Long Welded Rails

June 2017

INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING
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FOREWORD TO THIRD EDITION

The Long Welded Rail is synonymous with modern track structure with major portion of Indian Railway track having long welded rail. This publication i.e. 3rd revised edition is an updated version with a completely new look incorporating latest correction slips on various provisions of LWR Manual.

The book on Long Welded Rail was originally published in 1988 and then 1st & 2nd revised edition was printed incorporating thirteen correction slips. It is a very useful book for the field engineers because the theoretical basis of various LWR manual provisions are discussed in detail in this book.

It is hoped that the book will be found useful by the field engineers involved in laying and maintenance of LWR track.

The suggestions for improvement are welcome.

N. C. Sharda
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June - 2017

PREFACE TO THIRD EDITION

The book on LWR was originally published in 1988 and this book is 3rd revised edition on the subject of laying and maintenance of Long Welded Rail.

In this 3rd revised edition, the basic concepts involved in LWR maintenance have been further elaborated with few more sketches & case studies for better understanding of field Engineers.

The Chapter on Maintenance of LWR Track, Destressing of LWR, Permitted locations & track structure, Hysteresis curves for LWR have been redrafted. Few more sketches and case studies alsoincorporated for better appreciation of LWR manual provisions. The correction slip upto 16 incorporated.

I am thankful to Shri N. C. Sharda, Director, IRICEN who inspired me and provided valuable guidance. Shri Pravin Kotkar, Sr. Instructor/Track-1 also rendered valuable assistance in preparation of sketches & DTP work.

I dedicate this 3rd revised edition of book for the cause of "an efficient & safe track maintenance practices on Indian Railways".

Ramesh Pinjani
Senior Professor/Bridges

June - 2017

PREFACE

Long Welded Rail (LWR) has now become synonymous with modern track structure with a major portion of Indian Railways track having long welded rails. It is imperative that permanent way men understand all its facets, be it welding, laying or maintenance so that full benefits are reaped. With this objective, IRICEN publication on LWR was printed in 1988 which of course requires revision. This publication is an updated version with a completely new look incorporating the latest correction slips and provisions of the LWR Manual.

The publication highlights the evolution of the LWR over the years with brief references to the research work carried out in RDSO and foreign railways on various aspects of the LWR. A brief description of the various SEJ layouts now available, latest provision of LWR on bridges with comments on the state of art, neutral temperature and its measurement are also included. It is hoped that this publication will go a long way in helping track engineer to understand the intricacies involved in laying and maintaining LWR track.

This book has been authored by Shri Ajit Pandit, Sr. Professor & Dean of this Institute. If there are any suggestions or discrepancies, kindly write to the undersigned.

Shiv Kumar
Director IRICEN

ACKNOWLEDGEMENT

While covering the subject on Long Welded Rails at IRICEN the absence of an updated publication on the subject covering the state of art and latest instructions was acutely felt. The publication printed in 1988 required revision to incorporate the provisions of the LWR Manual 1996, including the latest correction slips.

This IRICEN publication is a result of the desire to fill the gap and produce a documentation which would be useful for all practicing civil engineers on Indian Railways.

It would be appropriate to mention the support and assistance rendered by IRICEN faculty and staff in preparing this publication. Special mention may be made of Shri Sunil Pophale, Head Draftsman who rendered valuable assistance in preparing the drawings. Shri Dhumal, PA assisted in editing the manuscript. Shri R.K. Verma, Senior Professor/Track gave valuable suggestions from time to time.

Above all, the author is grateful to Shri Shiv Kumar, Director/IRICEN for his encouragement and guidance for preparing the document.

Ajit Pandit
Senior Professor & Dean

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CHAPTER - 1

INTRODUCTION TO LONG WELDED RAILS

1.1 Evolution of Long Welded Rails

1.1.1 At the beginning of the 19th century the standard length of rail was generally 12 m/13 m. The maximum length of manufactured rail was governed by the length of cooling boxes in the rail manufacturing steel plant (as controlled cooling after the rolling process was necessary), in addition there was logistic considerations for rail transportation including it loading and unloading related issues.

Subsequent advancements in the manufacturing process have enabled rolling of longer rails.

1.1.2 In India in the nineteen thirties, the GIP Railway had undertaken welding of rail joints using the electrical process. From 1947 to 1966 large number of 5-rail panels (65m in BG and 60m in MG) and 10-rail panels (130m in BG and 120M in MG) were put into track. The purpose was to reduce the maintenance efforts by reducing the number of joints. However, large scale maintenance problems were reported by various railways regarding the behavior of 5-rail and 10-rail panels due to:

i) Increased rail battering and hogging;

ii) Elongated fish-bolt holes;

iii) Bent fish-bolts.

Taking cognizance of these problems, the Railway Board

in January 1966 appointed a committee consisting of 3 Engineers to investigate into the behavior of 5-rail panels and 10-rail panels at the first instance and thereafter for Long Welded Rails.

1.1.3 The committee found that the IRS fishplate design as per current standards is inadequate to cater to the expansion and contraction occurring in 5-rail and 10rail panels. While the capacity of the IRS fishplate design is to accommodate a movement of 15 mm, the actual movements of a 5 rail or 10 rail panel are much larger resulting in large gaps, bent fishbolts and elongated fishbolt holes. The 3-rail panel therefore appears to be roughly the longest rail which could be laid in the track with the conventional fish plated joints. The committee, therefore, recommended that:

1) Welding of 5-rail and 10-rail panels to be discontinued,

2) Existing 5-rail and 10-rail panels to be cut into two and half rail panels;

3) RDSO to conduct further studies for deciding the track structure, temperature and ballast conditions for laying the LWR.

Note : Presently SAIL Bhilai Steel Plant is manufacturing rails of 65 m length & after welding by flush butt welding, panels of 260 m length (20 rail panel) are dispatched from plant.

1.2 Advantages of Long Welded Rail

The LWR is synonymous with modern track. The LWR makes train travel more safe, economical

and comfortable due to following reason:

1) LWR track eliminate fish plated joints, leading to safety as sabotage at fish plated joints has been a major worry for the Indian Railways

2) Fish plated joints are source of large dynamic forces. As a result fish plated joints exhibit large scale rail wear and development of cracks from fish bolt holes and fractures. In some instances premature rail renewal may have to be carried out due to excessive fractures.

3) Due to development of large dynamic forces at the rail joints the track geometry at the rail joint gets disturbed frequently resulting frequent attention of track. It has been estimated that there is as much as 25% to 33% savings in the track attention/ maintenance with LWR track.

4) Due to impact at rail joints there is an added wear and tear of rolling stock wheels to an extent of 5% and as the wheel has to negotiate the gap there is added fuel consumption to an extent of 7% on jointed track.

5) Due to elimination of noise and vibrations at the rail joints, passenger comfort is substantially increased.

1.3 Important Definitions

1) **Long Welded Rail (LWR)** is a welded rail, the central part of which does not undergo any longitudinal movement due to temperature variations.

   A length of greater than 250 meter on Broad Gauge and 500 m on Meter Gauge will normally

function as LWR (Fig. 1.1). The maximum length of LWR under Indian conditions shall normally be restricted to one block section.

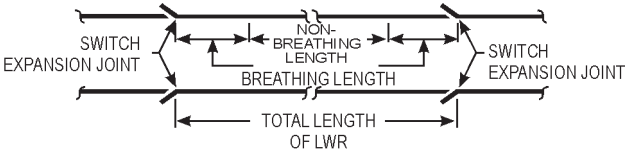


Fig. 1.1 : Long Welded Rails

As the central portion of LWR/CWR does not expand/ contract i.e. it does not under go any longitudinal movement, therefore, thermal forces builds up in the central portion due to temperature variations. The thermal force (P), is to be resisted by suitable track structure.

$$P = A E \alpha t$$

Where, A = Area of cross section of the rail (sq.cm)

($A = 66.15\ cm^2$ for 52 kg rail & $A = 76.86\ cm^2$ for 60 kg rail)

E = Modulus of elasticity of rail steel, (2.15×10^6 Kg/sq.cm)

α = Coefficient of linear expansion of steel, (1.152×10^{-5} /°C)

t = Variation of rail temperature from t_d / t_o (°C)

For a temperature change of 1^0C, the value of induced thermal force (P) works out 1.638 ton for 52 Kg & 1.903 ton for 60 Kg rail section.

2) Continuous Welded Rail (CWR) is a LWR which would continue through station yards including points and crossings.

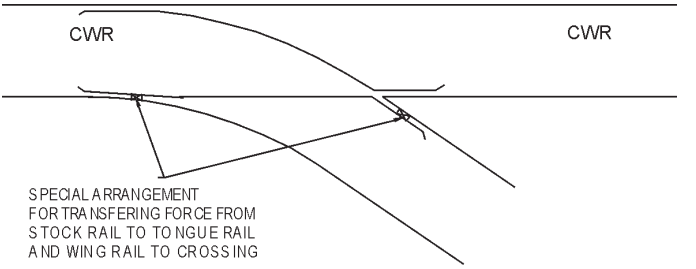


Fig. 1.2 : Continuous Welded Rail

3) Short Welded Rail (SWR) is a welded rail, which contracts and expands throughout its length.

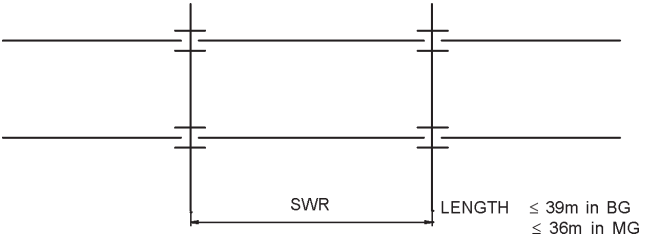


Fig. 1.3 : Short Welded Rail

Note: Normally the length of SWR is 3 x 13 meter for BG & 3 x 12 meter for MG.

4) 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 for various sleepers under four temperature zones (I to IV) is shown below.

Breathing length (in meters) on PRC sleeper track (BG)

Sleeper density	1540 Nos. /Km				1660 Nos. /Km			
Rail section ↓ /Zone →	I	II	III	IV	I	II	III	IV
60 Kg (UIC) rails	60	69	77	82	58	66	74	79
52 Kg rails	52	59	66	71	50	57	64	68
90 R	38	44	51	55	37	43	49	53

Breathing length (in meters) on MG track with 1540 sleeper density

Type of Sleeper	Steel sleeper				CST-9 sleeper			
Rail section ↓ /Zone →	I	II	III	IV	I	II	III	IV
90 R	134	156	179	192	152	178	202	217
75 R	111	130	149	160	126	147	168	181

Note: The Breathing lengths given above are indicative and are likely to vary based on site conditions, i.e. based on magnitude of longitudinal ballast resistance getting mobilized, which depends upon Type of sleepers, Sleeper density, Condition of packing, any track work under taken in the recent past, Ballast profile, Passage of traffic etc.

5) 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 (Refer Fig. 1.1 above).

6) Buffer Rails are, a set of rails provided in lieu of SEJ at the ends of LWR/CWR to allow expansion/contraction of adjoining breathing lengths due to temperature variations. These will be laid with prior approval of Chief Engineer at locations where provision of SEJ is not permitted. Buffer rails may also be temporarily laid to facilitate maintenance/renewal operations.

7) Rail Temperature is the temperature of the rail at site as recorded by an approved type of rail thermometer as

laid down in LWR manual Para 2.1. This is different from ambient temperature which is the temperature of air in shade at the same place. The Indian Railways has been divided in 4 temp zones as under:

ZONE	Range of Rail temp.
I	40 to 50^0C
II	51 to 60^0C
III	61 to 70^0C
IV	71 to 76^0C

8) Mean Rail Temperature (t_m) for a section is the average of the maximum and minimum rail temperatures recorded for the section.

9) Destressing is the operation undertaken with or without rail tensor to secure stress free condition in the LWR/ CWR at the desired/specified rail temperature.

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) Destressing Temperature (t_d) is the average rail temperature during the period of fastening the rails to the sleepers after destressing LWR without the use of rail tensor. If rail tensor is used, td for all practical purposes is equal to to as defined in Para 1.13 of LWR manual(Stress-free Temperature). The Range of td or to shall be within the limits of rail temperature shown below

Zone	**Rail section**	**Range for t_d**
I, II & III	All Rail sections	t_m to t_m + 5°C
IV	(i) 52 Kg & heavier	t_m + 5°C to t_m + 10°C
	(ii) Other rail sections	t_m to t_m + 5°C

12) Prevailing Rail Temperature (t_p) is the rail temperature prevailing at the time when any operation related to track maintenance on LWR track is carried out.

13) Stress-free Temperature (t_o) is the rail temperature, at which the rail is free of thermal stress. When tensors are utilized for the destressing operation the work has to be carried out at tp, which shall be lower than stress-free temperature. The extension to be applied by the tensor shall be calculated from the following formula:-

$$\text{Extension} = L \cdot \alpha \ (t_o - t_P)$$

Where 'L' is the length of segment of the rail to which the extension is applied and 'α' is the coefficient of linear expansion of rail steel.

14) Rail Tensor is a hydraulic or mechanical device used for stretching the rail physically.

15) 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 purposes, this may be taken as equal to 2.5 meter per degree Celsius of ($t_o - t_P$) for BG and 4.5 meter per degree Celsius of ($t_o - t_P$) for MG track.

16) Hot Weather Patrol is the patrol carried out when the rail temperature exceeds t_d +25°C on PSC sleeper track with sleeper density 1540 Nos/km or more, in all other cases it shall be introduced when rail temperature exceeds t_d + 20^0C. In addition, the period for regular hot weather patrolling during summer shall be laid down by the Chief Engineer for each section and patrol charts prepared wherever necessary.

17) Cold Weather Patrol is the patrol carried out during

cold months of the year in specified sections as per instructions of Chief Engineer. In addition the Cold weather patrolling shall also be introduced when the rail temperature is less than t_d – 30^0C.

18) Consolidation of Track is the process of building up ballast resistance against the tendency of movement of sleeper either initially before laying LWR or making up subsequent loss of resistance by anyone of the following:-

i) Track consolidation by traffic passage:

a) **BG Concrete sleeper track:** For the track structure consisting of BG concrete sleepers, passage of at least 50,000 gross tonnes of traffic or 2 days whichever is later. It can be reckoned/ considered, in terms of days based on traffic density of line, as placed here under:

Traffic density of the line	Consolidation period in days (approx.)
10 GMT and above	2 days
Between 10 GMT- 5 GMT	4 days
Below 5 GMT	7 days

Note: *Route/ line having traffic density of 1 GMT will have train passage of 2700 tons per day. 10 GMT route will have train passage of more than 50,000 tons in 2 days i.e. 2 days x (10 GMT) x (2700 ton per GMT per day) = 54,000 ton*

b) **Other than BG concrete sleeper track:** For the track structure consisting of other than BG concrete sleepers, the period of consolidation will be as under:-

With compaction of ballast using → Type of track structure ↓	Hand operated compactors/ rammers	Mechanised shoulder & crib compactor
BG with other than concrete sleeper	3,00.000 gross tonnes of traffic	50,000 gross tonnes of traffic
MG with other than concrete sleeper	1,00.000 gross tonnes of traffic	20,000 gross tonnes of traffic
MG with concrete sleeper	20,000 gross tonnes of traffic	

ii) **Track consolidation by DTS:** Minimum one round of stabilisation by Dynamic Track Stabiliser (DTS).

iii) **Track stabilisation by track tamping machines:** For newly laid LWR/CWR, at least three rounds of packing, last two of which should be with on-track tamping machines.

19) Longitudinal ballast resistance (R): The longitudinal ballast resistance (R) gets geared up whenever thermal change takes place in LWR track, causing rail sleeper assembly (fastened together by elastic fastenings) to move in the ballast mass, so there is relative motion of the sleepers with respect to the ballast in the longitudinal direction. Value of 'R' depends upon following factors:

i) Type of sleepers

ii) Sleeper density

iii) Condition of packing

iv) Influence of any work on the track like through packing, machine tamping, deep screening etc.

v) Ballast profile

vi) Passage of traffic

The value of ‘R’ for BG concrete sleeper track is 13.28 Kg/cm/rail for sleeper density 1540 Nos. per Km & 13.74 Kg/cm/rail for sleeper density 1660 Nos. per Km.

20) Approval for installation of LWR: Installation of LWR/CWR or change in its constitution at a later stage shall have the approval of Chief Track Engineer in each case on a detailed plan prepared. However for any deviation from the provision of LWR manual, the approval of Principal Chief Engineer shall be obtained.

■ ■ ■

CHAPTER - 2

PRINCIPLES OF LONG WELDED RAIL

2.1 Basic Principles of Long Welded Rail:

A metal rod supported on frictionless rollers can theoretically expand and contract freely with variations in temperature. It will expand / contract equal to $L \alpha t$, where L is length of metal rod, α is the coefficient of linear expansion and t is the variation in temperature.

Now if this rod is fixed at ends i.e. it is restrained to expand / contract due to temp variations then thermal strain & stress will get induced in this rod.

Thermal strain will be equal to = $L \alpha t / L = \alpha t$
Thermal stress = E x Thermal strain= $E \times \alpha t$
Thermal force P = A x thermal stress= $A E \alpha t$

The rail in the track cannot be compared to the metal rod supported on frictionless rollers; it is restrained from free expansion and contraction over the sleeper seat due to:

i) Creep resistance on account of friction between the rail and sleeper at the rail seat.

ii) Creep resistance offered by the rail sleeper fastenings.

In LWR track the rail is held down/ fixed to the sleeper by elastic fastenings which have adequate toe load, thereby preventing any relative movement between rail and sleeper. Thus with any change in temperature it is not the rail alone but the rail-sleeper frame as a whole tends to move.

Here again the rail sleeper frame is not entirely left unrestrained. The frame is under restraint because of the resistance offered by the ballast in which the sleepers are embedded. The resistance offered by the ballast to the movement of the track frame in the direction of the track is called longitudinal ballast resistance. This longitudinal ballast resistance builds up progressively from the ends of the long welded rail towards the centre/ middle of LWR.

If the track frame was not restrained, then the rail would expand or contract with variation in temperature and consequently no force would build up in the rail. However, since there is a restraint now offered by the longitudinal ballast resistance, thermal forces are induced in the rail. If the temperature variation (from the temperature at which the rail was fastened to the sleeper initially while laying / destressing) is small, then the induced thermal force will be less, as it is dependent upon temp variation t and therefore a small length of track at the end called breathing length would be sufficient to develop longitudinal ballast resistance against the tendency for free movement of the rail, once the adequate ballast resistance gets develop, there is no movement in LWR beyond it, called central portion of LWR.

However, if the temperature difference is more, the value of induced thermal force increases and a longer length of track at the ends (breathing length) would be called upon to develop the necessary longitudinal ballast resistance against the free movement of the ends of the rails

There is however, a limit up to which the temperature differences can build up. This limit is dictated by the maximum, minimum rail temperature of the area and the temperature at which the rail is fastened to the sleeper.

The temperature at which the track can be attended for regular or special track maintenance operations is governed by the sole consideration that the thermal force in the track should be within safe limits, to avoid the incidence of buckling/ fractures the LWR.

2.2 Force Diagram of LWR:

L.W.R is defined as a long welded rail or a panel in which central portion does not undergo/ exhibit any longitudinal movement due to thermal variations

Let us assume the LWR central portion to undergo an increase in temperature by t °C temperature. If the central portion of length 'L' had been free to expand it would have expanded by an amount equal to '$L\alpha t$'. However since the central portion of the LWR does not move, the compressive strain induced in central portion is equal to

$\frac{L\alpha t}{L} = \alpha t$, where t is the change of temperature in LWR with respect to the temp at which it was laid or destressed and α is the coefficient of linear expansion.

If P is the force induced in central portion (compressive force) and A is the cross section area of rail, then P/A is the compressive stress in the rail.Since stress /strain = E (Young's modulus of rail steel)

$$\frac{P/A}{\alpha t} = E$$

In other words $P = A E \alpha t$.

where P is in newton, A is in mm^2, and E is in N/mm^2, As t represents the change of temperature of the rail w.r.t. the temperature it is stress free, a technically correct

formula for the thermal force in the LWR will be $P = A E \alpha (t_P - t_n)$ where t_P is the prevailing rail temperature and t_n is the rail neutral temperature, which is the temperature at which the LWR is free of longitudinal thermal stress.

When $t_P = t_n$, $P = 0$, when $t_P > t_n$, P is a compressive force and when $t_P < t_n$, P is is a tensile force.

As tn is not known it is assumed that $t_n = t_L$ or t_d, temperatures at which LWR was laid (t_L)or destressed (t_d).

The force at the end of LWR i.e. near SEJ is zero, and in the central portion equal to $A E \alpha t$. This change of force from zero to a peak value occurs over the breathing length. The shape of the force diagram is therefore as given in Figure 2.1

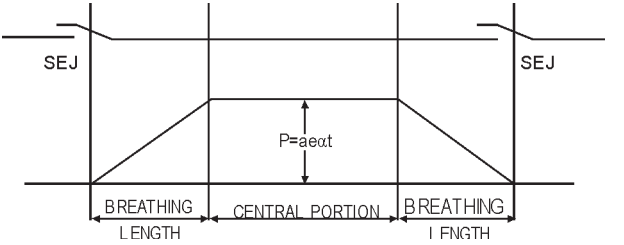


Fig. 2.1

Estimation of thermal force due to 1^0c change of temperature:

P = $A E \alpha t$

A = Area of cross section of the rail (sq.cm) ($A = 66.15\ cm^2$ for 52 kg rail & $76.86\ cm^2$ for 60 kg rail)

E = Modulus of elasticity of rail steel, (2.15×10^6 Kg/sq.cm)

α = Coefficient of linear expansion of steel, (1.152×10^{-5}/°C)

t = Variation of rail temperature from t_d / t_o (°C)

For a temperature change of 1^0C, the value of induced thermal force (P) works out 1.638 ton for 52 Kg & 1.903 ton for 60 Kg rail section. Accordingly at td +10^0C the induced compressive force shall be 16.38 t / 19.03 t for 52 kg / 60 kg rail section respectively.

2.3 Rail Temperature

From the expression for thermal force in LWR, $P = AE\alpha(t_P - t_n)$, it can be seen that force developed in the LWR depends primarily on the prevailing rail temperature and the rail neutral temperature

2.3.1 Rail Temperature Measurement:

Thermometers

The following are the different types of approved thermometers for measuring rail temperature

i) Embedded type - This is an ordinary thermometer inserted in a cavity formed in a piece of rail-head, the cavity filled with mercury and sealed. The rail piece is mounted on a wooden board which is placed on the cess and exposed to the same conditions as the rail inside the track. This type of thermometer takes 25 to 30 minutes for attaining temperature of the rail.

ii) Dial type - This is a bi-metallic type thermometer which is provided with a magnet for attaching it to the rail. The thermometer is attached on the

shady side of the rail web as this location is approximating the average rail temperature to the greatest extent. A steady recording of the rail temperature is reached within 8 minutes.

iii) Continuous recording type - It consists of a graduated chart mounted on a disc which gets rotated by a winding mechanism at a constant speed tocomplete one revolution in 24 hours or 7 days as applicable, giving a continuous record of rail temperature. The sensing element is attached to the web of the rail and connected to the recording pen, through a capillary tube which is filled with mercury. in the latest version of equipment the sensor is connected to main unit which display the temperature in digital form in place of graph

iv) Any other type of thermometer approved by RDSO/ Chief Engineer.

2.3.2 Rail Temperature Zones and RDSO Studies:

In order to understand the correlation between the rail temperature and ambient temperature, RDSO conducted rail temperature studies between 1969 and 1971 over a two year period. 22 stations were identified over the Indian Railways where Standard Measuring Arrangements for Rail Temp (SMART) were set up. (Fig. 2.2) SMART consisted of a full-length rail laid in the east-west direction on wooden sleepers with ACB plates and boxed with standard ballast profile. The rail temperature was measured by means of a thermometer placed in a mercury-filled hole in the rail head. Rail temperature readings were taken on an hourly basis between August 1969 and August 1971, and the corresponding air temperatures obtained from the Meteorological office. Correlation equations between the rail temp and air temp

were derived using a computer based regression analysis (Details available in RDSO/C/ 146, Reference-3) for each of the identified 22 stations. Using these correlation equations and the maximum and minimum air temperatures at 180 stations over the Indian Railways, obtained from the Weather office over a period of 90 years, it was possible to determine the maximum and minimum rail temperatures obtainable at these stations. This is indicated in Fig 2.3

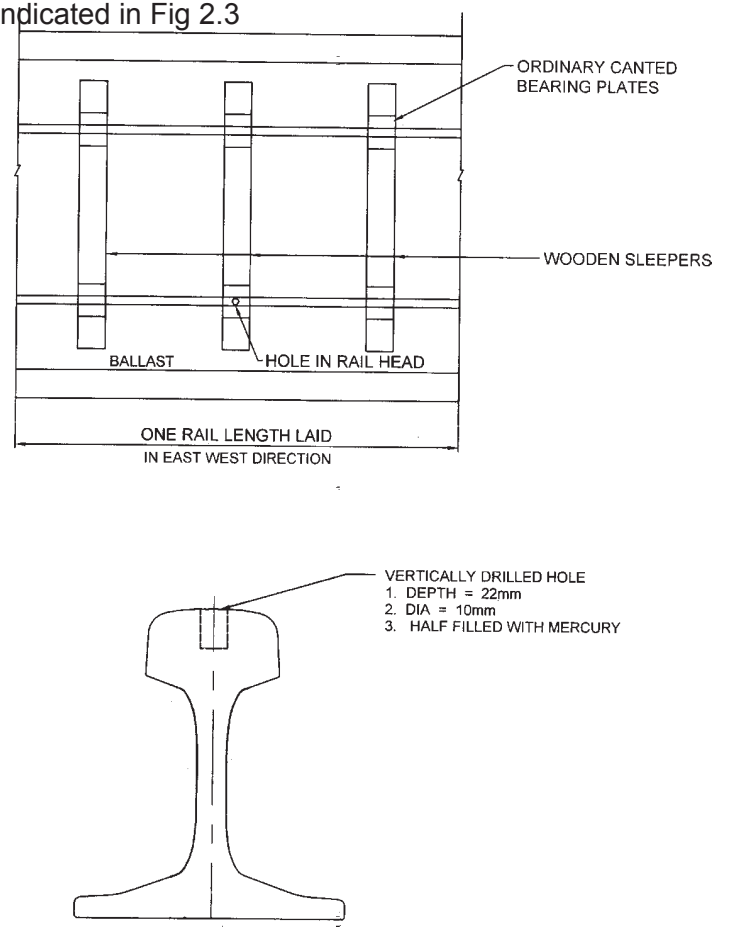
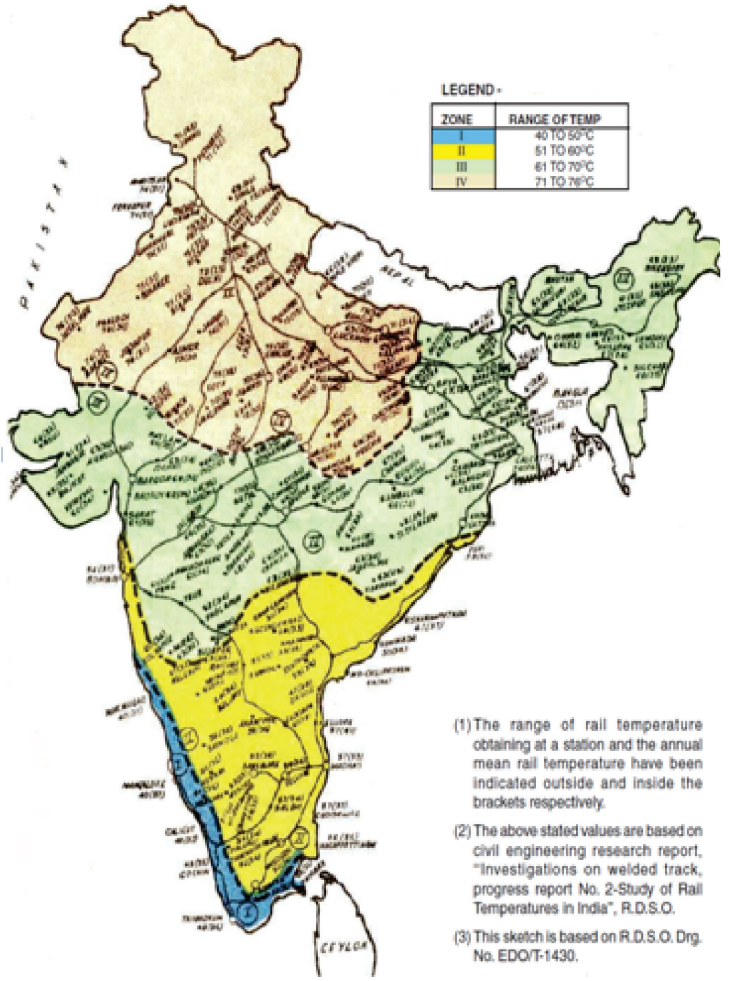


Fig. 2.2: Standard Measuring Arrangement for Rail Temperature

MAP OF INDIA SHOWING RAIL TEMPERATURE ZONES



(1) The range of rail temperature obtaining at a station and the annual mean rail temperature have been indicated outside and inside the brackets respectively.

