RDSO GUIDELINES FOR CARRYING OUT RAIL-STRUCTURE INTERACTION STUDIES ON INDIAN RAILWAYS

BS 114 Version 2

Provisions with Commentary

August 2016

RESEARCH DESIGNS AND STANDARDS ORGANISATION, LUCKNOW

FOREWORD to First Version

Long Welded Rails on bridges is a dream for track maintenance engineers. Elimination of free joints on bridges help in following ways:

1. Maintenance is reduced due to lesser vibrations and impact, leading to reduced wear and tear.
2. Noise on bridge is reduced.
3. Safety is enhanced as the settlement on free joints is eliminated, leading to reduced twist in track.
4. The track is less prone to sabotage as there are no fish-bolts that can be opened by unscrupulous elements.

LWR manual of Indian Railways have allowed to lay LWR on girders with bearings only with rail-free fastenings so far. This has created problems in field as bridges with even single span ballasted deck girders had to be isolated by providing SEJs on either approach to isolate the LWR. Efforts were made first by HAG committee comprising of Director IRICEN, PCEs SE Rly and SC Rly, ED/Track-I/RDSO and ED/B & S/RDSO and then by B & S dte of RDSO to study the phenomenon of Rail-Structure Interaction. The contribution of Sh A K Goel, the then Director/IRICEN, Sh Ajay Goyal, then Senior Professor/Bridges-I/IRICEN and all members of HAG committee in this field is very important. This document is ultimately a compilation of work done on the subject till now. This document borrows heavily from the “RDSO Guidelines for Carrying out Rail-Structure Interaction studies for metro systems” Ver 2, issued in January 2015 and the contributors to that report are also acknowledged.

Work done at RDSO by Sh V B Sood, Director/B & S/SB-II and his team comprising Sh B P Singh, DD/SB-II, Sh Uma Shanker JE/Design, Sh Nilesh Kumar, SSRE and Sh Prakash Kumar Ranjan, JRE/Design who have carried out RSI studies for over 35 bridges on Indian railways and have done hundreds of trials with different configurations with an aim to understand the phenomenon and to lay down these guidelines is also commendable.

Feedback/ suggestions/ questions on issues regarding these guidelines may kindly be directed to directorsteel2@gmail.com.

A K Dadarya
Executive Director/B & S
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Lucknow,
November 2015

FOREWORD to Version 2

RDSO has made great strides in the field of conducting RSI ever since this BS report was published. Different types of bridges with girders like PSC, composite etc, bearings like elastomeric, sliding, POT/PTFE etc and foundations like open, pile, well etc have been done. Till date, 51 cases have been examined and 46 bridges were found suitable for continuing LWR.

The problems have been noticed in bridges with pile foundations and elastomeric bearings or, in one case, where the bridge layout was very badly planned. Some errors have been found in provisions of earlier version of this report, mainly in working out stiffness of cracked RCC piers and well foundations. One issue has been found that the thermal effects and vehicle effects need to be worked out separately if the bridge supports are asymmetric such as in case of POT/PTFE bearings or if the spans are dis-similar. Some minor typographical errors too have been found. These corrections have been made in this report along with the example.

Feedback/ suggestions/ questions on issues regarding these guidelines may kindly be directed to directorsteel2@gmail.com.

A K Dadarya
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Lucknow,
August 2016.

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1.0 INTRODUCTION

1.1 GENERAL

The purpose of these guidelines is to define the methodology for carrying out the Rail Structure Interaction (RSI) to be considered on bridges of Indian Railways. The guidelines provide a basis for carrying out RSI studies and thus to work out the forces induced in rails and bridge components due to the interaction effects and to assess if the arrangement will be safe under the interaction effects.

Paras 2.8.1(d) and 2.8.2.4.3 of Bridge Rules which were reintroduced/ modified in 2014 (Correction Slip no 45 which introduced this para is placed at Appendix A). The clause 2.8.2.4.3 of Bridge Rules refers to UIC 774-3R for carrying out RSI till the forces due to continuation of LWR/CWR on bridges in Indian conditions are finalized. **This document explains methodology to be adopted to use UIC 774-3R for Indian Railways specific scenario.** Also, certain aspects of RSI on which UIC 774-3R is silent have been explained with references to provisions available in other codes like European codes, Spanish National codes or Korean codes etc. Data required for RSI and example of RSI carried out by RDSO with explanatory notes has been given at the end.

C1.1

UIC Leaflet 774-3R 2001 is the basic code on which subsequent codes have evolved. The UIC leaflet is based on earlier research on the related phenomena. The leaflet describes methodology to be adopted for carrying out interaction studies, based upon numerical methods that idealize the behavior of all the elements and actions involved for the computation of stresses and displacements. Specific clauses of other codes, wherever used, have been mentioned in the commentary.

1.2 ADAPTATION / MODIFICATION TO EXISTING RULES

These guidelines are meant to supplement and explain (but never replace) provisions of Bridge Rules and/or other codes/ specifications already in vogue for design/ detailing of bridges. This document gives some simplified methods to model the structure/ structural behavior but **it shall remain the responsibility of the designer to ensure that the behavior of actual structure is as per the simplified assumptions given in these guidelines.**

C1.2

These specifications cover only one aspect, namely RSI, and do not specify the loads to be used for design, and other checks required for stability/ safety of the structure. There are other closely linked phenomena like dynamic analysis and the vehicle – track – bridge interaction etc which are not covered in these guidelines. The basic principles of structural analysis are also required to be adopted to capture the structure behavior realistically.

1.3 RELEVANT CODES & STANDARDS

- Rules specifying the loads for design of super-structure and sub-structure of bridges and for assessment of the strength of existing bridges

C1.3

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(**Bridge Rules**)

- **UIC 774-3R** October 2001: Track/Bridge Interaction – Recommendations for calculations.
- IRS Code Of Practice For Plain, Reinforced & Prestressed Concrete For General Bridge Construction (**IRS Concrete Bridge Code, Reprint Sept 2014**)
- **UIC 776 2R**: Design requirements for rail bridges based on interaction phenomena between train, track and bridge.
- **Korean Design Standard:** Railway Design Manual (*Volume* Track)
- Eurocode 1: Actions on structures — Part 2: Traffic loads on bridges (**EN 1991-2 – 2003**)
- **TCRP report 155, 2012:** Track Design Handbook for Light Rail Transit, second volume,

1.4 IMPORTANT POLICY DOCUMENTS

The following documents are important for RSI studies on bridges:

- A & C Slip No 45 to Bridge Rules.
- Policy letter no CT/IM/LWR/Part Dated 19/25.03.2014 issued by ED/Track-I/RDSO regarding providing LWR on bridges on trial basis for bridges upto 110 m length (individual spans upto 24.4 m with fixed-free bearings and 45.7 with elastomeric bearings) with the approval of PCE.
- Letter no CBS/Project/LWR Dated 05.09.2014 issued by ED/B & S/RDSO which covers the software to be procured and how the infrastructure shall be created for starting the RSI analysis work on Indian Railways.

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C1.4

These policy documents are placed at Annexure A. The current policy position regarding LWR on bridges for Indian Railways is:

- **All ballasted deck bridges shall be designed for LWR effects.**
- Parameters for carrying out these studies for bridges on straight have been specified. For others, in the absence of these parameters, the RSI studies cannot be carried out hence LWR cannot be provided except by using other codes for which appropriate approval from railway Board shall be obtained.
- The LWR can be laid on trial for bridges upto 110 m length and individual spans upto 24.4 m with fixed-free bearings and 45.7 with elastomeric bearings with the approval of PCE.
- For other bridges also, new bridges have to be checked for RSI effects but provision of LWR is not yet allowed.

2.0 SCOPE

C2.0

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These guidelines explain the interaction phenomenon, parameters affecting RSI, provide guidance on choosing representative stretches for conducting RSI, methodology to be adopted for carrying out RSI, special cases in RSI, use of computer programs for carrying out RSI and options available for modification in track if the RSI results indicate excessive stresses/ deformations.

These guidelines cover steel/concrete bridges with simply supported or continuous spans, on straight alignment, both level as well as those on gradient, having any type of bearings on Indian Railways. However, **these guidelines do not cover the bridges on curves or bridges with long/special spans such as cable stayed bridges, Bow-string arch girders etc** where the typical structural behaviour of spans affects RSI phenomenon requiring specialized studies to be carried out or where span arrangement induces excessive movement in track which is beyond the capacity of a typical Switch Expansion Joint (SEJ) to accommodate.

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The Rail-Structure Interaction phenomenon originates from the fact that the bridge is moveable under thermal and live load effects whereas the rails as part of LWR/CWR are not free to move. This difference in movements induces stresses in rails/ bridge components which need to be studied.

Different bearings/ bridge forms need to be modelled such as to reflect their actual behaviour under the RSI phenomenon. In structures like cable stayed bridges, the flexibility of deck and non-linear response due to presence of cables supporting the deck require more complex models that capture all phenomenon accurately. RDSO has no experience presently with these models and so these are beyond the scope of these guidelines. Similarly, for large movements in track, specialized solutions are required to be worked out. These are site-specific solutions, and track experts are required to study the site conditions and design these arrangements.

3.0 GENERAL CONCEPTS

General concepts describing the RSI phenomenon covering the effect of train loads (vertical as well as longitudinal) and the effect of thermal changes are given in this section.

C 3.0

The long term phenomena like effect of dead loads, deformation of deck under creep/ shrinkage etc are considered to be dissipated during various track maintenance operations and hence are not considered while carrying out the RSI studies.

3.1 INTERACTION PHENOMENON

In jointed track, the analysis of effect of various loads on rails and on bridge is carried out separately. However, this type of analysis is not appropriate when the continuously welded rails (which restrict the free movements) are laid on the structure because then the track-structure interaction shows non-negligible effects.

The presence of deck under the tracks induces extra stresses in the rails due to interaction phenomenon and this affects stresses in bridge components also. **The extra stresses in the rail are induced by thermal expansion/ contraction of bridge deck(s)/tracks, deflection of sub-structure**

C 3.1

In jointed track, lots of gaps are available normally in joints and the track/ bridge can move independently to some extent. For rail-free fastenings also, the track and bridge move independently, so there is no interaction between these. Hence, for these, there is no requirement for carrying out RSI studies.

The purpose of RSI analysis is to examine these extra stresses in rails due to the actions of temperature change, braking / traction of rolling stock combined with the vertical bending caused due to live loads. These stresses are required to be kept within

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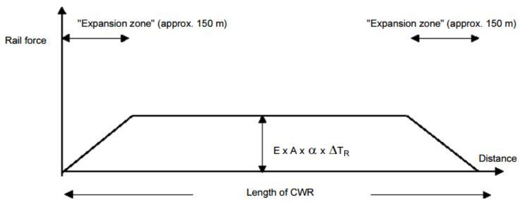
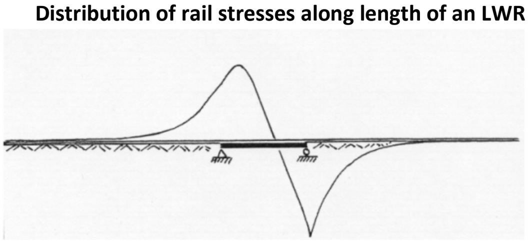
under tractive/ braking forces from the trains and the end rotations caused by vertical bending under vertical train loads.

The magnitude of these extra stresses in the CWR mainly depends on the stiffness of various elements of bridge, resistance offered by the track structure to deformation and the boundary condition of rails (i.e. whether these are continuous or have expansion joint(s) in between). The RSI describes the effects, under various loads, of structural collaboration of rails and bridge by means of their connection elements.



Distribution of rail stresses along length of an LWR



Distribution of rail stresses affected by presence of bridge due to change in length of bridge deck under thermal/ live load changes

The difference between LWR/CWR on ground vis-à-vis LWR/CWR on bridge is that a bridge has lesser stiffness which results in its deformation under various loads/ thermal effects. **The track is supported on the bridge and has to respond to these movements. But the rails, being continuous, are not free to move and resist these movements, which induces loads in them. These loads cause the track as a whole to move, which relieves part of the loads, which are transferred back to the structure. The final deformations/ stresses in track and viaduct depend on this interaction, which is basically governed by the stiffness of track and that of the bridge.** This interaction between track and the bridge structure is studied as RSI effect.

The RSI phenomenon, as explained above, is non-linear which can only be solved by an iterative procedure to get a solution that satisfies all boundary conditions. There can be no formula to be directly

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allowable limits so that the track is safe under tension as well as compression, and the bridge elements are to be proportioned to take all the loads. If the RSI study indicates extra stresses in rails beyond permissible limits, these can be brought within limits by altering either the stiffness of the structure and/or the fixing arrangement of the rails to the bridge structure and/ or introducing expansion joints.

The interaction phenomenon can be summed up as the interplay of stiffnesses of different components namely track, girders and supports (Bearings, sub-structure and foundations). The component which is stiffer will attract more stresses. If the sub-structure is flexible, it will move under loads and the rails will be subjected to higher stresses, which can be unsafe for the train operations. Quite often the purpose of RSI is to ensure that the bridge is stiff enough such that the track is safe.

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used to determine the stresses or deformations etc. The results can be obtained by two ways: we can use the charts given in the UIC 774-3R or we can model the bridge, track and approaches and find out the results using Finite Element Method based computer programs which try to solve the non-linear problem through convergence of results through iterations. The relative stiffness's of different elements like track, deck, sub structure and bearings play important role in determining the results. The designer has to change the stiffness's/ arrangement to optimize the performance and costs.

3.2 PARAMETERS AFFECTING RSI

3.2.1 Expansion Length

Expansion length is defined as the distance between the thermal center point and the opposite end of deck. In simple terms, this means it is the length over which structure is allowed to expand/ contract by the supports. Free/ moveable bearings allow expansion/ contraction to take place whereas fixed bearings do not allow the same. Expansion length depends on the type of support configuration adopted in a structure. Expansion length is defined and indicated on different type of structures in para 1.1.3.1 of UIC 774-3R 2001.

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Before start of RSI study, data on bridge and LWR shall be available at hand. **Complete list of data required for the same is given in Appendix B.**

C 3.2.1

What shall the expansion length be for different cases? **This question needs to be answered if graphs as per UIC 774-3R are being used for RSI computations.** This shall be worked out as follows:

- **For simply supported spans** with one end having fixed bearing and other end having free bearing, expansion length is the distance between the fixed bearings.
- **For continuous spans** having a fixed bearing somewhere in the middle, there are two expansion lengths, one on each side. For succession of decks, the expansion length at a joint is equal to the sum of expansion lengths of nearest two spans.
- **If the structure does not have fixed bearings** and arrangement has neoprene or sliding bearings, the expansion length has to be worked out between thermal center-point (i.e. point which will not move under thermal effects) of the deck and its extremities.

Para 1.3.1 (Figure 6) of UIC 774-3R 2001 may be referred to determine expansion length for

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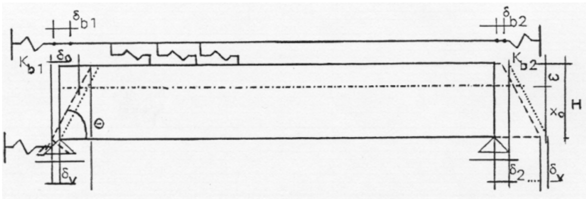
different types of support configurations commonly adopted in bridges.

3.2.2 Span Length

The vertical train loads cause rotation at ends of decks. Since the rails are not fitted at the neutral axis of the deck, the length of fibers at the track level changes under these loads. This leads to longitudinal displacement, and thus, stresses in tracks which depends on the magnitude of load as well as span length. The span length is measured as center to center of bearings on supports.



