fitted with a milling tool to reprofile the running surface of the rail head and the other one with a milling tool to reprofile the inside guiding radius of the rail head. Thus, it can reprofile the running surface and the inside guiding radius of the rail head in one continuous pass. The plant can handle rails with the following characteristics.

1. Rail type – flat bottom rails
2. Metric weight – 30 to 70 kg/M
3. Tensile strength – Up to 90 kg/mm^2
4. Hardness (HB) – Up to 260
5. Length of rails – from 6 m to unlimited length

Output

Daily output in an 8 hour shift is 700 to 1200 metres depending upon rail condition and operator's skill. With the adoption of unigauge policy on Indian Railways, important MG routes are all being converted into BG. Very little use of these plants has therefore been made on Indian Railways.

20.12 RECONDITIONING OF CAST IRON SLEEPERS

Long length of track on Indian Railways are laid with CST-9 sleepers. These sleepers require renewal primarily on account of wear at the rail seats and the jaws. A method of reconditioning these sleepers has been developed which restores the rail seat and jaws to its original condition. The sequence of operation is as under:

1. Cleaning of rail seat and jaws.
2. Deposit of weld metal using special low heat electrodes on worn out surfaces.
3. Grinding of weld metal with special purpose machines to restore the rail seat area to the dimensional tolerances of the new sleeper.

The hardness of the welded surface of the reconditioned sleeper is around 280 to 320 (HB) as compared to the hardness of 180–200 (HB) of the parent metal and 230 of rail steel. The reconditioned sleeper therefore is expected to have much longer life in track as compared to new sleepers. The present day cost of reconditioning per sleeper is quite low compared to the cost of new sleepers. The reconditioning work can only be done in the depot.

ANNEXURE 1

Table 1 Traffic Mix: Dedicated HH Axle Load: 30–34
Terrain: <875 Metre Radius Traffic Density: 50+ MGT

Traffic density	*Rail*		*Crossties*	*Fasteners*	*Ballast*	*M/L switch and crossing work*	*Geometry inspection*	*Flaw inspection*
	Type	*Weight*						
>50 MGT	Standard tangent premium in curves	136 RE or UIC 60	Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete	Elastic – curves Elastic or spikes – tangent	300 mm select crushed rock + 200 mm sub-ballast 300 mm shoulders	Premium rail tangential, spring point premium frog	3–6 months with profile monitoring	3 month intervals

Wheels		*Bogies*	*Profiles and maintenance*		*Lubrication wheel/rail*	*Wear limits*
Type	*Profile*		*Wheel*	*Rail*		
Prem HT curve plate AAR class C 900 mm dia	Specifically designed	Improved standard 3-piece or self-steering	Limit hollow wear to 2 mm	Periodic grind to remove corrugation and surface damage and to treat rail joints (material flow)	Curves: Gauge face U < 0.25 – 0.30 Rail head U < 0.35 – 0.40 U < 0.10 – 0.15 L-R Tangent: rail head U > 0.35	Measure frequently to ensure economic optimum

Table 2 Traffic Mix: Dedicated HH Axle Load: 30–34
Terrain: <875 Metre Radius Traffic Density: 30–49 MGT

Traffic density	*Rail*		*Crossties*	*Fasteners*	*Ballast*	*M/L switch and cross-ing work*	*Geometry inspection*	*Flaw inspection*
	Type	*Weight*						
30-40 MGT	Standard tangent premium in curves	136 RE or UIC 60	Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete	Elastic curves Elastic or spikes – tangent	300 mm select crushed rock + 200 mm sub-bal-last 300 mm shoulders	Pre-mium rail Fixed point pre-mium frog	4–6 months with profile monitor-ing	4 month intervals

Wheels		*Bogies*	*Profiles and maintenance*		*Lubrication wheel/ rail*	*Wear limits*
Type	*Profile*		*Wheel*	*Rail*		
Prem HT curve plate AAR class C 900 mm dia	AAR 1B or equivalent	Improved standard 3-piece or self-steering	Limit hol-low wear to 3mm	Periodic grind to remove cor-rugation and surface damage and to treat rail joints (material flow)	Curves: Gauge face U < 0.25 – 0.30 Rail head U < 0.35 – 0.40 U < 0.10 – 0.15 L-R Tangent: rail head U > 0.35	Measure frequently to ensure economic optimum

Table 3 Traffic Mix: Dedicated HH Axle Load: 30–34
Terrain: <875 Metre Radius Traffic Density: 20–29 MGT

Traffic density	*Rail*		*Crossties*	*Fasteners*	*Ballast*	*M/L switch and crossing work*	*Geometry inspection*	*Flaw inspection*
	Type	*Weight*						
20-29 MGT	Standard tangent premium in curves	136 RE or UIC 60	Prem: Wood or concrete monobloc nominal spacing 500 mm wood 600 mm concrete	Elastic – curves Elastic or spikes – tangent	250 mm select crushed rock + 100 mm sub-ballast 300 mm shoulders	Premium rail Fixed point premium frog	6 months with profile monitoring	6-month intervals

Wheels		*Bogies*	*Profiles and maintenance*		*Lubrication wheel/rail*	*Wear limits*
Type	*Profile*		*Wheel*	*Rail*		
Prem HT curve plate AAR Class C 900 mm dia	AAR 1B or equivalent	Improved standard 3-piece or self-steering	Limit hollow wear to 2 mm	Periodic grind to remove corrugation and surface damage and to treat rail joints (material flow)	Curves: Gauge face U < 0.25 – 0.30 Rail head U < 0.35 – 0.40 U < 0.10 – 0.15 L-R Tangent: rail head U > 0.35	Measure frequently to ensure economic optimum

Chapter 21

Special Types of Tracks

21.1 NEED FOR SPECIAL TYPES OF TRACKS

Conventional railway track structure consists of rails fixed on to the sleepers at gauge distance apart. Adequate profile of ballast provides vertical, lateral and longitudinal support to the sleepers. In addition, the ballast acts as an elastic medium for absorbing energy and vibrations.

Situations arise, on account of certain constraints, when it is not possible to provide conventional sleepers and ballast to hold the rails in position.

At such locations special types of tracks are provided, which are designed to perform all the function of the conventional track to the best possible extent. Such special tracks are required to be provided on girder bridges without ballasted deck, washable aprons, carriage examining and washing lines. Special tracks in the form of ballastless tracks are also being adopted in tunnels and on Metros to achieve economy in tunnel construction and to reduce the track maintenance time and cost. These types of special tracks are discussed in the following paragraphs.

21.1.1 Track Structure on Bridges

On bridge girder, rails are fastened to bridge timbers, which in turn are held to main girders, or rail bearers. On such tracks, in the absence of ballast, there is a sudden change of track elasticity which causes load variation of wheels and induces vibrations in the rolling stock. Bridge girders deflect under loads, and to compensate that effect camber is provided in bridge girders of over 30.5 m span. Track laid over such bridges are likely to experience variations in longitudinal levels as well.

Rail joints on bridges cause heavy dynamic loadings. It is therefore, desirable to avoid them, or locate them at places where they are least harmful.

Both rails and steel girders expand and contract under temperature variations. It is always advisable to adopt rail-free fastenings on girder bridges, so that thermal stresses of rails do not ride over the girders or vice versa. But to avoid excessive creep in rails or excess gap at the time of rail fractures, some controlled fixity of rails is needed in the spans and/or on the approaches.

With this background, the following guidelines have been laid down for the installation and maintenance of tracks on bridges.

21.1.2 Rail and Rail Joints on Bridges

Longitudinal Profile of Rails In standard plate girders no camber is provided. Open web girders of span 30.5 m and above are provided with camber. Track on these bridges are laid correctly following the camber of the bridge. When re-timbering is done, it should be ensured that the longitudinal levels of rails follow the camber of girders.

Rail Cant On bridges, the rail should be laid with an inward cant of 1 to 20 by continuing the same cant as on the approaches.

Rail Joints Over the Bridge In the case of small bridge opening less than 6.1 m, rail joints should be avoided. For other spans, the preferred position of the rail joint is at 1/3 the span from either end.

SWR on Bridges Section 9.7.2 gives the details required for track for SWR on bridges.

LWR/CWR on Bridges In the case of laying LWR/CWR, provisions of Sec. 10.6 are to be followed.

Precautions for Arresting Creep Track on girder bridges laid with standard single rails and fishplated joints should be isolated from the SWR if existing on approaches on either side by providing at least two well anchored standard rail lengths. Similarly, the track on girder bridges not laid with LWR/CWR shall be isolated from LWR/CWR by a minimum length of 50 m of well anchored SWR on either side.

21.1.3 Bridge Timbers

Minimum Requirements of Depth, Length and Spacing Provisions in the schedule of dimensions, indicating the minimum length of sleeper, minimum depth of sleeper and the maximum clear distance between the sleeper for the three gauges are summarised (nearest to 5 mm) in Table 21.1.

Table 21.1

Gauge	*Clear distance between consecutive sleepers not to exceed*	*Depth of sleepers (exclusive of notching) not less than*	*Length of sleepers*
BG girder	510 mm	150 mm	Distance outside to outside of flanges plus 305 mm but not less than 2,440 mm
MG girder	305 mm	125 mm	Distance outside to outside of flanges plus 305 mm but not less than 1,675 mm
NG girder	125 mm	105 mm	Distance outside to outside of flanges plus 305 mm but not less than 1,525 mm

Note: The details are for timbers directly resting on longitudinal girders.

Thickness of Bridge Timber Table 21.2 shows the minimum thickness of timber in mm required, exclusive of notching for various girder spacings for BG and MG.

Table 21.2

BG		*MG*	
Centre to centre of girder/rail bearer	*Thickness of Bridge timber*	*Centre to centre of girder/rail bearer*	*Thickness of bridge timber*
1880 mm	150 mm		
1850 mm	150 mm	1220 mm	140 mm
1830 mm	150 mm	1525 mm	165 mm
1980 mm	190 mm	1650 mm	190 mm
2300 mm	230 mm	2000 mm	230 mm

Clear Distance between Joint Sleepers The clear distance between joint sleepers should not exceed 200 mm both for BG and MG.

Treatment Bridge sleepers should initially receive a coating of boiling coal tar before their use. Underside of the sleeper resting on girders should receive two coats. To each litre of coal tar, 50 gm of quick-lime should be added. In case this treatment has not been given in a depot, the PWI should paint the sleepers with coal tar before insertion. Retarring of sleepers after insertion may be done once in 5 to 7 years, as found necessary.

End Binding To prevent splitting at the ends, the sleeper ends after being pressed, should be bound firmly with wire or hoop iron, or clamped. End bolts may be provided only when the sleepers supplied are severely split. Alternatively, clamping may be resorted to.

Dating and Branding The year of laying sleepers should be cut or branded on each sleeper at the centre or at the end omitting the first two digits of the year. All dates shall be in one direction which in the case of double line shall be in the direction of traffic and in the case of single line in the direction of increasing kilometrage.

Cambering Sleepers of standard thickness should be preferably used. Where pad plates are necessary, it should be ensured that their width shall cover the full sleeper seat and hook bolts shall also pass through the pad plate.

Use of Packing Plates Packing plates are used to make up for the difference in levels on the top boom of the girder due to cover plates, etc. These plates should be of mild steel, as thick as the cover plates, and of sufficient width to take the hook bolts. In case cover plates exist only for part width of the girder, the sleepers are to be notched to the same shape.

Preparation of Timber before Laying

1. The position of sleepers should be marked on the top flange of the girder.
2. Sleepers are numbered serially on every sleeper span-wise.

3. For accuracy and increased output, it is desirable to prepare a standby bracing two pieces of RSJs about 600 mm long. The distance between the centres of flanges of RSJs should be the same as that of the centres of the girders on the bridge.
4. Figure 21.1 describes the details of the method of notching to be carried out in the sleeper. The sleeper should be kept as shown in Fig. 21.1 (a) and checked for rocking. Rocking should be eliminated by planning the seats of the sleepers.

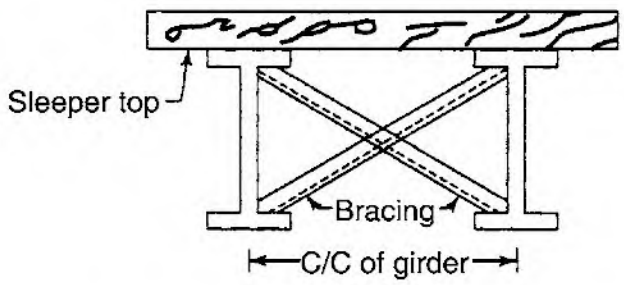


Fig. 21.1 (a) Preparation of bridge timber making rail seats in one plane

5. The position of sleeper seats should be marked on the both faces of the sleepers. The sleeper should then be placed with level (non-rocking) surface on the RSJ stand. The required depth of sleeper is marked along with the length of the sleeper seat, as shown in Fig. 21.1 (b).

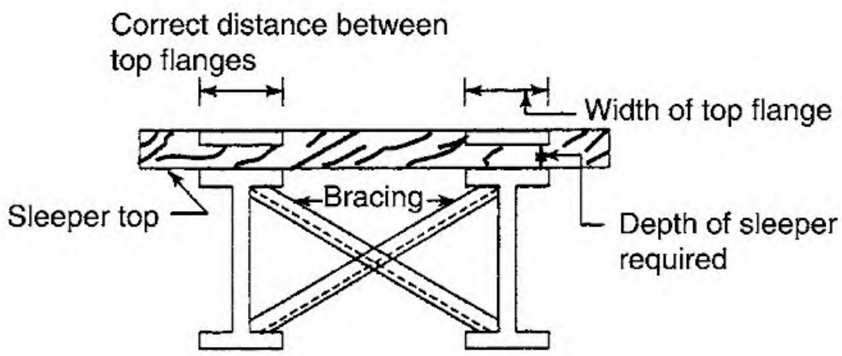


Fig. 21.1 (b) Making of notches for seating on girder flanges

6. A notch should be made up to the depth marked as shown in Fig. 21.1 (c).

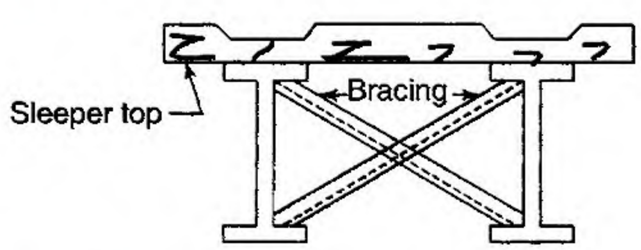


Fig. 21.1 (c) Notches cut in sleeper

7. The notched surface should be tested with a template. The two notched bearing surfaces will be in one plane when the template sits evenly and does not rock, as shown in Fig. 21.1 (d)
8. The holes for the hook bolts should be drilled from the notched side to ensure full grip of the bolts.
9. The new cut surface of the sleeper should be coal-tarred.

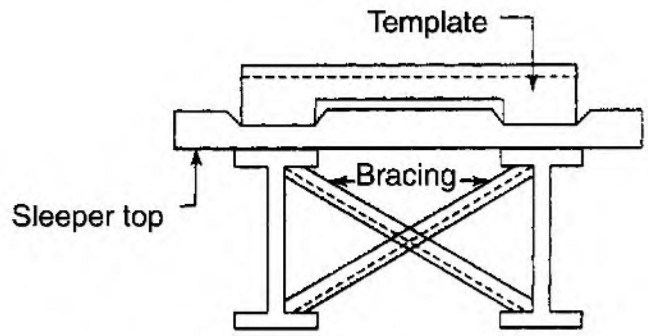


Fig. 21.1 (d) Checking of notches surfaces to be in one plane

Laying of Sleepers

1. Creep should be adjusted before taking up the work of re-sleepering. Rail and old sleepers should be removed under line block.
2. The contact surface of steel work between the sleepers and girders (top of flange under sleeper seat), should be painted after thorough scraping.
3. Sleepers are then placed in position and with a light mallet the sleeper is hammered sufficiently for the rivet head to mark their position on the notched surface, when pad plates are not provided.
4. Then gouging or grooving is done on these marks to house the rivet heads.
5. The sleeper should be prepared 3 mm thicker than required and finally levels adjusted by stretching a string over the rail seats from one end of the girder to the other. A levelling instrument may be used, if necessary, to fix levels. Standard MS canted bearing plates with 4 rail screws should be fixed in position after tightening the hook bolts. Care should be taken to ensure that the rails on the bridge are in alignment with the approach track.

Fixing up of Hook Bolts

1. There are two types of hook bolts (22 mm dia) one with straight lip suitable for securing sleepers to plate girders and other with sloping lip for securing sleepers to RSJs. In both types the hook is an integral part of the bolt. A 75 × 75 × 6 mm MS square washer is used along with each hook bolt to prevent the nut from cutting into the sleeper.
2. Two hook bolts are used for each sleeper. The hook bolts must be on the outside of the girder and not on the inside. The diameter of the hole augured should not be more than the diameter of the hook bolt. On the top end of each hook bolt, there will be an arrow mark chiselled indicating the direction of the hook of the bolt. The arrow grooved on the top end of the bolt should be perpendicular (square) to the rail and pointed towards it when the hook holds the girder flange. This enables the maintenance staff to see from above and ensure that the lips of the hooks are in proper position.

Rail to Sleeper Fastenings Rail free fastenings such as canted MS bearing plates with four rail screws may be used on wooden sleepers. No anticreep bearing plates should be used. If channel sleepers are used, suitable designed canted bearing plates with rubber pads and rail free clip and bolt type fastening should be used.

21.1.4 Guard Rails

Location Guard rail should be provided on all girder bridges (including pre-stressed concrete girder bridges without deck slab), whether major or minor.

On all flat top, arch and pre-stressed concrete girder bridges with deck slab, where guard rails are not provided, the whole width of the bridge between the parapet walls is to be filled with ballast up to the sleeper level.

Design of Guard Rails The typical arrangement of the guard rail with the important dimensions for BG, MG and NG are shown in Fig. 21.2 and Table 21.3. The height of the guard rail should not be lower than the running rail, by more than 25 mm. In the case of bridges on curves with canted track, the difference should be measured with reference to a straight line connecting the running tables of inner and outer rails.

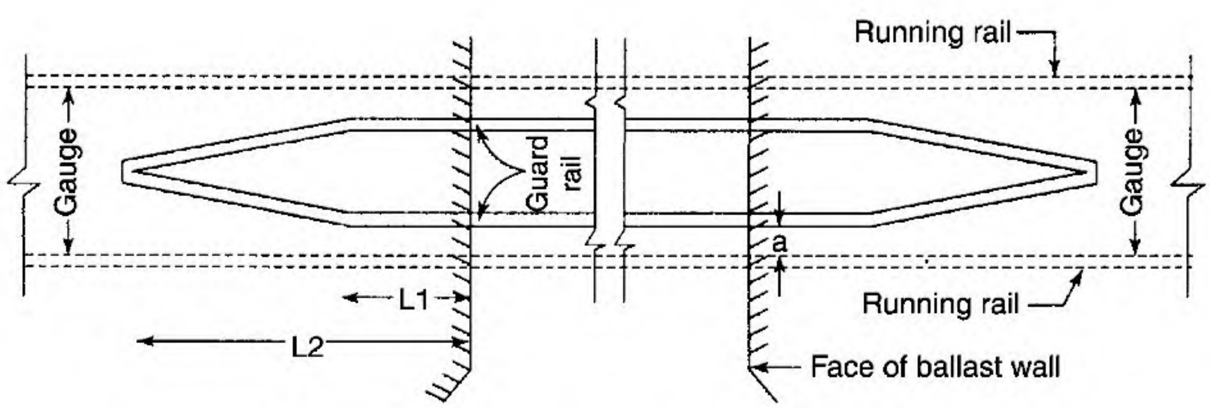


Fig. 21.2 A typical arrangement of a guard rail

Table 21.3

Particulars	*Sketch No. Ref*	*BG*	*MG*	*NG*
Clearance between guard rail and running rail	"a"	250 ± 50 mm	200 ± 25 mm	150 ± 25 mm
Length of guard rail outside ballast wall and mentioned to clearances mentioned in the first item	L1	1,825	1,825	1,825
Length of guard rails to be bent so as to be brought together at the middle of the track	L2	4,875	3,655	3,200

Fixing of Guard Rails The ends of guard rails should be bent vertically and buried and a block of timber fixed at the end to prevent entanglement of hanging loose couplings. To ensure that guard rails are effective, they should be spiked down systematically to every sleeper with two spikes towards the centre of the track and one spike on the opposite side. Notching of the rail foot for spikes fixing the guard rail should be done on every alternate sleeper.

Splaying of Guard Rails In the case of through girder bridges on double lines, the guard rails should be splayed on both ends on both lines. In the case of bridges other than through bridges on double lines, the splaying need be done only on the facing direction of the particular line. However, the non-splayed end should be bent downwards after it is stopped at the end of the abutment and wooden block provided.

Provision of Walkways Over all girder bridges, footways (walkways) should be provided in the centre of track over sleepers to help the engineering staff for inspection.

21.1.5 Inspection and Maintenance of Track Approaches of Bridges

1. Track geometry on the approaches should be maintained to the best possible standards.
2. Rail joints should not be within three metres of a bridge abutment.
3. The condition of the ballast wall should be checked and repairs carried out whenever necessary.
4. Full sections of ballast should be maintained for at least 50 m on the approaches. This portion of the track should be well anchored.

21.1.6 Inspection and Maintenance of Track on Girder Bridges

1. The condition of track should be ascertained, whether it is central on the rail bearers and the main girders, and in good line and level.

   Departure from line is caused by incorrect seating of girders, shifting of girders laterally or lengthwise, incorrect seating of sleepers on girders or rails on sleepers, varying gauge or creep. Departure from level is caused by errors in level of bed blocks or careless sleepering. The adequacy of clearance of running rails over ballast walls or ballast girders at the abutments and condition of timbers and fastenings on the run-off and skew spans should be inspected.
2. The condition of sleepers and fastenings should be checked. The spacing of sleepers should not exceed the limits laid down in Table 21.2. Squareness of sleepers should be ensured. Sleepers requiring renewals should be marked with paint, and renewals carried out. End bolts should be provided on sleepers which have developed end splits.
3. Hook bolts should be checked for their firm grip. Position of arrows on top of the bolts should be at right angles to the rails pointing towards the rail. Hook bolts should be oiled periodically to prevent rusting.
4. Creep and joint gaps should be checked and rails pulled back wherever necessary. Rail fastenings should be tight. Defective rails should be replaced. Where switch expansion joints

are provided on the girder bridge, it should be ensured that free movement of the switch is not hindered.

5. Adequacy of guard rail arrangements should be checked. Correct distance between the running rail and guard rail should be maintained as per the prescribed dimensions.
6. Camber packing where provided should be in sound condition.
7. On girder bridges, adequacy of path ways for inspection should be checked.
8. Sand bins which are provided for putting out fire should be filled with dry and loose sand.

21.2 TRACK FOR WASHABLE APRONS

Washable aprons are provided on platform lines where trains halt for long periods during morning hours and the track gets littered with human excreta discharged from the toilets provided in the coaches. These aprons facilitate easy cleaning of the tracks.

Special tracks provided on these washable aprons have the following features:

1. They have no ballast, sleepers/sleeper blocks rest directly on concrete beds.
2. Only the fourth sleeper is a through sleeper. This is necessary to provide sufficient inter-space for working and cleaning of aprons.
3. Through sleepers provide the necessary gauge holding power to the track.
4. Sleepers and sleeper blocks are placed high on concrete pedestal, to provide sufficient clearance under the rails for easy cleaning.
5. Sleeper/sleeper blocks are held to the concrete underneath with long rag bolts.

21.2.1 Design of Washable Aprons

Cast in situ Design In this design, a traffic block of about 6 weeks duration is sought and the concrete slab is cast at site.

Design with Pre-cast RCC Slab In this design, the RCC blocks are pre-cast and in the limited traffic blocks, the old track is ripped open and the new track is laid in position on pre-cast slabs.

In both the designs, the rails are held on to the sleeper with canted bearing plates. The sleeper/sleeper blocks in turn are held to concrete slabs with long rag bolts (Fig. 21.3).

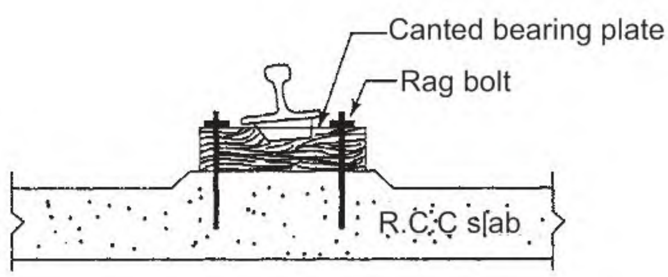


Fig. 21.3

Experience with the washable aprons, made to the above designs, has shown that they crack in service and thus have a limited service life. Main cause of cracks has been attributed to the ingress of water below the slab, affecting the bearing capacity of the soil underneath.

Washable Aprons on Under Reamed Piles To overcome the problems of loss of bearing capacity of the soil, washable aprons designed with the use of under-reamed piles has been developed. In this design, each sleeper block is supported on two under-reamed piles, which go about 4 m deep in the ground (Fig. 21.4). The rails in this design are fastened to sleeper block with the help of pandrol clip and special cast iron bearing plates which in turn are fixed in position with rag bolts embedded in concrete. Rubber pads are provided under the rail seat to absorb shock and variations (Fig. 21.5). Washable aprons of this design have been giving good service. They can be used with LWR and a speed up to 75 kmph is permitted over them.

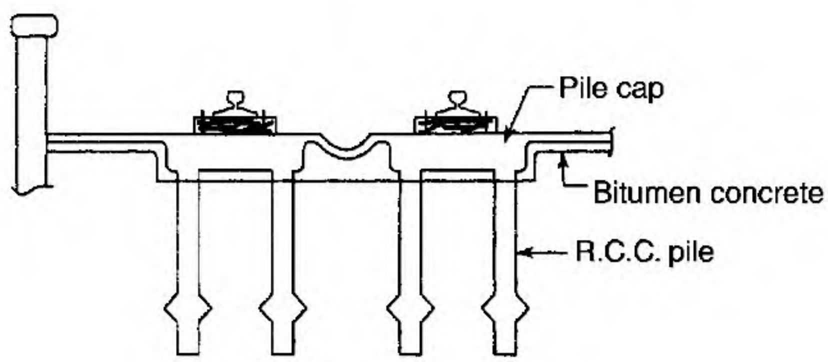


Fig. 21.4

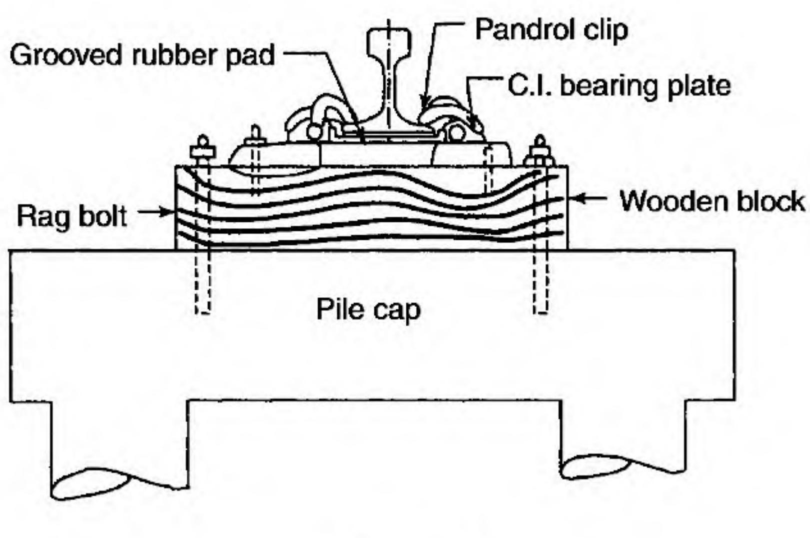


Fig. 21.5

21.3 TRACK FOR CARRIAGE EXAMINING AND WASHING LINES

Carriage examining and washing lines are provided with long pits to facilitate examining of the under carriages. Paved surfaces are provided, under and all around the carriages for the proper flow and disposal of water used for carriage washings.

Special track provided on these lines have the following features.

1. Rails are fixed direct to the concrete of the side walls of the examining pits.
2. No cross sleeper or tie bar is provided to hold the gauge.
3. Rails are held with the help of steel plates and loose jaws or with the cast iron anti-creep bearing plates. In the former case, the steel plate is welded or rivetted to a rail which is longitudinally embedded in the concrete. In the latter case, rag bolts are used for holding the cast iron bearing plate in position in the concrete. Figures 21.6 and 21.7 show the two types of designs.

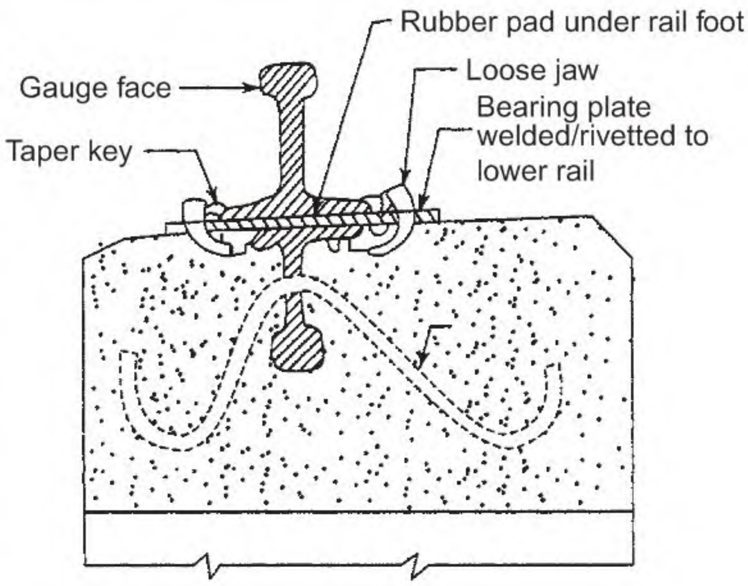


Fig. 21.6

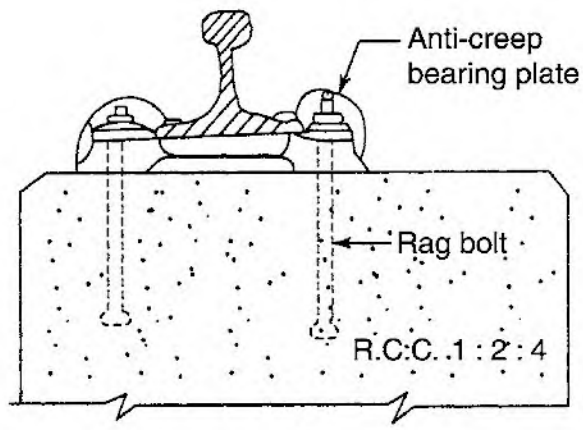


Fig. 21.7

To reduce the impact on concrete, it is advantageous to provide rubber pads between the cast iron bearing plates and the concrete surface. Nuts used on rag bolts should also be provided with double coil spring washers. Such an arrangement has been shown in Fig. 21.8.