(2) The above stated values are based on civil engineering research report, "Investigations on welded track, progress report No. 2-Study of Rail Temperatures in India", R.D.S.O.

(3) This sketch is based on R.D.S.O. Drg. No. EDO/T-1430.

Fig. 2.3

2.3.3 Rationale behind Choice of t_d

The LWR neutral temperature or t_d should be chosen in such a manner that the thermal force developed in the LWR is within the desired limits.

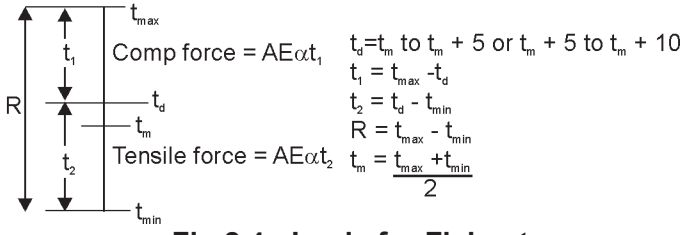


Fig 2.4 : Logic for Fixing t_d

Now refer to table - 2.1. It shows the maximum range of rail temperature in the four temperature zones. The rail can be fixed to the sleepers by fastenings after destressing, at a temperature anywhere within this range, between maximum and minimum rail temperatures.

Table- 2.1 Maximum Temperature Range for Various Zones

ZONE	Zone-I	Zone-II	Zone-III	Zone-IV	Zone-IV
Max. temp Range	50	60	70	76	76
t_d	t_m to $t_m + 5$	t_m to $t_m + 5$	t_m to $t_m + 5$	t_m to $t_m + 5$	$t_m + 5$ to $t_m + 10$
Max. temp range	When $t_d = t_m + 5$ $t_{max} = t_d+20$ $t_{min} = t_d-30$	When $t_d = t_m + 5$ $t_{max} = t_d+25$ $t_{min} = t_d-35$	When $t_d = t_m + 5$ $t_{max} = t_d+30$ $t_{min} = t_d-40$	When $t_d = t_m + 5$ $t_{max} = t_d+33$ $t_{min} = t_d-43$	When $t_d = t_m + 10$ $t_{max} = t_d+28$ $t_{min} = t_d-48$
	When $t_d = t_m$ $t_{max} = t_d+25$ $t_{min} = t_d-25$	When $t_d = t_m$ $t_{max} = t_d+30$ $t_{min} = t_d-30$	When $t_d = t_m$ $t_{max} = t_d+35$ $t_{min} = t_d-35$	When $t_d = t_m$ $t_{max} = t_d+38$ $t_{min} = t_d-38$	When $t_d = t_m +5$ $t_{max} = t_d+33$ $t_{min} = t_d-43$

1. Let us see what happens if we fasten the rail to the sleeper at the minimum rail temperature (t_{min}). As the rail temperature rises compressive thermal forces will be built up and when the rail temperature reaches tmax compressive forces proportional to the full range of rail temperature will be built up. Such large compressive forces could be very dangerous to the stability of the LWR and the track can buckle. In this case there is of course no danger of any tensile force developing in the rail and consequently of rail fracture, in other words

   If $t_d = t_{min}$ then $t_2 = 0$, Tensile force = 0, $t_1 = R$ compressive force = $AE\alpha$ (R)

2. Let us see what happens if the rail is fastened to the sleeper at the maximum rail temperature (t_{max}). Since temperature cannot rise any further, there is no likelihood of compressive thermal stresses developing in the rail, and consequently there is no danger of buckling. However, since the rail temperature can fall through the complete range of temperature at this place, tensile stresses and forces in the rail could develop to a very large magnitude making rail fracture very probable, in other words.

   If $t_d = t_{max}$ then $t_1 = 0$, Comp. force = 0, $t_2 = R$ Tensile force = $AE\alpha$ (R)

3. Logic suggests that we should fix the destressing temperature exactly mid-way between maximum and minimum rail temperatures. i.e. at mean rail temperature. In that case the extent of maximum compressive or maximum tensile forces would be equal and half of what it would otherwise be as in case of either of the two previous situations, in other words

If $t_d = t_m$ then $t_1 = t_2 = R/2$,
So comp. force = Tensile force = $AE\alpha(R/2)$

4. So when t_d is fixed at t_m, the same magnitude of compressive forces and tensile forces are bound to develop and so the possibility of buckling as well as fracture will exist. A fracture will create a gap in the rail. However, in the case of fractures, the alignment of the rail is not immediately distorted. Also fractures rarely occur on both rails and at the same location simultaneously. Thus it is possible that least few trains can pass over a fractured rail without accident meanwhile the fracture can be attended to. However, if the track buckles due to excessive compressive forces in the rail, alignment of track gets distorted and safe running of trains is endangered.

   Therefore considering buckling more dangerous, it is considered prudent to fix the destressing temperature higher than the mean rail temperature so that the compressive forces built up in the track is slightly less though at the cost of introducing higher tensile forces. This is the basis for fixing t_d on the Indian Railways at a temperature above t_m.

   The destressing temprature on I.R is fixed accordingly as under:

ZONE-I, ZONE-II, ZONE-III :	**t_m to t_m+ 5**
ZONE-IV 52 kg & higher section:	**t_m+5 to t_m+ 10**
ZONE-IV 90 R & lighter section:	**t_m to t_m+ 5**

Note: Since 90R &lighter sections do not have adequate margin to accommodate the resulting thermal tensile

stresses, t_d for such rails has been fixed between t_m and tm + 5^0C in all the temp zones.

For heavier sections i.e. 52 kg and 60 kg rails having greater section modulus can accommodate relatively larger thermal tensile stresses and so t_d for these rails has been fixed between t_m + 5 and t_m + 10^0C for Zone-IV where temp range is maximum i.e 76^0C, In addition to the above consideration of avoiding buckling while risking the chances of fracture there are some more reasons why the destressing temperature has been fixed at a level slightly higher than t_m.

1) Studies on LWR behavior have indicated that the stability of the track gets adversely affected at temperatures above t_d + 10^0 C. accordingly LWR manual stipulates maintenance operation within tempreture of t_d + 10^0 C. If the destressing temperature of the rail is lowered the prevailing rail temperature could rise beyond t_d +10^0C more frequently reducing the availability of maintenance hours. This would either entail limited working hours to the gangs, night working or working in split shifts.

2) Similarly hot weather patrolling should be introduced when t_P rises above td + 20^0C/t_d +25^0C. Again if td is set at a lower temp. The prevailing rail temperature could rise above t_d + 20/25^0C quite often leading to an increase in the scope of hot weather patrolling.

3) There is manual provision for imposition of speed restrictions where after track maintenance operation, temperature rises beyond t_d + 20^0C during the period of consolidation. If t_d is fixed at a lower level, this would necessitate imposition of a large number of restrictions at work sites,

whenever the rail temperature rises beyond t_d +20^{0}C during the period of consolidation. This situation is unacceptable.

Keeping the above factors in mind td has been fixed at a higher level as compared to t_m.

2.4 Breathing Length

2.4.1 As discussed earlier, the ballast resistance builds up in the LWR in the breathing length from the free end. The tendency of the rail sleeper assembly to movement is resisted by this longitudinal ballast resistance. It is denoted by R and its unit of measurement is in kg/cm/ rail. The longitudinal ballast resistance is mobilized when there is a relative movement between the sleeper and the ballast. If Lb is breathing length and R the longitudinal ballast resistance, then Lb x R represents the total resistance offered by the ballast in the breathing length.

The maximum force in the LWR = P = AE α t

L_b x R = AE α t or L_b = AE α t/ R

The above expression for the breathing length indicates the various factors which govern the breathing length as under:

1) The breathing length is proportional to the temperature change. Therefore the breathing length is maximum in Zone IV and minimum in Zone I.

2) Larger the cross sectional area of the rail, the larger is the breathing length.

3) The larger the value of 'R' the smaller is the breathing length. As BG sleepers have a larger value of R the breathing length of BG LWRs is smaller as compared to MG LWRs.

2.5 Longitudinal Ballast Resistance

The longitudinal ballast resistance ‘R’ comes into play when there is relative motion of the sleepers with respect to the ballast in the longitudinal direction.

2.5.1 RDSO conducted a number of experimental studies on the various aspects of the longitudinal ballast resistance. These studies are described in RDSO Report No. C-148 (Reference 4).

Experimental Set- up: These studies were conducted experimentally on a running track as well as on a freshly laid track in the lab. A track section comprising of short length rails and three sleepers embedded in ballast was pushed in the longitudinal direction and the displacement versus load curve plotted. The tests were conducted on a running line where a traffic block of 90 minutes was taken. The load was applied to this test panel by a hydraulic jack with a remote controlled pumping unit. The load applied was measured with the help of a proving ring and the longitudinal movement of the panel was recorded with the help of dial gauges. The instantaneous loads and movements were measured as the load was increased gradually till it reached a peak and fairly steady value. After the test, the short length rails were replaced by the normal rails. (Refer to figure 2.5)

The maximum value obtained from the proving ring was divided by twice the number of sleepers in action to get the ballast resistance per sleeper per rail. This figure divided by the sleeper spacing in metres gives the value of 'R' in kg/m/rail.

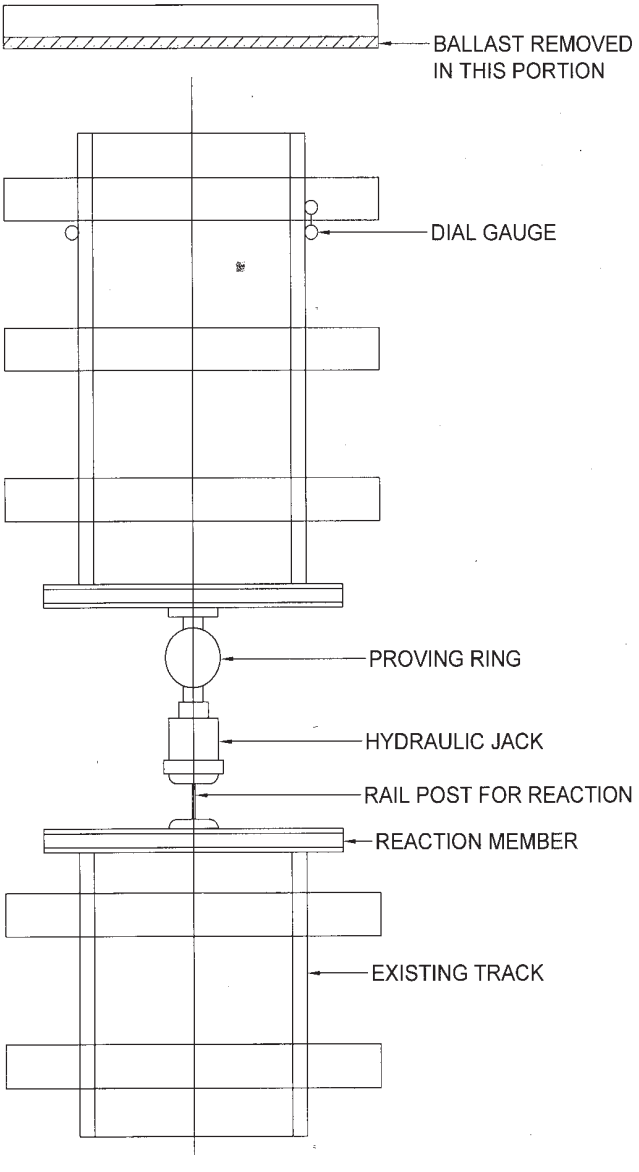

BALLAST REMOVED
IN THIS PORTION
DIAL GAUGE
PROVING RING
HYDRAULIC JACK
RAIL POST FOR REACTION
REACTION MEMBER
EXISTING TRACK

Fig 2.5

Findings of the study:

1. In BG, concrete sleepers give the highest longitudinal ballast resistance in all conditions ie. In consolidated and through packed conditions.
2. Through packing causes a reduction in ballast resistance. For both BG & MG concrete sleepers the average reduction is 23%.
3. Deep screening causes a greater reduction in ballast resistance.
4. The effect of traffic on the growth of the ballast resistance is substantial. BG concrete sleepers attain 86% of the consolidated value on passage of 1 GMT of traffic.
5. Ballast resistance per sleeper decreases as the sleeper spacing reduces, but the ballast resistance per unit length of track remains more or less constant for sleeper densities from 1200 nos. to 1500 nos. per km. For larger sleeper densities the value of the longitudinal ballast resistance again increases due to heavier track structure.
6. A heaped up shoulder ballast gives a higher ballast resistance as compared to the standard shoulder for both BG and MG. This increase is maximum for concrete sleepers.

A summary of values obtained for different sleepers under different conditions is given in Table 2.2, Table 2.3.

Table - 2.2
Longitudinal Ballast Resistance (kg/m/rail)
(Effect of sleeper type and track maintenance activities)

Gauge	Sleeper Type	Consolidated	Through packed	% Loss	Deep Screened	% Loss
BG	PRC	1244	1027	17	885	29
	Steel	1051	744	29	433	59
	CST-9	933	551	41	276	71
MG	Steel	298	231	22	209	30

Adapted from RDSO/C-148

Table 2.3
Longitudinal Ballast Resistance (kg/m/rail)
(Effect of movement of traffic)

Sleeper	consolidated Value	LBR on passage of 1 GMT of traffic	% of consolidated Value
PRC	1244	1072	86
Steel	1051	740	70
CST- 9	933	580	62

Adapted from RDSO/C-148

2.6 Lateral Ballast Resistance

The lateral ballast resistance comes into play when the track has a tendency to get displaced in the lateral direction due to buildup of compressive forces. RDSO studies conducted on various aspects of lateral ballast resistance have indicated the values of lateral ballast resistance as given in the Table below. The test setup is given in Fig. 2.6.

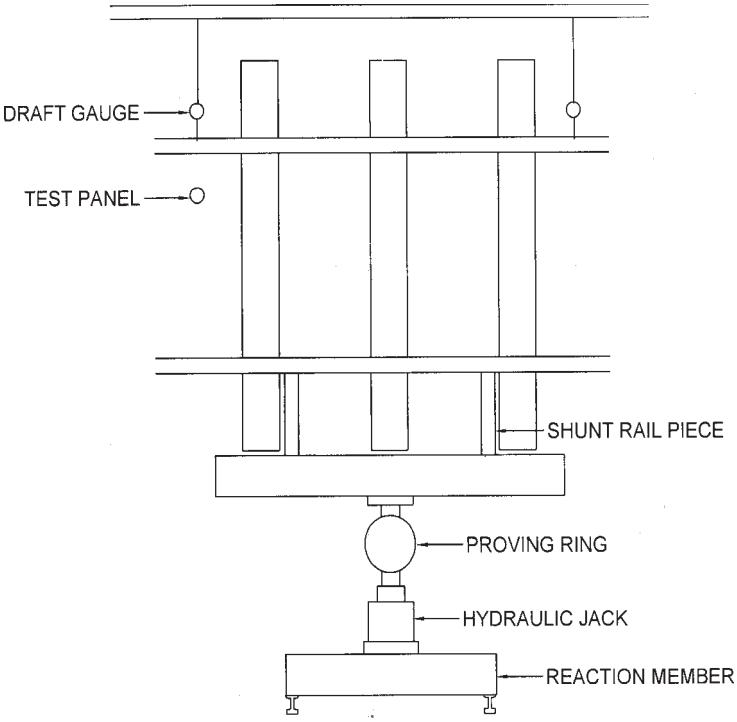


Fig. 2.6

Values of Lateral Ballast Resistance in Kg/m of track

Gauge: BG Sleeper	Consolidated packed	Through Screened	Deep Screened
PRC	1470	1226	1040
CST-9	1640	1100	532
Steel	1430	825	540

Adapted from RDSO/C-156

Findings from Study :

1. The higher resistance recorded by metal sleepers

is due to the central keel in the case of CST-9 sleepers and turned down ends in case of steel sleepers which get embedded in the ballast core and offer better resistance to the lateral movement.

2. The reduction in the lateral ballast resistance on through packing and deep screening is quite significant for CST-9 and steel sleepers and much less for PRC sleepers.

3. Tests conducted have further revealed that: Track surfacing and ballast tamping even with a minor amount of rail lift (0.5 to 1 inch) can cause significant reduction in lateral track strength.Depending upon the ballast type, recovery of strength loss due to traffic could vary from 0.3 GMT to 9 GMT.Dynamic track stabilizers could significantly accelerate ballast consolidation or strength recovery. For instance for granite ballast, the dynamic track stabilizer may produce a consolidation equivalent to 0.3 GMT.

■ ■ ■

CHAPTER - 3

THERMAL MOVEMENTS AND HYSTERESIS

3.1 Estimation of Thermal Movements

It is only in the breathing lengths where LWR displays the property of longitudinal movements. At the ends of the LWR since the restraint offered by the longitudinal ballast resistance is nil, the movement is observed to be the maximum. As the longitudinal ballast resistance exerted on the sleepers progressively builds up complimentary forces in the rail increase from A towards B.(Fig.3.1) At B, which is the junction between the breathing and fixed lengths, the movement reduces to zero. The movements recorded in the field at various points in the breathing length of the LWR corroborate the above mentioned observations. It is possible to make certain simplifying assumptions and estimate the movement at any point in the breathing length.

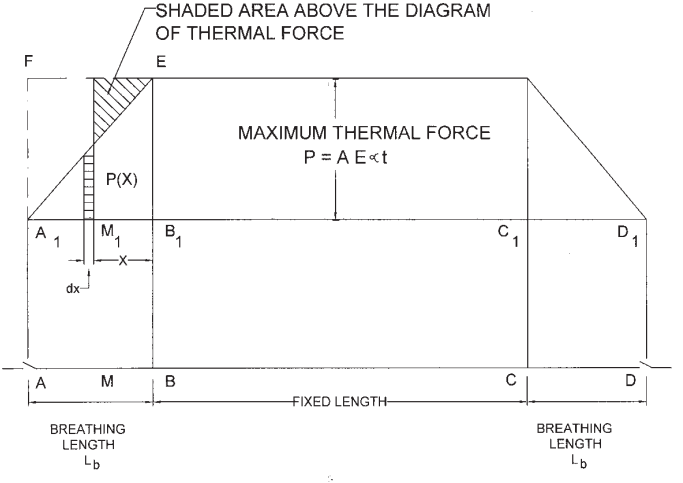


Fig. 3.1

Take a small length of rail dx at any arbitrary point M at a distance 'x' away from B (refer fig. 3.1).

It is possible to calculate the amount of free expansion of the small rail of length 'dx' due to change of rail temperature as well as the amount of contraction due to presence of thermal force present in the rail at that length:

i) Free expansion of this small length dx due to a rise in rail temperature by t^0C = dx α t.

ii) The amount of contraction of this length dx, due to presence of comp. force is equal to $\frac{P(x)\,dx}{E\,A}$

where P(x) is the thermal force present in the small length of rail dx at a distance x away from B.

The net expansion of the small length of rail dx will therefore be the difference between the above two values. If this net expansion is called *dy*, then

$$dy = dx\,\alpha\,t - \frac{P(x)\;dx}{AE}$$

$$= \frac{(\mathrm{AE}\alpha\mathrm{t} - \mathrm{P}(x))\;dx}{\mathrm{AE}}$$

Integrating the net expansion of all such small lengths of rails starting from B towards M, we can obtain the total expansion or displacement of points M as

$$Y = \int_0^x dy = \frac{1}{AE}\int_0^x \left[P - P(x)\right] dx$$

It can be observed from Fig. 3.1 that the expression $\int_0^x (p - px)\,dx$ is nothing but the area of the shaded diagram appearing above the diagram of thermal force.

Thus the amount of maximum contraction or expansion at any point in the breathing length of a LWR can be computed by dividing the shaded area from B, upto that point as in the Fig. 3.1 by AE. Extending this logic, the cumulative value of expansion or contraction at the end of the LWR i.e. at 'A' or 'D' can be obtained as follows:Maximum expansion or contraction at 'A' or 'D' =

$$\frac{\text{Area of Triangle } A_1 FE}{AE}$$

$$= \frac{1}{2} \times \frac{PL_b}{AE} \text{ .....(Equation 1)}$$

As P = AE α t, equation (1) above can be simplified as maximum movement at the end of a LWR,

$$= \frac{L_b \alpha t}{2} \text{ .....(Equation 2)}$$

Therefore the maximum movement of the end of the LWR is half the corresponding value if only the breathing length Lb of the LWR is allowed to expand or contract absolutely freely. The variation of movement along the breathing length is given in Fig.3.2.

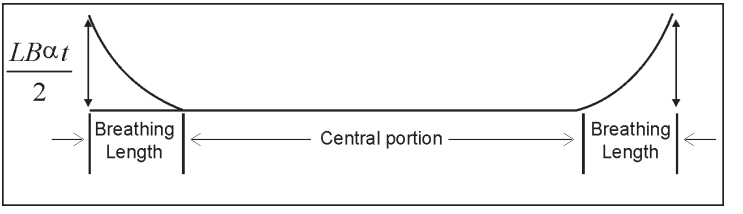


Fig.3.2 Variation of Movement in Breathing Length

The maximum movement at the end of the LWR i.e. m = ($L_b \alpha$ t)/2 can also be rewritten as: P α t/2R

$$m = \frac{AE(\alpha t)^2}{2R} \quad \text{.....(Equation 3)}$$

It should be noted that in the above calculations an important assumption has been made that in a breathing length of LWR, the sleepers have equal values of longitudinal resistance.

Illustration: To find out maximum movement near SEJ at t_{max} & t_{min}

Gauge: BG, Sleepers: PRC, Rails: 52kg ($A=66.15cm^2$)

Sleeper density 1540 sleepers/km, Zone IV with temp. range $=76^0C$

R = 13.28 kg/cm/rail

$A = 66.15\ cm^2$, $E = 2.15 \times 10^6\ kg/cm^2$

$t_d = t_m + 10^0C$

$t_{max} = 28^0C$ for temp. rise,

$t_{min} = 48^0C$ for temp. fall

$\alpha = 1.152 \times 10^{-5}\ /^0C$

$$\Delta = \frac{AE(\alpha t)^2}{2R}$$

For a temperature rise of 28^0C,

$$\Delta_1 = \frac{66.15 \times 2.15\times10^6\ (1.152\times10^{-5} \times 28)^2}{2\times13.28}$$

$$\Delta_1 = 5.57mm$$

(Expansion)

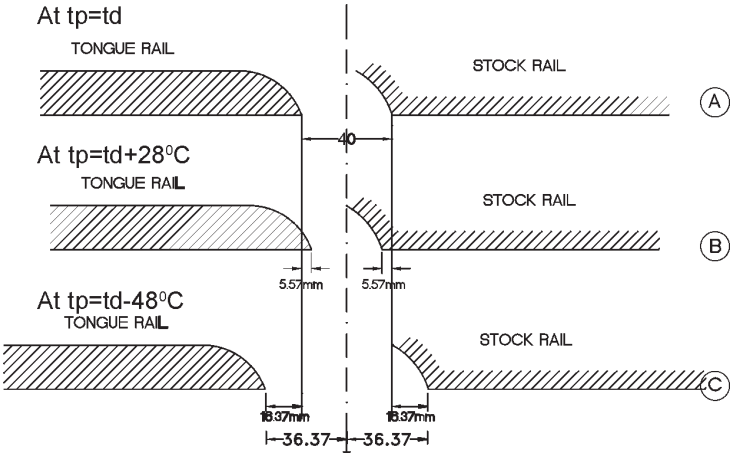


Fig 3.3

For a temperature fall of 48⁰C

$$\Delta_2 = \frac{66.15 \times 2.15\times10^{6}\ (1.152\times10^{-5}\ \times48)^{2}}{2\times13.28}$$

16.37 mm (Contraction)

Total movement at the SEJ joint = = 2 x (5.57 + 16.37) = 2 x 21.94 = 43.88 mm

The movements which occur at the SEJ due to thermal variations are shown in Fig. 3.3 with values as calculated in the above example.

3.2 Switch Expansion Joints (SEJ):

The thermal movement in the breathing length of LWR is accommodated at the switch expansion joint (SEJ). An SEJ typically consists of a pair of tongue rails and stock rails, the tongue rail is laid facing the direction of traffic. Modern SEJs are laid on concrete sleepers with rail free fastenings. The tongue rails and stock rails are machined

and given suitable bends to accommodate each other.

Tongue rails and stock rails have typically straight alignment and hence these SEJs cannot be laid in curves sharper than 0.5^0. The distance between the tip of the tongue rail and notch of the stock rail is typically kept as 40 mm for 52kg/60kg rail section at the destressing temperature. Various types of SEJs used on Indian Railways are described below:

Drawing No.	Description
RDSO/T-4160	Assembly for Switch Expansion Joint with 80 mm max gap for LWR BG 52 kg on Concrete sleepers
RDSO/T-4165	Assembly for SEJ with 80 mm max gap for LWR BG 60 kg on concrete sleepers
RDSO/T-5748	Assembly for SEJ with LWR BG 60 kg (UIC) on PSC sleepers laid on curve with curvature from 0.5^0 to 1.5^0
RDSO/T-6039	Assembly for SEJ with 190 mm max gap for bridge approaches for LWR BG 52 kg on concrete sleepers
RDSO/T-6263	Assembly for SEJ with 190mm max gap for bridge bridge approaches for BG 60 kg(UIC) on PSC sleepers
RDSO/T-6257	Assembly for SEJ for 80 mm max gap with BG CR – 120 crane rails on PSC sleepers

RDSO/T- 4160 and RDSO/T- 4165 are the conventional straight SEJs with 80 mm maximum gap. Each SEJ has a pair of tongue rails and stock rails, with 6 special sleepers to RDSO drawing No.RDSO/T4149. All these are 300 mm

wide sleepers with sleepers Nos 10 and 11 with special fastenings and sleeper No. 8, 9, 12 and 13 with similar fittings. The centre line of sleeper No. 10 coincides with the tip of the tongue rail and the 40 mm initial gap is provided with the tip of the tongue rail coinciding with the centre of the sleeper No. 10. The centre to centre spacing of sleeper No. 10 and 11 is 700 mm while the sleepers spacing from 1 to 10 and 11 to 20 may be 600 mm or 650 mm depending upon the sleeper density. Fig. 3.5 (a) gives details of a typical SEJ layout and 3.5 (b) gives the details of location A.