Schematic indication of longitudinal displacement of deck fibres at rail level under vertical loads (Springs indicate restraints due to track and supports)

C 3.2.2

The center to center distance (or effective span) between supports is the span length for this purpose. As against this, normally the expansion length for simply supported spans is overall length of girder. **To simplify the computations,** sometimes, analysis is done considering overall length for both. **Alternately**, the span can be modeled and the actual rotation at ends under live loads can be determined.

3.2.3 Bending Stiffness of Deck

The bending stiffness of each deck is required to calculate the vertical deformation effects on structure under the vertical loads of rolling stock.

C 3.2.3

The stiffness of deck is required to be computed to get the deck rotation under loads. As explained above, this deformation leads to change in deck length and tries to change the length of track which induces the interaction effect. In case the cross-section varies along span length, exact computation may be done. **Alternately, to simplify computations,** if the cross-section at center has lesser section modulus than that at ends, the cross-section at center may be adopted. If section at center is higher section modulus than that at ends, an average section may be considered without too much error.

3.2.4 Deck Height & Rotation Distance

The change in length of the deck fibers supporting rails is affected by the distance between deck level supporting track and the neutral axis of the deck which is termed as rotational distance and the total distance from bearing to the top of deck, called deck height.

C 3.2.4

The longitudinal displacement of deck is described in clause 1.3.3 of UIC 774-3R 2001. It is evident that if the track is supported nearer to neutral axis of girder, this effect will be lesser, and vice versa.

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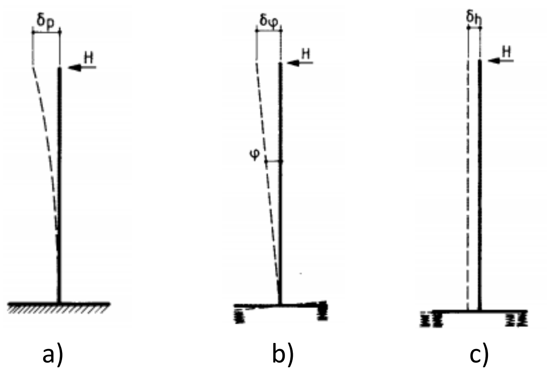
3.2.5 Support Stiffness

A major source of interaction phenomenon is the stiffness (or, more correctly, flexibility) of bridge supports under longitudinal actions (braking/tractive loads and temperature variations). The longitudinal stiffness of sub structure depends on stiffness of individual components viz, foundation, sub structure and bearing. Stiffness of different parts should be combined to get total stiffness Ktotal as follows:

$$\frac{1}{K_{total}} = \frac{1}{K_{pier}} + \frac{1}{K_{bearing}}$$

where Kpier is stiffness of each sub-structure (pier/abutment) and Kbearing is stiffness of bearing. Kpier has further components as described in figure below:



Longitudinal displacement of deck due to a) Elastic deformation of sub structure, b) Rotation of foundation and c) Longitudinal movement of foundation.

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C 3.2.5

The effects of longitudinal loads on the substructure is described in clause 1.3.2.2 of UIC 774-3R 2001. The stiffness of the sub structure, $K_{pier} = H/\Sigma\delta_i$ where δ_i is the deflection of sub structure due to:

1. Displacement due to elastic deformation of sub structure.
2. Displacement due to rotation of support.
3. Displacement due to longitudinal movement of foundation.

All the above displacements have to be worked out at the top of bearing level. While computing stiffness, for sustained temperature loading analysis, long-term Young's modulus shall be used, whereas for the short-term effects of braking and tractive loading, instantaneous modulus shall be used. **Young's modulus should be determined as per IRS-CBC:2014 and the Young's modulus for long term effect is normally taken as half the Young's modulus for short term.**

3.2.6 Track Stiffness

The track stiffness is a measure of resistance offered by the track to longitudinal movement. Stresses are induced in track as a response to all the movements in deck/ bridge via interaction through track stiffness. The track stiffness is dependent on multiple factors like:

- Type and condition of track structure.
- Load on Track.
- Maintenance condition of Track.

Deformation of track is a bilinear curve as suggested in clause 1.2.1 of UIC 774-3R. Typical track stiffness curve is as follows:

C 3.2.6

In RSI, the movement of bridge under different loads is considered. The stresses induced in the track due to these movements and actual movement of track depends on the interaction effect which is dependent on the track stiffness curve. **Track stiffness is a very important parameter in RSI and can be manipulated by changing the track characteristics to allow movement at critical locations thus ensuring that extra stresses on account of RSI are within limits.**

The curves given in para are idealized form of actual behaviour of track, as indicated below:

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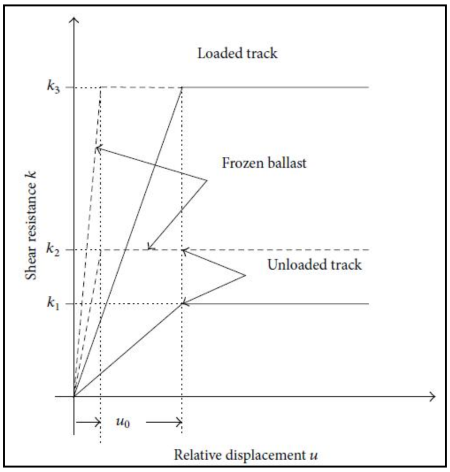

Longitudinal resistance of track is provided by fasteners in ballast less track and by ballast in ballasted track. **In idealized curve, resistance is proportional to the displacement of rail relative to the supporting deck until a relative displacement of u_0 is reached, which corresponds to elastic limit. Beyond this point, the fasteners/ballast cannot resist any further load and perfectly plastic behaviour of track is assumed:** the resistance force is constant while the movement continues (plastic shear resistance). **The elastic limit is different for frozen and unfrozen ballasts. Analogous to frictional behavior, plastic shear resistance of the ballast is higher when an additional vertical load i.e. train load is applied to the track.**

As per clause 2.8.2.4.3 (d) of Bridge Rules, the track resistance in ballasted deck bridges **for track structure minimum 52 kg 90 UTS rails and PRC sleepers at density 1540 nos/KM with elastic fastenings shall be:**

- **25 kN per meter of unloaded track**
- **50 kN per meter of loaded track**

A note for capturing this behaviour by computer programs: The behavior of track under longitudinal

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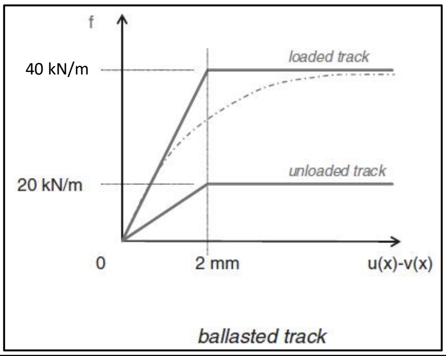

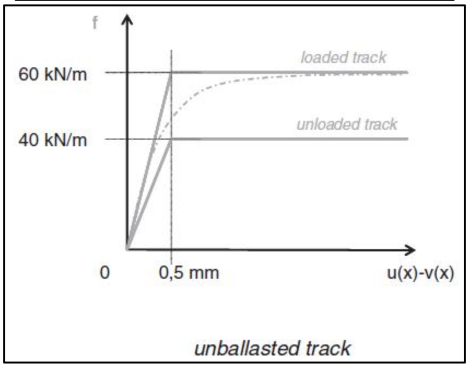

The elastic limit is 0.5 mm for ballastless track (and for frozen ballast) and 2 mm for ballasted track (unfrozen) as per clauses 1.2.1 and 1.2.2 of UIC 774-3R 2001.

The track resistance values for ballastless track have not been laid down in IRS Bridge Rules, so if such track is used and RSI computations are to be done, these values shall be taken from track design engineers.

For guidance, limiting plastic track resistance given in the clause 1.2.2 of UIC 774-3R 2001 for unballasted deck can be **referred**

- 40 kN/m for unballasted track (unloaded).
- 60 kN/m for unballasted track (loaded).

The frozen ballast also acts quite like ballastless track.

The implementation of connector elements representing ballast/ fasteners in the

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forces is quite complex. When the direction of displacement changes, the ballast behavior becomes elastic again, but the relative displacement from sliding is not recovered. **Any computer program to be used for carrying out RSI studies shall be capable of capturing this behaviour realistically as per actual behaviour in field.**

3.2.7 Sectional Properties of Rails

The cross sectional area of the rails in track, Young's modulus of the rail-steel and other parameters of rails are required to work out stresses in rails.

3.2.8 Temperature variations

The temperature changes induce change in length of deck and/or rails. The decks with bearings permit expansion/ contraction with change in temperature. The temperature variation is measured with respect to reference temperature. If the deck/rail length changes, the interaction phenomenon described above kicks in.

As per the clause 2.8.2.4.3(f), no checks are required for forces/effects due to continuation of LWR/CWR on integral bridges like Arches, RCC Boxes and slabs without bearing which are not free to expand/ contract, and are quite stiff.

The temperature variations are determined separately for deck and rails. **The rail temperature variation is important only if Switch Expansion Joint is provided on the bridge or within 100 m on approaches.** Otherwise, the LWR does not change in length during thermal variations and the reference temperature of rail/ its temperature variation is not required to be considered.

3.3 VERIFICATION OF TRACK AND BRIDGE CONFIGURATION THROUGH RSI COMPUTATIONS

Parameters to be verified during RSI studies are

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interaction phenomenon causes many other complications, including that **activation and deactivation of elements is a function of the presence of train load.** These cannot be realized in many engineering FEM programs commercially available. This aspect needs to be examined before an FEM program is chosen/approved for carrying out RSI analysis.

C 3.2.7

C 3.2.8

For deck, reference temperature is the temperature at which the rails are fastened to the deck. Fastening of rails to deck is done either at the time of initial laying or during subsequent distressing/ other maintenance operations. **During maintenance, rails shall be fixed to deck at near about the reference temperature for which the RSI computations were carried out for the viaduct.**

Temperature variation shall be the difference between actual installation temperature of LWR and the maximum/ minimum temperature at the location. In the higher of the two differences, 5^0C shall be added. This 5^0C will give flexibility of $\pm 5^0$C for fastening rails in future.

For rails, reference temperature is the stress-free temperature of the rail, which is determined on the basis of rail temperature zone given in LWR manual or actual temperature records. **The stress-free temperature shall be as decided by track engineers. It shall be ensured that the stress-free temperature for LWR on bridge is not altered without consulting with the bridge design engineer regarding RSI effects.**

C 3.3

The combined response of track and structure,

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the following:

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as studied by RSI, can have unfavorable effects on either the bridge structure or the rails. Design/ layout/ dimensions of the bridge or the track configuration may have to be changed to keep these unfavorable effects within limits.

3.3.1 Additional Stresses in Rails

The additional rail stresses due to the various actions should be limited to ensure that no rail fracture takes place due to overstressing and the track structure does not buckle. The additional stresses permitted for the RSI phenomenon shall be laid down by track design engineers looking at the rail stress computations done for the rolling stock, LWR and other effects.

Bridge Rules Clause 2.8.2.4.3 (b) specifies that **on tangent tracks**, the additional stresses in rail as per RSI computations shall not exceed values as given below:

Rail Section	Maximum additional stresses in compression	Maximum additional stresses in tension
60 Kg 90 UTS Rail	60 N/mm^2	75 N/mm^2
52 Kg 90 UTS Rail	50 N/mm^2	60 N/mm^2

C 3.3.1

The additional stresses allowed for the interaction effect are within the total rail stresses. **The term 'additional stresses' has been used as this component is being verified separately to ensure proper functioning of track under RSI phenomenon.** The margin for additional stresses is derived from the total stresses by limiting the curvature on bridges while considering the RSI effects, and from the fact that the track is better maintained on bridge as compared to normal ground.

The additional allowable stresses are lower for compression as compared to tension to keep additional factor of safety towards possibility of buckling. For ballastless track, the possibility of buckling is not there, which shall be considered while determining the allowable stresses.

For Indian Railways, the additional stresses for curved track have not been specified in IRS Bridge Rules. So, if any new bridge is being planned with curvature, the allowable additional stresses shall be specified by track design engineers/RDSO.

3.3.2 Displacements of Bridge Elements

Too much displacement in the bridge structure can cause instability in track structure. Therefore, as per clause 2.8.2.4.3 (c) of Bridge Rules, the limits laid down in UIC 774-3R 2001 on the displacements of bridge elements shall be satisfied.

C 3.3.2

The ballast packing can get loose or the entire track assembly can get unstable if too much displacement is there in bridge elements. These checks also control passenger comfort and, indirectly, the additional stresses in rails.

3.3.2.1 Longitudinal displacement of Deck due to movement of substructure

Due to tractive/braking loads, the displacement of rails and deck needs to be limited. The absolute horizontal displacement of the deck, worked out for tractive/braking loads through RSI studies, shall not exceed:

C 3.3.2.1

The limits are as per clause 1.5.3 of UIC 774-3R 2001. Excessive movements of decks can result in deconsolidation of ballast / deformation in the track plinth due to which proper performance of track cannot be

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- **5 mm in case CWR runs through one or both ends of the bridge.**
- **30 mm in case of bridge with jointed track/ expansion devices.**

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ensured. This limit also indirectly controls the rail stresses.

If the deck movement worked out as per RSI comes to be more than permissible, the options are either to discontinue LWR/CWR on the bridge by providing SEJs on either approach (and provide jointed track on bridge), or to provide switch expansion joint at one or both ends of the girders. **As per clause 2.8.2.4.4 of Bridge Rules, the option (Of not providing LWR on bridge or providing LWR with one or more SEJ(s)) shall be as per approval of Principal Chief Engineer of the zonal railway.**

3.3.2.2 Longitudinal displacement of Deck due to rotation of deck

Due to vertical loads, the longitudinal displacement of upper surface of deck end from embankment or between tops of two consecutive decks **shall not exceed 8mm.**

C 3.3.2.2

The limit is as per clause 1.5.4 of UIC 774-3R 2001. This check is given to ensure stability of ballast under the various deformations. To work out the longitudinal displacement of deck due to rotation of deck, the deck rotation at ends shall be worked out and same shall be multiplied by the distance between neutral axis of girder and rail. For open web/U-girders, if neutral axis is above the location of deck, this value can be negative. For plate/ composite girders, this value is always positive.

3.3.2.3 Relative displacement between rail and deck or between rail and embankment

The relative displacement between the rail and deck or between rail and embankment under tractive / braking forces **shall not exceed 4mm.**

C 3.3.2.3

The limit is as per clause 1.5.4 of UIC 774-3R 2001. This relative displacement determines the stability of track structure. Para 2.1.2.1 of UIC 774-3R mentions that "….relative rail displacement is not needed for verifying the effects of temperature variation and always lies within the limit value for the effects due to braking as long as absolute displacement of the deck stays within the limit value of 5 mm."

3.3.2.4 Vertical displacement of upper surface of deck with respect to adjoining structure

The vertical displacement of upper surface of deck in relation to the adjacent structural elements also needs to be checked. UIC 774-3R 2001 does not

C 3.3.2.4

Vertical displacement of the deck is a source of discomfort for the passengers and this has to be limited based on the speed of train

PROVISIONS | **COMMENTARY**

specify any limits for this and leaves the same to the concerned authorities to decide. **These limits have not specified in Bridge Rules and this check may not be performed normally for bridges on Indian Railways. However, where higher speed trains are moving, the values as per EN codes may be used.**

operations.

As per clause 6.5.4.5.2 of EN 1991 – 2003 part 2, the maximum vertical displacement shall be 3 mm for maximum speeds upto 160 km/h, and 2 mm for maximum speeds greater than 160 km/h.