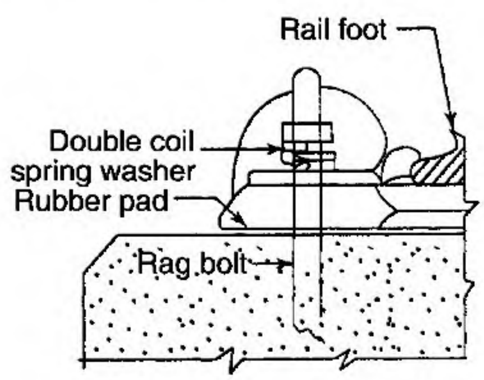


Fig. 21.8

21.4 BALLASTLESS TRACK

21.4.1 Evolution of Ballastless Track

In a ballastless track, rails are fixed directly to the concrete slab without any sleepers or ballast, with the help of specially designed elastic fastenings.

In ballasted tracks, the impact forces of running trains are absorbed by way of a change in the composite contact relationship among the ballast particles. This change is cumulative in nature. The major part of work in the track maintenance, therefore, consists to correct the surface geometry by rebuilding the deformed ballast. Unless ballast is replaced by some other material having true elastic properties, no tangible reduction in the track maintenance works can be visualised. This has led to the evolution of what is termed as "ballastless track". In this type of track, the elastic characteristics of ballasted track are simulated by providing suitably designed track assemblies in which elastomeric pads plays an important role. On world railways, ballastless track is being increasingly adopted in Metros and high-speed lines. It is also being adopted on Viaducts and in tunnels where concrete foundation for ballastless track is naturally available as part of basic structural concrete. Main characteristics of ballasted and ballastless track are discussed in the succeeding paragraphs.

21.4.2 Main Characteristics of Ballasted Track

In ballasted track, impact forces generated by the oncoming loads are dissipated by the elastic deformation of ballast and the formation underneath, approximately 50% by each of them. In this process, there is also permanent settlement of ballast and formation. In course of time, the ballast gets pulverised/contaminated, loosing its elastic property. Periodical building and recuperation of ballast is required for the ballast to function effectively. Deep screening of ballast is carried out when finer particles in the ballast increase the specified limit (more than 30 percent passing through a 22.4 mm sieve).

The advantageous of ballasted track over ballastless track are:

(i) Known and proven method, up to a speed of 350 kmph. high-speed lines in France and Spain have been constructed with ballasted track.
(ii) Low Construction cost.
(iii) Availability of highly mechanised construction technology.
(iv) Good elasticity for efficient absorption of noise and vibrations
(v) Reasonably good maintainability with track machines.
(vi) Less Sensitive to construction defects.

Disadvantages of ballasted track when compared to ballastless track are:

(i) Track tends to move both vertically and laterally- requires frequent tamping.
(ii) Limited uncompensated lateral acceleration possible due to limited lateral ballast resistance.
(iii) At the speed of 275 kmph and above, ballast churns up damaging both rail and wheels.
(iv) Elasticity gets affected with pulverization and contamination-periodic deep screening required.

21.4.3 Main Characteristics of Ballastless Track

Ballastless track rests on solid foundation with no or very little settlement. The elastomeric pads replace the ballast. No maintenance is required except periodical replacement of elastic components after their life span is over. There is considerable scope for the reduction of cost of construction of track structure when laid in tunnels or on viaducts.

Some of the advantageous of ballastless track are:

(i) High operational availability-time required for maintenance is almost nil.
(ii) Long lasting good track geometry.
(iii) Long life of track structure, 40 to 50 years.
(iv) Predictable behaviour of track components and thus of track geometry.
(v) High resistance to lateral and longitudinal forces permitting steeper grade and higher speed.
(vi) Regularity of the rheological (transmission of electric current) properties.
(vii) Quiet vehicle running, even at high speed.

Ballastless tracks however suffers from the following drawbacks:

(i) Comparatively higher construction cost, particularly when laid on earth formation. The cost is about 2.5 times in tunnels and three times on earth foundations, compared to ballasted track.
(ii) Highly sensitive to construction defects.
(iii) Less absorption of sound radiations and vibrations.
(iv) Mechanisation of track construction and renewals still in infant stage.

21.4.4 Design Philosophy of Ballastless Track

Ballasted track assemblies are expected to provide the same degree of elasticity on all directions as it available in ballasted track. This is necessary to contain the static and dynamic forces within acceptable limits. Ballastless track assemblies are also expected to perform the following two functions.

(i) Dampen the high frequency vibrations of the rail. For that purpose, all ballastless track assemblies have an elastomeric rail pad under the rail seat, on which the rail is expected to be under compression at all times. This is similar to the arrangement with the concrete sleepers in ballasted track.
(ii) A medium to distribute the oncoming loads and absorb the energy generated, the functions, which are performed by the ballast in the ballasted track. This function is performed by different arrangements in the ballastless track assemblies.

21.4.5 Ballastless Track Assemblies Commonly in Use

(i) *Plinth type, single plate, ballastless track assemblies* (Figs 21.9 and 21.10)
Ballastless track assemblies adopted by Kolkata and Delhi Metros come into this category.
M1-A assembly adopted by Kolkata Metro has the following components.

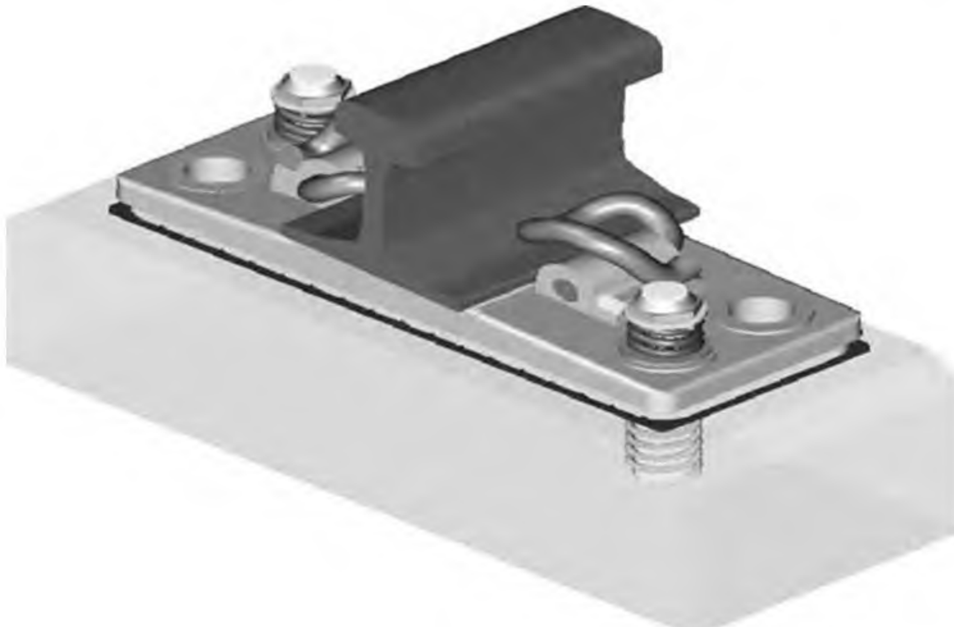


Fig. 21.9 M.1.A assembly adopted by Kolkata Metro (See also Color Plate 18)

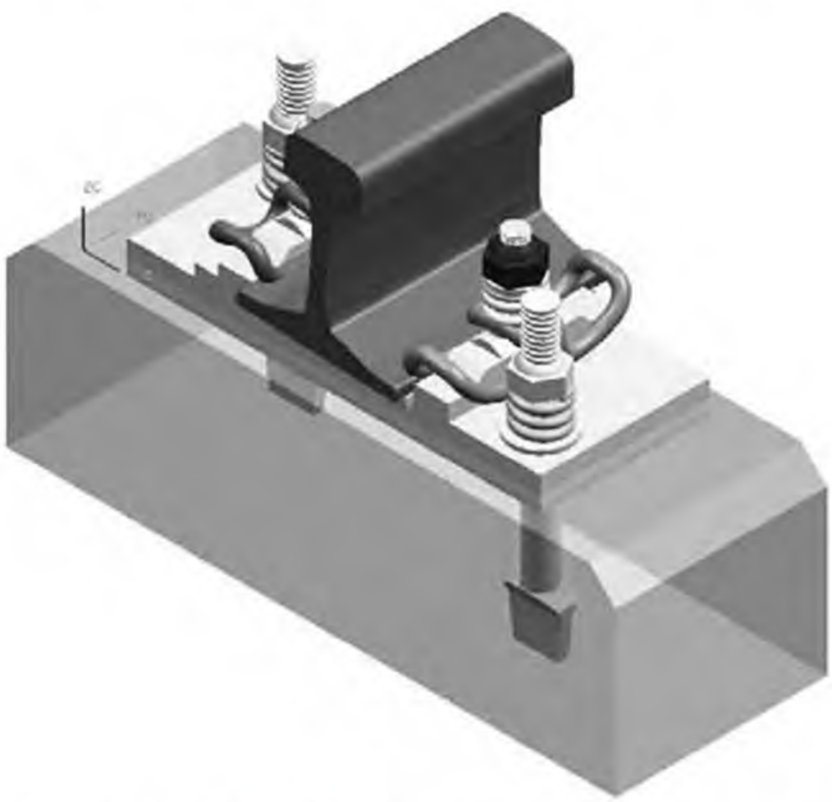


Fig. 21.10 Vossloh 336 ballastless track assembly adopted by Delhi Metro (See also Color Plate 19)

- 6 mm thick elastic rail pad
- Mark 3 elastic rail clips
- Cast iron base plate
- 12 mm thick elastic base plate pad
- High tensile steel bolts screwed into high density polythene inserts
- Triple coil spring washers

- Eccentric insulating washers for insulation and lateral adjustment.
- Steel plates for vertical adjustments.

Vossloh 336 ballastless track assembly adopted by Delhi Metro is of similar type. Its main components are:

- 6 mm thick elastic rail pad
- Vossloh elastic rail clip
- Malleable cast iron base plate
- 10 mm thick elastic base plate pad
- 5 mm thick plastic pad
- High tensile steel anchors, cast in concrete
- Triple coil spring washers
- Eccentric insulating washers for insulation and lateral adjustment

Logwell India has evolved ballastless track assembly LM-1 which incorporates the best of the features of both M. 1 (A) and Vossloh 336 assemblies (Fig 21.11).

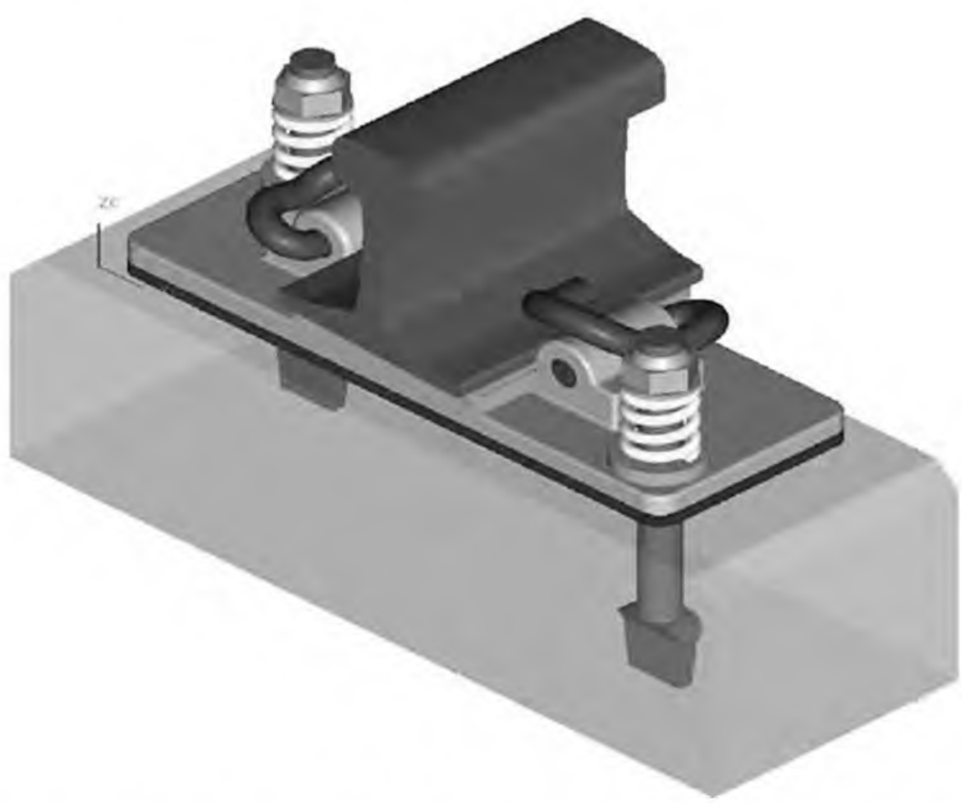


Fig. 21.11 Logwell Ballast less Track Assembly (LM-1) (See also Color Plate 19)

- It uses Logwell G Clip for fastening rail to the base plate having a toe load of 900–1200 kg, equivalent to Vossloh Clip. The base plate is anchored to the concrete in a manner similar to Vossloh design, there by having a stronger fixing arrangement. The assembly has been provided with base plate pad 10 mm thick and plastic pad of 5 mm thickness similar to Vossloh design.

(ii) *Plinth type double plate ballastless track assemblies* (Fig 21.12)
In these assemblies, two plates are used sandwiching the elastomeric pad between the two. The anchor bolts in these assemblies are not subjected to bending stresses and thus have much greater resistance to lateral forces. Such assemblies are usually adopted for main lines. Pandrol Vipa system and Vossloh 1403 are such assemblies. M/s Logwell Forge India has also evolved an indigenous ballastless track assembly, LH-1 on the same pattern. Main advantage of this system is that it affords quicker restoration of traffic after any derailment. It is also possible to provide guardrails with this assembly.

Fig. 21.12 Plinth type ballastless track assemblies for main lines (See also Color Plate 20)

(iii) *Other ballastless track assemblies*
A number of different types of ballastless track assemblies have been adopted on high-speed lines. These have been drawn in Chapter 18.

21.5 RAIL-CUM-ROAD TRACKS AT LEVEL CROSSINGS

The conventional arrangement for rail-cum-road track at level crossings, using wooden sleepers, has been discussed heretofore. Arrangement with the use of concrete sleeper has been discussed earlier in the book. In both the arrangements, the road structure is built with standard road building material of stone metal and tar topping. On such level crossings, at least once a year, the track is required to be overhauled; on heavy density, high speed lines, the track requires more frequent attention. In the conventional arrangement, for every track attention, the sequence of operation has necessarily to consist of:

1. Arranging road closures
2. Opening out the road surface
3. Carrying out track maintenance operation and
4. Putting back the road material and its compaction

This method is not only costly, time consuming, but also requires lot of coordination with the road authorities.

Systems have now been developed in which removable panels of concrete, rubber and other synthetic material, are used for the preparation of road surface at the level crossings. These panels can be fixed in position, in much less road closure time, and can be easily removed, as and when the track at the level crossing needs attention.

The following two systems are proposed for trial on the Indian Railways.

21.5.1 STRAIL—The Flexible Level Crossing (Fig. 21.13)

In this system, rubber panels are used to form the road surface. The rubber panels rest on the sleepers and on the specially prepared bed in the cess area where there are no sleepers. Different sizes of panels have been made for placement in the inter-rail space and for the outside area. The panel can be handled manually without any handling crane, and the whole operation of providing these panels on level crossings can be completed in a period of 4/5 hours. Other important advantages with the use of rubber panels are:

1. They have a long life. If damaged due to some abnormal occurrence, the panels can be repaired.
2. Absorb impact loading of road traffic and thus track geometry is less disturbed.
3. Have high electrical resistance.

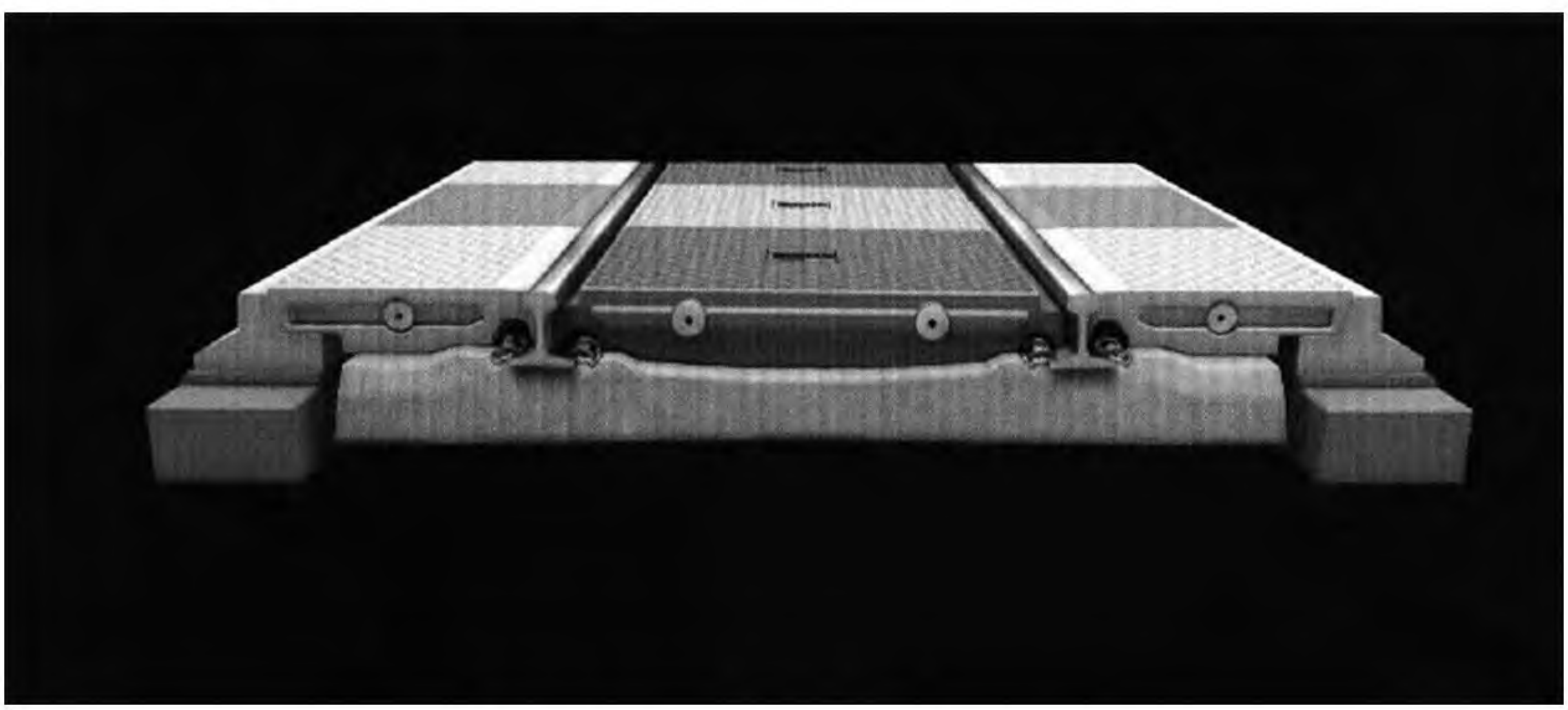


Fig. 21.13 (See also Color Plate 20)

21.5.2 Bodan Level Crossing (Fig 21.14)

M/s Gmundner Fertigteile, an Austrian company has evolved Bodan level crossing system. In this system, light, high-strength polymer concrete panels are used as the road surface. The panels at their ends rest on rail foot and thus the sleepers underneath have no load on them. With this arrangement, the loads from the road traffic is transmitted at the rail seats of the concrete sleepers, similar to the transmission of load from the rail traffic. Lightweight poly concrete panels can be easily installed in a short traffic block. They can also be removed for permitting continuous tamping of track through level crossings. Track insulation is ensured by having rubber bearings for the concrete panels.

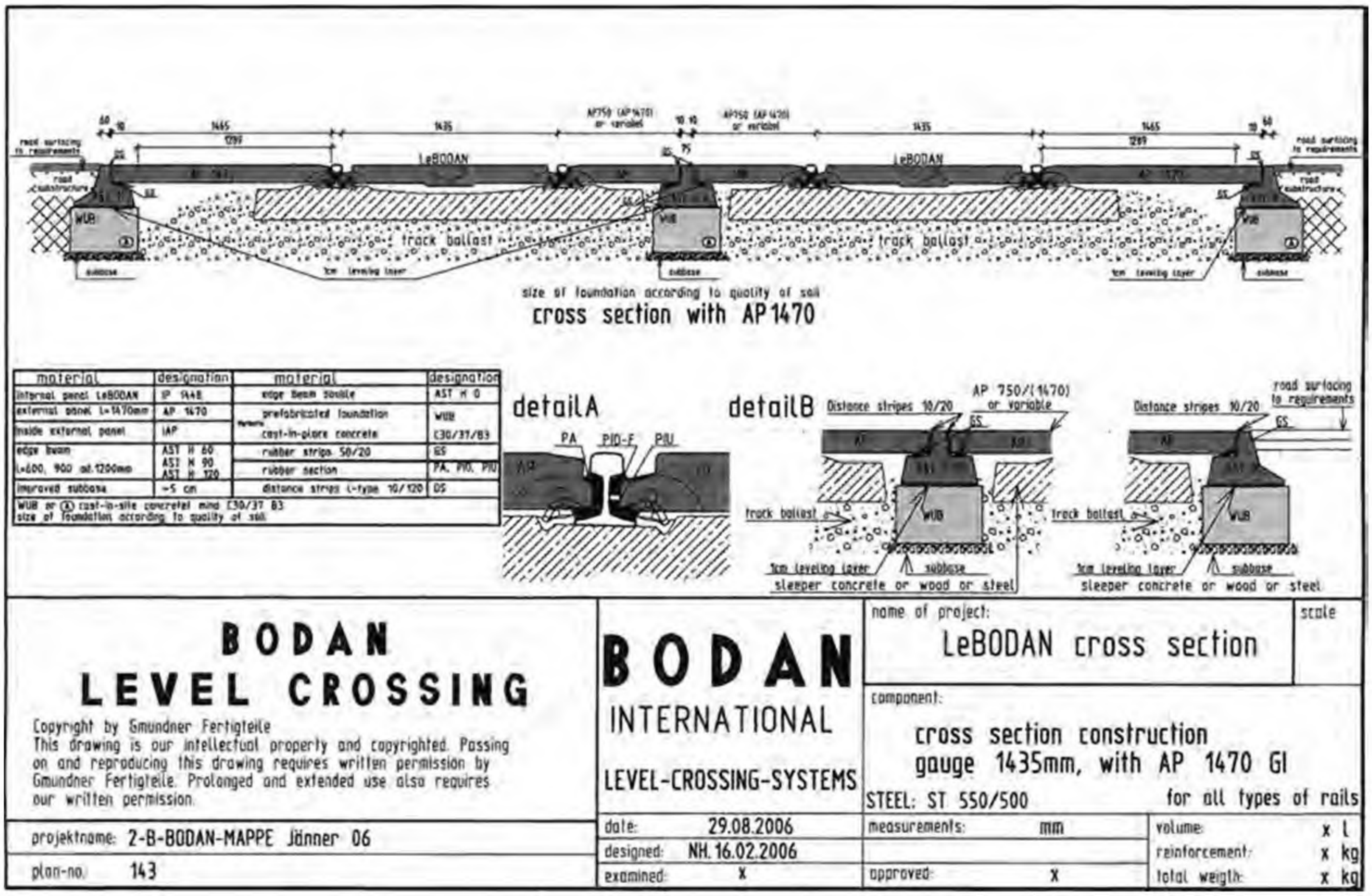


Fig. 21.14

22 Chapter

Derailment Investigations

22.1 ACCIDENTS AND THEIR CAUSES

Rail transport is internationally accepted as the safest mode of transport. Yet, accidents do occur, which cost money, cause anguish to rail users, and bring bad name to the railways. Therefore, investments made to improve safety standards are worth it.

After an accident, the first task is to arrange rescue and relief of the victims and the restoration of traffic. It is also equally important to find out the cause of the accident. This is to know where the system has failed and what measures should be taken to avoid the repetition of similar accidents. Accidents may occur due to the following reasons.

Natural Calamity This could be an earthquake, a flash flood, a lightning effect or a tornado. In such cases, although the cause is beyond control, it has to be ascertained if some timely action could be taken to stop the train to avoid the accident or reduce the damage.

Sabotage The investigations about such accidents lie in the domain of state security. The railway administration has however to find out ways and means of making the railway installations less vulnerable to sabotage attempts.

Public Lack of Safety Sense The cases such as, persons run over by trains, accidents at unmanned level crossings, collisions, ignoring the railway right of way, etc. come under this category.Increased public awareness on the issue through publicity media could help in reducing such accidents.

Failure of Railway Component Sudden fracture or failure of track, vehicle or other railway component which has contributed to the accident come under this category. Such accidents indicate that the existing system of preventive checks is not functioning satisfactorily requiring modification, improvement or replacement.

Failure of Railway Staff These are the accidents which occur on account of the negligence of railway staff in carrying out their assigned duties and responsibilities. It is worth finding out as to what prompted the delinquent staff to ignore safety regulations. It is a freak case of individual dereliction or a part of a widespread malady? What measures in the form of, proper motivation, training, work or rest facilities, punitive action, etc., would avoid their recurrence.

Limitation of the System Accidents in the form of derailment do sometimes occur, though rarely, when the wheels of a well maintained vehicle mount over the rail head of a well maintained track. Such derailments are on account of the inherent characteristics of the rail wheel interaction. They occur only when a particular type of vehicle, loaded to a particular extent, moving at a particular speed, meets with wave lengths of track irregularities of a specific pattern (all within acceptable safety limits) gets sufficient excitation, on account of resonant phenomenon, to mount and derail. Better understanding of vehicle-track interaction could help in reducing such accidents.

22.2 DERAILMENT INVESTIGATIONS AND MECHANISMS

Of the various categories of accidents, derailments are of considerable concern to permanent way men. Unless the cause is obvious, e.g. a tree or boulder fallen on track, a breach or a washaway, a formation failure etc. the contribution of track, if any, in causing derailment, has to be investigated. Some of the important theoretical aspects relevant to investigation of derailments are:

1. Derailment mechanism
2. Vehicle oscillation
3. Wheel off-loading and
4. Lateral stability of track

There are two broad categories of derailments

1. Sudden Derailment by wheel set (Fig. 22.1) jumping the rail. Such a derailment indicates that the derailing forces were high enough to suddenly force the wheel off the rails.
2. Derailment by Flange Climbing i.e. by wheel mounting on rail in relatively gradual manner. It indicates that derailing forces were powerful enough to overcome the normal stabilising force, yet not sufficient to cause a sudden derailment.

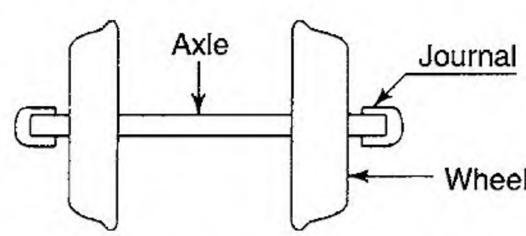


Fig. 22.1 Wheel set

The probable cause of derailment for category, 1 is easier to find. For category 2, it is comparatively difficult.

22.2.1 Mechanism of Flange Climbing

Because of various reasons, i.e., wheel tread conicity, track irregularities, and elastic characteristics, etc., the wheel set travels along the track, executing a variety of oscillations.

Lateral Oscillations It causes the wheel set to make flange contact either with the left or the right rail, and consequently flange forces result. Flange force is one of the derailing forces.

Vertical Oscillations It causes the wheel load to vary from the normal value. Wheel load is a stabilising force.

Normal wheel load is half the axle load under normal static condition while instantaneous wheel load is the actual load at any given moment of time during the motion of a wheel set.

When the instantaneous wheel load is greater than the normal wheel load, it is on-loading. If less, it is off-loading. At the instant of flange contact, if the disposition of flange force (derailing force) and that of instantaneous wheel load (stabilising force) is unfavourable, the wheel flange will start sliding up the rail edge as shown in Fig. 22.2.

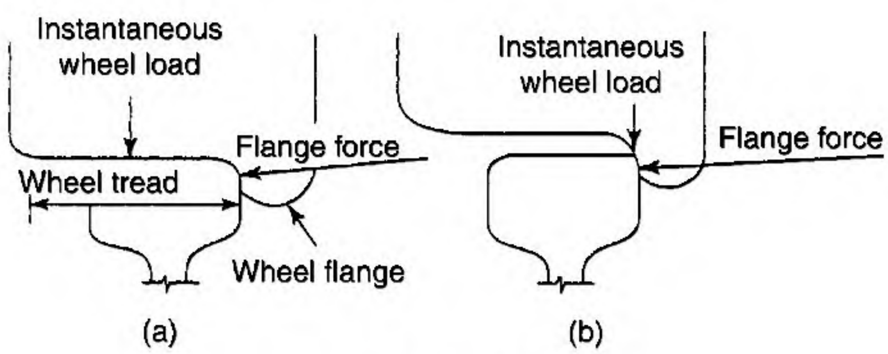


Fig. 22.2

22.2.2 Play between Wheel and Track

It means a wheel set cannot have a tight fit with track gauge. In such a condition, the wheel set will tend to run at the flange slope rather than at the tread, increasing the derailment proneness apart from straining the track fastenings. There has thus to be a play between wheel set and track.

This designed play between a standard wheel set and the normal track gauge is called standard play (σ_s). See Fig. 22.3.

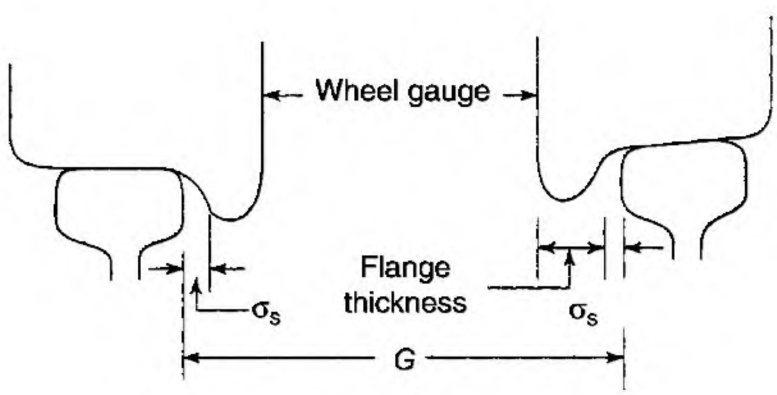


Fig. 22.3

$$\begin{aligned} \sigma_s \text{ for BG } &= 1676 - (\text{wheel gauge} - 2 \times \text{flange thickness for BG}) \\ &= 1676 - (1600 - 2 \times 28.5) \\ &= 19 \text{ mm} \end{aligned}$$

$$\sigma_s \text{ for MG} = 1000 - (930 - 2 \times 25.5)$$
$$= 19 \text{ mm}$$

Owing to tolerances and wear, the actual play can be different from the standard play.