Fig. 3.4 : Convensional SEJ

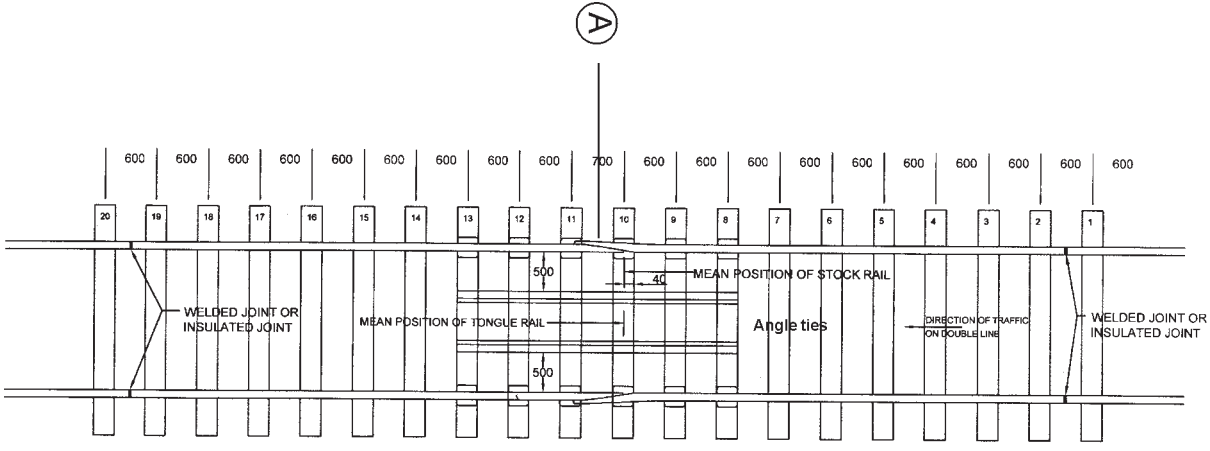


Fig. 3.5 (a) : Typical SEJ Layout

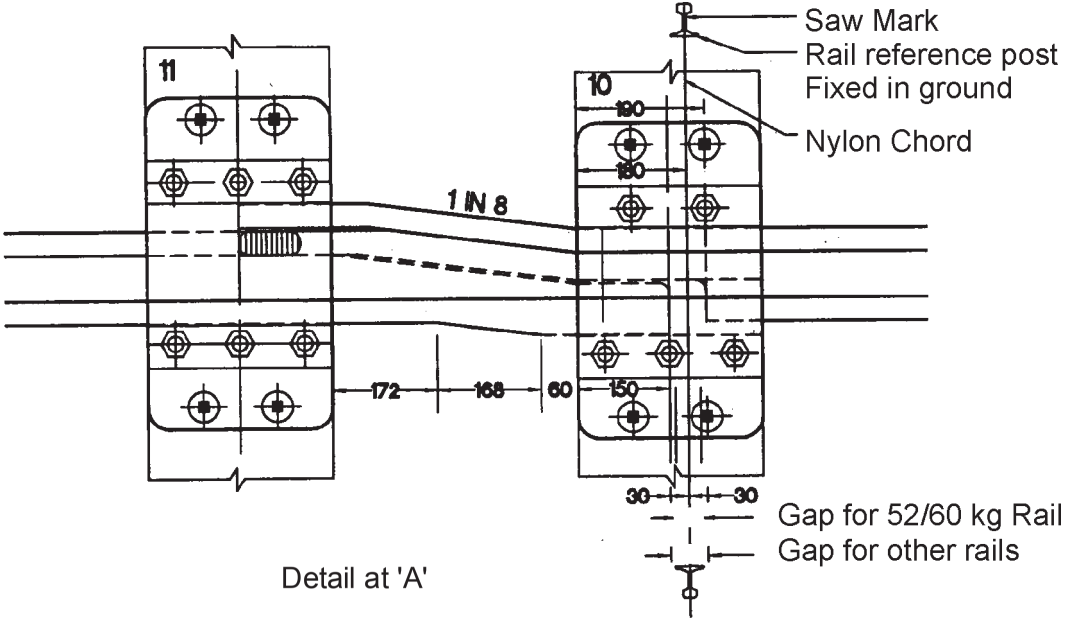


Fig. 3.5 (b) : SEJ Detailing at A

(i) RDSO/T-6039 & RDSO/T-6263 : These are wide gap SEJs for bridge approaches where the maximum gap permitted is 190 mm, the

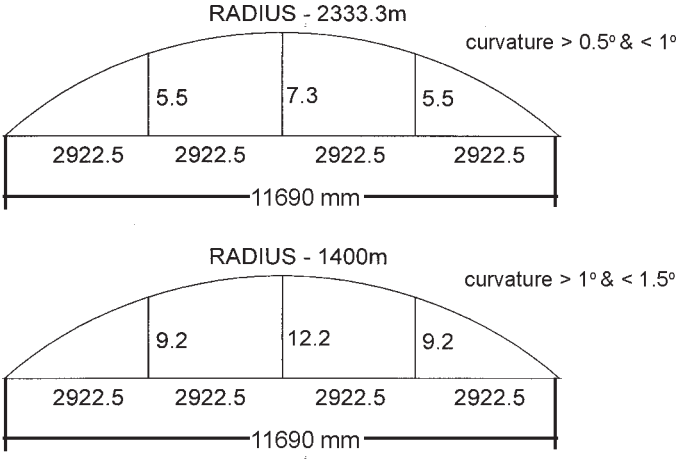


Fig. 3.5 (c) : Typical SEJ Layout

mean position is kept at 166 mm from centerline of sleeper No. 10 to enable the tongue rail to remain on the sleeper even when the entire expansion takes place. Sleepers No. 7, 8, 9, 10, 11, 12, 13 are special sleepers with sleeper nos. 9, 10 and 11 with special fastenings. Use is made of ERC Mark II clips with flat toe designed with a toe load of 350 / 400 kg/clip to enable free rail movement. Sleepers other than 7 to 13 are approach concrete sleepers with normal fittings. When gap is more than 100mm for passing diplorries with smaller wheel diameter, use of an insertion piece in the gap should be made.

ii) RDSO/T-5748 : These SEJ layouts can be used when the SEJ hasto be laid in a curve sharper than 0.5^0 but not sharper than 1.5^0. The tongue rail and stock rail are given curvature as given (Fig. 3.5(c)).

The conventional SEJ design involves two bends in the stock rail and tongue rail which are locations of weakness resulting in fractures. Improved design SEJs developed by various industries are under trial on the Railways. A brief description of these layouts is given below:

(1) **SEJ with one gap :** This design has been developed by M/s Rahee Industries Ltd, Calcutta. (Fig 3.6) The design comprises of a pair of machined segments on the non-gauge face side of two non-bent running rails mounted with a gap between the juxtaposed rail ends and a third rail called a gap avoiding rail of predetermined length accommodated in the said machined segments parallel to and adjacent to the non bent straight length of the running rails. This rail is securely fitted to one of running rails with high tensile steel bolts. This running rail together with the gap avoiding rail is called the stock rail. The other running rail is called the tongue rail. The non-bolted segment of the gap avoiding rail braces the machined segment of the tongue rail.

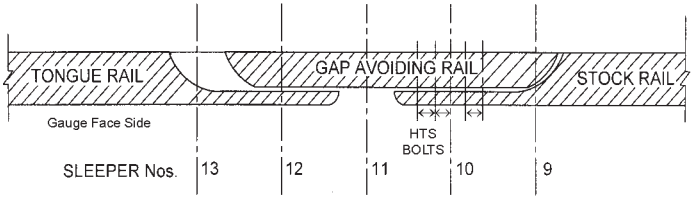


Fig 3.6 : One Gap SEJ

Features :

1) No bends in tongue and stock rail.

2) Only 5 special sleepers of standard SEJ on PSC assembly are used.

3) Check rails guard against excessive play of worn out wheels.

4) Design suitable upto 180 mm maximum gap.

(2) **SEJ with two gaps**

Two designs have been developed by two different firms (M/s Bina Metalway, Jamshedpur and M/s Chintpurni Engineering Works, Barabanki). In both these designs two gaps of maximum 80 mm each are provided in one SEJ. Thus a maximum gap of 80 mm is available for LWR on one side of the SEJ. Similarly a gap of 80mm is available for the LWR on the other side. The tongue rail is manufactured by cutting the rail at head and foot location. Two cut rails are joined together to make the stock rail.

Salient features of Bina Metalway 2-gap SEJ (Fig 3.7)
The stock rail is considered to be static with negligible expansion and contraction in length due to temperature changes. This SEJ makes use of 6 wider concrete sleepers each to Drg No. T/4149, with three sleepers located near each gap. The length of the SEJ is 5750 + 6950 + 5920 + 80 = 18700 mm.Hence a total gap of 18750 mm should be created while inserting this SEJ. The stock rail is fabricated out of two pieces of lengths 7140 mm and 5920 mm connected to each other by HTS bolts. While laying the SEJ it should be ensured that the ends of the stock rail are 40 mm away from the centre line of sleeper Nos. 12 and 22 with the tip of the tongue rail coinciding with the centre line of the sleeper.

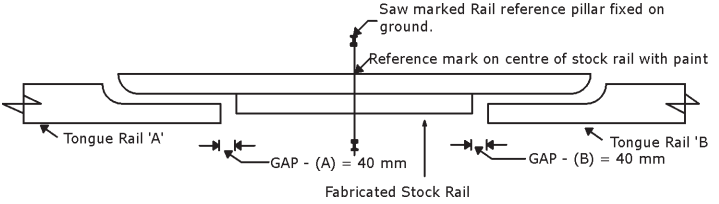


FIG 3.7 : Two Gap SEJ

1. Sleeper Nos. 1 to 31 should be at a spacing of 600 mm c/c.
2. Sleeper Nos. 10, 11, 12, 22, 23 and 24 are special sleepers to RDSO drawing No. T – 4149 and the BALANCE are normal PSC line sleepers.
3. Mean position of SEJ should be kept at centre line of sleepers No. 12 &22.
4. The mean gap is 40 mm on each end.
5. The tongue rails are kept at mean position at centre line of sleeper Nos. 12 &22, and stock rail end kept at 40 mm from mean position, thus creating a gap of 40 mm.
6. The mean position should also be marked on the rail posts erected on both sides of track.

3.3 Gap Measurements at SEJ :

At the SEJ a reference line is established between the tongue rail and stock rail. The gap between the tongue rail and stock rail will be equal to 40mm for 52kg and 60kg rail sections, and for other rail sections 60 mm.

Gaps g1 and g2 are not discrete values but the permissible range has been defined in the LWR Manual Annexure V for different track structures, different zones and at various prevailing temperatures. A sample page for filling up the

movements observed at SEJ as per annexure XIII A of the LWR Manual

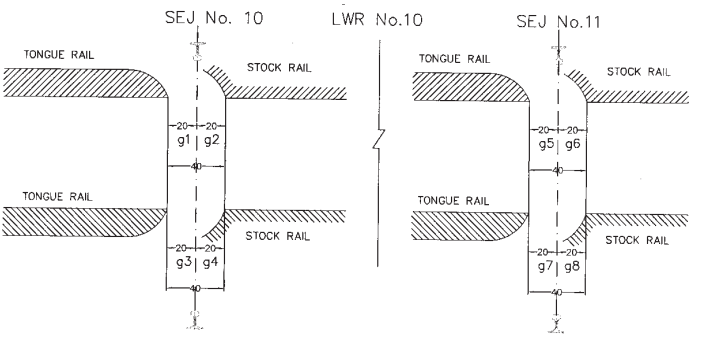


Fig. 3.8 Gap Measurement at SEJ

3.4 Laying of Buffer Rails

1. Buffer Rails may be provided with prior approval of Chief Engineer at locations where provision of SEJ is not permitted. Buffer rails may also be temporarily laid to facilitate maintenance/renewal operations.

2. In rail temperature zones I &II, 3 buffer rails, while in zones III &IV, 4 buffer rails shall be provided. Buffer rails shall be 6.5 meter long for BG and 6.0 meter long for MG.

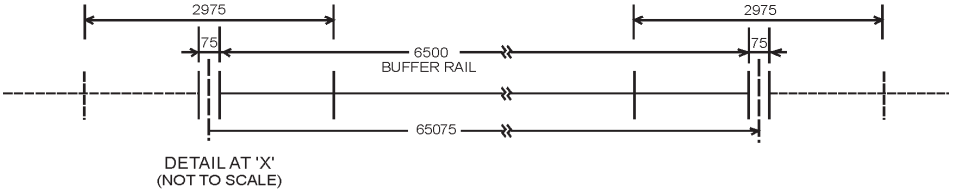
3. Buffer rails may be laid with J-clips. Standard fishplates shall be used at the joints. However, for effective tightness of bolts, bolt to drawing No. T-11599 may be used in lieu of that of drawing No. RDSO/T-1899.

4. A gap of 7.5 mm shall be provided at each of fish plated joints of buffer rail assembly at the time of initial laying/destressing.

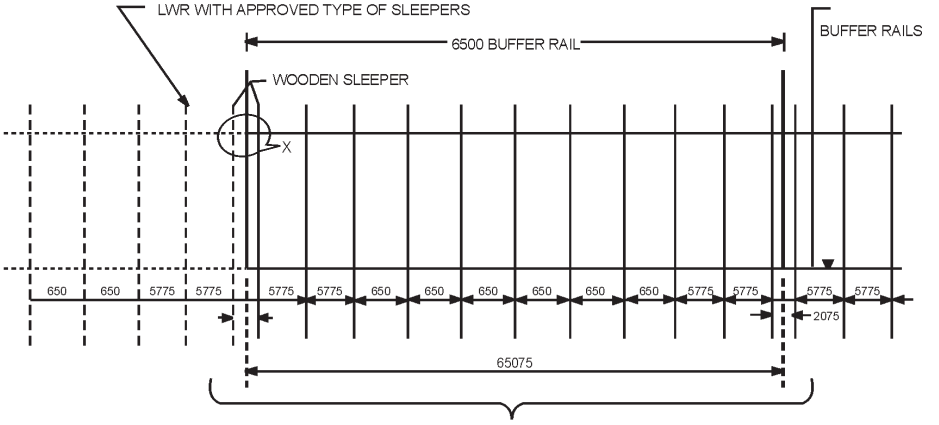
5. The fish plated joints of buffer rails shall be accurately fabricated. In case pre-drilled rails and standard fishplates are used, the dimensions and square ness of rail ends shall conform to the tolerances stipulated in the specifications IRS T - 12 for rails and IRS T-1 for fishplates. Holes drilled 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 3 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 of kinks and hogs.



DETAIL AT 'X'
(NOT TO SCALE)



PRC SLEEPERS WITH J CLIPS/WOODEN SLEEPERS WITH
MS CANDED BEARIG PLATES AND RAIL SCREWS

NOTE :
ALL DIMENSIONS ARE IN MILLIMETRES

3.5 Phenomenon of Hysteresis:

The behaviour of an LWR, as far as movement at the SEJ is concerned, is typical which will be evident form the (Fig. 3.8) shown below:

As the temp. uniformly rises above 'O', the movement or expansion at the SEJ follows the movement – temp. rise curve OF where

$$m = \frac{AE(\alpha t)^2}{2R}$$

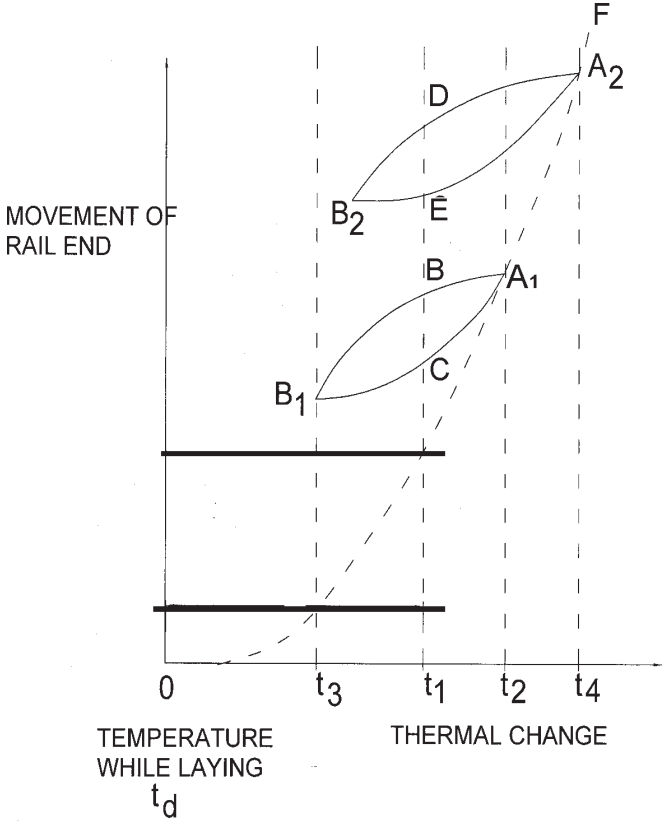


Fig 3.10 : Hysteresis Phenomena

At any given temperature t4 if the temp starts falling, then the movement at the SEJ does not follow the original path but traces out a new curve A2DB2. If at B2 the temp again reverses then the path traced out is B2EA2 rather than B2DA2 Loops in the form A2DB2EA2 are called hysteresis loops and are formed whenever there is a temperature reversal. In order to simplify matters, an annual hysteresis loop or curve is plotted which will envelope all the hysteresis loops formed on a daily basis.

Reason for Hysteresis: Hysteresis is due to the behavior of the longitudinal ballast resistance. A plot of the resistance offered by the ballast vis-à-vis the sleeper displacement is as given in Fig 3.11 here under

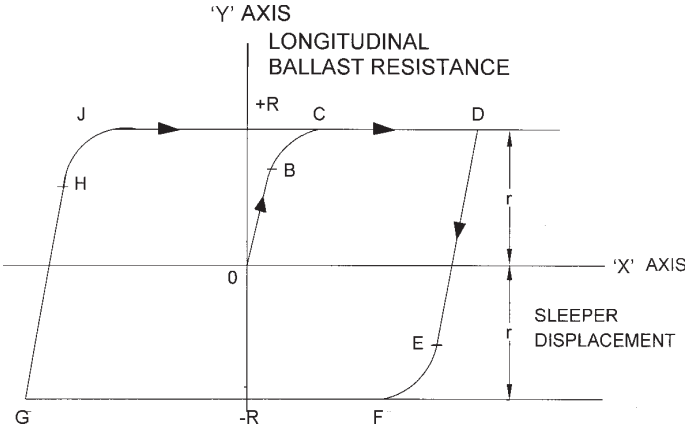


Fig. 3.11 : Development of Longitudinal Ballast Resistance

The ballast resistance first increases linearly with the sleeper displacement, then goes into the plastic zone and finally assumes a constant value R. If at this stage the temperature reverses then the value of the longitudinal ballast resistance drops to zero and then becomes (-R)

as shown above. This shows that at the time of reversal of temp the ballast resistance mobilized is 2R. Due to this effect, the path traced out at the end of LWR follows typical path loops leading to the hysteresis phenomenon.

This hysteresis loop can be traced in two ways :

1) Temp rise from t_d to t_{max}, fall from t_{max} to t_{min} and again a rise to t_{max} from t_{min}
2) Temp fall from t_d to t_{min} , rise from t_{min} to t_{max} and then a fall from t_{max} to t_{min}

Further destressing temp is a range of temp, where in one loop will form when t_d is fixed at lower limit & second loop will form when t_d is fixed at upper t_d limit, the present criteria on for t_d is as under:

a) Zone IV 52 kg & higher section : t_m+ 5 to t_m+10
b) All other sections in zone IV & Zone-I,II,III : t_m to t_m+5

For example, in zone-IV LWR for 52 & 60 kg rail section, the t_d can be fixed with in a temp range of tm +5 to t_m +10, accordingly the t_{max} & t_{min} shall vary as under:

i) When t_d is fixed at t_m +5, t_{min} will go up to t_d – 43 & t_{max} will go up to t_d +33
ii) When t_d is fixed as t_m +10, t_{min} will go up to t_d - 48 & t_{max} will go up to t_d +28.

In this case the movement can take place in the range of t_d – 48 to t_d +33 to take care of t_d at t_m+ 5 to t_m + 10, this is additional feature issue which is under consideration with RDSO

It is concluded that 4 hysteresis loops needs to be considered in each case. For example in zone-IV when t_d

is fixed as t_m +5 to t_m+10, the hysteresis loops shall be considered for following situations:

Hysteresis loop-1: Temp variation starts with lowering of temp up to $t_{min} = t_d - 43$, after destressing (when t_d is fixed at t_m+5)

Hysteresis loop-2: Temp variation starts with increase in temp up to $t_{max} = t_d + 33$, after destressing (when t_d is fixed at t_m +5)

Hysteresis loop-3: Temp variation starts with lowering of temp up to $t_{min} = t_d - 48$, after destressing (when t_d is fixed at t_m+10)

Hysteresis loop-4: Temp variation starts with increase in temp up to $t_{max} = t_d + 28$, after destressing (when t_d is fixed at t_m +10)

Zone = IV (t_d=t_m+5 to t_m +10)

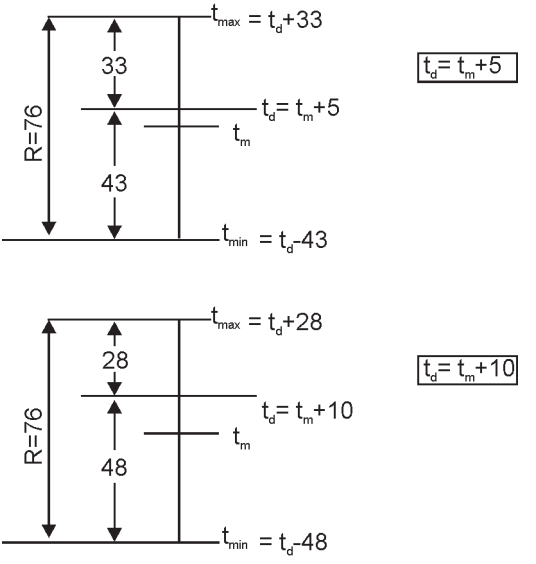


Fig. 3.12 : Temp Variations in Zone-IV

While plotting these curves it should be remembered that whenever there is a reversal of temperature, the longitudinal ballast resistance should be taken as twice its normal value (2 R instead of R). The final hysteresis loop shall be an envelope of the 4 hysteresis loops as discussed above.

Implications of hysteresis:

At temp. t_P the movement at the SEJ may be an expansion equal to 'a' or contraction 'b'. This would mean that the gap at the SEJ could be (20 – a) or (20 + b) if 20 mm is the initial gap. Hence, due to hysteresis the gap at SEJ is not a discrete value but a range.

LWR Manual Annexure V gives the permissible range of gaps at the SEJ for different track structures at various rail temp. for all zones.

■ ■ ■

CHAPTER - 4

PERMITTED LOCATIONS AND TRACK STRUCTURE

4.0 General Considerations for Laying LWR/ CWR

a) Complete Track renewals: As a rule, Primary complete track renewals shall provide for LWR/ CWR wherever permissible by the provisions of LWR Manual. Also existing rails on permitted locations may be converted into LWR/CWR, provided they meet the requirements laid down in the Manuals for Welding of Rail Joints by Alumino - Thermic (SKV Process)/Gas Pressure/ Flash Butt Process, as the case may be.

b) Construction Works: New constructions/ doublings/gauge conversions/retired alignment/ permanent diversion shall be opened with LWR/ CWR, wherever permissible by the provisions of LWR Manual.

c) Goods Lines: 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.

4.1 Formation:

The LWR shall be laid on stable formation. The formation width shall be 7.85 m for single line track & 13.16 m for double line track. The formation width will be same for embankment & cutting.

4.2 Ballast Cushion and Section:

The minimum clean stone ballast cushion (below the bottom of the sleeper) to be provided at the time of installation of LWR/CWR shall be as under:

Speeds up to 130 kmph - 250 mm

Speeds higher than 130 kmph on BG & 100 kmph on MG - 300 mm

The profile of ballast section shall be as shown below in Fig.4.1 (a) & (b). The ballast section and cushion provided for LWR/CWR shall be continued over SEJ and up to 3 rails beyond it, wherever it is followed by SWR/ fish plated track.

Ballast Profile (BG Single line in embankment/cutting)

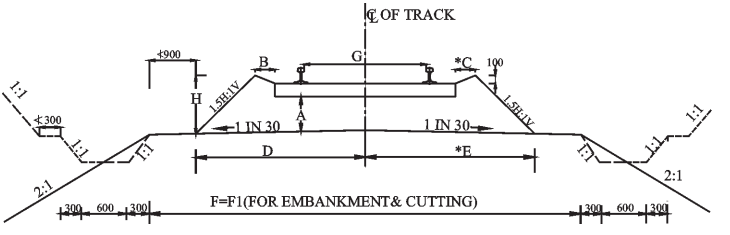


Fig. 4.1 (a)

A	B	*C	D	E	F	H	Min. Cess in	
							Straight	Curve
250	350	500	2648	2804	7850	620	1277	1121
300	350	500	2723	2880	7850	670	1202	1045
350	350	500	2797	2954	7850	720	1128	971

Ballast Profile (BG Double line in embankment/ cutting)

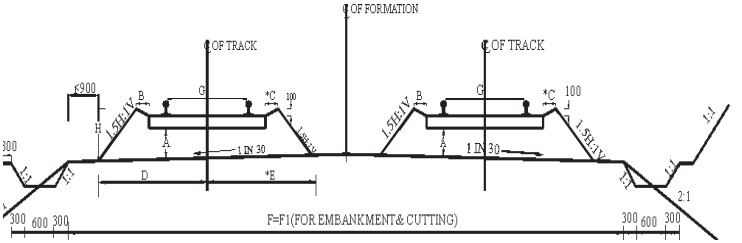


Fig. 4.1 (b)

A	B	*C	D	E	F	H	J	Min. Cess in	
								Straight	Curve
250	350	500	2689	2847	13160	648	5300	1241	1083
300	350	500	2764	2922	13160	698	5300	1166	1008
350	350	500	2839	2997	13160	748	5300	1091	933

Note:

1. *Cross-slope of 1 in 40 has been replaced with 1 in 30 for new construction works. However, existing formation need not be disturbed.*
2. *Ballast side slope shall be 1.5 H: 1V.*
3. ** On outer side of curves only.*

4.3 Sleepers & Fastenings

4.3.1 Type of Sleeper

a) Broad Gauge

i) Concrete sleepers with elastic fastenings

ii) Steel trough sleepers with elastic fastenings for speed not exceeding 130 kmph.

b) Meter Gauge

i) PRC sleeper & steel trough sleeper with elastic fastenings preferably for speeds above 75 kmph

ii) Steel & CST-9 sleepers with keys for speeds not exceeding 75 kmph

4.3.2 Sleeper Density

The minimum sleeper density (number of sleepers/km) in LWR/CWR shall be as shown below.