4.0 STEPS IN CHECKING A STRUCTURE UNDER RSI

C 4.0

4.1 CHOOSE REPRESENTATIVE STRETCH FOR RSI STUDY IN LONG VIADUCTS

C 4.1

Track on very long stretches of viaducts pose the issue of choosing stretches on which RSI study is to be done.

Representative stretches for RSI studies shall be identified along the viaduct by studying the following :

- **Change in Pier Stiffness:** This occurs at locations of
  - Integral Spans.
  - Change in Bearing Arrangement.
  - Extended Pier Caps.
  - Change in soil conditions.
- **Change in Span Stiffness:** This occurs at locations of
  - Change in span length.
  - Change in girder type.
  - Steel Bridges
  - Composite Girders.
- **Change in Span Arrangement:** including:
  - Stations on viaduct.
  - Cross Over Locations on viaduct.

Normally bridges on Indian Railways are not that long and entire bridge can be taken for RSI studies. But long viaducts can be planned in hilly or built up areas, so these paras are included.

The results of RSI are dependent on the stiffness of different elements and it is quite clear that any stiff element will attract more force. Choosing representative section is very important to get the worst scenario possible. The changes in the lateral stiffness of span supporting elements and bending stiffness of the deck have a major impact on the vertical deck deformation and lateral deck movement.

The RSI studies for a viaduct shall be done for stretches. **A stretch is defined as viaduct from station to station or from its start to next station or complete viaduct.** The evaluation shall be done as follows:

- Small stretches of viaducts upto 20 spans can be fully modeled and studied under RSI.
- For longer stretches, RSI studies shall be conducted on representative stretches of the viaduct such as to cover the worst combinations of long spans/ flexible sub structure/ curved alignment/ stations/ any other special features of alignment. **If a clear cut representative section is not identifiable, or there are multiple critical locations, multiple representative sections shall be chosen for analysis.**
- In addition to complete stretch evaluation, any special spans (special from span length, sub

The RSI evaluation for viaducts can be done for the stretches and in case the stresses/ movements are above the laid down limits, additional analysis shall be undertaken to identify the trends of stresses/ deformations and possible remedial actions. Based on these analyses, remedial action to alter the viaduct design or track arrangement shall be determined and RSI studies carried out again.

PROVISIONS

structure height, span type etc considerations) should be evaluated in a standalone analysis.

- **The stretches taken up for RSI study must include minimum 100 m track (whether on viaduct or embankment) beyond the stretch/span/location of interest.**

COMMENTARY

100 m track length (whether on viaduct or embankment) on either side of the viaduct/ stretch/span of interest has been specified since this length is required to anchor the rails and to dissipate the longitudinal forces. As per para 1.7.3 of UIC 774-3R "The model shall also include a part of the track on the adjacent embankments over at least 100m."

4.2 VERTICAL TRAIN LOADS

As per clause 2.8.2.4.3 (a), the vertical train load shall be as per design loading or the heaviest trains actually running on the route, depending on the type of analysis being done. Train loads shall be enhanced by the appropriate Coefficient of Dynamic Augment (CDA) specified in the Bridge Rules. The placement of load shall be done such as to create maximum rotation at the ends.

To avoid running the multiple trains specified in Bridge Rules for each loading, as an alternate method, Uniformly distributed loads may be used as a substitute to the actual loads, with the following magnitude:

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
25 T Loading 2008	182.95	104	47	22	0	34	13
MBG Loading	182.91	91	47	18	0	34	13

Notes:

1. For other loadings like BGML/RBG/CC+6+2/CC+8+2 loadings, the UDL for MBG 1987 may be used to be on conservative side.
2. The vertical loads in tables above include full impact load also. If some bridge has restriction on speed, the impact load may be reduced according to IRS Bridge Rules provisions.
3. **If the bridge fails marginally in RSI with EUDL approach, actual train loads may be used for exact analysis.**
4. **For bridges with uniform spans, the UDL shall be**

C 4.2

The loading standards specified in IRS Bridge Rules consider multiple trains for each loading, which will require RSI studies to be done multiple times for different trains. This is likely to be very tedious and time consuming. The complexity of problem can be gauged from the following:

- EUDL for smaller loaded lengths has more intensity of load, which goes down as the loaded length increases.
- Impact factor changes with the loaded length.

To simplify the computations, the approach with uniformly distributed trains has been devised. RDSO has done correlation studies of load specified with the actual maximum load for spans >10 m, and upto 125 m. The best correlation was found if we divide the load into two parts (First 12 m separate and rest of the load separate). The maximum load is captured with an error less than 5% on lower side. The error on higher side is also reasonable for most spans, going upto 20% for few intermediate span lengths only. Extra margin may be available in many cases, so it has been recommended that if a bridge fails with uniformly distributed load, it may be rechecked with the actual axle loads.

Note: It is generally not necessary in RSI to capture effects for less than 10 m span as slabs and other type of structures used for lesser spans are not required to be studied for RSI effects.

Another benefit of using the UDLs is that

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applied at one end of span and moved by 1/10th of span in each increment. If dis-similar spans are there, the increment shall be worked out such that beginning of load is placed at each end of span (i.e. on each pier and abutment).

5. If the bridge is symmetric, UDL loads given above may be run in one direction only. But if the bridge is asymmetric in span configuration or in stiffness of the bridge elements or in cases of fixed-free bearings such as POT-PTFE bearings, the UDL loads shall be run in both the directions.

6. To determine the individual effects viz, thermal and live load effects, multiple models may have to be analyzed. For bridges with uniform spans and expansion type bearings at both ends, only one model with thermal effect and live load run from one side shall suffice. By deducting the thermal stresses from peak stresses, we can get the effect due to live loads. However, in asymmetric bridges, such linear deduction gives erroneous results. In such cases, to work out the correct peak effects, the live load shall be run with longitudinal loads in both the directions. To get the live load effect alone, thermal variation shall be given zero value. (Total three cases need to be analyzed)

COMMENTARY

the loads need not be placed at close intervals to capture the peak response. It has been found that placing load at beginning of span and increment by 1/10th of span captures the peak behavior. It is important to capture the full span loaded case in addition to part span loaded cases.

This phenomenon of non-linearity in case of asymmetric bridges is there due to difference in the location of peak stress due to thermal effects and that due to live loads.

4.3 BRAKING AND TRACTIVE LOADS

The braking and tractive (acceleration) forces from vehicles are longitudinal forces applied parallel to the path on top of rails, uniformly distributed along the train length. To avoid running the multiple trains specified in Bridge Rules for each loading, as an alternate method, Uniformly distributed loads given in tables in para 4.2 above may be used as a substitute to the actual loads.

These loads shall be applied concurrently with vertical loads such as to create the most adverse effect on the structure. For girders at gradients, the live load has a component which is applied as longitudinal load on the bearings/ sub structure. This load shall be applied along with the tractive/braking loads, as per the direction of movement of trains.

For multiple tracks supported on same girder, the tractive and braking loads shall be applied as per normal traffic operations with appropriate mode i.e. braking or traction such as to produce worst effect on the substructure. **For more than two tracks, only two tracks shall be considered loaded when carrying out**

C 4.3

The braking forces are applied along the direction of train movement and the tractive forces are applied reverse to the direction of movement of train. Normal train operations in double line are in opposite directions and the braking forces from one track are in the direction of tractive forces from the other track and their effect is additive. However in yards and other locations, train movements might be occurring in same direction and in this case, simultaneous braking (or tractive, whichever are more critical) forces on both tracks shall be considered. The EUDL for longitudinal loads shall be considered for the same lengths as for the vertical loads specified in para 4.2 above.

Clause 1.4.3 of UIC 774-3R provides that load from two tracks only need to be considered. Since the longitudinal loads are not always applied at the full level by all the

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RSI analysis.

If there are multiple tracks supported on different girders, the sub-structure stiffness may be divided appropriately to reflect the share of each track, and analysis may be done for individual tracks.

COMMENTARY

trains, this is reasonable. The same clause provides that tractive load on one track and braking load on other shall be considered. However, if regular operation conditions are not like this, the actual loads for these conditions shall be applied.

4.4 LOAD FACTORS

The RSI case is an SLS check, the load factors may be taken from load combination 3/4 of IRS Concrete Bridge Code. The load factors for the vertical, longitudinal and thermal loads shall be taken as 1 for simply supported as well as continuous spans.

C 4.4

This also matches with the load factors given in clause 1.5.1 of UIC 774-3R.

4.5 STIFFNESS PARAMETERS OF STRUCTURE

4.5.1 Pre-dimensioning of structure

To start with, the structure has to be given certain dimensions. These can be assumed through the experience of the designer, or from other similar structures already constructed in the past or guidance can be taken from the pre-dimensioning method specified in clause 1.6.1 of UIC 774-3R 2001.

C 4.5

C 4.5.1

The pre-dimensioning allows the designer to assume structural stiffness and run an RSI before the actual design is taken up. After getting the idea of stresses/ displacements for the assumed stiffness, the designer can optimize the design and run RSI again to verify if the results are acceptable. The procedure is iterative till the desired level of optimization is achieved.

4.5.2 Determining stiffness of sub structure

The stiffness of sub-structure has to be determined using the principles of structural analysis. The deflection of foundation mainly depends on soil stiffness. If computer program is used, soil has to be modeled as springs and for this soil spring stiffness needs to be worked out. **A suggested methodology for computing support stiffness for different type of structures is given in Appendix C.**

C 4.5.2

Soil behavior under different conditions is quite complex and working out soil stiffness/ soil spring stiffness is quite a difficult task and requires understanding of the engineering properties of soils in subgrade and their behaviour under loads.

4.5.3 Determining stiffness of bearings.

The bearings can be fixed/free type or elastic bearings. The fixed bearings can be considered as rigid, permitting no movement and the free end can be modeled as free, neglecting the friction. **A suggested methodology for considering bearing stiffness for different type of bearings is given in Appendix D.**

C 4.5.3

The friction in bearings shall be assumed realistically. Para 2.1.3.5 of UIC 774-3R states that “The effects of friction on rail stresses and displacements are always favourable especially when the support stiffness is low, so that ignoring friction is in general conservative for safety.” Accordingly, the roller/ PTFE ends may be considered to be “free”.

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4.6 ANALYSIS METHODOLOGY

4.6.1 Analysis methodology using graphs given in UIC 774-3R

Annexure A and B of UIC 774-3R 2001 have graphs which have been plotted for single 60 Kg track bridges with fixed bearing at one end having single span less than 110 m. These can be modified for multiple track, different rail section, different temperature variations, single deck with multiple spans etc.

C 4.6

C 4.6.1

The graphs are applicable for single span/ single deck only. For succession of spans/ decks, computer program has been recommended by UIC 774-3R in para 3.2 even though simplified rules for analysis of bridges with succession of decks have been given in para 3.3. These rules are applicable for succession of decks subject to certain conditions. **It may be noted, however, that the results obtained using these rules are generally conservative. With easy availability of computer programs, it is not recommended to use graphs for design. These can, however, be used for initial dimensioning of the bridge elements.**

4.6.2 Choosing computer program for carrying out RSI

RSI studies can be done using computer program or can be done using graphs given in UIC 774-3R. **Due to several limitations of the graphs, computer programs are generally used.** Any computer program which has the capability to model the actual complex non-linear behaviour of the bridge and track elements can be used. **The computer program shall, however, be validated before being permitted for use. The validation shall be done using the test cases given in Appendix D of UIC 774-3R.** A computer program shall be considered validated when the error on the single effects as well as on overall effect is less than 10% with respect to corresponding type of analysis (sum of effects or global effect). Larger tolerances, upto 20%, can be accepted if error is on safe side.

C 4.6.2

The use of an FEM based computer program for numerical simulation of RSI is allowed as per para 3.4 of UIC 774-3R. Validation of software with the test cases given in UIC 774-3R, or better still, against other such software also is required before starting to rely on the results given by a particular software. The validation of software is covered in para 1.7.1 of UIC 774-3R.

4.6.3 Analysis methodology using FEM

This section describes the approach(es) that can be followed to obtain prudent results in a numerical simulation for RSI analysis.

C 4.6.3

4.6.3.1 Recommendations for FEM Modeling

The study of the track-deck interaction involves the

C 4.6.3.1

These recommendations are given in para

PROVISIONS

implementation of numerical models that captures the actual configuration and properties of the structure and the track. The model should be able to adequately represent the structural behaviour under different loads. **Few important aspects of model are as follows:**

a) Normally line modeling is done as we are not interested in detailed stresses. However, if complete model is prepared for design of elements like girders, sub structure etc, then the same may be used for carrying out RSI also.

b) In a model, the elements corresponding to the rails and deck should be located at the level of respective centers of gravity. Likewise, the connections corresponding to support devices should be placed at the level of their centers of rotation. This will capture the bending effects properly.

c) The longitudinal behaviour of the track-deck connection shall be modelled as a bi-linear spring which can capture load/displacement relation similar to that illustrated in clause 3.2.6 above. **Separate springs shall be used for loaded and unloaded elements.**

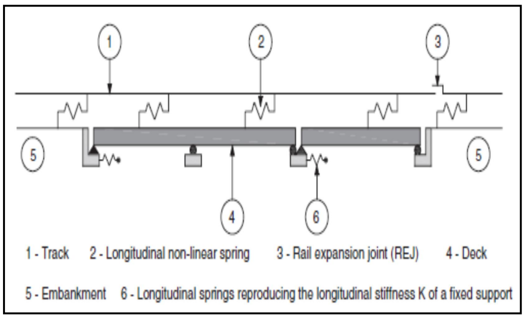
d) In some cases, it is possible to replace the mentioned elements by a connection of equivalent stiffness to that of the foundation/column/support group.

e) The maximum element length shall not exceed 2 m.

f) **An example of RSI study done by RDSO using software LUSAS Bridge Plus explaining all steps is placed at Appendix E.**

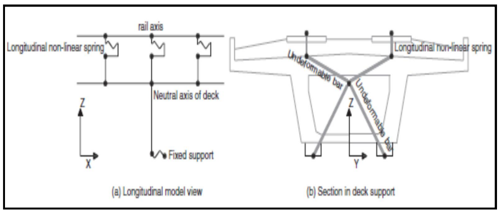
COMMENTARY

1.7.3 of UIC 774-3R. There are more recommendations in UIC 774-3R but all of these have not been reproduced for the sake of brevity. Actual leaflet may be referred to study the complete recommendations.



Elements of a typical model

Capturing the non-linear behaviour of connection between rail elements and deck elements is the most important and involved part of modeling for RSI and deserves close attention from the design engineer.



Equivalent model of girder

4.6.3.2 Recommendations for FEM Analysis

C 4.6.3.2

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The analysis using a computer assisted modeling can be achieved by two methodologies as follows:

- **Simplified Analysis:** A simplified analysis calls for running thermal and live load actions individually and then arithmetically combining them using factors.
- **Complete Analysis:** A complete analysis calls for applying the thermal loads and then, on the deformed stiffnesses of bilinear springs, running an additional live load analysis.

In the simplified analysis, first step is application of thermal loading. The longitudinal resistance of ballast is taken from **Unloaded stiffness curve** and is limited by the Limit of resistance of **unloaded track**.

Separately, train loading is applied and analyzed. In this case, longitudinal resistance of ballast is taken from **Loaded stiffness curve** and is limited by the Limit of resistance of **loaded track**.