For similar reasons, i.e. to avoid undue strain on vehicle components during movement, there have to be some longitudinal and lateral clearances at the axle box level and also play between the bearing and journal (Fig. 22.4).

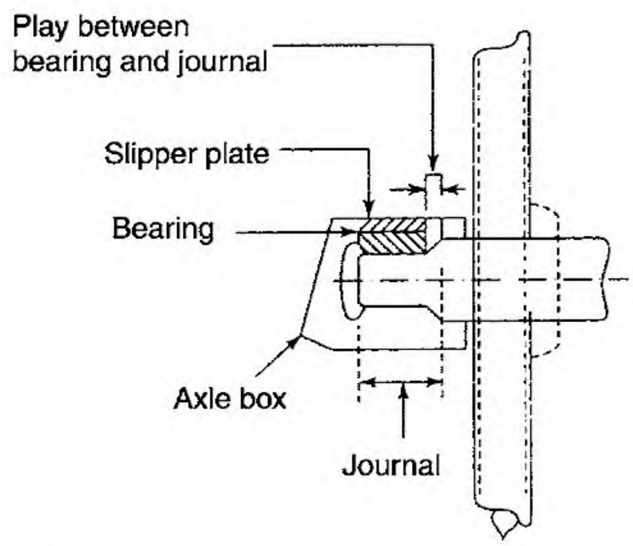


Fig. 22.4 Play between bearing and journal

Due to such a play and clearances, the wheel set is able to become angular to the rails. The wheel set thus rarely runs exactly parallel to the rail, but moves with varying degree of angularity. Besides, while negotiating a curve or a turnout, only one axle in a rigid wheel base, if at all, may attain a radial position and the rest have necessarily to be angular to the rails (Fig. 22.5).

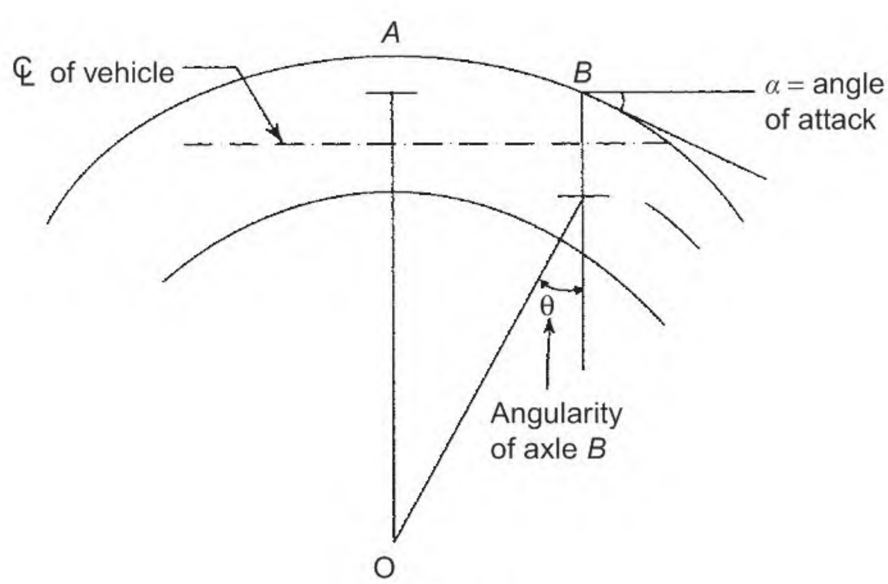


Fig. 22.5

22.2.3 Angularity of the Axle

To appreciate the configuration of flange contact in various positions of angularity, one may examine horizontal section through the wheel flange at the level of the flange contact. As the angularity of the axle changes, the flange contact can be ascertained by correspondingly aligning the sectional plan (Fig. 22.6).

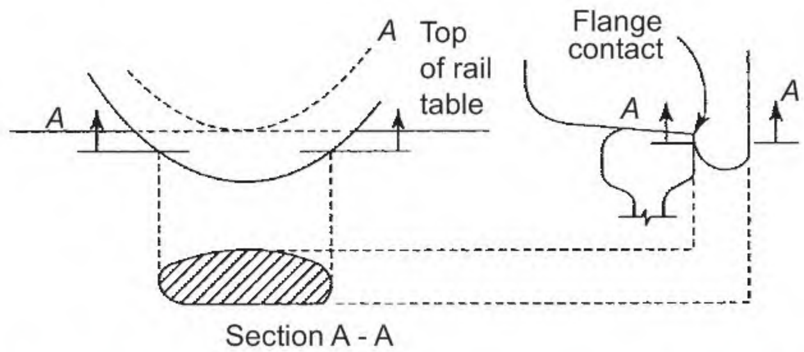


Fig. 22.6 Sectional plan of wheel flange at level of flange-to-rail contact

In general there are three basic configuration of the axle (a) zero angularity (b) positive angularity and (c) negative angularity.

For ascertaining whether the particular angularity of an axle is positive or negative, it is necessary to know the direction of the motion and whether the flange contact is with the left rail or right rail (as seen in the direction of motion).

Zero Angularity The wheel set is parallel to the rail and thus angularity with the rails is zero (Fig. 22.7). From the position of head contact and flange contact, it may be seen that the longitudinal eccentricity between the two is zero.

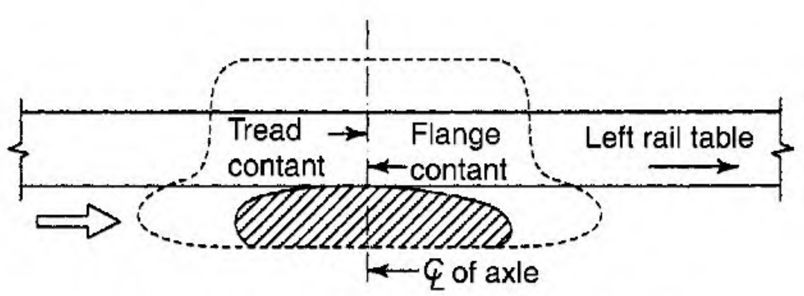


Fig. 22.7 Zero angularity (plan)

Positive Angularity In this case the wheel set is angular to the rail so that the wheel makes the flange contact near its leading edge (Fig. 22.8).

Negative Angularity In this case, the wheel set makes a flange contact near its trailing edge (Fig. 22.9). The flange contact trails the tread contact. It is case of trailing contact; the longitudinal distance between the two contacts is called negative eccentricity. The angle between the wheel alignment and the rail is negative angle of attack, say (8).

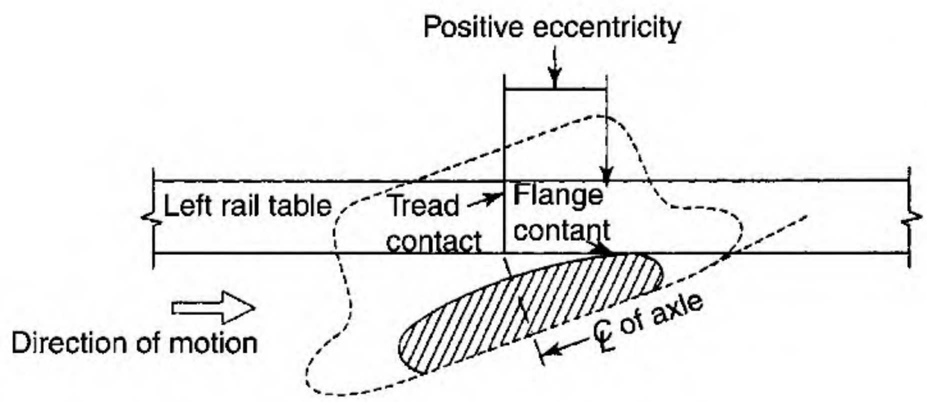


Fig. 22.8 Positive angularity (plan)

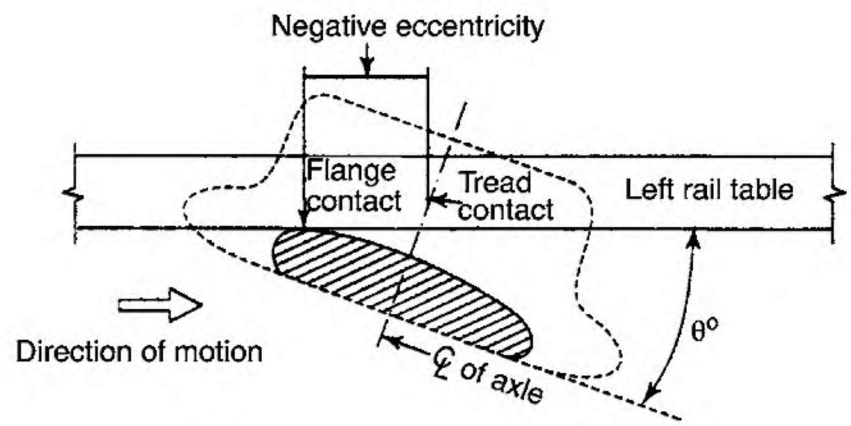


Fig. 22.9 Negative angularity (plan)

22.2.4 Forces at Rail-wheel Contact

On Positive Angularity In this case, if derailment, were to take place, the disposition of forces will be as shown in Fig. 22.10. The Forces acting are:

(a) Vertical instantaneous wheel load $= Q$
(b) Lateral flange force $= Y$
(c) Normal reaction from the rail $= R$
(d) Frictional force acting along the flange slope $= \mu R$

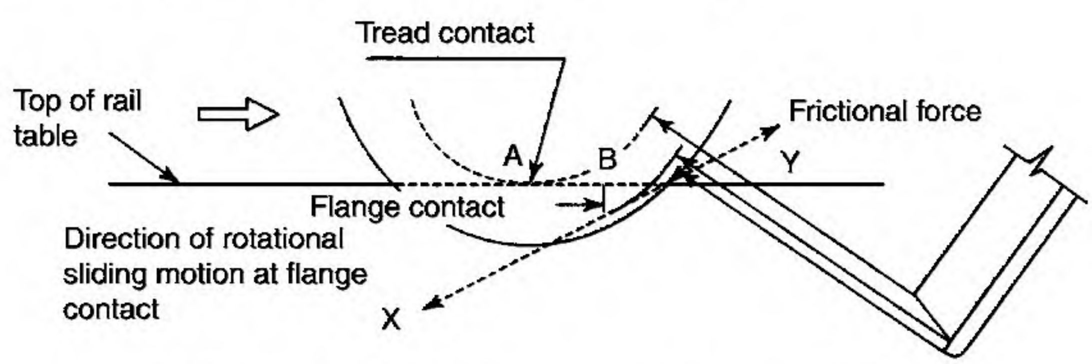


Fig. 22.10 Positive angularity (elevation)

(μ is the coefficient of friction between the flange and rail.) Point A is the tread contact and B is the flange contact. As frictional force acts, opposite to direction of motion at the surface of contact, its direction at B will be BY, the direction of movement being BX, tangential to the circle drawn through B.

Thus in positive angularity, the wheel flange rubs against the rail head edge in a downward arcing motion (also referred to as the downward biting action of the wheel flange), resulting in frictional forces acting upwards.

On Negative and Zero Angularity It may be seen from Figs. 22.11 (a) and (b), that in case of negative angularity or trailing contact, the frictional forces will be directed downwards, and in case of zero angularity, the frictional forces act horizontally. At zero angularity, although frictional forces have no vertical components, but in the event of wheel sliding up, the frictional force starts acting downwards, i.e. opposite to the direction of sliding motion.

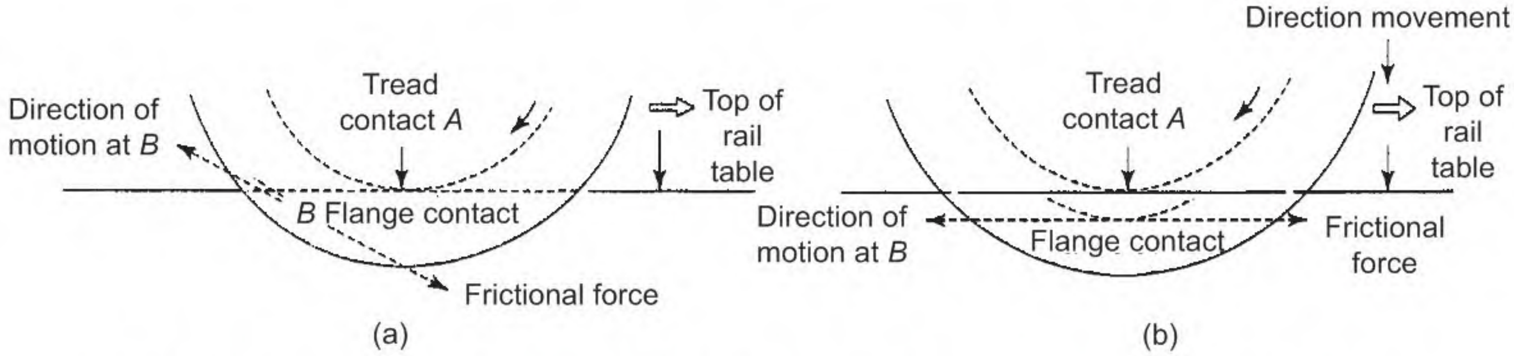


Fig. 22.11 (a) Negative angularity (elevation) (b) Zero angularity (elevation)

It can now be seen that in zero and negative angularity, when the wheel moves up in the process of derailment, the frictional force acts downwards and hence functions as one of the stabilising force: whereas, in positive angularity, the friction force acts upwards and hence functions as one of the derailing forces.

Positive Angularity Most Critical Positive angularity is therefore the most critical of the three conditions, derailment proneness being the highest when the wheel makes flange contact with the positive angle of attack. Therefore, study of forces in this condition only is relevant. On a straight track, this configuration occurs only during certain periods of the oscillating motion of the wheel set, but on curves, it occurs more or less throughout the period of curve negotiation. On a straight track all the wheel set position as shown in Fig. 22.12, fall in the category of positive angularity, while travelling in one or the other direction.

Nadal's Formula At the moment of incipient derailment, viz., when the wheel flange is in the process of climbing, forces acting at the rail wheel contact, in condition of positive angularity, would be as shown in Fig. 22.13.

For safety against derailment, derailment force should not be greater than the stabilising force. Resolving the forces along the flange slope, i.e. at angle β with the horizontal, the above condition implies that:

$$Y \cos \beta + \mu (Q \cos \beta + Y \sin \beta) \ngtr Q \sin \beta$$

$$\frac{Y}{Q} \ngtr \frac{\tan \beta - \mu}{1 + \mu \tan \beta} = \text{say } (S)$$

This is well known Nadal's formula; Y/Q is called the derailment coefficient.

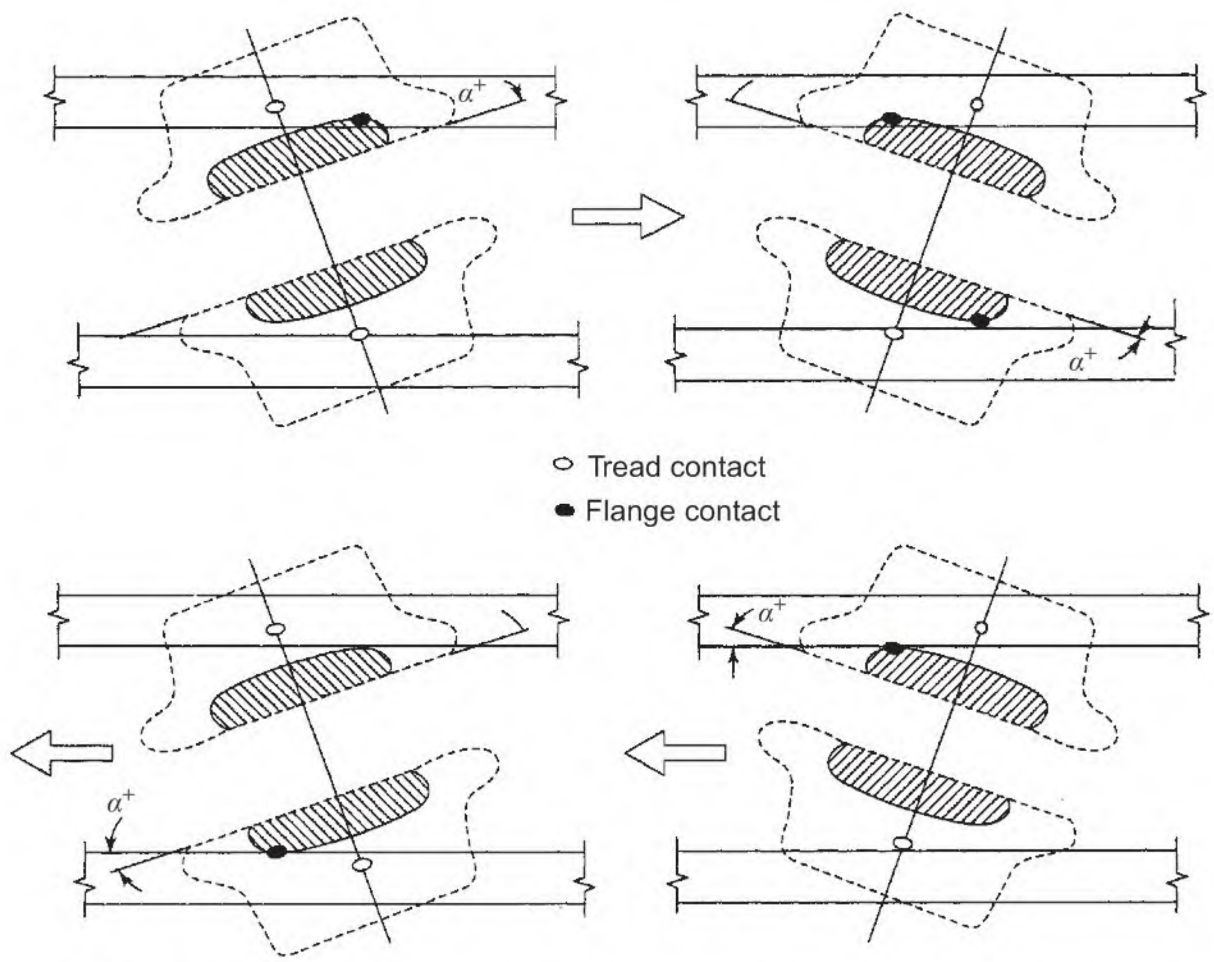


Fig. 22.12 Examples of wheel set configuration with positive angularity

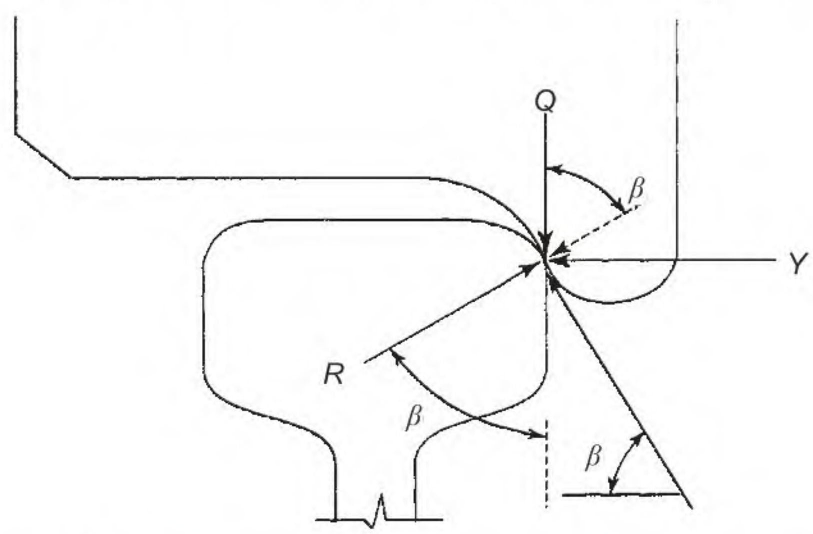


Fig. 22.13 Forces at rail-wheel contact at moment of incipient derailment with positive angularity of axle

When Y = Flange force

Q = Instantaneous wheel load

R = Normal reaction from rail

= $(Q \cos \beta + Y \sin \beta)$

β = Flange angle

μR = Friction force acting upwards (μ being the coefficient of friction between wheel flange and the rail).

22.2.5 Application of Nadal's Formula in Derailment Investigation

It will be seen from the Nadals formula, that for safety to be ensured, either the left hand side, i.e. Y/Q should be smaller or the right hand side, i.e. $\tan\beta - \mu/1 + \mu \tan\beta$ should be larger. This will happen in a comparative manner if Y is low, Q is high and μ is low.

With regard to flange angle [β] the issue is somewhat complex. How the expression $\tan\beta - \mu/1 + \mu \tan\beta$ varies with values of μ and β will be clear from Fig. 22.14. The formula thus indicates that for safety against derailment, β should be large; its value could be as high as 90°. But in such a case, even with a minute angularity only, the flange contact would shift to near the tip of the flange, the safety depth of the flange, would be almost zero, and derailment proneness would increase. As there is play between wheel set and the track, angularity of axles is an inherent feature of vehicle movement, owing to sinusoidal motion on the straight, and axles in a rigid wheel base, not being radial while negotiating curves (Fig. 22.15). For this reason only, the flange slope is provided, so that within the possible range of angularity of axle, the flange contact remains away from the flange tip.

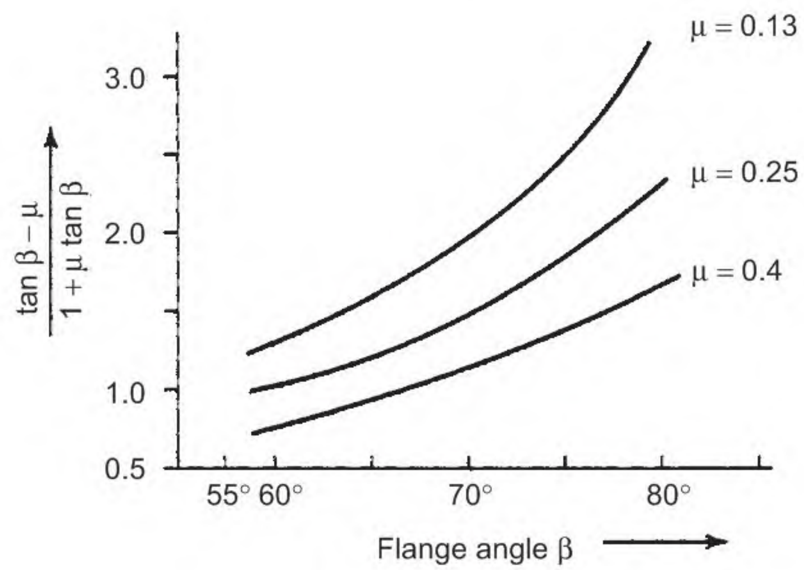


Fig. 22.14

In fact the greater the angularity occurring in vehicle movement, less should be the flange angle β (Fig. 22.16). In the Indian Railways, a flange slope of 2.5 to 1 ($\tan\beta = 2.5$, i.e. $\beta \approx 68° 12'$) is adopted for new wheel profile. For locomotives, value of $\beta \approx 60°$, as they encounter greater angularity while negotiating curves and turnouts. With wear, [β] increases. Wear also causes flange to become sharper increasing its biting action and thereby increasing values of μ. This reduces safety.

Besides as discussed, larger β causes the eccentricity to increase and safety depth of flange to reduce with minute values of angularity. Thus for ensuring safety, β the flange angle must be maintained within strict tolerances.

Other factors, which indirectly influence the Nadal formula are as follows.

1. *Positive angle of attack* μ increases with increasing angle of attack. For α between 0 and 12°, there is gradual increase in value of effective μ from 0 to 0.27.

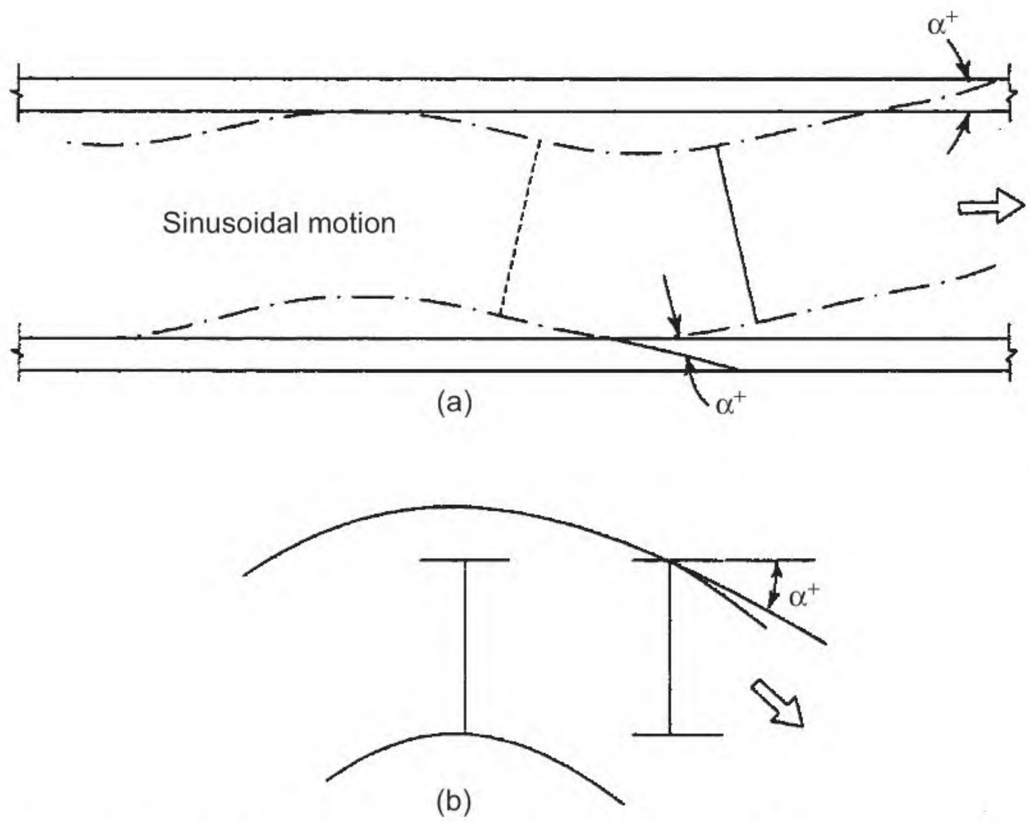


Fig. 22.15 Angularity of axle, (a) on straight (b) on curve

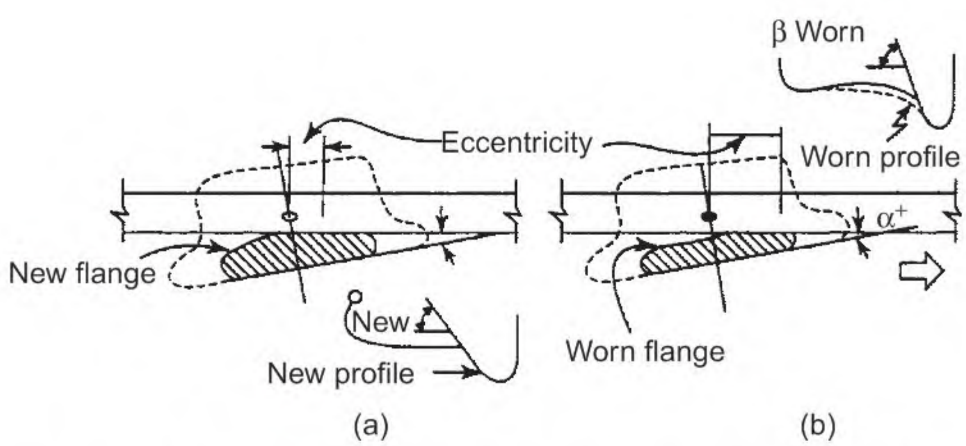


Fig. 22.16 Increase in eccentricity with increase in β

2. *Positive eccentricity* For a given angle of attack, a larger eccentricity increases derailment proneness; as it implies that flange contact is nearer to the flange tip and the flange safety depth is nearly zero.
3. *Persistent angular running of axle* Since derailment proneness becomes appreciable only with a positive angle of attack, a condition in which axle moves with a persistently positive angularity of the axle is only intermittent.

When investigating a derailment, it is neither possible nor necessary to work out the quantitative values in the Nadal formula. All track and wheel defects, and operational features, which could have caused one or more of the following to occur, should be listed as possible contributory causes.

(a) Y to increase (b) Q to decrease (c) μ to increase (d) positive, angle of attack to increase (e) positive eccentricity to increase and (f) persistent angular running of axle.

The list of such contributory defects and the features should be arranged in a descending order of their assessed contribution. This will enable one to finally arrive at the most probable cause of derailment. How the various rolling stock and track defects, and operational features, contribute towards derailment, through one or more of the above six effects, will be discussed later in this chapter. Some of the general defects are discussed in the following paragraphs.

22.2.6 General Defects and Features as Causes of Derailment

Defects and Features that Effect μ

1. The features of a rusted rail becomes particular critical if occurring on curve or turnout. New rails lying on cess get rusted. Rails on emergency crossovers get rusted because of infrequent use. It is a good practice therefore to lubricate the gauge face of rails on curves and turnouts as a regular maintenance practice. Values of μ (generally 0.25), for various conditions of rail are:

Dry rail	0.23	Lubricated rail	0.13
Wet rail	0.25	Rusted rail 0.6 or even higher	

2. Newly turned wheel particularly with tool marks.
3. Sanding of rails.
4. Effective μ increases with positive angularity. Conditions under which positive angularity increases are: (a) Increased play between wheel set and track and (b) sharp curves and turnouts.
   (a) Excessive slack gauge
   (b) Thin flange
   (c) Excessive clearance between horn cheek and axle box groove and
   (d) Excessive play between brass bearing and journal.

Defects and features which increases positive eccentricity Positive eccentricity increases primarily through the wheel flange slope becoming steeper. This reduces the safety depth and thus increases the derailment proneness of vehicles.

