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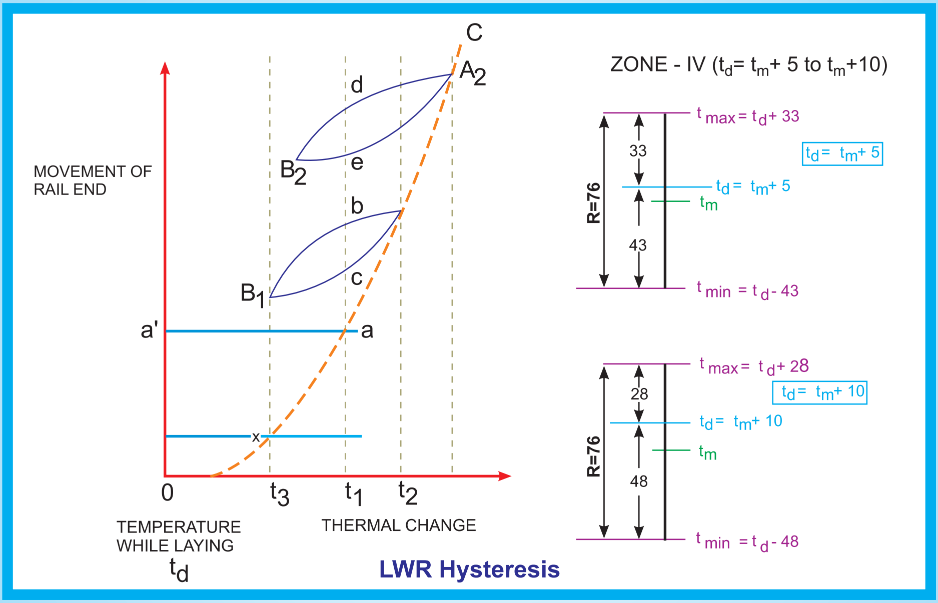
To Beam As A Beacon of Knowledge

LONG WELDED RAILS



LWR Hysteresis

December 2023

Indian Railways Institute of Civil Engineering
Pune 411001

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INDIAN RAILWAYS INSTITUTE OF CIVIL ENGINEERING, PUNE 411001

FOREWORD TO FOURTH EDITION

Long Welded Rail is synonymous with modern track structure with major portion of Indian Railway track is having LWR. This publication i.e., the 4th revised edition is an updated version with a completely new look, incorporating the updated provisions of the new IRPWM 2020.

This book on Long Welded Rail was originally published in 1988 and then 1st, 2nd and the 3rd revised editions were printed subsequently, incorporating the correction slips issued until then.

Indian Railways is constantly upgrading and striving for excellence. After the publication of the updated IRPWM in June 2020, Indian Railways has seen many changes, especially on the introduction of high speed and the consequent need for CWR track as well as a rethink on continuation of LWR over Girder bridges.

Further, with the length of LWR in the existing track of IR increasing to one block section length, the importance of inspection of LWR has attained more importance. These topics have been incorporated in this 4th edition so as to make it more useful for the field engineers.

This book aims at explaining the theoretical basis of various provisions of LWR in the IRPWM in a simple, yet, effective way so that the field engineers can appreciate the provisions of the IRPWM with respect to LWR / CWR better. 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.

Pune
November 2023

R. K. Yadav
Director General
IRICEN / PUNE

PREFACE TO FOURTH EDITION

The book on LWR was originally published in 1988, with 3 revised and updated editions were also published subsequently. This book is the 4th revised edition on the subject of laying and maintenance of Long Welded Rail.

In this 4th revised edition, the basic concepts involved in LWR maintenance have been further elaborated with few more sketches for a better understanding of field Engineers. The concept of maintenance of LWR has been emphasized with an added focus on the inspection of LWR.

The Chapters on Maintenance of LWR Track, Destressing of LWR, Permitted locations & track structure, Hysteresis curves for LWR have been redrafted. Few more sketches also incorporated for better appreciation of the provisions of LWR in the IRPWM 2020.

The introduction of High Speed on Indian Railways has necessitated the need to move towards faster adoption of LWR / CWR on Indian Railways. This has also led to more focus on the changes needed in the concept of continuation of LWR on existing girder bridges. The importance of the continuation of LWR through P&C is also addressed in this book. The need for a more qualitative analysis of LWR inspection and maintenance has also gained importance and emphasised in this updated edition of the book.

We are thankful to Shri R. K Yadav, Director General / IRICEN, who has been inspirational and provided valuable guidance in bringing out the 4th edition. This is also acknowledged in the updation of this edition of the book in line with the latest provisions of IRPWM 2020.

We dedicate this 4th revised edition of the book on LWR to the cause of “efficient, safe & improved track maintenance practices on Indian Railways”.

Sivakumar A.
Professor Works
IRICEN / PUNE

Satya Prakash
Additional Director General
IRICEN / PUNE

FOREWORD TO THIRD EDITION

The Long Welded Rail is synonymous with modern trackstructure 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
Director/IRICEN
director@iricen.gov.in

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
director@iricen.gov.in

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

March 2005 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 ocumentation 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

March 2005 Senior Professor & Dean

CONTENTS

CHAPTER - 1

INTRODUCTION TO LONG WELDED RAILS

1.1 Evolution of Long Welded Rails

(a) At the beginning of the 19th century the standard length of rail was generally 12m / 13m. 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 of rail transportation including its loading and unloading related issues.

Subsequent advancements in the manufacturing process have enabled rolling of longer rails possible. Presently SAIL Bhilai Steel Plant and Jindal Steel roll rails in 130m length, with one FBW, 260m rail panel is supplied to site in special rakes.

(b) 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 behaviour 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 behaviour of 5-rail panels and 10-rail panels at the first instance and thereafter of Long Welded Rails.

(c) 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 up to 15mm, the actual movements of a 5 rail or 10 rail panel are much larger resulting in large gaps, bent fish bolts and elongated fish bolt 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:

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

ii) Existing 5-rail and 10-rail panels be cut into 2½ rail panels;

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

1.2 Advantages of Long-Welded Rail

LWR is synonymous with modern track. LWR makes train travel more safe, economical and comfortable due to following reasons:

1) LWR track eliminates 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 efforts for track attention / track maintenance

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%.

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

6) With the aim of higher speeds of up to 160KMPH, maintenance methodologies / maintenance standards, Maintenance effort vs Outputs etc., on SWR track would be impractical and thus, LWR track becomes the de-facto need, rather than the exception.

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 track greater than 250 meter on Broad Gauge and 500m on Meter Gauge will normally function as LWR (Fig. 1.1). With introduction of weldable CMS crossings, LWR is continued through turnouts and longer length of LWR are being converted to Continuously Welded Rails. (CWR).

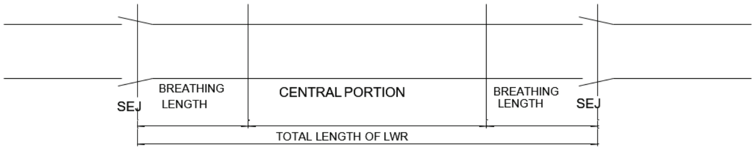


Fig 1.1 LWR Line Sketch

As the central portion of LWR does not expand/contract, i.e., it does not under go any longitudinal movement, therefore, thermal forces are built up in the central portion due to temperature variations. The thermal force (P), calculated below, 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, (2.11×10^6 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 to 1.688 ton for 52 Kg & 1.868 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 below)

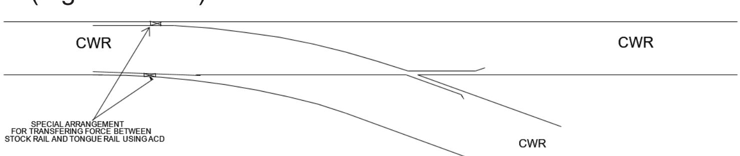


Fig 1.2 CWR Line Sketch

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

Note: *Normally the length of SWR is 3 x 13 meter for BG & 3 x 12 meter for MG. Provisions for laying and maintenance of SWR are contained in Chapter 3, Part 'C' of Indian Railways Permanent Way Manual (IRPWM).*

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) {into which, Tracks on Indian Railways have been divided, as stipulated under IRPWM (Annexure 3/16) (Rail Temperature)}, is as shown below.

Zone	**Sleeper Density**	**Breathing length(in meters)**	
		60 Kg/m (UIC)	**52 Kg/m rails**
I	1540	60	52
	1660	58	50
II	1540	69	59
	1660	66	57
III	1540	77	66
	1660	74	64
IV	1540	82	71
	1660	79	68

Note: *The Breathing lengths given above are indicative and are likely to vary as per 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

6) **Rail Temperature** is the temperature of the rail at site as recorded by an approved type of rail thermometer as laid down in IRPWM Para 332. This is different from ambient temperature which is the temperature of air in shade at the same place. Indian Railways has been divided in 4 temperature zones as under:

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

7) **Mean Rail Temperature (t_m)** for a section is the average of the maximum and minimum rail temperatures recorded for the section, taken over a period of 5 years

8) **Destressing** is the operation undertaken with or without rail tensor to secure stressfree conditions in the LWR/CWR at the desired/specified rail temperature.

9) **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.

10) **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, t_d for all practical purposes is equal to t_o .The Range of t_d 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) Other rail sections	t_m to t_m + 5°C
	(ii) 52 Kg & heavier	t_m + 5°C to t_m + 10°C

Note: *with the use of heavier wider base sleeper, the destressing temperature may be considered for reduction by 5 degrees from the range prescribed above on trial basis.*

11) 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.

While measuring the prevailing rail temperature t_p and reporting it, it is desirable and a good practice that the temperature is always reported with reference to the t_d of that LWR, such as "t_d + x °C" or "t_d – x°C" as the case may be, instead of being reported simply as "y °C", where x is the difference between the prevailing rail temperature t_p ie y and the destressing temperature t_d.

- For e.g., if the prevailing rail temperature is 52°C and the destressing temperature of the LWR, t_d, is 43°C, it is desirable that the temperature is reported / spoken out / told as t_d +9°C instead of reporting it as 52°C.
- This is likely to bring in awareness among the staff responsible for maintenance of LWR about the nature of forces prevailing the LWR.

NOTE: *In the above cases, the prevailing force in the LWR is easily inferred as compressive if it is reported with the "plus" sign, else the prevailing force in the LWR is inferred as tensile, if it is reported with the "minus" sign.*

12) 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 t_p, which shall be lower than stress-free temperature. The extension to be applied by the tensor shall be calculated from the following formula:

Extension = $L\alpha (t_o – t_p)$

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.

13) Rail Tensor is a hydraulic or mechanical device used for stretching the rail physically.
14) 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 at least 2.5 m per degree Celsius of ($t_o – t_p$) for BG.
15) Hot Weather Patrol is the patrol carried out when the rail temperature exceeds a pre-determined rail temperature to guard against the possibility of track buckling. Current provisions in the IRPWM are to introduce Hot Weather Patrolling when rail temperature exceeds t_d+25°C on PSC sleeper track with sleeper density 1540 per km or more, in all other cases it shall be introduced when rail temperature exceeds t_d+20^{0}C.

    In addition, the period for regular hot weather patrolling during summer shall be laid down by the Chief Track Engineer for each section and patrol charts prepared where necessary.

    However, considering that now wider and heavier sleepers have been introduced on IR, leading to a better track modulus, with the past experience of better track structure / maintenance practices and better quality of fittings, the following may be considered in future:

Hot weather patrolling may now be considered for introduction when prevailing rail temperature, t_p, exceeds t_d+30°C for conventional PSC sleeper and wider base sleeper having sleeper density of 1660 per km.

However, if deep screening is done in last one-year, Hot Weather Patrolling shall be introduced beyond t_d +25°C.

Provision for introducing Hot Weather Patrolling after deep screening and machine tamping till consolidation of track may be considered to be:

"t_d +10°C after deep screening and/or track renewal till ballasting and consolidation of track as per Para 337 (5) of IRPWM.

"t_d +20°C after machine tamping till consolidation of track as per Para 337 (5) of IRPWM".

16) Cold Weather Patrol is the patrol carried out during cold times of the year in specified sections as per instructions of Sr. DEN / Co of the Division to safeguard against unsafe conditions due to a rail fracture occurring at extreme low rail temperatures.

    Thus, Cold weather patrolling shall be introduced when the rail temperature is less than t_d – 30^{0}C. In case of freshly deep screened track, cold weather patrolling shall be introduced when the rail temperature is less than t_d – 20^{0}C.

17) Consolidation of Track is the process of building up ballast resistance against the tendency of movement of sleeper, either immediately after initial laying of LWR or making up subsequent loss of resistance during maintenance by anyone of the following:

    i) **Track consolidation by traffic passage:** 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*

- **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.

18) Longitudinal ballast resistance (R) : The longitudinal ballast resistance (R) gets mobilised 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 12.98 Kg/cm/rail for sleeper density 1660 per Km & 11.76 Kg/cm/rail for sleeper density 1540 per Km.

19) 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 in the IRPWM, the approval of Principal Chief Engineer shall be obtained.

***

CHAPTER II
PRINCIPLES OF LONG WELDED RAIL

2.1 Basic Principles of long welded rail

(a) A metal rod, supported on frictionless rollers, can theoretically expand and contract freely & proportionately, with variations in temperature. It will expand / contract equal to a value that is derived by the formula, Expansion = L α 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 temperature variations, then thermal strain & stress will get induced in this rod.

Thermal strain will be	= L α t / L	= α t
Thermal stress	= E x Thermal strain	= E x α t
Thermal force P	= A x thermal stress	= A E α t

(b) 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, 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. (Toe Load)

   iii) The entire rail Sleeper fastening assembly is embedded in ballast.

   iv) The ballast being supported on a stable formation.

   Thus, with any change in temperature, it is not the rail alone but the rail-sleeper frame as a whole tends to move.

(c) 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 (LBR). 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 sleeper frame 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.

(d) 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 temperature 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 adequate ballast resistance gets developed, there is no movement in LWR beyond it, called central portion of LWR.

(e) However, if the temperature difference becomes 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:

(i) The maximum or the minimum rail temperature of the area and

(ii) The temperature at which the rail is fastened to the sleeper.

(f) The temperature at which the track can be attended under regular track maintenance, the temperature at which the patrolling of the track should be introduced, etc. are governed by the sole consideration that the thermal forces at any time in the track should be within safe limits, to avoid the eventualities of buckling / fractures in the LWR.

2.2 Force Diagram of LWR

LWR 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

(1) Let us assume the LWR central portion is to undergo an increase in temperature by t^0C. If the central portion of length 'L' had been free to expand it would have expanded by an amount equal to 'Lαt'. 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 of LWR with respect to the temperature at which it was laid or destressed and

α is the coefficient of linear expansion.

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

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

Solving the above equation, we get

$P = A\ E\ \alpha\ t$

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

$$\mathbf{P = A\ E\ \alpha\ (t_p - t_n)}$$

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.

(3) Thus, we can infer that

(i) When $t_p = t_n$, P = 0, (or Rail is in a stress-free condition)

(ii) when $t_p > t_n$, P is a compressive force, and

(iii) when $t_p < t_n$, P is a tensile force.

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

The force at the beginning of the LWR i.e. near SEJ is zero, and in the central portion equal to A E α 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 below

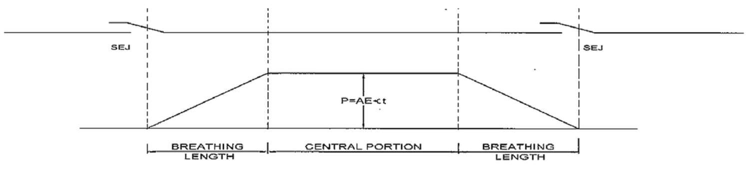


Fig 2.1 Force Diagram in LWR

(4) 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 & A = 76.86 cm^2 for 60 kg rail)

E = Modulus of elasticity of rail steel, (2.11 x 10^6 Kg/sq.cm)

α = Coefficient of linear expansion of steel, (1.152 x 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 1.608 ton for 52 Kg & 1.868 ton for 60 Kg rail section. Accordingly, at t_d +10°C the induced compressive force shall be 16.08 t / 18.68 t for 52 kg / 60 kg rail section respectively.

Considering the range of rail temperature as laid down for destressing of LWR (as discussed in Chapter 1), the maximum range from t_d to t_{max} and t_{min} is as under

Zone I	= varies from +25°C to – 30°C
Zone II	= varies from +30°C to – 35°C
Zone III	= varies from +35°C to – 40°C
Zone IV	= varies from +33°C to – 48°C

We can accordingly, calculate the force that is expected to be available in a LWR at the t_{max} and $t_{min.}$ at all 4 temperature Zones.

Thus, concept of Hot Weather Patrolling and Cold Weather Patrolling, its need and its monitoring can be understood better.

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 t_p and the rail neutral temperature, t_n. (Also called as Stress-free temperature, t_0)

2.3.1 Rail Temperature Measurement:

(a) 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 about 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 to complete 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 as well as record the data in digital formats as well.

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

v) Accordingly, the following shall be ensured:

(1) The existing SSE/P.Way (In-charge) shall record rail temperature using preferably a well-calibrated continuous recording type thermometer and data to be updated in TMS.

(2) 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.

(3) These temperature records shall be analysed to assess the probable availability of time periods during different seasons of the year for track maintenance, de-stressing operations and requirements of hot/cold weather patrolling etc.

(4) The rail thermometer shall also be available with each Gang and sectional JE/SSE/P.Way to enable the Gangs to work within the prescribed temperature ranges.

(b) Periodic Check on Accuracy of Thermometers:

Where a number of thermometers are used to measure the rail temperature at one place, as in case of laying of LWR, de-stressing etc., or during routine tools inspection at office of SSE / P. Way, any of the thermometer showing erratic readings, appreciably different from the other adjoining thermometers, shall be considered as defective.

(c) Reporting of Rail temperature:

(i) Whenever, any activity pertaining to track maintenance that involves disturbance / replacement / renewal of rail / track fittings / ballast or its consolidation is to be undertaken, measurement of the prevailing rail temperature is mandatory.

(ii) While reporting the prevailing rail temperature, it is a good practice to report the same with reference to the t_d of that LWR rather than report it as a mere temperature.

For e.g., if the prevailing rail temperature is 52°C and the destressing temperature of the LWR, t_d, is 43°C, it is desirable that the temperature is reported / spoken out / told as t_d +9°C instead of reporting it as 52°C.

This is likely to bring in an awareness among the staff responsible for maintenance of LWR about the nature of forces prevailing the LWR.

NOTE: *In the above cases, the prevailing force in the LWR is easily inferred as compressive if it is reported with the "plus" sign, else the prevailing force in the LWR is inferred as tensile, if it is reported with* *the "minus" sign.*

(iii) This measurement of prevailing rail temperature shall be done frequently at site till the work as described at (i) above is completed at the site for the day.

2.3.2 Rail Temperature Zones and RDSO Studies:

(a) 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.

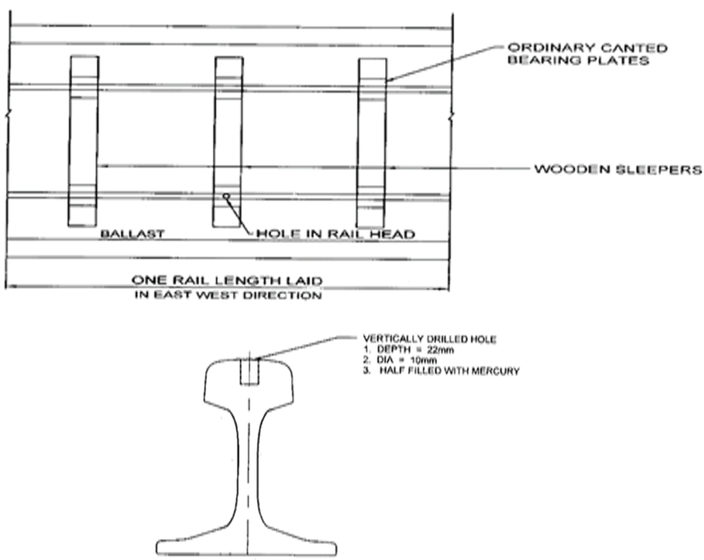


Fig. 2.2: standard measuring arrangement for rail temperature

(b) 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 temperature and air temperature were derived using a computer-based regression analysis (Details available in RDSO/C/146) 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.

(c) The maximum daily variation of rail temperature and the mean rail temperature (t_m) for the section shall be ascertained from the temperature records available with the SSE/P.Way(In-charge) or as built up as per Para 2.3.1 (a) (v) (1) above and available on TMS.

(d) 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. 2.3 below), shall be adopted.

2.3.3 Rationale behind choice of t_d

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

Refer to table in S.No.6 of Chapter 1. It shows the maximum, minimum and 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 the range between maximum and minimum rail temperatures.

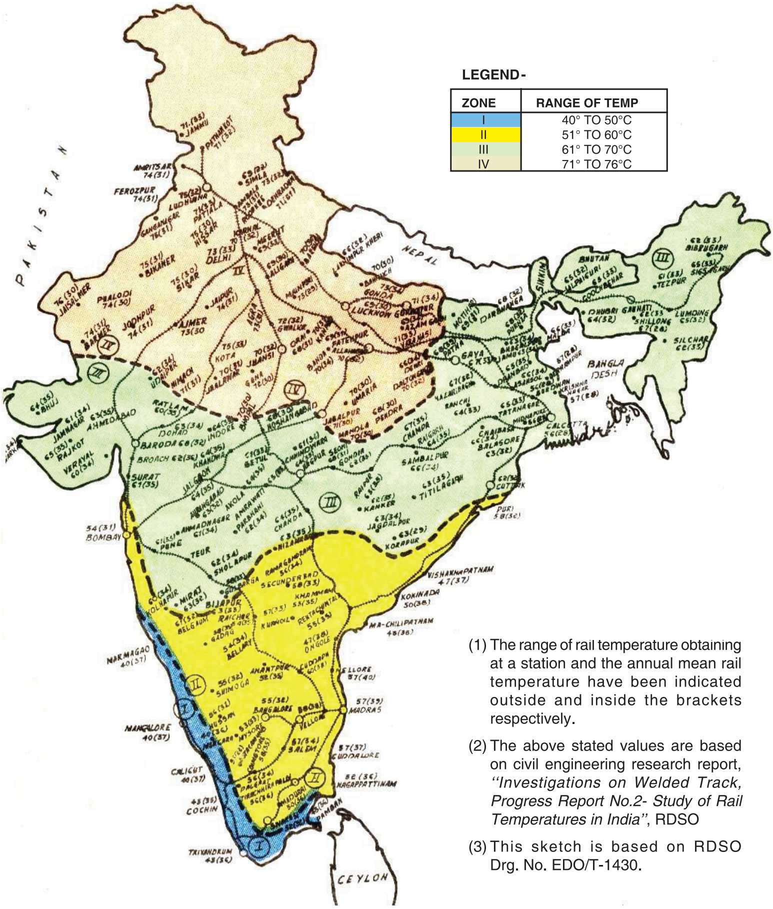
1. Let us see what happens if we fasten the rail to the sleeper at the minimum rail temperature (t_{min}). As the rail temperature rises, compressive thermal forces will be built up and when the rail temperature reaches t_{max} compressive forces proportional to the full range of rail temperature will 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.