Type of sleeper↓ / Zone →	**I & II**	**III & IV**
PRC sleeper	1340	1540
Other than PRC sleeper	1540 in all temperature zones	

4.4 Rails

4.4.1

i) On BG 90 R/52kg/60kg Rails & on MG 75 R/ 90R rails shall be welded into LWR/CWR. LWR/ CWR, already laid with 60 R rails on MG may be allowed to continue

ii) In one LWR, two different rail sections, are not permitted. In case of any change in the rail section of LWR arising out mostly due to TRR work, the LWR shall be bifurcated into two different LWR's, by providing SEJ. It is due to following reasons:

a) Thermal forces generated in rails of different cross sectional areas are different. This makes the behavior of the LWR non uniform. The destressing temperatures are also different for 52 kg and 90 R rails in zone-IV.

b) While permitting two different rail sections in a LWR, combination welded joints is to be provided, as the gauge faces have to be matched, the

eccentricity is induced in the axial forces, resulting in additional stresses in the rail.

c) The ultrasonic flaw detection of combination welds is not completely fool proof.

Note: In case of LWRs laid on concrete sleepers having different rail section on either side of SEJs, instead of providing three normal rail lengths of each rail section between SEJs, two 3 rail panels, one of each rail section shall be provided with combination fish plated joint, between the two panels. The track structure suggested at the junction of a 52 kg and 60 kg LWRS is shown in Fig below

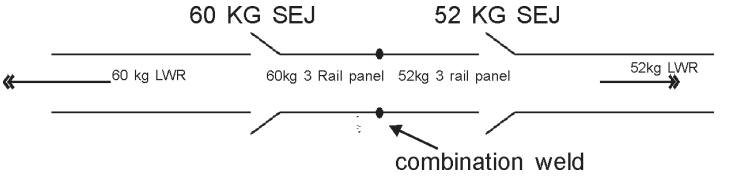


Fig. 4.2

4.4.2 While converting existing fish plated/SWR track into LWR/CWR, following precautions shall be taken:-

i) The rails shall be tested ultrasonically and all defective rails replaced before conversion into LWR/CWR.

ii) Rail ends which are bent, hogged, battered, or having history of bolt-hole cracks shall be cropped before welding for conversion into LWR/CWR.

4.4.3 New rails used in LWR/CWR shall, as far as possible be without fish-bolt holes. Joining of rail ends temporarily during installation of LWR/CWR shall be done with 1 meter long fishplates and special screw clamps/joggled fish-plates having slotted grooves & bolted clamps.

4.5 Glued Joints: All insulations for track circuiting in LWR/CWR shall be done by providing glued joints G3 (L) type.

4.6 Continuity of track structure: Wherever LWR/CWR is followed by fish plated track/ SWR, the same track structure as that of LWR/CWR shall be continued for three rail lengths beyond SEJ.

a) **Continuity on level crossing:** Level crossings situated in LWR / CWR territory shall not fall within the breathing lengths

b) **Continuity on Points and Crossings:** LWR shall not normally be taken through points and crossings. Three normal rail lengths shall be provided between stock rail joint (SRJ) and SEJ as well as between the heel of crossing and SEJ.

These normal rail lengths shall be provided with elastic rail clips/anchors to arrest creep. However, where concrete sleeper turnouts are laid, instead of three normal rail lengths, one three rail panel shall be provided between SEJ and SRJ as well as between heel of crossing and SEJ.

Note: LWR shall not normally be taken through points &crossings. For any exceptions in this regard i.e. in case CWR is to be constituted then the special arrangements as required shall have the prior approval of RDSO.

4.7 Alignment

a) **General: Basic concepts involved in curved track:** As indicated in Fig. 4.3 (a) below, the external equilibrium of a curved elastic beam of radius R subjected to a longitudinal force 'P'

requires a continuously distributed external force of magnitude ‘f’

Where f = P / R kg / m. This will be derived from the lateral ballast resistance t and t-P/R is the effective lateral resistance against buckling phenomene. In order to ensure that the stability of the LWR in curve is the same as in straight the lateral ballast resistance in curve should be made higher by at least P/R kg/m. Hence a larger shoulder width on curves and a restriction on the degree of curvature is prescribed. On Broad Gauge a shoulder ballast width of 500mm has been prescribed.

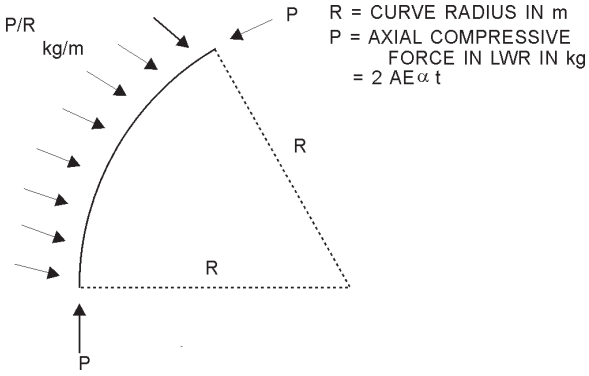


Fig. 4.3 (a) : External Equilibrium of Curved LWR Track

b) LWR/CWR shall not be laid on curves sharper than 440 meter radius (4^0 Curve). However, in temperature Zone - I, LWR/CWR may be laid on curves up to 360 meter radius (5^0 Curve) on BG with following additional precautions:

(i) Minimum track structure should be 52 kg rail on PSC sleeper, M+7 sleeper density with 300 mm clean ballast cushion.

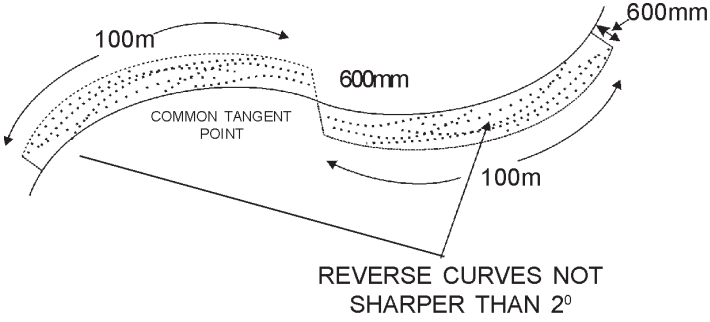
(ii) Shoulder ballast for curves shaper than 440 m radius should be increased to 600 mm on outside of curve and should be provided for 100 m beyond the tangent point.

(iii) Reference marks should be provided at every 50 m interval to record creep, if any.

(iv) Each curve of length greater than 250 m should preferably be provided with SEJ on either side.

(v) SEJ should be located in straight track at 100m away from the tangent point.

c) Reverse curve: LWR/CWR may be continued through reverse curves not sharper than 875 meter radius (2^0 Curve). For reverse curves sharper than 1500 meter radius, shoulder ballast of 600 mm over a length of 100 meter on either side of the common point should be provided.



Note : Shoulder width of 600mm for 100m on either side of common tangent point for reverse curves with radius less than 1500m.

Fig. 4.3 (b) : Laying LWR Through Reverse Curves

d) Transition curve: The SEJ shall not be located on transition of curves.

4.8 Gradients

a) **Permitted Gradient :** The steepest grade permitted is 1:100.

(This is because the steeper grades imply larger longitudinal forces due to traction & braking which would be detrimental to the health of LWR causing an increase in the longitudinal stresses in the rail)

b) **Vertical Curve:** A vertical curve shall be provided at the junction of the grade when the algebraic difference between the grades is equal to or more than 4 mm per meter or 0.4 percent, as laid down in Para 419 of IRPWM.

(The vertical curve smoothen the geometrical transition and introduce a gradual change in the direction of longitudinal force)

The minimum radius of the vertical curve shall be kept as under:

Group/ Route	A	B	C, D, E & MG all routes
Minimum radius	4000 meter	3000 meter	2500 meter

4.9. Location of SEJ:

The exact location 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. The SEJ with straight tongue and stock shall not be located on curves sharper than 0.5 degree (3500 m radius) as far as possible. For curves 0.5^0 and up to 4^0, the SEJ with curved tongue rail & stock rail shall be used.

4.10 Approval for Laying of LWR :

Installation of LWR/CWR or change in its Constitution at a later stage shall have the approval of the Chief Track Engineer in each case, on a detailed plan, however, for any deviation from the Provisions of LWR Manual, the approval of Principal Chief Engineer shall be obtained.

4.11 LWR on Bridges:

4.11.1 General: Basic concepts involved in laying LWR over bridges:

Let us consider the effect of thermal variation alone as the cause of interaction between the girder and the LWR. As a result of thermal variation the girder has a tendency to expand or contract being provided with bearings. On the other hand the central portion of the LWR is fixed in position irrespective of the temperature changes that occur. This results in an interplay of forces between the girder and the LWR, the magnitude of the force being dependent upon the nature of fastenings being provided between the rail and sleeper.

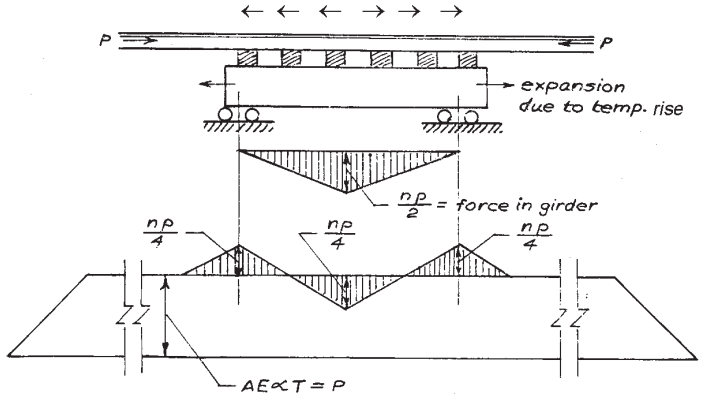
To clarify this aspect of interplay of forces between rail and girder, consider the case of a girder bridge provided with fastenings between the rail and sleeper with a creep resistance equal to ‘p’ kg per rail seat. The bridge sleepers are rigidly fixed to the top flange of the girder by means of hook bolts. On variation of temperature due to the creep resistance of the fastenings, free expansion/contraction of the girder is prevented. Consequently additional forces are developed both in the girder as well as in the rail.

The magnitude of this force developed depends upon the value of ‘p’(the creep resistance) and orientation/ nature of the bearings provided in each span of the bridge.The following cases are considered here under:

Single span bridge	a) One end fixed, other end free.
	b) Both ends of girder with free bearings.
Multiple span bridge	a) One end fixed and the other free with dissimilar bearings on a pier
	b) One end fixed and the other free with similar bearings on a pier
	c) Free bearings at both ends.

The forces developed in the rail and girder for each of the above cases are discussed here under:

Case -1 Single span with sliding bearings at both ends.

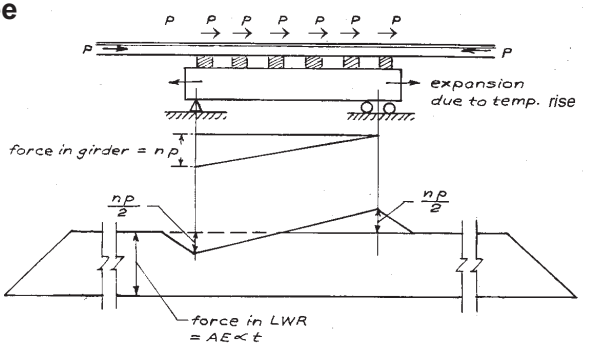


n = No. of sleepers per span
p = creep resistance per rail seat

Fig. 4.4 (a)

Implications: For sliding bearings at both ends of the girder, the increment of force in the LWR is np/4, where 'n' is the number of sleepers per span with creep resistant fastenings and 'p' is the creep resistance per rail seat

Case -2 Single span with one end fixed and other end free

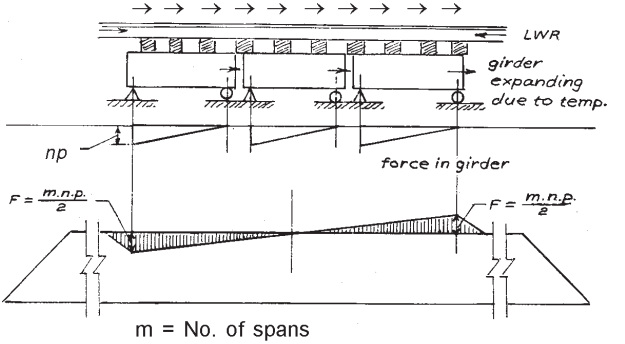


n = No. of sleepers per span
p = creep resistance per rail seat

Fig. 4.4 (b)

Implications: In girders with one end fixed and the other end free the increment of force in the LWR at the roller end is np/2 for a single span bridge, where n = number of sleepers in the span with creep resistance of 'p' kg per rail seat

Case -3 Multiple span with one end fixed and other end free with disimilar bearings on pier



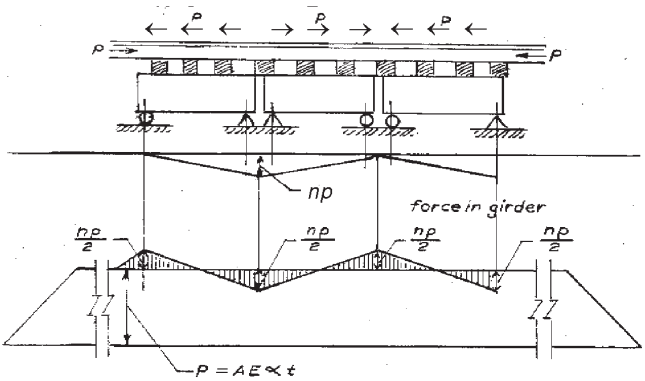
m = No. of spans
n = No. of sleepers per span
p = creep resistance per rail seat

Fig. 4.4 (c)

Implications: IIn girders with one end fixed and the other end free the increment of force in the LWR at the roller

end is np/2 for a single span bridge, where n = number of sleepers in the span with creep resistance of ‘p’ kg per rail seat But with multiple span bridge having ‘m’ number of spans, the increment of force in the LWR at the roller end will be m× n× p/2

Case - 4 Multiple span with pier support similar nature bearings

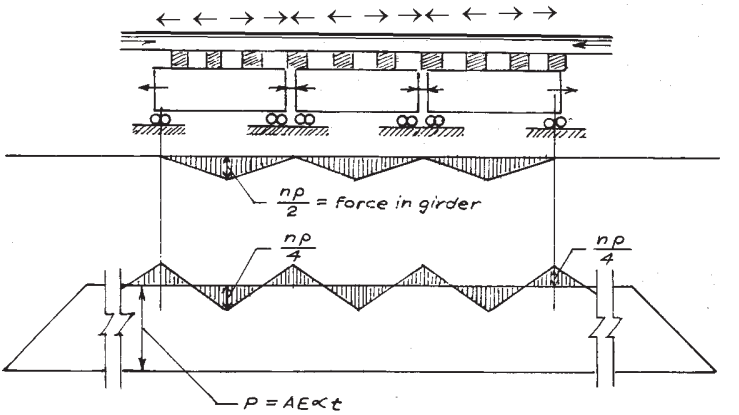


n = No. of sleepers per span
p = creep resistance per rail seat

Fig. 4.4 (d)

Implications: There could be a situation where a pier supports similar nature bearings i.e. the bearings of the two girders are either fixed or free. In this case there will be no cumulative buildup of force

Case - 5 Multiple span with free bearings at both ends.



n = No. of sleepers per span
p = creep resistance per rail seat

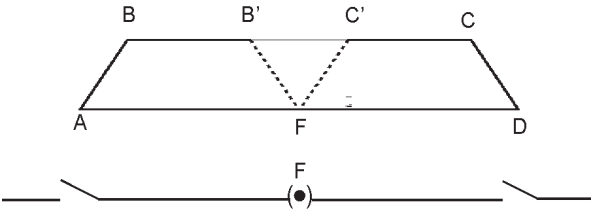
Fig. 4.4 (e)

Implications: For sliding bearings at both ends of the girder, the increment of force in the LWR is np/4, this increment of force will remain the same irrespective of the number of spans of the bridge

4.11.2 Use of rail free fastenings:

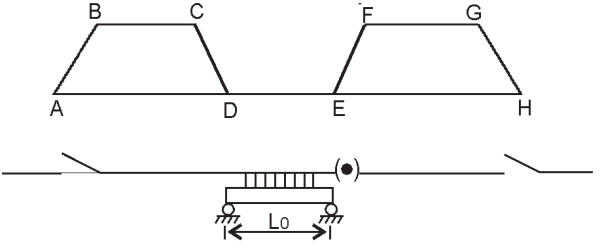
Now In order to avoid interplay of forces between the LWR and girder a possible solution would be to provide rail free fastenings between rail and sleeper on the girder bridge. It is with this assumption that the provisions for laying an LWR over bridges have been framed in the LWR manual.

On the Indian Railways we have been traditionally using dog spikes and rail screws as rail free fastenings although now ERC has come up with a zero toe load. Use of rail free fastenings on bridges where LWR is proposed to be used is now mandatory due to requirement of minimizing the interaction of forces between the LWR and the girder. However, this results into other problem i.e. larger gap during fracture, when the fracture occurs on the approach of bridge laid with LWR.



Fracture in LWR, laid on formation/ballasted track

Fig. 4.5



Fracture in LWR, on approach of girder bridge

Fig. 4.6

4.11.3 Implication of Fracture near Girder Bridge Approach:

Consider a LWR laid on normal formation with the usual force diagram A B C D. in the event of fracture at location 'F' the stress in the LWR is released at that location and two new breathing lengths BF and CF are formed on either side of the fracture location. (Fig 4.5)The gap g1 at the fracture location will be given by

$$g_1 = \frac{AE(\alpha t)^2}{2R} \times 2 \text{ .....i)}$$

[Assuming equal movement on either side of F]

R represents the longitudinal ballast resistance mobilized at the time of the fracture, which is generally about 50% to 60% of the normal R value, due to the sudden nature of occurrence of a fracture.

However, if the same fracture occurs in the approach of a bridge provided with LWR and rail free fastenings the modification of the force diagram will be as given in the figure 4.6.
In this figure, ABCDEFGH represents the altered force diagram.
Gap at fracture in this case will be

$$g_2 = \frac{AE(\alpha t)^2}{2R} \times 2 + L_0 . \alpha t \text{ .....ii)}$$

Where L_0 is the span length of the bridge provided with rail free fastenings.

Expressions (i) and (ii) indicate that the gap at fracture is enhanced by an amount equal to $L_0 \alpha t$, when a girder bridge with rail free fastenings is located in the central portion of the LWR.

Indian Railways have fixed the permissible gap at fracture as 50 mm where by expression (ii) becomes

$$\frac{AE(\alpha t)^2}{2R} \times 2 + L_0 . \alpha . t < 50 \text{ mm -------iii)}$$

This expression is applicable for both BG and MG tracks. However, as the wheel diameter of MG stock is smaller than BG, the fracture gap of 50 mm is more critical for MG.

This equation-(ii) forms the conceptual basis for LWR manual provisions with regard to LWR on girder bridges & over the years attempts have been made to increase the value of L_0 by adopting various measures.

1) Measures to improve value of longitudinal ballast resistance on approaches to control movement of breathing length in the event of fracture: LWR manual para 4.5.7.1 (i) stipulates the additional measures reduce contraction of free rails on bridge approach

2) Measures to control contraction of free rails on girder bridge in the event of fracture: LWR manual para 4.5.7.1 (ii) stipulates the additional measures to reduce contraction of free rails on bridge proper.

In addition the LWR Manual also provides some more methods for carrying LWR over bridges. These are discussed below:

a) Providing SEJ on each pier with rail free fastenings on the bridge. In order to avoid creep four sleepers on each span will be box-anchored. These sleepers will be at the fixed end of the girder, if the girder is having rollers at one and rockers on the other side. These box anchored sleepers will be at the centre of the span if the girders are having sliding bearings on both sides.

b) Providing SEJ at the far end approach of the bridge using rail free fastenings over the girder bridge Fig 4.7(a) In this arrangement the SEJ is provided at the far end approach of the bridge at a distance of 10 m away from the abutment with rail free fastenings on the bridge proper. The SEJ will have to cater to the free expansion or contraction of the rail on the bridge as well as movement of the breathing length on one side approach. Hence the SEJ will have to be a wide gap SEJ capable of accommodating larger movements. The permissible span lengths with 120 mm gap SEJs and 190 mm gap SEJs are stipulated under LWR manual para 4.5.7.1(iv).

4.11.4 LWR Manual Provisions:

1) **Bridges with ballasted deck (without bearing):** LWR/CWR can be continued without any restriction on maximum span length, over bridges without bearings like slabs, box culverts and arches,

2) **Bridges with bearing (with/without ballasted deck) Concrete / steel girders**

   a) LWR/CWR shall not be continued over bridges with overall length as specified below for BG and not more than 20 meter for MG

   b) Bridges on which LWR/CWR is not permitted/provided shall be isolated by a minimum length of 36 meter well anchored track on either sides.

i) Bridges provided with rail-free fastenings (single span not exceeding 30.5 meter and having sliding bearings on both ends)

Overall length of the bridge should not exceed the maximum as provided in Table-1 below with following stipulations:-

Table- 4.1

Maximum Overall Length of the Bridge in Meters (Para 4.5.7.1 (i))

Rail section / Zone	Zone I	Zone II	Zone-III	Zone IV
60 Kg	30	11	11	11
52 kg	45	27	27	27

a) Rail-free fastenings shall be provided throughout the length of the bridge between abutments.

b) The approach track up to 50 m on both sides shall be well anchored by providing PRC sleepers with elastic rail clips with fair 'T' or similar type creep anchors.

c) The ballast section of approach track up to 50 meter shall be heaped up to the foot of the rail on the shoulders and kept in well compacted and consolidated condition during the months of extreme summer and winter.

ii) Bridges provided with rail-free fastenings and partly box-anchored (with single span not exceeding 30.5 meter and having sliding bearings at both ends)

Overall length of the bridge should not exceed the maximum as provided in Table-2 given below with following stipulations:-

Table - 4.2

Maximum Overall Length of the Bridge in Meters (Para 4.5.7.1 (ii))

Rail section / Zone	Zone I	Zone II	Zone-III	Zone IV
60 Kg	77	42	23	23
52 kg	90	58	43	43

a) On each span, 4 central sleepers shall be box-anchored with fair 'V' or similar type creep anchors and the remaining sleepers shall be provided with rail-free fastenings.

b) The track structure in the approaches shall be laid and maintained to the standards as stated in sub para (i) (b) & (c) above.

c) The girders shall be centralized with reference to the location strips on the bearing, before laying LWR/CWR.

d) The sliding bearings shall be inspected during the months of March and October each year and cleared of all foreign materials. Lubrication of the bearings shall be done once in two years.

iii) 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 other side. In case of girder supported on sliding bearings on both sides, the central portion of the welded rails over each span shall be box-anchored on four sleepers.

iv) LWR/CWR may also be continued over a bridge with the provision of SEJ at the far end approach of the bridge using rail-free fastenings over the girder bridge. The length of the 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 bridges with the above arrangement that can be permitted in various rail temperature zones for LWR/CWR with SEJs having maximum movement of 120 mm and 190 mm are as follows:-

Table - 4.3

Rail Temp. Zone	Max. Movement of SEJ used (in mm)	Max. Length of bridge with SEJ (in meter)	Initial gap to be provided at t_d (in cm)	
I	120	50	4.0	Note: SEJ is to be installed 10 meter away from the abutments.
	190	160	6.5	
II	120	20	4.0	
	190	110	6.5	
III	190	70	7.0	
IV	190	55	7.0	

v) Welded rails may be provided over a single span bridge with rail free fastenings and SEJs at 30 meter away from both abutments. The rail shall be box anchored on four sleepers at the fixed end of the bridge if bridge is supported on roller on one side and rockers on other side. In case of bridge supported on sliding bearings on both sides, the central portion of the welded rails shall be box anchored on four sleepers. On both side of approaches fully creep anchored fastening shall be used. The length of single span bridge permitted temperature Zone–wise shall be as under:

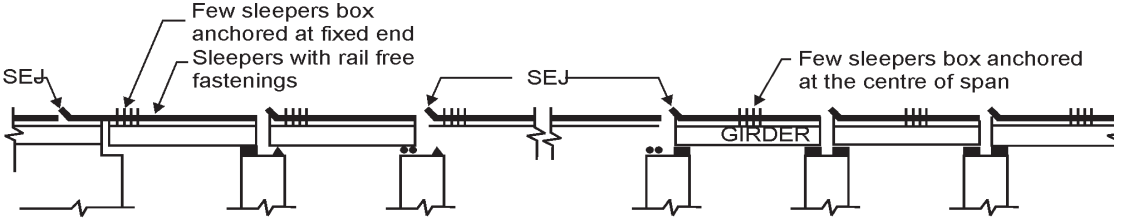
Table - 4.4

Temp - Zone	Maximum length of single span girder bridge with SEJ (190mm gap) at 30m away from both abutments with full creep resistant fastenings at approaches ($t_d = t_m$)
I	146 m
II	110 m
III	87 m
IV	75 m

Illustration: There is a girder bridge 3 x 18.3 m with overall length of 60 m with 52 kg rail section in a construction project, which falls under Zone-III.

Whether LWR can continue on the girder bridge and if it can continue, then what arrangements are required.

(a)

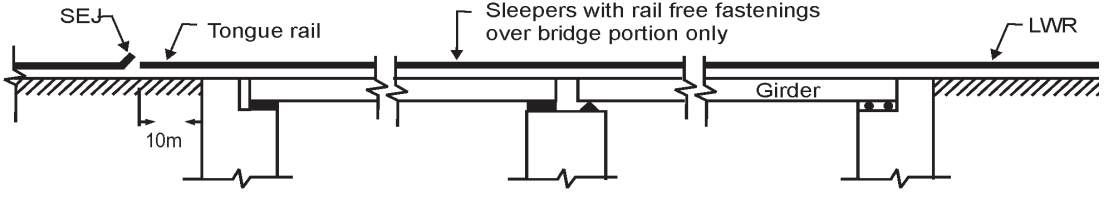


Note : Tongue rail shall be in continuation to the free end of the girder

Welded rails on girder bridge (pier to pier)

Fig. 4.7 (a)

(b)



LWR / CWR on girder bridge with SEJ at the far end approach of the bridge

Legend
- ▲ Rocker bearing
- ● ● Roller bearing
- ▬ Sliding bearing

Note : SEJ to be installed 10 m away from abutments

Fig. 4.7 (b)

Solution: it can be seen that LWR can continue on this girder bridge as per sub-para (iv) i.e. using rail free fastenings on girder bridge with SEJ (with 190 mm gap) at far end approach (to be installed 10 m away from the abutment).

In this case the max length of bridge permitted under sub para (i) & (ii) is restricted to 27 m & 43 m respectively (for 52 kg rail section) hence LWR cannot continue with provisions mentioned under sub para (i) & (ii).