The **sub-structure/ foundation behaviour is short term in either case**. However, the rubber bearings have different stiffnesses for thermal loads which are slow acting loads and the live loads. To get the exact results, separate stiffnesses can be used. **However, the sub-structure forces as well as track stresses are lesser with thermal if the bearing stiffness is lesser. So, only one analysis can be performed with bearing stiffness for rapid acting loads. In case of marginal cases, exact analysis can be performed**

The results are then combined by superposing the results of train load case on the results from thermal load case. The error arises in this case because there is an apparent increase in the resistance of the ballast due to ignoring the resistance already mobilized by the track for the thermal loading while considering the train loading. **This results in an assumption of greater yielding load for track than the actual curve. Results of this approach give higher stresses in the rails and slightly lower substructure deflections and reactions.**

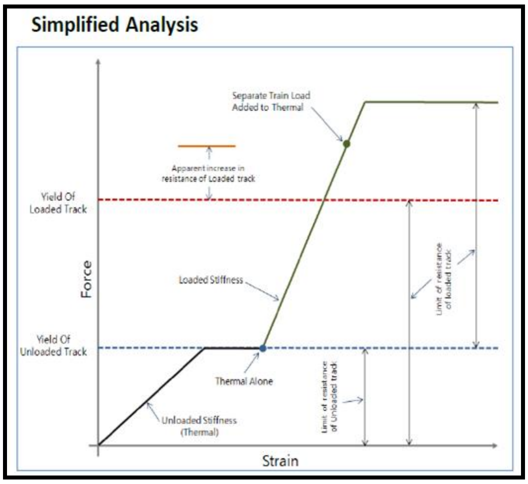
In complete analysis, first step is application of thermal loading similar to simplified analysis using the **Unloaded stiffness curve**. In second step, however, train loading is applied on the results obtained from the first step. In this case, longitudinal resistance of ballast is taken from **Loaded stiffness curve** and is limited by the Limit of resistance of **loaded track**. In this case, there is no overestimation of the track

COMMENTARY

Both type of analyses are allowed as per para 1.7.3 of UIC 774-3R. The choice of analysis option is largely dependent on the situation being evaluated.

In case of simply supported spans, simplified analysis will provide reasonable results. For optimization of design and in case of special spans such as arch bridges, cable stayed bridges and truss bridges etc, use of complete analysis will be required.

Difference in approach of the two types of analysis is illustrated graphically as below:



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resistance.

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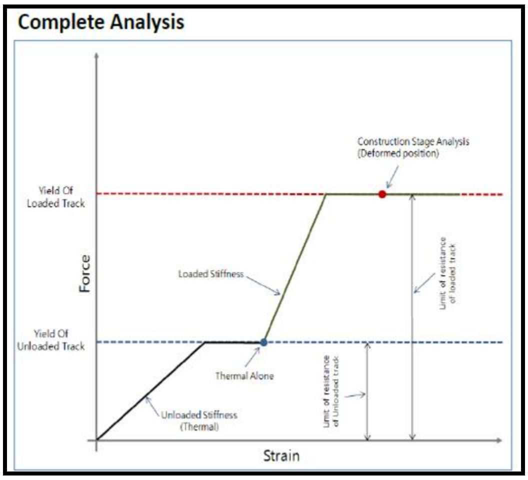

4.7 ANALYSIS FOR FRACTURE OR REMOVAL OF RAIL(S) FOR MAINTENANCE

In ballastless track laid on bridges, analysis of the scenarios of fracture on bridge or replacement of rails are also important. The effects to be considered include:

a) Gap created in rail in the event of fracture.

b) **Stress accumulated in sub-structure after fracture:** Proper repairs to rail/weld fractures and proper procedure for removing rails for maintenance/renewals using rail tensors to minimize the stresses locked up in the sub-structure due to track maintenance is important in this case.

Therefore, following proper track maintenance guidelines is very important for LWR on ballastless bridges.

C 4.7

Most of the track on bridges on Indian Railways is yet ballasted and this phenomenon is not important. The gap at fracture in ballasted track is governed by the track resistance and the effect of bridge is not going to be substantial in this case. The stresses transferred to substructure due to fracture of rail are also limited by the ability of ballast to transfer the load and the effect is dissipated over time under movement of track.

For further guidance on this aspect, "RDSO guidelines for carrying out Rail-Structure Interaction studies on metro systems" may be referred.

5.0 SPECIAL CASES IN RSI

Following special cases in RSI need more involved studies:

C 5.0

These are conditions which occur in typical railway systems but are not covered by UIC 774-3R. **The parameters for these studies have also not laid down in IRS Bridge Rules and currently these studies, if required to be done, will have to be done using other codes only for which appropriate approval from RDSO/Railway Board might be required.**

5.1 HORIZONTAL CURVATURE ANALYSIS

Due to the horizontal alignment of track on curves, axial forces in the rail and superstructure have an

C 5.1

The magnitude of the radial force is a function of rail temperature, rail size, curve radius, and

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outward component, resulting in radial forces on bearings and sub-structure. The track structure interaction analysis in case of horizontal curvature, consequently, is more involved. For such cases, the analysis for thermal case and tractive/braking loads has to be carried out separately.

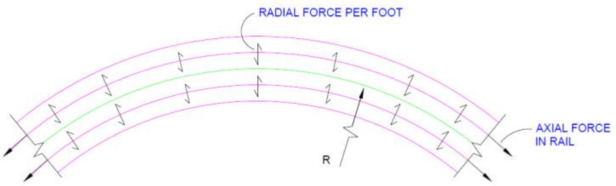
Following forces are recommended to be considered in the two cases:

5.1.1 Thermal Analysis

This analysis shall consider the following effects:

- Temperature Gradient
- Tangential Expansion

The rail forces due to the temperature can be predicted mathematically as follows:



$$\text{Radial Force Per Length of Rail} = \frac{E\alpha\Delta T A_{rail}}{R} + \frac{K_f L_{Radial}}{n_{track}}$$

Where, E = Modulus of Elasticity of Rail Section

α = Coefficent of Thermal Expansion

ΔT = Temperature Gradient

A_{rail} = Cross – Sectional Area of Rails

K_f = Fastner Slip value divided by spacing

L_{Radial} = Radial Length

n_{track} = number of tracks

R = Radius of Rail Curve

5.1.2 Braking / Tractive Analysis

This analysis shall consider the following effects:

- Braking / Tractive forces
- Nosing Force on Rail
- Lurching (Vertical Bending)

The effect of tractive/ braking forces has to be studied through modeling duly considering the effects of curvature.

The additional stresses as per RSI studies shall be compared with the permissible additional compressive/tensile stresses specified by the track design engineers looking at the curvature, other track

COMMENTARY

longitudinal fastener restraint.

C 5.1.1 The radial interaction of the rails in curved portion both for the thermal based analysis and braking analysis have a very different response owing to the radial redistribution of the stresses / forces in the track and plinths.

C 5.1.2

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features and forces on track etc.

5.1.3 Allowable additional stresses in rails

The allowable additional stresses in rails for curved track cannot be the same as those for straight track. These have to be separately studied and specified by the track design engineers. **No values for allowable stresses for curved track have been specified for Indian Railways so far and hence it is not possible to carry out the RSI studies for curved ballasted track as yet.**

5.2 RSI FOR TURNOUTS ON VIADUCT

5.2.1 Introduction

The presence of turnout in track affects the distribution of stresses in rails in RSI studies as the stiffness turnout structure is much more as compared with the normal track. When CWR (continuous welded rail) is continued through a turnout on viaduct, RSI effects can cause movements/thermal stresses which may cause damage to anti-creep arrangement between the straight tongue rail and stock rail.

5.2.2 FEM Modeling of Turnouts

The connecting element system of stock rail/lead rail should be modelled with spring to model the interaction behavior. The track resistance for the turnout portion shall be modelled as bi-linear curve similar to the normal track, with appropriate values.

COMMENTARY

C 5.1.3 For information of the reader, allowable additional stresses in rails for curved alignment have been specified in the Korean Design Standard: Railway Design Manual (Volume Track), enumerated below:

For Ballasted Track: To allow for the lower stability of track on curved alignment which is subject to lateral loads from trains:

The permissible additional Compressive stresses on account of RSI shall not exceed:

For R≥1500	: 72 N/mm^2
For 1500>R≥700	: 58 N/mm^2
For 700>R≥600	: 54 N/mm^2
For 600>R≥300	: 27 N/mm^2

The permissible additional Tensile stresses on account of RSI shall not exceed: 92 N/mm^2

For Ballastless Track: Since the load is taken by fasteners, which can be designed for the load actually coming and there is no problem of stability, the permissible additional Tensile as well as Compressive stresses on account of RSI shall not exceed: 92 N/mm^2. However, the fasteners in this case need to be checked for additional stresses.

C 5.2

C 5.2.1

The designs of turnouts having such anti-creep arrangement are not yet available for Indian Railways and the consequently CWR are not passed through the turnouts on Indian Railways.

C 5.2.2

The curvature of the stock rail / lead rails can be ignored owing to the close spacing of fasteners/ sleepers. The close fastener spacing provides enough radial restraint to prevent any instantaneous buckling. The heel joint is recommended to be modeled using spring with a linear stiffness curve depicting its longitudinal resistance.

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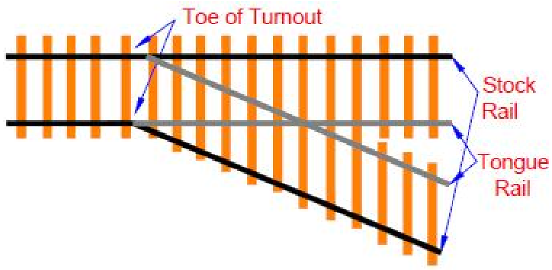
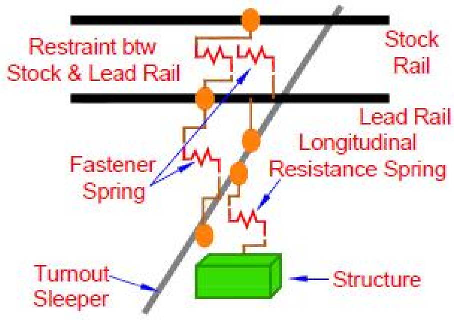


A Typical idealized turnout



Modeling of turnout to capture its behaviour

6.0 CONTROLLING RSI EFFECTS

The control of RSI effects viz, stresses in rails and/or deflection of bridge components beyond the limits laid down in UIC 774-3R is the next question which arises after the RSI analysis is completed.

The obvious option available is to redesign the bridge elements to make the girders and/or sub-structure stiffer. However, if this is not required from other structural reasons, making structure stiffer only for RSI effects might be uneconomical. RSI effects can also be controlled by adopting any of the following measures individually or in combination. The decision in this regard shall be taken on techno-economic considerations, which shall be a joint decision of track and viaduct design engineers.

C 6.0

Making elements stiffer might not always be good from other considerations like seismic loads. This balance also has to be stuck by the bridge designer.

6.1 MODIFICATION OF BEARING ARRANGEMENT

If additional rail stresses due to RSI exceed the limits, changing the expansion length can be an option to reduce these. By choosing different locations of fixed bearing in case of continuous spans, the expansion length can be changed. Changing the bearing type, their stiffnesses and their locations is another option which helps in controlling bridge deflections as well as track stresses.

C 6.1

Changing bearing configuration is a much cheaper option as compared to making the structure stiffer. This is an important parameter for optimization of design. Using fixed-free bearings in place of sliding/ neoprene type bearings can help increase the stiffness at minimal cost. Also, on a less stiff pier, the free bearings can be provided so that the deflections and stresses are controlled.

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6.2 PROVIDING SWITCH EXPANSION JOINT (SEJ)

SEJs are devices provided at the ends of LWR/CWR which permit longitudinal movement of rails and at the same time maintain correct guidance/ support to the wheels. Allowing LWR to move will reduce the stresses in rails and can be a solution in locations with longer spans/ taller piers where the rail-stresses are beyond permissible limits. Due to the SEJ(s), the horizontal deck forces are not transferred to approaches but to the fixed bearings, alleviating the effects on the rail. These also provide relief in the desired stiffness of the sub-structure as the allowable movement of decks for locations where SEJ is provided is also 30 mm as against 5 mm where LWR/CWR is continued through.

The decision of providing SEJ in track shall be taken jointly by the bridge designers and the track maintenance engineers. The decision shall be taken on techno-economic considerations. **On Indian Railways, this decision shall be taken be approved by Principal Chief Engineer of the zonal railway as per clause 2.8.2.4.4 of Bridge Rules.**

6.3 PROVIDING LOW TOE LOAD FASTENERS

Another method to modify the behaviour of LWR on bridge is to change the behaviour of track under loads. Low toe load fasteners are special fasteners having reduced slip resistance on rails. These alter the track stiffness curve, thus ensuring more movement of rails. This can relieve stresses in rails. However, adequate care needs to be exercised that the reduction in clamping force on rail does not jeopardize the stability of rail.

These are required to be provided, for example, in long spans where the thermal stresses built up in the rails or rotation of deck might induce large stresses, especially near the ends of spans. To remedy this situation, the low toe load fasteners may be provided in small stretches near the supports. The toe load required and lengths upto which these need to be provided shall be designed taking different field scenarios of thermal and train loads into account.

COMMENTARY

C 6.2

Generally speaking, bridges with <u>expansion lengths</u> of the order of 100m may be designed without resorting to rail expansion devices. Expansion lengths of the order of 300m to 400m will very probably necessitate at least one rail expansion device. Expansion lengths greater that this may necessitate at least two expansion devices or different track arrangement to cater to the large movements of deck end. While deciding the location of SEJ(s), it shall be ensured that these are not adversely affected by bending effects in the rail due to the close proximity of end of bridge deck etc.

SEJs are generally undesirable from the point of view of track maintenance. These shall be provided only where unavoidable, and after consultation with the track design engineers.

C 6.3

The locations where low toe load fasteners are to be provided shall be clearly identifiable in field and appropriate maintenance instructions shall be issued for ensuring that these are not disturbed/ replaced by improper fasteners during maintenance activities.

Such long spans may also require more movement of rails than can be accommodated in the conventional SEJs. For this, special arrangements which can permit large movement in track need to be designed and provided.

-0-0-0-0-

Appendix A: Important Documents which covers the RSI studies

A & C Slip No 45 to IRS Bridge Rules 1964:

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS
(RAILWAY BOARD)

BRIDGE RULES

(IN SI UNITS)

RULES SPECIFYING THE LOADS FOR DESIGN OF SUPER-STRUCTURE AND SUB-STRUCTURE OF BRIDGES AND FOR ASSESSMENT OF THE STRENGTH OF EXISTING BRIDGES

Adopted – 1941
Revised – 1964
Reprinted in 1989
(Incorporating Correction Slips 1 to 39)

Addendum and Corrigendum Slip No. 45 dated 27.09.2013

The existing para 2.8.2.4.3 may be replaced by the following para:

2.8.2.4.3: Forces due to continuation of LWR/CWR – Till such time the forces due to continuation of LWR/CWR on bridges in Indian conditions are finalized, provisions of UIC 774-3R October 2001 edition, with uptodate modifications, should be provisionally used for design and checking of substructure on bridges located in tangent track only with the following parameters:

(a) Actual longitudinal forces prevailing on the bridge as per loading standard/ rolling stock to be operated shall be used.

(b) It shall be ensured that the additional stresses in rail as per computations done using provisions of UIC 774-3R do not exceed the values given in table below:

Rail Section	Maximum additional Stresses in Compression	Maximum additional Stresses in Tension
60 Kg 90 UTS Rail	60 N/mm^2	75 N/mm^2
52 Kg 90 UTS Rail	50 N/mm^2	60 N/mm^2

(c) Span and sub structure arrangement shall be such that the various checks on rotation/ deflection specified in UIC 774-3R are satisfied.

(d) **Track Resistance in Ballasted Deck Bridges:** For track structure minimum 52 kg 90 UTS rails and PRC sleepers at sleeper density 1540 nos/KM with elastic fastenings, the value of track resistance for computations as per UIC 774-3R shall be taken as 25kN per meter of track in unloaded condition and 50 kN per meter of track in loaded condition.