Defects and Features which Causes Persistent Angular Running of the Axles

1. *Difference in wheel diameter on the same axle* A difference of 0.5 mm only is permitted between the wheel dia on the same axle (wheel dia is measured at a location 63.5 mm from the back of the wheel in case of BG wheel and at 57 mm in case of MG wheel). See Fig. 22.17. If the difference in wheel dia is more, it will cause the axle to run persistently angular.
2. Incorrect adjustment or uneven application on brakes.
3. *Hot axle* With hot axle, bearing friction on each journal will be different, causing angular running.

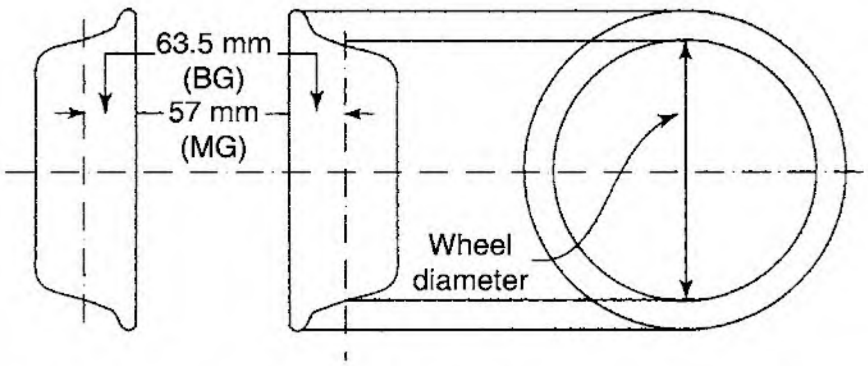


Fig. 22.17 Measurement of wheel diameters on the same axle

22.2.7 Safe Value for Y/Q Nadal's Formula

In Nadal's formula, for safety against derailment,

$$\frac{Y}{Q} = \frac{\tan\beta - \mu}{1 + \mu \tan\beta}$$

With $\beta = 68°$ and $\mu = 0.25$

$$\frac{\tan\beta - \mu}{1 - \mu \tan\beta} = 1.4$$

Thus for safety against derailment Y/Q should not exceed 1.4. This is a threshold value. To allow certain margin or factor of safety, a limiting value of 1.0 for Y/Q has been laid down for Indian Railways.

This criterion has however to be qualified by the time factor. Based on the research results of various world railway systems, this time is taken as 1/20s or 0.05s. Thus the final form of criterion adopted on Indian Railways is that the derailment co-efficient Y/Q should not exceed 1.0; the said co-efficient being measured over a duration of 0.05s.

22.2.8 Chartet's Addition to Nadal's Formula

A useful refinement to Nadal's formula has been made by Chartet. For analysing the equilibrium of forces at the moment of incipient derailments, it is necessary to consider the force pattern at the non-derailing wheel of the same axle, in addition to that of the derailing wheel, both being integrally connected. When the derailing wheel moves laterally towards the central position, this would cause the non-derailing wheel to slide over rail head, thus generating frictional forces, opposite to the direction of the movement of the wheel. Under the influence of these frictional forces, it has been found by Chartet, that even if the flange force on derailing wheel is zero, the wheel can still climb and derail, in case the instantaneous wheel load Q goes below 35 percent of the normal wheel load or the wheel off loading increases by more than 65 percent. Thus for safety against derailment $Y/Q > 1.0$ and $Q < 0.35$ of the normal wheel load.

22.3 VEHICLE OSCILLATIONS AND THEIR EFFECTS

A vehicle while travelling on track moves with a variety of oscillations. These are called "parasitic oscillations", because like parasites, they feed themselves on the forward motion of the vehicle on track i.e. their energy is derived from the energy of the forward motion of the vehicle.

These oscillations effect Y and Q values and thus can be important contributory factors in derailment.

For the convenience of reference and analysis, it is customary to classify these oscillations according to the three-axis coordinate system. The three axis are:

X-axis-along the track
Y-axis-lateral to track
Z-axis-vertical direction

In reference to any axis, an oscillations can be linear or rotational. Thus, there are in all the following six modes of oscillations as illustrated in Fig. 22.18.

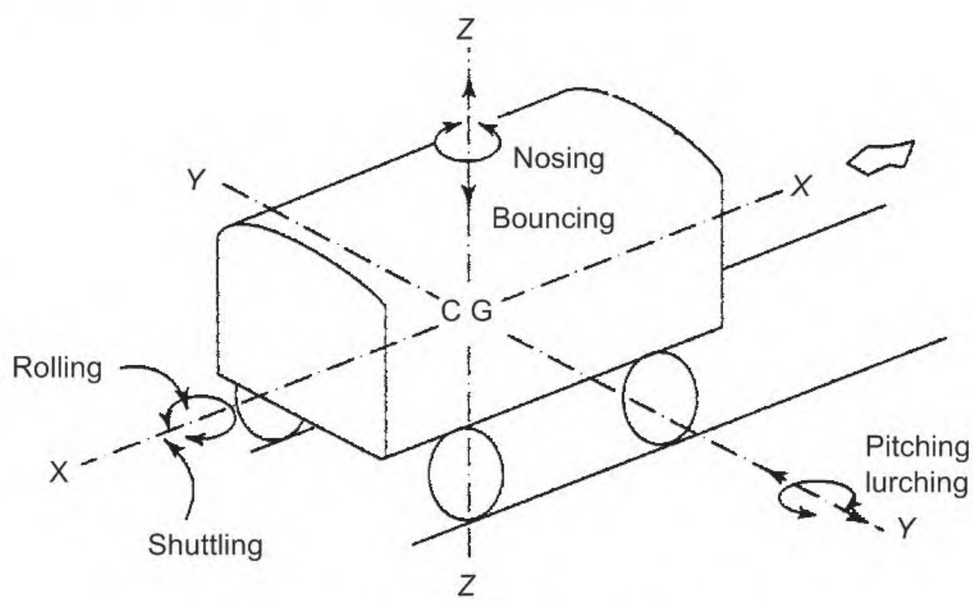


Fig. 22.18 The six modes of oscillation

	Mode of oscillation	
Axis	*Linear*	*Rotational*
X	Shuttling	Rolling
Y	Lurching	Pitching
Z	Bouncing	Nosing (also calld 'yaw')

The combined effect of rolling and nosing when violent is called 'hunting'. There are two broad categories of oscillations.

1. *Self excited* These are due to wheel conicity.
2. *Other than self excited* These are due to track irregularities, varying elastic characteristics of tra ck, suspension characteristics of vehicle, disposition of load on vehicle and vehicle operation features.

22.3.1 Self Excited Oscillations on Account of Wheel Conicity

Since the inception of the railways, the concept of coning has been introduced to provide a simple guidance system for the wheel set requiring a minimum use of flanges. With coned wheels, when a wheel set shifts, say to the left of the track centre, the left rolling diameter becomes larger than right one. The left wheel thus has to travel a long distance for a certain revolution of the axle, which can happen only if the wheel moves in a curving motion towards the right. In this motion, the wheel set crosses the central position due to momentum and the right rolling diameter becomes larger than the left one, which makes the wheel go back toward the left and so on. Hence the wheel conicity makes the wheel set come back whenever it tries to shift from the track centre, thus providing a built-in guidance system (Fig. 22.19). Only when the lateral shift is excessive, will the flange come into play and prevent the wheel set from derailing.

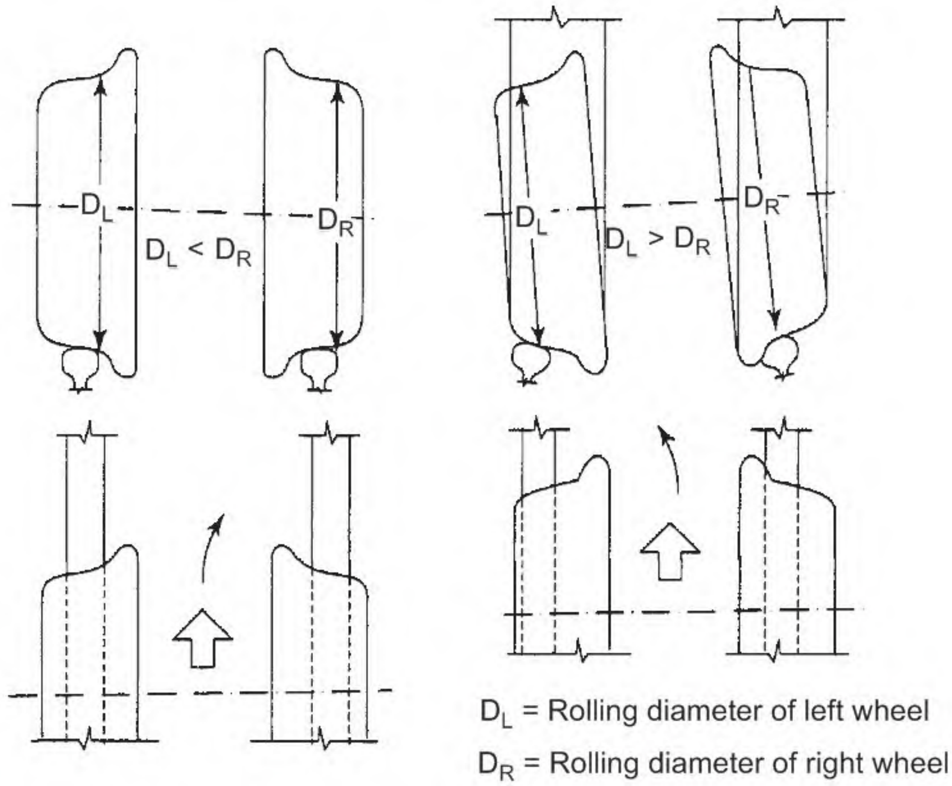


Fig. 22.19 Wheel set guidance by tread conicity through change in rolling dia

On the other hand, with cylindrical wheels, even with minor cross-level difference, the wheel flange would hug the lower rail and continue to do so with either the left rail or the right rail whichever happens to be lower. This would wear out the rail and wheel flange much sooner.

However with wheel conicity, the resulting motion of wheel set is a sinusoidal one causing the wheel set to oscillate sideways (Fig. 22.20). This is self-excited motion of the wheel set. The motion is called sinusoidal, as it is similar to wave formed by a sine curve. It has a definite period of oscillation, say T seconds, in which the wheel set comes to the same position with respect to one rail or the other. The distance pertaining to that period is called wavelength, say L, and the maximum lateral displacement that the wheel set undergoes from its position of equilibrium is called amplitude say a (Fig. 22.21). If V is the speed of the vehicle, then $L = VT$ or $T = L/V$. The number of times a periodic motion repeats

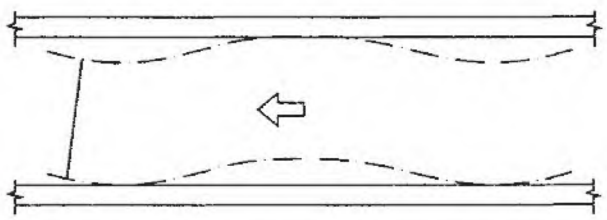


Fig. 22.20 Sinusoidal motion of wheel set

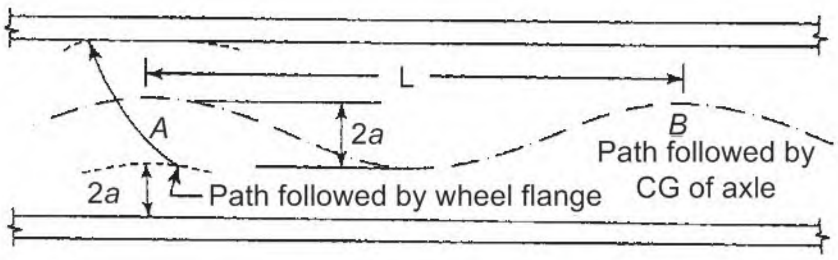


Fig. 22.21 Sinusoidal motion of centre of gravity of coned wheel set

itself in one unit of time (usually 1s) is known as frequency say f. It is expressed in cycles per second. As T is the time of one cycle, the number of cycles per second, i.e. $f = 1/T$ or $f = V/L$.

22.3.2 Relationship between the Conicity of Wheel, Wavelength and Frequency of Oscillation of Vehicle

It can be established that as the conicity of wheel increases, wavelength decreases and frequency of oscillation of vehicle increases, causing instability to the moving vehicle. An excessively worn wheel, which will have greater conicity than 1 in 20, has thus an adverse effect on vehicle stability. In derailment investigations, therefore, conicity of wheels of the derailing vehicle should invariably be checked, measured and commented upon.

The conicity is measured between two definite tread contact points, i.e. one when the wheel set is central and the other when the wheel is making a flange contact (Fig. 22.22).

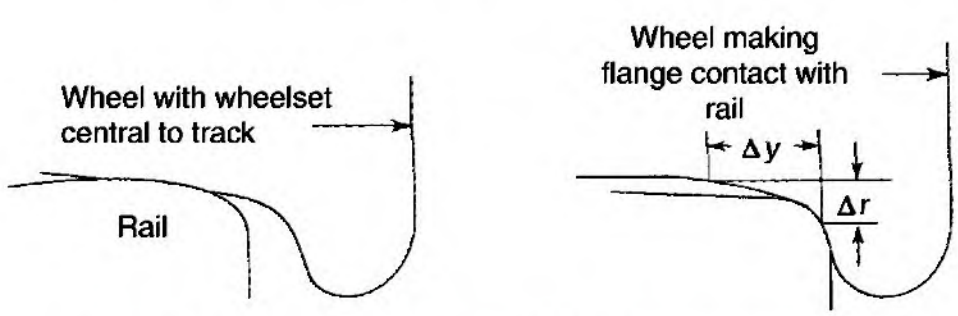


Fig. 22.22 Measurement of effective conicity

22.3.3 Effect of Rigid Wheel Base on Self Excited Oscillations

It has been found that longer the wheel base, the greater is the wavelength of oscillation and thus better the stability of the vehicle. A longer wheel base is therefore better from the point of view of running stability on straight track. Longer wheel base however creates problems while negotiating curves, particularly transitions.

On straight in general, a shorter wheel base wagon being susceptible to more oscillations, is more prone to derailment as compared to a larger wheel base wagon. This does not apply to bogie vehicles, as bogies are not free to oscillate on account of the rotational friction caused by weight of the vehicle body carried by the bogie.

22.3.4 Effect of Play on Lateral Acceleration and Lateral Force Y

A wheel set can oscillate laterally only to the extent of play is available between wheel set and the track. In sinusoidal wave motion, the wheel set has the maximum lateral acceleration and thus the maximum lateral force, when approaching the place of maximum amplitude. It has been found that lateral acceleration is directly proportional to the amplitude (a) and varies inversely as square of wavelength of oscillation (L). The greater the play between the wheel set and the track, greater is the possibility of increased lateral acceleration and hence increased lateral force Y. The amplitude (a) being directly proportional to conicity of the wheel, greater conicity would therefore also result in greater lateral acceleration.

An increased lateral acceleration also results in increased vertical oscillation through the effect of coning. Thus both Y and Q are adversely effected.

It is for these reasons that the standard play should be as small as can possibly be kept. In the Indian Railways, standard play on BG is 19 mm, which on account of permissible lateral wear of 12.5 mm on each wheel gets increased to $19 + 2 \times 12.5 = 44$ mm, causing high lateral and vertical acceleration. Based on the European practice, on high speed routes in the Indian Railways, a decision has been taken to reduce the standard play to 16 mm by adopting a 3 mm tighter gauge.

22.3.5 Cyclic Track Irregularities and the Phenomenon of Resonance

Consider a BG fishplate track, with standard 13 m rails having a series of low joints (Fig. 22.23).

When a vehicle travels over such a track, it will be subjected to an excitation every time it passes over a low joint, viz. at the rate of 1 excitation every 13 m. The resulting oscillation of the vehicle would be in bouncing or pitching mode. If the speed v of the vehicle is 13 m per second (= 47 kmph), the vehicle will have excitation every one second. The frequency of oscillation of vehicle will thus be 1 cycle per second on low joints. If the vehicle speed is doubled, the frequency of oscillations will be 2 cycles per second. So at different speeds, a cyclic track irregularity would cause a different frequency of oscillation.

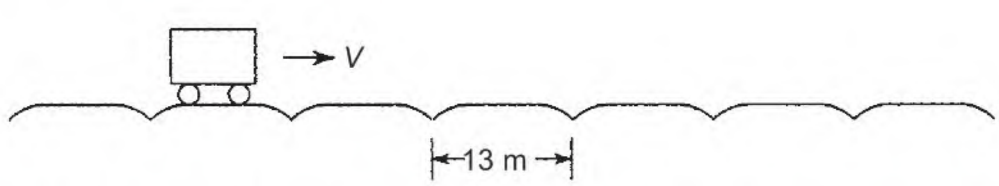


Fig. 22.23 Series of low joints—An example of cyclic track irregularity

A vehicle suspension comprises a system of springs, and it has its own natural frequency of oscillation in each of the six oscillation mode (rolling, pitching, etc.). Natural frequency is an inherent property of a suspension system. When a suspension system is given an initial excitation in a particular mode by an external force and that force is removed, the frequency with which the system oscillates freely (without any further external excitation) is called its natural frequency in that mode. If the forcing frequency in a particular mode equals natural frequency in that mode, the phenomenon called resonance occurs, if there is no damping in the system, the amplitude of oscillations at resonance tends to become infinite. This build up of oscillation amplitude at resonance can be controlled only by suitable damping. This brings out the crucial importance of damping in a vehicle suspension system. There can be instances when cyclic track irregularities well within permissible limits can excite resonance frequencies in a vehicle, leading to unsafe conditions, when the damping system is not effective. The following irregularities in track would roughly generate the oscillation indicated against each (Table 22.1).

Table 22.1

Track irregularity	*Mode of oscillation*	*Effects*
Low joint, unevenness, loose packing, etc.	Bouncing and pitching	*Q*
Alignment or gauge fault	Lurching, noising or rolling	*Y* and *Q*
Twist	Rolling	*Q*

Thus in derailment investigation, it is important to check the condition of damping system in reference to what is required to be provided and maintained as per the design of the system.

22.4 EFFECT OF TRACK OR VEHICLE TWIST ON WHEEL OFF-LOADING

Another parameter having crucial impact on safety aspect of vehicle-track interaction is the track and vehicle twist.

22.4.1 Track Twist

In general, twist between any four points is defined as the normal distance by which any one of the points lies outside the plane formed by the other three points. If all the four points be in one plane, the twist is zero.

When referring to track, twist is defined as rate of change of cross-levels. Suppose

Cross-level at station A = +5 mm (left rail is higher than right rail by 5 mm).
Cross-level at station B = – 7 mm (left rail is lower by 7 mm)

and *A* and *B* are 3 metres apart

$$\text{Track twist} = \frac{+5-(-7\,\text{m})}{3} = \frac{12\,\text{mm}}{3}$$

= 4 mm per metre, or more appropriately
= 12 mm on 3 m base

22.4.2 Effect on Track Twist

If a springless vehicle stands on a track with twist, the situation is the same as that of a wooden table standing on an uneven ground which keeps on rocking about a diagonal. The same is the behaviour of a vehicle with infinitely stiff springs.

Now suppose we introduce springs under the legs of the table (Fig. 22.24). When the ground under one leg, say *D*, is lowered, the contact will not be lost, as the spring which was compressed under the weight of the table will have a chance to elongate. If the elongation is not total, some of the load will still be shared by *D*. A loaded spring has the capacity to compress further or elongate. Both these factors help a vehicle to negotiate track twist without excessive off-loading. The spring over the wheel, which encounters twist elongates and thus helps to keep some load on the wheel. At the same time the increase in load on the other wheels causes other springs to compress, which further helps in bringing back some more load on the off-loaded wheel. Thus, springs perform a very important function, i.e. to enable the vehicle to negotiate normal track irregularities in twist parameter, without much off-loading of wheels, thereby ensuring safety (Fig. 22.25).

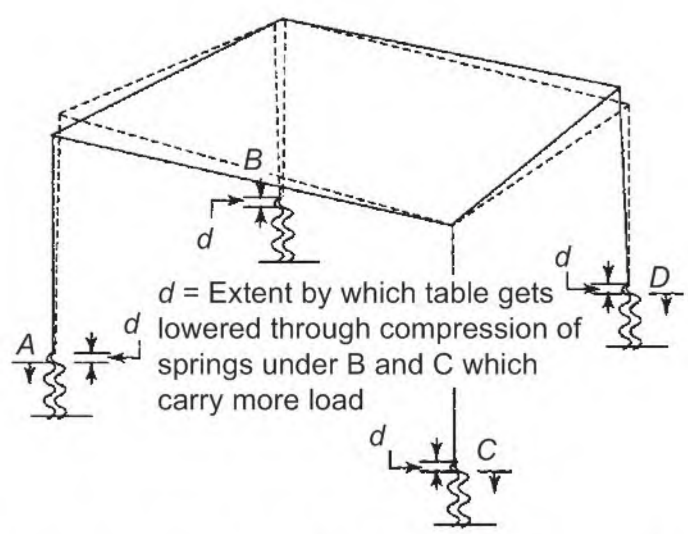


Fig. 22.24 Table on ground level conditions with legs resting on springs instead of directly on ground

The question as to how much the track under the wheel of a 4-wheeler can be depressed till the wheel load reduces to zero or to an unsafe level, is answered in the following equation drawn by Kereszty.

$$Z_o = fT\left(\frac{G}{a}\right)^2$$

where Z_o= The track twist that would cause the wheel off-load completely

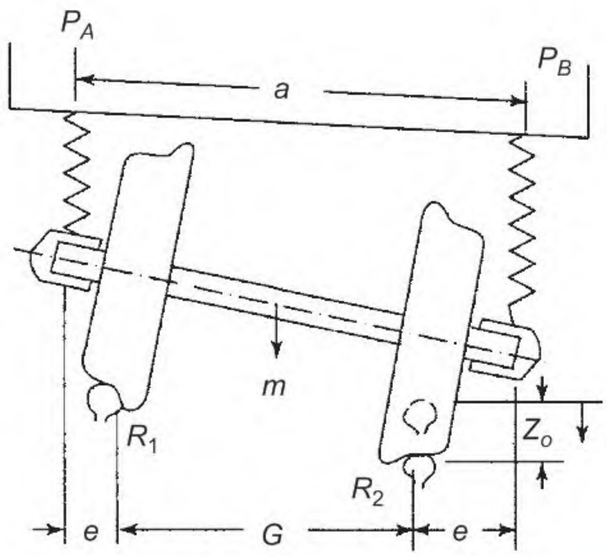


Fig. 22.25 Effect of spring deflection and hence on wheel load as rail under a wheel is depressed

T = Total weight of a 4-wheeler.
f = Specific deflection (i.e. deflection per unit load) of the springs.
G = Dynamic gauge (centre to centre of the rail head).
a = Distance between centres of the springs.

It would be clear from the equation, that higher the value of Z_o the better it is. This means for a wheel to off-load completely, a greater track twist would be needed, a condition which is safer.

We however know that derailment conditions are created when wheel load drops to 0.35 of the nominal wheel load. Accordingly, the permissible track twist will be 0.65 Z_o.

In general, the greater the value of Z_o, greater is the capacity of the 4-wheeler to negotiate a given track twist. This implies, that in the formula, values of f, T and the ratio G/a should be as high as possible. The influence of these three factors is discussed in the succeeding paragraphs.

f-specific Deflection or Stiffness of Spring: For f to be greater, the deflection per unit load should be high, which means a softer spring is safer from the twist point of view. For practical consideration, to ensure that buffer heights of wagons do not vary much under empty and loaded conditions, too soft a spring cannot be used. In a vehicle, if for any reason, the springs become stiffer, it reduces the extent of twist that such vehicles can safely negotiate. Common causes, which render a leaf spring stiff are: (a) rusting of leaf spring or lack of lubrication, (b) introduction of thicker or stiffer leaf plate.

T-effect of Empty or Loaded Condition of the Vehicle: In the equation, for Z_o to be higher T, the total weight should be high. Greater load produces greater deflection of the springs and hence affords greater ability of the vehicle to negotiate a given track twist with a safe residual wheel load. An empty vehicle is thus more prone to derailment than a loaded one.

G/a-Ratio of dynamic gauge to distance between the spring bearing on a wheel set:
Z_o is higher with higher value of G/a.

G/a value for common BG and MG 4-wheelers are

$$BG = 0.78\left(\frac{G}{a}\right)^2 = 0.161$$

$$MG = 0.71\left(\frac{G}{a}\right)^2 = 0.5$$

This partly explains why MG 4-wheelers are more prone to derailment as compared to BG 4-wheelers.

Apart from the above three factors considered by Kereszty, the following factors have influence on the extent of twist that can safely be negotiated from the consideration of wheel off-loading.

Variation in Specific Deflection of Springs Under a Vehicle Spring deflection of different springs of a vehicle under the same load are rarely the same. Such variation has exactly the same effect on wheel off-loading as that of track twist. The position is worse when the two diagonal springs of a 4-wheeler have the same defect.

Torsional Stiffness of Vehicular Under-frame A 4-wheeler wagon having a flexible underframe would deflect with the track twist. Deflection of an underframe is similar to the deflection of a spring. Thus softer the underframe torsionally, the better it is from safety consideration. In general, torsional stiffness for 4-wheelers are: (a) BG-13 mm and (b) MG-5 mm.

Vehicles with torsionally stiffer under-frames are: (a) wagons with welded underframes (revitted underframe is more flexible) and (b) tank wagons. These are more prone to derailments.

Transition Portion of a Curve Transition curves have in-built twist in them. A 1 in 720 cant gradient will have an in-built twist of 1.4 mm per metre. If permitted, twist on track is 4 mm/m, 1.4 mm/m is taken away by the transition and the balance margin of 2.6 mm/m would be available for track maintenance. The track would therefore need more frequent maintenance to ensure that permissible value of twist, i.e. 4 mm/m is not exceeded on the transition. For the same reasoning, the flatter the cant gradient on a transition, the greater is the safety margin.

On transition curves, the problem is more severe with the wagons with longer wheel base. On 1 in 720 cant gradient, a wagon with 4 m rigid wheel will get a twist or track depression of 4×1.4 mm = 5.6 mm. The longer the wheel base, the lesser is the margin available for track maintenance. However, generally, longer wheel base vehicles are more flexible. Hence some of their adverse effects are off-set. But if a longer wheel base wagon is also torsionally stiff, it will be more derailment prone on transition curves. Such is the case with tank wagons.

Taking into consideration the influence of various factors, the net track twist Z_{perm} that can be permitted from safety consideration in reference to wheel off-loading, would be:

$$Z_{perm} = 0.65\ Z_o - Z_s + Z_u - Z_b \text{ (if one spring is defective)}$$
$$= 0.65\ Z_o - 2\ Z_s + Z_u - Z_b \text{ (if two diagonally opposite springs are defective)}$$

where Z_o = Track twist that would cause a wheel to off-load completely.
Z_s = Spring effect expressed in terms of equivalent track twist
Z_u = Torsional flexibility of vehicle expressed as additional track twist
Z_b = Twist owing to cant gradient on a transition curve.

Note: If the depth (call if Zf) of the straight portion of the wheel flange viz. 9 mm for BG wheel and 8 mm for MG wheel is also considered, the above Z_{perm} be increased by the said value (Fig. 22.26).

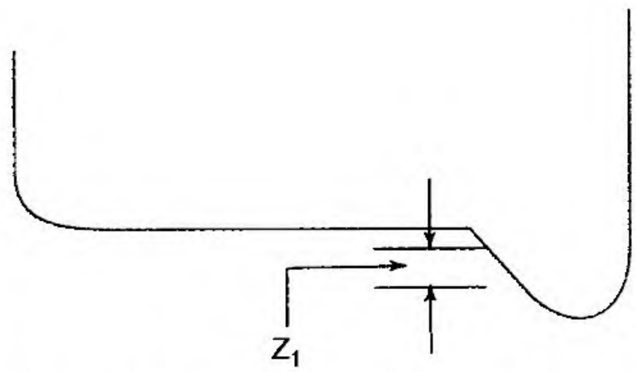


Fig. 22.26 Safety depth of flange

Table 22.2 gives values of Z_{perm} for commonly used BG and MG 4-wheeler empty wagons. From the table, it will be seen that the safety margin available for MG empty 4-wheeler is considerably lower than that for BG wagons.

Table 22.2 Net value of Z_{perm}

S. No.	*Cant grade*	*Z_{perm} (mm) for empty wagons*					
		Meter gauge			*Broad gauge*		
		CA	*C*	*KC*	*C (SWB)*	*C*	*KC*
1	1 in 720*	12.4	13.8	13.3	13.6	37.0	38.2
2	" **	7.8	9.2	8.7	8.5	31.8	33.0
3	1 in 360*	7.3	9.6	8.2	9.5	30.6	33.3
4	" **	2.7	5.0	3.6	4.6	25.4	28.1
5	1 in 240*	2.2	5.4	3.1	5.6	24.2	28.4
6	" **	(–) 2.4	0.8	(–) 1.5	0.7	19.0	23.2

*:13 mm defect in one spring
**:13 mm defect in each of the two diagonally opposite springs

22.5 LATERAL STABILITY OF TRACK

So far we have discussed derailment involving phenomenon of flange climbing, assuming the track to be stable. There can be a situation, when under the action of high flange force the track gives way first, before the flange has a chance to climb. This is called track distortion, which can become a cause of derailment.

It will be obvious that a track could distort if any or both the following occur (a) the lateral strength of track reduces or (b) the lateral forces exerted by the vehicle are excessive. In either case, the track distortion occurs when the lateral forces exceed the lateral strength of the track.

There are two internationally accepted formulae for determining the lateral strength of track to limit the lateral forces within that.

(a) Blondels formula

$$Hy \ngtr 0.4P + 2 \text{ tonnes}$$

(b) Prudhomme formula

$$Hy \ngtr 0.85(1 + P/3)$$

P = axle load in tonnes in both the formulae.

In the Indian Railways, Blondels formula is followed. The Prudhomme formula gives much lower lateral strength of track and has been adopted by many of the world railways for limiting the lateral forces exerted by the vehicles on track. It may be mentioned that strength of track is the one, which an average track will have after thorough packing including attention by MSP.

In this backdrop one should identify the following at the time of derailment (a) the defects in rolling stock, that could have caused forces Y to increase and (b) the defects in track that could have caused a reduction in its lateral strength.

22.6 SITE INVESTIGATIONS AFTER DERAILMENT

It is necessary to proceed to the site of derailment quickly, not only for reason of protection of track, to organize rescue and restoration, but also for collection of all possible evidence before it is tampered with and destroyed.

It is most important to locate and examine the wheel mounting marks at the initial point of derailment to identify the category of derailment, i.e. whether the derailment is a sudden one by wheel jumping the rail or it is by flange climbing. This enables the scope of investigation to the narrowed down.