Thus, If $t_d = t_{min}$, then t_2=0, Tensile force = 0, t_1 = R

compressive force = AEα(R)

Where R = Range & Temperature



The Rail temperature Range = Max Rail temperature – Min Rail Temperature

Mean Rail Temperature = (Max Rail temperature + Min Rail Temperature) / 2

Fig 2.3 – Map of India showing Rail Temperature Zones

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 this case there is of course no danger of any compressive force developing in the rail and consequently of any buckling tendencies either.

Thus, If $t_d = t_{max}$ then $t_1 = 0$, Comp. force = 0, $t_2 = R$

Tensile force = $AE\alpha(R)$

Where R in the temperature range

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.

Thus, If $t_d = t_m$ then $t_1 = t_2 = R/2$,

so compressive force = Tensile force = $AE\alpha$ (R/2)

Where R in the temperature range

So, when t_d is fixed at t_m, same magnitude of compressive forces and tensile forces are bound to develop and so the possibility of buckling as well as fracture will exist, in equal measure.

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. The other track parameters such as Gauge, cross-level, packing etc., are also not greatly disturbed. Thus at least a few trains may pass over a fractured rail without accident till the fracture is attended to.

However, if the track buckles due to excessive compressive forces in the rail, alignment of track gets distorted. The other track parameters such as cross-level, surfacing, packing etc., are likely to be very badly distorted and safe running of trains is endangered, significantly more vis-à-vis the case of a rail fracture.

Therefore, considering that buckling is 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 would be within reasonable limits, though at the cost of introducing higher tensile forces. See Fig 2.4 below. This is the basis for fixing t_d on the Indian Railways at a temperature above t_m.

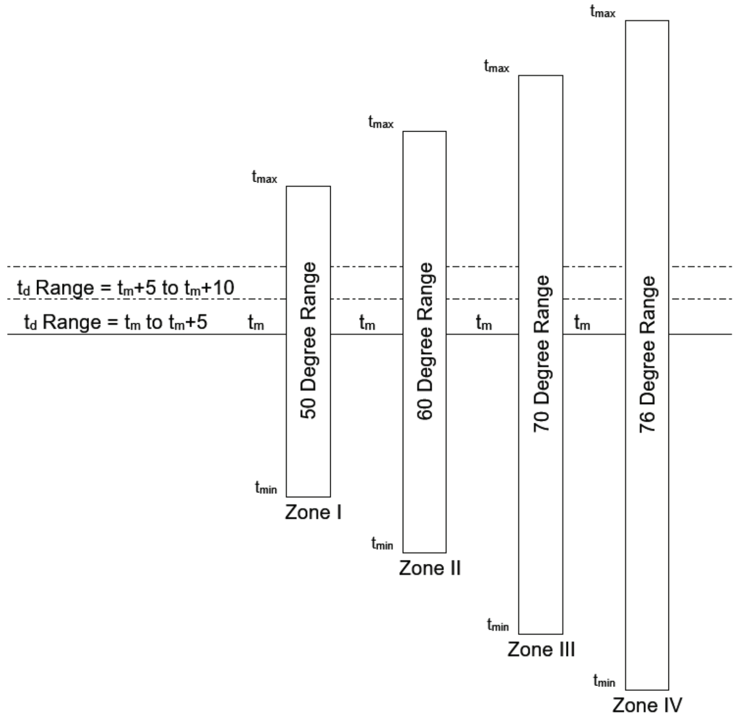


Fig. 2.4: Variation of Temperature with respect to td In Different Zones.

5. Thus, the t_d on I.R is fixed accordingly as under:

ZONE-I, ZONE-II, ZONE-III	t_m to t_m+5°C
ZONE-IV 52 kg & higher Section	t_m+5°C to t_m+10°C
ZONE-IV Other sections	t_m to t_m+5°C

Heavier sections i.e. 52 kg and 60 kg rails having greater sectional area, relatively larger thermal tensile compressive force will be developed, which will have to be resisted by same ballast resistance and so t_d for these rails has been fixed between t_m + 5 and t_m + 10°C in Zone-IV where temperature range is maximum i.e., 76°C, however for Zone-I, II, III t_d is fixed at t_m to t_m+5, so as to control tensile force in the winter as rail/weld fractures in last few years have caused number of serious accidents. Therefore it has been considered prudent to keep t_d within t_m to t_m+5 temperature range.

ZONE	Zone-I	Zone-II	Zone-III	Zone-IV	
Max. temperature Range	50	60	70	76 (other Sections)	76 (52 Kg & higher sections)
Destressing Temperature 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. temperature range that can be expected	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 $t_d = t_m + 5$ $t_{max} = t_d + 33$ $t_{min} = t_d - 43$
	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 $t_d = t_m + 10$ $t_{max} = t_d + 28$ $t_{min} = t_d - 48$
Maximum range in all possibilities	+25 to -30	+30 to -35	+35 to -40	+38 to -43	+33 to -48

2.4 Breathing Length

2.4.1 As discussed earlier, the force build up in the LWR starts in the breathing length at the free end. The tendency of the rail sleeper assembly to expand or contract is resisted by the resistance of the ballast called the longitudinal ballast resistance. It is denoted by R and its unit of measurement is in kg/metre/rail. The longitudinal ballast resistance is mobilized when there is a relative movement between the sleeper and the ballast. If L_b is breathing length and R the longitudinal ballast resistance, then L_b x R represents the total resistance offered by the ballast in the breathing length.

The maximum force in the LWR = $P = AE\alpha t$

Thus, implying that $L_b \times R = AE\alpha t$ or $L_b = AE\alpha t/ R$

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

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

b) The larger the cross-sectional area of the rail, the larger the breathing length.

c) The larger the value of 'R' the longitudinal ballast resistance, the smaller 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, for the same rail section.

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)

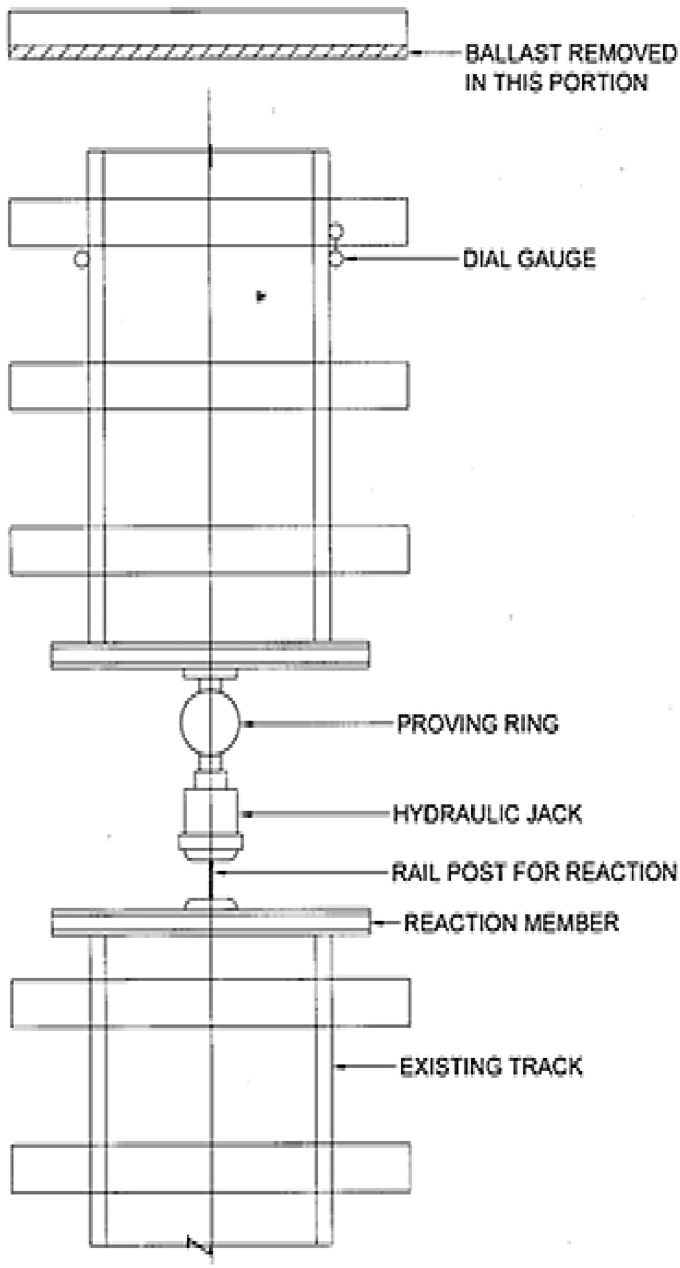


Fig 2.5 – Setup for Studying Longitudinal Ballast Resistance

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.

Findings of the study:

1. In BG, PRC sleepers give the highest longitudinal ballast resistance in all conditions. In consolidated and through packed conditions other sleepers in order of decreasing longitudinal resistance are: Steel, CST-9 and Wooden. In deep screened or freshly laid track, the order is PRC, Steel, Wooden and CST-9.
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.
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 to 1500 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.

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 build-up 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.

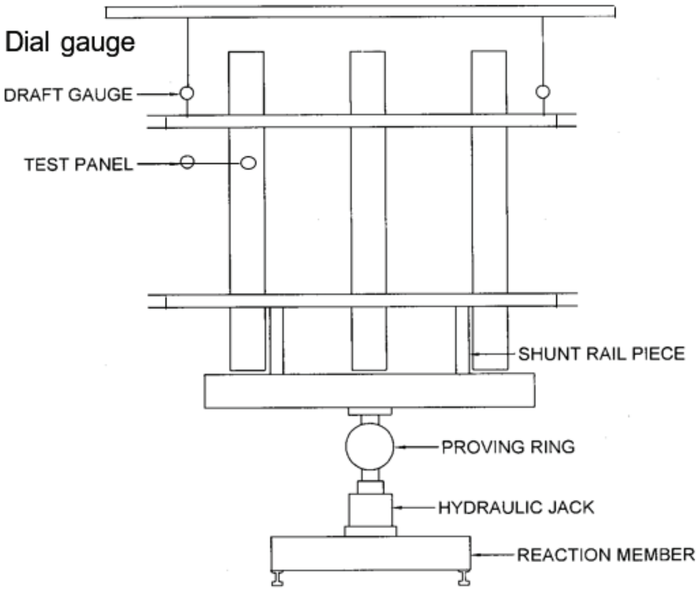


Fig 2.6 – Setup for Studying Lateral Ballast Resistance

Values of Lateral Ballast Resistance in Kg/m of track Adapted from RDSO/C-156

BG Sleeper	Consolidated	Through packed	Deep Screened
PSC	1470	1226	1040
Reduction Over		=(1470-1226)/1470 = 16.6% Reduction	=(1470-1040)/1470 = 29.25% Reduction

Tests conducted have revealed that:

Track surfacing and ballast tamping even with a minor amount of rail lift (12 to 25mm) 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.

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CHAPTER III
THERMAL MOVEMENTS AND HYSTERESIS

3.1 Estimation of Thermal Movements

It is only in the breathing lengths that a 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 portion, 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.

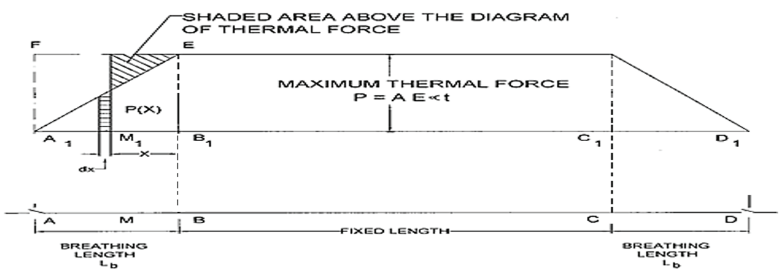

Fig. 3.1 – Estimation of Thermal Movements

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°C = dx α t.

ii) The amount of contraction of this length dx, is equal to <u>P(x) dx / AE</u>

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

iii) 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

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

iv) 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

$$Y = \int_0^x dy = \frac{1}{AE}\int_0^X (P - PX)\, dx$$

v) It can be observed from Fig. 3.1 that the expression (P-Px)dx is nothing but the area of the shaded diagram appearing above the diagram of thermal force.

v) 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, up to 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' =

(Area of Triangle A_1FE) / AE

= 1/2 x (PL_b / AE ....(Equation 1)

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

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

vii) Therefore, the maximum movement of the end of the LWR is half the corresponding value if only the breathing length L_b 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.

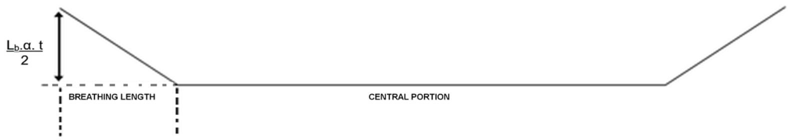

Fig 3.2 Variation of Movement in breathing length

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

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

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: PSC, Rails: 52kg ($A=66.15cm^2$) Sleeper density 1540 sleepers/km, Zone IV with temperature range $=76^0C$

R taken as, say, 13.28 kg/cm/rail, $A = 66.15\ cm^2$, $E = 2.11 \times 10^6\ kg/cm^2$, $td = tm + 10^0C$

$t_{max} = 28^0C$ for temperature rise, $t_{min} = 48^0C$ for temperature fall

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

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

For a temperature rise of 28^0C,

$$\Delta_1 = \frac{66.15 \times 2.11 \times 10^6 \times (1.152 \times 10^{-5} \times 28)^2}{2 \times 13.28} = \Delta_1 = 5.46\ mm \quad \text{(Expansion)}$$

For a temperature fall of 48^0C

$$\Delta_2 = \frac{66.15 \times 2.11 \times 10^6 \times (1.152 \times 10^{-5} \times 48)^2}{2 \times 13.28} = \Delta_2 = 16.07\ mm..\text{(Contraction)}$$

Total movement at the SEJ joint = 2 x (5.46 + 16.07) = 2 x 21.53 = 43.06mm

The movements which occur at the SEJ due to thermal variations are shown in Fig. 3.3 (A, B, C) with values as calculated in the above example.

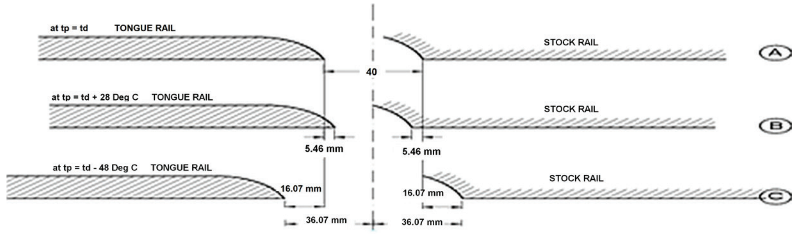

Fig 3.3 Movement at SEJ

3.2 Switch Expansion Joints (SEJ)

The thermal movement in the breathing length of LWR are accommodated at the switch expansion joint (SEJ). An SEJ typically consists of a pair of tongue rails and stock rails. Conventionally, 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.

The distance between the tip of the tongue rail and notch of the stock rail is typically kept as 40mm at the destressing temperature. Earlier the gap used to be 60mm and has now been reduced to 40mm considering the improvement in track resistance values due to upgradation of track structure from Wooden / ST / CST-9 sleepers to the present-day PSC sleepers.

Conventional SEJ : -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, 300 mm wide. Since in these Conventional SEJs, tongue rails and stock rails have typically straight alignment and hence these SEJs cannot be laid in curves sharper than 0.5^0. 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. 3.4 gives details of a typical SEJ layout and its spacing.

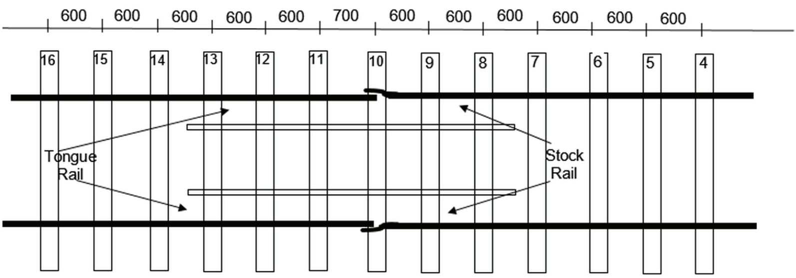

Fig 3.4 Conventional SEJ

The conventional SEJ design involves two bends in the stock rail and tongue rail which are locations of weakness resulting in fractures.

Improved SEJ : Improved design SEJs (earlier developed by various industries) have been adopted on Indian Railway. A brief description of these layouts is given below:

1) SEJ with one gap : 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 of 80mm between the juxtaposed rail ends. (Fig 3.5)

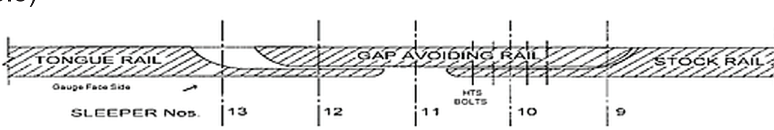

Fig 3.5 single gap SEJ

A third rail called a gap avoiding rail of predetermined length (now deemed not required) 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.

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 (called Gap avoidance rail) guard against excessive play of worn out wheels. This Gap avoidance rail is now not necessary and since been removed.

2) SEJ with two gaps :

In this design, two gaps of maximum 65 mm each are provided in one SEJ. Thus, a maximum gap of 65 mm is available for an LWR on one side of the SEJ. Similarly, a gap of 65 mm 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.

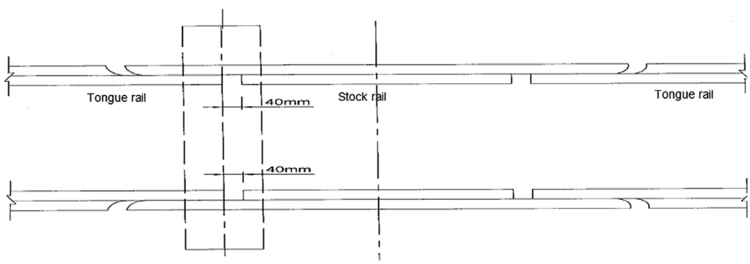

FIG 3.6 double gap SEJ

Salient features of Double gap Improved SEJ (Fig 3.6)

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.

Note: - * Dimensions subject to changes

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 rest 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 (but tip of tongue rail is kept 20 mm from the reference line).
5. The tongue rails are kept at mean position at centre line of sleeper Nos. 12 & 22 and stock rail end kept at 20 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 and for both the gaps.

3.3 Gap measurements at an SEJ

At the SEJ, a reference line is established between the tongue rail and stock rail by erecting rail pegs embedded in Concrete / Mortar on the cess. The mean position of stock / Tongue rail (as the case may be) shall be always be maintained by ensuring stock rail corner or tongue rail tip is kept at 20 mm from the reference line.

The measured distances from the reference line to stock / tongue rail (as the case may be), called as Gaps g_1 and g_2 (Fig 3.7 below) are not discrete values but the permissible range as defined in IRPWM Annexure 3/9 for different track structures, different zones and different prevailing temperatures.

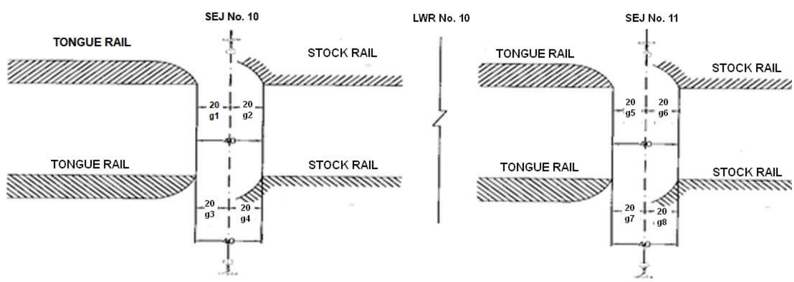

Fig. 3.7 gap measurement at an SEJ

3.4 Phenomenon of Hysteresis

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

As the temperature uniformly rises above 'O' (after the destressing), the movement or expansion at the SEJ follows the movement – temperature rise curve OC where

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

At any given temperature t_4 if the temperature starts falling, then the movement at the SEJ does not follow the original path but traces out a new curve A_2DB_2.

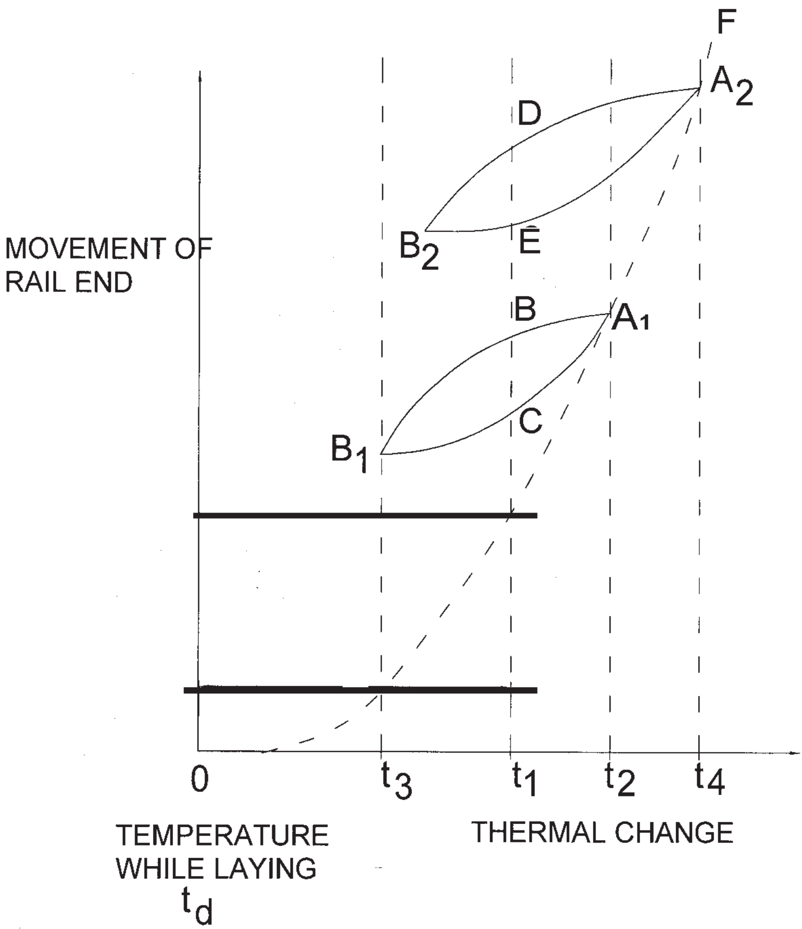

Fig 3.8 hysteresis phenomena

If at B_2 the temperature again reverses then the path traced out is B_2EA_2 rather than B_2DA_2. Loops in the form $A_2DB_2EA_2$ are called hysteresis loops and are formed whenever there is a temperature reversal. Such loops form all the time, throughout the year and each loop is different from the other based on the temperature ranges prevailing at that given time range, thereby giving rise to multiple such loops in a year. 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 behaviour 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 3.9 here under

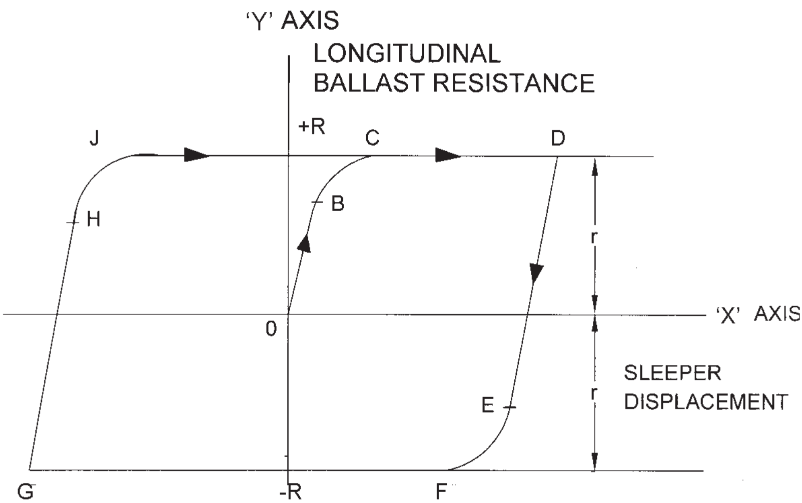

Fig 3.9 - Resistance offered by the ballast vis-à-vis the sleeper displacement

The ballast resistance first increases linearly as 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 temperature the ballast resistance mobilized is 2R. Due to this effect, the path traced out at the end of LWR follows an irregular path leading to the hysteresis phenomenon.