(e) The computations can be done either using graphs or simplified approach or computer program as indicated in UIC 774-3R provided the conditions specified for their adoption are satisfied. The computer program shall be validated with methodology given in UIC-774-3R before use.

(f) Ballasted deck bridges without bearings (slabs, box culverts and arches) need not be checked for forces/effects due to continuation of LWR/CWR.

(g) If rail-free fastenings are provided as per provisions of Manual Of Instructions On Long Welded Rails, such that there is no interaction between the rail and the bridge, then there is no need for checking for forces/effects due to continuation of LWR/CWR.

A new para 2.8.2.4.4 may be introduced as follows:
2.8.2.4.4: In case the stipulations given in para 2.8.2.4.3 above are not fulfilled, measures such as provision of suitable expansion joint or non-provision of LWR/CWR on that particular bridge shall be adopted as decided by Principal Chief Engineer of the zonal railway.
The para 2.8.1 (d) kept in abeyance vide correction slip no 33 is hereby reintroduced.

BY ORDER

27/9/13
(A K Dadarya)
Executive Director (B&S)
R.D.S.O., Lucknow

ED/Track-I/RDSO's letter no CT/IM/LWR/Part Dated 19/25.03.2014:

9268
25/3/14

2/25/3/14

SN 192

भारत सरकार - रेल मंत्रालय
अनुसंधान अभिकल्प और मानक संगठन
लखनऊ - 226 011
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Government of India-Ministry of Railways
Research Designs & Standards Organisation
Lucknow - 226 011
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DID (0522) 2465310

अ अ मा सं RDSO

No. CT/IM/LWR (Part) Date 19.03.2014.

25

To

Principal Chief Engineer,
All Zonal Railways (as per mailing list)

Sub.: Continuation of LWR/CWR over ballasted deck bridges on Indian Railways.
Ref.: Railway Board letter no. 2011/CE-II/TK/LWR, dated 05.02.2014.

1.0 Based on recommendations of Track Standard Committee during 78th meeting, an HAG committee was nominated vide Railway Board letter no. 2007/CE-II/TSC/1 dated 19.08.08. The committee submitted the report vide letter no. CT/IM/LWR/Part dated 08.07.2013. Railway Board vide letter no. 2011/CE-II/TK/LWR dated 24.09.13 have approved the recommendation made by HAG committee for continuation of LWR on ballasted deck bridges with the fulfillment of conditions as mentioned in the report of HAG committee and directed to circulate the approved instructions to all Zonal Railways for compliance.

2.0 "Instructions on continuation of LWR/CWR on ballasted deck bridges with bearings on Indian Railways" as approved by Railway Board vide letter referred above is enclosed as Annexure-I.

3.0 In compliance to instructions contained in letter under reference, the special maintenance instructions for bridges where LWR/CWR is continued as per these provisions has been framed and is enclosed as Annexure-II. These instructions are only indicative and will be reviewed based on results of instrumentation and feedback from Zonal Railways.

4.0 Further necessary action shall be taken by Zonal Railways in this regard.

DA: As above.

दिनांक......................
पुल एवं संरचना निदेशालय
कार्यoनिदेo / पुल एवं संरचना
निदेशक / एसoबीo-I
निदेशक / एसoबीo-II
निदेशक / परीoएवं निरीo
संयु निदेशक / निरीo
सहाoअधिoअभिo / एसoबीo-I
अधिo / पुoसंo

P.S. GM
3/3

24/3/14

(Satish Kumar Pandey)
Executive Director/Track-I
for Director General/Track

Copy to: (i) Director/IRICEN, Pune for information.
(ii) Executive Director/Civil Engineering/Planning, Railway Board, New Delhi for information.
(iii) Executive Director/B&S/RDSO for information and necessary action.

Mailing List

The Principal Chief Engineer,	प्रमुख मुख्य अभियन्ता,
1. Central Railway, Mumbai CST - 400 018.	1. मध्य रेलवे,मुम्बई सीएसटी 400018
2. Eastern Railway, Fairlie Place, Kolkata-700 001.	2. पूर्व रेलवे, फेयरली प्लेस, कोलकाता 700001
3. East Central Railway, Hajipur – 844 101.	3. पूर्व मध्य रेलवे, हाजीपुर 844101
4. East Coast Railway, Bhubaneshwar – 751016	4. पूर्व तटीय रेलवे, भुवनेश्वर–751016
5. Northern Railway, Baroda House, New Delhi-110 001.	5. उत्तर रेलवे, बड़ौदा हाउस, नई दिल्ली–110001
6. North Central Railway, Allahabad – 211 001.	6. उत्तर मध्य रेलवे, इलाहाबाद 211001
7. North Eastern Railway, Gorakhpur-273 012.	7. पूर्वोत्तर रेलवे, गोरखपुर 273012
8. North East Frontier Railway, Maligaon, Guwahati – 781 001.	8. पूर्व सीमान्त रेलवे, मॉलीगॉव, गुवाहाटी 781001
9. North Western Railway, Jaipur – 302001.	9. उत्तर पश्चिम रेलवे, जयपुर 302001
10. Southern Railway, Park Town, Chennai-600 003.	10. दक्षिण रेलवे, पार्क टाउन, चेन्नई–600003
11.South Central Railway, Rail Nilayam, Secunderabad- 500 371.	11. दक्षिण मध्य रेलवे, रेल निलायम, सिकन्दराबाद 500371
12. South Eastern Railway, Garden Reach, Kolkata-700043.	12. दक्षिण पूर्व रेलवे, गार्डनरिच, कोलकाता–700043
13. South East Central Railway, Bilaspur- 495004.	13. दक्षिण पूर्व मध्य रेलवे, बिलासपुर 495004
14. South Western Railway, Hubli – 589020.	14. दक्षिण पश्चिम रेलवे, हुबली 589020
15. Western Railway, Churchgate, Mumbai-400 020.	15. पश्चिम रेलवे, चर्चगेट, मुम्बई–400020
16. West Central Railway, Jabalpur – 482001.	16. पश्चिम मध्य रेलवे, जबलपुर 482001

Annexure- I

Subject: Instructions for continuation of LWR/CWR on Ballasted Deck Bridges with bearings on Indian Railways

1. LWR/CWR can be continued, with approval of Principal chief Engineer, as trial on Ballasted deck Bridges up to total bridge length of 110m on Tangent track, subject to the following:

1.1 Individual Span:

1.1.1 Individual span does not exceed 24.4 m, if bearings are of fixed and free type (such as roller/rocker or POT-PTFE type).

1.1.2 Individual span does not exceed 45.7 m, if elastomeric bearings without restraint in longitudinal direction are used.

1.1.3 Total length of bridge from abutment to abutment does not exceed 110m.

1.2 Track Structure:

1.2.1 Track structure on bridges consists of minimum 52 Kg 90 UTS rails, PRC sleepers with elastic fastenings and density 1540 nos/KM.

1.2.2 Full ballast cushion as per provisions of IRPWM is available on bridge and approaches.

1.2.3 The track alignment on the bridge is straight.

1.2.4 There is no Switch Expansion Joint within 100 m on either side approach of the bridge.

1.2.5 Full component of fittings in track on bridge proper and 100 m on either side approach of the bridge is ensured.

1.2.6 All welds on bridge and 100 m approaches on either side are joggle fish plated with clamps or two far end bolts.

1.3 Other Stipulations:

1.3.1 USFD testing is carried out on bridge and 100 m approaches on either side as per provisions of Manual for Ultrasonic Testing of Rails and Welds – 2012 with latest correction slip and corrective action is ensured.

1.3.2 The loads plying on the bridge are not heavier than MBG 1987 (including CC + 8 + 2 axle loads).

1.3.3 The other general provisions of Manual for LWR and IRPWM are complied with and there shall not be any unusual/ recurring problem with the bridge superstructure/ substructure/ bearings or track/formation on bridge and within a distance of 100 m on either side of the bridge.

1.3.4 The LWR/bridge shall be kept under observation and inspected at officer level at least once in a month for proper behavior of LWR and bridge.

2. Principal Chief Engineer of zonal railway, before permitting continuation of LWR, shall ensure check of bridge structure including bearings and rail stresses for rail-structure interaction effect as per advance correction slip no 45 to IRS Bridge Rules. The parameters defined in clause 2.8.2.4.3, as amended vide correction slip no 45, of IRS Bridge Rules shall

over-ride any provision in UIC-774-3R, wherever in deviation. The check shall be done using graphs given in UIC leaflet. Alternately, detailed computer analysis as laid down in UIC-774-3R may also be used. No limits for vertical bending of deck have been specified. This check may not be done in the trial bridges.

3. **The initial one or two bridges selected for continuation of LWR on trial shall be instrumented as per scheme enclosed as Annexure A. The results of instrumentation and reports shall be advised to RDSO for analysis and acceptance.**

4. B & S Directorate of RDSO shall be approached for any clarifications in this regard.

Annexure A

Instrumentation scheme for specified bridges

1. Long Welded Rail/ Continuous welded Rail (LWR/CWR) as defined in LWR manual shall be continued on a bridge only after permission of Principal Chief Engineer (PCE). PCE while permitting continuation of LWR, on trial, will satisfy himself that the computations have been done as per para 2.8.2.4.3 incorporated vide correction slip no 45 to IRS Bridge Rules and the bridge has been found safe from longitudinal forces point of view, the rotations/ deflections of the structure are within limits specified in the UIC 774-3R and the additional stresses in rails due to LWR/CWR are within limits specified in IRS Bridge Rules para 2.8.2.4.3.

2. In order to validate the assumptions of UIC leaflet for broad gauge track on Indian Railways, it is essential the results of detailed analysis are compared and verified with results obtained after detailed instrumentation. Thus, instrumentation is to be done for initial one or two bridges on each Zonal Railway, where continuation of LWR is planned. For such bridges, the analysis of Rail-Bridge interaction shall be done using FEM analysis software using parameters specified in IRS Bridge Rules para 2.8.2.4.3 and UIC 774-3R. Any software used must be validated to be as per provisions of UIC 774-3R. Guidance/ assistance of B & S Directorate of RDSO shall be taken in carrying out the analysis.

3. **The criteria for choosing the bridge to be instrumented shall be as follows:**

   a. Complete design/ drawings of the bridge shall be available.
   b. Bridge shall have multiple simply supported ballasted deck concrete/ steel-RCC composite spans.
   c. The height of piers shall not be too less nor shall it be too much. Height in the range of 4 m to 10 m shall be most suitable.
   d. At the fixed end of the girder, space shall be available for fixing the reaction frame etc required for instrumentation.

4. **Before start of testing, the following action is to be taken:**

   a. The design and details of the bridge shall be collected by design office and computations of rail-bridge interaction shall be done to determine whether the bridge is suitable for continuing the LWR/CWR or not. Details of any repairs/ rehabilitation of the elements of bridge shall also be collected and their effect on performance of the bridge shall be assessed. B & S directorate of RDSO shall be consulted for carrying out the computations.
   b. Additional free bearings (Roller or POT-PTFE) along with properly designed reaction frame shall be got fabricated as described in instrumentation scheme (para 5 (c) below) or action may be taken as per the instrumentation scheme finalized.
   c. Instrumentation work shall continue for minimum six months so as to cover the hottest and coldest months in a year.
   d. Test trains with known actual axle loads and axle spacing comprising of multiple locomotives and as heavy load as possible, close to the heaviest loads plying in the

section (subject to maximum of MBG-1987/ CC + 8 + 2) shall be arranged for testing in two rounds, preferably in the hottest/ coldest months. The two rounds of testing shall not be conducted less than 4 months apart.

5. **Instrumentation scheme:**

The rail-structure computations as per UIC 774-3R for the bridge instrumented shall be done and the stresses/ forces expected are worked out. In case, the work is outsourced, the agency selected shall carry out the analysis and submit details to railways. Based on calculations, the detailed instrumentation scheme shall be finalized, comprising of number/type of sensors to be deployed along with their locations which shall cover the following:

a. **Rails shall be instrumented** at either approach of the spans being tested just beyond the spans so as to measure the longitudinal stresses continuously from the date of installation of the gauges (i.e. before the first round of testing) to the finish of the second round of testing. The measurement shall be correlated with the temperature readings.
b. **Temperature sensors shall be installed** on each of the spans to be tested to take temperature measurements of rail as well as bridge deck as defined in the UIC-774-3R continuously from the date of installation of the gauges (i.e. before the first round of testing) to the finish of the second round of testing.
c. **The longitudinal forces coming on the fixed bearing end (or both ends in case of neoprene bearings) on two typical spans of the bridge shall be measured.** If the bridge is having fixed bearing on an abutment, that span shall be included as one of the spans to be instrumented.

   It is suggested that fixed bearings (or both end bearings in case of neoprene bearings) in span to be instrumented shall be replaced by free bearings and then **load cell(s) shall be installed between the girder end and a suitably designed reaction frame** to measure the longitudinal force coming on the span in either direction during the passage of test train over the bridge and for at least 20 trains normal traffic passing over the bridge. Minor modifications may be required to be done to the girder for fixing the load cells. Alternately, the agency doing the instrumentation may suggest any alternative for measuring the longitudinal forces coming on the fixed end of the bearing which may be examined and approved if found suitable.
d. **Rotation sensors** shall be installed to measure rotation at the girder ends.
e. **Displacement transducers** shall be provided to measure the horizontal deflection of the pier/ abutment under longitudinal loads.
f. **Any other sensor** required for satisfactory submission of the test report.

6. **Preparatory works Just before start of testing:**

a. LWR/CWR shall be laid on the bridge if not already laid. LWR/CWR on the bridge and at least 250 m on either side shall be destressed, preferably with rail-tensor, or alternately, by other methods so that the Stress Free Temperature is established. Any destressing done within last six months will also be OK if no rail fractures or other unusual events have occurred in the LWR/CWR in the stretch mentioned above since the date of destressing. Otherwise, fresh destressing may be done.

b. Rails shall be instrumented and temperature sensors shall be installed on the rail and bridge deck and continuous data recording shall start.

c. The reaction frame already fabricated shall be fixed on the pier/ abutment. The fixed end bearing (or both end bearings in case of neoprene bearings) shall be replaced by the new free bearings already fabricated and the girder and the reaction frame shall be connected to transfer the longitudinal loads in either direction to the reaction frame. The newly provided free bearing shall continue to transfer all vertical loads. The connection of reaction frame shall be done such that the bending properties of the girder are not affected.

d. Strain gauge shall be installed on the couplers of the test train, rotation sensors shall be installed at girder ends and load cells shall be installed between the free bearing newly introduced and the reaction frame.

e. Test train shall be passed over weigh-bridge so as to determine the actual axle loads.

7. **Testing Work:**

In each round of testing, the measurements shall be taken for the following cases:

a. **Measurements under test train:**
Test train comprising of multiple locomotives and the heaviest loads permitted on the section shall be run multiple times on the bridge with the following operation conditions **(Clarifications, if required, on these tests shall be taken from RDSO's report no BS-106)**:

i. **Test train static** at three locations on span being tested so as to validate the end rotations and to determine the load cell readings under "no longitudinal force" condition.

ii. **Maximum tractive effort:** The locomotive shall be stationary at the test span or near it and shall try to exert the maximum tractive effort for which brake binding may be introduced in a few wagons. The coupler forces in the locomotive shall be measured and correlated with the location of the test train during the entire duration of test. For locos which give indication of tractive effort generated, these readings shall also be taken.

iii. **Maximum braking force:** Test train moving at maximum permitted speed on bridge/ section shall apply emergency brake just at the approach of the test spans such as to exert the maximum braking force. The coupler forces in the locomotive shall be measured and correlated with the location of the test train during the entire duration of test.

iv. **Maximum speed test** during which the test train shall be passed over spans at maximum permissible speed on the bridge/ section.

b. **Measurements under normal traffic:**

The measurements of stresses/ forces shall also be taken for the normal traffic plying on the bridge for minimum 20 trains. The data collected shall be correlated with the type of train passing on the bridge.