22.6.1 Sudden Derailment

This is characterized by a sudden mark across the rail table or no mark at all. It indicates that the derailing forces were high enough to suddenly force the wheel off the rail. Once should therefore look for features that would cause sudden development of high flange forces. Probable causes, acting singly or in combination, may be the following.

1. Sudden shifting of load
2. Improperly loaded vehicle
3. Excess over maximum permissible speed on curve or a turnout
4. Resonant rolling, nosing or hunting
5. Sudden variation in draw bar pull induced by braking or acceleration

6. Broken wheel
7. Failure of vehicle or track component
8. Obstruction on track
   (above list is illustrative, not exhaustive)

22.6.2 Gradual Derailment by Flange Climbing

A long mark, which may be as long as 10 m or more on the rail, indicates a gradual derailment by classic flange climbing. In this case, it may be relatively more difficult to establish the cause. Yet, it is this category in which Nadal's formula finds its application in affording a means of going about the task of investigation.

The standard method of site investigation should cover the following.

1. Identification and critical examination of wheel marks on the rail head, fastenings, sleepers, and ballast, the wheel trail marks, and the corresponding marks on the wheel set of the derailed and other vehicles, to identify the wheel set which derailed first and to establish the initial point of derailment.
2. Detailed examination of wheel marks on the rail head, fastening, sleepers, and ballast, at the initial point of derailment, to establish the category of derailment.
3. Investigation and recording of track parameters and track geometry.
4. Dynamic behaviour of such rolling stock on the above track geometry.
5. Investigation and recording of operation features, and analysis of the dynamic behaviour of rolling stock in reference to the same.

22.6.3 Accident Sketch

This should be prepared with great care to show all the relevant details of the accident site. The sketch should be such that a person who has not visited the site of accident at all, should be able to get a complete picture of the accident from the sketch itself. See Fig. 22.27.

22.7 ROLLING STOCK SUSPENSION SYSTEM

There are three distinct portions of rolling stock as described here.

Wheel Set Two wheels and an axle form a wheel set.

Suspension System The principle of suspension system embraces two basic features, i.e. springs and dampers.

Springs Spring provide a vehicle the ability to negotiate track twist without much off-loading of wheel. The main bearing spring may be provided in a vehicle suspension in either single or double stage.

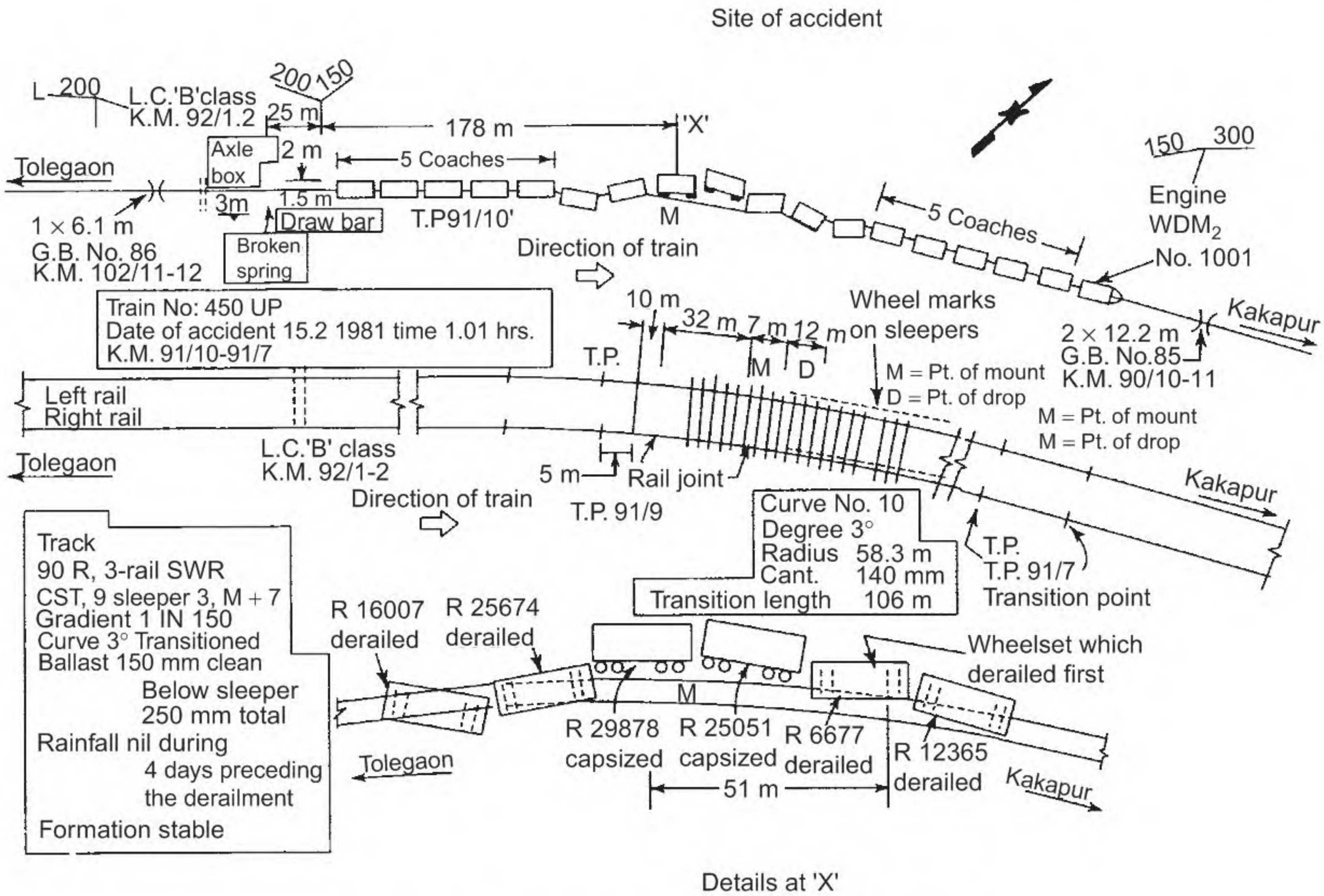


Fig. 22.27 Typical sketches of accident site

Single Stage Suspension In this system, there is only one stage of springs between the wheel set and the vehicle body. The most common example is the ordinary 4-wheeler wagon. Normally all freight stock have single stage suspension. Some of the diesel and electric locomotives have single stage suspension.

Double or Two Stage Suspension In this system, the springs are provided in two stages between the wheel set and the vehicle body, viz. primary and secondary stage.

Primary Stage Comprises the set of springs which bear on the axle box directly or indirectly. Such springs are called primary springs and the suspension, primary suspension.

Secondary Stage Consists of the set of springs which through a bolster (a beam) bear directly the weight of the vehicle body and transmit it to a bogie frame, which further rests on the primary springs. Such springs are called secondary springs and the suspension, secondary suspension. Coaching stock normally has two stage suspension. Some of the diesel and electric locomotives have two stage suspension.

Damping System Damping has an important safety function. Without adequate damping in a suspension system, the amplitude of oscillation would tend to become very large during resonance.

This can lead to dangerous off-loading in the case of vertical oscillation. Such a situation can arise any time during the vehicle travel, being dependent on vehicle speed, the wavelength of track irregularity and the natural frequency of oscillation of the vehicle.

When lateral shock absorbers are provided to control the oscillations in the lateral mode, a defect in such a damper, would cause build-up of Y forces during resonance in lateral oscillation.

In general, the suspension system has to perform the following functions

1. Transmit the vertical load from the vehicle body to the wheels.
2. Hold the wheel sets (forming a rigid wheel base) laterally and longitudinally parallel to one another, at the same time permitting unhindered relative vertical movement between the suspension system and the wheel sets to enable the springs and dampers to function freely.
3. Transmit the longitudinal tractive and braking forces from vehicle body equally on the two wheels of a wheel set.
4. Permit the bogie or trucks to undergo unhindered but damped rotation or rotation and lateral sliding for negotiation around curves and turnouts.

Vehicle Body In general, a vehicle underframe should not have excessive twist. Beside, the rectangular underframe should not be distorted into a parallelogram.

22.8 ROLLING STOCK DEFECTS

Rolling stock defects which lead to unsafe conditions, and are more or less common to various types of rolling stock, are discussed in the following paragraphs. The Indian Railway Conference Association (IRCA) has laid down certain rolling stock tolerances for components having bearing on safety. Important among these have been reproduced against the relevant rolling stock component.

Defects in Wheel Sets As per IRCA the following defects in wheel sets are considered unsafe in all BG and MG goods and coaching stock.

1. Wheel shifted on axle.
2. Tyre defects namely, reduced tyre thickness or flange thickness, worn tread profile causing hollow tyre and deep flange reduction of flange root radius, formation of sharp edge on flange and flat places on tread.
3. Tyre, loose, cracked or broken.
4. More than one stud deficient or loose on stud fastened tyres. More than four counter sunk rivets deficient or loose on a Marsell ring fastened tyre (for good stock only).

Defects in Wheel Profile The profile of a new wheel with standard flange commonly used in the Indian Railways is shown in Fig. 22.28.

When such a profile gets worn, it may reach condemning limits to any one or more of the following conditions (a) thin flange, (b) sharp flange, (c) worn root, (d) deep flange and (e) hollow tyre or false flange. Typical tyre defect gauges for checking the wheel profile of BG and MG are given in Fig. 22.29.

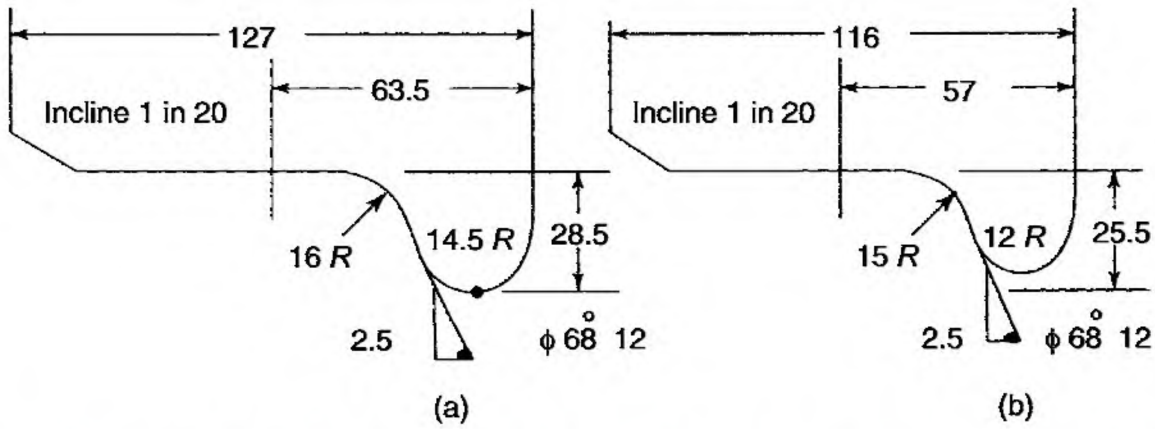


Fig. 22.28 Profile of a new wheel with standard flange (a) BG wheel (b) MG wheel, (all dimensions in mm)

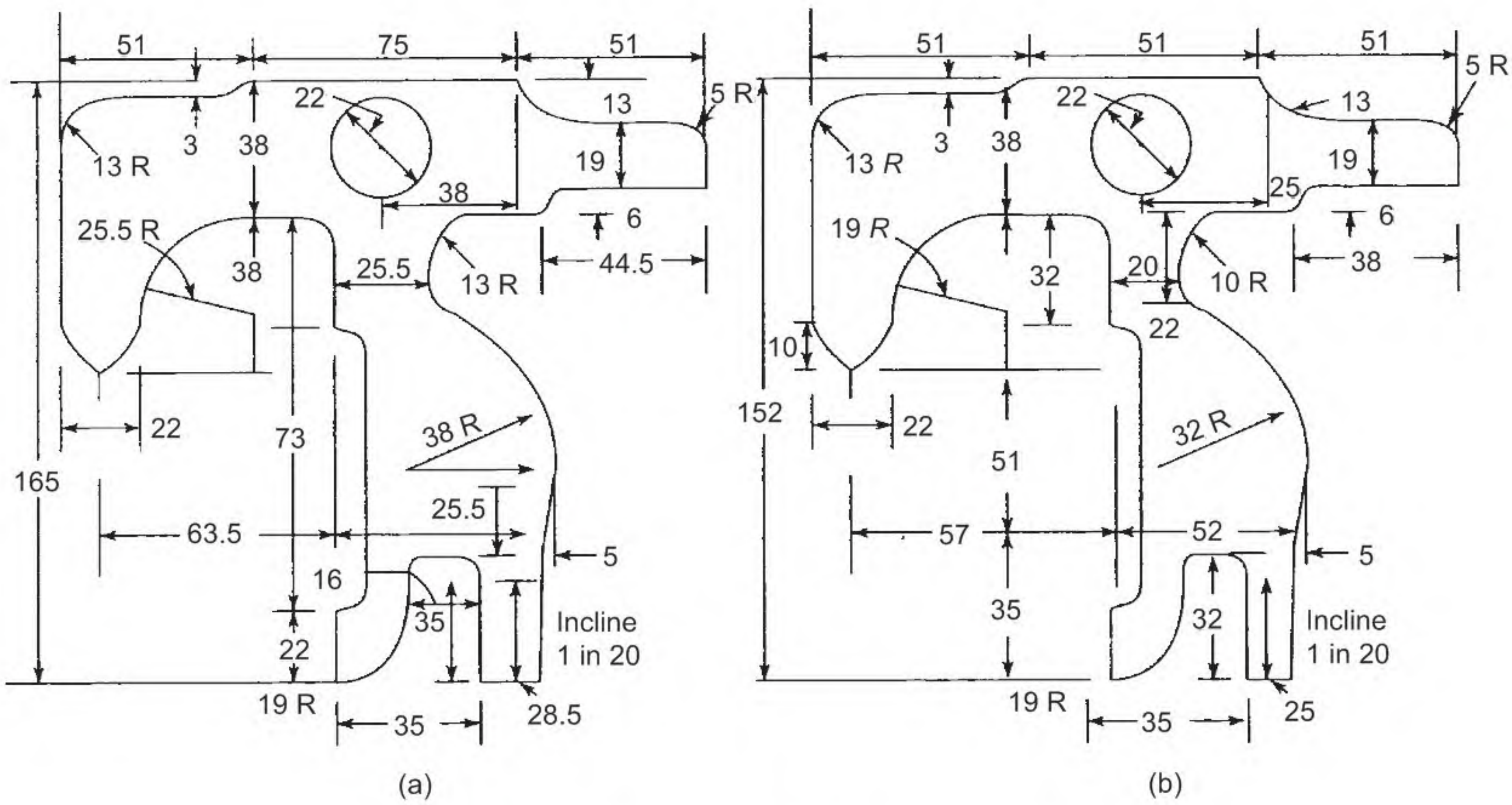


Fig. 22.29 Type defect gauge (a) BG (b) MG

Thin Flange When the flange thickness (of BG or MG wheels) reduces to less than 18 mm, the condition is called thin flange (Fig. 22.30). Thickness of flange is normally reckoned at a distance of 13 mm from the flange tip of BG and MG wheels.

Effect on Safety A thin flange implies greater play between the wheel set and the track, which increases derailment proneness as under:

(a) Oscillation increase due to greater play adversely affecting Y and Q
(b) Angularity of axle increases
(c) Affects flange way clearance at switch assembly

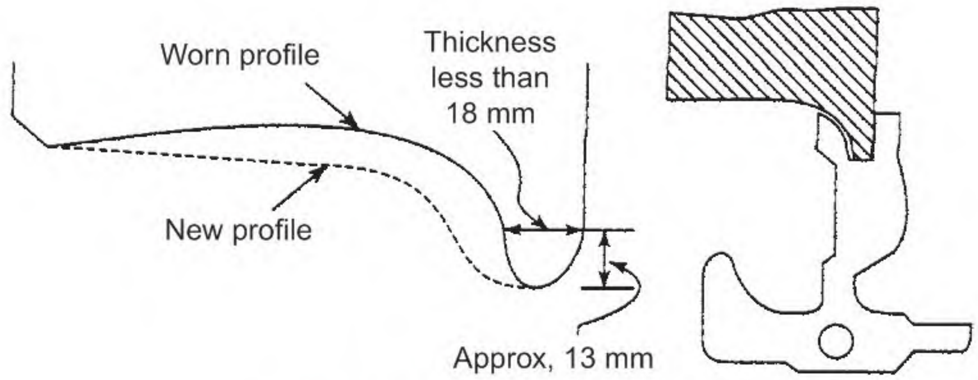


Fig. 22.30 Thin flange

Sharp Flange When the radius of the flange tip reduces to less than 5 mm, the condition is called a sharp flange (Fig. 22.31).

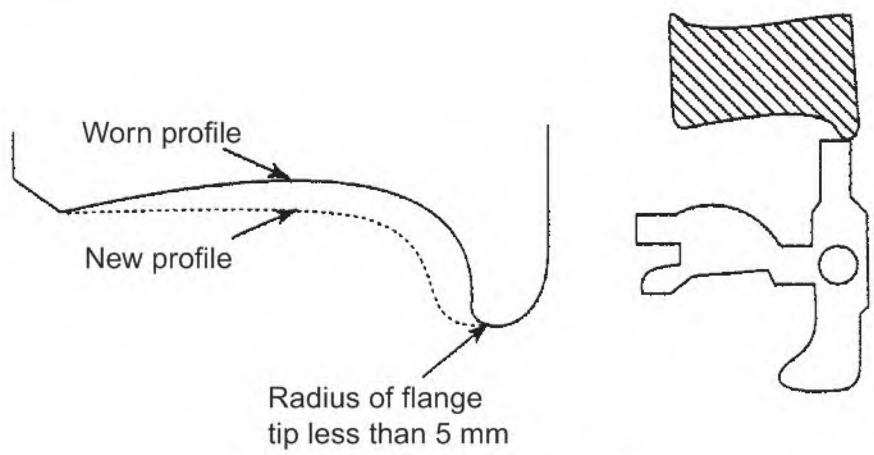


Fig. 22.31 Sharp flange

Effects on Safety Derailment proneness increases through the following:

(a) Increase in the value of μ
(b) Increase the positive eccentricity
(c) Wheel set can take two roads at slightly gaping points or an movement over a chipped tongue rail.

Worn Root When the radius of the root curve reduces to less than 13 mm (BG or MG), the condition is called worn root. See Fig. 22.32.

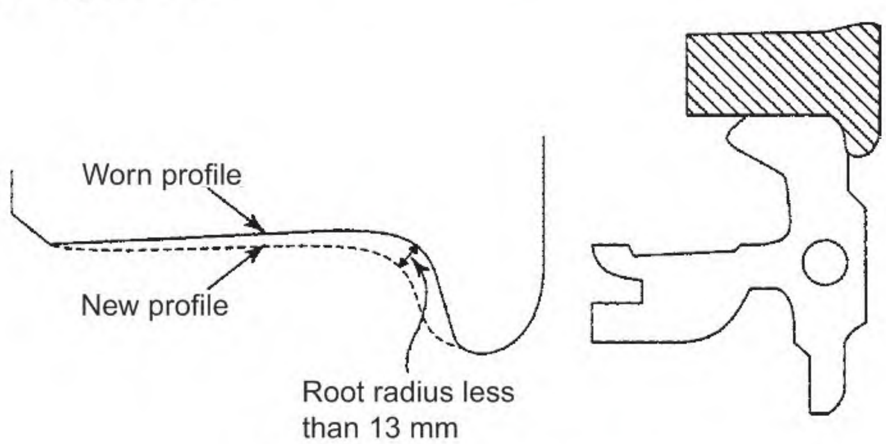


Fig. 22.32 Worn root

Effect on Safety (a) μ increases with the increase in value of R (b) increase in positive eccentricity.

Deep Flange When the depth of the flange as measured from the flange top to a point on the wheel tread (63 mm away from the back of BG wheel and 57 mm for MG) becomes greater than 35 mm (BG) and 32 mm (MG), the condition is called deep flanges. In this conditions, the wheel flange coupled with vertical wear of rail seat, would tend to ride on the fishplates and check blocks (Fig. 22.33).

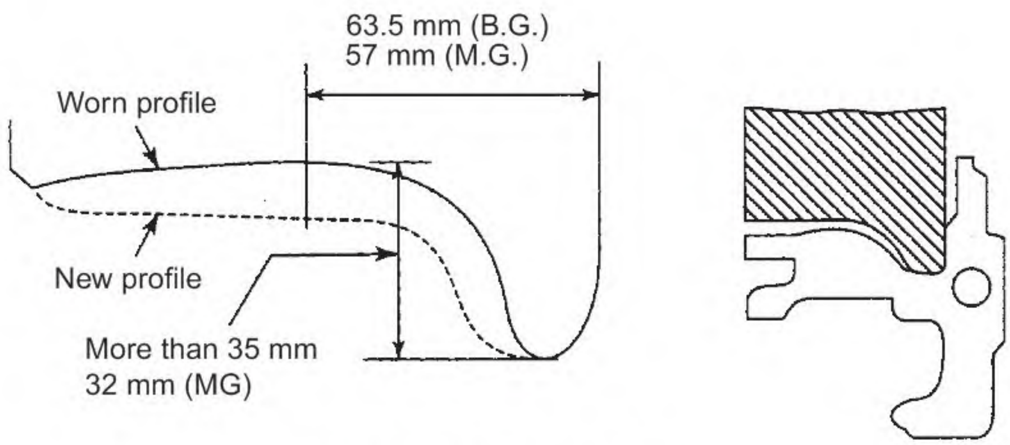


Fig. 22.33 Deep flange

Hollow Tyre of False Flange When the projection of the edge of the wheel tread below the hollow tyre exceeds 5 mm, then the outer edge of wheel is called false flange, and the worn tread is called hollow tyre (Fig. 22.34).

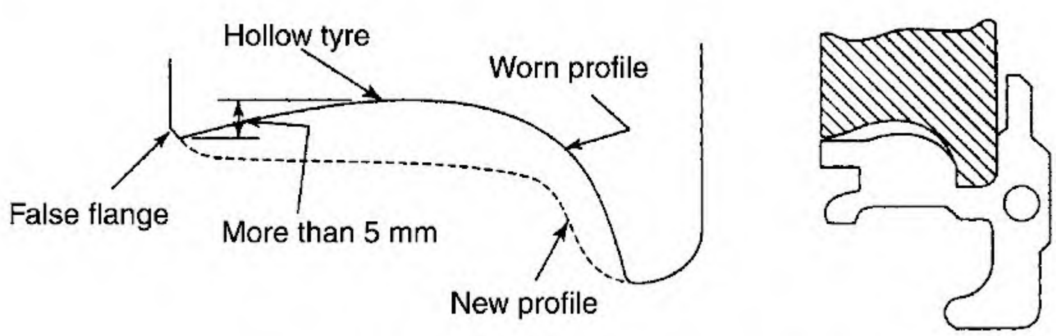


Fig. 22.34 False flange/hollow tyre

Effect on Safety A false flange may split open points while traveling in trailing direction, as the false flange may tend to get wedged in between the tongue rail and the stock rail. At crossing, the false flange will ride over the wing rails causing unstable conditions. On diamond crossings, when check rail guidance is not available, through the gap, it may lead to derailment.

22.8.1 Effective Conicity of Wheel-tread

With wear, the effective conicity increases, which has adverse effect on running stability.
Flat Tyre The maximum permissible length of flat on wheel tyre for BG.

1.	Goods stock 4-wheeler	75 mm
2.	Goods stock (bogie type)	63.5 mm
3.	Coaching stock (BG and MG)	51 mm

Wheel having flats on tyre causes high dynamic augments on the rail and lead to rail fractures.

Difference in Wheel-tread Diameters The wheel diameter is measured on the tread at a distance of 63.5 mm from the back of the wheel for BG and 57.00 mm for MG. Two measurements, viz. across the quarter points, is taken for each wheel (Fig. 22.35).

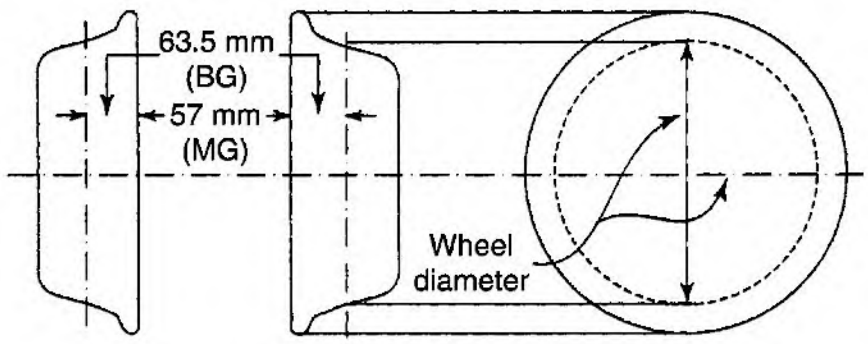


Fig. 22.35 Measurement of wheel tread diameter

The difference in wheel diameters should not exceed the maximum permissible limits indicated in Table 22.3. Of greater significance is the wheel tread diameter on the same axle. If the difference exceeds the permissible limit, the axle will move persistently angular, thereby increasing the derailment proneness appreciably. Excessive difference in wheel diameters on different axles of the same vehicle, has an adverse effect on buffer height and slope of the vehicle floor.

Table 22.3

	On the same axle		*On the same trolley*		*On the same wagon*	
	BG (mm)	*MG (mm)*	*BG (mm)*	*MG (mm)*	*BG (mm)*	*MG (mm)*
Four-wheeled trolleys	0.5	0.5	13	10	25	13
Six-wheeled trolleys	0.5	0.5	6	6	6	6
Six-wheeled units	0.5	0.5	6	6	6	6
Four-wheeled units	0.5	0.5	—	—	—	—

Wheel Gauge Wheel gauge is the back to back distance on a wheel set (Fig. 22.36). The wheel gauge should be checked at quarter points. No variation whatsoever is permitted among the values of wheel gauge measured at quarter points. Any variation in these values indicates a bent axle. A bent axle on motion will start wobbling, causing severe variations between the bearing and the journal, and consequently greater wear and friction between the two. This would result in the axles running hot, with all the bad consequences.

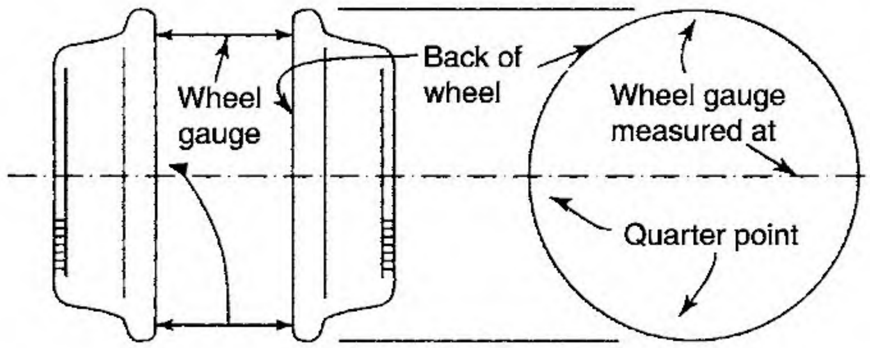


Fig. 22.36 Wheel gauge

Subject to the above condition, the actual values of wheel gauge can vary from the nominal values, between + 2 mm and – 1.0 mm for goods stock and ± 1.5 mm for coaching stock for both BG and MG.

In case the wheel gauge is more than the permissible tolerances, there would be a possibility of a relatively new wheel hitting the nose of a crossing, as wheel gauge is one of the parameters which decides the clearance at the check rail opposite the nose of the crossing.

Journal The portion of the axle, on which the bearing rests is called the journal (Fig. 22.37). The cross-sectional centre of the journal has to be coaxial with those of the axle and the wheel: otherwise the journal centre itself would revolve causing severe vibrations in the bearing journal assembly leading to hot axle. Similar is the position when the journal's sectional wear is uneven. As journal diameter wears down, a thicker bearing can be used to maintain the axle box level.

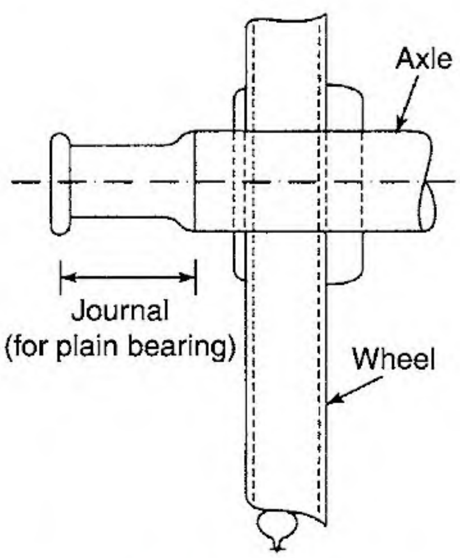


Fig. 22.37 Journal

Axle Box Axle boxes are basically of two types.

1. *Plain bearing axle box*: In this type of axle box, a brass bearing with its bottom portion formed of white metal ensures, along with lubrication, a low coefficient of friction between the bearing and the revolving journal (Fig. 22.38). The axle box top plate rests on the bear-

ing, with a slipper plate in between for adjustment of levels of the axle box top. The axle box contains oil soaked packing for lubrication of the journal.

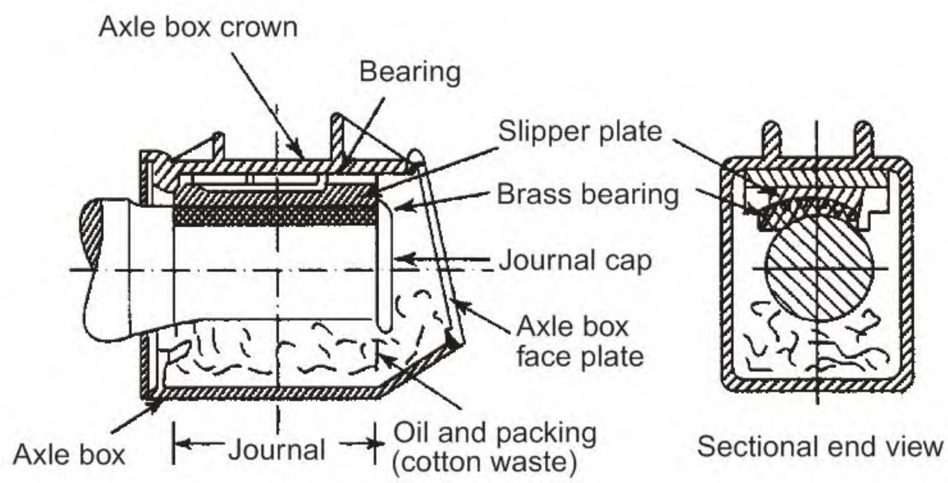


Fig. 22.38 Plain bearing axle box

Defect which affect safety are as follows:

(a) Bearing brass of in correct size to meet the journal.
(b) Bearing brass not seated uniformly on the journal.
(c) Axle box level not adjusted by correct thickness of slipper plates.
(d) Oil or packing deficiency.