This hysteresis loop can be traced in two ways:

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

In this context, it is further to be emphasized that, in fact, 4 possible combinations of hysteresis loops needs to be considered because destressing temperature 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 criterion for t_d is as under:

Zone IV 52 kg & higher section : t_m+5 to t_m+10

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 temperature range of t_m+5 to t_m+10, accordingly the t_{max} & t_{min} shall vary as under (Fig 3.10):

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 tm +10, t_{min} will go up to t_d - 48 & t_{max} will go up to t_d +28.

On over all basis, the movement at SEJ 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.

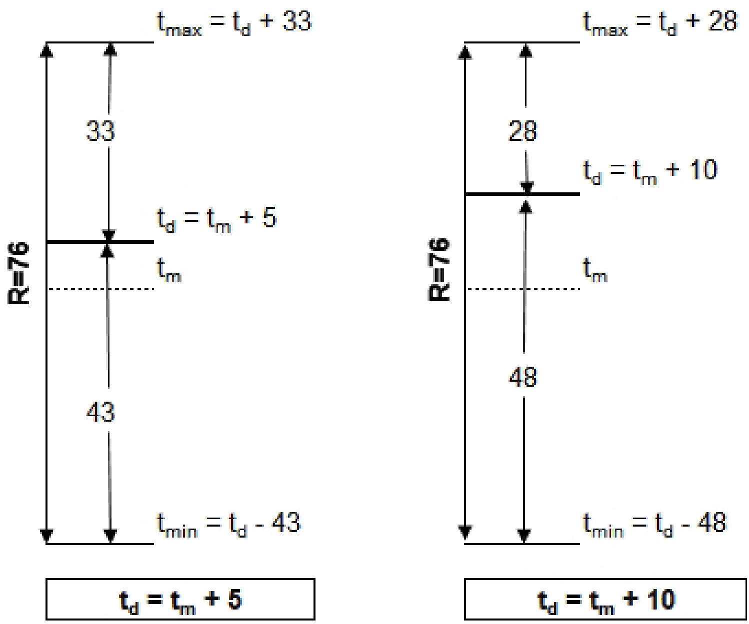

Fig 3.10 – Example for Fixing of t_d

It is accordingly brought out that 4 hysteresis loops are 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 : Temperature variation starts with lowering of temperature up to $t_{min} = t_d - 43$, after destressing (when t_d is fixed at t_m+5)

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

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

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

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 four hysteresis loops as drawn above.

Implications of hysteresis:

At temperature 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. IRPWM Annexure 3/9 gives the permissible range of gaps at the SEJ for different track structures at different rail temperature for different Zones as given here under for 52Kg/60 Kg rails on PSC sleeper with Sleeper density of 1540 or 1660

3.5 Gap between Reference Mark & Tongue Rail Tip/Stock Rail Corner of SEJ

3.5.1 Gaps between the Reference Mark & Tongue Rail Tip / Stock Rail Corner of SEJ for various Temperatures in °C in mm.

FOR BG, PSC SLEEPER, Zone-I

Rail	**60 kg/m**		**52 kg/m**	
Sleeper Density	**1660**	**1540**	**1660**	**1540**
Ballast Resistance (kg/ cm/rail)	**12.98**	**11.76**	**12.98**	**11.76**
t_d + 25°	15	14	16	15
t_d + 20°	15 to 17	14 to 17	16 to 18	15 to 17
t_d + 15°	15 to 19	15 to 19	16 to 19	15 to 19
t_d + 10°	16 to 21	15 to 21	16 to 21	16 to 21
t_d + 05°	16 to 22	16 to 23	17 to 22	17 to 22
t_d	17 to 24	17 to 24	18 to 23	18 to 24
t_d - 05°	19 to 25	18 to 25	19 to 24	19 to 25
t_d - 10°	20 to 26	20 to 26	20 to 25	20 to 26
t_d - 15°	21 to 27	22 to 27	21 to 26	21 to 26
t_d - 20°	23 to 27	24 to 28	23 to 26	23 to 27
t_d - 25°	25 to 27	26 to 28	24 to 26	25 to 27
t_d - 30°	27	28	26	27

FOR BG, PSC SLEEPER, Zone-II

Rail	60 kg/m		52 kg/m	
Sleeper Density	**1660**	**1540**	**1660**	**1540**
Ballast Resistance (kg/cm/rail)	**12.98**	**11.76**	**12.98**	**11.76**
$t_d + 30°$	13	12	14	13
$t_d + 25°$	13 to 15	12 to 15	14 to 16	13 to 15
$t_d + 20°$	13 to 18	12 to 17	14 to 18	13 to 18
$t_d + 15°$	13 to 20	13 to 20	14 to 20	14 to 20
$t_d + 10°$	14 to 22	14 to 22	15 to 22	14 to 22
$t_d + 05°$	15 to 24	15 to 24	16 to 23	15 to 23
t_d	16 to 25	16 to 26	17 to 24	16 to 25
$t_d - 05°$	18 to 26	17 to 27	18 to 26	18 to 26
$t_d - 10°$	19 to 28	19 to 28	19 to 27	19 to 27
$t_d - 15°$	21 to 28	21 to 29	21 to 27	21 to 28
$t_d - 20°$	23 to 29	23 to 30	22 to 28	23 to 29
$t_d - 25°$	25 to 30	26 to 31	24 to 28	25 to 29
$t_d - 30°$	27 to 30	28 to 31	26 to 29	27 to 30
$t_d - 35°$	30	31	28 to 29	29 to 30
$t_d - 40°$	-	-	-	-

FOR BG, PSC SLEEPER, Zone-III

Rail	60 kg/m		52 kg/m	
Sleeper Density	**1660**	**1540**	**1660**	**1540**
Ballast Resistance (kg/cm/rail)	**12.98**	**11.76**	**12.98**	**11.76**
$t_d + 35°$	10	9	11	10
$t_d + 30°$	10 to 13	9 to 12	11 to 14	10 to 13
$t_d + 25°$	10 to 16	9 to 15	12 to 16	11 to 16
$t_d + 20°$	11 to 18	10 to 18	12 to 19	11 to 18
$t_d + 15°$	12 to 21	11 to 21	13 to 21	12 to 21
$t_d + 10°$	12 to 23	12 to 23	13 to 22	13 to 23
$t_d + 05°$	14 to 25	13 to 25	14 to 24	14 to 25
t_d	15 to 27	14 to 27	16 to 26	15 to 26
$t_d - 05°$	16 to 28	16 to 29	17 to 27	17 to 28
$t_d - 10°$	18 to 30	18 to 31	18 to 28	18 to 29
$t_d - 15°$	20 to 31	20 to 32	20 to 29	20 to 30
$t_d - 20°$	22 to 32	23 to 33	22 to 30	22 to 31
$t_d - 25°$	25 to 32	25 to 34	24 to 31	25 to 32
$t_d - 30°$	27 to 33	28 to 34	26 to 31	27 to 32
$t_d - 35°$	30 to 33	31 to 35	29 to 31	30 to 33
$t_d - 40°$	33	34 to 35	31	32 to 33
$t_d - 45°$	-	-	-	-

FOR BG, PSC SLEEPER, Zone-IV

Rail	60 kg/m		52 kg/m	
Sleeper Density	**1660**	**1540**	**1660**	**1540**
Ballast Resistance (kg/cm/rail)	**12.98**	**11.76**	**12.98**	**11.76**
t_d + 33°	11	10	12 to 13	11 to 12
t_d + 30°	11 to 13	10 to 13	12 to 14	11 to 14
td + 28°	11 to 15	10 to 15	12 to 16	12 to 15
td + 25°	11 to 17	10 to 17	12 to 17	12 to 17
t_d + 20°	12 to 20	11 to 20	13 to 20	12 to 20
t_d + 15°	12 to 23	12 to 23	13 to 22	13 to 23
t_d + 10°	13 to 25	12 to 26	14 to 24	14 to 25
t_d + 05°	14 to 27	14 to 28	15 to 26	15 to 27
t_d	15 to 30	15 to 31	16 to 28	16 to 29
t_d - 05°	17 to 31	17 to 33	17 to 30	17 to 31
t_d - 10°	19 to 33	18 to 34	19 to 31	19 to 32
t_d - 15°	21 to 35	21 to 36	20 to 33	20 to 34
t_d - 20°	23 to 36	23 to 37	22 to 34	22 to 35
t_d - 25°	25 to 37	25 to 39	24 to 35	25 to 36
t_d - 30°	27 to 38	28 to 40	26 to 35	27 to 37
t_d - 35°	30 to 38	31 to 40	29 to 36	29 to 37
t_d - 40°	33 to 39	34 to 41	31 to 36	32 to 38
t_d - 43°	34 to 39	36 to 41	32 to 36	34 to 38
t_d - 45°	36 to 39	37 to 41	33 to 36	35 to 38
t_d - 48°	37 to 39	39 to 41	35 to 36	37 to 38

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CHAPTER IV
PERMITTED LOCATIONS AND TRACK STRUCTURE

4.0 General Considerations for Laying LWR/CWR

Complete Track renewals: As a rule, Primary complete track renewals shall provide for LWR/CWR wherever permissible by the provisions of IRPWM. 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) / Flash Butt Process, as the case may be.

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

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 having stipulated formation width.

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:

a) The minimum depth of the ballast cushion below the bottom of the sleepers at the rail seat for BG should be 300mm. 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) with PSC sleepers

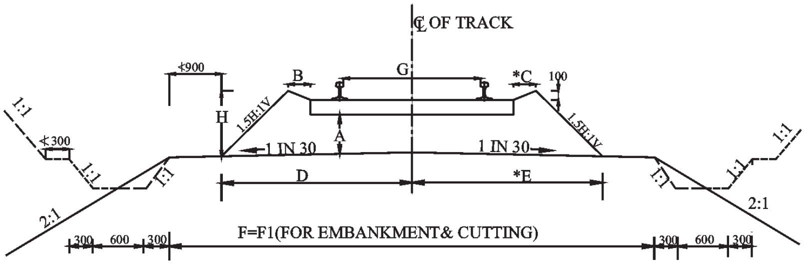


Fig. 4.1 (a)

A	B	C*	D	E*	F	H	Quantity of Ballast per meter in M3	
							Straight Track	Curved Track
250	350	500	2693	2851	7850	646	2.030	2.120
300	350	500	2772	2930	7850	698	2.304	2.401
350	350	500	2851	3009	7850	751	2.585	2.690

Note:

1. *Depth of ballast cushion should be provided as per Para 212(2) of IRPWM.*
2. *Cross-Slope of 1 in 30 shall be provided for New Works.*
3. *Minimum Formation width of 7850 mm shall be ensured for new works in both embankment and in cuttings (excluding side drains).*
4. *Suitable dwarf walls shall be provided in case of cuttings, if necessary, for retaining ballast.*
5. **On outer side of curves only.*
6. *Super elevation has not been considered in calculation of ballast quantity for curved track.*
7. *The cess width on existing track is to be increased on programmed basis wherever required so that minimum cess width as per side slope given above is ensured.*
8. *All dimensions are in mm.*

Ballast Profile (BG Double line in embankment/cutting) with PSC sleepers

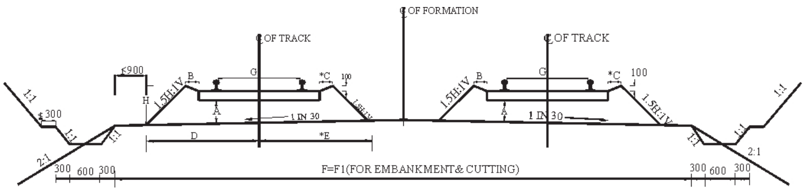


Fig. 4.1 (b)

A	B	C*	D	E*	F	H	J
250	350	500	2785	2943	13160	707	5300
300	350	500	2864	3022	13160	760	5300
350	350	500	2943	3101	13160	812	5300

Note:

1. *Depth of ballast cushion should be provided as per Para 212(2) of IRPWM.*
2. *Cross-Slope of 1 in 30 shall be provided for New Works.*
3. *Minimum Formation width of 13160 mm shall be ensured for new works in both embankment and in cuttings (excluding side drains).*
4. *In doubling work of existing lines, cross-slope of 1 in 40 in existing old formation need not be disturbed.*

   However, the cross slope of 1 in 30 shall be provided in widened formation width, newly constructed for doubling.
5. *Suitable dwarf walls shall be provided in case of cuttings, if necessary, for retaining ballast.*
6. **On outer side of curves only.*
7. *Super elevation has not been considered in calculating various dimensions.*
8. *The cess width on existing track is to be increased on programmed basis wherever required so that minimum cess width as per side slope given above is ensured.*
9. *All dimensions are in mm.*

4.3 Rail, Sleepers & Fastenings

(1) Type of sleeper: Broad Gauge: Concrete sleepers / Ballastless track with elastic fastenings. The minimum sleeper density for all track renewals (Complete Track Renewal / Through Sleeper Renewal), Doubling, Gauge Conversion, New Line construction works for main lines shall be 1660 per km and for loop lines & sidings (permissible speed up to 50 Kmph) it shall be 1540 per km. For sidings with permissible speed more than 50 Kmph minimum sleeper density shall be 1660 per km.

Note: Higher sleeper density may be provided with approval of Principal Chief Engineer.

(2) RAILS

(a) Minimum rail section to be used shall be 52kg/m in B.G.

(b) (i) In an LWR/CWR, two different rail sections are not permitted.

(ii) In case of LWRs laid on concrete sleepers having different rail section on either side of SEJs, combination SEJ to RDSO Drg. No T-6782 (52kg / 60 Kg) shall be provided.

(iii) Alternatively, two 3 rail panels (39 m), one of each rail section shall be provided with combination fish plated joint, between the two panels.

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 4.2 below

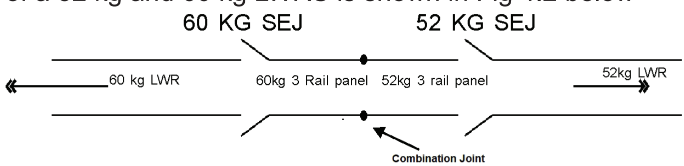


Fig.4.2

The above arise mostly due to TRR work with different rail section than existing. In such cases, the LWR shall be bifurcated into two different LWR's by providing SEJ as above. It is because of the thermal forces generated in rails of different cross-sectional areas are different. This makes the behavior of the LWR non uniform.

(c) New rails used in LWR/CWR shall, as far as possible, be without fish-bolt holes.

(d) Joining of rail ends temporarily during installation of LWR/CWR shall be done by 1m long fishplates with special screw clamps/ joggled fish-plates having slotted grooves & bolted clamps as per IRPWM with speed restrictions indicated in Annexure - 3/8 of IRPWM.

(e) Bolt holes, if any, shall be chamfered.

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

4.4 General Precautions while laying LWR

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.

iii) 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 by 1-meter long fishplates with special screw clamps/joggled fish-plates having slotted grooves & bolted clamps.

4.5 Continuity of track structure for LWR

(a) 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.

(b) Level Crossing: Level crossings situated in LWR / CWR territory shall not fall within the breathing lengths

(c) Continuity on Points and Crossings: In case, LWR is terminated near Points & Crossings, one three rail panel (39 m) shall be provided between stock rail joint (SRJ) and SEJ as well as between the crossing and SEJ. This length shall be provided with elastic fastenings with adequate toe load to arrest creep.

(d) In case, LWR/CWR is taken through Points & Crossings, the provisions contained in RDSO report no. CT-48 shall be followed. In order to reduce number of fish plated joints, it is preferable to continue LWR through turnout by using weldable CMS crossings. The salient features of RDSO Report CT-48 are summarised herein under for ready reference:

Salient points of RDSO CT-48 report on Continuation of LWR through Turnouts

1) On Indian Railway system, station yards are located at an interval of 8-10 km. With a view to eliminate free joints from track, it is desirable to continue LWR through turnouts, thereby improving the safety on turnout and yard. This will also improve running on turnouts, enhance passenger comfort. The wear and tear due to lesser impact would get reduced and the problem of working out of liners, rubber pads and ERCs at joint sleepers will also be taken care of.

2) On most of the main lines of important routes of IR, 60kg Turnouts are being used. Weldable CMS crossing enables welding of such crossings with adjacent rails (including the Tongue rails) and allows continuation of LWR through crossing portion without any discontinuity.

3) Thus, the arrangement of 1 in 12 turnout with the use of Thick Web Switches (TWS) & Weldable Cast Manganese Steel Crossing (WCMSC) for 60kg on PSC Sleepers with special arrangements is suggested for CWR. Fastenings with Elastic Rail Clips Mk-V in the complete turnout zone and up to four adjacent rail lengths on either side of turnout, with Specially designed creep arresting device (ACD) with HTS bolts and nuts between Sleeper no. 22 & 23 in switch portion of turnouts are suggested. The joints of tongue rail with lead rail and that at heel & toe ends of crossing to be welded. Spring Setting Device (SSD) to be used at junction of rail heads (JOH). Check rail to be kept same as fabricated of standard 60kg (UIC) rail section and connected to running rail through check rail blocks.

4) Based on the calculations of thermal force within the breathing length portion on the two inner lead rails welded to the two tongue rails, it is estimated that about 110 sleepers (60 to 70 metres) from ATS towards crossing portion is expected to be the breathing length and is the most critical length in the P&C zone which needs special monitoring. This length needs to have effective fittings to counteract the forces in the P&C. This

can be achieved by use of ERC Mk-V with adequate toe load.

5) Thus, within the breathing length portion consisting of both the tongue rails and the connected inner lead rails and the WCMSC, the tongue rails are free to expand/contract up to Heel block and the lead rails from Heel to the Toe of Crossing portion is restrained, but not adequately, for expansion and contraction with variation in temperature. The maximum expansion/contraction of inner lead rails (connected to the two tongue rails) from mean position is theoretically calculated to be 11.02mm to 20.87 mm. For detailed calculations, RDSO report CT – 48 may be referred.

6) Actual Movement of tongue rails (measured at ATS) is likely to be less as Turnout sleepers are longer and heavier, therefore actual ballast resistance will be more than that considered in the calculations for the plain track. In addition, creep anchors are also proposed to be used in tongue rail portion of turnouts which permit for movement of 14mm only.

7) LWRs may be continued through turnouts, with following arrangements on Main Line:

   a) Track structure should consist of minimum 60kg/90 UTS rails, PSC sleeper with ERC Mk-V and sleeper density 1660 per km in LWR portion. Sleeper arrangement in turnout portion shall be as per standard layout.

   b) Use of Thick web switches laid on PSC sleepers with elastic fastenings and 25 mm dia bolts in heel and distance blocks.

   c) Use of ERC Mk-V in the complete LWR including turnout.

   d) Use of a specially designed creep arresting device / creep anchors behind heel of switch in tongue rail portion of turnouts. (For details, please refer RDO report CT-48). This arrangement will act as a tell-tale indicator for creep in lead / switch portion enabling any abnormal behavior to be noticed by P.Way officials.

   e) Use of weldable CMS crossing.

   f) Welding of tongue rail & lead rail joints.

   g) It shall be ensured that SEJs are provided in such a way that turnout shall not fall in breathing length zone.

   h) Ballast profile shall be maintained as per provisions of IRPWM. Minimum ballast cushion of 300mm shall be ensured in complete LWR through turnout. Minimum clean ballast cushion as per IRPWM would be maintained at all times. Stable formation and other provisions of LWR in IRPWM shall also be ensured.

i) It shall be ensured that there are Zero missing / loose fittings in complete LWR including turnout. Regular monitoring of toe load shall also be done and remedial measures be taken in case toe load is found to be less than 1000kg.

j) Deep screening should be done in the P&C portion as per provisions of IRPWM.

k) There is a need to measure movement of switch and crossing in field to ascertain behavior of LWR through P&C. Creep shall be monitored at the following locations by erecting creep posts at:

    i) Actual toe of switch (ATS) for stock rail & tongue rail tip.

    ii) Actual nose of Crossing (ANC).

    iii) Central portion of LWR as per provisions of IRPWM.

    iv) Centre of lead portion.

    v) 20m from ATS at approaches.

    vi) 50m beyond ANC at approaches.

l) A separate register should be maintained for measurement of creep and recording condition of fittings and fixtures of turnouts including unusual behavior, if any, every month by SSE (P.Way) and ADEN independently. Special monitoring is required in two hottest and coldest months to see the behavior of LWR through turnout.

m) Behavior of trial LWR on turnout (CWR) shall be kept under strict observation and performance be evaluated as per the provisions of the IRPWM. Suitable action be taken immediately on observing unusual behavior, if any and the same shall be reported to RDSO subsequently for necessary action.

n) The condition of bolts at Heel blocks, distance blocks in switch area ACD, and check rail blocks in crossing area needs to be monitored.

8 The Standard RDSO drawings, with the provision of Anti-Creep Device (ACD) as amended from time to time, shall be referred for details.

SN	Drawing No.	Description
1.	RDSO/T-8779	1in 12 turnout with 10125 mm Zu-1-60 thick web switch (curved) with anti creep device & weldable CMS crossing B.G. (1673mm) for 60Kg (UIC) on PSC sleepers.
2.	RDSO/T-8780	10125mm curved switch with Zu-1-60 thick web tongue rails and anti creep device for 1 in 12 turnout B.G. (1673mm) for 60Kg (UIC) on PSC sleepers.
3.	RDSO/ T-8780/1	Details of Zu-1-60 thick web tongue rails & 60Kg (UIC) stock rails with provision for anti-creep device for 10125mm curved switch B.G. (1673mm) for 60Kg (UIC).
4.	RDSO/T-8781	1 in 12 weldable cast manganese steel crossing B.G. (1673mm) for 60Kg (UIC) on PSC sleepers.
5.	RDSO/T-8782 & RDSO/T-8783	Anti creep device for 10125mm curved switch with ZU- 1-60 thick web tongue rails B.G. (1673mm) for 60Kg (UIC) on PSC sleepers.
6.	RDSO/T-8784 & RDSO/T-8785	Hardened Packing plate for anti-creep device for use with thick web switches for 60Kg (UIC).
7.	RDSO/T-8786 & RDSO/T-8787	27 dia. HTS Bolt & Nut for Anti creep device for use with thick web switches for 60Kg (UIC).