4.11.5 Track Bridge Interaction Based on UIC 774-3R Report:

1. Introducing a bridge under a CWR track means that the CWR track is resting on a surface subject to deformation and movement hence causing displacement of the track. Given that both track and bridge are connected to one another either directly or through the medium of ballast and are able to move, any force or displacement that acts on one of them will induce force in the other.
2. All actions which lead to interaction effects are those that cause relative displacement between the track and the deck. These are :-
   - i) The thermal expansion of the deck only in the case of the CWR or the thermal expansion of the deck and of the rail whenever a rail expansion device is present.
   - ii) Horizontal braking and acceleration forces.
   - iii) Rotation of the deck on its supports as a result of the deck bending under vertical traffic loads.

iv) Deformation of the concrete structure due to creep and shrinkage.

v) Effects of temperature gradient.

Out of these 5 factors, the first 3 are more important.

3. The forces created due to interaction between track and bridge are dependent on a number of parameters of bridge and track both. The bridge parameters affecting the interaction forces are:

(1) Expansion length of the bridge (L): For a single span simply supported bridge the expansion length is the span length. For a continuous bridge with a fixed support at the end, it is the total length of the deck. If the fixed elastic support is located at some intermediate point, the deck is considered to have two expansion lengths on either side of fixed elastic support.

(2) Support stiffness: The resistance of the deck to horizontal displacement is a fundamental parameter as it affects all interaction phenomena. This factor is determined primarily by the total stiffness of the supports. The total support stiffness is composed of the stiffness of each support. The stiffness of each support is in turn composed of the stiffness of the bearing, pier, base, foundation and soil. The stiffness K of the support including its foundation to displacement along the longitudinal axis of the bridge is given by

$$k = \frac{H\,(KN)}{\sum \partial i(cm)}$$

With $\partial i = \partial p + \partial \phi + \partial h + \partial a$

Where, ∂p = displacement at the head of the support due to deck's deformation

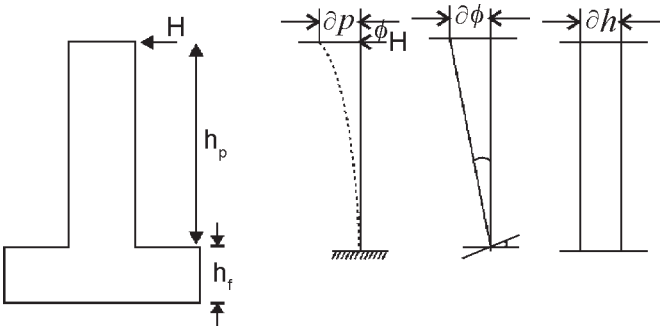


Fig. 4.8

(this could be calculated assuming the pier to be a cantilever fixed at the base)

$\partial \phi$ = displacement at the head of the support due to foundation rotation.

∂h = displacement due to horizontal movement of the foundation.

∂a = relative displacement between upper and lower parts of the bearing

The value of the displacement component is determined at the level of the bearing as shown in Fig 4.8.

3) Bending stiffness of the deck: As a result of bending of the deck the upper edge of the deck is displaced in the horizontal direction. This deformation also generates interaction forces.

4) Height of the deck: The distance of the upper surface of the deck slab from the neutral axis of the deck and the distance of neutral axis from the centre of rotation of piers

affects the interaction phenomena due to bending of the deck.

Track parameters: The resistance ‘k’ of the track per unit length to longitudinal displacement ‘u’ is an important parameter. This parameter in turn depends on a large number of factors such as whether the track is loaded or unloaded, ballasted or frozen, standard of maintenance etc. The resistance to longitudinal displacement is higher on loaded track than on unloaded track as can be seen from Fig. 4.9 & Fig. 4.10 The value of k has to be established by each railway system as per its track structure.

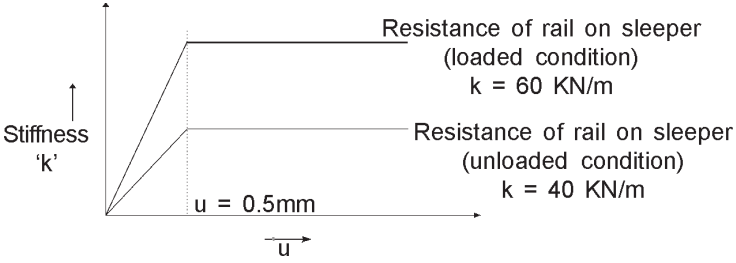


Fig. 4.9 : Track Stiffness Parameters (Frozen Ballast)

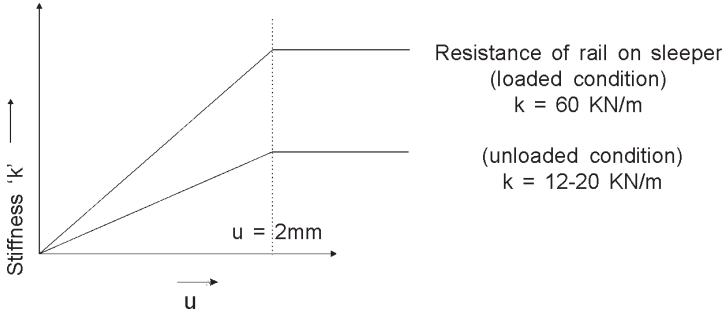


Fig. 4.10 Track Stiffness Parameters (Normal Ballast)

Once the values of K, the stiffness of the bridge structure and k, the stiffness of the track have been evaluated, use can made of the interaction diagrams given in UIC774-3R for calculation of additional stresses in the rail and additional forces at the bridge support due to each of the actions causing interaction effects: namely

(1) Change of temperature

(2) Acceleration and braking forces

(3) Deck deformation.

1. Changes in temperature: It is assumed that there is change of temperature of ± 35^0C from the reference temperature for the bridge while for the rail could deviate by ± 50^0c. Due to change of temperature additional stress will develop in the rail and additional force at the support. These are obtained from the interaction charts given in UIC774-3R.

2. Actions due to braking and acceleration:
The braking and acceleration forces applied at the top of the rail are assumed to be distributed over the length under consideration with the following standard values:

Acceleration = 33 KN/m per track
Braking = 20 KN/m per track

These values could be modified to take into account the longitudinal loadings given in the Bridge Rules.

3. Actions due to bending of deck
Vertical traffic loads cause the deck to bend, which in turn causes rotation of the end sections and displacements of the upper edge of the deck. The design curves for the evaluation of the interaction due to vertical bending of the bridge deck have been evaluated with respect to the

standard longitudinal plastic shear resistance equal to 20 KN/m and 60 KN/m for unloaded and loaded track respectively.

The design curves are given for the following two different situations:

Deck Bridge: – the track lies on the top of the bridge deck (deck neutral axis below track axis)

Through Girder Bridge: – deck neutral axis above track axis.

Combining load cases: For calculation of the total support reaction and in order to compare the global stress in the rail with the permissible value set by each railway, the global effect $\sum$ R is calculated as follows:

$\sum R = \alpha R (\Delta T) + ßR$ (braking) + Y R (bending)

α, ß,Y are the combination factors.

Permissible additional stresses in continuous welded rail on the bridge

Theoretical stability calculations on UIC 60kg CWR of a steel grade giving at least 900 N/mm^2 strength, minimum curve radius 1500 m, laid on ballasted track, with concrete sleepers and consolidated ballast cushion greater than 30 cm give a total possible value for the increase of rail stresses due to track/bridge interaction as indicated below:

The maximum permissible additional compressive rail stress is 72 N/mm^2,

The maximum permissible additional tensile rail stress is 92 N/ mm^2.

For structures consisting of one deck, the values of the interaction effects can be calculated by using the design graphs in Appendix ‘A’ – page 36 and Appendix ‘B’ page 42 give in UIC report 774 – 3R.

■ ■ ■

CHAPTER - 5

LAYING & DESTRESSING OF LWR

Part–A: LAYING OF L.W.R

5.0 Pre requisites for laying of LWR track

An important prerequisite for proper functioning of LWR/ CWR is its initial laying to a high standard and its subsequent maintenance by trained personnel possessing valid competency certificates and level of authorization not lower than what is laid down in the LWR manual.

5.1 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) Identification of location where LWR cannot be laid
LWR/CWR cannot be laid at some locations due to constraints such as

i) Bridges having substructure/superstructure in a distressed condition

ii) Sharp curves

iii) Steep gradients

iv) Point& crossings

v) Bridge locations

vi) Unstable formation etc.

The above locations / stretches shall be identified and these shall be isolated from the remaining portion of LWR/ CWR by provision of SEJs at either end.

b) Identification of Preliminary works

Locations where preliminary works are required to be carried out shall be identified for completion, before laying of LWR/CWR, these works are:-

i) Recoupment of ballast as per LWR ballast profile

ii) Replacement of insulated joints by glued joints

ii) Realignment of curves

iii) Lifting or lowering of track to eliminate sags and humps

iv) Laying /improvement of vertical curves

v) Stabilisation of troublesome formation

vi) Rehabilitation of weak bridges

c) LWR Plan

A detailed plan shall be made showing the exact locations of SEJs and of various other features mentioned in Sub-Para (a) & (b) above. A sample of the detailed plan is placed as Fig. 5.1 The plans may be prepared to a horizontal scale of 1:5000.

5.2 Temperature Records

a) The maximum daily variation of rail temperature and the mean rail temperature (tm) for the section shall be ascertained from the temperature records available with the SSE/P.way-In charge or as built up as per LWR manual Para 2.2.1(Temperature Measurements).

b) 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-1.7 of LWR manual), shall be adopted.

5.3 Materials Required

Following materials are required for laying one LWR

i) Four numbers of 6.5 meter or longer rail pieces of the same rail section as LWR, (closure rail).

ii) Two sets of SEJs with sleepers and fastenings.

iii) Adequate numbers of 1 meter long fishplates with special screw clamps/ joggledfish plates with slotted grooves &bolted clamps.

iv) Rail closures of suitable sizes.

v) one meter and 10 cm straight edges.

vi) Rail cutting equipment.

vii) Destressing equipment i.e. rollers, rail tensor, wooden mallets & side rollers for curves.

viii) Alumino-Thermic welding equipment and consumables.

ix) Equipment for protection of track

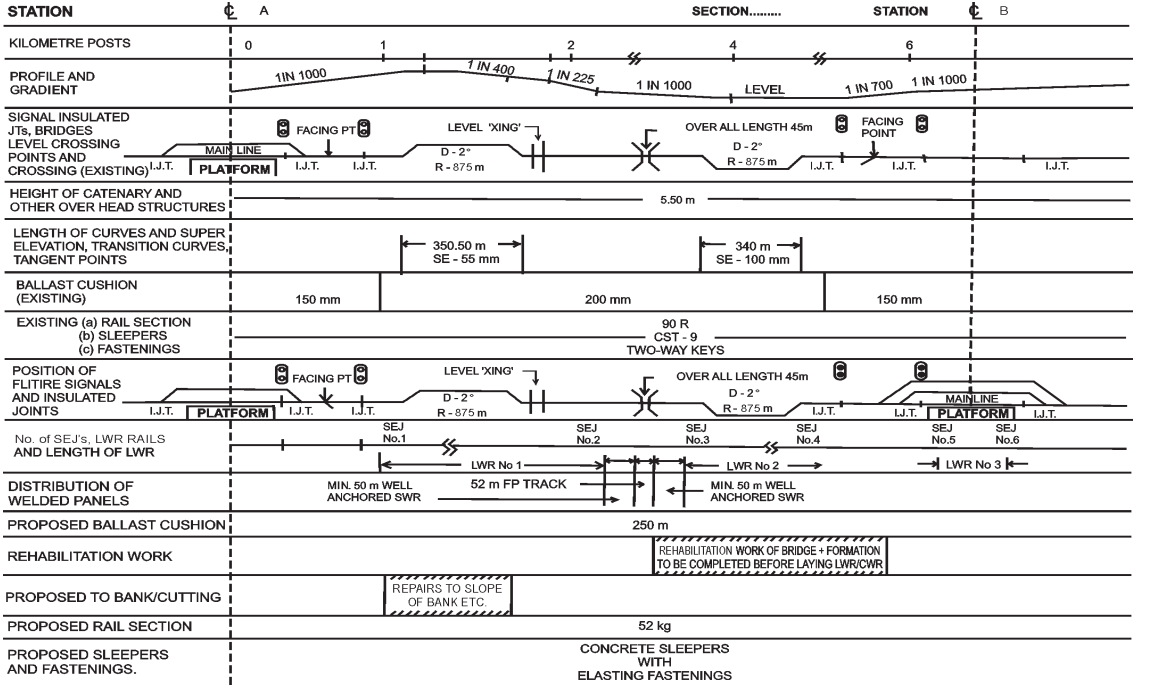


Fig. 5.1 : LWR Plan

5.4 Preliminary Works

a) Deep screening of ballast along with lifting or lowering of track, if required, should precede laying of LWR/CWR. Standard ballast section as stipulated for LWR/CWR shall be provided.

b) All other preliminary works identified i.e. Replacement of insulated joints by glued joints, Realignment of curves, Lifting or lowering of track to eliminate sags and humps, Introduction and improvement of vertical curves, Stabilisation of troublesome formation, Rehabilitation of weak bridges involving removal or lifting of rails or introduction of temporary arrangements shall also be completed before laying of LWR/CWR.

c) 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, destressed and joined with already laid LWR/CWR.

5.5 Welding of Rails to Form LWR

a) **Welding of rails:** Rails shall normally be welded into sufficiently long panels of 10 to 20 rail lengths or more by flash butt welding/mobile welding plant, either in the welding depot or on cess or in-situ. The joints for joining these 10/20 rail panel only shall be welded by Alumino-thermic welding (SKV process).

b) While unloading 880 grade (90 UTS) or higher grade rails, laid down instructions for handling should be followed. The fracture toughness of 90 UTS rail is less compare to 72 UTS rail so handling, unloading at site of these rails require special precautions.

c) **Insertion of SEJ's at both ends:** 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 pre-determined locations with gaps in mean position as per laid down norms for initial gaps at SEJ. Closure rails of 6.5 meter or longer length shall be provided adjecent to SEJs to facilitate adjustment of gaps and expansion/contraction of LWR panel during destressing operation.

d) **Unloading & laying of welded panels:** The 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 shall be undertaken as soon as possible.

Need for temporary destressing at higher temperature: Under unavoidable circumstances where destressing could not be done soon after and not likely to be done within a reasonable period, a strict vigil shall be maintained on the prevailing rail temperatures, and if the rail temperature rises more than 20^0C 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 10^0C below the maximum rail temperature likely to be attained until final destressing.

If the rail temperature comes down appreciably, cold weather patrolling should be introduced. Final destressing shall be done after consolidation of track has been achieved and when temp with in normal t_d range are available.

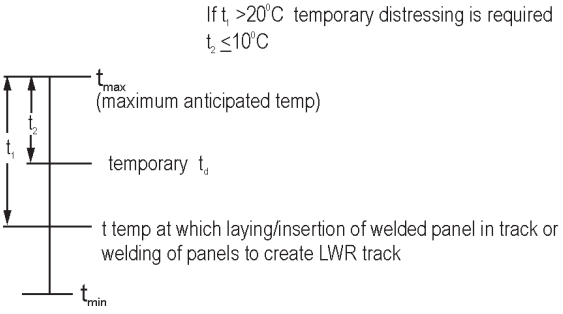


Fig 5.2 : Need for Temporary Destressing While Laying LWR

e) Speed restriction: Temporary speed restriction of 30 kmph shall be imposed on the length of track (BG & MG both) where welded panels are joined by 1 m long fishplates with special screw clamps or joggled fish plates with slotted grooves &bolted clamps, in all other cases permitted speed shall be 20 kmph (BG & MG both)

5.6 Gaps at SEJ

a) Gaps at SEJ shall be adjusted at the time of laying/subsequent destressing of LWR/CWR to the initial laying gaps, which is 40 mm for 52 Kg/ 60 Kg rail section at td and for other rail section it is 60 mm.

b) **During service life / maintenance of LWR** the measured gap between the reference mark and tongue rail tip/stock rail corner at various rail temperatures shall not differ by more than ± 10 mm from the theoretical range as stipulated in LWR manual annex - V

c) Where fish plated or SWP track is joined 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 from the theoretical range.

Part-B: DESTRESSING OF L.W.R TRACK

5.7 Destressing of LWR

5.7.1 Need for destressing:

The destressing is the operation undertaken with or without rail tensor to secure stress free conditions in the LWR/CWR at the desired/specified rail temperature. The destressing of LWR is to be carried out:

1. On Initial laying of LWR
2. During Maintenance of LWR track :

   i) When the gap observed at SEJ

      a) Differs beyond limits specified in sub Para 5.6 (b) & (c) above i.e. the gaps between the reference mark and tongue rail tip/stock rail corner at various rail temperatures differ by more than ± 10 mm from the theoretical range as specified in LWR manual annexure-V

      b) Exceeds the maximum designed gap of SEJ

      c) When stock/tongue rail crosses the mean position.

   ii) After special track maintenance operations namely through fitting renewal, deep screening, lowering/ lifting of track, major realignment of curves, through sleeper renewal, rehabilitation of bridges and formation causing disturbance to track.

   iii) After restoration of track following an unusual occurrence namely rail fractures, damage of SEJ/ buffer rails, buckling or tendency towards buckling, factors causing disturbance to LWR/ CWR such as accidents, breaches

iv) If number of locations where temporary repairs have been done, exceed three per km.

3. i) In addition one round of temporary destressing is to be done 10^0C below the maximum rail temperature likely to be attained during the work related to special track maintenance operation of long duration such as deep screening, through sleeper renewal, where the rail temperature during the track work is likely to fall outside t_d +10^0C & t_d -20^0C.

ii) Similarly during laying of LWR, if the rail temperature rises more than 20^0 C above the rail temperature at which welding of rails/ laying of welded panels is done, the temporary destressing shall be undertaken at a rail temperature 10^0C below the maximum rail temp likely to be attained during the work.

5.7.2 L.W.R Destressing Operation

5.7.2.1 General

i) The work of destressing shall be done under the personal supervision of a SSE/JE/P. Way, during a traffic block of adequate duration at appropriate temperature.

ii) It is preferable to impose a speed restriction of 30 km/h before actually obtaining the traffic block, to loosen/remove fastenings on alternate sleepers so as to reduce total duration of the traffic block.

iii) Remove impediments to free movement of rail such as rail anchors, guard rails, check rails etc. in advance

iv) The destressing operation provides an opportunity to examine & replace Rubber pad,

ERC & liner if required accordingly plan for replacement of bad Rubber pad, Liner, damaged ERC, recycling of greased ERC, shifting of liner bite rail zone wherever necessary, at the time of destressing.

v) During destressing operation, the rail is required to be lifted and placed on rollers at every 15th sleeper to permit the rails to move freely.

vi) 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, for destressing with tensor

Where,

$$n = \frac{\{\text{Radius of curve (R)} \times \text{No. of sleeers per rail length}\}}{50 \times (t_0 - t_P)}$$

In case of destressing without tensor the value of n can be taken as Radius of curve (R) / 50.

vii) The outside supports shall be used in addition at the rate of one for every three inside supports.

5.7.2.2 Destressing of LWRs/CWRs without use of rail tensor

In case rail temperature at the time of destressing is within the range specified for destressing temperature, detailed procedure without using rail tensor, as given below, may be adopted.

1. 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 mentioned below, during the rail fastening down operation.

Zone	Rail section	Range for t_d
I, II & III	All Rail sections	t_m to t_m + 5°C
IV	90 R, 75 R	t_m to t_m + 5°C
	52 Kg & heavier	t_m + 5°C to t_m + 10°C

2. Before the block is actually taken, a speed restriction of 30 km/h should be imposed and fastenings on alternate sleepers loosened.

3. When the block is taken, the closure rails shall be removed, the SEJs adjusted to stipulated initial gap i.e. SEJ gap shall be kept 40 mm for 52 Kg/ 60 Kg rail section & 60 mm for other rail section & SEJ fastened.

4. The remaining sleeper's fastenings on both running rails shall be removed starting from the ends near the SEJs and proceeding towards the center of LWR. The rail shall be lifted and placed on rollers at every 15th sleeper to permit the 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.

5. The rollers shall then be removed, the rails lowered to correct alignment and fastenings tightened, starting from the middle of LWR and proceeding towards both ends simultaneously. The tightening of fastenings shall be completed within the temperature range for td as specified. The actual range of temperature during the period of tightening shall be recorded by SSE/JE/P. Way along with the time and date.

6. Simultaneously with the tightening of fastening, arrangements for insertion of closure rails

between the SEJ and LWR shall be started. The four gaps shall be measured individually and the rails of required length cut keeping required gaps for AT welding. The closure rails shall then be placed in position fastened to the sleepers and welded at each end. Fastenings for 20 meter on each end of the LWR shall be removed before welding. Joints shall be clamped for 20 minutes after welding.

7. The entire work shall be done under personal supervision of the SSE/JE/P. Way.

5.7.2.3 Destressing of LWRs/CWRs with use of rail tensor

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 meter at location 'B' i.e. centre of LWR (Fig. 5.3). Introduce rail closure as required and fasten with 1 m long fish plates and special clamps. Allow traffic at restricted speed of 30 km/h with 24 Hrs. watch on the joint.

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. 5.3.(a).

Note: *The anchor length 'l_a' should be determined on the basis of the lowest value of t_P at which the destressing is likely to be carried out.*

iii) Erect marker pillars W_o W_1 etc., on each of the length A_2 Band C_2B.

Transfer the marks W_o onto the rail foot

Note: *The distances W_o W_1, W_1 W_2 etc. shall be marked at about 100 meter intervals.*

iv) During the second traffic block, when t_p, is less than the desired to (Fig. 5.3(b), destressing operation shall be carried out for the lengths A_2 B and C_2 B as described below:-

a) Remove the closure rail from location 'B.' Unfasten and mount on rollers the portion from A_2 C_2. Measure the rail temperature t_P at this stage

b) Fix the rail tensor across the gap at 'B' and apply tension so as to obtain some movement at W_o to remove any kinks or misalignment and to minimise the friction in the rollers etc. Release the tension and note the movement Y_o at W_o.

c) Transfer marks W_1, W_2, ... onto the rail foot and note temperature t_P.

d) Calculate the required movement at W_1 as under:-

Movement at $W_1 = Y_0$ + elongation of length W_0 W_1 (L) due to temperature difference $(t_0 - t_P) = Y_0 + L\alpha\ (t_0 - t_P)$

Calculate the required movement at W_2 as under:- Movement W_2 = Movement at W_1 + elongation of length W_1W_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 extensions with respect to the transferred marks referred at (c) 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_1W_2. Similarly, check the remaining marks, adjust the tension as required and fasten down each segment before proceeding to the next.

Note:

1) Extension table given after Para 5.9 of LWR manual, gives the value of $L\alpha$ (t_o-t_p) for different values of L and (t_o-t_p).

2) Only one reading of t_p is to be taken i.e. at the time of marking W_1, W_2 etc. on the rail foot. The value of tp is not required to be taken thereafter. The variation of temperature, if any during the destressing operation shall automatically be taken care of by reduction or increase in the tensile force from the tensor, while coinciding the reference mark on rail with the corresponding mark on pillars.

3) If for any reason, both the lengths A_2B and C_2B cannot be fastened down simultaneously, the final adjustment in pull and fastening down of the individual segments may be done in series, first from $A_2$to B and then from $C_2$to B.

e) After the fastening down of the last length A_2B and C_2B is completed, make a paint mark near free end of one rail at a distance of (6.5 meter + 2 x 25 mm -1 mm), measured from the end of the other rail across the gap spanned by the rail tensor.

f) Remove the tensor, close the 1 meter gap temporarily using 1 m long fish plate & special clamps and allow traffic at restricted speed of 30 km/h and 24 Hrs. watch on the joint (Fig. 5.6.3 (c).

v) During third traffic block, cut the rail at the paint mark, insert a rail closure of length exactly equal to 6.5 meter and weld one end thereof (Fig. 5.6.3 (d)). If the gap at the other end is also 25 mm, it can be welded in the same block. Otherwise, fasten with 1 meter long fishplates with special screw clamps with speed restrictions 30 Km/h and 24 Hrs. Watch In the latter case, during a subsequent block, when t_P is not greater than t_o, 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 (Fig. 5.3 (e)); refasten the rail and weld the joint. Release the tensor after a lapse of a minimum of 20 minutes after pouring of the weld metal.

vi) During fourth traffic block, when t_P is less than t_d, t_o equalise the forces in the rail by releasing the fastenings over a length of 100 meter on either side of location 'B' and tapping with wooden mallets etc. (Fig. 5.3 (f)). Fasten down the rail and allow traffic.

vii) During fifth traffic block, when t_p is within the range of temperature specified for t_d in Para 1.11, of LWR manual destress the end 100 meter from SEJ. Thereafter, weld the closure rail next to SEJ duly ensuring setting of the SEJ as per initial laying gap i.e. SEJ gap shall be kept 40 mm for 52 Kg/ 60 Kg rail section at t_d.

Note : *Alternatively the complete destressing work with rail tensor can be completed in 2 traffic blocks of adequate duration as detailed below:*

In the first traffic block, when prevailing temperature t_P is less than t_d, rail to be cut at mid-point i.e. location B for 6.5 m length and destressing operation shall be carried out for the lengths A_2 B and C_2 B as described above under Para 5.7.2.3 (iv).

In th second block when prevailing temperature t_P is within t_d, the operations mentioned under Para 5.7.2.3 (v), (vi) & (vii) may be carried using 2 teams one working in middle portion at location B for operations specified under Para 5.7.2.3 v) & vi) & other near SEJ's for operations specified under Para 5.7.2.3 vii) above.