8. **Report on Testing:**

At the end of tests a report shall be submitted. The report shall provide the following minimum information:

a. A summary report on temperature variation of the rails during the entire recording period including trends and any unusual patterns.
b. A summary report on temperature variation of the deck during the entire recording period including trends and any unusual patterns.
c. A summary report of the variation of the rail temperature vis-à-vis the temperature of deck by juxtaposing the readings from the different temperature sensors.
d. Expected results of the additional stresses in rail and longitudinal forces as per Rail-Bridge interaction studies as per UIC-774-3R for the actual temperature, vertical load and longitudinal loads actually coming on the bridge during the passage of test trains.
e. A summary report of actual variation of additional stresses in rail, rotation of spans and longitudinal forces during passage of test trains and their comparison with the theoretically worked out values as per UIC 774-3R. Analysis of the comparison including possible reasons for the variation and conclusions to be drawn from the same shall also be brought out.
f. A summary report of the peak values of additional stresses in rails on either end and longitudinal forces on the fixed bearing end during passage of normal traffic on the bridge.
g. Report on the performance of bridge under rail-structure interaction as per UIC 774-3R, including comparison of results expected as per UIC code and actually seen and reasons for the variation.
h. Any other conclusion based on the data collected.

9. **Action after testing is over:**

The new free bearings/ reaction frames or other alterations in bridge provided for testing shall be replaced by original bearings and the bridge shall be restored to original configuration.

10. **Care shall be taken:**

During the period in which the original bearings have been replaced by free bearings/ reaction frames, the span shall be kept under observation by open line as well as bridge organization.

Annexure-II

Special maintenance instructions for LWR/CWR on Ballasted Deck Bridges:

All the provisions mentioned in Manual of Instructions on Long Welded Rails-1996 and provisions of Indian Railways Permanent Way Manual-2004 related to maintenance of LWR/CWR shall be followed strictly. The salient instructions are reiterated below, for ready reference along with certain other items where attentions are required for maintaining LWR/CWR on ballasted deck bridges:-

1. The 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. Bearing shall be monitored for unusual movements, loose bolts, other signs of distress etc. {Para 4.5.7.1 (ii) (e) of LWR Manual}.

2. On the bridge approaches, sleepers with arrangement for fixing guard rails should be provided for provision of guard rails as per Para 275 of Indian Railway Permanent Way Manual. {Para 277 a (1) of IRPWM}.

3. On the bridge approaches, for a length of about 100 meters, width of cess should be 90 cm clear of full ballast section to maintain ballast profile. For maintaining ballast section, suitable ballast retaining arrangement should also be provided. {Para 277 b (2) of IRPWM}.

4. Full complement of track fittings on bridge and approaches upto 100 metres should be provided to maintain required track geometry and effort should be made to immediately recoup deficiency noticed, if any. {Para 277 a (2) of IRPWM}.

5. All welds on bridges and 100 m approaches on either side are joggle fish plated with clamps or two far end bolts.

6. Creep of LWR shall be monitored on approaches, 20m from either abutment for which creep posts shall be provided.

7. The toe load of elastic fastenings shall not be less 600 Kg otherwise same shall be replaced with ERCs having better toe load.

8. The regular track maintenance in LWR/CWR shall be confined to hours when rail temperature is between $t_d + 10^0C$ and $t_d - 30^0C$ and shall be completed well before onset of summer. {Para 6.2.1 (i) (a) of LWR Manual}.

9. Mechanized cleaning of shoulder ballast shall be undertaken when prevailing rail temperatures are within the limits prescribed in para 6.2.1(i) of Manual of Instructions on Long Welded Rails together with the precautions mentioned therein. {Para 6.2.2 (iii) of LWR Manual}.

10. During the period of deep screening, if there is any possibility of minimum temperature falling 30^{0}C below td /temporary distressing temperature, cold weather patrol as per para 9.1.2 (ii) of Manual of Instructions on Long Welded Rails should be introduced to detect/ guard against rail fractures.

11. 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 td-30°C or maximum does not go beyond td+10°C, upto 100 sleeper spaces may be opened under the direct supervision of PWI. 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. {Para 6.2.3 (iii) of LWR Manual}.

12. Tamping in LWR/CWR with general lift not exceeding 50 mm in case of concrete sleeper including correction of alignment shall be carried out during the period when prevailing rail temperatures are as per para 6.2.1 (i) of Manual of Instructions on Long Welded Rails together with precautions laid down therein. {Para 6.2.2 (i) of LWR}.

13. Lifting where needed, in excess of 50 mm in case of concrete 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 Para 1.18 of Manual of Instructions on Long Welded Rails Manual is achieved prior to taking up the subsequent lift. {Para 6.2.2 (ii) of LWR Manual}.

14. When crow bars are used for slewing, care shall be taken to apply these in a manner so as to avoid lifting of track. In this connection, the instructions in Para224 (d) (ii) of Indian Railway Permanent Way Manual shall be followed {Para 6.2.1b (iv) of LWR Manual}.

15. Duties and responsibilities at various levels shall be discharged meticulously as laid down under Para 9 of LWR Manual.

ED/B & S/RDSO's letter no CBS/Project/LWR Dated 05.09.2014:

SL-No-

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• Rly.-42120(O) 43120(Res.)
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सत्यमेव जयते

भारत सरकार – रेल मंत्रालय
अनुसंधान अभिकल्प और मानक संगठन
लखनऊ – 226011
Government of India-Ministry of Railways
Research Design & Standards Organisation
Lucknow- 226011

No.CBS/Project/LWR **Dated: 09.05.2014**

I. GM/C/North East Frontier Railway, Maligaon, Guwahati-781 061
II.

Chief Administrative Officer (Constn.)		Chief Bridge Engineers:	
(i)	Central Railway, Chhatrapati Shivaji Terminus, Mumbai –400 001.	(i)	Central Railway, Mumbai CST-400 001.
(ii)	Eastern Railway, Fairlie Place, Kolkata-700 001.	(ii)	Eastern Railway, Fairlie Place, Kolkata-700 001.
(iii)	East Central Railway, Hazipur-844 101.	(iii)	East Central Railway, Hazipur.
(iv)	East-Coast Railway, Bhubaneshwar-751 023.	(iv)	East-Coast Railway, Bhubaneshwar.
(v)	Northern Railway, Kashmere Gate, Delhi-110 006.	(v)	Northern Railway, Baroda House, New Delhi- 110 001.
(vi)	North-Central Railway, Allahabad-211 001.	(vi)	North-Central Railway, Allahabad.
(vii)	North-Eastern Railway, Gorakhpur- 273 001.	(vii)	North Eastern Railway, Gorakhpur-273 001.
(viii)	N.F. Railway, Maligaon, Guwahati-781 061.	(viii)	Northeast Frontier Railway, Maligaon, Guwahati-781 061.
(ix)	North-Western Railway, Jaipur-302 006.	(ix)	North-Western Railway, Jaipur.
(x)	Southern Railway, 18, Basaveshwara (Millers) Road, Bangalore-560 046.	(x)	Southern Railway, Park Town, Chennai-600 003.
(xi)	South Central Railway, Rail Nilayam, Secunderabad-500 371.	(xi)	South Central Railway, Rail Nilayam, Secunderabad-500 371.
(xii)	South East Central Railway, Bilaspur (Chattisgarh).	(xii)	South East Central Railway, Bilaspur.
(xiii)	South-Eastern Railway, Bhubaneshwar (Orissa).	(xiii)	South Eastern Railway, Garden Reach, Kolkata-700 043
(xiv)	South-Western Railway, 18, Basaveshwara (Millers) Road, Bangalore-560 046.	(xiv)	South-West Railway, Hubli.
(xv)	Western Railway, Churchgate, Mumbai-400 020.	(xv)	Western Railway, Mumbai-400 020.
(xvi)	West-Central Railway, Jabalpur (M.P.).	(xvi)	West-Central Railway, Jabalpur (M.P)

Sub: Rail-structure Interaction studies for continuing LWR/CWR on ballasted deck bridges.

Ref: 1) This office letters of even no. dated 25.02.2014 and 27.03.2014.
2) This office letter no. CBS/PBR dated 27.09.2013

****

1. Vide letter under reference 2), correction slip no. 45 to IRS Bridge Rules was issued as per which **it is now mandatory to conduct Rail Structure Interaction studies for all new bridges with ballasted deck girders.**

2. For conducting these studies, suitable software such as MIDAS with wizard for RSI computations, LUSAS Bridge Plus, etc. needs to be procured, which may be done at your end.

3. **RDSO has procured LUSAS Bridge Plus and had arranged a training from 22.04.2014 to 25.04.2014 in which design engineers were called from your office.** Out of expected 31,12 designers have attended the training at RDSO and can now work on RSI studies.

4. To help kickstart the work in your design offices, it has been planned that initial two/three problems will be checked by RDSO. Thereafter, this work shall be done by zonal railways themselves.

This is a very important field having implications in train safety, passenger comfort and track maintenance, so your personal attention is requested in this matter.

For any assistance/queries, may kindly contact RDSO at **e-mail: directorsteel2@gmail.com.**

09/5/14

(A K Dadarya)
Executive Director (B&S)

Copy to: EDCE (B&S)/Rly. Board and ED/Track/RDSO

Appendix B: Data Required for Carrying out RSI Analysis

1. **Bridge Details:**

a **Bridge Number.**
b **Location of Bridge**
c **Section**
d **Between Stations**

2. **Span details:** Complete drawings shall be available, having the following details

a **No. of spans** in the Bridge.
b **Span Lengths:** Clear span, effective Span, overall length of each of the spans.
c **Type of Girder**: I-type (single I, Double I , four I) , BOX, U - type etc.
d **Location of Rails:** The location of rails w.r.t. girder.
e **C/C of Girder leaves:** Center to center distance between girder leaves, no of girder leaves.
f **Details of Material:** Grade of concrete M45 , M35 , M30 , M25 etc, Grade of Steel etc.
g **Properties of Material:** Young's Modulus, Poisson's Ratio ,Coefficient Of thermal expansion etc.
h **Details of Different Cross-Sections:** The cross-sections of girders at different locations including height of different members, depth of neutral axis,

Note:

i. In RSI analysis, considering overall length of span in computations will be slightly conservative. (Actually overall length shall be used for thermal effects and effective span for bending of deck).
ii. For complete analysis, varying cross-section of girders at different locations can be considered. For simplification, the cross-section at the middle only can be taken if the cross-section in center is less than that the ends or an average of the cross-sections at canter/ ends if the cross-section at center is higher than that at ends may be taken.

3. **Loading Details**

RSI analysis shall be done for either standard loadings like 25T Loading 2008, MBG, RBG & DFC Loading Or actual loads for which the section/bridge is fit (as per clause 2.8.2.4.3(a) of Bridge Rules) such as GC Loading, CC+8+2 etc. EUDL charts shall be available which give the bending loads for different spans.

4. **Track Details**

a **Type of track:** Ballasted or non-ballasted
b **Rail section:** 60kg or 52kg etc.
c **Rail Material properties:** Young's Modulus, poisson's Ratio, Coeff. Of thermal expansion.
d **Track details:** Height of sleepers, Depth of ballast cushion etc.
e **Fastener Details:** Sleeper density, type of fasteners.
f **Location of SEJ**, if any, within 100 m of either abutment.
g **Curvature and gradient in track**, if any.

5. **Temperature Details**

a **Maximum rail temperature**
b **Minimum Rail Temperature**
c **Stress-Free temperature of LWR** (Shall be maintained within $\pm 5^0$C, else RSI studies are required to be done again).

d **Maximum annual deck temperature**

e **Minimum annual deck Temperature**

f **Temperature of deck at the time of laying LWR/CWR** (±5^{0}C variation shall be allowed later on, else RSI studies are required again)

6. **Bearings Details:** Complete drawings shall be available, having the following details

a **Type of bearing:** Elastomeric, Sliding, POT-PTFE Bearing etc.

b **No. of bearings per span:** No. of bearing provided in each end of girders etc.

c **Details of Sliding Bearings or POT-PTFE bearings:** Coefficient of Friction considered in design, vertical reaction on each bearing in Dead Load + Superimposed dead load condition

d **Details of Elastomeric Bearings:** Dimensions of bearing(L x B x h where L- length across the track, B- width along the track, h- total height of bearing), Thickness of elementary layers of neoprene, cover at top/ sides, Shear modulus of rubber, etc.

7. **Sub-structure Details:** Complete drawings shall be available, having the following details

a **Type of Piers and abutments**

b **Material of construction:** Grade of concrete M45 , M35 , M30 , M25 etc, steel grade etc and masonry properties.

c **Properties of Material:** Young's Modulus, Poisson's Ratio, Coeff. of thermal expansion etc.

d **Dimensional details:** Heights and length/ width of different cross-sections including pier cap/ pile cap/ well cap etc.

e **Reinforcement Details:** Type of reinforcement, spacing of bars etc.

8. **Foundation And Soil Details:** Complete drawings and soil bore-log shall be available, having the following details

a **Type of Foundation:** Open, pile, well etc

b **Details of Open Foundation:** Heights and length/ width of different cross-sections.

c **Details of Pile Foundation:** No. of piles per abutment/pier, Diameter of piles, Length of piles, details of pile like concrete grade, reinforcement details etc.

d **Details of Well Foundation:** Diameter of well, Length of well.

e **Soil details:** In open foundations, bearing capacity of soil is required. In pile foundation, the complete bore-log details including the type of soil, depth of different soil layers and characteristics of soil in different layers etc are required. For well foundations, normally soil characteristics are not required.

9. **Flood Details:**

a **Rail Level:**

b **Bottom of Girder:**

c **High Flood Level:**

d **Bed level**: .

e **Scour Level:**

f **Level at which rock/ non-erodible strata is there.**

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Appendix C: Working Out Stiffness of Sub-structures of Different types

Stiffness is the ratio of longitudinal load applied and deflection of the sub-structure at the bearing level, units being kN/mm or t/mm. The different components that support a girder are: a) Foundation, b) Sub-structure (pier/abutment) and c) Bearings. By algebraically combining deflections of individual elements, we can get the total deflection at the bearing level (This is not strictly correct, as the secondary effects are neglected, but the error associated is acceptable for the normal bridges with upto, say, 30m height from top of bearing to scour level). In this appendix, the stiffness computations of two components, viz, foundations and sub-structure are explained. The stiffness computations for bearings are explained in the next appendix.

1. **Stiffness of Sub-structure (Pier/abutment):** The portion of structure between bearing and the top of foundation is referred to as sub-structure here. For pile foundations, the top of foundation is at the top of pile cap while that for well foundation is at the top of well cap. For open foundations, there is no clear cut demarcation between the sub-structure and foundation. In this clause, the interaction of the foundation with the soil is considered as stiffness of foundation and all other effects are considered as stiffness of sub-structure. The effects on sub-structure have been described in para 3.2.5 above. For modelling, the structure may be considered fixed at the pile cap level or well cap level or at the base of foundation level and other effects can be added algebraically. Alternately, the complete sub-structure, foundations (including piles/ wells) and soil (as appropriate springs) can be modeled so that we can get the combined effect of all effects.

The sub-structure deflects longitudinally under the bending effect of longitudinal loads. The bending moment increases from top to bottom as the lever arm for bending increases, and the deflection effects are also more for the lower portions of sub-structure. There are two usual types of sub-structure encountered:

a) Gravity structures constructed with mass concrete or brick/stone masonary etc which usually don't develop any tension, or permit very little tension.
b) Reinforced concrete structures which can develop tension and reinforcement steel is provided to take care of the same.