Note : *RDSO drawings above are subject to changes. Please refer the updated drawings.*

4.6 Alignment

General: Basic concepts involved on 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 danger. 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 high by at least P/R kg/m. Hence a larger shoulder width on outside of curves and a restriction on the degree of curvature is prescribed. On Broad Gauge a shoulder ballast width of 500mm on outside of curves has been adopted.

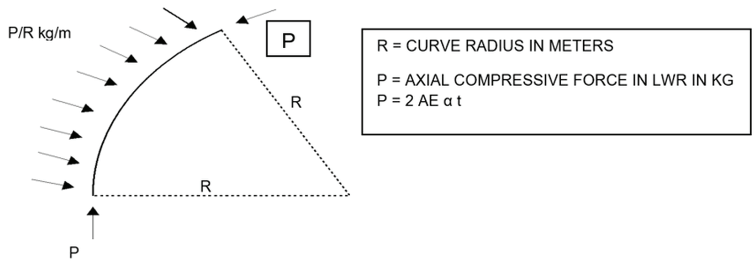


Fig. 4.3 (a) External Equilibrium of Curved LWR Track

(a) LWR/CWR shall not be laid on curves sharper than 440 m radius.

(b) However, in temperature Zone-I, LWR/CWR may be laid on curves up to 350 m radius (5^{o}Curve) with following additional precautions:

  (i) Minimum track structure should be 52 kg/m rails on PSC sleeper 1540/km sleeper density with 300 mm clean ballast cushion.

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

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

  (iv) Each curve of length greater than 250 m should preferably be provided with SEJ on either side. SEJ should be located in straight track at 100 m away from the tangent point.

(c) LWR / CWR may be continued through reverse curves. Shoulder ballast of 600mm over a length of 100 m on both side of the

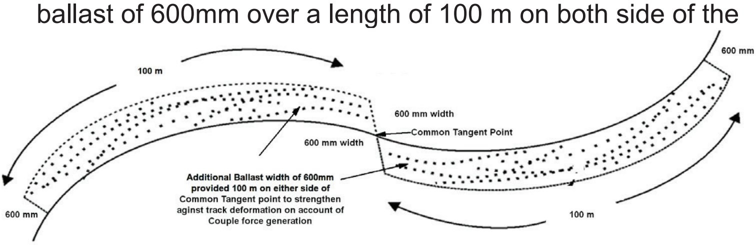


Fig. 4.3 (b)

common point of a reverse curve would be provided. In case there is a straight track between the reverse curves, this 100m would be considered from the center of the straight track. No such measure would be required if the length of straight track between the reverse curves is more than 50 m.

4.7 Gradient : The steepest permitted grade for LWR/CWR shall be 1 in 100.

(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)

4.8 Vertical Curve: A vertical curve shall be provided at the junction of the grades 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 417 of IRPWM so as to 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 Routes
Minimum radius	4000 meters	3000 meters	2500 meters

4.9 Location of SEJ

(1) The exact location of SEJ shall be fixed taking into account the location of various obligatory points such as level crossings, bridges, points and crossings, gradients, curves and insulated joints. The various designs of SEJs in use on Indian Railways are as per Para 225 of IRPWM.

(2) The conventional SEJ (RT-4160 and RT-4165) with straight tongue and stock shall not be located on curves sharper than 0.5° (3500 m radius).

(3) The improved SEJs (RT-6902, RT-6914, RT-6922, RT-6930) may be located on curves up to 2°.

(4) SEJ beyond 2° and up to 4° shall be laid with approval of CTE in RT-8926 (65 mm gap) for 60 kg RT-8924 (80 mm gap). These SEJ are manufactured for 2.5, 3.0, 3.5 and 4.0 degree curvature separately.

(5) The SEJ shall not be located on transition of curves.

4.10 IRPWM provisions pertaining to LWR on Bridges

4.10.1 General

In the preceding paragraphs, 4.1 to 4.9 and as discussed elsewhere in this book, the locations where LWR can be laid or permitted to be laid have been discussed. In summary, it is evident that for effective behaviour of LWR, the P force that is generated shall have to be counter-acted by the track Resistance R which is mobilised as a reaction to the P force.

It is also evident that for the R to be mobilised, all the 5 factors contributing to the creation / mobilization of R viz., (1) Rails, (2) sleepers, (3) consolidated Ballast, (4) fastening and (5) a stable formation acting together as a composite unit is a mandatory requirement. Thus, it is seen that the permitted locations as detailed in the various relevant paragraphs of the IRPWM are basically designed to keep the intricate balance between P and R as stable as possible so that LWR track remains in a stable condition.

However, the situation becomes a bit different when the issue of permitting LWR over a bridge is to be considered. The LWR can be required to pass through a bridge which can either be a

(a) ballasted deck bridge with normal toe load fastening system or

(b) girder bridge with zero toe load fastening system or

(c) girder bridge with specially designed toe load fasteners.

Let us now see the various scenarios that can be encountered at field in :

(a) ballasted deck bridge with normal toe load fastening system – this type of ballasted deck bridge can be

   (i) Without bearings or

   (ii) The bridge can be with any suitable type of bearings.

(b) girder bridge (without ballasted deck) is

   (i) Normally designed with Zero Toe Load fasteners

   (ii) Specially designed with fasteners with toe load.

Before the provisions in the IRPWM in connection with the above combinations are understood, a basic knowledge of behaviour / interaction of track on bridge is needed.

4.10.2 Basic concepts involved in laying LWR over bridges

(a) 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 and thus may be provided with bearings. On the other hand, the central portion of the LWR remains 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.

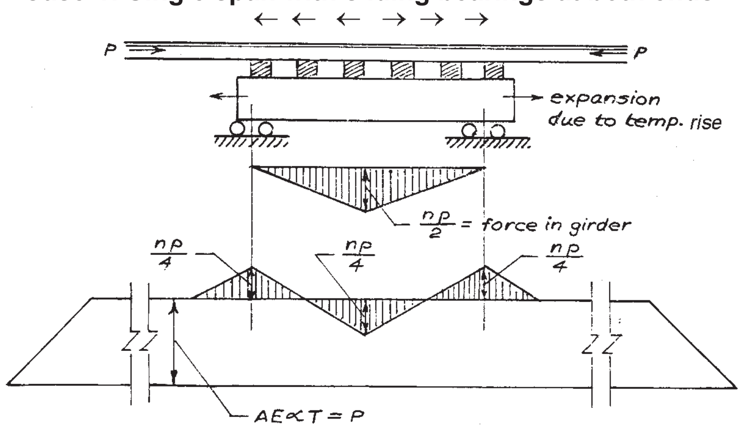
The magnitude of this force developed depends upon the value of ‘p’ (the creep resistance) and orientation/nature of the bearings provided in each span of the bridge.

The following cases are considered here under:

Single span bridge	a) Both ends of girder with free bearings.
	b) One end fixed; other end free.
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.

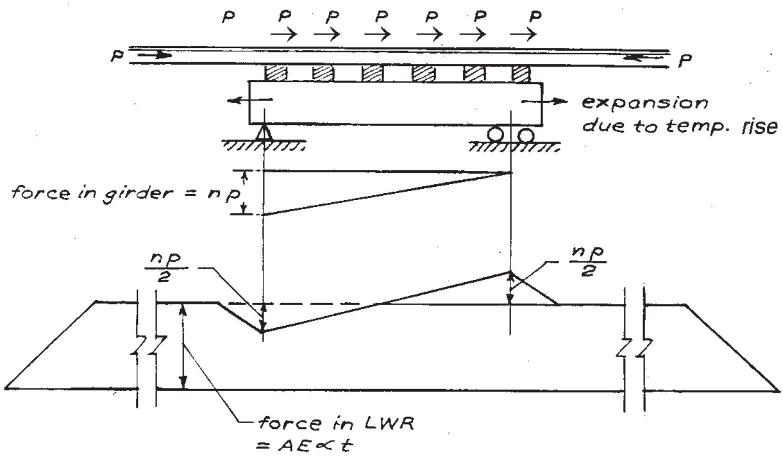


n = No. of sleepers per span
p = creep resistance per rail seat

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.

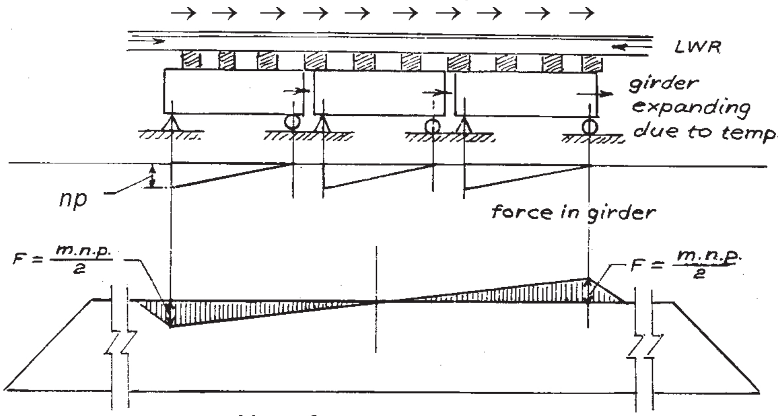


n = No. of sleepers per span
p = creep resistance per rail seat

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 dissimilar bearings on pier.

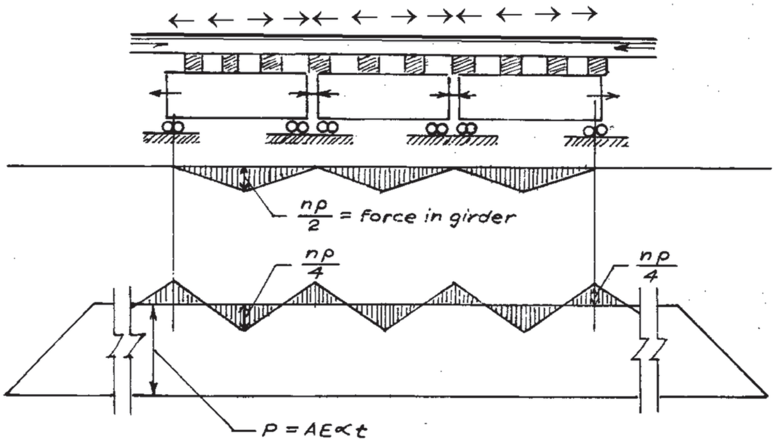


m = No. of spans
n = No. of sleepers per span
p = creep resistance per rail seat

Fig 4.4 (c)

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 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 free bearing at both ends.

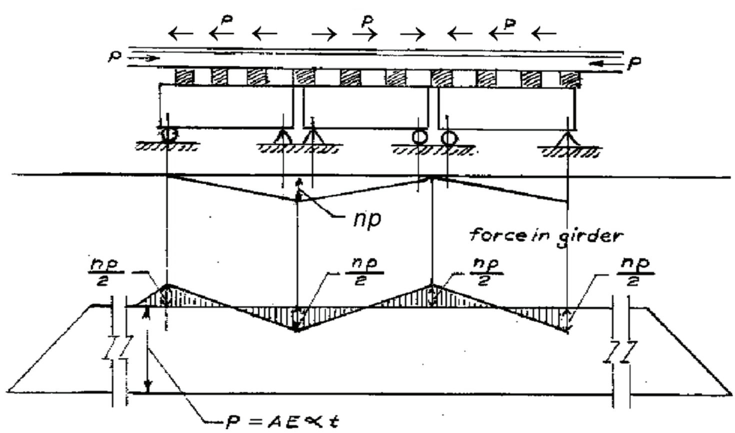


n = No. of sleepers per span
p = creep resistance per rail seat

Fig 4.4 (d)

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.

Case-5: Multiple span with pier support similar nature bearings.



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

Fig 4.4(e)

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 build-up of force

(b) **Use of Rail free fastenings :** 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. <u>It is with this assumption that the provisions for laying an LWR over bridges have been framed in the IRPWM.</u>

On Indian Railways, traditionally dog spikes and rail screws are used as rail free fastenings although now zero longitudinal restraint fastenings are used. 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.

(c) **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 B'F and C'F are formed on either side of the fracture location. (Fig 4.5) The gap g1 at the fracture location will be given by

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

[Assuming equal movement on either side of F]

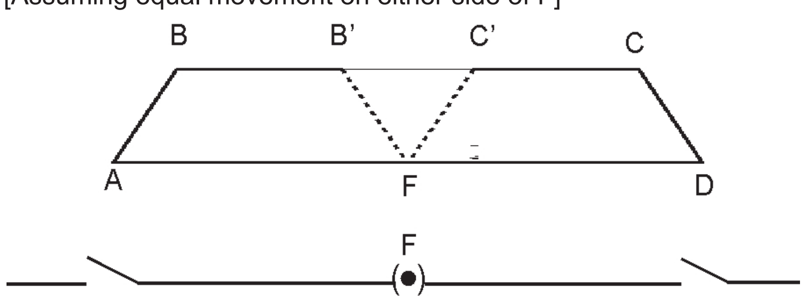


Fig 4.5 – Fracture on LWR on Normal Ballasted Track

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 had occurred 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 next page.

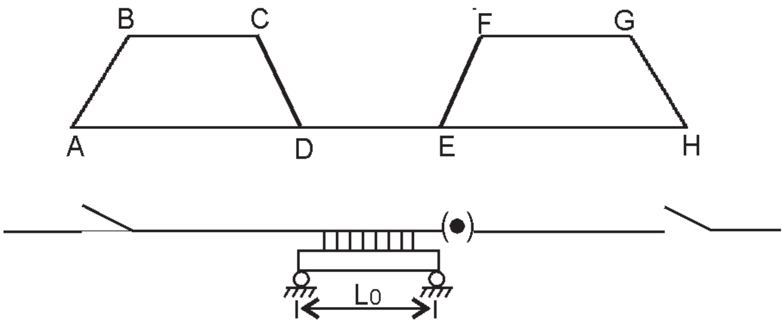


Fig 4.6 – Fracture on LWR on approach of Girder Bridge

In this figure, ABCDEFGH represents the altered force diagram.

Gap at fracture in this case will be

$$g_2 = \frac{AE(\alpha t)^2}{2R} X\ 2 + L_o.\alpha.t \qquad ......(ii)$$

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 50mm where by expression (ii) becomes

$$\frac{AE(\alpha t)^2}{2R} X\ 2 + L0.\alpha.t < 50\ mm \qquad ......(iii)$$

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.

<u>This equation (iii) forms the conceptual basis for the IRPWM provisions with regard to LWR on girder bridges</u> & over the years, attempts have been made to increase the value of L_0 by adopting various measures.

Measures to improve value of longitudinal ballast resistance on approaches to control movement of breathing length in the event of fracture: IRPWM Para 331 stipulates the measures to improve ballast resistance on bridge approach

Measures to control contraction of free rails on girder bridge in the event of fracture: IRPWM Para 331 also stipulates the measures to improve longitudinal resistance on bridge proper.

4.10.3 IRPWM provisions pertaining to LWR on Bridges

After having understood the intricacies of LWR on bridges as discussed in Paras above, various combinations possible of type of bridge with continuation of LWR over these bridges, the provisions of IRPWM in connection with the continuation of LWR over a bridge can be appreciated better and are as under:

(a) Para 329 of IRPWM - Bridges with Ballasted Deck (without bearing) : LWR/CWR can be continued over bridges with ballasted deck without bearings like slabs, box culverts and arches.

Explanation : In the above case where the bridge is having ballasted deck, all the components required for the mobilization of track resistance, i.e., Rails. Sleeper, ballast, fittings (with toe load) are available with the function of the formation being played by the immovable deck slab. Such a scenario is possible in cases of small slab bridges, Arches, box culverts etc. In case of bridge without bearings, bridge is not free to expand and contract hence there is no appreciable displacement between track and bridge so the interaction of forces between track and bridge is minimal. Thus, normal track conditions of P force being counteracted by the mobilized R is observed, thus, LWR can be continued without any restrictions.

4.10.4 Track Bridge Interaction based on UIC 774-3R report:

<u>This is also known as Rail Structure Interaction (RSI) Study</u>

(a) Introducing a bridge (with bearing) under a LWR track means effectively that the LWR 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.

(b) All actions which lead to interaction effects are those that cause relative displacement between the track and the deck. These are:

i) Thermal expansion of the deck only in the case of the LWR 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.

c) The forces induced due to interaction between track and bridge are dependent on a number of parameters of bridge and track both.

4.10.4 (I) Bridge parameters affecting the interaction forces are:

(i) 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.

(ii) 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 (Fig 4.7 below).

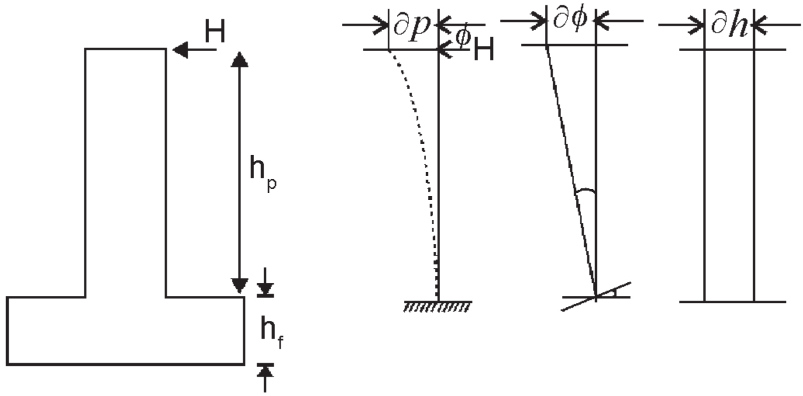


Fig 4.7 – Support Stiffness

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 $\partial i = \partial p + \partial \varphi + \partial h + \partial a$

Where, $\partial \rho$ = displacement at the head of the support due to deck's deformation

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

$\partial \varphi$=displacement at the top 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 4.7

(iii) 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.

(iv) 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.

4.10.4 (II) 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. 4.8 and 4.9. The value of k has to be established by each railway system as per its track structure.

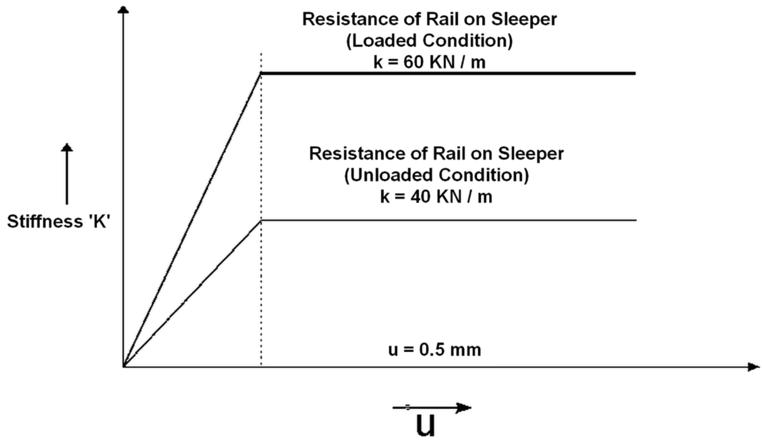


Fig. 4.8 track stiffness (frozen ballast or ballastless track)

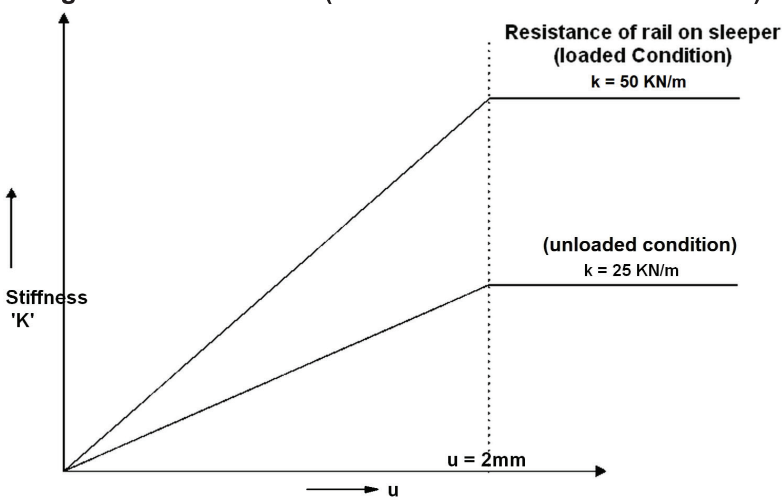


Fig. 4.9 track stiffness (ballasted track)

4.10.4 (III) Once the values of K, the stiffness of the bridge structure and k, the stiffness of the track have been evaluated, interaction charts given in UIC 774-3R can be used for calculation of additional stresses in the rail and longitudinal force at the bridge support due to each of the actions causing interaction effects: namely

(i) Change of temperature

(ii) Acceleration and braking forces

(iii) Deck deformation.

(i) Changes in temperature: In UIC 774-3R interaction charts, variation of deck temperature is taken as ± 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 UIC 774-3R.

(ii) 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. Longitudinal load considered in UIC 774-3R charts is

Acceleration = 33 KN/m

Braking = 20 KN/m as per Load Model (LM)-71 of UIC

RDSO BS-114 (Guidelines for carrying out Rail – Structure Interaction studies on Indian Railways) in its para 4.2 gives simplified loading (to be used for RSI Analysis) is given as under:

Loading	**Vertical Load Intensity with Impact (kN/m)**		**TE intensity (kN/m)**			**BF Intensity (kN/m)**	
Length of UDL→	0-12	12- ∞	0-12	12-40	40-∞	0-12	12-∞
DFC Loading	233.72	136	47	22	0	36	16
HM Loading	219.04	135	47	25	0	32	14
25T Loading 2008	182.95	104	47	22	0	34	13
MBG Loading	182.91	91	47	18	0	34	13

(iii) 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 longitudinal track resistance equal to 25 KN/m and 50 KN/m for unloaded and loaded track respectively.

The design curves are given in UIC 774-3R 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.

Vertical load given in table in above para is to be used for bending of deck for IRS loading.

4.10.4(IV) 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:

$\sum R = \alpha R\ (\Delta T) + \beta R\ (\text{braking}) + \gamma\ R\ (\text{bending})$

α, β, γ are the combination factors.

Since RSI is serviceability condition, α, β, γ factor may be taken as 1.

4.10.4 (V) Permissible additional stresses in continuous welded rail on the bridge

UIC 774 – 3R Provision

Theoretical stability calculations on UIC 60kg CWR of a steel grade giving at least 900 N/mm2 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.

IRS Bridge Rules Provisions

In IRS Bridge Rules para clause 2.8.2.4.3(c) additional compressive and tensile stresses are given as 60N/mm^2 and 75 N/mm2 for 60 Kg rails and 50 N/mm^2 and 60 N/mm^2 for 52 Kg rails for tangent track. They are to be used for RSI Analysis of bridges on IR.

Since UIC 7743R track bridge interaction charts are prepared for UIC LM-71 loading, it is preferable that RSI Analysis software i.e. MIDAS Civil, LUSAS may be used for RSI Analysis. RDSO BS-114 (Guidelines for carrying out Rail – Structure Interaction studies on Indian Railways) are very useful. RDSO Guidelines for carrying out Rail-Structure Interaction Studies on Metro Railways may be used for RSI Analysis on Metro Railways.