Any of the above defects can lead to hot axle condition which further leads to persistent angular running of the axle and off-loading with the burning of the white metal.

Roller Bearing Axle Box This type of bearing needs less maintenance attention. There is a possibility, however, of roller bearing getting fractured and causing a jam or lubrication may be inefficient. These defects can lead to hot axle conditions.

PRO and PR Plates PRO and PR plates are fitted on the wagon body which indicate the date and station where a particular level of attention was last given to the bearing axle box.

In PRO, P stands for periodical overhaul, R for repacking and O for oiling for plain bearing. In PR plates, P stands for periodical overhaul, and R for reexamination and greasing of axle boxes—for roller bearings. When investigating derailment involving axle boxes, it should be checked up as to whether bearings have received their scheduled attention or not.

Play of Bearing at the Journal Minimum and maximum lateral play between the bearing brass and the journal (Fig. 22.39), is as follows.

$$\text{BG}\frac{-5\,\text{mm}}{+10\text{ mm}}$$

$$\text{MG}\frac{-3\,\text{mm}}{+6\text{ mm}}\text{ for trolley and }\frac{-3\,\text{mm}}{+10\text{ mm}}\text{ for 4-wheeler}$$

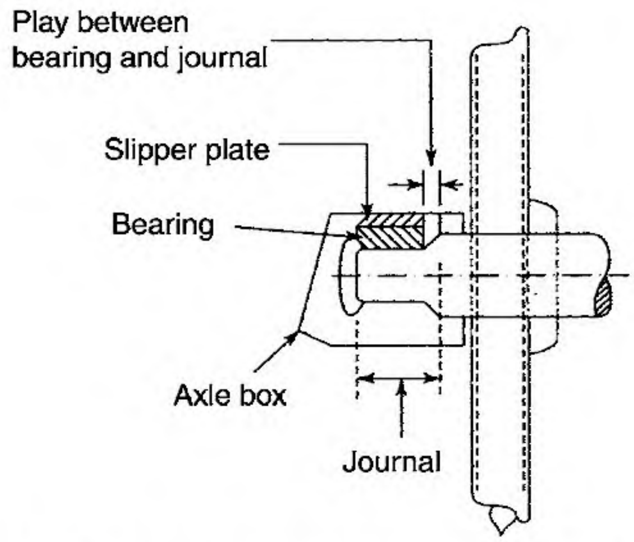


Fig. 22.39 Play of bearing at journal

If play is excessive than (1) lateral oscillations increase, affecting Y and Q adversely and (2) angularity of the axle increases.

Axle Guard and Axle Box Groove Axle guard, horn cheeks passing through the axle box grooves (Fig. 22.40), perform three important functions.

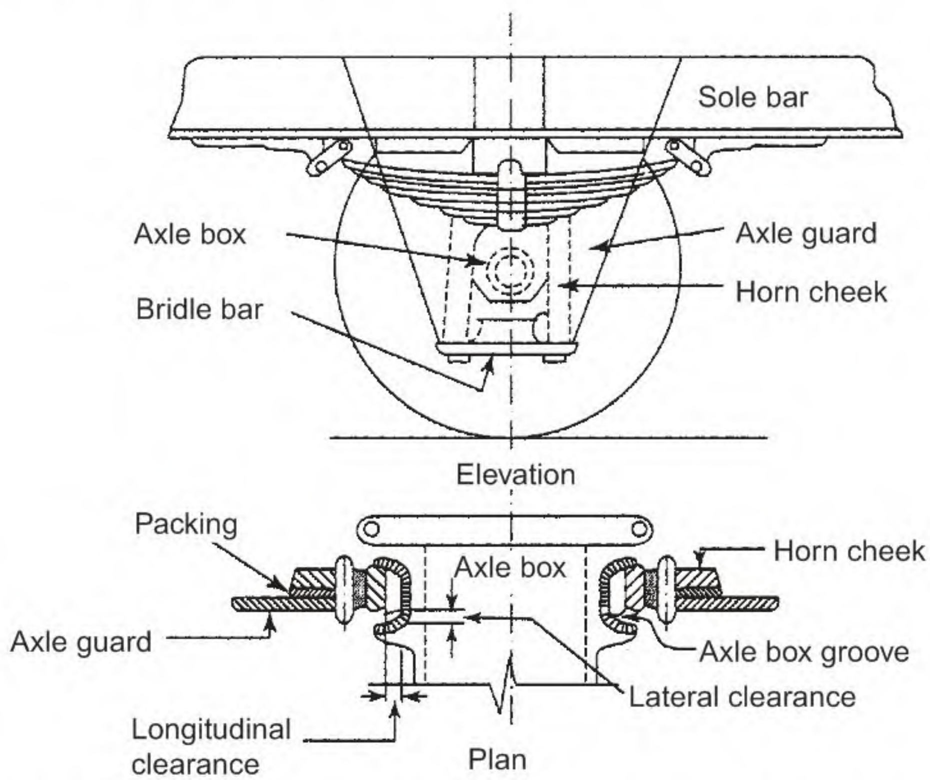


Fig. 22.40 Axle guard, horn cheek and axle box groove

1. To hold the axle in position in a rigid wheel box.
2. To permit unhindered relative vertical movement between the vehicle body and the axle, to enable the springs to deflect and function freely.
3. To transmit the tractive and braking forces to the axle.

To ensure maximum life of the axle guards, a piece called horn cheek is riveted to the axle guard. The horn cheek passes through the axle box groove and rubs against the groove's surfaces. On wearing out, the horn cheek can be replaced by a new one, without the need for replacing the entire axle guard. In 4-wheelers, the axle guards on either side of the axle box are connected together by a bridle bar below the axle box.

Clearance between the Horn Cheek and Axle Box Groove The minimum lateral and longitudinal clearance, between the axle guard and axle box or the horn cheek and the axle box, with plain bearing are indicated in Table 22.4.

Table 22.4 Goods and Coaching Stock, Bogie and 4-wheeler BG and MG

	Lateral clearance	*Longitudinal Clearance At* (for coaching stock only)	
Maximum	6 mm	3 mm	After POH
Minimum	10 mm	10 mm	any time in service
		2. *Box wagons*	
Minimum	20 mm	12 mm	After POH
Maximum	25 mm	18 mm	any time in service

Note: Longitudinal clearance for 4-wheeler goods stock are not specified, but axle box should not be worn out.

Effects on safety with increased clearance are as follows:

1. Lateral oscillations will increase causing adverse effect on Y and Q.
2. Increased angularity of axle.

Defects in axle guards considered unsafe as per IRCA. These are given below:

1. Axle guard worn or expanded sufficient to permit either leg to work out of its groove in the axle box.
2. Any portion of the axle guard horn cheek broken or deficient.
3. Axle guard so bent as to permit free movement of axle box.
4. Axle guard cracked.
5. One or more rivets deficient, broken or of wrong size.
6. Any axle guard leg shaking due to slack rivets.
7. Bridle bar broken or deficient.
8. Bridle bar without jaws or turned ends.

Additional for coaching stock, they are mentioned hereunder:

1. Two or more rivets slack in any one leg of an axle guard.
2. Bridle bar of wrong size.

Note: In some rolling stock, viz., WDM_2 diesel loco, there is no bridle bar.

Any tendency for jamming of the axle guards in the axle box groove would interfere with the working of the spring and thus increase the derailment proneness of the vehicle.

When axle guards transmit the tractive or braking forces, only one of them can bear against the axle box groove wall. If the bridle bar is not there, only one particular axle guard will transmit the load and may get bent in the process. This would prevent its free movement in the groove and interfere with the working of the spring. The bridle bar thus enables the two axle guards to share the transmission of tractive and braking forces, apart from functioning as a connecting member between the two axle guards and thus imparting rigidly to them. In some rolling stock, where axle guards are extra strong, the bridle bar may not be provided.

22.8.2 Springs

Springs commonly used are of two types.

Leaf or Laminated Spring A number of plates of graded length, held together by a spring buckle form a leaf spring or laminated spring. The ends of the longest plate are bent into eyes (Fig. 22.41).

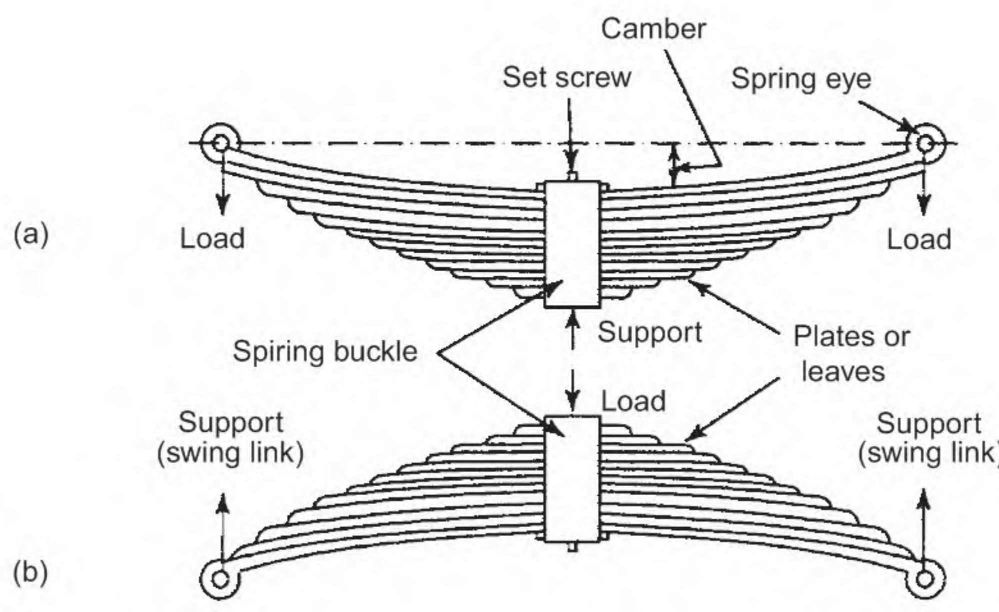


Fig. 22.41 Leaf or laminated spring (a) normal (b) inverted

The camber when the spring is free without any load is called a free camber. Under load, the spring deflects and camber changes. Such camber which varies with load is called the working camber.

Helical Spring A rod or wire coiled with a certain pitch forms a helical spring. When the outer coil has one or more inner concentric coils, it is called a nest of springs.

Spring Gear Defects and Tolerances The defective behaviour of a leaf or laminated springs is determined by checking its free camber and working camber.

Tolerance permitted in free camber are:

1.	Loco and carriage springs	– 0 + 3 mm
2.	Goods stock BG	– 0 + 6 mm
3.	Goods stock MG	– 0 + 5 mm

For measuring the working camber of the springs, the vehicle should be made to stand on a level track and then loaded to full carrying capacity ensuring that the load is not eccentric. In case of a 4-wheeler wagon, the difference in working cambers between any two of four springs should not exceed 13 mm. If the defect is in two diagonally opposite springs, the vehicle becomes more derailment prone.

Shackle Plates and Scroll Iron The common assembly by which a vehicle, e.g. 4-wheeler goods wagons, is suspended from the ends of a laminated spring is known as shackle suspension (Fig. 22.42).

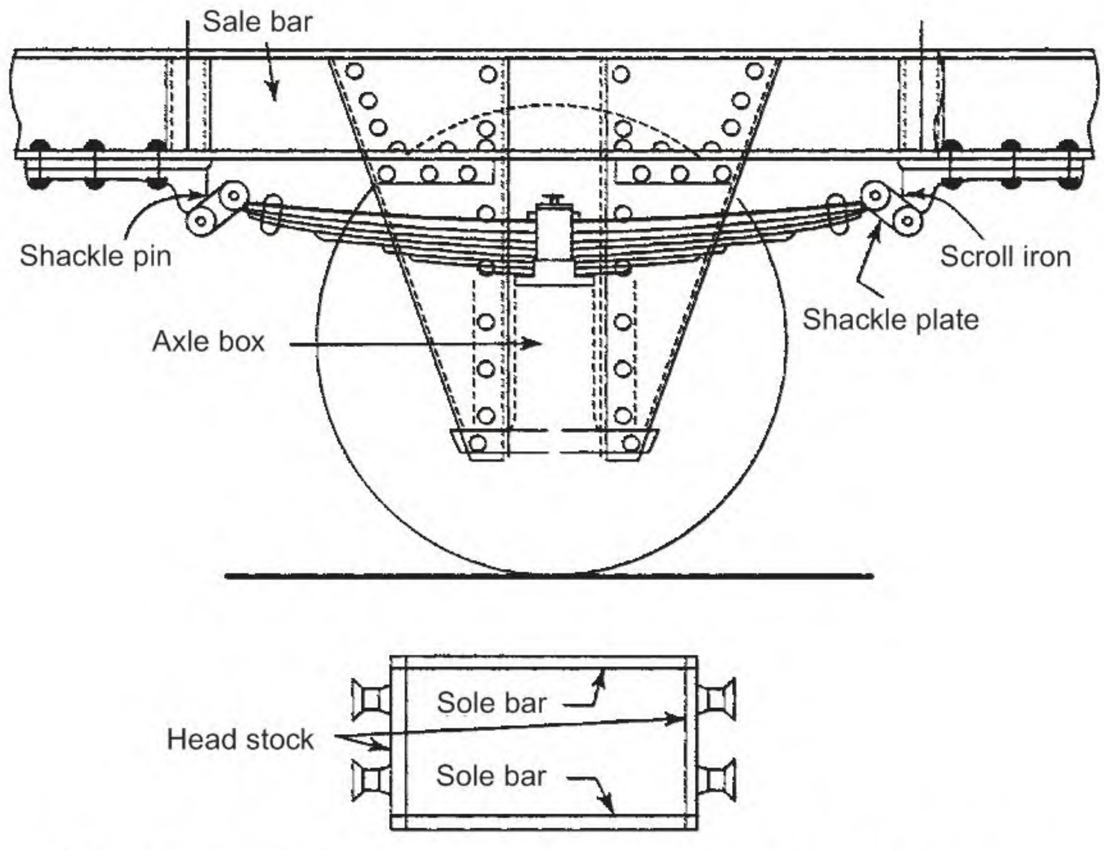


Fig. 22.42 Shackle suspension of 4-wheeler goods wagon

For such goods and coaching stock suspension, the following conditions are ensured.

1. Eye hole is laterally parallel, smooth and free from burrs and not bell mouthed. Eye end is clear of the top plate surface by at least 2 mm.
2. Eye holes are parallel to each other on the top plate.
3. Clearance at the shackle pin:

(a) Initial lateral clearance between shackle pin and shackle plate or between shackle pin and scroll iron not exceed 1.5 mm.
(b) Initial lateral clearance between shackle pin and spring eye shall not exceed 1.5 mm. Above clearance (i) after P.O.H. shall not exceed 2 mm, (ii) maximum in service will be 4 mm.
(c) Clearance along the length of shackle pin shall not exceed (i) 1.5 mm for shop tolerance and (ii) 3.0 mm during service.

Defects in springs and spring gears which are unsafe as per IRCA are as follows:

1. Any plate of a laminated bearing spring or any coiled bearing spring cracked or broken.
2. Bearing spring buckle loose, broken, cracked and/or packing plate loose or deficient.
3. Any plate or buckle loose and/or displaced from its central position by 13 mm or more.
4. Bearing spring shackle not sitting square in the axle box housing or crown packing where fitted.
5. Flange of any wheel within 25 mm of the bottom of a wagon.
6. Incorrect type of bearing spring for a particular design of wagon.
7. Scroll iron fractures, deficient of a rivet or fitted with a loose or a wrong size rivet.
8. Scroll iron shifted or out of alignment by more than 25 mm.
9. Shackle spring hanger cracked or broken or nut or jib cotter deficient or defective.
10. Bearing spring hanger cracked or broken or nut or jib cotter deficient or defective.
11. On MG wagon, bearing spring shoe fractured or with a rivet, bolt or stud, broken or deficient or bolt or stud of wrong size.
12. Bearing spring eye or shackle plate touching the sole bar in static or dynamic condition. The defect in dynamic condition can be confirmed by the presence of rubbing mark at the bottom surface of the sole bar. When a laminated spring deflects, it elongates thereby causing the shackle plate to move up as shown in Fig. 22.43.

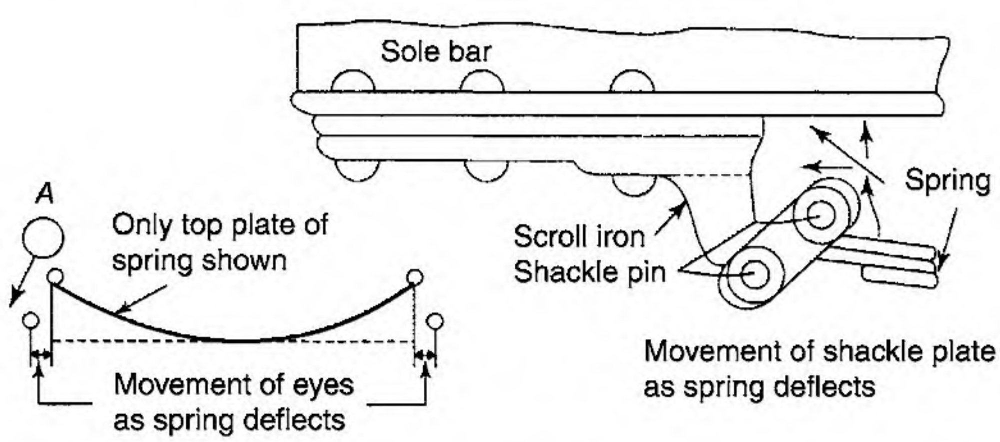


Fig. 22.43 Under load, spring eyes move outwards. For such movement of spring eye to be possible, shackle plate has to move arcing outwards which results in vertical component of movement

Thus if the movement of shackle plate is prevented, it, in effect, prevents the deflection of the spring and renders it ineffective and hence derailment prone.

Additional Defects for Coaching Stock

1. A variation in the type of bearing spring under the same vehicle, i.e. difference in the number, thickness, or width of spring plate only. It is however permissible for the top plate of a bearing spring to be thicker by 3 mm than the other plates of the other spring and the top plates of the spring of a vehicle. This however does not apply to TLRs which are fitted with springs of different sizes on the two trolleys.
2. Side control springs (left type) and/or drag link broken are deficient on BEML type.

Stiffness of Springs It should be checked whether the spring leaves are so rusted as to render the spring stiff, as this condition would reduce the ability of the vehicle to negotiate track twist without the residual wheel load dropping to too low a value.

Helical Spring Defects Common defects in helical springs are:

1. Cracked or broken spring.
2. Shifted spring.
3. Spring fully compressed.
4. Loss of elasticity resulting in the spring getting fully compressed in dynamic condition causing shocks.

22.8.3 Damping

Friction Damping The commonest example of friction damping is the laminated spring itself. As a laminated spring deflects under load, relative sliding takes place at the inter-surfaces of the various plates, causing interleaf friction. A laminated spring has thus built in damping and normally no separate damper is required. Spring loaded friction snubber provided between bolster and bogie frame is another example of friction damping (Fig. 22.44).

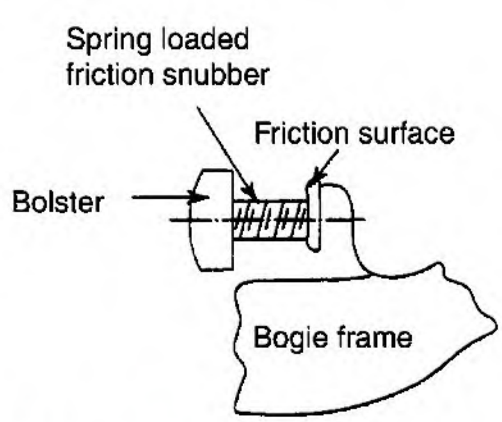


Fig. 22.44 Spring loaded friction snubber

Hydraulic Damping Telescopic cylindrical guards immersed in oil, commonly known as dash pots, is a common type of hydraulic damper.

Defects in Damping System Any defect that tends to reduce the amount of damping in the system would contribute to derailment proneness through adverse effect during possible resonance. In a hydraulic damper, the level of oil has to be correctly maintained within stipulated limits. In the case of ICF, the oil level in the hydraulic dash pot is required to be checked every month and oil replenished if it is below 80 mm incase of BG and 71 mm in case of MG-ICF bogies. Overfilling of oil in the dash pot should be avoided as it renders the suspension stiff.

Under IRC rules, a broken dash pot on ICF trolleys comes under unsafe category.

Bogie Rotation Any hindrance to bogie rotation is an important defect to look for in the event of any bogie stock being involved in a derailment. It has the effect of increasing the effective rigid wheel base, thereby causing high positive angularity and flange forces to occur. If jammed on a curve it will result in persistent angular running of the axle on the straight.

Possible defects are (a) uneven wear at the supporting surfaces, (b) lack of lubrication, where needed and (c) ingress of dirt, coal ash etc., between the surfaces in contact (Fig. 22.45).

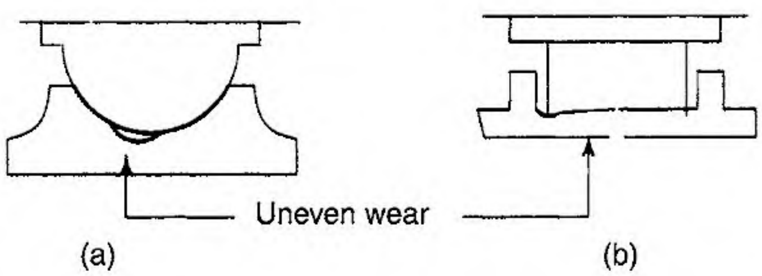


Fig. 22.45 (a) Uneven wear in hemispherical pivot (b) Uneven wear in flat pivot

Brake Gear On application of brakes, the brake pressure on the two wheels of an axle should be more or less equal, otherwise the wheel which is braked less would tend to travel more causing the axle to become angular. In such a situation, the axle would run persistently angular during brake application. The defects which would cause the above condition to occur are:

1. Deficient brake block.
2. Incorrect centralization and adjustment of brake rigging and brake blocks.
3. Uneven application of brake power and wear in gear.
4. Uneven wear in brake block on the same axle.

The defects which are unsafe for *goods and coaching stock* (BG anaxle and MG) are described below:

1. Vacuum cylinder trunnion or bracket broken or any bolt or rivet deficient or welding failed.
2. Brake block deficient, broken at the eye, not secured properly by correct size cotter, nut with split pin and/or leg with split pin, or so worn and thin that the flange of the wheel is 6 mm or less from the brake beam collar on brake application.
3. Any defect in brake rigging, preventing application of release of brakes.
4. Any brake rigging pin, split pin or cotter free to work out deficient or broken.
5. Safety hanger or bracket for brake beam or pull/push rod deficient, broken, wrong size or not properly secured.

For Coaching Stock Beside the above facts vacuum reservoir suspension bracket broken, deficient or not secured properly are also unsafe defects.

22.8.4 Twist in Underframe

Longitudinal Twist This can be defected by measuring the length of the diagonals joining the four corners of the underframe after keeping the vehicle on a level track. A longitudinal twist would cause the axle to remain persistently angular to the track thus increasing the derailment proneness.

Vertical Twist The vertical twist is defected by measuring the height of the sole bar at the four corners of the underframe above the rail level, keeping the vehicle on a level track. A twist in underframe is equivalent to a twist in the track and thus will increase the derailment proneness of the vehicle. A vertical twist of 20 mm can appreciably increase the derailment proneness.

The underframe defects unsafe as per IRCA Rules in Goods and Coaching Stock (BG and MG) are as follows:

1. Crack visible on both sides of the web or loose patch on any rolled or pressed section or built up girder forming part of the underframe. A weld unsupported by a patch on a web or a patched member which shows sign of crippling.
2. Head stock bent so that the centre of the buffer face is displaced in any direction more than 35 mm from its normal position in case of BG goods stock or 38 mm in case of BG coaching stock. However it is strictly to be observed that no packing is permitted on wagons for repairs.
3. Truss rod brackets deficient or fractured.

22.8.5 Buffers

Buffer defects have significant effect on derailment proneness. It is basically due to the eccentricity of buffing forces caused by such defects. The eccentricity in buffing forces can be in the following directions:

1. Vertical direction, in which case Q values are effected.
2. Horizontal direction, when Y values are effected.
3. Inclined direction, when both Y and Q are effected.

22.8.6 Examples of Such Deficiency

1. *Defect Resulting in Vertical Eccentricity of Buffing Forces*
   (a) Difference in height of buffers of adjoining vehicles. This can happen at the junction of a set of empty and a set of loaded wagons (Fig. 22.46).

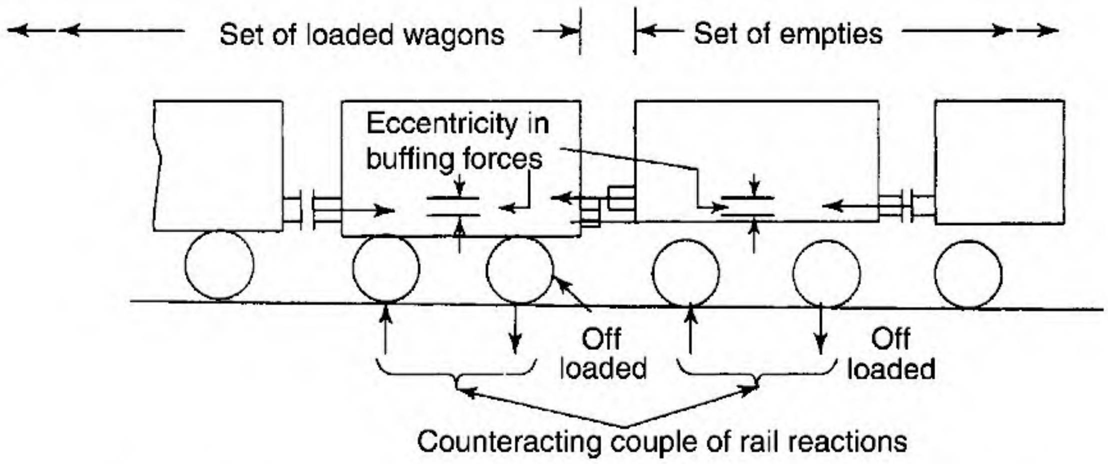


Fig. 22.46 Effect of vertical eccentricity in buffing forces at junction of a set of empties and a set of loaded wagons

Maximum and minimum permissible buffer height in BG and MG stock (goods and coaching) are shown below:

	Empty maximum	*Loaded minimum*
BG	1,105 mm	1,030 mm
MG	585 mm	535 mm

Note: To make up the buffer heights to maximum permissible limits due to reduced diameter of wheels, a packing piece of required design and size may be interposed between axle box crown and spring buckle.

(b) Drooping buffer.

(c) Buffer displaced vertically from its normal position due to head stock being bent (limits given in Sec. 22.8).

2. *Defects Resulting in Horizontal Eccentricity of Buffing Forces*

(a) Buffer deficient

(b) A dead buffer, i.e. when it is ineffective and when its projection from the head stock (on BG) is below the prescribed minimum limit.

(i) Good stock — for long base – 584 mm
for short base – 406 mm
(Maximum limits are 635 mm and 456 mm respectively).

(ii) Coaching stock – 584 mm
(maximum limit is 635 mm)

Note: Nor more than one dead buffer is permitted on two consecutive wagons on a train. However, no dead buffer is permitted for coaching stock.

3. *Defects Resulting in Eccentricity Forces in both Directions* Buffer face displayed from its normal position in an inclined direction due to head stock being bent. On BG maximum permissible displacement of buffer face due to head stock being bent is 35 mm in any direction from its normal position in case of coaching stock.

Listed below are also defects in Buffing gear which are unsafe as per IRCA Rules.

BG Goods Stock

1. Buffer deficient.
2. More than one dead buffer one two consecutive wagons on a train.
3. More than three rivets or counter sunk bolts missing from a buffer plunger.
4. Buffer spindle broken or nut deficient or of incorrect size.

BG Coaching Stock

1. Buffer deficient or drooping.
2. Any buffer dead.
3. Buffer spindle broken or nut deficient.

MG Goods and Coaching Stock

1. Wagon fitted with a buffer of other than a screw coupling type.
2. Buffer or its component parts deficient or so defective as to prevent tight coupling.
3. One wing of the buffer face cracked or missing if below level of *"U"* in the buffer face.
4. Buffer spring deficient, broken in more than two pieces or of incorrect size.
5. Buffer coupling hook bolt not secured according to relevant IRCA rules.
6. Wagons not fitted with buffers of a non-rotatable type or with some form of anti-turning device other than a liner.
7. Buffer shank worn more than 13 mm through any section or less than 45 mm diameter over tread.
8. Buffer shank with nut, check nut split pin or cotter deficient or of wrong size (when split pin is used, a check nut must be fitted).
9. Buffer head cracked 19 mm or more from coupling pin hole.

Irregular Loading (*BG stock*)

1. Difference of height from rail level of more than 64 mm between any two buffers on the same vehicle measured at the head stock.
2. Flange of any wheel within 25 mm of the bottom of the vehicle.

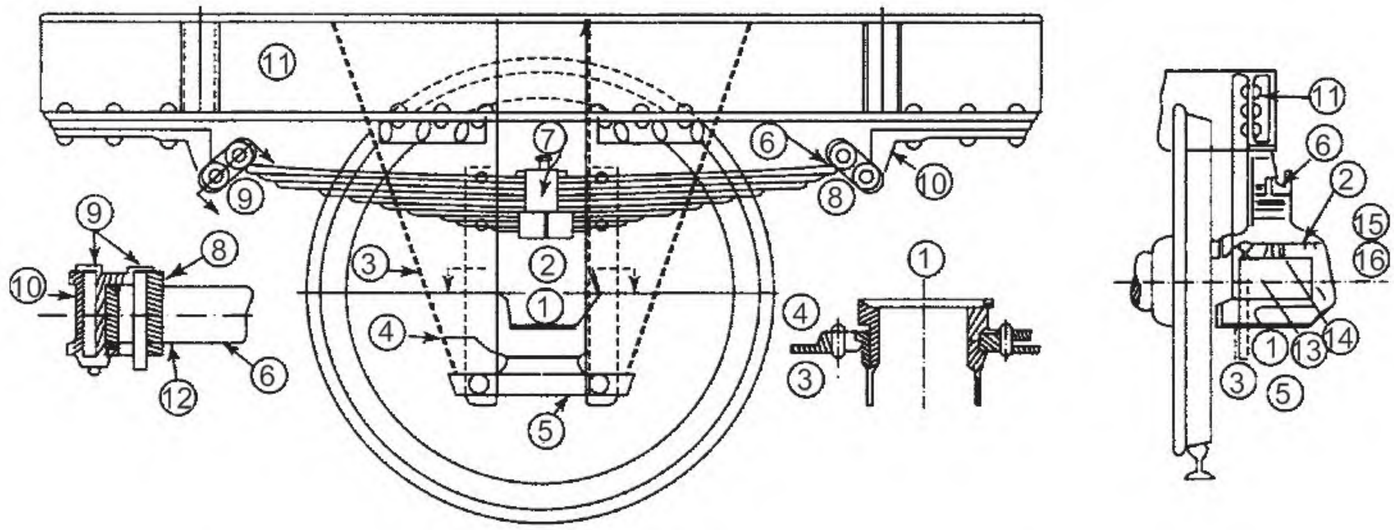
22.9 IMPORTANT FEATURES OF THE MAIN TYPES OF ROLLING STOCKS USED ON INDIAN RAILWAYS

At the time of derailment investigation, the permanent way officials, who generally form part of the investigation team, have to comment on the road worthiness of the rolling stock involved in the derailment. For that purpose, it is necessary that the permanent way officials acquaint themselves with the functioning of the rolling stock bogie system and the tolerance permitted for their safe operation.