For non-cracked RCC or gravity structures, the deflection is easy to work out and requires the bending moments and section modulus at different heights to be worked out.

The sub-structures are generally having non-uniform (tapered or stepped or both) sections, and the deflection can worked out by modeling the sub-structure in some structural analysis software which can model the tapered and stepped sections.

For cracked RCC structures, the problem is a bit complicated. The cracked depth of an RCC structure depends on deformation of the structure. But since the deformation of structure depends on the sectional modulus, which depends on the depth of cracking, the problem is an iterative one. The deflection can be worked out by modifying the effective E for the RCC structure by multiplying E with diminishing ratio of (I_{eff}/I_{gr}) for arriving at effective value of E for cracked RCC structure. As given in ANNEX C- 2.1 of IS: 456-2000, I_{eff} can be worked out as follows:

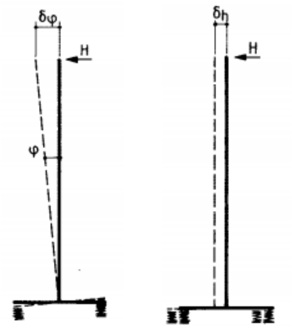
$$I_{eff} = \frac{I_r}{1.2 - \frac{M_r}{M}\frac{z}{d}\left(1-\frac{x}{d}\right)\frac{b_w}{b}};\ \text{but } I_r \le I_{eff} \le I_{gr}$$

Where,

I_{eff} = Effective moment of inertia of cracked RCC section,

I_{gr} = Gross moment of inertia, in mm^4,
I_r = Moment of inertia of cracked section=$bx^3/3+mAst\,(d-x)^2$, in mm^4,
$M_r = \frac{f_{cr} * I_{gr}}{y_t}$ = Cracked moment of resistance, in N.mm,
f_{cr} = Modulus of rupture of concrete,
y_t = Distance from centroidal axis of cross section, neglecting the reinforcement, to extreme fibre in tension,
M = Maximum moment in the section, in N.mm,
Z = Lever arm = d - x/3, in mm,
X = Balance depth of neutral axis, solved by duly equating moment in tension and compression, in mm,
d = Effective depth of the section, in mm,
b_w = Breadth of the web,and
b = Breadth of compression face.

2. **Deflection of Open Foundations:** The structures with open foundations deflect in two ways under the effect of longitudinal loads. The foundation as a whole rotates and the foundation translates under the effect of longitudinal load, as shown below:



a) b)

Longitudinal displacement of deck due to a) bending of foundation and b) longitudinal movement of foundation.

The translation of the foundation under the longitudinal loads as mentioned in para 3.2.5 figure (c) is not appreciable under normal loads and this effect can be neglected without error in computations.

2.1 Computation of Deflection of open foundation due to rotation of foundation:

The foundation can rotate under the longitudinal loads if the foundation is resting on soil. The soil in this case behaves like a spring. The soil can be considered to act like a spring as it is compressed by vertical load and gap will not appear on the side rotating upwards if the rotation is small (which is the case in railway bridges). The value of spring stiffness to represent the soil is quite difficult and no definitive values are available. The designer shall take the spring stiffness values carefully as the soil behavior under different loading conditions is different. The problem is compounded by the fact that on railway bridges, the soil investigation is not done to determine this value. The angle through which the foundation will rotate is given by the formula (see *step 9 and fig 8.6 (Page 90) in the chapter 8: Distribution of Externally-Applied and Self-induced Horizontal Forces among Bridge Supports in Straight-Decks, in the book "Concrete Bridge Practice Analysis, Design and economics" by Dr V K Raina, Third Edition, First Reprint November 2009, published by Shroff Publishers & Distributors Pvt Ltd*) :

$$\tan \emptyset = \frac{12M}{ab^3c}$$

Where M = Bending moment at the base of open foundation, = 1.00 * h if we consider 1 kN (or 1 t) load applied at a distance of h meters (distance between top of bearing and bottom of open foundation);

a = plan dimension of open foundation normal to bridge;

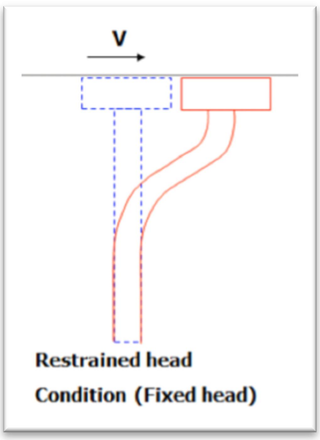
b = plan dimension of open foundation parallel to bridge; and

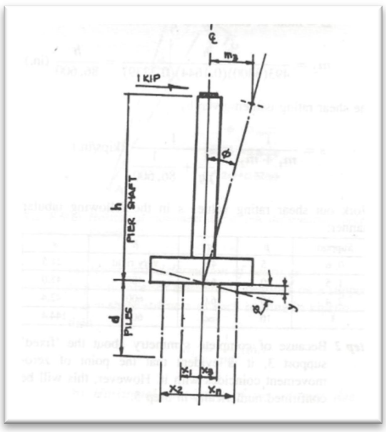
c = Coefficient of subgrade reaction of soil

Design tip: The open foundations on Indian Railways are mostly allowed on rocks. In such cases, the spring to be considered shall be very stiff. Even these values are not available. For such cases, RDSO is using the values of spring stiffness given in the table no 3-2 at page no 409 in the Chapter-"Special Footings And Beams On Elastic Foundations", of book "Foundation Analysis And Design", by Joseph E. Bowles. **For soft rock, the spring stiffness value given in the table for dense sand i.e. 128000 kN/mm is adopted presuming that the actual spring stiffness value will be higher for rocks.** For hard rock, this phenomenon can be considered negligible.

Care to be exercised: The values given above are not related to the soil properties like cohesion and angle of internal friction etc. These values shall not be taken in case the open foundation is resting on soil. For these cases, spring stiffness shall be taken from soil investigation carried out to work out the same. Literature of geotechnical engineering may be referred on methods for working out spring stiffness of soil.

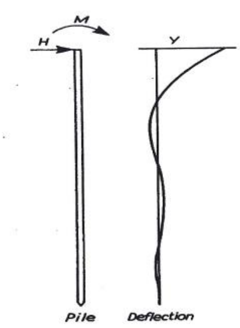
3. **Deflection of Pile Foundations:** The pile foundations deflect under longitudinal loads structures through two actions, as figuratively shown below:





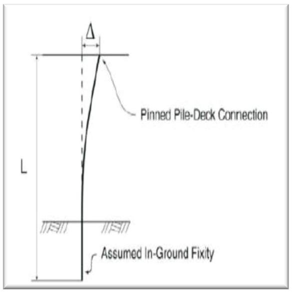
Deflection of pile under longitudinal loads; Axial Deformation of piles causing rotation of pile cap under bending loads

The combined effect of the two effects is quite complicated and looks something like this:



However, for simplicity sake, without too much error, the two deflections can be worked out independently and added up to get the required total deflection. These deflections can be worked out individually as follows:

3.1 Bending of piles in longitudinal direction: The piles bend under longitudinal loads. If the pile is socketed in rock, the deflection can take place about this fixed point. In most cases, piles are not resting on rock, or there is considerable layer of soil between the rock level and scour level, and the bending of piles takes place about a 'point of fixity' which develops by considering the soil as springs which compress on one side and extend on other side under longitudinal loads, as shown below:



The pile below the point of fixity does not bend or deflect under loads. This point of fixity is below the point of maximum scour. The point of fixity shall be worked out as per paras C-4.1 and C-4.2 of Annexure C of IS 2911-2010 Part 1, Section 2. The following aspects may be seen:

i. The values for sand and normally loaded clays are very close to each other. **The clays may not be considered pre-loaded for most railway bridges in absence of detailed soil properties being available.**
ii. Railway bridges have group of piles with stiff pile cap on top, hence **the piles shall be considered to be fixed headed**.
iii. The point of fixity shall be worked out as per para C-4.1 of the annexure mentioned above.
iv. The total deflection due to lateral deflection of piles shall then be worked out as per type of soil between scour level and the fixity level.

3.2 Rotation of pile cap due to elastic deformation of piles under differential axial loads: Under bending effects, the piles are subjected to compressive/ tensile loads depending on location with respect to the neutral axis. The piles, consequently, axially deform, increasing in length if subjected to tensile loads and shortening in length if compressive load is there. This change in length gives rise to rotation of the pile cap which, in turn, rotates the sub-structure giving rise to deformation at top of sub-structure. Procedure for working out this effect shall be as follows:

i. The 'free-standing' length of pile from bottom of pile cap to the point of fixity worked out above is required to determine the change in length.
ii. Load on individual pile shall be worked out by considering the bending moment, location of pile and the stiffness of pile group, using method similar to one used to determine the load on individual rivets/ bolts in a group, as given below:

$$P_i = \frac{M * x_i}{\sum_i {x_i}^2}$$

Where M = Bending moment at the pile cap level;

P_i = Axial load in pile i;
x_i = Distance of individual pile from the neutral axis; and
$\sum_i x_i^2$ = Summation of square of distances of all i piles from neutral axis.

iii. Rotation of pile cap can then be worked out by dividing the deflection of outermost pile by the spacing.

4. **Structures with Well Foundations:** The structures on well foundation are resting on single or multiple wells. Diameter of wells is generally quite high as compared to the piles. The principles given below are for single wells (cross-section may be circular or D-shaped or double D-shaped or multi-cellular etc) which are the most commonly used well-form on Indian Railways. Wells are rigid and due to large size have appreciable bottom friction. (Refer book "Theory and Practice of Foundation Design" By N. N. Som & S. C. Das).

A heavy well under a lateral load will rotate about its base, and the force diagram will be as shown in Fig. 10.6. For soil below scour level, submerged unit weight γ' is considered.

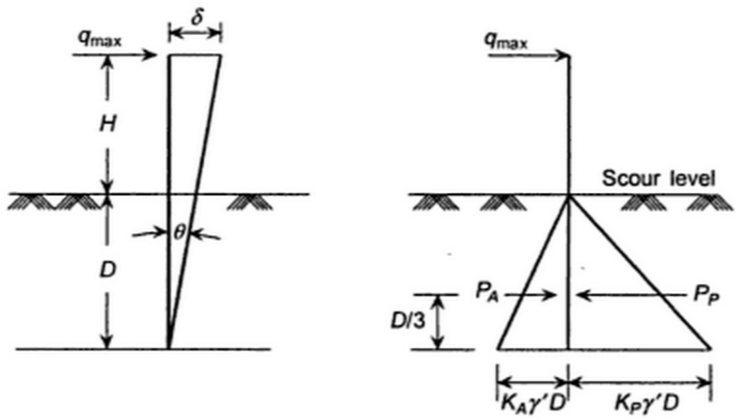


Fig. 10.6 Force and deflection diagrams of a well for rotation about base.

Accordingly, it is recommended that well shall be modelled with a fixed support at the bottom, and supported by point springs (multilinear unsymmetrical) with stiffness equal to difference between passive earth pressure and active earth pressure. For working out stiffness of multilinear springs, full pressure may be considered to have been mobilized at the X/H ratio as given in table 6.4 of "Geotechnical Engineering Handbook" by Braja M Das. The values for mobilization of passive pressure may be used. The table is extracted below:

Table 6.4: *Movement(X) of wall required to activate active and passive conditions*		
Type of Backfill Soil	**X/H for Active state**	**X/H for passive state**
Dense sand	0.0005	0.0002
Loose sand	0.002	0.006
Soft clay	0.02	0.04
Stiff clay	0.01	0.02

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Appendix D: Working Out Stiffness of Different types of Bearings

1. **Fixed-free bearings such as POT-PTFE Bearings:** The structures with fixed-free bearings such as those with roller-rocker bearings, those with POT-PTFE/Spherical/cylindrical bearings are easy to model. The fixed end is considered rigid for the loads and has infinite (or very-very high) rigidity in modelling. The free end offers frictional resistance to the longitudinal loads. This friction need not be considered in modelling and the rigidity of these bearings is considered zero. There is slight error due to this assumption but the magnitude of this error is less as the girder is not permitted by the fixed end to move and only slight movement takes place at the free end due to bending of girder under loads. Para 2.1.3.5 of UIC 774-3R states that "The effects of friction on rail stresses and displacements are always favourable especially when the support stiffness is low, so that ignoring friction is in general conservative for safety." Therefore, generally, considering the fixed end bearing as infinitely rigid and free end bearing as infinitely flexible is OK. However, if exact analysis is desired, or in marginally failing cases, the friction of free bearing can be considered.

Special Note: a) Some elastomeric bearing designs have special stoppers which convert one end of girder to fixed while other end is free to move. The behaviour of these bearings needs to be seen and appropriate decision about modelling needs to be taken. If the free end neoprene bearing stiffness is to be considered, the stiffness shall be determined as per procedure given in para 3 below.

b) In case of phosphor bronze bearings, the phosphor bronze plate is provided at one end of girder and the other side has steel to steel interface which is not greased. The friction in the ungreased steel to steel interface is quite high and this end is virtually fixed. The other end has lower coefficient of friction (0.15 as per clause 2.7.1 of Bridge rules). The coefficient of friction of phosphor bronze end can be neglected, or considered as per procedure given in para 2 below, at the discretion of designer carrying out the RSI analysis.

2. **Expansion Bearings (Including sliding bearings):** All structures have moving bearings at one end. The movement can be permitted by steel to steel interface, or through rollers, or through stainless steel on PTFE etc. Some structures like plate girders have no fixed bearings and the girder can move at both ends over sliding bearings. (The restraint is provided by high coefficient of friction between the bearing and the bed plate.)

2.7 FRICTIONAL RESISTANCE OF EXPANSION BEARINGS

2.7.1 Where the frictional resistance of the expansion bearings has to be taken into account, the following coefficients shall be assumed in calculating the amount of friction in bearings:

For roller bearing	0.03
For sliding bearings of steel on cast iron or steel bearing	0.25
For sliding bearing of steel on ferro bestos	0.20
For sliding bearings of steel on hard copper alloy bearings	0.15
For sliding bearings of PTFE/Elastomeric type	0.10
For concrete over concrete with bitumen layer in between	0.50
For concrete over concrete not intentionally roughened	0.60

The clause 2.7.1 of Bridge rules (Reproduced alongside) gives the coefficient of friction for different sliding arrangements. This friction opposes the movement of the girder. This resistance divided by the total movement can be considered as the resistance offered by the bearing to oppose that movement i.e. the stiffness of that bearing. Movements (expansion/ contraction) under thermal effects takes place under permanent loads like dead load (self-weight) and Superimposed dead loads including load of track, ballast, pathways etc.

The stiffness of this bearing for thermal load can be computed as follows:

S No	Item	Formula/ Notation	Actual Value for Bridge No 20, Km 56.875 in KQR-GRD Section, EC Railway. (Composite Girder with sliding bearing)
If	No of bearings on each end of girder	n	2
	Vertical Load (DL + SIDL) on one bearing (kN)	W=Total Load/No of bearings	4650/(2*2) = 1162.5
	Span Length (Overall) (m)	L	19.775
	Coefficient of thermal expansion for deck (per ^{0}C)	α	1.17 * 10^{-5}
	Coefficient of Friction at the interface	μ	0.25 (For sliding bearing)
	Total thermal variation of desk from mean (^{0}C)	(+/-) Δt	±20
Then	Total expansion/ contraction of girder, ΔL (mm)	(+/-) 0.5 * L * α * Δt	±0.00231*1000 = ±2.31
And	**Stiffness of bearing (kN/mm)**	**μ * W / ΔL**	**125.8**

For loaded case, the stiffness will work out higher as live load is also there in addition to dead load and superimposed dead load already present. Therefore, for exact analysis, the stiffness needs to be worked out for unloaded case and loaded case separately and the analysis needs to be carried out twice with the two different values. However, since the movement of bearing under load is not much, the stiffness worked out for the unloaded case (in which the major amount of movement also takes place) can be used for both the thermal as well as loaded case.