4.10.5 Provision of LWR on Ballasted Deck Bridge with Bearing:

Based on the discussion as explained in Para 4.10.4 above pertaining to RSI (Rail Structure Interaction), the provision of LWR on a ballasted deck bridge provided with bearings is as per IRPWM Para 330:

Para 330 of IRPWM - Bridges with Ballasted Deck and Ballast Less Track (BLT) (with bearing)

Detailed calculations shall be done by the Design office of Chief Bridge Engineer / CAO (C) to ascertain the effect of LWR on such bridges and its effect on the sub-structure of the bridge as per Para 2.8.1.2 of "Bridge Rules".

The LWR / CWR may be permitted on a case-to-case basis based on the above calculations. In case detailed calculations are not done, LWR on ballasted deck bridges (with bearings) may be permitted as per Para 331 of IRPWM for bridges with un-ballasted deck. The LWR / CWR on BLT Bridges may only be permitted, if found satisfactory on the basis of above calculations. Chief Bridge Engineer / CAO (C) may further permit use of special arrangements to control RSI effects as stipulated in the RDSO report no. BS-114.

Explanation: As can been above, the introduction of a bearing in the ballasted deck bridge has warranted the need for Rail Structure Interaction RSI study. In case the above RSI study is not done, the provisions pertaining to continuation of LWR over a girder bridge, which are comparatively more restrictive in nature shall be adopted. The same are discussed in para below:

4.10.6 Para 331 of IRPWM - Bridges with Un-Ballasted Deck:

LWR/CWR shall be continued over such bridges with overall length as specified in sub-Para (a) to (c) below:

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

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

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

(ii) SEJ of the LWR should be located such that bridge does not fall in the breathing length of the LWR. The approach track up to 50 m on both sides shall be well anchored by providing PRC sleepers with elastic rail clips with adequate toe load so as to arrest creep.

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

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

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

(i) Central sleepers shall be anchored with anchoring arrangement (two each in end spans and one each in the middle spans) with fair V type or Fair T Type anchors as approved and the remaining sleepers shall be provided with rail-free fastenings.

(ii) The track structure in the approaches shall be laid and maintained to the standards as stated in (1) (b) & (c) above.

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

(iv) *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.*

Maximum Overall Length of Bridges Permitted on LWR/CWR (in m) Para – 331(a) & 331(b) of IRPWM

Temperature zone	Rail section	Rail-free fastenings on bridges as per Para 331(1) with PRC sleepers on approaches	Rail-free fastenings on bridges and partly box-anchored as per Para 331(2) and with PRC sleeper on approaches
I	60 Kg/m	30	77
	52 Kg/m	45	90
II	60 Kg/m	11	42
	52 Kg/m	27	58
III	60 Kg/m	11	23
	52 Kg/m	27	43
IV	60 Kg/m	11	23
	52 Kg/m	27	43

Explanation: In the above case described under 4.10.6 (a) and (b) above, it is to be noted that the above girder bridge is falling with in the central portion of the LWR, i.e., there is no longitudinal movement of rail over the bridge, but the force in the LWR, P, is maximum that can be generated as per difference between t_p and t_d.

Further, the bridge length in the above case is constrained by the maximum amount of gap that can be created being restricted to 50mm due to the presence of rail free fastenings on the bridge. Thus, as can be seen from the above, the maximum length of bridge that can be accommodated in LWR is not very large.

(c) *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 (Fig. 3.5(b)) of IRPWM. 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 under:*

Rail Zone Temp	Max. Movement of SEJ used (mm)	Overall Length of Bridge for this case scenario	Initial Gap to be provided at t_d with PRC sleepers on approach sleepers
IV	190	55m	7.0 cm
III		70m	7.0 cm
II		110m	6.6 cm
I		160m	6.5 cm
II	120	20m	4.0 cm
I		50m	4.0 cm

Note:

(i) *SEJ is to be installed 15 metre away from the abutments.*

(ii) *Improved SEJ with 2 gaps of 65 mm (max.) each (Drawing no. RDSO/T-6922 and RDSO/T-6930) may also be used for laying at far end approach of bridges in lieu of IRS design SEJ with 120 mm max gap.*

Explanation: In the above case described under 4.10.6, rails on bridge are not having any force as they are free to expand and contract.

Further, the bridge length in the above case is constrained only by the maximum gap in the SEJ provided at the far end of Bridge (one side only) which can accommodate the expansion / contraction on account of LWR breathing length (split in two parts, viz., 15 m on one approach and other approach of the bridge) plus the free expansion / contraction of the rail on the bridge that is provided with rail free fastening.

(d) *In case, the bridge cannot be accommodated within a LWR as provided vide Para 4.10.1 to 4.10.6 above, there shall be no option, but to isolate the bridge by providing SEJ on both abutments at a distance of 30 m away and having SWR of 26m / 13m rail over the intervening track length alternatively either of the following may be considered to avoid SWR plated joints on the bridge.*

(i) *In case of multiple span bridge, providing an 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 anchors will be provided at the fixed end of the girder, if the girder is having rollers at one and rockers on the other side. These anchors will be at the centre of the span if the girders are having sliding bearings on both sides (Fig 4.10).*

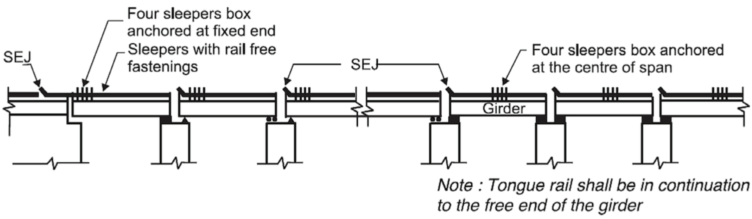


Fig 4.10 Welded Rail on Bridge to isolate from adjoining LWR

<u>or</u>

(ii) *In case of Single span Bridge, Welded rails may be provided on such a single span bridge with rail free fastenings and SEJ with 190 gap at 30m away from both abutments. 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 normal SEJs and 190mm maximum gap SEJs are given in table below. Rails shall be box anchored at fixed end on 4 sleepers.*

Temperature zone	Maximum length of single span girder bridge
IV	75 m
III	87 m
II	110 m
I	146 m

<u>Note: In both these arrangements (d) (i) & (ii) above, rails on bridge are free to expand and contract hence they are not called LWR, they are called welded rails. The SEJ is not a part of a LWR but is only a part of the Welded rail over the bridge. Hence, the Gap at such SEJ</u>

<u>is not required to be measured and recorded.</u>

4.11 Approvals & Deviations for LWR

The above discussed provisions of the IRPWM deal with the permitted location for LWR. The IRPWM Para 326 (4) pertaining to Approvals & deviations stipulates that:

(a) 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,

(b) The above approval shall be obtained on a detailed plan prepared in accordance with Para 336 (1) (c) of the IRPWM based on the various provisions discussed in this chapter.

(c) However, for any deviation from this provision, approval of Principal Chief Engineer shall be obtained.

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CHAPTER V
LAYING & DESTRESSING OF LWR

Part – A: LAYING OF LWR

5 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 IRPWM.

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 due to constraint locations such as the following subject to the permitted locations discussed earlier.

i) Bridges having substructure/superstructure in a distressed condition

ii) Sharp curves

iii) Steep gradients

iv) Bridge locations

v) 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. In special cases, such locations that do not adhere to the provisions of Permitted Locations, may be considered for laying of LWR with approval of PCE , on a case to case basis, subject to taking adequate extra precautions that are required for keeping P force and the mobilised Track resistance R in equilibrium in all situations.

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

iii) Realignment of curves

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

v) Introduction and improvement of vertical curves

vi) Stabilization of troublesome formation

vii) Rehabilitation of weak bridges

viii) Deep screening of ballast along with lifting or lowering of track if required.

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 (t_m) for the section shall be ascertained from the temperature records available with the SSE/P. Way-In charge or as built up as per TMS records pertaining to Temperature Measurements.

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 (Para 334 of IRPWM), shall be adopted.

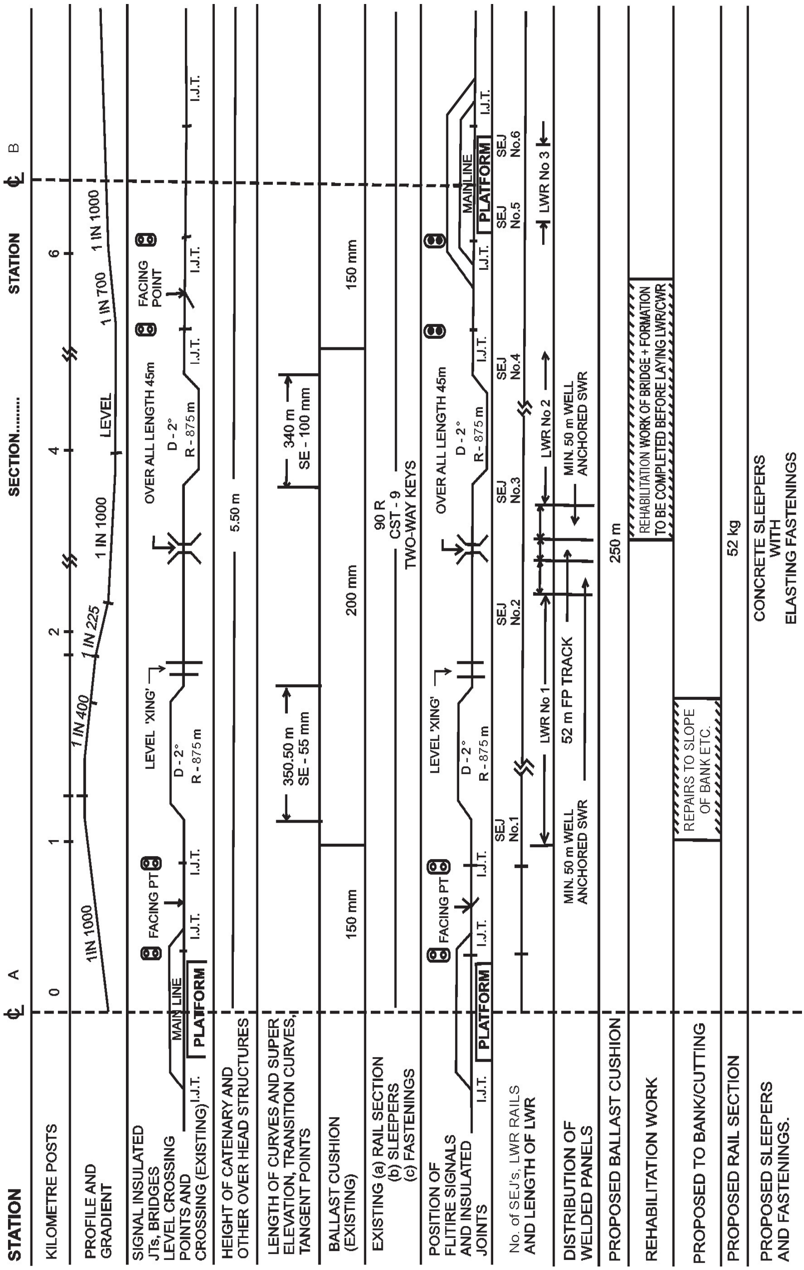


Fig 5.1 – Proposal for LWR

5.3 Materials required

Following materials are required for laying one LWR

- i) Four numbers of min 4.0 meter or longer rail pieces of the same rail section as LWR.
- ii) Two sets of SEJs with sleepers and fastenings.
- iii) Adequate numbers of 1-meter long fishplates with special screw clamps/ joggled fish 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, mallets & side rollers for curves.
- viii) Alumino-Thermic welding equipment and consumables.
- ix) Equipment for protection of track

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 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 in between only may 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.

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 at LWR side/sides of SEJs to facilitate adjustment of gaps during destressing operation.

d) While unloading 880 grade (90 UTS) or higher-grade rails, laid down instructions for handling should be followed.

e) 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.

f) 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. See fig 5.2 below

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

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)

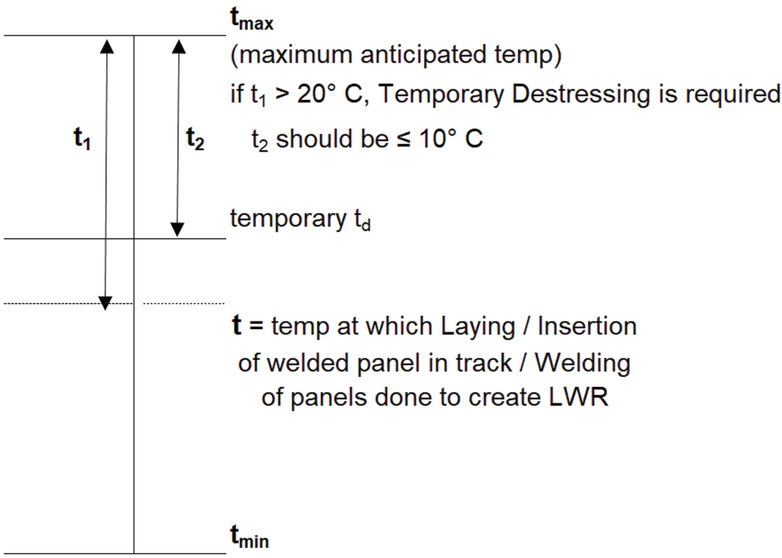


Fig 5.2 Need for Temporary Destressing while laying LWR

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 t_d.

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 IRPWM

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 LWR TRACK

5.7 Destressing of LWR

Destressing is done to secure LWR/CWR in stress free condition at desired or specified rail temperature.

5.7.1 Need for destressing:

(1) Abnormal behaviour of LWR/CWR can be inferred by observing one or more of the following:

- (a) When the gap observed at SEJ
  - (i) Differs beyond limits specified in Annexure - 3/9 of IRPWM.
  - (ii) Exceeds the maximum designed gap of SEJ
  - (iii) When tip of tongue rail/corner of Stock Rail crosses the reference line
- (b) In case of excessive creep of more than 20 mm in the central portion of LWR is noticed.

(2) In such cases as in Sub Para (1) above, LWR/CWR shall be inspected by ADEN for

- (a) deficiency of ballast,
- (b) poor compaction / consolidation of ballast,
- (c) deficiency of fittings,
- (d) poor toe load of ERC
- (e) formation trouble if any,
- (f) whether procedures as per Para 349 of IRPWM were followed during permanent repairs after earlier rail fracture(s),
- (g) the possibility of defective thermometers being used by the staff.

After the above inspection, the deficiency shall be made good at the earliest by suitable corrective action, to improve the track resistance. Thereafter, the SEJ/LWR shall be kept under close observation by active monitoring by the JE/SSE/P.Way. If LWR/CWR still behaves abnormally, a decision shall be taken by ADEN for de-stressing of

LWR/CWR.

(3) After special maintenance operations mentioned in Para 346 of IRPWM, de-stressing shall be undertaken.

(4) After restoration of track following an unusual occurrence mentioned in Para 348 of IRPWM, de-stressing shall be undertaken.

(5) If number of locations where repairs by way of replacement of rail / weld have been done, exceed three per km, de-stressing of affected portion of LWR / CWR shall be done.

(6) Apart from the above need based requirements, destressing shall have to be carried out immediately after lay of LWR.

In all the above, when destressing is to be carried out, the destressing operation is undertaken with or without rail tensor to secure stress free conditions in the LWR/CWR at the desired/ specified rail temperature.

5.7.2 L.W.R. Destressing Operation

5.7.2.1 General

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

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

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

ii) The destressing operation provides an opportunity to examine & replace Rubber pad, ERC & liner wherever necessary 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.

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

iv) Side rollers shall also be used while undertaking destressing on curved track. side supports on the inside of curve should be spaced at every n^{th} sleeper, for destressing with tensor

Where,

$$n = \frac{\{\text{Radius of curve (R) x No. of sleepers per rail length}\}}{50 \times (t_o - t_p)}$$

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

v) 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 in Para 335 of IRPWM (Destressing temperature) reproduced below, during the fastening down operations.

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

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

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 t_d 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 by saw 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.

5.7.2.3 Destressing of LWRs/CWRs with use of Rail tensor

For destressing of LWR using rail tensor, the following procedure shall be adopted:

i) Mark the anchor length A_1 A_2 and C_1 C_2 each equal to la at either end of the length A_2C_1 to be destressed (Fig. 5.3.(a)).

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

ii) Erect marker pillars Wo W1 etc., on each of the length A_2B and C_1B and Transfer the marks Wo onto the rail foot (Fig: 5.3(a)).

Note: The distances W_o W_1, W_1 W_2 etc. shall be marked at about 100-meter intervals, the distance from the previous pillars and the last pillar WB may be less than 100 meters.

iii) On the day of the block, alternate fittings may be removed after imposing a speed restriction of 30Kmph on the manageable length between the anchor lengths.

iv) During the 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_1B as described below:-

a) Cut the rails at centre of LWR marked as ‘B’ and move cut ends side way to allow free movement of rails. Unfasten and mount on rollers the portion from A_2C_1.

b) Fix the rail tensor across the location 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.

   Note: The movement at Wo should ideally be noted to be towards the anchor length side and the value noted. In case the movement at Wo is noted to be away from the anchor length but towards the centre of the manageable length, the value of Y_o shall be ignored.

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

d) Calculate the required movement at W1 as: Movement at $W_1 = Y_o$ + elongation of length W_0W_1 (L) due to temperature difference $(t_o - t_p)$ = Yo + $L\alpha\ (t_o - t_p)$

e) Calculate the required movement at W_2 as: Movement W_2 = Movement at W_1 + elongation of length W_1W_2 (L) due to temperature difference $(t_o - t_p)$.

   Similarly, calculate the required movements successively at each of the remaining points.

f) 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.

g) 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 Wo W1.

h) 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:

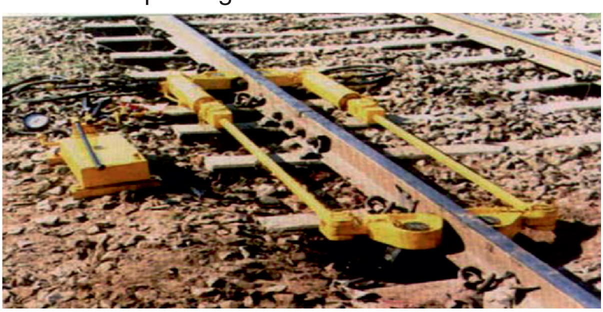
   1) *Extension table given in IRPWM, gives the value of L $\alpha\ (t_o - t_p)$ for different values of L and $(t_o - t_p)$.*

2) ***<u>Note: Only one value of t_p has to be taken at the time of marking W_1, W_2 etc. on the rail foot. The value of t_p is not required to be taken thereafter.</u>*** *The variation of temperature, if any during the destressing operation shall automatically be taken care of by reducing or increasing the tensile force from the tensor, while coinciding the reference mark on rail with the corresponding mark on pillars.*

3) *If for any reason, both the lengths A_2B and C_1B 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.*

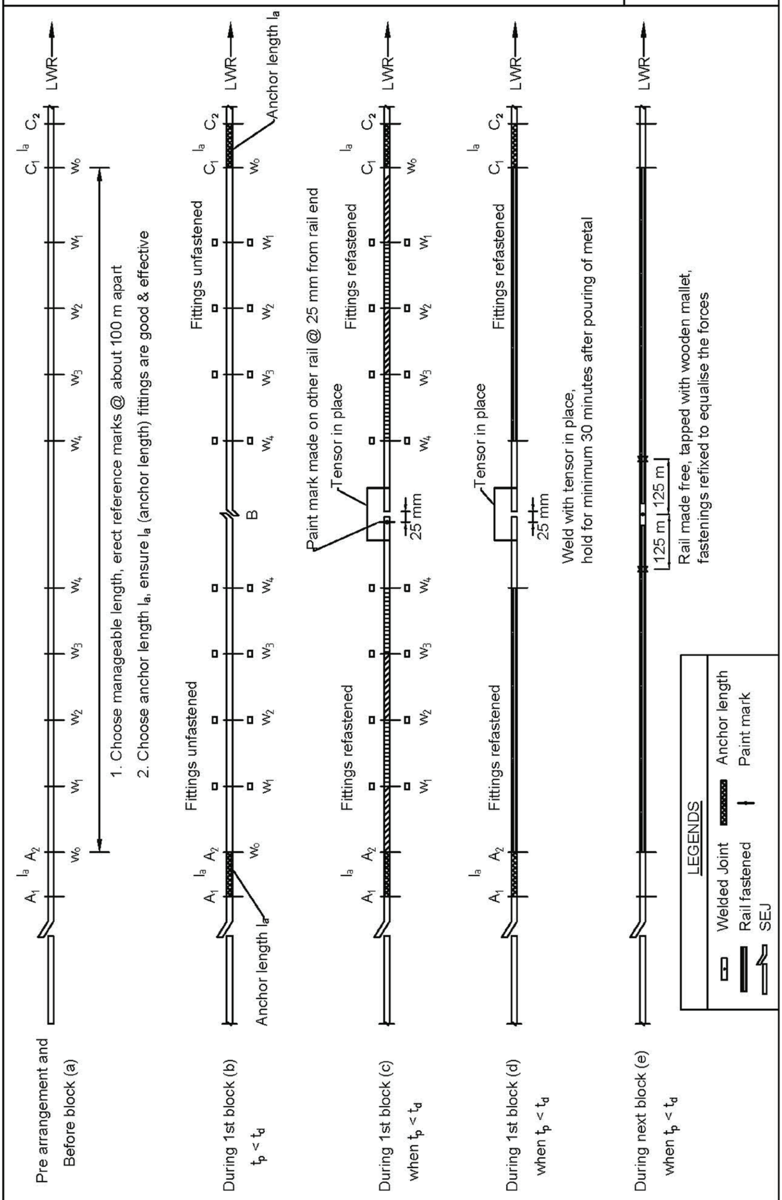
i) After the fastening down of the last length A_2B and C_2B is completed, make a paint mark near free end of one rail at a distance of 25 mm measured from the end of the other rail across the gap. See fig 5.3 (c).

j) During the same traffic block, ensuring that t_p is not greater than to, cut the rail at the paint mark, with rail tensor in place, to get the desired gap of 25 mm (Fig. 5.3 (d)); Do the welding of the joint. Release the tensor, only after a lapse of a minimum of 30 minutes after pouring of the weld metal.



k) During next traffic block, when t_p is less than td, equalise the forces in the rail by releasing the fastenings over a length of 125 meter on either side of location 'B' and tapping with wooden mallets etc. (Fig. 5.3 (e)). Fasten down the rail and allow traffic.

DESTRESSING OF LWR WITH THE USE OF RAIL TENSOR	Fig : 5.3



l) During next traffic block, when t_p is within the range of temperature specified for t_d as per IRPWM, destress the end 125 meter from SEJ. Thereafter, weld the closure rail next to SEJ duly ensuring setting of the SEJ as per provisions of IRPWM, i.e., SEJ gap shall be kept 40 mm for 52 Kg/ 60 Kg rail section at t_d.