Fig. 5.4 : Hydraulic Rail Tensor

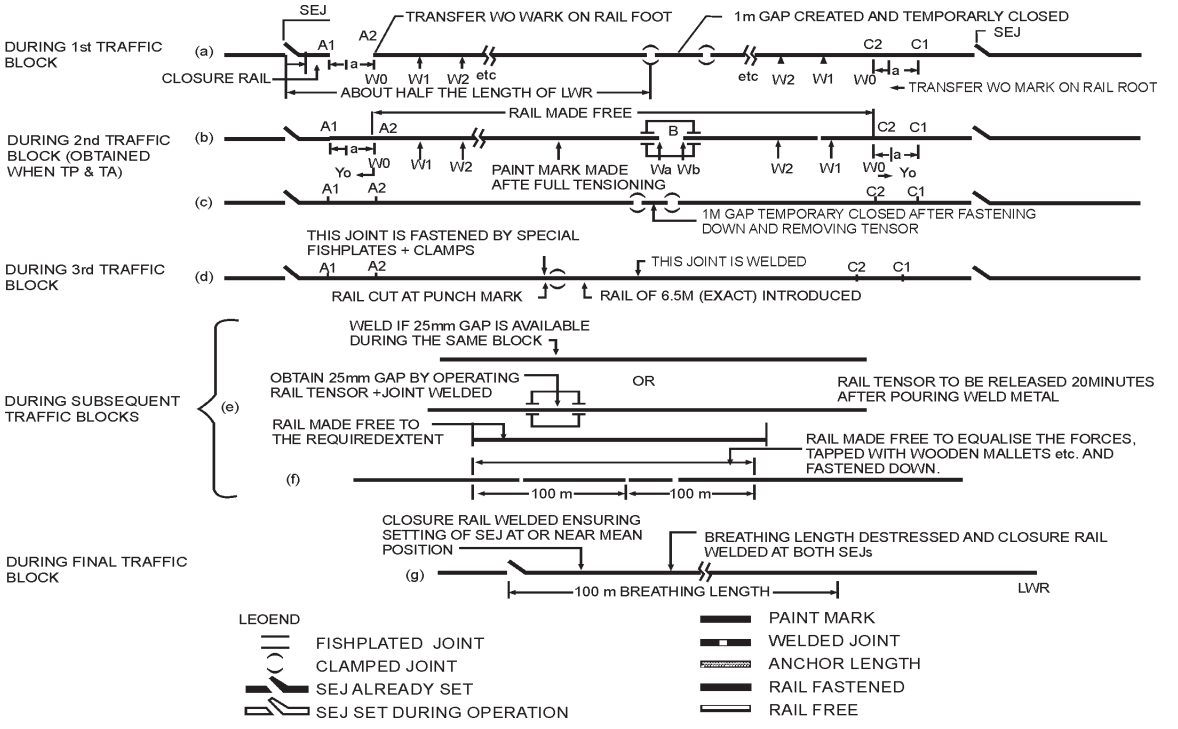

DURING 1st TRAFFIC BLOCK
(a)
SEJ
A1
A2
TRANSFER WO WARK ON RAIL FOOT
1m GAP CREATED AND TEMPORARLY CLOSED
SEJ
C2
C1
CLOSURE RAIL
a
W0
W1
W2
etc
ABOUT HALF THE LENGTH OF LWR
etc
W2
W1
W0
a
TRANSFER WO MARK ON RAIL ROOT
DURING 2nd TRAFFIC BLOCK (OBTAINED WHEN TP & TA)
(b)
RAIL MADE FREE
A1
A2
B
C2
C1
a
Yo
W0
W1
W2
PAINT MARK MADE AFTE FULL TENSIONING
Wa
Wb
W2
W1
W0
a
Yo
(c)
A1
A2
C2
C1
1M GAP TEMPORARY CLOSED AFTER FASTENING DOWN AND REMOVING TENSOR
DURING 3rd TRAFFIC BLOCK
(d)
THIS JOINT IS FASTENED BY SPECIAL FISHPLATES + CLAMPS
A1
A2
THIS JOINT IS WELDED
C2
C1
RAIL CUT AT PUNCH MARK
RAIL OF 6.5M (EXACT) INTRODUCED
DURING SUBSEQUENT TRAFFIC BLOCKS
(e)
WELD IF 25mm GAP IS AVAILABLE DURING THE SAME BLOCK
OBTAIN 25mm GAP BY OPERATING RAIL TENSOR +JOINT WELDED
OR
RAIL TENSOR TO BE RELEASED 20MINUTES AFTER POURING WELD METAL
RAIL MADE FREE TO THE REQUIREDEXTENT
RAIL MADE FREE TO EQUALISE THE FORCES, TAPPED WITH WOODEN MALLETS etc. AND FASTENED DOWN.
(f)
100 m
100 m
DURING FINAL TRAFFIC BLOCK
CLOSURE RAIL WELDED ENSURING SETTING OF SEJ AT OR NEAR MEAN POSITION
BREATHING LENGTH DESTRESSED AND CLOSURE RAIL WELDED AT BOTH SEJs
(g)
100 m BREATHING LENGTH
LWR
LEOEND
FISHPLATED JOINT
CLAMPED JOINT
SEJ ALREADY SET
SEJ SET DURING OPERATION
PAINT MARK
WELDED JOINT
ANCHOR LENGTH
RAIL FASTENED
RAIL FREE

Fig. 5.3

Case study

1) Details of the incident:

1	Date and Time	May 1990, Time 16.00
2	Railway	Northern Railway
3	Gauge	Double line section
4	Location	Sirhind-Ludhiana Section
5	Train Involved	No train involved
6.	Cause for Buckling	Due to improper temporary destressing

2) Observations at site

The work of deep screening with ballast cleaning machine was being carried out in peak summer season at the rail temperature of 50 to 55^{0}c in CWR track.

Before deploying the BCM machine at a particular location, the CWR track was being cut in length of 500 meter approx. &temporarily distressed at high temp i.e. 50 to 55^{0}C

The work of deep screening was completed satisfactorily in 2 block sections.In the 3rd block section from outer most point to first SEJ there was welded panel of length 200 - 250 m approx., so before bringing the machine, the PWI on previous day temporarily distressed this welded panel / stretch, However next day when BCM started cleaning the ballast, the track got buckled

3) Reason for buckling of track:

On the day of temporary distressing it was cloudy day and when the track was fastened back it was hardly 25 to 30^0C rail temp, so the temp distressing was done at a much lower temp. During ballast cleaning operation due to poor ballast resistance and with rail under high thermal force (because of lower t_d) got buckled.

4) Learning Points:

Destressing is the operation undertaken with or without rail tensor to secure stress free conditions in the LWR/ CWR at the desired/specified rail temperature.

Therefore the temperature at which the destressing operation is carried is very important since this temperature decides the subsequent behavior of LWR.

If destressing is carried out at relatively high temp, the problem in winter is likely to increase by way of more fractures due to higher tensile forces, where as if destressing is done at relatively low temp, the problem is likely to increase in summer by way of track buckling due to higher compressive forces. So destressing is required to be done at appropriate temperature as prescribed in LWR manual.

■ ■ ■

CHAPTER - 6

MAINTENANCE OF LWR TRACK

6.1 Basic Concepts in LWR Maintenance:

1. LWR is a welded rail/panel, the central part of which does not undergo any longitudinal movement due to thermal/temp variations. Due to this in the central part of LWR, thermal strain & thermal stress / force gets induced. The magnitude of this thermal force is $AE\alpha t$.
2. Whenever there is a temp change, the rail try to move over the sleeper seat, however creep resistance due to friction at rail sleeper seat & creep resistance offered by sleeper rail fastening does not allow the rail to move alone over the sleeper seat, therefore the rail & sleeper as a frame moves in the surrounding ballast mass. The ballast core gets deflected due to this frame movement, hence ballast resistance gets mobilized, offering resistance to movement of rail-sleeper frame.

In certain length (L_b) the longitudinal ballast resistance (r kg/cm/rail) is geared up-to the extent / value of thermal force $P = AE\alpha t$ ($Lb \times r = P$), beyond this point there is no movement in LWR, the same is explained here under:

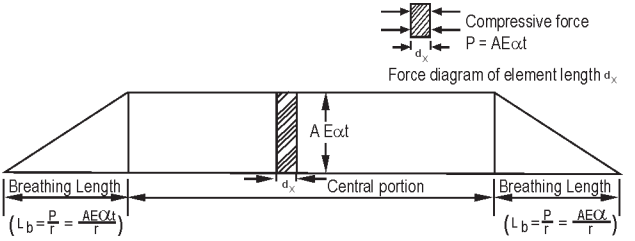


Fig 6.1 : LWR Force Diagram

Consider an element of d_x length in the central part of LWR.

i) When temp rises by t °C above t_d, the expansion of this element is = $d_x \cdot \alpha \cdot t$.

ii) This element is under the effect of compressive force P, (as the temp has increased above initial laying/ destressing temp).This compressive will create shortening of this element by

$$\Delta L = \frac{PL}{AE} = \frac{Pdx}{AE} = \frac{AE\alpha\, tdx}{AE} = dx\,\alpha t$$

iii) The net elongation of the element due to increase in temp = $d_x \cdot \alpha t$ (expansion due to increase in temp.) – $d_x \cdot \alpha t$ (shortening due to comp. force) = 0

Therefore there is no expansion / contraction & thus no movement in any element located in the central part of LWR.

3. Based on above discussions, it is derived that for the satisfactory behavior of LWR track, following is essential.

a) The elastic fastenings should be complete and these should behave satisfactorily, otherwise the rail will creep over the sleeper seat.

b) Adequate ballast as per laid down profile in well consolidated condition should be available, otherwise inadequate ballast will lead to lower longitudinal & lateral ballast resistance & this may lead to buckling.

c) The magnitude of thermal force in central portion is $AE\alpha t$, which is independent of length of LWR There fore for a given rail section & location (temp zone) it depends upon t only i.e. temp variation. Accordingly working in higher temp ranges, beyond the laid down temp limits will lead to generation of higher thermal forces, which may lead to buckling.

Therefore the maintenance operations should be strictly carried out within specified temp limits

d) Excessive lifting, slewing during maintenance operation will lead to reduction in lateral ballast resistance, This may lead to buckling Therefore lifting & slewing during maintenance operation should be done only within permissible limits.

e) During maintenance operations, metal equilibrium must be observed i.e. metal inserted during repairs should be equal to metal taken out from LWR, otherwise t_d will get affected. Improper fracture repair by way of addition of metal will cause lowering of t_d, resulting higher comp, forces during summer.

f) During manual maintenance operations, ballast in crib and shoulder is opened to expose sleeper bottom for packing of sleeper seat unlike machine maintenance. This causes significant drop in ballast resistance, therefore only 30 sleepers to be opened at time leaving 30 boxed sleepers on both sides. (In exceptional cases 100 sleepers

can be opened under direct supervision of PWI provided LWR behavior is satisfactory).

g) LWR should be laid on stable formation, because the unstable formation will require frequent track attention, which is against the LWR maintenance philosophy of "Do not touch the track unnecessarily"

It is therefore summarized that, the satisfactory behavior/ functioning of LWR depends upon the condition & performance of elastic fastenings, availability of well consolidated & compacted ballast as per laid down ballast profile, lifting / aligning / opening of track within permissible limits as laid down in the manual, adhering to specified temperature limits while carrying out various track maintenance operations & maintaining metal equilibrium during fracture repairs.

6.2 Regular Track Maintenance

Regular track maintenance in LWR/CWR includes operations namely

a) Mechanised track maintenance involving

   i) Tamping/packing

   ii) Lifting of track.

   iii) Shoulder cleaning / shallow screening

b) Manual maintenance

c) Casual renewal of sleepers

d) Renewal of fastenings

e) Maintenance of buffer rails

6.2.1 General (Temperature limits for working):

i) The regular track maintenance operations in LWR/CWR shall be confined to 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. After the maintenance operation if rail temperature exceeds t_d+20°C during the period of consolidation, then following action shall be taken.

a) BG Concrete sleeper track: on BG PRC sleeper track the speed restriction of 50 km/h shall be imposed, till the period of consolidation is over. The period of consolidation for BG PRC sleeper track is taken as passage of at least 50,000 gross tonnes of traffic or 2 days whichever later OR one round of DTS OR w.r.t. newly laid track, 3 round of packing, last 2 of which are with on track tamping machine.

b) Other than BG concrete sleeper track: The speed restriction shall be imposed as under till the period of consolidation is over, in addition to posting a mobile watchman.

Status of shoulder & crib compaction → Type of track structure ↓	When shoulder & crib compaction has been done	When shoulder & crib compaction has not been done
BG with other than concrete sleeper	50 Kmph	30 Kmph
MG with other than concrete sleeper	40 Kmph	20 Kmph
MG with concrete sleeper	40 Kmph, but no mobile watchman is required	

The period of consolidation for other than BG concrete sleeper track is specified under LWR manual Para 1.18.

6.2.2 Important precautions specific to particular operation: In addition to Para 6.2.1 above, the important precautions which are required to be observed during regular track maintenance operations are given here under, each activity wise:

a) Mechanised Maintenance

i) Maintenance tamping:

Tamping in LWR/CWR on concrete sleeper track shall be done with general lift not exceeding 50 mm including correction of alignment; In case of sleepers other than concrete sleepers the general lift shall be restricted to 25 mm.

ii) Lifting of track:

Lifting on concrete sleeper track where needed, in excess of general lift of 50 mm & 25 mm in other sleepers, shall be carried out in stages with adequate time gap in between successive stages such that full consolidation of the previous stage as per LWR manual Para 1.18 is achieved prior to taking up the subsequent lift.

iii) Cleaning of shoulder ballast:

Sufficient quantity of ballast should be made available for recoupment before taking up ballast screening work.

Authorized supervision level: SSE/JEP. Way.

b) Manual maintenance

i) At any time, not more than 30 sleeper 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 of 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 & 48 hours in case of other BG routes & MG routes.

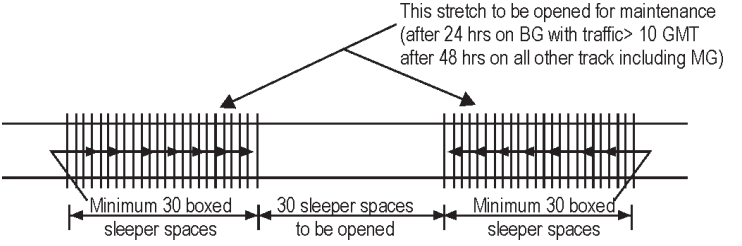


Fig 6.2 : Manual Maintenance

ii) 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 shoulder shall then be put back before opening out crib ballast for packing.

iii) In exceptional circumstances when more than 30 sleeper spaces have to be opened for any specific work, like through screening of ballast etc. during the period of the year when minimum daily rail temperature is not below t_d - 30°C or maximum does not go beyond t_d+10°C, up to 100 sleeper spaces may be opened under the direct supervision of SSE/JE/P. Way. It should however,

be ensured that rail to sleeper fastenings on the entire length of LWR are functioning satisfactorily and SEJs do not indicate any unusual behavior.

Authorised supervision level: Gang mate for manual maintenance involving up to opening of 30 sleepers & SSE/JE/P. Way for opening of more than 30 sleepers but up to 100 sleepers.

c) 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 temperature limit of (t_d+10) - (t_d - 30).

Authorised supervision level: Single isolated sleeper not requiring lifting or slewing of track - Gang mate.

Casual renewal of sleepers & fastenings over long stretches - PWM

d) Renewal of fastenings

Renewal of fastenings shall be done with following additional precautions

i) Renewal of fastenings not requiring lifting (e.g. ERC):

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 is required to be renewed at a time, then at least 15 sleepers in between shall be kept intact.

Authorised supervision level: Key man.

ii) Renewal of fastenings requiring lifting (e.g. Rubber Pad):

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 is required to be renewed at a time, then at least 30 sleepers in between shall be kept intact.

Authorised supervision level: Gang mate.

e) Maintenance of SEJs/buffer rails

i) 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 as per Para 6.4 of LWR manual.

ii) During his daily patrolling, Key man shall keep special watch on the SEJs falling in his beat.

6.2.3 General precautions :

In addition to Para 6.2.1 & 6.2.2 above, the general precautions required to be taken, in the regular track maintenance operations are:

i) Ballast section shall be properly maintained, especially on pedestrian & cattle crossings, 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.

Replenishment of ballast shall be completed

before onset of summer. Shortage of ballast in the shoulder at isolated places shall be made up 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 and a depth not exceeding 100 mm on BG.

On MG the above dimensions are, width not exceeding 350 mm and depth not exceeding 75 mm

ii) Sufficient quantity of ballast shall be collected to provide full ballast section before commencing any maintenance operation, specially lifting.

iii) When crow bars are used for slewing, care shall be taken to apply these in a manner so as to avoid lifting of track. The crow bar should be planted well into the ballast at an angle not more than 30° from the vertical.

iv) Special attention shall be paid to the L.W.R track at following locations

   a) SEJs/ Breathing lengths,
   b) Approaches of level crossings, points & crossings and un ballasted deck bridges
   c) Horizontal and vertical curves

v) All fastenings should be complete and well secured

6.3 Special Track Maintenance

6.3.1 Through Fittings Renewal

Whenever it is decided to carry out through renewal of fittings, the LWR shall be destressed along with the through fittings renewal. TFR is to be done under personal supervision of SSE/JE/P. Way.

6.3.2 Deep screening/mechanised cleaning of ballast

i) Provisions laid down in Para 238 of IRPWM will also apply to LWR/CWR (once the necessary changes have been made) with further provisions as mentioned hereafter in this Para. Wherever mechanised cleaning of ballast is resorted, the detailed procedure laid down in Para 238 (2) (e) of IRPWM for manual deep screening shall stand replaced by the sequence of operations of Ballast Cleaning Machine (BCM).

ii) Ballast Cleaning Machine (BCM), tamping machine and Dynamic Track Stabilizer (DTS) shall, as far as possible, be deployed in one consist.

iii) 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 options may be considered & 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 or

Wherever rail renewals are being carried out, LWR/CWR may be converted into three rail panels and deep screening done.

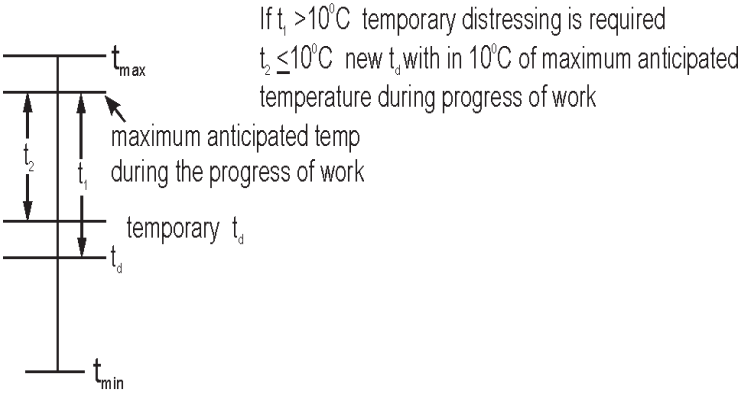


Fig. 6.3 : Need for Temporary Destressing while Special Track Maintenance Operation

Note: CWR shall be cut into LWRs of about 1 km length with two temporary buffer rails of 6.5 meter long, clamped with 1 meter long fishplates with special screw clamps/ joggled fish-plates having slotted grooves & bolted clamps with speed restrictions of 30 Kmph and 24 Hrs watch. When other clamps are used at a temporary rail joint, S.R of 20 Kmph shall be imposed Fish-bolt holes if any, shall be chamfered.

iv) Constant monitoring of rail temperature shall be done during the progress of work. Should the temperature rises 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 rail temperature varies appreciably.

v) During the period of deep screening, if there is any possibility of minimum temperature falling 30°C below td/temporary destressing temperature, cold weather patrol should be introduced to detect & guard against rail fractures.

vi) Sequence of operation: -

a) Deep screening of LWR may be done from one end of LWR to other end.

b) After deep screening and consolidation of track, destressing of LWR within normal td range shall be undertaken.

Note: *The period of consolidation for BG concrete sleeper track is taken as passage of 50000 tonnes of traffic or 2 days whichever later OR one round of DTS OR w.r.t. newly laid track, 3 round of packing last 2 of which are with on track tamping machine.*

6.3.3 Other special maintenance

i) Other types of special track maintenance constitute 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.

ii) Temp.records of the section shall be studied and action taken as under:

If range of rail temperature falls within t_d +10°C to t_d - 20°C	special track maintenance activity may be done without cutting LWR or temporary destressing
If range of rail temperature falls outside t_d +10°C to t_d - 20°C	temporary destressing shall be carried out 10°C below the maximum rail temperature likely to be attained during the period of work

iii) After completion of work, the affected length of track shall be destressed at the required destressing temperature and joined with rest of the LWR/CWR.

6.4 Planning of Maintenance Activities w.r.t Prevailing Rail Temperature.

L.W.R manual Para 2.2.1 stipulates that "Rail temp records shall be built up using preferably a well calibrated continuous recording type thermometer.The maximum and minimum rail temperature for a continuous period of at least 5 years shall be ascertained and the mean rail temperature (t_m) for the region arrived at. *These temperature records shall be analyzed to assess the probable availability of time periods during different seasons of the year for track maintenance, destressing operations and requirements of hot/cold weather patrolling etc."*

Illustrations: Planning of track activities w.r.t temperature limits.

Section: Pune – Lonavala (Pune division)

Pune rail temperatures: 61(34) (based on Fig. 1.7 of LWR manual)

Range of temperature $\Rightarrow$ $t_{max} - t_{min} = 61$

Mean of temperature $(t_{max} + t_{min}) / 2 = 34$

$t_{max} + t_{min} = 68$ Therefore $t_{max} = 64.5$ & $t_{min} = 3.5$

This section (Pune area) lies in Zone-III, accordingly t_d shall be fixed with in (t_m) - $(t_m + 5)$ Here $t_m = 34°C$, so t_d will lie between 34 to 39°C.

Suppose destressing is done at $t_d = 36°C$, then temp limits for various track maintenance operations shall be as under:

Track activities	Specified temp. limits as per LWR manual	Rail temp limits (in °C) for carrying out track activities
Destressing	t_m to $t_m + 5$	34 to 39 say $t_d = 36$
Machine tamping	$(t_d +10)$ --- $(t_d – 30)$	46 to 6
Manual Packing	$(t_d +10)$ --- $(t_d – 30)$	46 to 6
Deep screening	$(t_d +10)$ --- $(t_d – 20)$	46 to 16
Hot weather patrolling	$> t_d + 25$ & months specified by PCE	More than 61
Cold weather patrolling	$< t_d - 30$ & months specified by PCE	Less than 6

Now the temp. records of previous year & current year are to be studied in detail to find out the rail temp available during timings specified for integrated block working, and based on requirement of temperature ranges for various track maintenance activities as worked out above, the periods available during the year, for carrying out a specific maintenance activity is identified.

For example, suppose the integrated corridor block timings for Pune – Lonavala section is 10.00 to 12.00 hrs, & we are planning machine tamping blocks for the section, then we have to identify periods from available past temp

records when the rail temp is within 6 to 46 between 10.00 hrs to 12.00 hrs, the tamping machine shall be planned & deployed during such periods/ months of the year, when rail temp is within this permitted range of 6 to 46^0C.

Further, suppose there is an urgency during peak summer (when rail temp during 10 to 12 hrs. is more than 46^0C) to tamp few kms, then it can be preferably done during night hours or early morning hours when rail temp are relatively low & temp is with in permitted range of t_d +10^0C.

It may be noted that the option of temporary destressing for facilitating regular track maintenance operation beyond t_d + 10^oC is not a feasible solution, because it requires 2 rounds of destressing first at higher temp prior to maintenance operation/tamping & then second round of destressing at appropriate temp after maintenance operation / tamping operation.

Case Study – 1

1) Details of incident:

1	Date and Time	May 1999, Time 16.30 hrs.
2	Railway	Western Railway
3	Gauge	Double line section
4	Location	Vadodara-Surat Section
5	Train Involved	No train involved
6.	Cause of localised buckling	Localised buckling of track due to excessive lifting of LWR track during tamping operation
7.	Train involved	No train involved, block burst 2 to 3 Hrs.

2) Observations at site

The work of machine tamping i.e. maintenance packing with CSM machine was being carried out in summer season at about 15-16 hrs in CWR track.

There was a sag in the track and PWI wanted to lift this sag, so he instructed the machine foreman to pack this stretch of track again and again in order to eliminate the sag, at the end of third round of tamping in the same stretch the track developed misalignment kinks i.e. localised buckling of track

3) Reason for buckling

Due to repeated tamping in the same stretch during same block, the track was excessively lifted. This caused abnormal reduction in the lateral ballast resistance and lateral strength of track thereof, causing heavy mis-alignment in the track.

Further the PWI has not kept sufficient labor during machine tamping and when track developed misalignment kinks he could not restore it. The PWI was infact suspecting that the misalignment has occurred due to mal-functioning of CSM machine. The machine was brought back at nearest station to collect and take the labor to site to rectify misalignment kinks manually.

4) Learning points

Excessive lifting in LWR track may result into buckling of track due to abnormal reduction in lateral ballast resistance.

5) Relevant LWR manual provision:
Para - 6.2.2 Mechanised Maintenance

i) Maintenance tamping:

Tamping in LWR/CWR with general lift not exceeding 50 mm in case of concrete sleeper and 25 mm in case of other sleepers including correction of alignment shall be carried out when prevailing rail temp are within $t_d + 10$ & $t_d - 30$

ii) Lifting of track:

Lifting wherever 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 in between successive stages such that full consolidation of the previous stage is achieved prior to taking up the subsequent lift.

Case Study - 2

1) Details of Incident

1	Date and Time	24.03.03
2	Railway	Central Railway
3	Gauge	Double line section
4	Location	Adhartal-JBP Section
5	Train Involved	No train involved
6.	Cause of buckling	Buckling of track

2) Observations at site

On 24.03.2003, a case of buckling was reported in Adhartal-JBP Section by the Keyman. He saw the track buckled and stopped the traffic and protected the track. It was noticed that in addition to deficient ballast, a number of bad thermit welds were also existing in the track. Small patch of metal sleepers had been left in between the newly re-laid Concrete sleepers. The track had buckled at the junction of metal and concrete sleepers. The section gave a feeling of utter neglect in maintenance.

3) Reasons for buckling:

Poor & improper way of track maintenance

4) Learning points

Before taking up special track maintenance operation like sleeper renewal in long stretch, the stretch needs to be isolated by putting SEJ or buffer rails at ends. The temp records needs to study. In case during execution temp likely to exceeds t_d +10 then one round of temporary destressing at higher temperature is required so as to keep the track safe during execution of work at higher temp.

5) Relevant LWR manual provision : LWR manual Para-6.3.3

i) Other types of special track maintenance constitute 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.

ii) Temperature records of the section shall be studied and necessary action taken i.e. need for temporary destrssing to be assessed

iii) After completion of work, the affected length of track shall be destressed at the required destressing temperature and joined with rest of the LWR/CWR.

■ ■ ■

CHAPTER - 7

UNUSUAL OCCURRENCES, INSPECTION & RECORD KEEPING

PART-A: UNUSUAL OCCURRENCES

7.0 Introduction:

Unusual occurrences in LWR / CWR comprise of the following:-

i) Rail fractures or replacement of defective rail/ glued joint

ii) Damage to SEJ/buffer rails

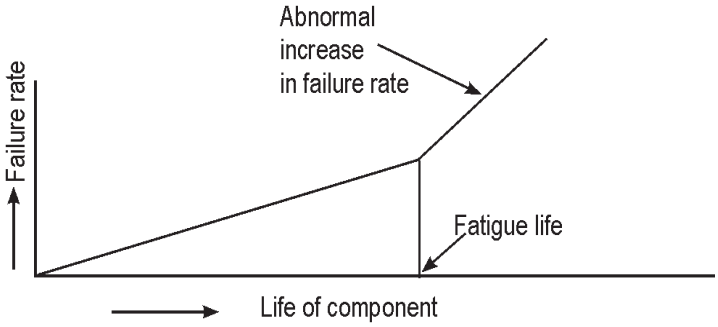
iii) Buckling or tendency towards buckling

iv) Accident, breaches, insertion of temporary girders & diversion etc.

7.1 Rail Fractures

7.1.1 Reasons for Rail fractures

1) Fatigue failures in rail & weld due to fact that rail &weld has out lived its life. (When the fatigue life is over, there is sudden increase in the rail & weld fractures rate).



2) The defective rail & weld not removed from the track.

3) Poor quality of rail or improper welding process.

4) Sudden failures due to

   a) Destressing at high temperatures / improper destressing.

   b) Cupped welds.

   c) Cacked ballast.

   d) Poor track geometry.

   e) Improper packing & support conditions.

   f) Flat tyre / over loaded wagons.

Note: Reason (b) to (f) above causes higher dynamic augment/force resulting sudden failures.

7.1.2 Important items to avoid fractures:

1) Regular monitoring of rail & weld by USFD testing & timely removal of defective rails & welds from track

2) Planning & timely execution of replacement of over ageing rails & welds

3) Maintaining very good track geometry to keep dynamic augment low including ensuring clean & well compacted ballast profile /section.