In the following paragraphs important features of the main type of rolling stock, have been explained with the help of sketches. The tolerances limits and the rules framed for their safe movement have also been brought out.

Items and features to be checked for defects during derailment investigation: Wheel set: Thin flange – Sharp flange – Worn root – Deep flange – False flange/hollow tyre – Flate tyre – Difference in wheel tread diameters – Wheel gauge.

Journal, bearing and axle box, axle guards, horn cheek and bridle bar Horn cheek – axle box groove guidance and clearances, Laminated bearing springs – free and working camber – Scrag test – general assembly of whole spring gear and clearances at shackle pins – whether rusted – top of spring eye or shackle plate, whether touching the bottom of sole bar (in static or dynamic condition) Scroll iron, shackle plates and shackle pins, Twist vertical or longitudinal in underframe, Buffing gear Brake gear. Any component of wagon loose, shifted, bent, cracked broken, deficient or missing.



1. Plain bearing axle box	5. Bridle bar	9. Shackle pins	13. Journal
2. Axle box crown	6. Laminated bearing spring	10. Scroll iron	14. Bearing brass
3. Axle guard	7. Spring buckle	11. Sole bar	15. Slipper plate
4. Horn cheek	8. Shackle plate	12. Spring eye	16. Packing and oil
			17. Wheel

Fig. 22.47 General suspension arrangement of conventional 4-wheeler wagon

22.9.1 BOX and BOX'N Wagons

Bogie goods stock on Indian Railways mainly consist of BOX and BOX 'N type of wagons. BOX wagons are fitted with UIC bogie having a primary suspension system (Fig. 22.48).

BOX wagons have been giving generally a satisfactory service in Indian Railways for the last three decades.

To improve the throughput of traffic, BOX 'N wagons are being progressively inducted into the system BOX'N wagons have shorter length and greater height compared to BOX wagons. With the same axle load, but by obtaining higher loading density, it is possible to accommodate greater gross trailing load on the existing loops, with the use of BOX 'N wagons.

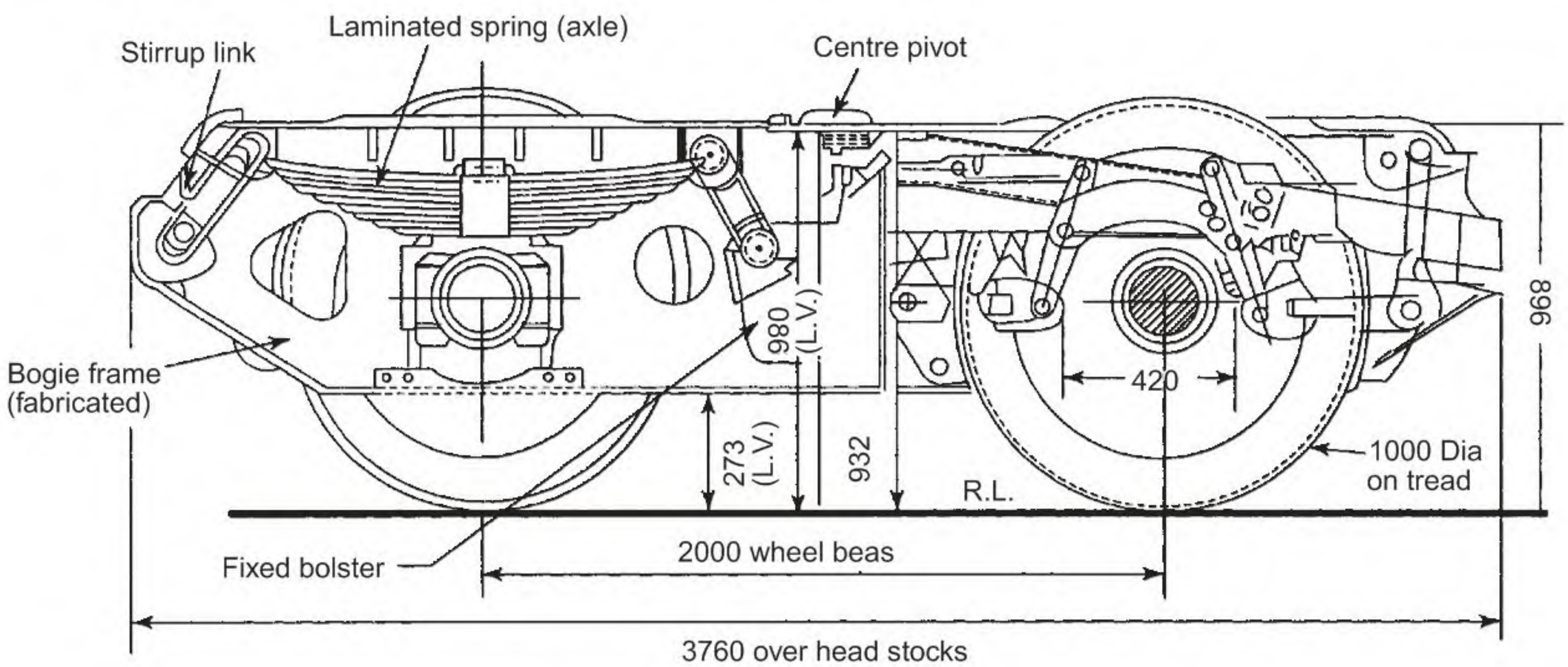


Fig. 22.48 UIC bogie (Box)

BOX'N wagons are fitted with CASNUB bogies having a secondary suspension system (Fig. 22.49).

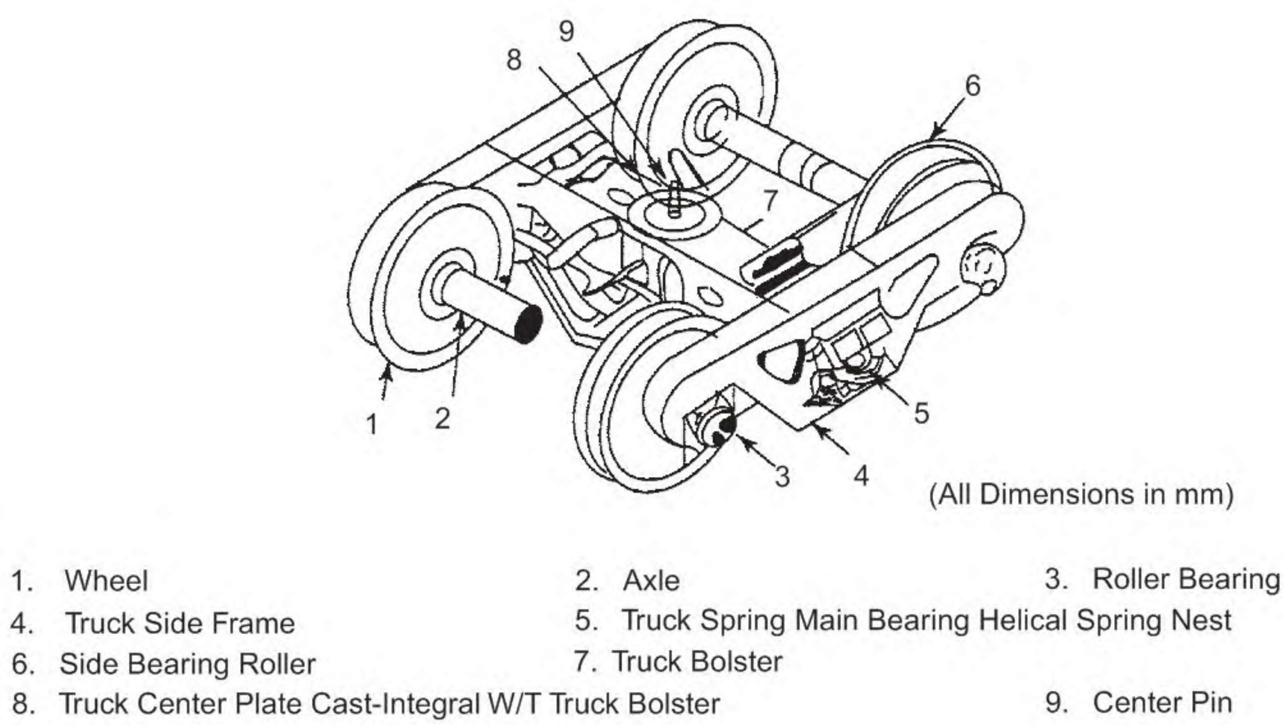


Fig. 22.49 CASNUB bogie (BOX'N)

To reduce rail/wheel wear problem, CASNUB bogie has been modified. The modified CASNUB-22 (M) bogie has been provided with Elastomeric pads at the primary level and side bearer rubber pads, which have improved its running characteristics.

Comparative parameters of BOX and BOX'N wagons are as follows.

Table 22.5

Items	*BOX wagon*	*BOX'N wagon*
Ht. of centre of gravity	X	X + 600 mm
Gross Wt. (t)	81.2	81.2
Length (m)	12.8	9.8
Pay: Tare ratio	2.24	2.72
Gross load/m (t)	5.92	7.59
Gross load/train (t)	3,500	4,500
Length over coupler faces (mm)	13,716	10,713
Length in side (mm)	12,792	9,784
Width inside (mm)	2,853	2,950
Ht. inside (mm)	1,880	1,950
Floor ht. (mm)	1,275	1,275
Overall ht. (mm)	3,155	3,255
Dia of wheel	1,000	1,000
Wheel base	2,000	2,000
C/c of journal	2,240	2,260
Area of pivot	630.5 sq.cm	618.sq.cm
Unsprung mass/Axle	1.97 t	2.34 t*

* Provision of elastomeric pad should reduce the effective unsprung mass.

22.9.2 Items Requiring Examination after Derailment

In addition to the normal examination of wheel set, suspension system and other bogie imperfections, some important tolerances applicable to BOX and BOX'N wagons are given in the following paragraph.

UIC BOX Bogie

Some important tolerances limit	*Minimum*	*Maximum*
Lateral play between axle box lug and horn cheek	20 mm	25 mm
Longitudinal clearance between axle box lug and horn cheek	12 mm	18 mm
Wheel gauge	1,599 mm	1,602 mm
Buffer height	1,030 mm	1,105 mm
Lateral play between brass and journal of trolley	5 mm	10 mm
Lateral clearance between axle box and horn cheek	6 mm	10 mm
Longitudinal clearance between axle box and horn cheek	4 mm	7 mm

Maintenance Schedule

Trip examination at originating and terminating stations
Routine overhaul once in 18 months at selected TXR depots, and sick line examination depots.

BOX'N Wagon

Important tolerance limits	*Nominal*	*Maximum*
Lateral clearance sideframe and bolster	18 mm	21 mm
Lateral clearance sideframe and axle box adapter	25 mm	28 mm
Longitudinal clearance sideframe and axle box adapter	2 mm	9 mm
Longitudinal clearance sideframe and bolster	4 mm	7 mm
Clearance between anti-rotation lug and bolster	4 mm	—

Maintenance Schedule

Period	*Nature of overhaul*
12 months	ROH (Routine overhaul)
24 months	IOH (Intermediate overhaul)
36 months	ROH (routine overhaul)
48 months	POH (Periodic overhaul)

22.9.3 Bogie Coaching Stock

There are basically four type of bogie coaching stock in Indian Railways.

1. IRS—Indian Railway Standard.
2. ICF laminated (schlieren)-Integral Coach Factory make.
3. BEML—Bharat Earth Movers Ltd.
4. ICF all coil.

All the above stock have two stage suspension bogies.
Bogie frame defects considered unsafe as per IRCA rules They are enumerated below.

1. Trolley frame visibly out of square/damaged.
2. Any member of trolley cracked or welding failed. This shall include knee plates, gusset plates, and diagonal bars with their rivets broken or deficient.
3. Bearing spring hanger bracket cracked or broken.
4. Bolster or spring plank cracked or broken or bolster improperly secured.
5. Bolster safety brackets cracked, broken or its pin or retainer deficient.
6. Rocker bar/swing link broken and/or top or bottom axle displaced, cracked or broken.
7. Pivot plate, casting or pin broken and/or nut deficient.
8. Any part of the side bearer assembly improperly secured or deficient.
9. Bolster rubbing block/plate (on BEML) deficient.
10. Centre bearing corner (on BEML) broken or cotter deficient.
11. Swing bolt or its safety bracket (on BEML) broken or deficient.
12. Bolster top truss (on BEML) broken/damaged and any of its pins deficient, broken or free to work out.

13. Bolster bottom bars (on BEML) cracked, broken or damaged on its bracket or bracket bolts deficient.
14. Bolster spring safety bolt (on BEML) broken or its nut deficient.
15. Axle box holding arm (on BEML trolley) broken or deficient or any of its securing stud/nut loose or deficient.
16. Anchor link broken or its pin deficient or free to work out.
17. Any safety strap bracket of wrong size or broken, deficient or improperly secured.
18. Equalising stay (on ICF all coil type) broken or deficient.

22.9.4 Diesel and Electric Locomotives

WDM_2 Locomotive Apart from the defects discussed for rolling stock in general, the following components need special examination.

1. The surface of the centre pivot as well as of the two side bearers should be checked to see if there is any tendency for causing hindrance to bogie rotation.
2. The condition of spring loaded friction snubbers should be checked to see whether damping is adequate or not.
3. The equalizing beam should swivel freely at their point of support on the axle boxes, otherwise off-loading of one wheel will not be shared by the adjacent wheel or wheels.

WDM_2 Modified Beyond 115 kmph, WDM_2 locomotive exhibit unsatisfactory riding characteristics in the lateral mode. To increase potential of this locomotive, resilient thrust units have been provided at the axle boxes of the outer axle of each bogie. With this modification and some other minor changes, WDM_2 (modified) locomotive has been cleared for a maximum operating speed of 120 kmph.

When the rubber cone in the resilient thrust unit wears out, its beneficial effect is lost and the loco behaves as WDM_2 only, for which the maximum permissible speed is 110 kmph. In WDM_2 (modified) loco, therefore, the resilient thrust should particularly be checked when the loco is scheduled to run at 120 kmph.

WDM_4 Locomotive Apart from the general defects, the following components need examination.

1. The surface of the centre pivot should be checked for any hindrance to bogie rotation.
2. Condition of resilient thrust unit; the rubber pad if worn out would have adverse effect on the lateral riding characteristics of the locomotive.
3. Condition of the spring loaded friction snubbers.

YDM_4 Electric Loco The defects to be checked during derailment investigations would be the same as in the case of WDM_2 loco.

22.9.5 Special Bogie Freight Stock

Broadly there are three categories of such stock in the Indian Railways. (a) box wagons, (b) diamond frame bogie and (c) three piece truck. All of them have the following features in common:

1. They have a high pay load to tare ratio.
2. Axle box is of roller bearing type.
3. Suspension is single stage.
4. Body weight is transferred to the bolster, primarily through the centre pivot, the two side bearers (one of them at a time) provide the requisite support during vehicle motion. Hence, in all these stocks, apart from the general rolling stock defects, the surface of the centre pivot should be checked for any tendency towards jamming or hindrance against rotation.

22.10 OPERATING FEATURES

The following are the general operating features which should be checked while investigating into a derailment.

1. Excessive speed.
2. Eccentric loading or sudden shifting of load.
3. Improper train operation viz., sudden application of brakes or traction forces.
4. Off-loading tendency of 3 axle bogies on sags or humps.
5. Marshalling of the train (a) a train is derailment prone at the junction of a set of loaded and empty wagons owing to difference in heights and (b) empty wagon marshalled between two loaded wagons, can get-off-loaded and derailed.
6. Lateral wheel slip on diamond crossings in the case of diesel and electric rolling stock leading to two road derailment. This is a more common occurrence in EMU rolling stock.

22.11 TRACK DEFECTS

These are broadly categorized into two types (a) defects which cause discontinuity of running lines and (b) defects in track geometry.

In the first category, track defects include rail fractures with a gap of more than 50 mm, track subsidence, obstruction on track, etc. In such cases, the cause of derailment is obvious.

To find out the contribution of defects in track geometry in a particular derailment is a complicated problem, as the safe running of vehicles on a particular track geometry is dependent upon a large number of factors. They are:

1. Speed of vehicle.
2. Type of vehicle.
3. Vehicle position in train composition.
4. Nature of defect in track geometry and the frequency of their occurrence on the approach track.
5. Possibility of the vehicle oscillation in any mode, with the track defect exciting that oscillation at a particular speed.

6. Behaviour of track under dynamic loading conditions, etc. For the safety of the vehicle, it is not only the track geometry at the place of derailment which is important, but the track defects and the periodicity of their occurrence on the approach also. The periodicity of a track defect will have different effects on different types of rolling stock and different effects even on the same rolling stock when running at a different speeds. In view of these complications, no country has been able to lay down safety tolerance for track.

22.11.1 Safety Limits for Track

The question is often asked as to why there are no safety tolerances for track, when safety limits for rolling stock components have been laid down. The answer lies in the fact, that the rolling stock components are factory products and they can be manufactured to desired tolerances. Their rate of wear is predictable and thus schedule can be laid down for their checking, adjustment and repair. All rolling stock have to run at a certain speed and therefore made to fit to run at that speed. No individual speed limit can be laid down for the rolling stock depending upon its condition.

As compared to that, track has a floating foundation. Its condition varies with the passage of each train. Its rate of deterioration is not clearly known. A track in its worst state can be considered safe for vehicles running at a crawling speed and thus speed restriction can be imposed for any track condition to make it safe for that speed. From the oscillation point of view, wavelength, frequency of track defects or combination of defects, their magnitudes are all different for different vehicles and for the same vehicle running at different speeds. This makes it extremely difficult to lay down safety limits of track for all types of vehicles and at all speeds.

22.11.2 Track Tolerances for Good Riding Comfort

Track tolerances for good riding comfort have been laid down by many of the world railways. Those laid down for the Indian Railways have been discussed in Chapter 17. Track is generally required to be maintained to these tolerances if unrestricted speeds are to be permitted. These tolerances are nowhere near the safety limits and thus cannot form the basis of determining the cause of derailment.

In the study of derailment mechanism, we have seen as to how the defects in track geometry make the vehicle more prone to derailment. This knowledge has to be made full use in determining the extent to which the defect in track geometry has contributed to a particular derailment. No quantitative guidelines can be laid down for this purpose and no railway in the world has been able to lay them down to some satisfactory standards.

Index

Color Plate 1

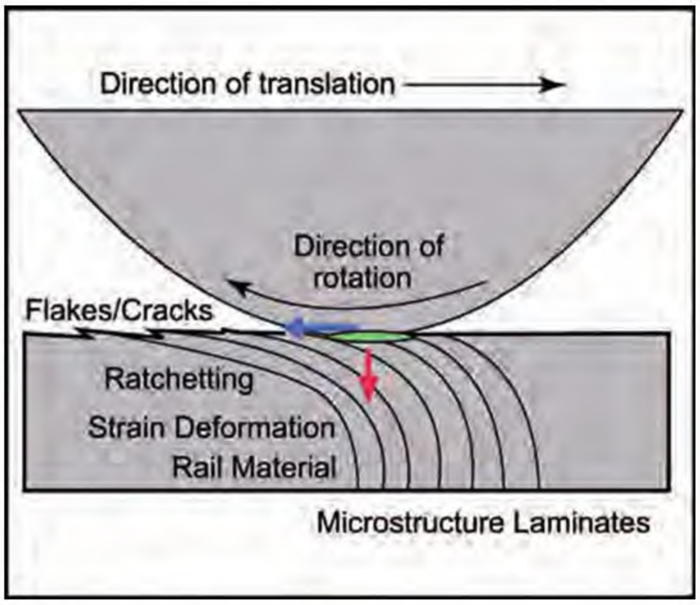


Fig. 2.4 Contact patch pressure and forces causing surface elasticdeformation of the rail microstructure, loading to RCF

Green Figure: contact patch. Blue arrow: longitudinal shear force. Red arrow: normal force

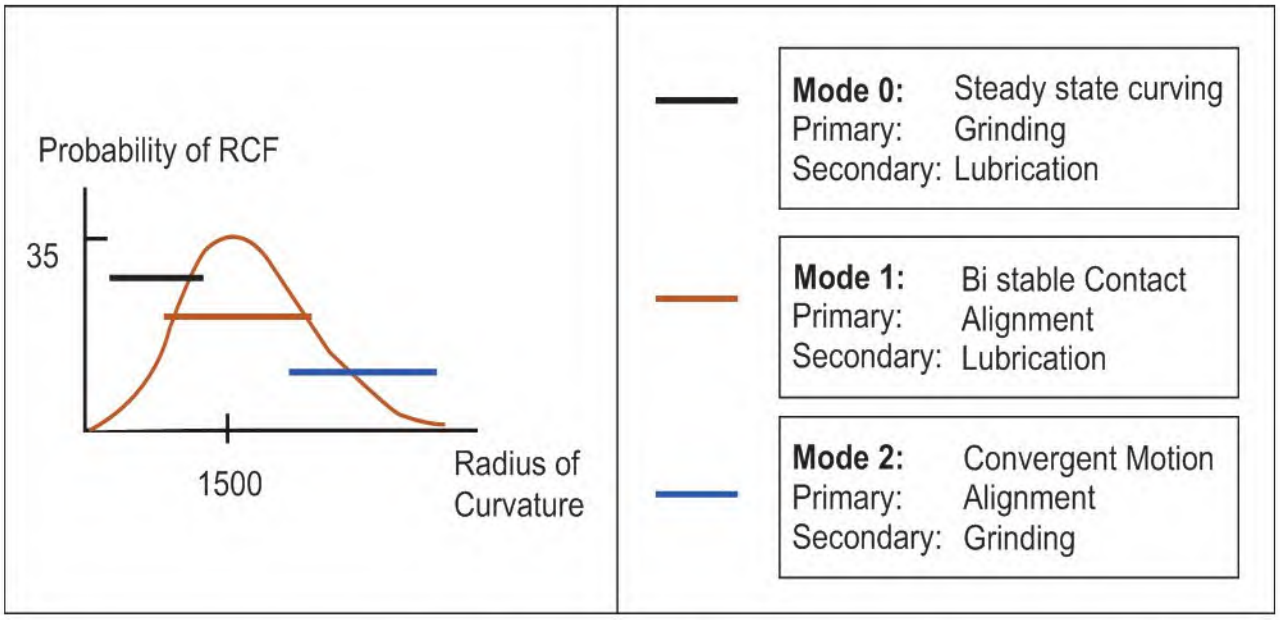


Fig. 2.5 RCF initiation modes as a function of curvature and recommended track based remediation. Overl apping influence rather than distinct boundaries exist between modes

Color Plate 2

Fig. 2. 6 (a)

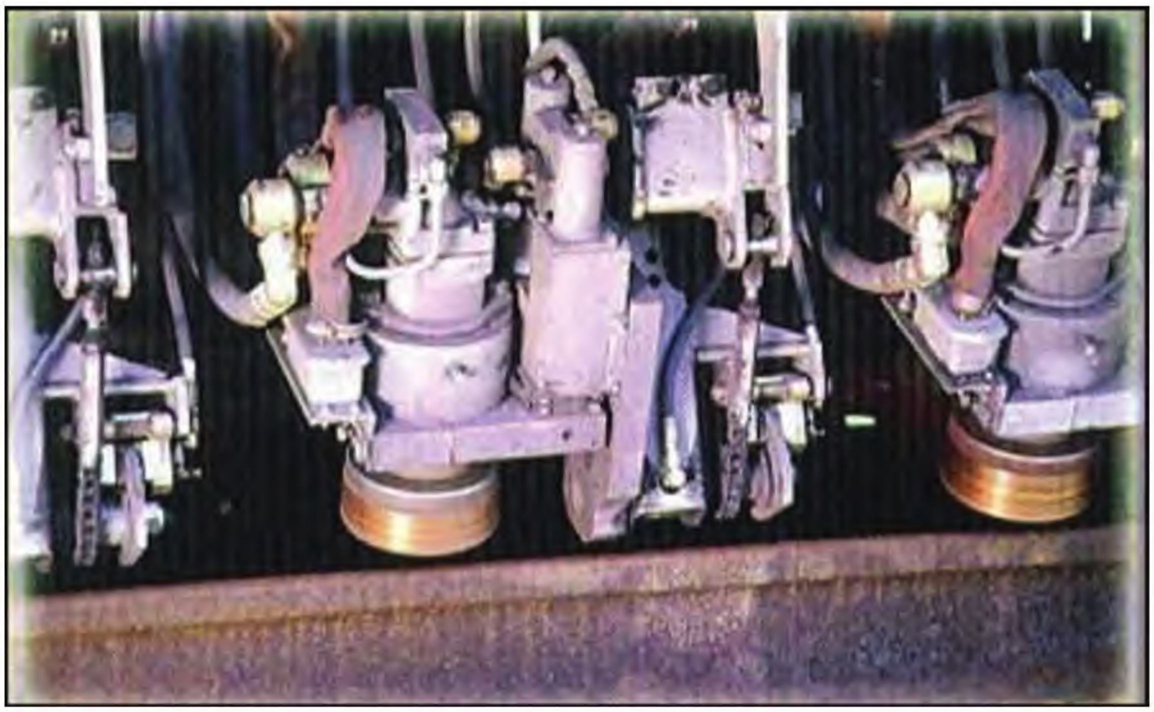


Fig. 2. 6 (b)

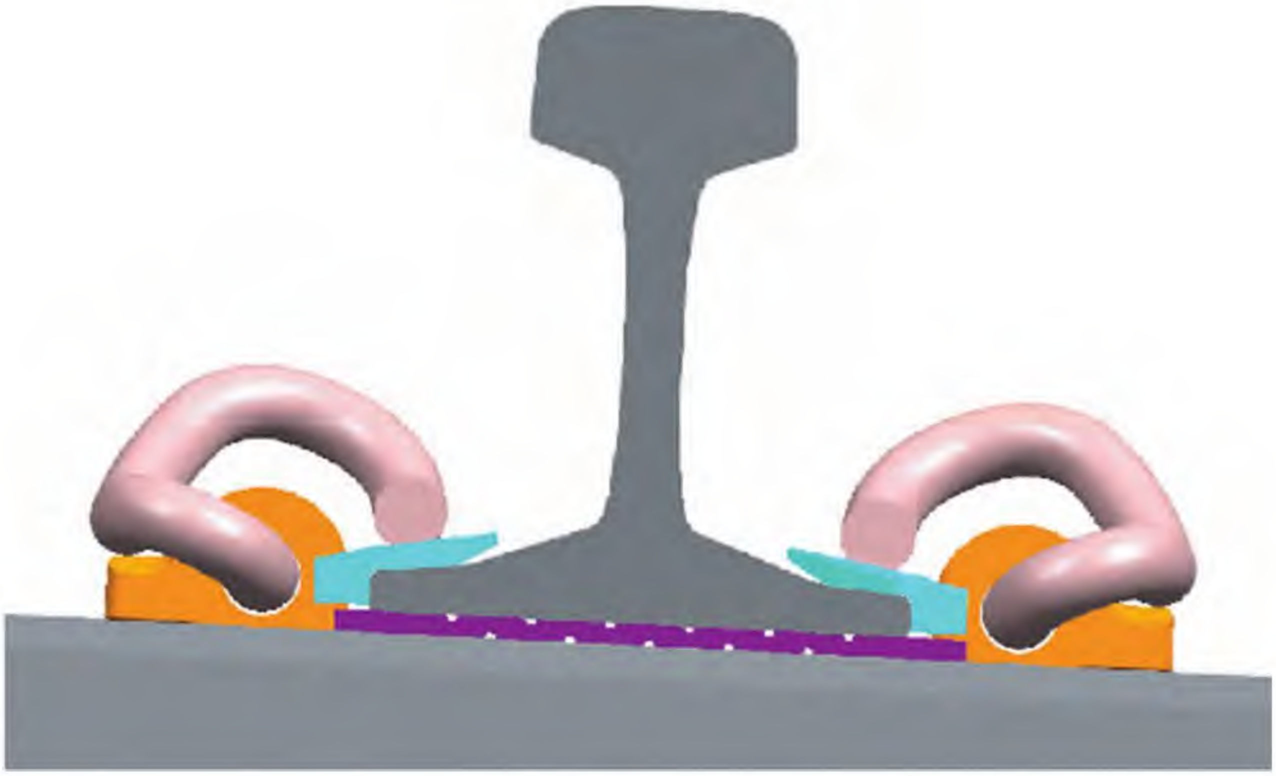


Fig. 5.33

Fig. 9.3 A single use crucible

Color Plate 4

Fig. 10.15 The rail scan equipment

Fig. 12.11 (a) Points and crossing tamping machine

Fig. 12.11 (b) Unimat 08-275 3S switches and crossing tamping machine

Color Plate 6

Fig. 12.13 09-CSM continuous action tamping machine

Fig. 12.14 (a)

Color Plate 7

Fig. 12.14 (b)

Fig. 12.15

Color Plate 8

Fig. 12.16 (a)

Fig. 12.16 (b)