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CHAPTER VI

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 temperature variations. Due to this, thermal stress / force gets induced in the central part of LWR. The magnitude of this thermal force is $AE\alpha t$.
2. Whenever there is a temperature change, the rail tries 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 over the sleeper seat independently, therefore the rail & sleeper as a frame moves in the surrounding ballast mass. The ballast core gets displaced due to this frame movement; hence ballast resistance gets mobilized, offering resistance to movement of rail-sleeper frame.
3. In certain length (L_b) the longitudinal ballast resistance (r kg/cm/ rail) is geared up-to the extent / value of thermal force $P = AE\ \alpha\ t$ ($L_b \times r = P$), beyond this point there is no movement in LWR, the same is explained here under (Fig 6.1)

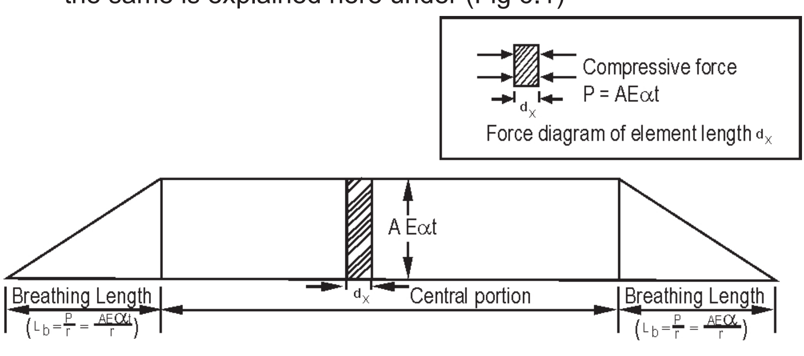

Fig 6.1 Consider an element of dx length in the central part of LWR.

i) When temperature rises by t^oC above t_d, the expansion of this element is = $dx\ \alpha\ t$.

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

$$\Delta L = \frac{P\,L}{A\,E} = \frac{P\,dx}{A\,E} = \frac{A\,E\,\alpha\,t\,dx}{A\,E} = dx\,\alpha\,t$$

iii) Therefore, the net elongation of the element due to increase in temperature

= dx α t (expansion due to increase in temperature) – dx α t (shortening due to compressive force) = 0

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

4. 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 w.r.t., creep resistance, 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 AEαt, which is independent of length of LWR & for a given rail section & location (temperature zone) it depends upon t, i.e., temperature variation. Therefore, working in higher temperature ranges, beyond the laid down temperature limits will lead to generation of higher thermal forces, which may lead to buckling. Therefore, the maintenance operations should be done within specified temperature limits

d) Excessive lifting, slewing during maintenance will lead to reduction in lateral ballast resistance. This may also lead to buckling. Therefore lifting & slewing only to be done 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 compressive forces during summer.

f) During manual maintenance operations, ballast in crib and shoulder needs to be 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 behaviour is satisfactory).

g) LWR should be laid on stable formation, because the unstable formation will involve change in consolidation of ballast in LWR and 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 behaviour /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 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

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 operations, if rail temperature exceeds t_d+20°C during the period of consolidation, then, in case of BG Concrete sleeper track, the speed restriction of 50 km/h shall be imposed, till the period of consolidation is over. The period of consolidation for existing BG PSC 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. For newly laid track (CTR/TSR) or freshly deep screened track, 3 rounds of packing, last 2 of which are by on track tamping machine are necessary.

6.2.2 **Important precautions specific to particular operation:** In addition to Para 6.2.1 above, the important precautions which are required to 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 IRPWM Para 337(5) 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 shoulder 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. (Fig 6.2)

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.

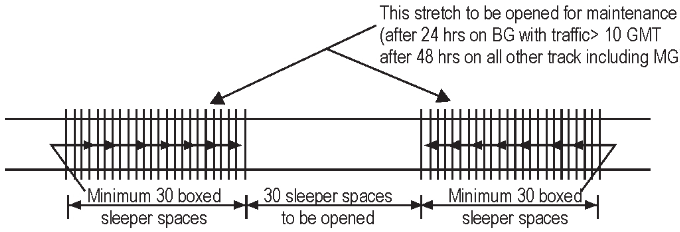

Fig 6.2 Manual maintenance

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 shoulders 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

Authorised supervision level: Single isolated sleeper not requiring lifting or slewing of track - Gang mate, Casual renewal of sleepers & fastenings over long stretches - JE/PWay-non-Sectional.

d) Renewal of fastenings :

Renewal of fastenings shall be done with following additional precautions

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

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.

Alternatively, if prevailing rails temperature is lower than t_d – 10°C, fastenings up to 5 sleepers on either side may be removed for replacement of rubber pad under the rail.

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 347 of IRPWM (Destressing of LWR).

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.

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°C 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 shall 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 346, 637 of IRPWM will apply to LWR/CWR with further provisions as mentioned hereafter in this Para. Wherever mechanised cleaning of ballast is resorted, the detailed procedure laid down in Para 637 (2) of IRPWM shall be followed.

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 including consolidation period.

iv) Constant monitoring of rail temperature shall be done during the progress of work. Should the temperature rise more than 10°C above 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 t_d I temporary destressing temperature, cold weather patrolling 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.*

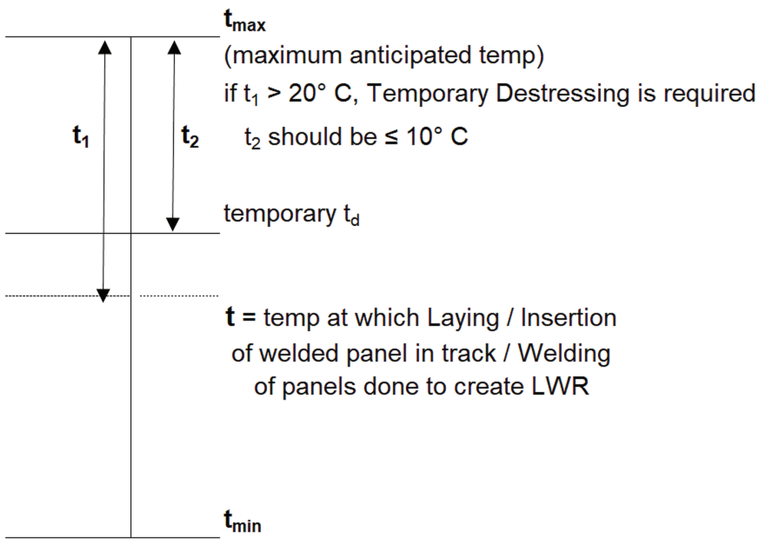

Fig 6.3 - Need for Temporary Destressing while doing special track maintenance Operations

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) Temperature 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.

IRPWM para 332 stipulates that "Rail temperature 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."

A sample illustration on how to for plan various track maintenance activities, is placed here under:

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

Section: Pune – Lonavala (Pune division)

Pune rail temperatures: 61(34)

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

Mean of temperature $(t_{max} + t_{min}) / 2 = 34 \Rightarrow$ $t_{max} + t_{min} = 68$

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

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

Now the temperature records to be studied in detail to find out the rail temperature 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, based on available past temperature records, the days / weeks / Months when the rail temperature was within 6°C to 46°C between 10.00 hrs to 12.00 hrs is identified. The tamping machine shall be planned & deployed during such periods / months of the year, when rail temperature is within this permitted range of 6°C to 46°C.

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

Track activities	Specified temp. limits as per IRPWM	Rail temperature 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) to (t_d – 30)	46 to 6
Manual Packing	(t_d +10) to (t_d – 30)	46 to 6
Deep screening	(t_d +10) to (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

Further, imagine there is an urgency during peak summer (when rail temperature during 10 to 12 hrs. is more than 46^{0}c) to tamp few kilometres, then it can be preferably done during night hours when rail temperature are relatively low & temperature is lower than the permitted range of t_d -30°C to t_d +10°C.

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

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CHAPTER VII

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).

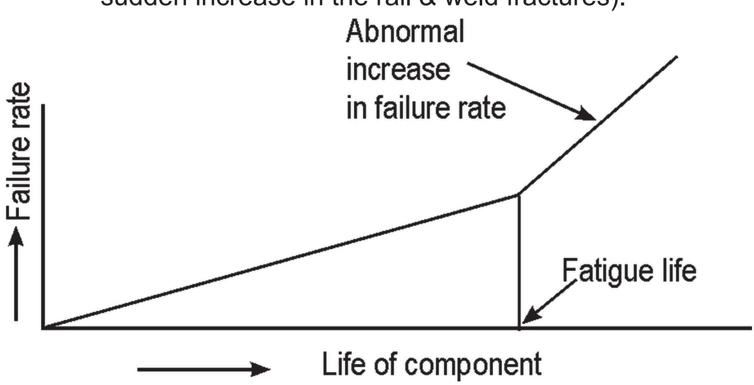

Fig 7.1

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) Caked ballast

   d) Poor track geometry

   e) Improper packing & support conditions

   f) Flat tyre

   g) Rubber pad missing on sleepers.

   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

4) Rectification of cupped weld joints

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

6) Check & monitor running of flat tyre

7.1.3 Rectification of Rail Fractures

Procedure for repairs

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 IRPWM manual Fig. 3.9, 3.10, 3.11 & 3.12 i.e., using 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 / Railway Cold Weather Patrolman with valid competency certificate.

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 IRPWM manual Fig. 3.9, 3.10, 3.11 & 3.12.

i) A traffic block shall be taken as soon as possible preferably when the rail temperature is within the range specified for t_d in Para 335 of IRPWM manual.

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). See Fig. 7.2.

In this case the inserted length of closure 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

The length of inserted rail closure + 2 x welds – 2 saw cuts = Length of rail pieces removed from LWR

$\Rightarrow$ 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 width 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. See Fig. 7.2

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 1 m long fishplate with special clamps has been provided, using the arrangements shown in IRPWM Fig. 3.23 (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 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. 50 mm. Once the closure rail is cut, the closure rail will be welded as given in sub Para (ii) above.

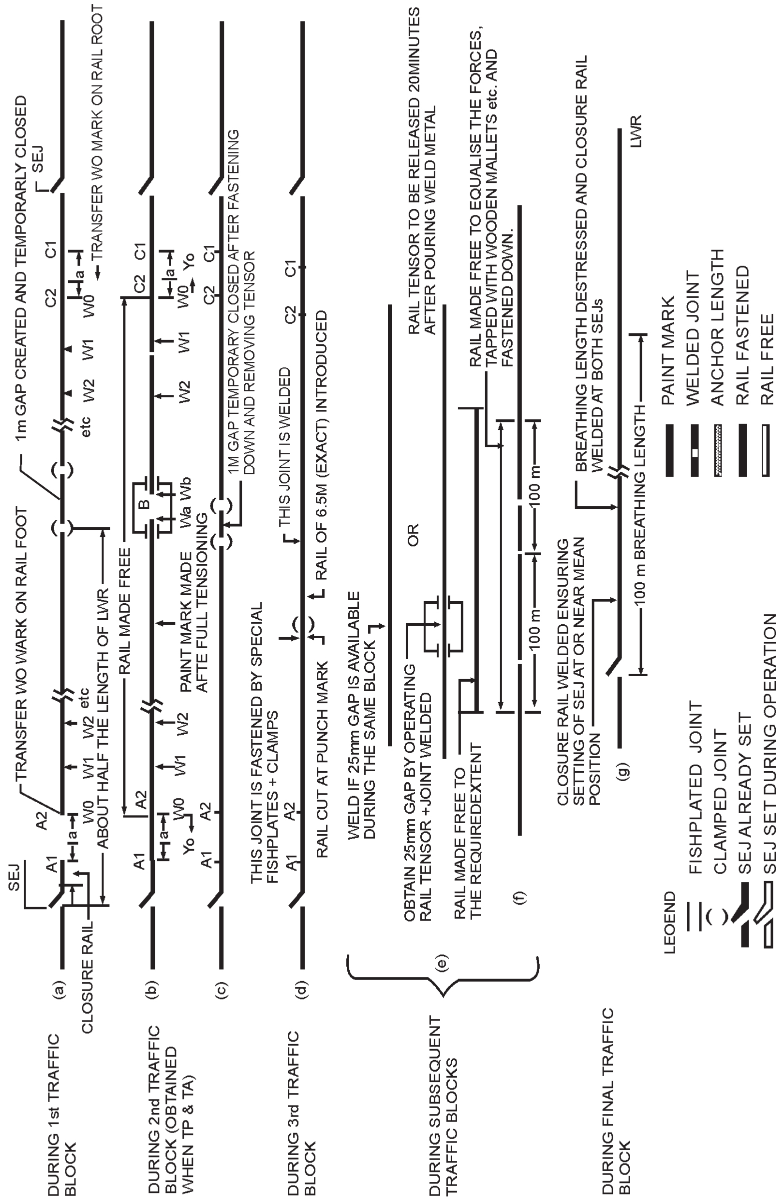

Fig 7.2 – Repairs to a Rail Fracture

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.

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 (including rail tensor).

v. Minimum 4.0-metre-long sawn rail cut piece of the same section as LWR duly tested by USFD

vi. Equipment for protection of track

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 IRPWM. 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 with special clamps and fish plates 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 with 24 Hrs. watch 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 ranges/ limits specified for working / maintenance on LWR.

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, there by dropping of stress-free temperature.

5) Excessive settlement of formation.

6) Misalignment kinks, improper packing of track.

7) Improper functioning of SEJ.

7.3.2 Important items to avoid buckling

1) Avoid laying LWR on unstable formation

2) Install LWR on proper destressing temperature

3) Observe specified temperature limits/ ranges during working

4) Avoid excessive lifting/ slewing of track during tamping

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 the cause of buckling ascertained. The position of tongue and stock rails of the SEJ shall be checked. The methods for rectification are 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 IRPWM 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 JE / SSE (P. Way)

   b) Permanent repairs

   As soon as possible the clamped joints shall be welded adopting the same procedure as in Para 349 of IRPWM manual .i.e. procedure followed for temporary repairs & permanent repairs in case of rail fracture. Additional pair of cut rails and rail cutting equipment shall also be required to adjust the gaps in case they have been disturbed in the intervening period.

   The traffic will be allowed after temporary repairs at 30 Kmph, provided 1 m long fishplate with special clamps has been provided 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 emergency repairs is JE / SSE (P. Way)

The speed restriction shall be removed after welding, carried out by taking up permanent repairs as outlined under Para 349 of IRPWM manual. The minimum authorized personnel to allow traffic at normal sectional speed after permanent repairs is JE / SSE (P. Way)

The track length (comprising of about 500 m approx. on either side of location of buckling) shall be destressed as soon as possible as per IRPWM Para 339)

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 t_d. 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.

Creep Monitoring

ii. The instances of Creep shall be very critically examined and inspected. The creep in LWR can be monitored by

(a) Measuring the creep at the Creep Posts erected for this purpose. Unfortunately, currently, the creep posts are available only at the SEJ and at the centre of LWR. Thus, with the length of a normal LWR being one block section length, the distance between two adjacent Creep posts is very large, at times ranging from about 4 to 6 km or more also.

Thus, if the creep posts are erected at every 500m the creep at all such locations can be monitored more effectively.

(b) Alternatively, the observation of creep indications on the Rail foot made by the visible shifting of the Liner from its seat can be a tell-tale marker which indicates the occurrence of creep. (Fig 7.3)

(c) The world over, the effect of creep has been studied in detail by the Railways. RDSO has identified that a creep of about 50 mm in to a track length of 500 m changes the stress-free temperature by about ~10° C.

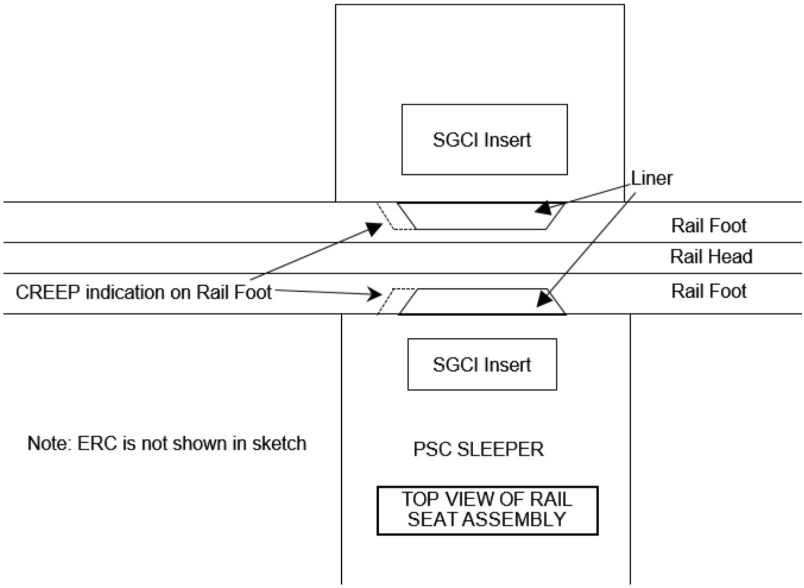

Fig 7.3 – Tell-Tale signs of Rail Seat Creep on Liner Location

(d) Even though, explicit creep may not be observed / measured, but indirect creep / change of track length between two fixed locations can always occur due to the following works and can have adverse implications on the behaviour of the LWR:

i. Track Slewing outwards (while re-alignment of curve) has an effect of increasing the stress-free temperature and thereby the fracture proneness increases. Conversely, inward slewing of track has the effect of reducing the stress-free temperature thereby buckling tendencies increase in such locations.

ii. Lifting of a long sag location between two points / fixed locations, say between two small bridges / LCs etc., has the same effect of Inward Slewing as discussed above. Conversely, a long gradual settlement of high embankment between two bridges has the same effect of outward slewing of track as discussed above.

iii. Introduction of additional rail length while doing restoration of rail fracture or removal of additional rail from track while attending to rail fracture also alters the stress-free temperature of the track. Thus, absolute care is required while replacing rail, by ensuring that rail removed from LWR MUST BE EQUAL to rail put in LWR, including the 2 Welds.

iv. Thus, it is imperative that additional creep post be erected for this purpose, Existing OHE masts / marks on platform coping / Hectometer post or other such fixed post as available may also be considered for monitoring creep (as shown below).

v. Toe Load monitoring is an important pre-requisite for understanding / observing the behaviour of LWR. Thus, timely and reliable Toe Load measurement is a mandatory requirement in LWR territory and implicitly, poor toe load shall be an early warning of abnormal behaviour of LWR.

vi. Poor Toe-Load, coupled with sharp curves and steep gradients can play a detrimental role in specific locations where tractive efforts (Acceleration / Braking) are more pronounced. Thus, toe load measurements must be done carefully.

vii. Use of Defective Thermometers can play an important role in disturbing the track at inappropriate times (which are not permitted by the IRPWM). Thus, timely assurance of correctness of thermometers is also an important pre-requisite for effective LWR Monitoring.

iii. 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 the patrols.

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

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

vi. Inspections of gaps at SEJ and creep/movement at central portion of LWR/CWR by Permanent Way officials would be done portion 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.

Note: Movement of SEJs indicate behaviour of breathing length of LWR where thermal forces are not maximum. Observation of creep in central portion is proper indicator of health of LWR.

7.5.2 Records

i. Record of LWR/CWR, as per the Proforma given in IRPWM 354, shall be maintained by JE / SSE / (P. Way) in a permanent register called the Sectional LWR/CWR Register. JE / SSE / (P.Way) shall be responsible for keeping this register up-to-date.

ii. An indication board similar to that suggested in Para 447 of IRPWM (for curves), 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 SSE or JE/P. Way/ADEN in Proforma shown in Annexure 3/14 & 3/15 of IRPWM.

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

v. ADEN shall analyse the observations of each LWR/CWR in his jurisdiction and give a certificate at the end of LWR/CWR register before onset of summer or on TMS regarding satisfactory behavior of all LWR/CWRs. DEN/Sr.DEN will scrutinise observations of each LWR/CWR, initial each page acknowledge it on TMS and exception report to be submitted to Chief Track Engineer only when his orders are required.

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CHAPTER VIII
ADVANCE CONCEPTS IN BUCKLING

8.1 Buckling Phenomena

As described earlier, buckling is the sudden lateral shift in the track alignment thereby resulting in the release of 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)

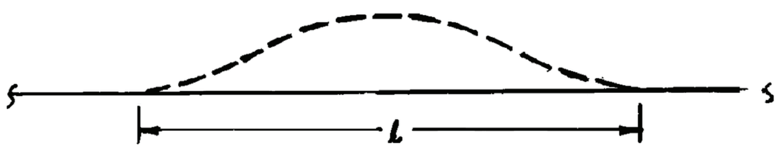


Fig 8.1 First Waveform

Buckling in the form of a 'C' could occur on a sharp curve (First wave form) while buckled track resembling an 'S' shaped curve is generally evidenced on straight tracks (2nd wave form) or multiple 'S' forms (3rd wave form). The force diagram after a buckle is shown in Fig 8.2.

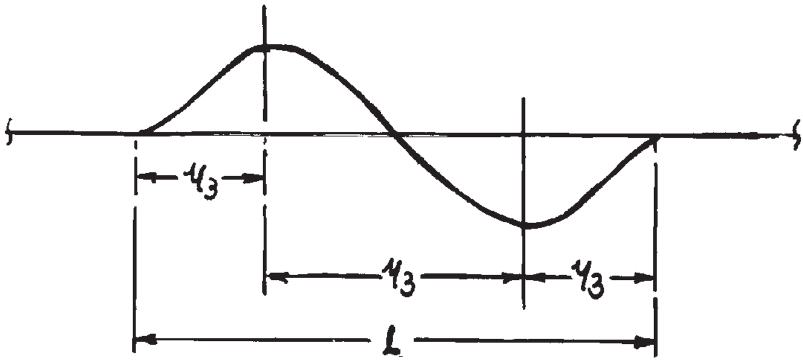


Fig 8.1 Second Waveform

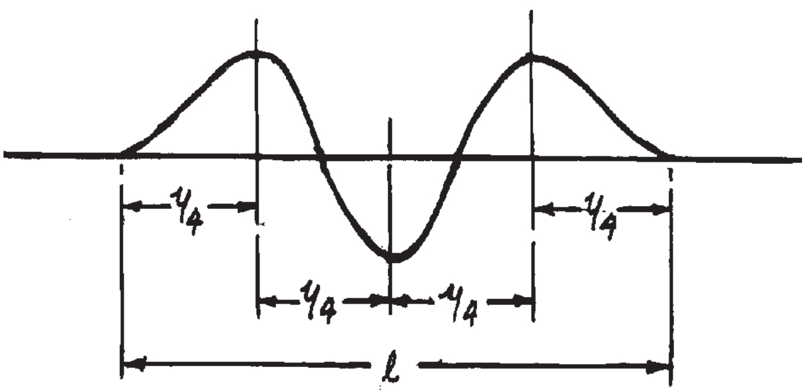


Fig 8.1 Third waveform

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’.