4) Rectification of cupped weld joints

5) Destressing LWR at appropriate temperatures, avoiding destressing at higher temperatures

6) Check & monitor running of flat tyre / over loaded wagons

7.1.3 Rectification of Rail Fractures

General : If any fracture takes place on LWR/CWR, immediate action shall be taken by the official who detected the fracture to suspend the traffic and to protect the line. He shall report the fracture to the Gang mate / Key man/SSE/P. Way/JE/P. Way, who shall arrange for making emergency repairs to pass the traffic immediately. Repairs shall be carried out in four stages as described below:-

a) Emergency repairs

b) Temporary repairs

c) Permanent repairs

d) Destressing.

a) Emergency repairs *(to facilitate passage of traffic)*
The fractured rails shall be joined by using the arrangements shown in LWR manual Fig. 4.4.3 (a) & (b) or (c) i.e. 1 m long fishplate or joggled fishplate etc. If the gap at fracture does not exceed 30 mm, insertion of any closure rail piece is not necessary.

The traffic may then be resumed at a speed of stop dead and 10 kmph for the first train and 20 kmph for subsequent trains.
The minimum authorized personnel to allow traffic after

emergency repairs is Keyman /Gang man.

b) Temporary repairs *(Insertion of closure rail of min. 4 m length)*

If a welding party is not readily available, the fracture shall be repaired by using a cut rail (not less than 4 metre long) and clamped/bolted as per arrangement shown in LWR manual Fig. 4.4.3 (a) & (b) or (c).

i) A traffic block shall be taken as soon as possible preferably when the rail temperature is within the range specified for t_d.

ii) a) Two points on either side of the fracture shall be marked on the rail such that the length of closure rail (not less than 4 meter) to be inserted is equal to the total length of the rail pieces removed from the track minus allowances for two welds and saw cut (normally 51 mm).

Note :
In this case the inserted length of closure piece satisfy material equilibrium of LWR i.e. Rail length removed from the track + 2 saw cut = Rail closure inserted in track + 2 weld length inserted in the track, accordingly.

$\Rightarrow$ *Length of inserted closure = length of rail pieces removed from track + 2 saw cuts – 2 x weld length*
$\Rightarrow$ *Length of rail pieces removed from track - 51 mm.*

In case closure rail length is inserted based on above, one of the joints may have to be provided with closure piece of adequate length and joined by one meter fish plate and clamps.

b) Alternately two points on either side of the fracture

shall be marked on the rail at a distance equal to the length of the available closure rail. The length of closure rail should not become less than 4 meter at the time of permanent repairs.

Note : *In this case the length of inserted closure rail is more than required by an amount equal to gap caused by the fracture, this additional length is to be cut during permanent repairs.*

iii) The traffic will be allowed after temporary repairs at 30 kmph provided 1m long fishplate with special clamps has been provided, using the arrangements shown in LWR manual Fig. 4.4.3 (a) & (b) or (c) with 24 hrs watch on the rail joint, in all other cases permitted speed shall be 20 kmph.

The minimum authorized personnel to allow traffic after temporary repairs is PWM / (JE/ P.way)

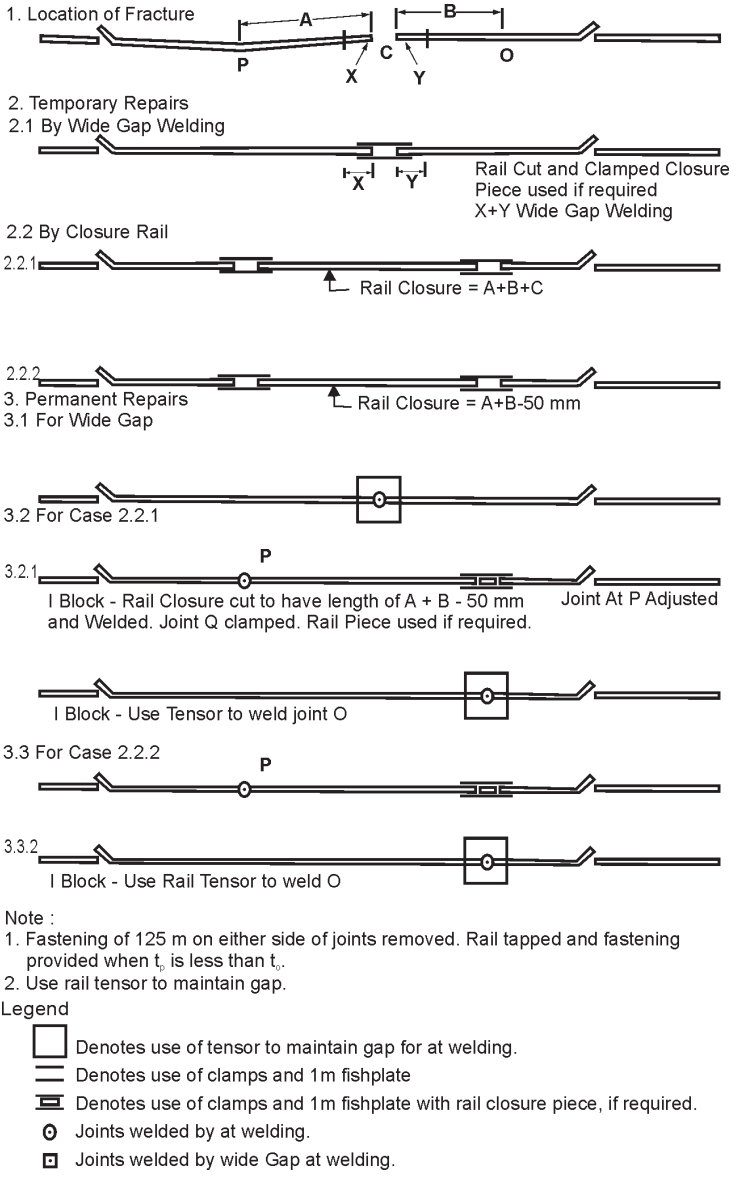
c) Permanent Repairs *(welding of joints after pulling by tensor to ensure insertion of appropriate closure length)*

i) If the fracture is such that, wide gap AT welding can be adopted, then the total length of fractured ends to be cut shall be equal to the gap required for wide gap welding. Once the two ends are cut, a gap required for wide gap welding will be created by using rail tensor and joint welded by wide gap AT welding technique.

ii) In case rail closure satisfying the metal equilibrium has been provided at the time of temporary repairs, one joint of the closure rail shall be welded without rail tensor after setting correct gap for welding. However, to ensure correct gap during welding of the other joint, tensor shall be used.

iii) In case rail closure not satisfying the metal equilibrium has been provided at the time of temporary repairs, the rail closure shall be suitably cut such that the length of the rail to be finally inserted in track is equal to length of rail removed from track after fracture minus allowances for two welds i.e. 51 mm. Once the closure rail is cut, the closure rail will be welded as given in sub Para (ii) above.

iv) After welding of joints, a length of track equal to breathing length or about 125 meters on either side be unfastened and tapped to ensure equalisation of stress and then refastened.



Note :

1. Fastening of 125 m on either side of joints removed. Rail tapped and fastening provided when t_p is less than t_o.
2. Use rail tensor to maintain gap.

Legend

- Denotes use of tensor to maintain gap for at welding.
- Denotes use of clamps and 1m fishplate
- Denotes use of clamps and 1m fishplate with rail closure piece, if required.
- Joints welded by at welding.
- Joints welded by wide Gap at welding.

Fig. 7.1 : Fracture Repair Methodlogy

Equipment required

i. Special 1 metre long fishplates with screw clamps and joggled fishplates with bolted clamps (for fractures at welded joints)

ii. Rail closures of suitable lengths

iii. Alumino-Thermic welding and weld finishing equipment

iv. Equipment for destressing

v. 6.5 metre long sawn rail cut piece of the same section as LWR duly tested by USFD

vi. Equipment for protection of track

vii. Hydraulic tensor

7.2 Damage to Switch Expansion Joint

a) The damaged/broken SEJ shall be replaced. The new SEJ shall be adjusted as per initial gaps as laid down in LWR manual. Traffic may be allowed if necessary at a restricted speed and thereafter restriction relaxed progressively.

b) If another SEJ is not available for replacement, both the damaged SEJ and the undamaged SEJ on the opposite rail at the same location, shall be replaced by a closure rail and connected to LWR/ CWR by using the arrangements shown in LWR manual Fig. 4.4.3 (a) & (b) or (c) i.e. 1 m long fish plate or joggled fish plate etc. with speed restrictions of 30 Kmph and 24 Hrs. Watch. When other clamps are used, speed restriction of 20 Kmph shall be imposed Fish-bolt holes if any, shall be chamfered. The restriction may be relaxed only after the new SEJ has been inserted in the correct

position and the clamped joint has been replaced with in situ weld.

7.3 Buckling of Track

7.3.1 Reasons for buckling

1) Failure to adhere to the temperature limits specified for working / maintenance of LWR track.
2) Inadequate lateral ballast resistance due to shortage of ballast in shoulders, or due to inadequate consolidation of track.
3) Use of ineffective elastic fastening or missing fastening resulting in loss of creep resistance.
4) Improper repairs of rail fractures causing addition of metal in LWR, thereby dropping of stress free temperature.
5) Excessive settlement of formation.
6) Misalignment kinks, improper packing of track.
7) Improper functioning of SEJ.
8) Excessive lifting/slewing of track during maintenance operation.

7.3.2 Important items to avoid buckling

1) Avoid laying LWR on unstable formation
2) Install LWR on proper stress free temperature
3) Observe specified temperature limits/ ranges during working / maintenance of LWR track
4) Avoid excessive lifting/ slewing of track during tamping / manual maintenance.
5) Check & control shortage of ballast ,Ensure

proper ballast section to generate adequate ballast resistance & availability of efficient elastic fastenings

6) Avoid misalignment & kinks in the track

7) Ensure proper fracture repairs.

7.3.3 Buckling & investigation

1) Tendency towards buckling will usually manifest itself through kinks in track. Kinks may also arise from incorrect slewing or lifting operations. By tapping sleepers for hollowness, it may be possible to notice if there is any tendency towards vertical buckling.

2) As soon as the tendency for buckling is detected, the traffic shall be suspended and the track protected. The track shall then be stabilised by heaping ballast on the shoulders up to the top of the web of the rail obtaining the ballast from inter-sleeper spaces between the rails.

   Thereafter full investigation shall be made to find out the cause of the tendency for buckling.

3) Each case or buckling shall be investigated by AEN soon after its occurrence and a detailed report submitted to DEN/Sr. DEN.

7.3.4 Repairs to buckled track

1) When the track actually buckles, the traffic shall be suspended and track is protected. The cause of buckling ascertained. The position of tongue and stock rails of the SEJ shall be checked. The method for rectification is explained below.

2) The rectification shall normally be carried out in

the following stages under the supervision of SSE/ JE/P. Way:-

a) Emergency repairs

b) Permanent repairs

c) Destressing

a) Emergency repairs (Cutting of buckled track of 6.5 m length by gas cut)

The buckled rails shall preferably be gas cut adequately apart not less than 6.5 meter. The track shall then be slewed to the correct alignment and cut rails of the required lengths shall be inserted to close the gaps making due provision for welding of joints on both sides. The cut rails shall then be connected by use of special fish plates and screw clamps as shown in LWR manual Fig. 4.4.3 (a) & (b) or (c). The traffic may then be resumed at a speed of stop dead and 10 kmph for the first train and 20 kmph for subsequent trains.

The minimum authorized personnel to allow traffic after emergency repairs is SSE/JE/P. Way

b) Permanent repairs

i) As soon as possible the clamped joints shall be welded adopting the same procedure as prescribed under Para 7.2.4 and 7.2.5 of LWR manual. i.e. procedure followed for temporary repairs & permanent repairs in case of rail fracture.

The traffic will be allowed after temporary repairs at 30 kmph, provided 1 m long fishplate with special clamps has been provided, using the arrangements shown in LWR manual Fig. 4.4.3 (a) & (b) or (c) with 24 hrs watch on the

rail joint. In all other cases permitted speed shall be 20 kmph. The minimum authorized personnel to allow traffic after permanent repairs is SSE/JE/P. Way.

The speed restriction shall be removed after welding, carried out by taking up permanent repairs as outlined under Para 7.2.5 of LWR manual. The minimum authorized personnel to allow traffic at normal sectional speed after permanent repairs is SSE/JE/P. Way.

c) Destressing

The entire panel shall be destressed as soon as possible as per LWR manual Para 5.7.

7.4 Accidents, Breaches, Insertion of Temporary Girders and Diversions

1) The affected portion shall be isolated by insertion of SEJs preferably within the temperature range specified for td. The track thus isolated shall be replaced by fish plated track which shall be box anchored, if necessary.
2) In the breached sections where the new banks are constructed, the formation shall be fully consolidated before laying LWR/CWR again.
3) In case of diversions and insertion of temporary girders, SEJ shall be inserted to isolate the portion where such work is required to be done.
4) LWR/CWR panels in the affected portion shall be destressed immediately after the LWR/CWR is restored.

PART-B: INSPECTIONS & RECORDS

7.5 Inspection and Records

7.5.1 Inspection

While requiring less maintenance, LWR/CWR necessitate intensive inspection at supervisory and officer's level.

i. The profile of the ballast section should be checked, especially at pedestrian/cattle crossings, curves, approaches of level crossings, points and crossings and bridges. Cess level should be correctly maintained. Replenishment of ballast shall be completed before the onset of summer.

ii. Inspection shall be more frequent in the afternoons during summer months. During inspections, look out shall be kept for kinks, incipient buckles and checks made on functioning of hot weather patrolling operation.

iii. Knowledge of staff in regard to prescribed maintenance practices shall be periodically checked and it shall be ensured that the work is done accordingly.

iv. Ultrasonic examination of rails should not be in arrears. Defective rails/welds should be replaced expeditiously.

v. **Inspections of gaps at SEJ and creep/ movement at centre of LWR/CWR by Permanent Way officials would be done as per following schedule:-**

   a) JE (P. Way) - Once in fortnight during two coldest and two hottest months of the year at about minimum and maximum temperatures otherwise once in two months by rotation with SSE (P. Way).

b) SE (P. Way) - Once in fortnight during two coldest and two hottest months of the year at about minimum and maximum temperatures otherwise once in two months by rotation with JE (P.Way).

c) Assistant Engineer: - At least once in six months, preferably during coldest and hottest months

7.5.2 Records

i. Record of LWR/CWR, as per the proforma given in LWR manual Para 9.2.6, shall be maintained by the SSE/P. Way up-to-date, in the TMS.

ii. An indication plate similar to that suggested in Para 212(4) of Indian Railways Permanent Way Manual shall be fixed on the cess at each SEJ showing the date of destressing, destressing temperature t_d / t_0 and length of LWR/CWR.

iii. Observations of gaps at SEJ and creep/ movement in fixed portion of LWR/CWR shall be recorded by the SSE or JE/P. Way/ADEN in proforma shown in LWR manual Para 9.2.6.3 (i) & (ii), to be maintained in the TMS.

iv. When creep in fixed portion of LWR/CWR exceeds 20 mm, full investigation shall be carried out and remedial measures undertaken.

v. ADEN will analyse the observation of each LWR/ CWR in his jurisdiction and give a certificate before onset of summer regarding satisfactory behavior of all LWR/CWRs. DEN/Sr.DEN will scrutinise observations of each LWR/CWR, and exception report to be submitted to Chief Track Engineer only when his orders are required.

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CHAPTER - 8

ADVANCE CONCEPTS IN BUCKLING

8.1 Buckling Phenomena

As described earlier, buckling is the sudden lateral shift in the track alignment to release the built up compressive forces in the rail. The strength of track against buckling or what is described as lateral stability of track has been investigated in great detail by various railways. The studies conducted by various railways and the results thereof have been discussed in this chapter.

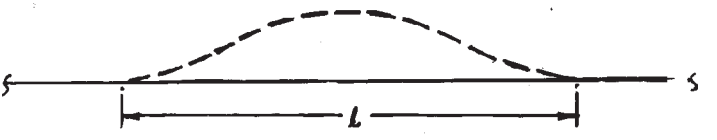
8.2 Tests by German Railways

Results of a series of track buckling tests conducted for the Federal German Railways were reported by F. Birmann and F. Raab in 1960. The test facility was located at the Technical University of Karlsruhe. The track section was 46.50m and was confined at both ends by reinforced concrete blocks. The following results were obtained from the tests :

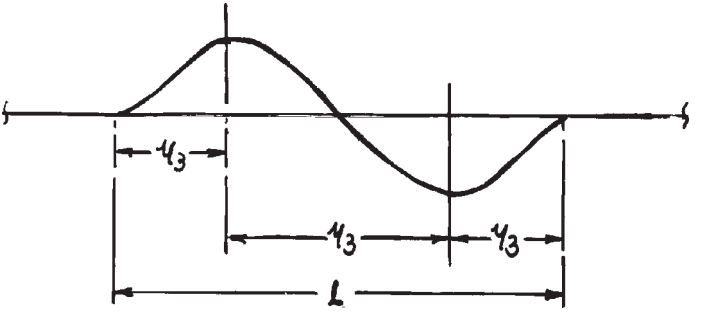
1) In all the tests the track buckled laterally. The buckling modes exhibited 2,3 or 4 noticeable half waves each of length 5 to 6 metres. The largest amplitude of displacements was about 25 centimetres. This implied that a buckled track could have several shapes with buckling taking place in several wave forms. (Fig 8.1) Buckling in the form of a 'C' could occur a on sharp curve (First wave form) while buckled track resembling an 'S' shaped curve is generally evidenced on straight tracks (2nd wave form). The force diagram

after a buckle is shown in Fig 8.2. It indicates that while a track physically buckles over a length 'l' the force diagram is affected over a length 'a' where 'a' is several times 'l'.

2) Straight tracks with smaller lateral imperfections buckled at much higher temperature increases than those tracks with noticeable lateral imperfections. Buckling of straight tracks occurred suddenly with a loud bang (explosive buckling) while the imperfect track buckled gradually and quietly (passive buckling).



First waveform



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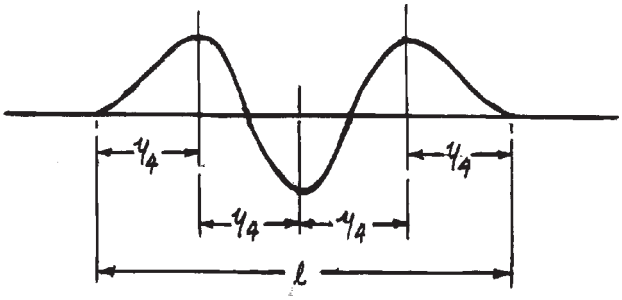


Third waveform

Fig. 8.1

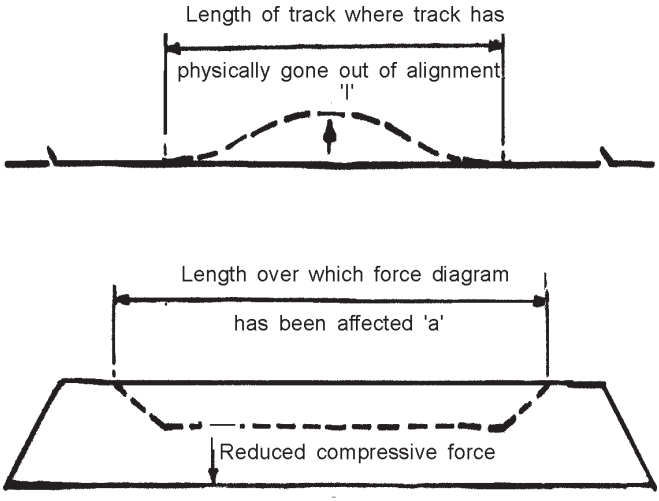


Fig. 8.2

3) With use of different fasteners, the buckling load varied byas much as 25%

4) Over a period of time with reversal of

temperatures there is an accumulation of undesirable permanent lateral track deformations for temperature increases which do not cause actual track buckling but definitely increase the buckleproneness. This is shown in Fig. 8.3.

8.3 Studies Conducted by British Transport Commission :

In order to study the conditions and factors affecting the stability of the Long Welded Rails a large testing program was started in 1953 by the Civil Engineering Laboratory of the Western Region of British Railways. These researches were carried out and described by Mr D.L.Bartlett, Assistant Director of Research (Engineering), Research Department, British Railways.

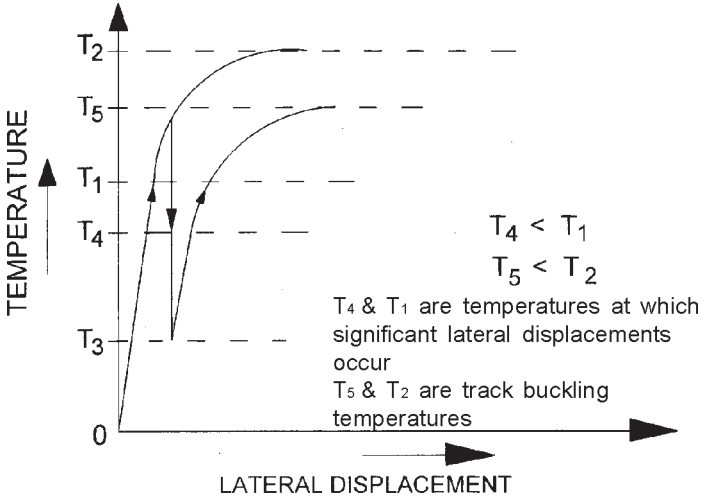
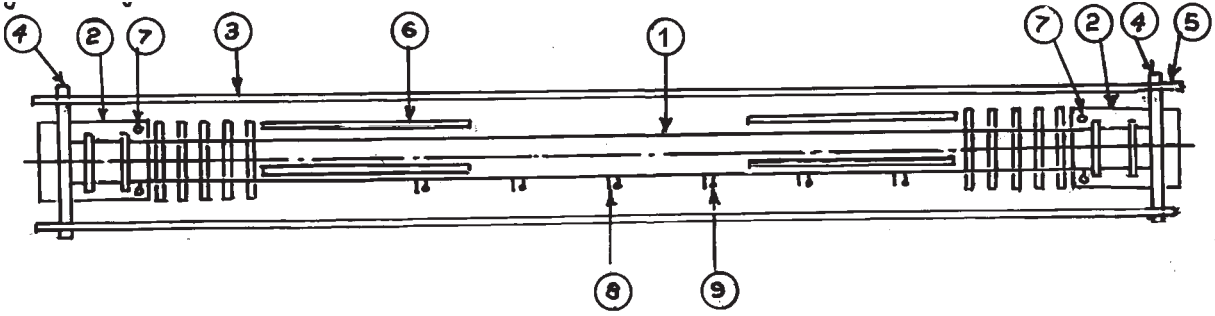


Fig. 8.3 Accumulation Of Lateral Displacements



1. 120 ft length of track
2. End anchorage blocks
3. Tie bars
4. Restraining beams
5. Hydraulic jacks
6. Electric heaters
7. Dial gauges registering longitudinal rail movement
8. Thermometers
9. Dial gauges registering lateral rail movement

Fig. 8.4

8.3.1 Test Arrangement (Fig. 8.4)

The main tests devised for the purpose of carrying out buckling tests was a 120 feet test bed upon which could be built, complete in every respect a length of track, the whole capable of being subject to thermal stresses. The arrangement of the test bed was such as to simulate the central portion of a long welded rail length on site which does not move longitudinally with temperature change. The test bed was laid inside a disused tunnel where a constant ambient temperature could be expected.

The 120 feet track rails were anchored at each end to concrete blocks sunk below ground level. This was sufficient to prevent rotation of the track and change of gauge but not to prevent the expansion of the rails. The latter was controlled by four tie bars, two on each side of and clear of the test track. Any tendency for the rails to expand could be counteracted by the jacks, although it must be stressed that the jacks were not directly used to induce compression in the rails. Four dial gauges altached to an independent datum registered any longitudinal movement of each rail end during the tests. By operating the jacks the rail lengths could be kept sufficiently close to their original values to be consistent with actual conditions in the field.

Heaters : Electric heaters with parabolic refiectors were used to simulate the heat radiation from the sun; they were situated on one side of each rail at a distance determined experimentally so that the rate of heating was not excessive.

Thermometer : Normal glass and mercury thermometers inserted in sockets drilled mainly in the head of the rail were used to measure the temperature.

Misalignment : This is the offset of the rail from the straight. The length of misalignment is the length over which misalignment occurs. The track was laid initially as straight as possible and then given a small misalignment over a given length.

Methodology of Test
Using the above setup, the longitudinal load required to buckle the track was determined experimentally for different types of sleepers, fastenings and ballast packing conditions. Using theoretical methods the longitudinal load required to buckle a track was determined and the same compared with experimental values.

8.3.2 Buckling load formula:

The formula derived for the lateral load required to buckle a straight track is :

$$P = \frac{\Pi^2 EIs}{L^2} + \frac{\Pi^2 C}{16D}\sqrt{\frac{\Pi L}{q}} + \frac{W_{\max} \; L^2}{\Pi^2 q}$$

Where
Is is the moment of inertia of the two rails put together in the horizontal plane.

L is the distance between the points of contraflexure of the buckled track.

C is the torsional coefficient for the given type of fastening

$T = C\sqrt{\alpha}$, Where T is the torque resisting buckling and

α is the angle of twist for the fastening due to rotation of the rail on the rail seat

D is sleeper spacing

q is the misalignment of the track over length L.

W_{max} is the lateral ballast resistance per meter length of track.

It may be noted that.

1) $\frac{\Pi^2 EIs}{L^2}$ represents the contribution of the rails to resistance against buckling. Little can be done to this term, as it is dependent mainly on the properties of the rail.

2) $\frac{\Pi^2 C}{16D}\sqrt{\frac{\Pi L}{q}}$ represents the contribution of the sleeper/ fastening combination to the resistance against buckling. Here clearly a reduction in sleeper spacing D or an increase in the fastening torsional co-effecient C will cause an increase in the overall resistance to buckling

3) $\frac{W_{\max} L^2}{\Pi^2 q}$ reperesents the contribution of the lateral ballast resistance.

Accordingly it is concluded that:

1. If the track is perfectly straight and points of equal load application central for each rail, then the track would not buckle even under very high compressive force. However, in practice no track exists under these ideal conditions and a misalignment of 'q' over a length 'L' will always be present. In any case, it is evident that the lower the L /q ratio, the smaller will be the buckling load. It means that large misalignments significantly reduce the strength against buckling.
2. Experimentally it has been observed that when buckling occurs, the sleepers remain at right angles to the original track alignment. For this to occur, the rail must rotate on the rail seat. Clearly,

only one thing resists such a rotational movement and this is the torsional resistance (denoted by torsional co-efficient C) offered by the fastenings. Clearly the buckling load is proportional to torsional resistance.

3. ‘L’ the length of buckled track is taken as 20 feet (6 meter) for all cases.In actual fact for a given combination of C,D, Wmax and q there exists only one value of ‘L’ which will yield a minimum value of ‘P’ (the buckling load). Hence for various combinations of these variables, a range of ‘L’ values would emerge. For practical use however, ‘L’ is chosen as 20 feet (6 meter) and the value of ‘q’ as 1/4 inch (6mm).

4. The relative contributions of rails, rail sleeper fastenings. and ballast would depend upon the actual conditions prevailing at site. Under normal conditions the percentage contributions could be 10%,30% and 60% respectively.

5. The buckling load values as determined experimertally show a fair correspondance (within a few per cent) with the values determined from theoretical calculations.