Color Plate 9

Fig. 12.17

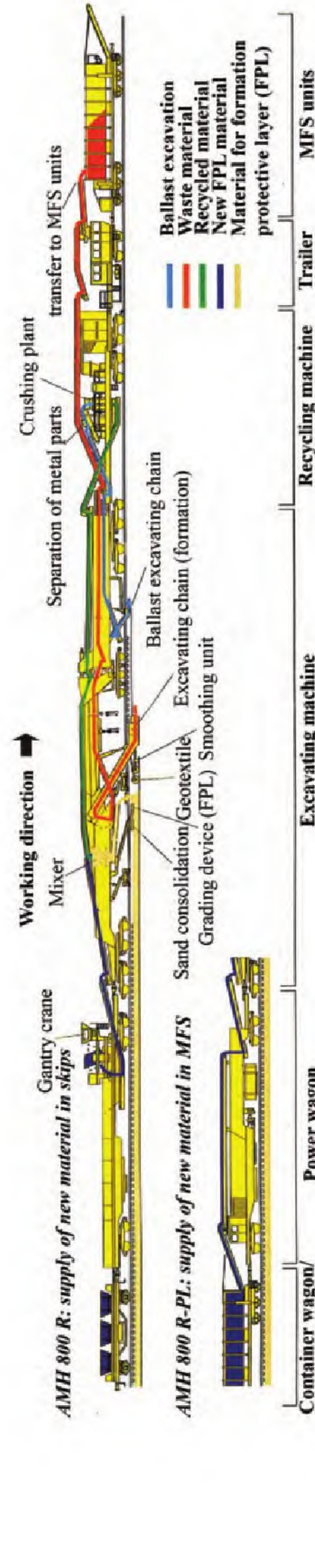


Fig. 12.18 Formation rehabilitation machine

Color Plate 10

Fig. 15.10 Changing of rails

Fig. 16.1

Fig. 16.2

Color Plate 11

Fig. 16.3

Fig. 16.4

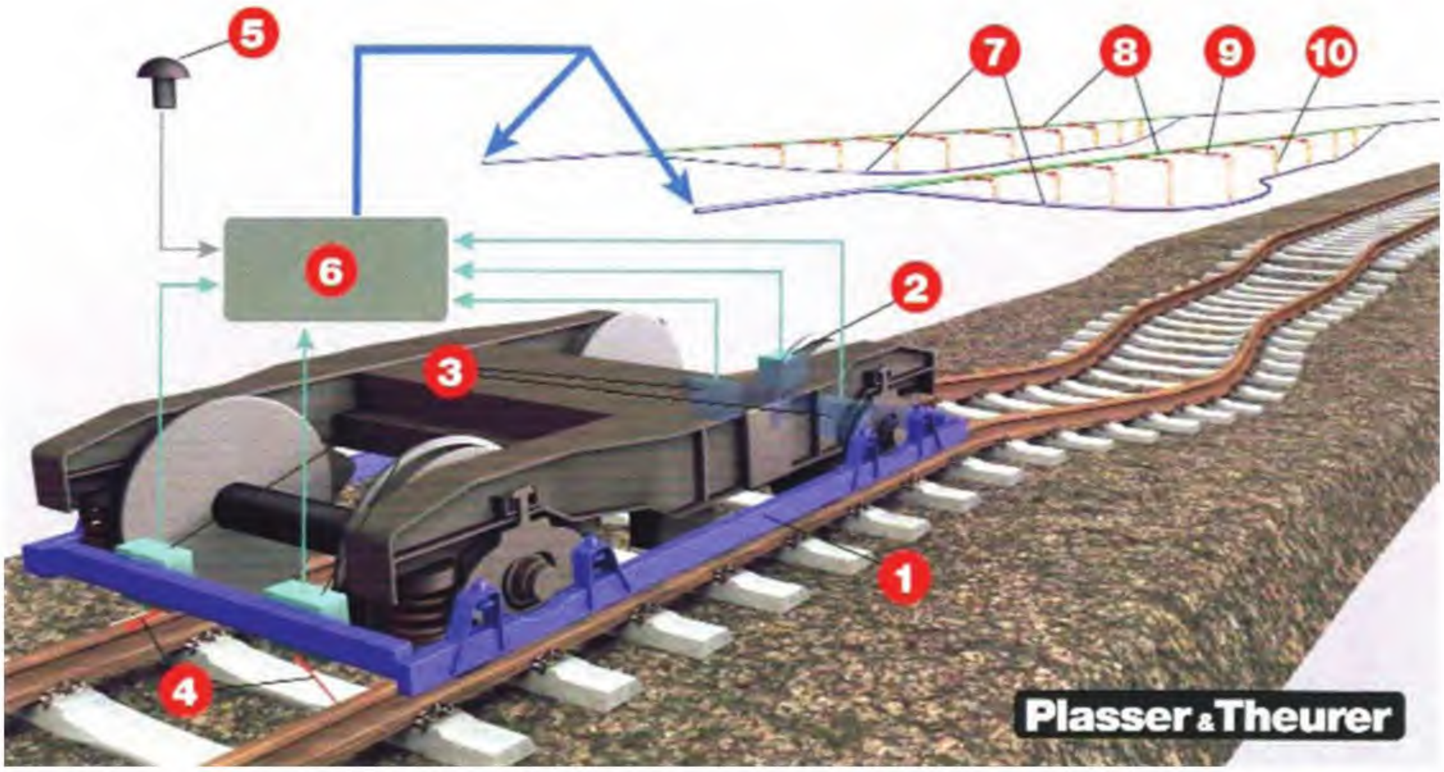
Fig. 16.5

Color Plate 12

Fig. 16.6

Fig. 16.7

Color Plate 13



1. Measuring frame with fixed vertical distance to the rail surfaces
2. Inertial measuring unit (IMU)
3. Sensors of the track gauge measurement
4. Laser beams to scan the track gauge
5. GPS antenna
6. Navigation computer
7. Blue curves: space curves of both rails derived from the measurements along the track, synchronised with GPS data
8. Green line: track design line
9. Red arrows (horizontal): alignment defects, calculated from the space curve
10. Orange arrows (vertical): longitudinal level defects, calculated from the space curve

Fig. 17.16 Working principle of the Plasser and Theurer track geometry measuring system.

Fig. 18.1 High-Speed track on Korean railway system

Fig. 18.2 Tilting train

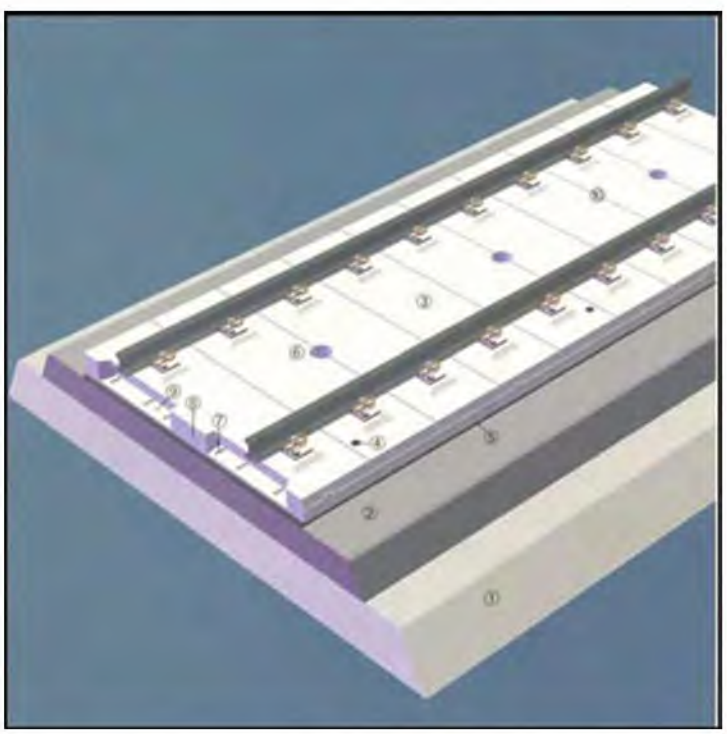


Fig. 18.3 Max bogl slab track system

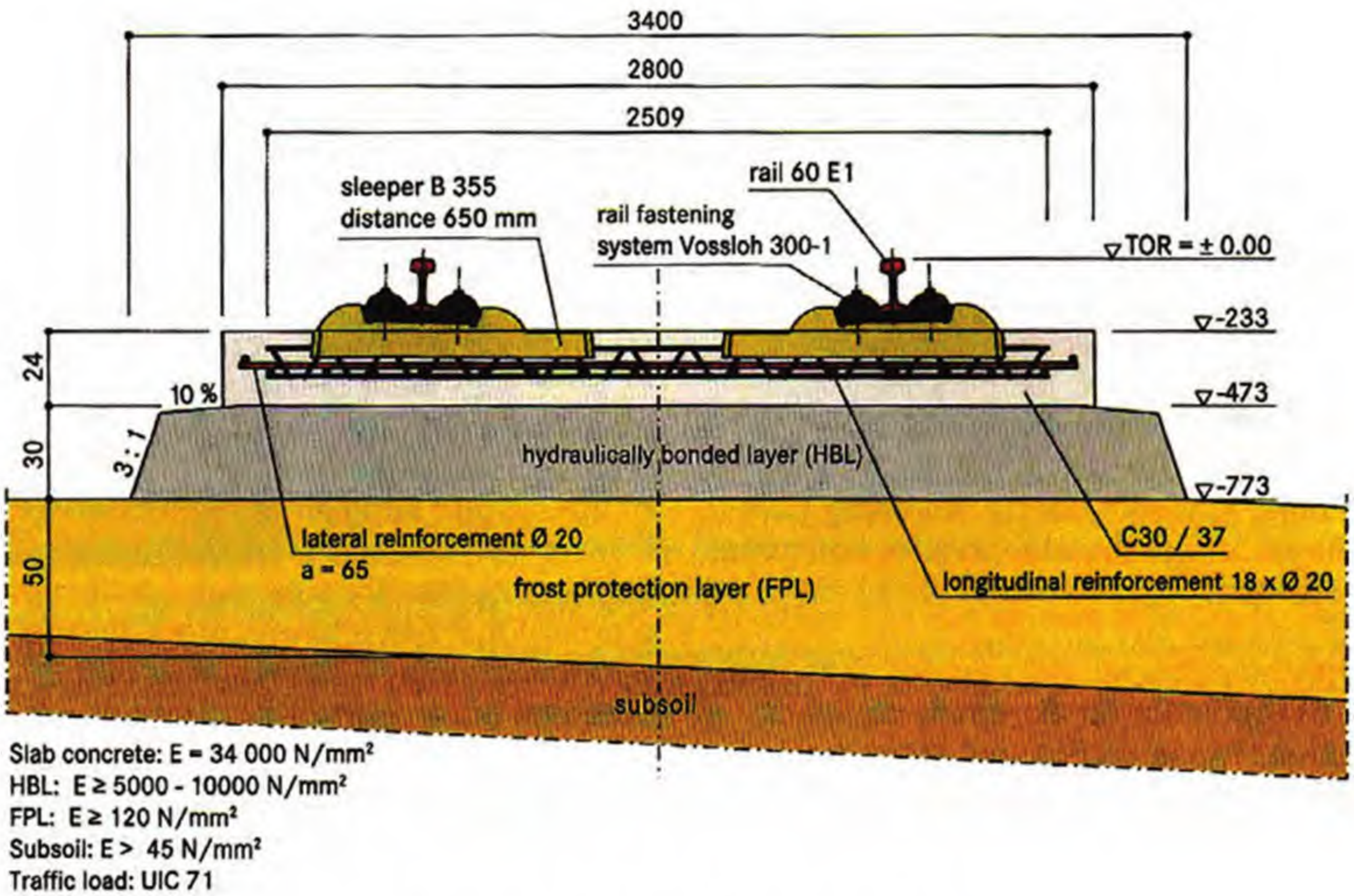


Fig. 18.4 REHDA ballastless track

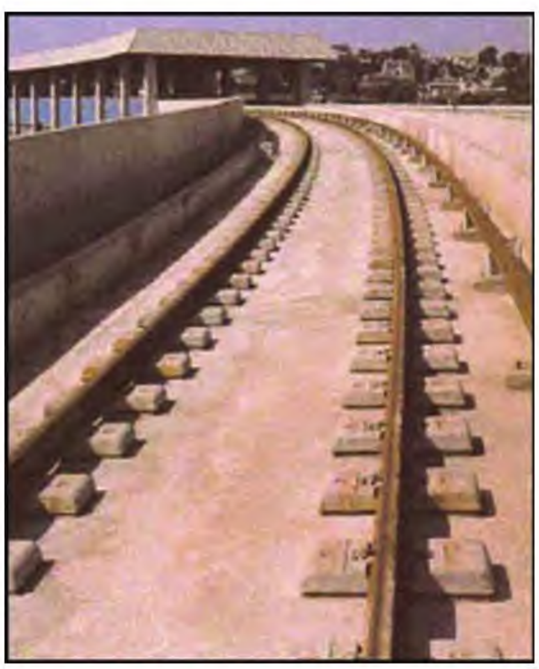


Fig. 18.5 Low vibration track

Fig. 18.6 NBO track system

Color Plate 16

Fig. 18.7 Edilon embedded rail system

Fig. 18.8 (a) Pandrol vipa ballastless track system

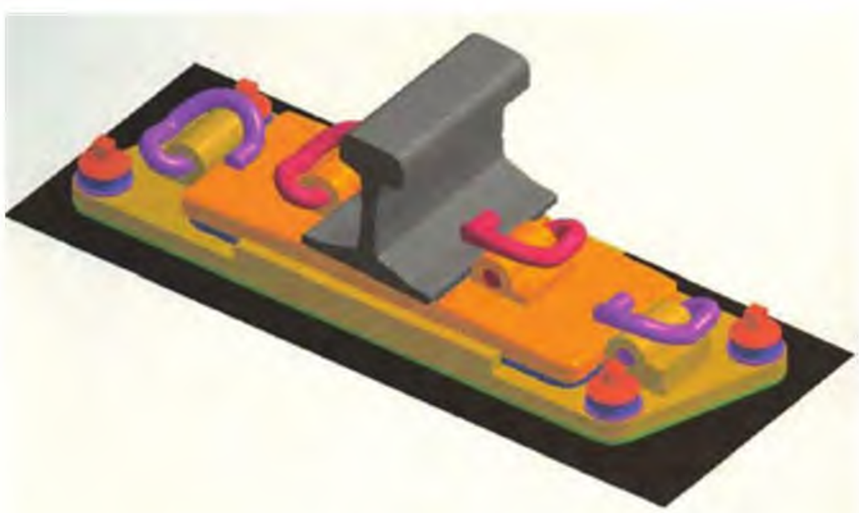


Fig. 18.8 (b) Logwell (India) ballastless track system

Color Plate 17

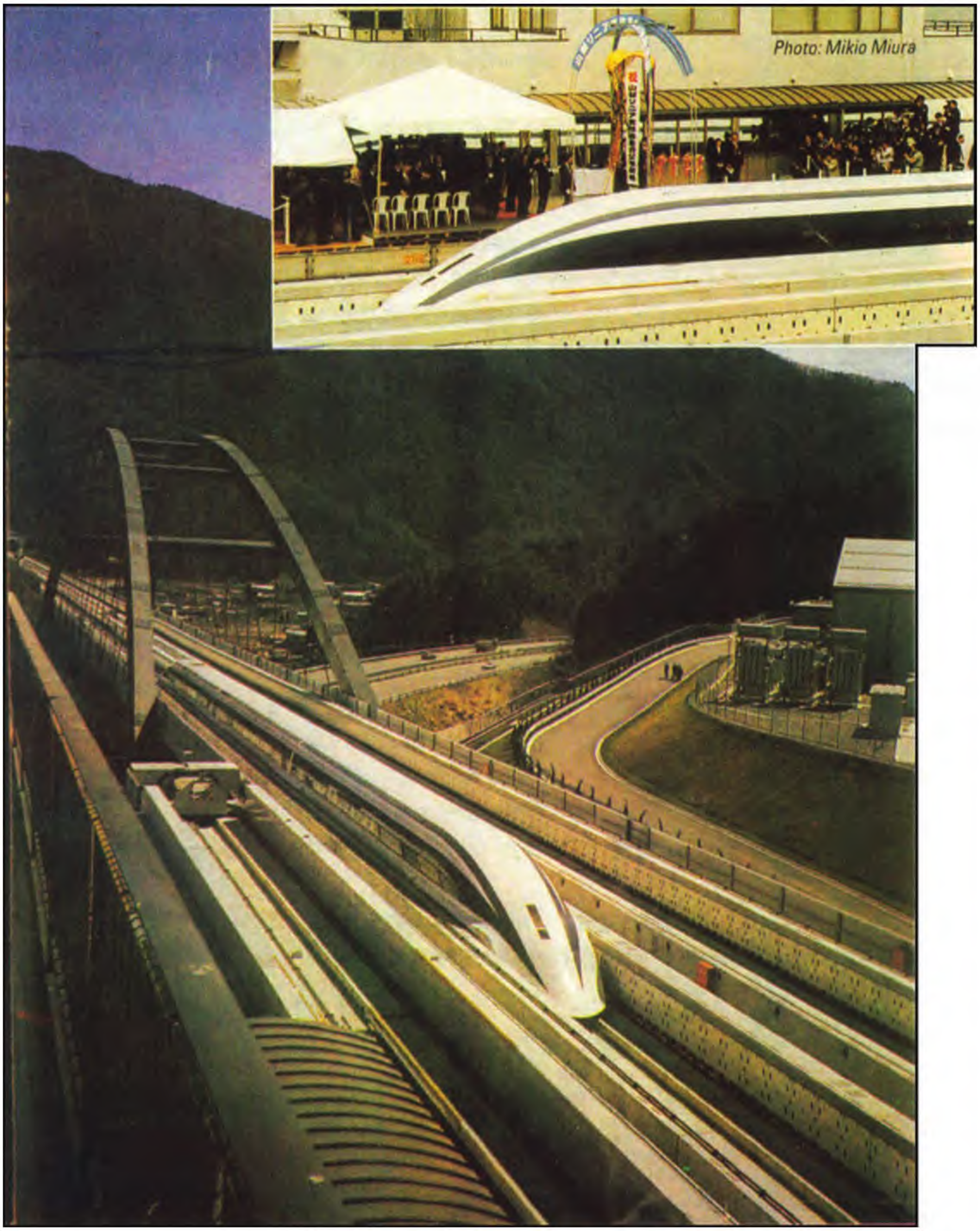


Fig. 18.9 Maglev guideway train

Color Plate 18

Fig. 18.12 Transrapid magnetic levitation train in Shanghai

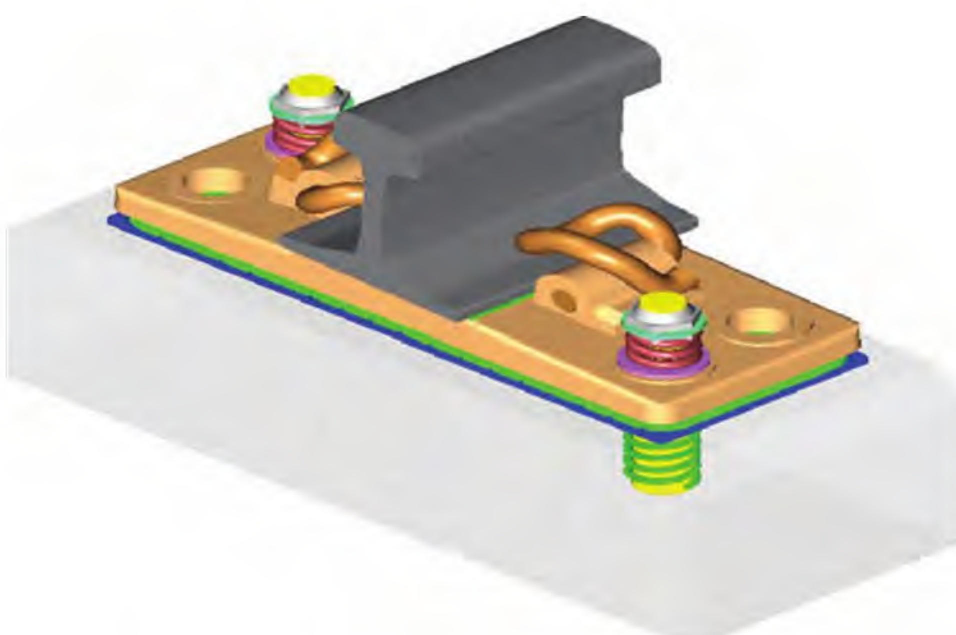


Fig. 21.9 M.1.A Assembly adopted by Calcutta Metro

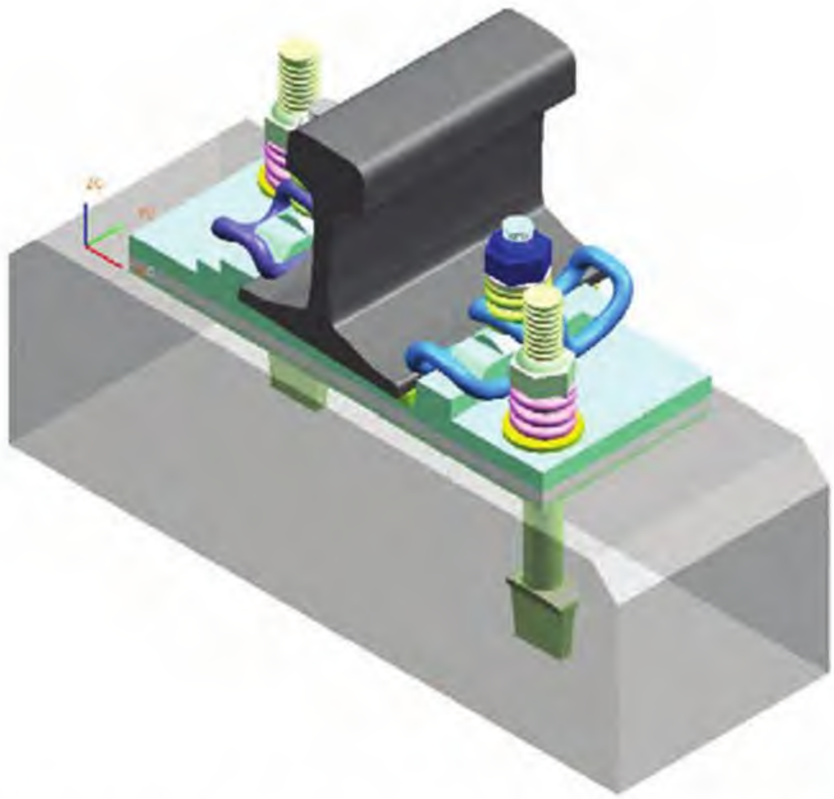


Fig. 21.10 Vossloh 336 ballast-less track assembly adopted by Delhi Metro

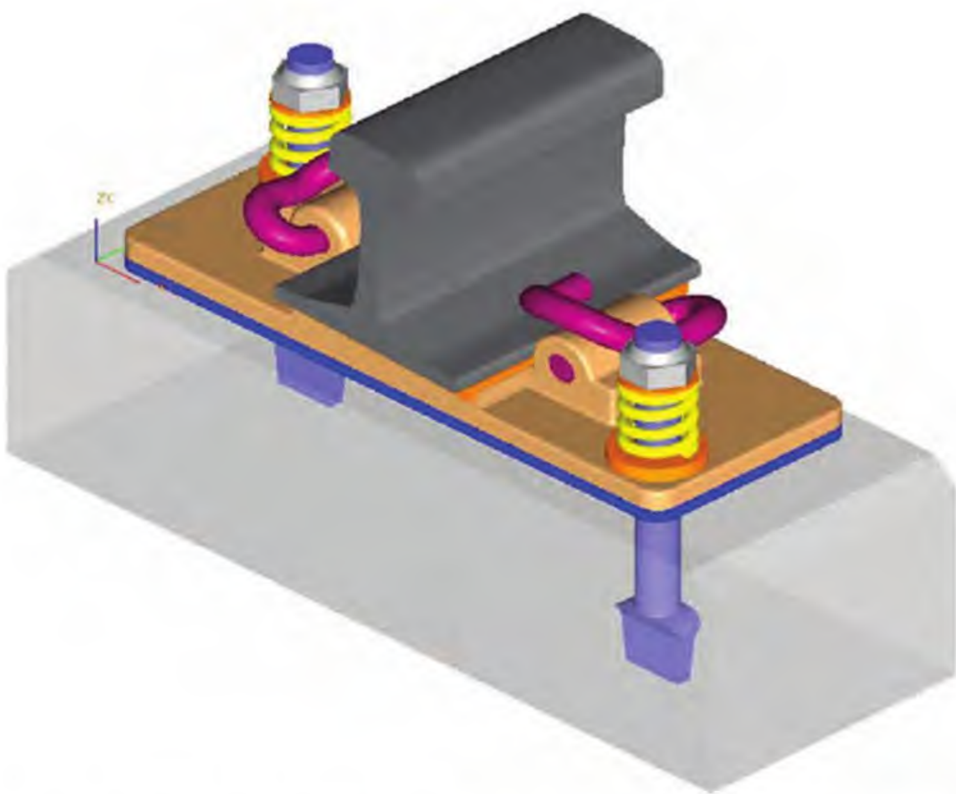


Fig. 21.11 Logwell ballastless track assembly (LM-1)

Color Plate 20

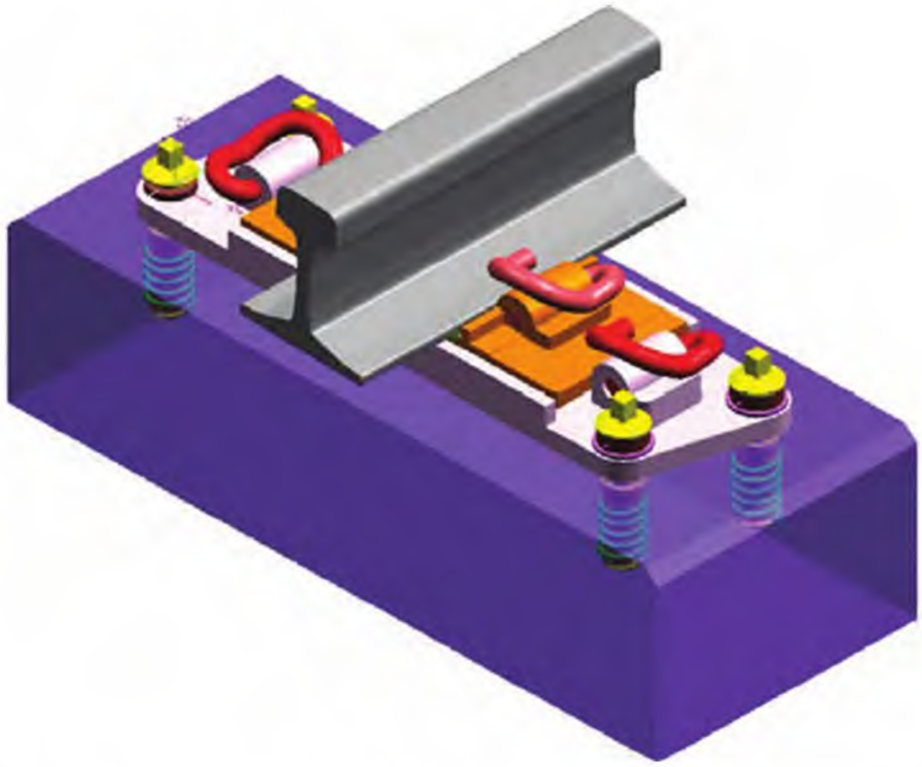


Fig. 21.12 Plinth type ballastless track assemblies for main lines

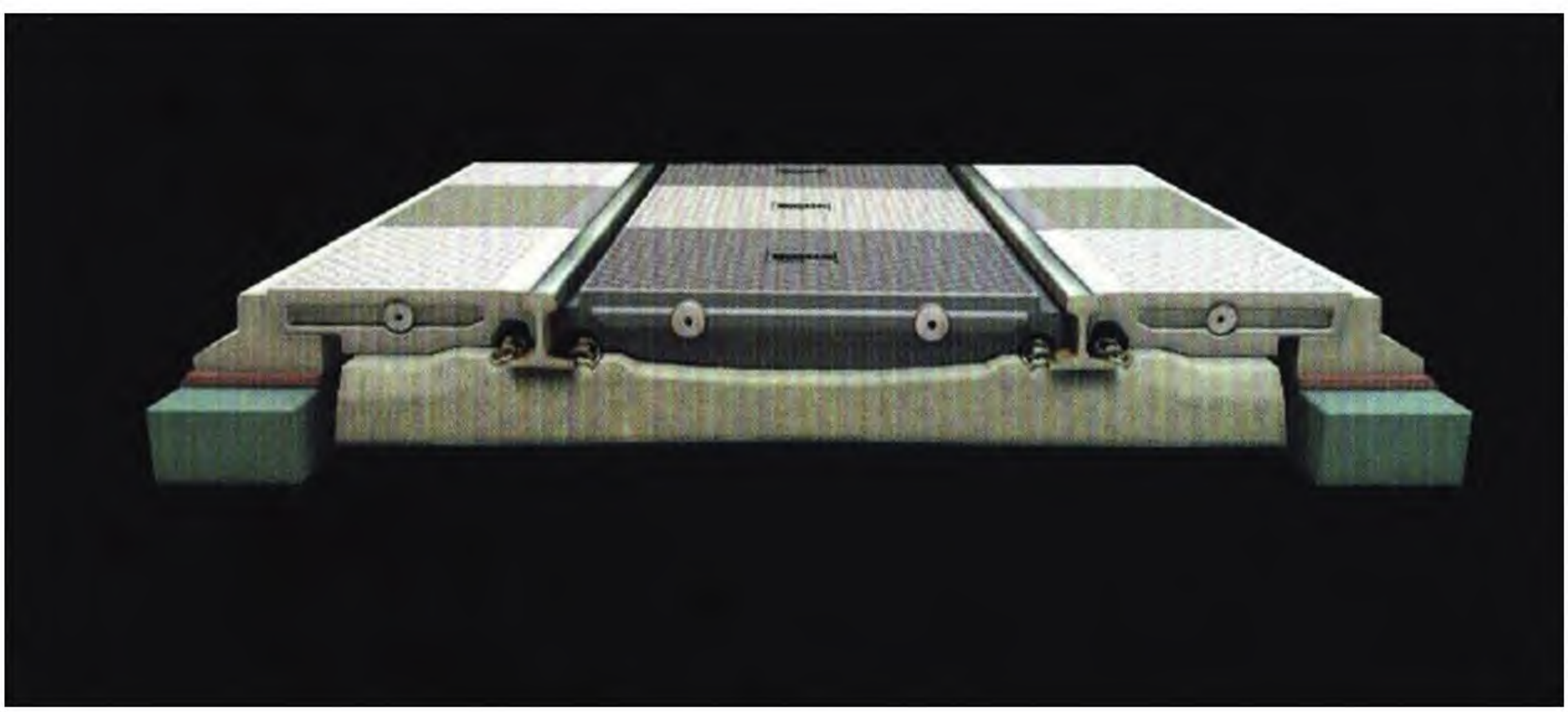


Fig. 21.13