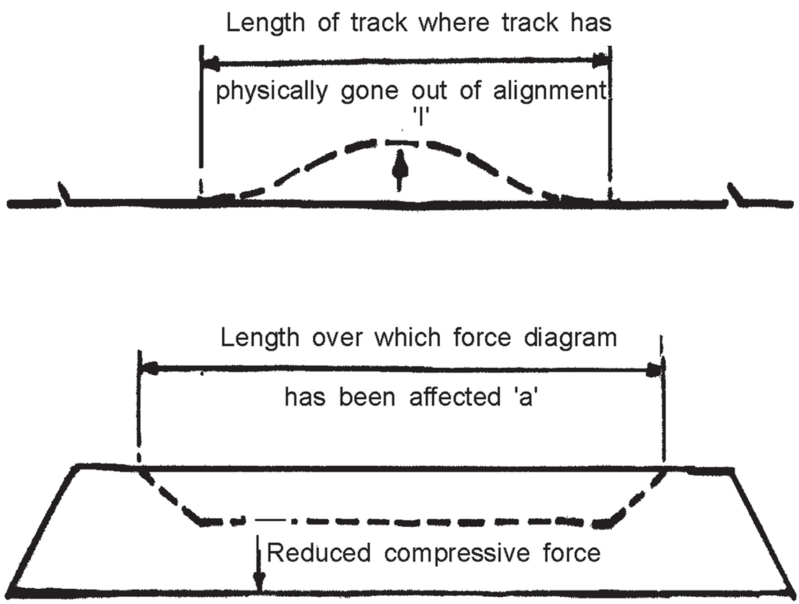


Fig 8.2

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).

3) With use of different fasteners, the buckling load varied by as 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 buckle proneness. This is shown in Fig. 8.3.

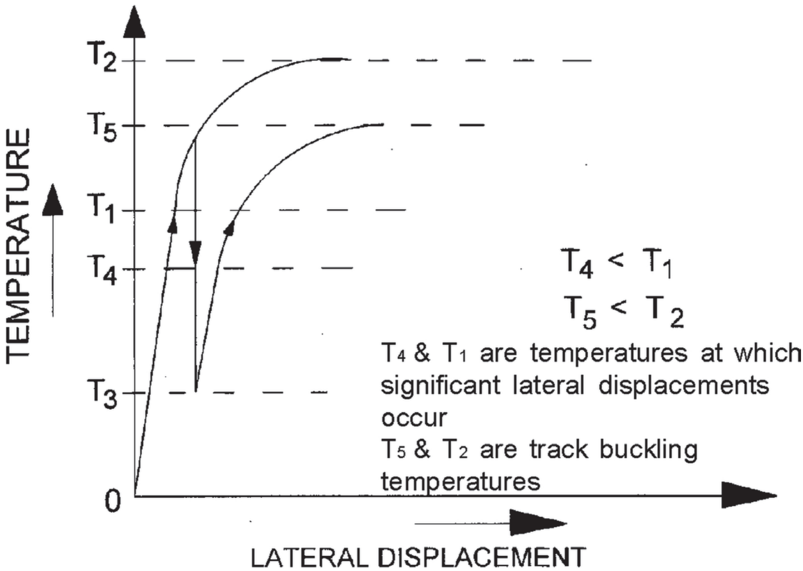


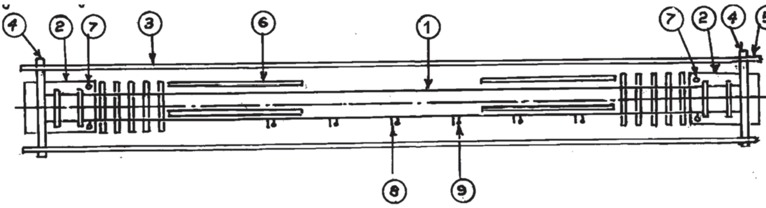
Fig. 8.3

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.

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.



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

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 attached 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 reflectors 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 longitudinal 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 contra flexure 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 and W is the lateral ballast resistance per sleeper then

$W_{max} = W/D$

Analysing the above expression, it can be seen 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-efficient C will cause an increase in the overall resistance to buckling

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

Accordingly, it is concluded that:

1. If the track were perfectly straight and points of equal load application central for each rail, then the track would not buckle however great the longitudinal 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 a 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) afforded by the fastenings. Clearly the buckling load is proportional to torsional resistance.
3. ‘L’ the length of buckled track is taken as 20 feet for all cases. In actual fact for a given combination of C, D, W_{max} 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 and the value of ‘q’ as ¼ 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 experimentally show a fair correspondence (within a few per cent) with the values determined from theoretical calculations.

6. JE / SSE (P. Way) can ensure that the track remains safe against buckling by:

a) Reducing the lateral misalignment in the track.

b) Ensuring that no sleeper rail fastenings are missing.

c) Providing full complement of ballast in the track as per prescribed ballast profile.

8.4 Static Buckling and Dynamic Buckling

The discussion so far has been centred on buckling caused by longitudinal compressive force build-up 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 front of, 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 could be critical enough to cause loss of contact between the ballast and the sleeper soffit resulting in the loss of lateral ballast resistance thereby making the track buckle-prone (Fig. 8.5 (a) & (b)).

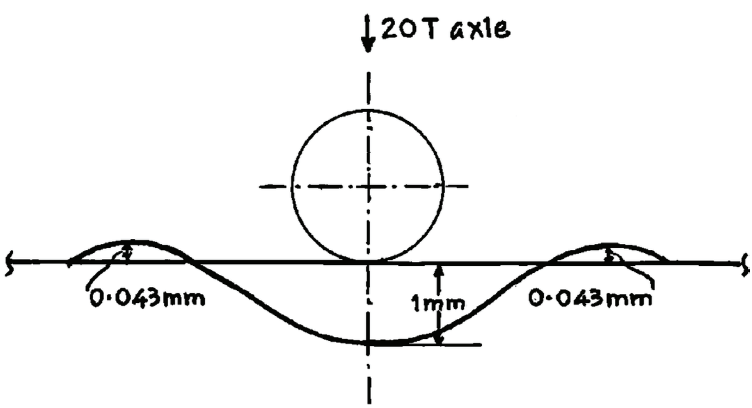


Fig 8.5(a)

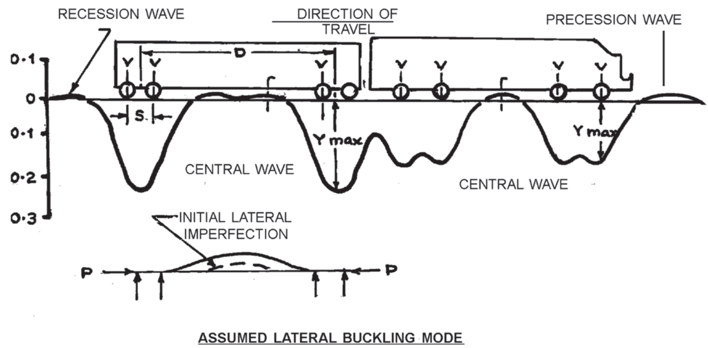


Fig 8.5(b)

2) Tractive and 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 buckling tendencies in the rail.

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

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

8.5 Buckling Analysis of Curved CWR Track

8.5.1 Methodology

In 1992 the International Union of Railways (UIC) commissioned a study from ERRI entitled “Improved knowledge of CWR, including switches” and the work was assigned to the ERRI D 202 Specialists’ Committee. As a part of this case study three models were developed. CWERRI one of the model analyses track stability in combination with longitudinal and vertical loads, including dynamic effect and yielding of ballast under combined load situation.

Using the CWERRI model, a sensitivity analysis was carried out on the track structure of Fig. 8.6, by varying such parameters as the half wavelength of the misalignment, the curve radius, the peak and limit resistance of the lateral ballast strength and the torsional stiffness of the fastening system [19].

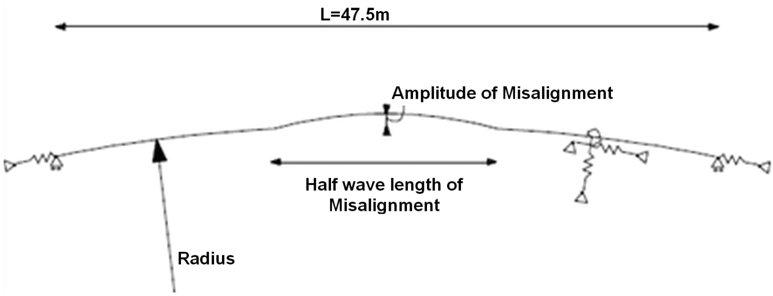


Fig.8.6 – Plan of track model

The track model was 47.5 m long, with a horizontal curve radius of 400 m. A longitudinal spring was added at the boundaries, in order to model the longitudinal behaviour of linear elastic tangent track up to infinity. The misalignment in the middle was characterized by a half sine wave with a length of 9.144 m and an amplitude of 0.0381 m. The track component properties were as follows:

Rails: AREA 136 (67.52 kg/m) rails, sleeper spacing: 0.61 m and vertical ballast stiffness: 68 900 kN/m per meter track. The constitutive behaviour of the ballast spring is given in Fig. 8.6. The track was loaded vertically by a hopper wagons with two bogies, represented by four vertical axle loads of 293 KN each, as indicated in Fig. 8.7.

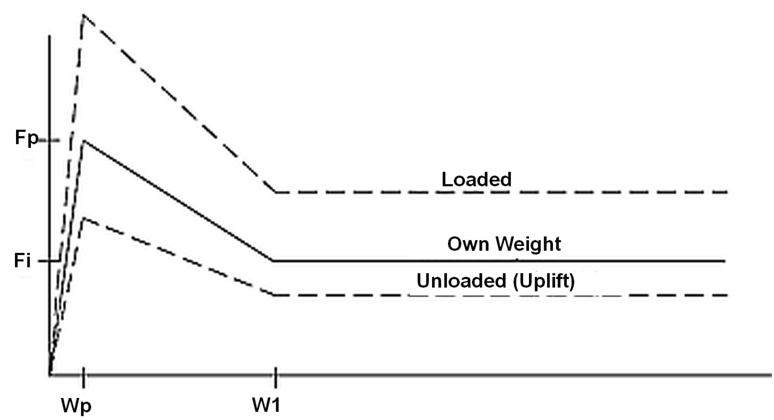


Fig.8.7 – Lateral ballast resistance under different loading conditions.

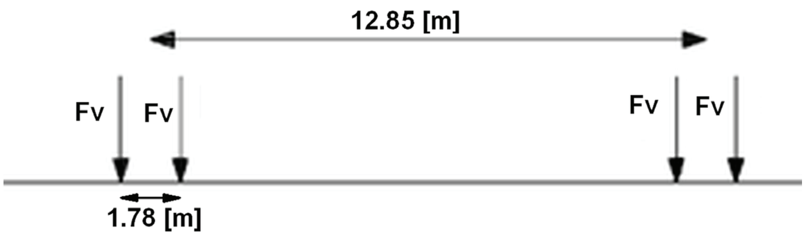


Fig.8.8 – Loading diagram of hoppers wagons (FV=293 kN)

The track was loaded by increasing the temperature from 0°C to 100°C. Fig.8.9 shows lateral deformation in the center of the model against temperature increase.

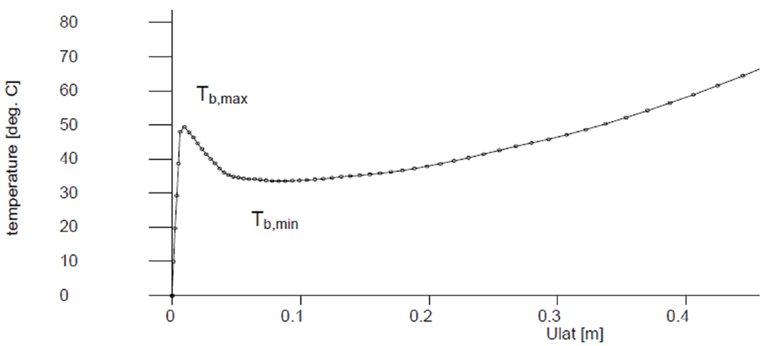


Fig.8.9 – Later deformation in the middle of the model.

The plot in Fig.8.9 is characterized by two points. The first point is the temperature $T_{b,max}$ (49.4°C), at which buckling starts, and which is the highest point in the figure. After this point, the temperature drops and deformations grow rapidly. The second point is the minimum temperature $T_{b,min}$ (33.5°C) that occurs after buckling has started. From a safety point of view this is the most important value.

8.5.2 Sensitivity analysis

In this study sensitivity of $T_{b,max}$ and $T_{b,min}$ to the parameter variations shown in Table 8.2 below was carried out. Each parameter was varied over a practical range while keeping all other parameters constant at the "fixed value".

Parameter	Fixed value	Range
Radius (m)	400	100-Tangent
Lateral peak resistance (Fp) (N/m)	17,508	8,754 – 26,262
Lateral limit resistance (Fl) (N/m)	9,630	4,815 – 14,445
Longitudinal stiffness (N/m)	13,78,000	100,000 – 1,00,00,000
Torsional stiffness (N/m)	11,12,500	0.0-3,00,000
Amplitude of misalignment [m]	0.0381	0.008 – 0.05
Half wavelength of misalignment [m]	4.572	1.2 – 9.6

Table 8.2 – Parameters in sensitivity study.

Fig. 8.9 shows the calculated results for $T_{b,max}$ and $T_{b,min}$ as a function of curve radius. The yield force is affected by the vertical track load. The reference value for the radius is 400 m. Buckling starts at lower temperatures in small-radius curves. $T_{b,max}$ and $T_{b,min}$ are referred to in some of the figures as T_{max} and T_{min}

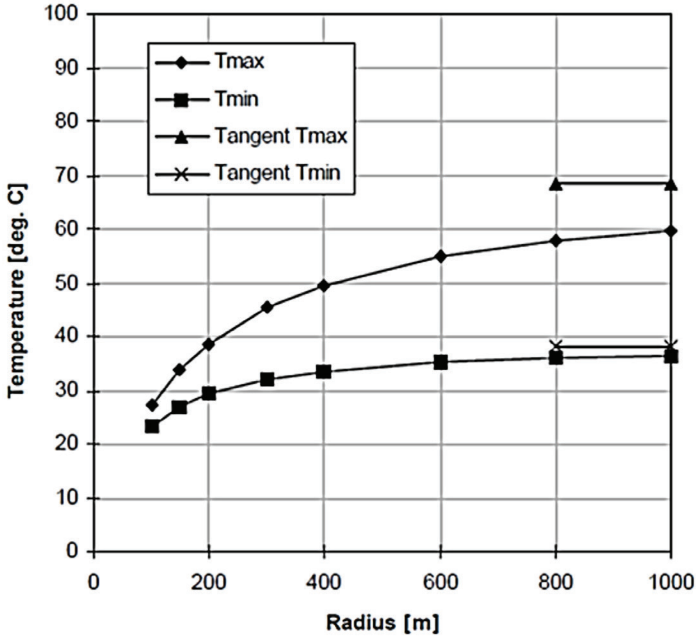


Fig.8.10 – Influence of radius on Tmax and Tmin.

The ballast behaviour, represented by the lateral peak and limit resistance, was varied over a range of 50% to 150% of the reference value and Fig. 8.11 shows $T_{b,max}$ to be more sensitive to this factor.

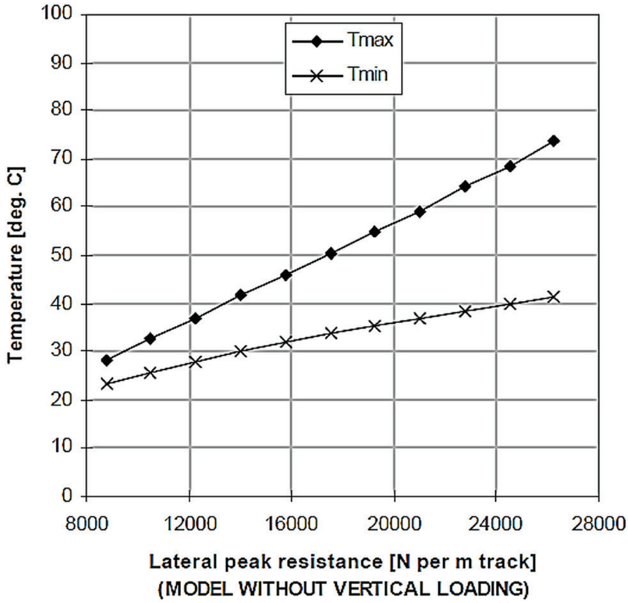


Fig. 8.11 – Influence of Peak lateral resistance.

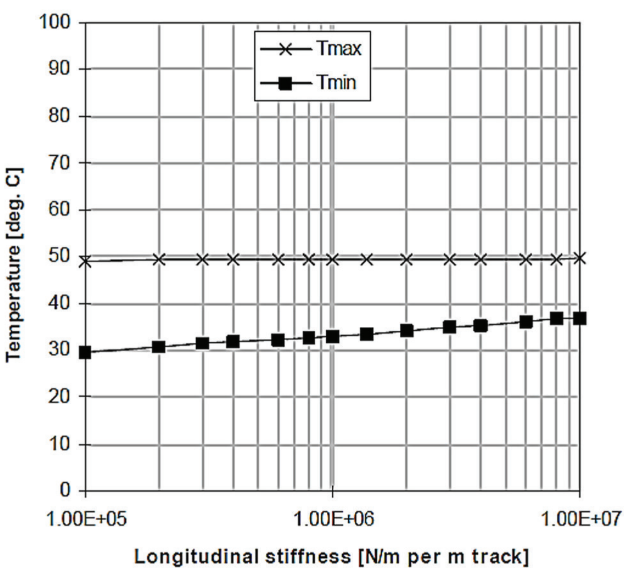


Fig.8.12 – Influence of longitudinal stiffness of track.

Fig. 8.12 indicates that varying the longitudinal ballast stiffness has little influence on $T_{b,max}$. The torsional stiffness, often associated with the frame stiffness of the track, influences neither $T_{b,max}$ nor $T_{b,min}$, as can be seen from Fig. 8.13.

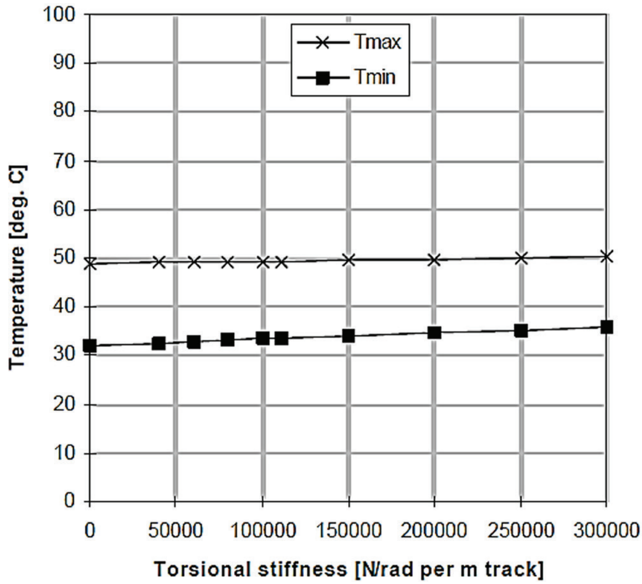


Fig.8.13 – Influence of torsional stiffness of track.

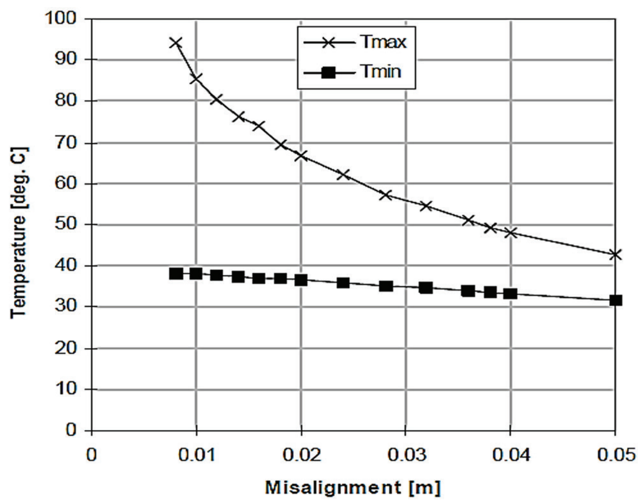


Fig 8.14

From Fig. 8.14, it is apparent that the amplitude of the misalignment has a marked influence on $T_{b,max}$, whereas $T_{b,min}$ is less affected.

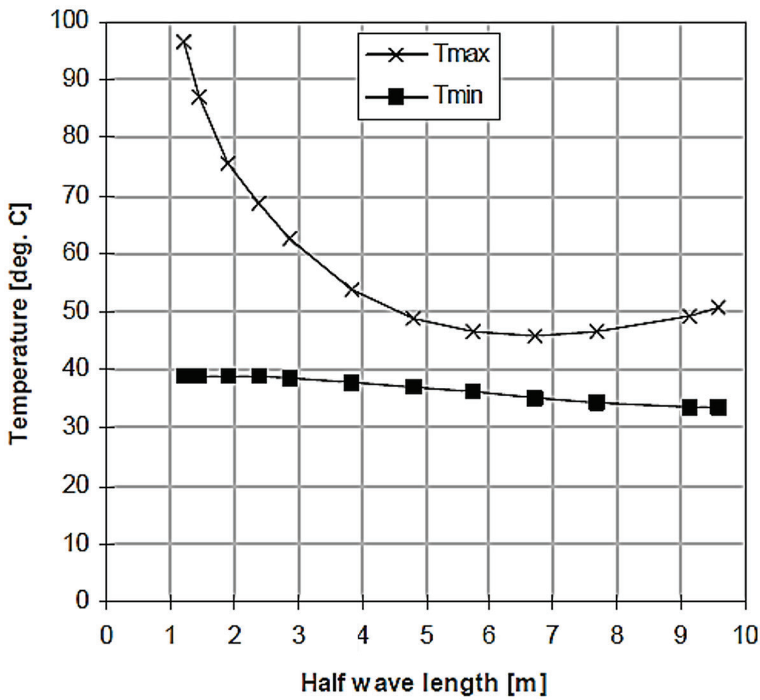


Fig.8.15 – Influence of amplitude of misalignment.

The half wavelength, shown in Fig.8.15, is related to the amplitude of the misalignment. In the calculations, a fixed relationship was assumed, based on statistical analysis of measurement data.

8.5.3 Safety analysis

Laser application of CWERRI is a smooth tool for safety analysis based on it safety criteria has been incorporated in UIC Leaflet 730. Results of the calculation are expressed in terms of temperature of the rail above neutral temperature. It is widely assumed that the track coupling in area between Tbmin and T_{bmax} depends on external addition of energy to the buckled track, e.g. by moving train for temperature close to T_{bmin} the amount of energy is much larger than close to T_{bmax} as evident from Fig. 8.16

below:

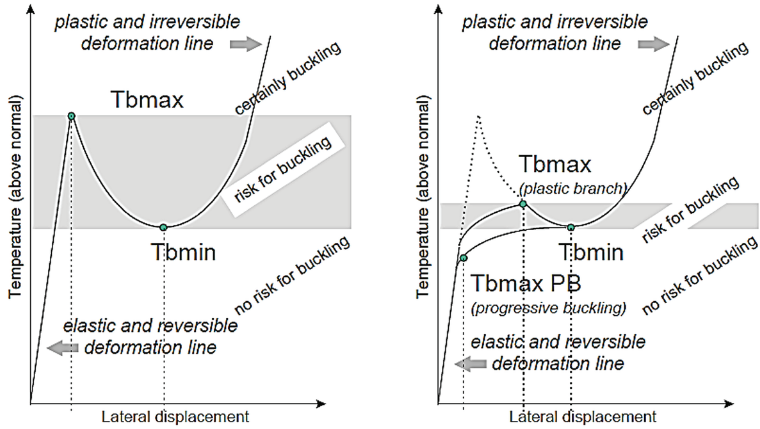


Fig.8.16 (a) – Temperature vs lateral displacement for consolidated ballast (left) and unconsolidated ballast (right).