6. A PWI can ensure that the track remains safe against buckling by:

    1. Reducing the lateral misalignment in the track.

    2. Ensuring that no sleeper rail fastenings are missing.

    3. Providing full complement of ballast in the track as per precribed ballast profile.

8.4 Static Buckling and Dynamic Buckling

The discussion so far has been centred on buckling caused by longitudinal compressive force buildup due to rise of temperature above the stress-free temperature. This buckling due to thermal loads alone is called static buckling. The industry today is more concerned with buckling caused by the movement of a train on the track in the presence of thermal loads. Such a buckling is called dynamic buckling. The effects of a moving train which could contribute to dynamic buckling are as given below :

1) Loaded axles of a moving train cause the track to be lifted in frontof, in the rear of or even between the moving axles. The wave so created as seen in the vertical profile of the rail in front of the engine is called the precession wave, in the rear the recession wave and in between the axles, the central wave. Any of these waves

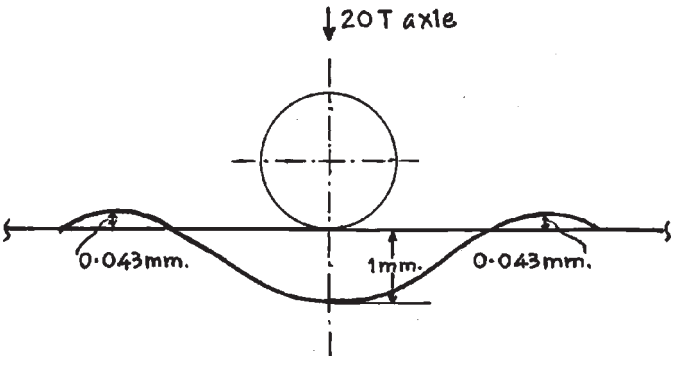
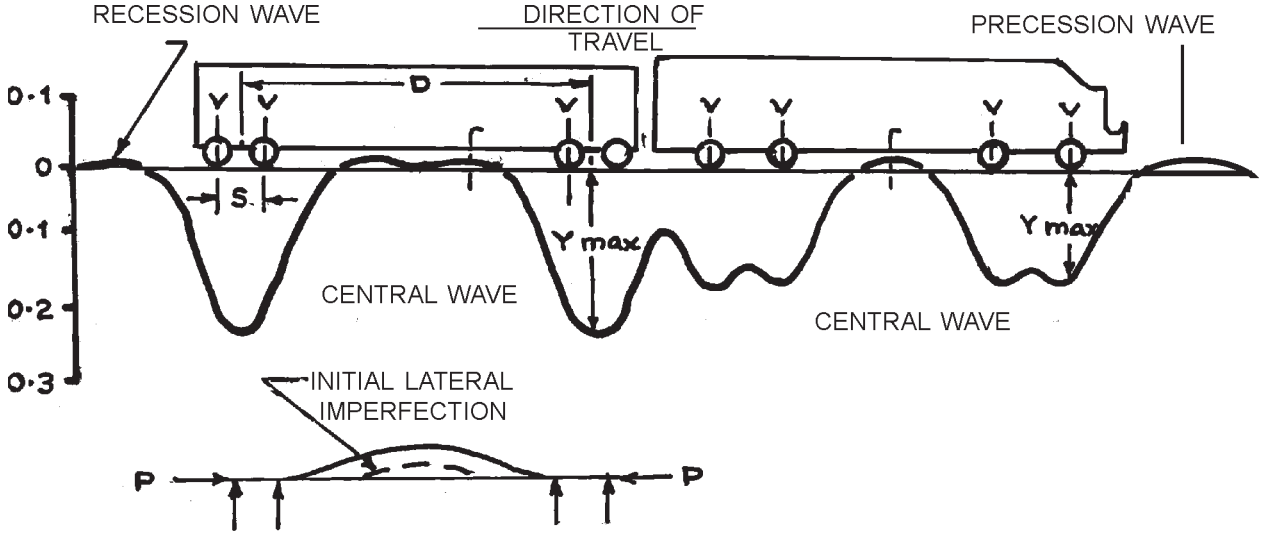


Fig. 8.5 (a)

could be critical enough to cause loss of contact between the ballast and the sleeper soffit resuting in the loss of lateral ballast resistance thereby making the track buckleprone (Fig 8.5 (a) & (b)).



ASSUMED LATERAL BUCKLING MODE

Fig. 8.5 (b)

2) Tractive and braking forces applied by the moving trainchange the force level in the LWR and continuous braking at a given location could result in buildup of compressive forces creating buckling tendencies in the rail.

3) The hunting motion of the moving train over lateralmislignments in the track could create large lateral forces producing buckling tendencies.

4) Vibrations induced by the moving train could disturb theballast and lower the lateral ballast resistance.

8.5 Dynamic Track Buckling Model:

The effect of a moving train increasing tendency of a track to buckle when the temperatures are rising or the response of the track to disturbing lateral forces is depicted by what is called DYNAMIC TRACK BUCKLING MODEL. This model is essentially a relationship between the lateral track displacement and the temperature increase over the force free or neutral temperature. The model is depicted in the figure (Fig 8.6).

The model has 3 limbs as shown: AB is the prebuckling limb while

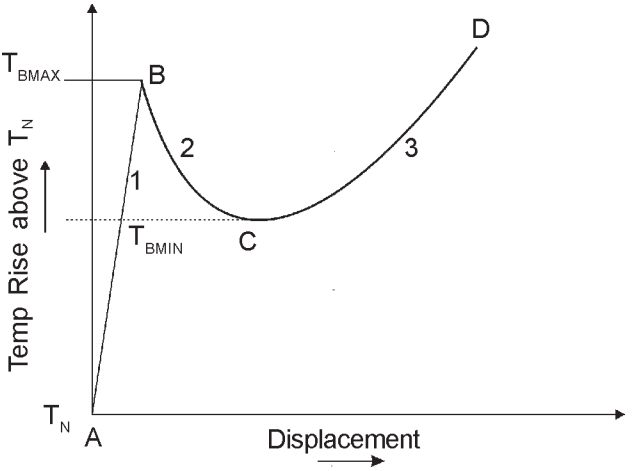


Fig. 8.6 Dynamic Track Buckling Model

BC and CD are post-buckling limbs. At B when the temp. rises to T_{BMAX}, the track becomes unstable where even an infinitesimal lateral force will cause the track to buckle. Below temp T_{BMIN} at point C, even a large force will not be able to buckle the track. Between points ‘B’ and ‘C’ a moving train could impart sufficient force to buckle the track. Between ‘B’ and 'C' the track on buckling will first move to an unstable buckled phase on curve BC and subsequently to a stable buckled phase on CD. It is assumed that if the track can be brought into position 2 it will automatically move into position 3. At T_{BMAX}, the energy required to buckle a track is almost zero while below T_{BMIN} the energy required to buckle a track is much larger than that which could be provided by a moving train. Between T_{BMAX} and T_{BMIN}, the transition from the pre-buckling stage to the unstable buckled state and to the stable buckled state could be effected under the influence of energy imparted by the moving vehicle.

Various softwares have been developed to predict the T_{BMAX} and T_{BMIN} temperatures for given track and rolling stock parameters. In the USA, the program developed is called CWR-BUCKLE. Other software programs are CWRSAFE and related programs. The inputs to these programs are :

1) Rail section
2) Track curvature
3) Rolling stock characteristics
4) Lateral ballast resistance
5) The misalignment in the track.

Using these programs the T_{BMIN} and T_{BMAX} of the given track for a given set of parameters are determimed. The policies regarding LWR maintenance can then be decided. These could include :

1) Allowable Temperature rise above tn for maintenance activities
2) Temperature at which track enters the danger zone, and necessitates hot weather patrolling.

8.6 CWR Safety Assurance Program:

The discussion above could form the basis of a continuous welded track buckling safety assurance program. For safe operations of CWR track with respect to buckling, the allowable temperature increase T_{ALL} over the neutral temperature should be greater than the difference between the maximum anticipated rail temperature T_{MAX} on a given day and the neutral or stress-free temperature T_n i.e. $T_{ALL} > (T_{MAX} - T_n)$

The expression on the right is the anticipated rail temperature rise over T_n while T_{ALL} is the allowable

temperature rise which could be determined from the values of T_{BMIN} and T_{BMAX}. T_{ALL} will be somewhere between these two extreme temperature values depending upon the track parameters,level of maintenance and monitoring and the degree of risk the railway administration is willing to take. A conservative approach would be to fix the T_{ALL} at T_{BMIN} value. However, a better approach would be to fix TALL higher than T_{BMIN} if the railway has good track maintenance and monitoring procedures in place.

The expression given above indicates that for a safe CWR assurance program two temperatures need to be determined:

(i) T_{ALL} which is the allowable temperature rise above the neutral temperature for a given set of track and vehicle parameters.The single most significant factor which will govern T_{ALL} for a given set of track and rolling stock parameters is the lateral ballast resistance. The ralationship between T_{ALL} and the lateral ballast resistance will be in the form of a graph. This could be given to the field maintenance engineer to enable him to predict the allowable temperature rise over the neutral temperature for a given value of the lateral ballast resistance. (Fig 8.8)

(ii) The neutral temperature or the stress free temperature ofthe track.

8.7 Field Determination of Lateral Ballast Resistance:

A convenient metod to determine the lateral ballast resistance per sleeper has been developed in the USA.It is called the single tie push test (STPT).

Test Methodology: The rail is freed from the sleeper by removing the fastenings and using a hydraulic jacking equipment the tie is pushed transversely to the track. With load transducers and gauges, the loads and corresponding displacements are recorded. The plot gives the maximum lateral resistance of ballast. For getting the average value the test could be performed on 3 sleepers over a 50 feet length. Once the lateral ballast resistance value is obtained

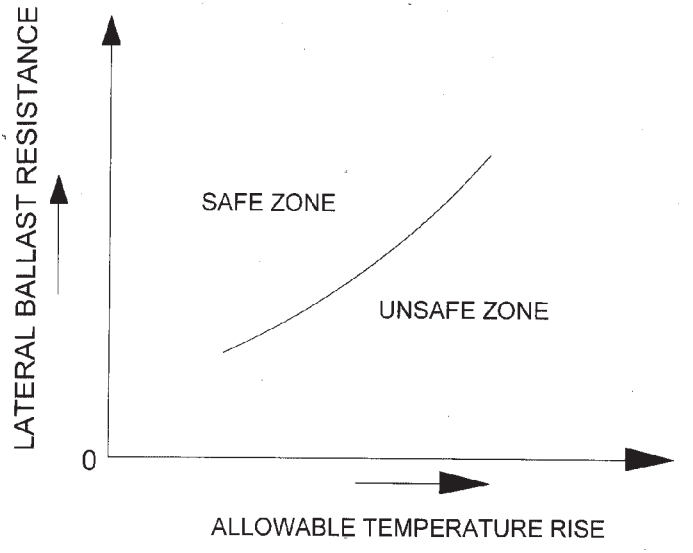


Fig. 8.8 Relationship between TALL and Lateral Ballast Resistance.

graph could be given to the field maintenance engineer to enable him to predict the allowable temperature rise TALL over the neutral temperature.

8.8 Neutral Temperature, its Variation and Determination

8.8.1 Introduction :

The neutral temprature tn or the stress-free temperature tois the rail temperature at which the rail is free of longitudinal stress, or longitudinal stress is zero. Till now the assumption was that once an LWR was destressed at temperature td, , td, was the stress free temperature of the rail. However, there is experimental evidence to indicate that the above assumption is not correct and the stressfree temperature of the rail tends to shift away from the destressing temperature. Accurate determination of the rail stress free temperature is of vital importance, because it is this temperature which determines the force level in the LWR

$$P = AE\alpha \left[t_P - t_n \right]$$

The above expression also indicates that if due to any reason the value of tn were to fall, it would automatically increase the compressive force in the rail and beyond a certain level could cause the track to buckle. Another way of putting it is that a change in the rail neutral temperature is equivalent to changing the force level in the rails for the same values of t_P.

8.8.2 Factors which could cause a shift in the Rail Neutral Temperature:

1) Movement of the rail in the longitudinal, lateral and vertical directions : If the CWR were to be fully constrained, then there would be no change in the neutral temperature. Since the rails cannot be fully constrained in all directions, elongation or contraction can occur whenever the track is subject to train and environmentally induced loads. Railway track motions relevant to t_n variation occur in the

following three basic kinematic modes :

(i) Rail longitudinal movement

(ii) Track lateral shift

(iii) Track vertical settlement.

Consider a CWR being laid at Temperature tL and there is no rail longitudinal force at this temperature. Assume that the rail displacements (u,v and w in the longitudinal, lateral and vertical directions respectively) are measured with respect to an initial equilibrium configuration when the rail temperature is tL. These displacements may be due to a number of causes, and in many cases are not recoverable due to the inelastic nature of the ballast. From the displacements, the longitudional strain ex in the rail at any given temperature tP can be calculated from the fundamental equations of theoretical mechanics.

$$\varepsilon x = -\left[\frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial \varpi}{\partial x}\right)^2\right] + \alpha\left[t_P - t_L\right]$$

$\alpha\left[t_P - t_L\right]$ is a compressive strain taken as positive in the longitudinal 'x' direction.

The force in the CWR at t_P in the longitudinal 'x' direction will be

P = AE εx

$$= AE\,\alpha\left[t_P - \left\langle t_L + \frac{1}{\alpha}\left\{\frac{\partial u}{\partial x} + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial \varpi}{\partial x}\right)^2\right\}\right\rangle\right] \text{--------}\mathbf{1}$$

If t_n is the neutral temperature of the CWR then

$$P = AE\ \left[t_P - t_n\right] \text{----------}\mathbf{2}$$

Comparing equations 1 and 2 it is quite evident that

$$t_n = t_L + \frac{1}{\alpha}\left\{\left(\frac{\partial u}{\partial x}\right) + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial \varpi}{\partial x}\right)^2\right\}$$

where $\frac{\partial u}{\partial x}$, $\frac{\partial v}{\partial x}$, and $\frac{\partial}{\partial x}$ are all tensile strains.

If the movement of the rail leads to additional tensile stress, then the neutral temperature will increase beyond t_L. On the other hand, if u, v and w the rail displacements cause compressive strains, they will cause t_n to drop below t_L. On a curve of radius 'R' if the track is shifted by an amount equal to 'V'

then $t_n = t_L + \frac{1}{\alpha}\left\{\left(\frac{\partial u}{\partial x}\right) + \frac{V}{R} + \frac{1}{2}\left(\frac{\partial v}{\partial x}\right)^2 + \frac{1}{2}\left(\frac{\partial \varpi}{\partial x}\right)^2\right\}$

Movement of the rail in the x, y and z directions may be due to the following reasons :

i) Rail Longitudinal Movement – This may occur due to train action (braking and accleration) or due to wheel rolling action.

ii) Track Lateral Shift – This may occur due to bogie hunting action, by wheels negotiating a lateral imperfection or in case of curves, by vehicles operating

in excess of or below the balance speed. For tangent track, the effect of lateral movement on the neutral temperature shift is likely to be small. For curved track, however, the shift can be significant.

iii) Track vertical Settlement – Vertical wheel loads can induce differential settlement of the ballast which would cause development of longitudinal strains in CWR specially for new or recently surfaced tracks.

,Apart from these displacements which could cause a shift in the rail neutral temperature, two more factors could cause a shift. These are :

1. Rail/Track Maintenance – Track maintenance activities involving lining, lifting, removal or application of rail anchors, trackline repairs all will cause a shift in neutral temperature.
2. Rail "Rolling Out" – Due to vehicle loads, plastic deformation occurs in the top layers of the rail head. Experiments conducted by the British Rail showed rolling out of rail is pronounced in first 3 months after laying new rails and continues for about an year. The basic mechanism involved is that the rolling contact loads change the residual tensile stresses in the top layer of new rails into compressive stresses. The rail residual stresses will affect the neutral temperature of the rail (Fig 8.8).

8.8.3 Neutral temperature measurement

8.8.3.1 A satisfactory neutral temperature measuring device should satisfy the following fundamental requirements :

1. The measuring instrument should be portable and not permanently attached to the rails.
2. The instrument should give absolute values and not relative values. Site specific calibration should not be involved.
3. The technique should be independent of longitudinal residual stresses in rail. The residual stresses are not associated with the rail longitudinal force since they are self-equilibrating in the sense that their resultant force and moment are zero. As a result, any technique which relies

on measurement of local stresses for the longitudinal force can have large errors.

4. The technique should be non-destructive.
5. The technique should be fairly accurate with measurements within +1^{0}C.

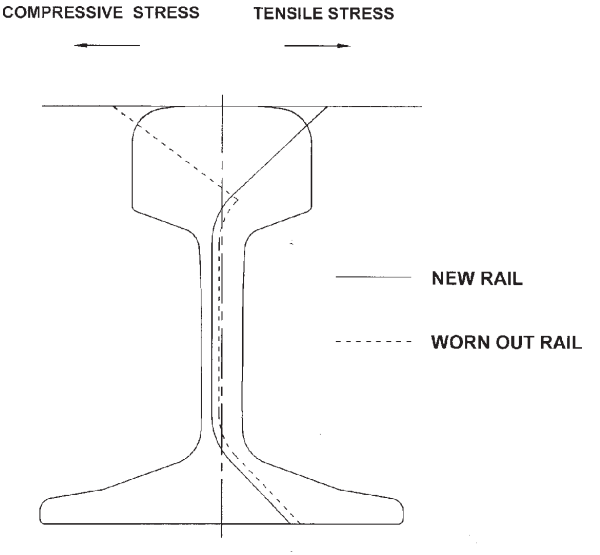


Fig. 8.8 Rail Residual Stresses

8.8.3.2 Of the number of techniques available for neutral temperature measurement, the following can be considered as reasonably developed :

- Berry Gauge – Simple mechanical gauge to measure change in length.
- British Rail Vibrating Wire – Measures the rail force as a function of the frequency of a wire vibrating in a hole in the rail web.

- Strain Gauge –Uses a four arm Wheatstone bridge to measure the rail strains.

Techniques under Research –

1. Flexural wave propagation
2. X-ray defraction
3. Accousto-elastic
4. Magnetic coercion
5. Barkhausen Noise – This principle is being used in Rail Scan Equipment.
6. Electromagnetic Accoustic Transducers
7. Laser 'Spackle'

8.8.3.3 Rail uplift method :

A new approach based on rail beam column response has shown considerable promise. It is based upon the fact that if the rail can be held at two points at some distance apart and a concentrated load applied at the centre of this portion, the rail behaves like a beam column and its deflection is influenced measurably by the longitudinal load in the rail. Clearly a compressive longitudinal load will increase its deflection, whereas a tensile load will reduce it.

Besides the longitudinal force, the deflection is dependent on the rail flexural rigidity, EI, applied load Q and the nature of the end constraints. It is necessary to design a rig such that for all locations and measurements, the end conditions are sufficiently repeatable. As far as the end conditions are concerned, they depend upon the nature of constraint provided by the rig. Generally, the conditions are elastic supports (in between pure simple supports and completely fixed supports). Fixed support conditions improve the sensitivity, but need large applied loads. Repeatability of the end conditions is an important consideration for

successful application of the technique.
The deflection Δ is given by

$$\Delta = \lambda \frac{QL^3}{EI} \frac{1}{1 - \frac{C}{P_c}} \text{---------} (1)$$

where C is the longitudinal compressive force in the rail

Q = Verticle load applied at centre of rail.

λ = Numerical constant value depending on the end conditions,

Pc = Critical buckling load for the beam column of length 2L for the specific end conditions.

The first factor in the above equation represents the deflection under the concentrated load in the absence of any longitudinal rail force. The second factor is the magnification factor due to longitudinal force.

The above equation shows that for a given value of C (rail longitudinal force), Q and Δ are proportional to each other. This is depicted in the given figures (Fig 8.9 & Fig 8.10)

8.8.3.4 Verse method

Practical use of this principle has been made in the technique called 'VERSE' developed by VORTOK International, UK and AEA Technology Rail. The equipment comprises of a frame featuring a hydraulic lifting device, a load transducer and a displacement transducer. The measurement systems are connected to a rugged handheld computer.

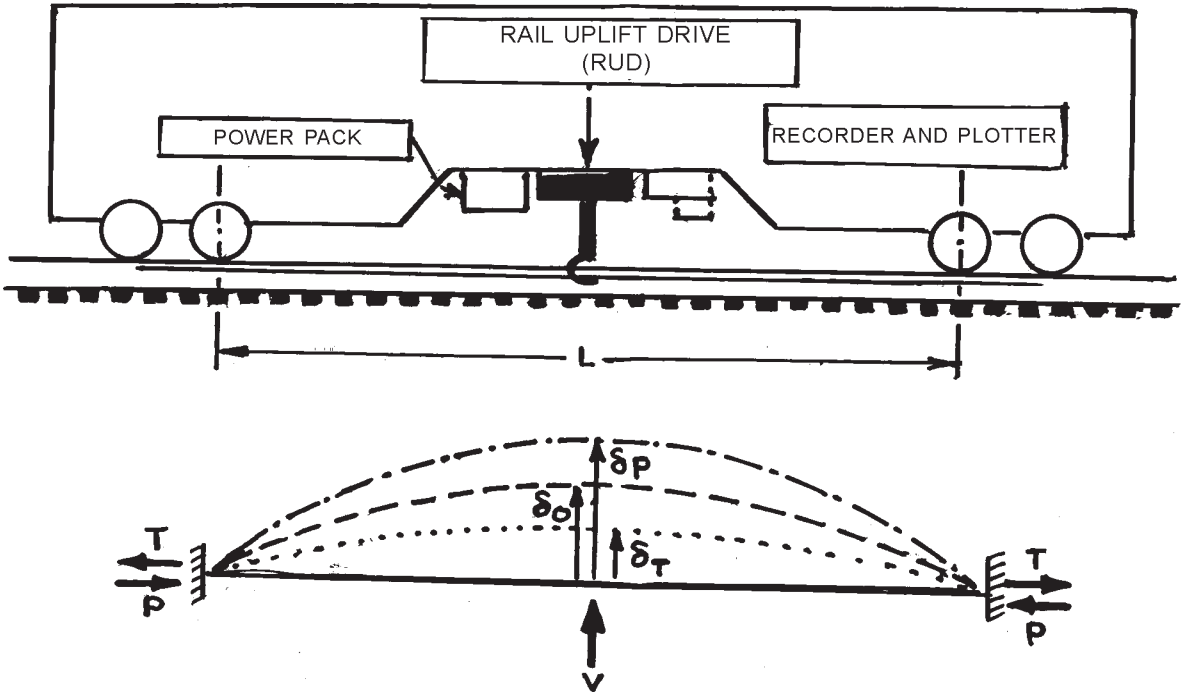


Fig. 8.9 Rail Uplift Method.

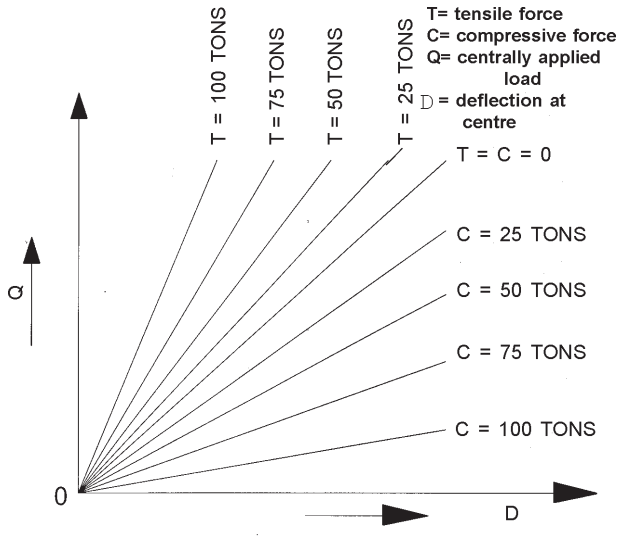


Fig. 8.10 Graphical Method for Neutral Temperature Determination.

The rail must be in tension at the time of measuring the stress free temperature (SFT). Taking measurements requires around 30 m of rail to be unclipped and placing rail support spacers at 10 m on either side of the measuring point (Fig 8.11). A maximum force of one tonne is applied and the load and displacements measured by the transducers relayed to the handheld computer. The measured data along with some other data such as ambient rail temperature, rail profile and height of rail is fed into the computer to obtain the SFT result. The height of the rail is included to take account of the rail head wear and rail grinding which will naturally affect the stiffness of the rail. Validation of VERSE technique has been carried out by AEA Technology, one of Britain's leading technology companies.

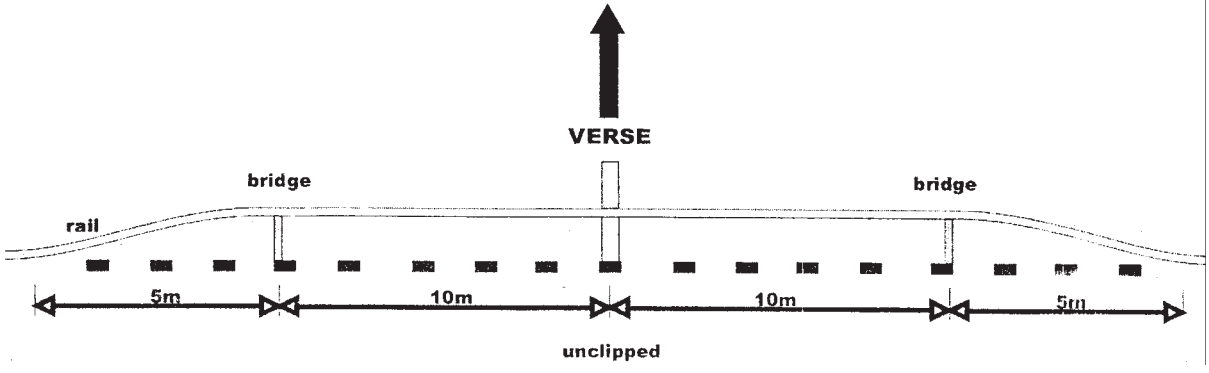


Fig. 8.11 Verse Method for Neutral Temperature Determination.

8.9 Important Conclusion w.r.t. Practical Aspects;

1. Straight track with small misalignment buckle at much higher temp compare to straight track having large misalignment i.e. misalignment in track acclerates buckling phenomena.
2. The higher sleeper density & increase in fastening torsional coefficient increases overall resistance to buckling.
3. The large misalignments significantly reduce the track strength against buckling.
4. In the track buckling strength, relative contribution of rails fastenings and ballast would depend upon the actual conditions prevailing at site. Under normal conditions the % contribution could be 10%, 30% & 60% respectively.
5. Tractive & braking forces applied by the moving train change the force level in the LWR and continuous braking at a given location could result in build- up of compressive forces creating dynamic buckling.
6. The hunting motion of the moving train over lateral misalignments in track could create large lateral forces producing buckling tendencies.
7. Vibrations induced by the moving train can disturb the ballast & reduce the lateral ballast resistance.
8. The movement of rail track in x, y & z direction due to rail longitudinal movement, track lateral shift & track vertical settlement will cause shift in the rail neutral temperature, i.e t_d will get modified.

9. To safe guard against buckling, following should be kept in mind during maintanance.

   a) Keep a check on lateral misalignment in the track

   b) Ensure adequacy & proper functioning of fastenings

   c) Ensure ballast section as per prescribed profile.

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