Track condition resulting in progressive buckling should not be permitted.

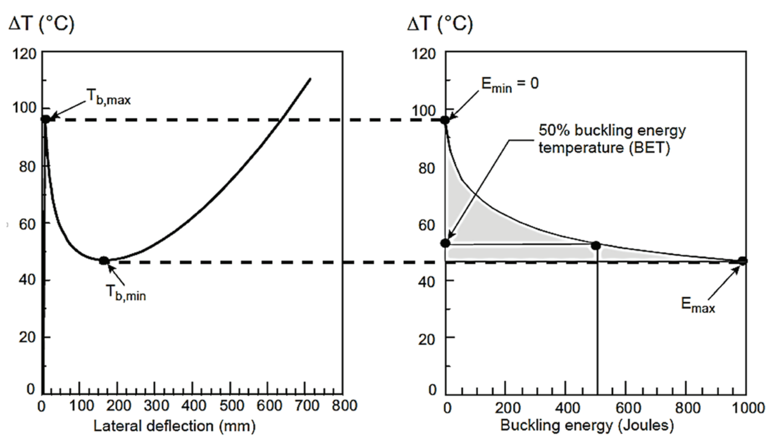


Fig.8.16 (b) – Buckling energy concepts.

Parameters	
Rail : UIC 60	Sleeper type : concrete
Misalignment: 12mm in 8m	R = 30m
Torsional resistance: medium	Longitudinal resistance: medium
Axle loads: UIC/D4	

For track safety, T_{allow} (allowable temperature) is the maximum allowable temperature above neutral temperature of rail that is considered safe against track buckling. T_{allow} can be considered as cushion with regard to increase in temperature or increase in compressive stress in rail pushing into buckling of rails. As mentioned in UIC 720

For Level 1 safety, $T_{allow} = T_{bmin.}$

For Level 2 safety, $T_{allow} = T_{bmin} + \Delta T$

Level 1 safety is more conservative i.e. safer than level 2 and the value of ΔT is to be determined based on safety consideration. Use of lower critical temperature T_{bmin} as base line for allowable temperature increase guarantee (although not absolutely) the safety of CWR track against buckling, as only above this temperature there exist possibility of track buckling. This provides high level of safety. However, influence of more complex train dynamic load, such as braking and traction, impact loads and localized thermal loads input due to wheel flanging are not included in the buckling models. T_{allow} provides some additional margin of safety against this dynamic effects (i.e. this dynamic effects indirectly accounted for by large buckling energy required to buckle the track at this temperature). Additionally difference between T_{max} and T_{min} should be larger than 200 C. In case $T_{bmax} – T_{bmin}$ is less than 5°C Tallow needs to be adjusted downwards by a factor ΔT which may be set as 5°C.

Level 2 safety based on $T_{bmin} + \Delta T$

If less conservative safety criteria is desired, T_{allow} may be dependent on each Railway organisation's ability to maintain track within desired tolerances and to control operating condition within acceptable dynamic load. T_{allow} may be increased to above level 1 value by a factor ΔT. However, choice of ΔT is not trivial as buckling potential rapidly increases above T_{bmin} as energy required to buckle the track sharply decreasing above T_{bmin}.

8.6 Dynamic Buckling of CWR Track

Theory, test and safety concept by Kish and Samavedam G suggest 50% buckling energy level allowable temperature above T_{bmin} which corresponds to 50% buckling energy temperature (50% BET) or Tall = $T(0.5\ E_{max})$= 50 % BET. However, this must be validated through full scale dynamic buckling tests. This choice is based on ERRI Committee D 202 parametric study employing CWERRI and CWR BUCKLE which close equivalence of two approaches.

If CWR-BUCKLE model is not available for determination of buckling energies an alternative definition of ΔT may be based on model prediction of T_{bmax} and T_{bmin} specifically $\Delta T = 0.25\ (T_{bmax}-T_{bmin})$. However while implementing any safety criteria based on T_{bmax} special attention must be paid to the accuracy of buckling model to predict T_{bmax} and extreme sensitivity of T_{bmax} on governing parameters

For level 1 and level 2 safety are illustrated in the Fig. 8.17

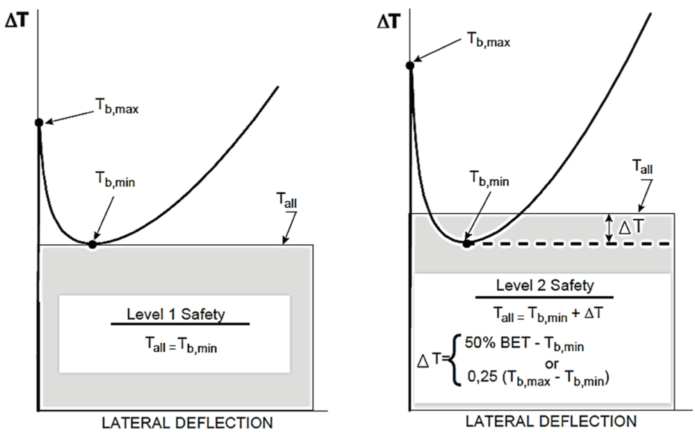


Fig 8.17- Safety criterial definition in terms of allowable temperature increase for safety Level 1 & 2

8.7 Buckling Safety Evaluation

Parameters

Rail: UIC 60	Axle loads: UIC/D4
Misalignment: 12mm in 8m	Sleeper type: concrete
Torsional resistance: medium	Longitudinal resistance: medium

NB: Estimate on lateral resistance ranges:

- Tamped to 0.2 GMT : 12-18 kN/m
- Stabilises (0.2 to 1 GMT) : 19-22 kN/m
- Consolidated : 23-28 kN/m

Buckling Safety Evaluation Safety Criterion:

$X = T_{all} - (T_{max} - T_n) \geq 0$

Where:

T_{max} = maximum rail temperature

T_n = stress-free temperature = fastening temperature – SFTN

SFTN = safety factor for T_n variation = 5^0C

Example:

For a weak (tamped R = 450m track fastened at T_f = 200C, and assuming a 12mm line defect, what is the permissible T_{max}?

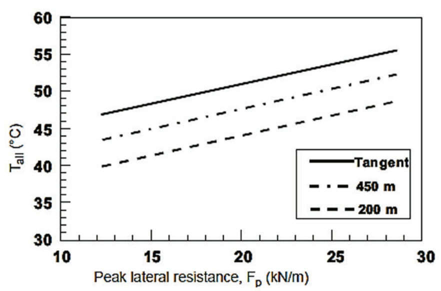


Fig. 8.18 – Buckling safety limits for CW track based on Level-1 safety criteria

Answer:

Determine $F_p \cong 15$ kN/m

Then, from figure above: $T_{all} = 45^0$C;

Then, $X = 45 - (T_{max} - 15) \geq 0$

T_{max} (permissible) = 60^0C

8.8 Track Lateral Shift Mechanism, Parameters and Allowable Misalignments

Figure 8.19 illustrates the fundamentals of track shift as a “moving load problem” in terms of number of axle passage required to produce a permanent (residual) deflection, which may be either stable (as shown by δ1 and δ2) or unstable (i.e. progressively increasing with number of passes). The key influencing parameters for these have been identified as Y/Q ratio, number of passage, loaded and unloaded lateral track resistance, rail longitudinal force. For high speed track operations, these levels of lateral misalignment are identified as

i) Initial misalignment after construction or realignment (δ_0)

ii) Maximum allowable "pre-maintenance" misalignment (δ_m),

iii) Critical misalignment at which operations are impacted and safety is potentially compromised (δ_c)

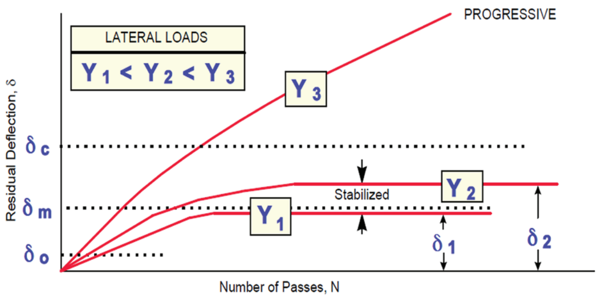


Fig. 8.19 Track Shift Mechanism

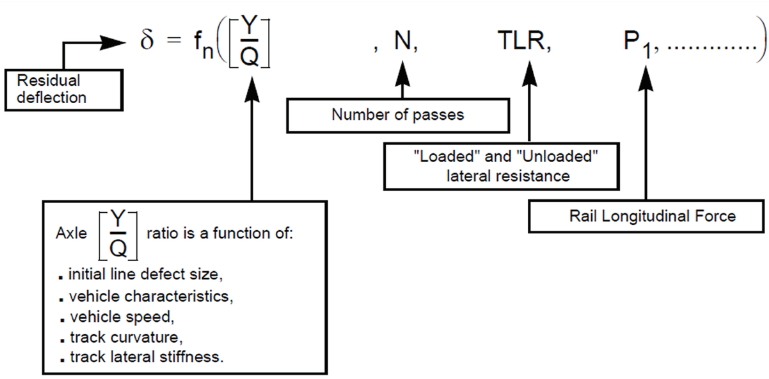


Fig. 8.20 Factors Influencing Track Shift Mechanism

Initial misalignment after realignment or construction tolerance for new track or relayed track is represented by δ_0 is typically of the order of 1-4 mm for high speed tracks. Maximum allowable misalignment prior to maintenance operation varies according to practice of individual railway δ_m, is of the order of 4-8 mm. The critical misalignment amplitude at which vehicle operation is impacted is δ_c. It may be determined by considering several failure modes i.e. sudden track shift potential, wheel climb, rail roll, buckling, inadequate ride quality and exceedance of vehicle design loads.

Displacements δ_1 and δ_2 are stable deflections at number of passes, and are reached (or allowed) only if δ_c is larger than these. For some high speed track conditions and parameters, stabilisation may not be reached prior to δ_c hence determination of δ_c for high speed tracks is key requirement for development of safety criteria which may be determined based on vehicle parameters, speed, track condition, lateral resistance and thermal loads.

Pre-maintenance misalignment δ_m can be determined on trade-off basis between frequencies of maintenance (GMT) and margin of safety based on critical misalignment δ_c. The construction tolerance δ_0, is usually determined by railways as a trade-off between cost of construction and (tolerance and quality assurance), maintenance and number passes that can be obtained between maintenance cycles.

8.9 Track Lateral Stability Mechanism

Stage	Event	Cause	Result
1	Formation of initial line defects (“small”)	(1) Initial imperfections (welds) and construction defects. (2) High Y/Q’s due to bogie hunting (3) Localized weak ballast conditions (4) Longitudinal forces	Lateral misalignment
2	Growth of misalignment (“small” to “moderate”)	(1) Net axle Y/Q increase due to line defects (2) High Y/Q’s due to bogie hunting (3) High longitudinal forces due to ΔT (4) Multiple wheel passes	Track lateral shift
3	Sudden formation of “large” misalignments	(1) High longitudinal force (2) Reduced Tn (stress-free temperature) (3) Misalignments generated by track shift (4) Dynamic uplift wave (5) Weakened lateral resistance	Track buckling

8.10 Long Term Behaviour of CWR Track

Neutral rail temperature may change in time in continuously welded rail tracks. Changes may be expected in places where rail creep may occur in the following conditions:

i) train acceleration, braking especially in combination with gradient.

ii) in sharp curves as an effect of inward/outward movement.

iii) As a consequence of track maintenance operations, like track tamping, destressing, ballast cleaning, etc.

The results of the existing work on long term CWR track response may be summarized by the following statements:

1. Changes of NRT (Neutral Rail Temperature) during service may reach 10°C. General tendency was for the NRT to shift down wards,
2. For typical train loads and track structure the longitudinal residual displacements due to track creep are equal to a few millimetres. In particular cases for very heavy trains, longitudinal residual displacements may reach about 500 mm per year,
3. Thermal loading of turnout and adjoining zones may be characterized as follows:
    a) Longitudinal force in switch rails zone may increase up to 50% in relation to the thermal force for straight track,
    b) Longitudinal displacements in the straight track reaches 2 to 10 mm.
4. Longitudinal track response due to elongation/shortening of bridge deck practically does not depend on service time.

    Long-term investigations of CWR track behaviour were conducted in Hungry and Poland in 21 sections:
    a) Straight line sections (6 sections in Poland and 2 sections in Hungary)
    b) Sharp curves (6 sections in Poland and 4 sections in Hungary)
    c) Interaction between welded turnouts and adjoining zones (3 sections in Poland)

(a) Short Term Response on Straight Section:

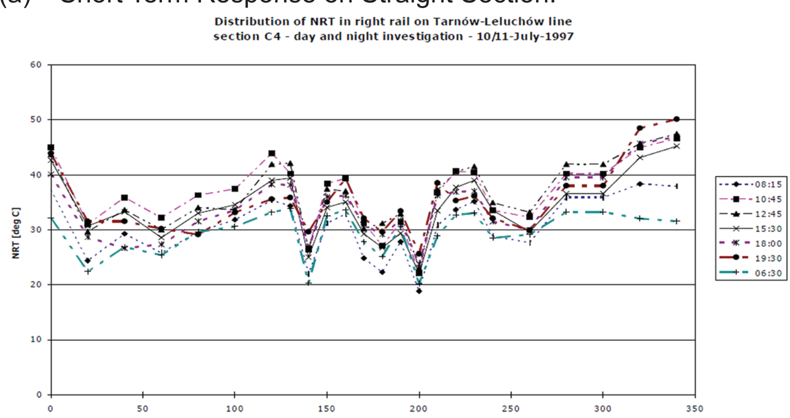


Fig 8.21a Short term Response on Straight Section

(b) Long Term Response of CWR Track

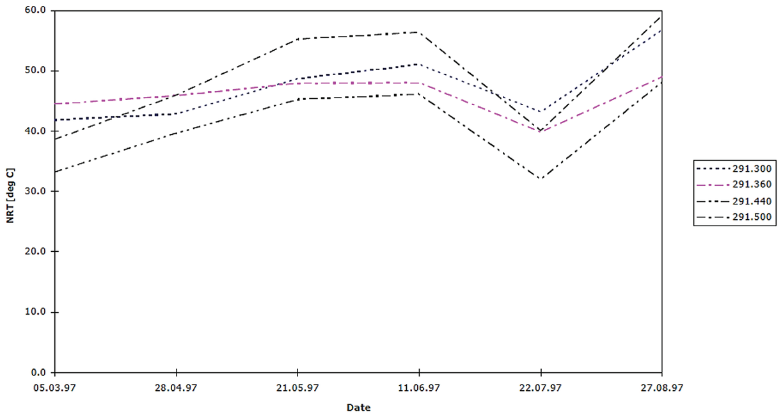


Fig. 8.21b Long Term Evolution of Neutral rail Temperature (NRT) in left rail Section S3

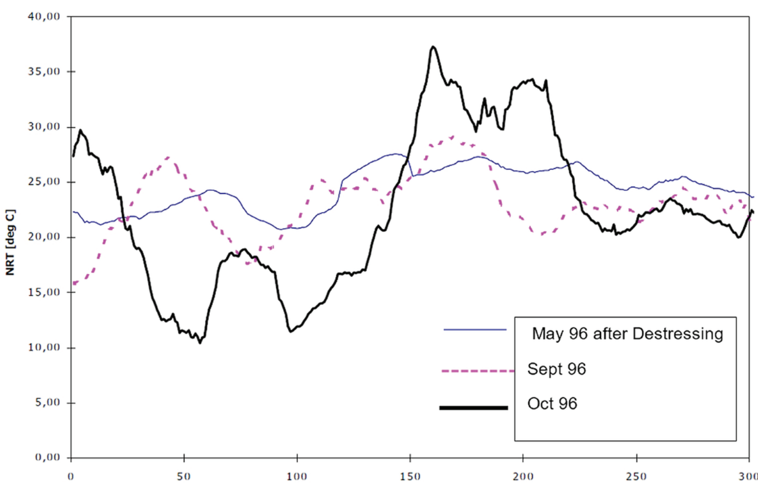


Fig. 8.22 Distribution of Neutral Rail Temperature (NRT) in right rail section Hatvan

From the results presented and additional analysis following conclusions could be formulated:

1. Changes in NRT during service reached 5 to 20^{0}C.
2. Changes of NRT during service had, in general, a form of a

random variation without distinct trend.

3. CWR track with concrete sleepers gave more stable NRT during service in relation to the track with wooden sleepers.
4. The average NRT values calculated for the test sections were not constant in the curves but shown the annual periodicity of the rail temperature.
5. Lateral displacements in the switch zone of welded turnouts may reach ±2 to 3 mm. It means that special protection (in particular for turnouts with wooden sleepers) must be introduced for limitation of displacement only to the elastic response.
6. Use of devices with NRT measurement accuracy at the level of ±3°C and displacement measurement accuracy of about 0.1 to 0.2 mm are practically sufficient for investigation of CWR track behaviour without considering special local effects (e.g. distribution of residual stresses in rail cross-section, local changes of rail material microstructure etc.).
7. Measurement of actual NRT of a given section before major track maintenance operations may be done to enable use of most suitable technology.

8.11 Neutral Temperature Measurement

8.11.1 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°C.

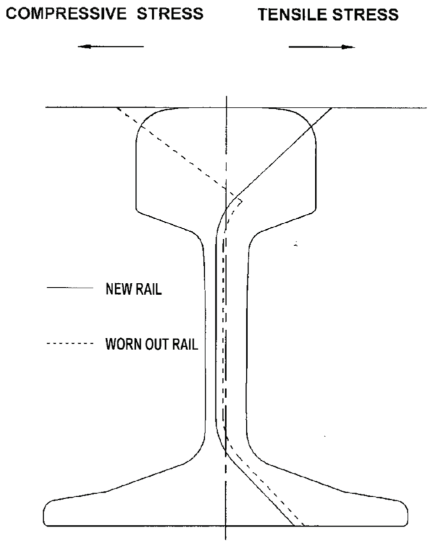


Fig. 8.23 Rail residual stresses

8.11.2 Out 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’

8.11.3 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 A 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 = Vertical load applied at centre of rail.

λ = Numerical constant value depending on the end conditions,

P_C = 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 8.24 & Fig 8.25)

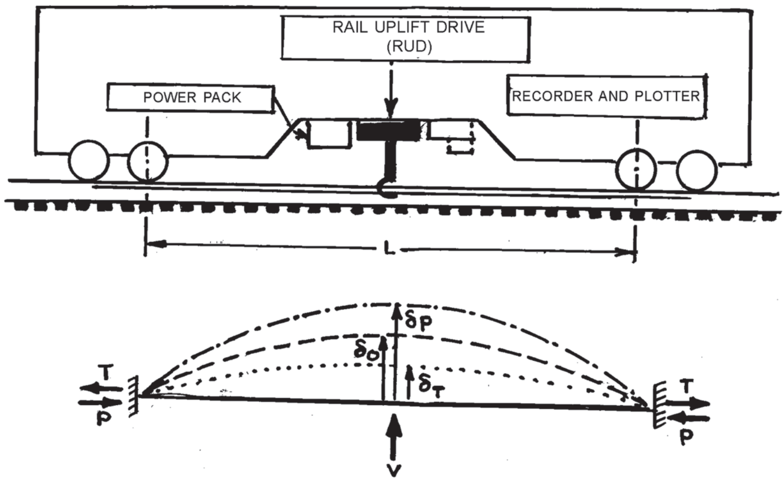


Fig 8.24 Rail Uplift Method

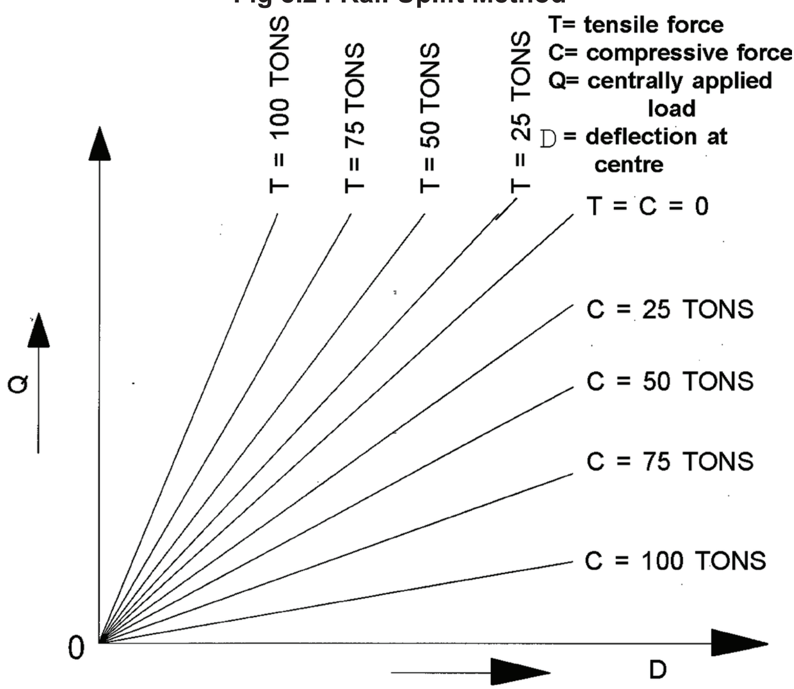


Fig 8.25 Graphical Method for Neutral Temperature Determination

8.11.4 Verse Method (Vertical Rail Stressing Equipment)

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.

The rail must be in tension at the time of measuring the stress free temperature (SFT). Taking measurements requires around 30m of rail to be unclipped and placing rail support spacers at 10 m on either side of the measuring point (Fig 8.26).

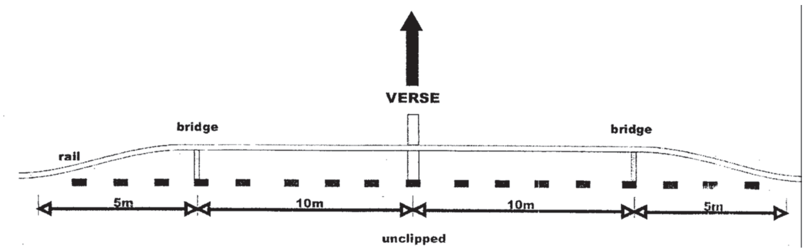


Fig 8.26- VERSE Usage Diagram

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.

8.12 Important conclusion w.r.t. practical aspects:

Straight track with small misalignment buckle at much higher temperature compared to straight track having large misalignment.

The higher sleeper density & increase in fastening torsional coefficient increases overall resistance to buckling.

The large misalignments significantly reduce the strength against buckling.

In the 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% (Rail), 30% (Fastenings) & 60% (Ballast).

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 buckling namely dynamic buckling tendencies in the rail.

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

Vibrations induced by the moving train can disturb the ballast & lower the lateral ballast resistance.

The movement of rail in x, y & z direction (axis) due to rail longitudinal movement, track lateral shift & track vertical settlement will cause shift in the rail neutral temperature.

To safe guard against buckling, following should be kept in mind

Reducing lateral misalignment in the track

Ensure adequacy & proper functioning of fastenings

Ensuring ballast profile as per prescribed profile.

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