3. **Structures with Neoprene Bearings:** The stiffness of neoprene bearings can be worked out if we know the plan dimensions, thickness of rubber bearings and the number of rubber layers. The stiffness can be worked out as follows:

S No	Item	Formula	Actual Value for Bridge No 374, Km 123/222 in Bangalore-Hassan Section, SW Railway (PSC Girder with neoprene bearings)
If	**Length of bearing (mm)**	**L**	**560**
	Width of bearing (mm)	B	360
	Side cover (mm)	c	6
	No of rubber layers (Nos)	n	3
	Thickness of each layer (mm)	t	12
	Load on bearing (kN)	W	100
	Static Shear Modulus (kg/mm^2)	G	0.1
Then	**Static stiffness of bearing$^\$$**	**2*G*(9.81/1000)*(L-2*c)*(B-2*c)/(n*t)**	**10.39**
$^\$$ The dynamic shear modulus is double the static shear modulus as per UIC 772-2R, Clause 3.1.3			

The above stiffness worked out is for loaded case. Under thermal loads, the static shear modulus has to be considered and for this, the stiffness works out to be half of the above value. The RSI analysis shall be done for thermal case considering the static shear modulus whereas for train loads, dynamic shear modulus shall be used.

Note: It may be seen that the stiffness of elastomeric bearings is quite low as compared with the sliding bearing worked out above. Thus, when the bridges having elastomeric bearings are analyzed for RSI effects, the displacement under longitudinal loads becomes critical controlling parameter. This flexibility of supports means that the track disperses higher loads in such cases as compared with the sliding bearings or fixed-free arrangements.

Appendix E: Explanatory example outlining Methodology to be Followed for RSI studies Using FEM Program

1. **Bridge Details:** Bridge No 531, NW Railway

a **Bridge Number:** 531.

b **Location of Bridge:** 204/9-10,CH:207802.16

c **Section: UDAIPUR-HIMMATNAGAR**, NW Railway.

d **Between stations:** SES-RDD.

2. Span details:

a **No. of spans**: 3.

b **Span Lengths:** Clear span: 16.93 m, effective Span: 17.85 m, overall length: 19.05 m for all spans.

c **Type of Girder**: PSC 4I-Girder,RDSO/B-10245R.

d **Location of Rails:** At deck level.

e **C/C of Girder leaves:** 1.23m; **Total Depth:** 1.5 m.

f **Details of Material:** Grade of steel: IS:2062 Grade B; RCC Deck: M40.

g **Properties of Material:**

	Concrete (Short term)	Steel
Young's Modulus	31000 N/mm^2 (Cl 5.2.2.1 of CBC)	2.1x10^5 N/mm^2 (cl 3.8 of SBC)
Poisson's ratio	0.2	0.3
Coeff. of Thermal expansion	1.08x10^{-5}/^{0}C	1.17x10^{-5}/^{0}C

h **Details of Different Cross-Sections:** Uniform cross-section of girder. Critical Values computed: X-Section Area:5.69 m^2; I_{yy}:6.79722 m^4; I_{zz}:1.48946 m^4; J:6.97722 m^4; A_{sy}:3.38027 m^2; A_{sz}:1.87711 m^2; y_{top}: 0.559303m (All values are worked out for short term loading as the live loads are transient loads; thermal effects are slightly over-estimated due to this).

Note: To be on conservative side, overall length 19.05 m used for all computations (The effect is very minor).

3. Loading Details: 25t Loading, Full speed (125 KMPH for goods and 160 KMPH for passenger).

4. **Track Details**

a **Type of track:** Ballasted, 350 mm cushion.

b **Rail section:** 60kg 90 UTS.

c **Rail Material properties:** Young's Modulus: 2.1e+5 N/mm^2, poisson's Ratio: 0.3, Coeff. Of thermal expansion: 1.17e-5.

d **Track details:** Height of sleepers: 0.21 m, Depth of ballast cushion: 0.35 m, Wearing coat: 0.08m.

e **Fastener Details:** Sleeper density: 1660 nos/KM, type of fasteners: Elastic (ERC).

f **Location of SEJ within 100 m of either abutment:** NIL.

g **Curvature and gradient in track, if any:** NIL.

5. **Temperature Details**

a **Maximum rail temperature:** 55^{0}C

b **Minimum Rail Temperature:** 7^{0}C

c **Stress-Free temperature of LWR** (Shall be maintained within ±5^{0}C, else RSI studies are required to be done again): 36^{0}C.

d **Maximum annual deck temperature:** 51^{0}C

e **Minimum annual deck Temperature:** 7^{0}C

f **Temperature of deck at the time of laying LWR/CWR**: 29^{0}C

Accordingly, maximum deck temperature variation from mean temperature to be considered for RSI: 34^0C (Actual variation 29^0C; ±5^0C margin for maintenance);

Maximum rail temperature variation from mean temperature to be considered for RSI: NIL as there is no SEJ within 100 m on either side of the bridge.

6. **Bearings Details:** Complete drawings shall be available, having the following details

a **Type of bearing:** Elastomeric Bearing.

b **No. of bearings per span:** 4 in each end of girder.

d **Dimension of Elastomeric Bearings:** 550x 400x 78 mm.

7. **Sub-structure Details:** Complete drawings shall be available, having the following details

a **Type of Piers and abutments:** PCC piers and abutments.

b **Material of construction: Grade of concrete, Piers:** M30; **Bed Block:** M30..

c **Properties of Material:** Young's Modulus, Poisson's Ratio, Coeff. of thermal expansion etc.

Concrete M30	
Young's Modulus	28000 N/mm^2 (Cl 5.2.2.1 of CBC)
Poisson's ratio	0.2
Coeff of Thermal expansion	1.08x$10^{-5}/^0$C (Assumed)

d **Dimensional details:** As per Drg No DyCE(C)137-UDZ/790/D-UDZ-HMT. Abutments are rectangular/ tapered twin, spill-through type and piers oval in shape. Bed blocks are cuboid in shape. Piers and abutments have different heights.

8. **Foundation And Soil Details:** Complete drawings and soil bore-log shall be available, having the following details

a **Type of Foundation: A1, A2, P1, P2:** Open foundation.

b **Details of Open Foundation: Single Step A1:** 9.345m x17.204 m x 0.915 m; **P1:**11.116 m x 16.116 m x 1.220 m, **P2**:11.723m x16.272m x0 .920m, **A2**:10.33 x 17.204x1.220m.

c **Soil details:** Open Foundation, soft rock; **Bearing capacity:** 46T/m^2.

9. **Flood Details:**

a **Rail Level:** 291.033 m.

b **Bottom of Girder:** 288.843 m.

c **High Flood Level:** 280.055 m

d **Bed level**: 277.705m.

e **Scour Level:** 276.500 m for both abutments and piers .

f **Level at which rock/ non-erodible strata is there:** 274.106m.

10. Computation For Stiffness

(1)Stiffness of Elastomeric Bearing:

Formula used for calculating Stiffness of elastomeric bearing,

$$k=\frac{(2*G*9.81)}{1000}*\frac{[(a-2c)*(b-2c)]}{n*hi}$$, in kN/mm.

In this bridge Elastomeric bearing used is as per RDSO drawing: RDSO/BA-10245R, Dimensions of the bearing deduced from above drawing are as follows:

Size of bearing: 550*400*78 mm.
G= static shear modulus= 0.1 kg/mm^2,
Length of bearing, a= 550 mm,
Width of bearing, b= 400 mm,
Cover, c= 6mm,
Individual layer thickness, h_i= 10 mm
Number of layers of elastomers, n=5
Putting above values in the above equation gives the stiffness of elastomeric bearing as below,

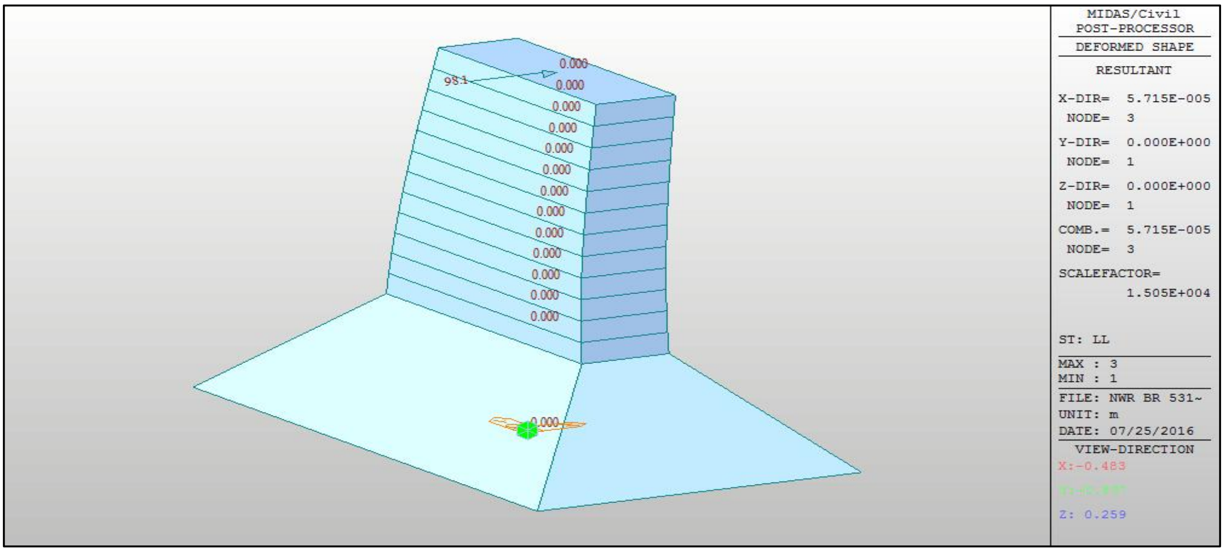
∴ k= (2*0.10*9.81/1000)*[(550-12)*(400-12)/10*5]=8.19 kN/mm

(2) Stiffness of Abutments A1 & A2 with open foundations: To simplify the computations, open foundations are considered supported vertically with soil springs and the effect of soil on sides of foundation is neglected. This assumption is on safe side.
The stiffness of soil springs (k_s) supporting open foundation vertically is taken as 128000 kN/m³ (This soil Stiffness is for dense sand as on page no: 409 of **foundation analysis and design "by Joseph E Bowel's** Book .Normally open foundations are founded on hard strata/rock hence this assumption is OK or on safe side. **(See Para 2.1 (Design tip) of Appendix-C of these guidelines).**

The deflection of sub-structure has two components:
(i) Deflection Due To Rotation of Foundation δ1: This is to be worked out as per Para 2.1 of APPENDIX-C of these guidelines. Data in this case:
A1: a=9.345m, b=17.204m, h=11.417m, A2: a=10.33m, b=17.204m, h=13.537m. Using above formulae for given values of a, b and h for Abutments A1& A2 as per GAD of the bridge.

For A1, δ1=2.56807E-07 m.
For A2, δ1=3.26609E-07 m.

(ii) Elastic deformation of Abutments (δ2): Modeling of Abutments A1 & A2 was done by MIDAS CIVIL software and 98.1kN longitudinal force was applied at bearing level. If Abutments is of mass concrete, then Ec given in IRS concrete bridge code is to be used. The deflected shape from modeling was as follows:



As per modelling, elastic deformation per kN of longitudinal force For A1, δ2=5.83E-07 m, For A2, δ2=7.72E-07 m.

∴Total deformation at bearing level per kN of longitudinal load:

For A1, δ = δ1 + δ2 = 2.56807E-07 + 5.83E-07 = 8.39E-07m = 0.000839mm;

For A2, δ = 3.26609E-07 + 7.72E-07 = 0.0011 mm.

Finally stiffness for Abutments A1 & A2:

For A1 = 1/δ = 1/0.000839 = 1191.36 kN/mm.

For A2 = 1/δ = 1/0.0011 = 910.35 kN/mm.

(3) Stiffness of piers (P1, P2) with open foundations:

The deflection of sub-structure has two components:

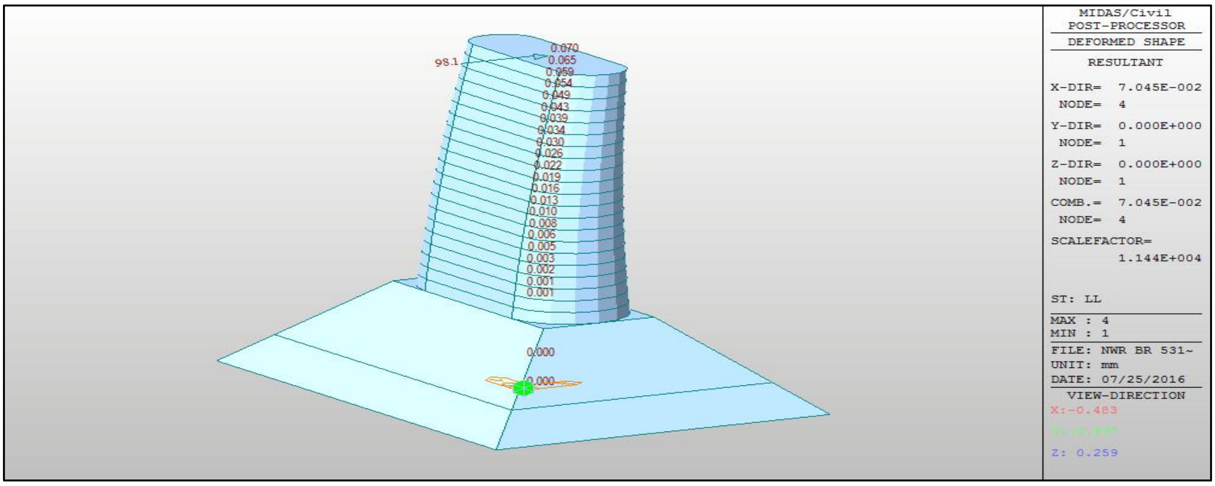
(i) Deflection Due To Rotation of Foundation δ1: This is to be worked out as per Para 2.1 of APPENDIX-C Of these guidelines. Data in this case:

P1: a = 11.116m, b = 16.116m, h=13.86m, P2: a = 11.273m, b = 16.272m, h = 14.737m. Using above Formulae for given values of a, b and h for Piers P1& P2 as per GAD of the bridge.

For P1, δ1 = 3.87059E-07 m.

For P2, δ1 = 4.19206E-07 m.

(ii)Elastic deformation of piers (δ2): Modeling of piers P1 &P2 was done by MIDAS CIVIL software and 98.1kN longitudinal force was applied at bearing level. If Pier is of mass concrete, then Ec given in IRS concrete bridge code is to be used. The deflected shape from modeling was as follows:



As per modelling, elastic deformation per kN of longitudinal force For P1, δ2=7.18E-07 m, For P2, δ2=8.60E-07 m

∴Total deformation at bearing level per kN of longitudinal load:

For P1, δ = δ1+δ2 = 3.87059E-07 + 7.18E-07 = 1.11E-06m = 0.00111mm;

For P2, δ = 4.19206E-07 + 8.60E-07 m = 1.28E-06 m = 0.00128 mm.

Finally stiffness for Piers P1&P2:

For P1= 1/δ = 1/0.00111 = 904.81kN/mm.

For P2= 1/δ = 1/0.00128 = 781.65kN/mm.

11.**Live load and increments to be considered**:

(i) Assuming left and right hand approach lengths = 200m (This shall be of adequate length to accommodate train to be run.) and left hand abutment is the reference point.

(ii) Total length of deck/bridge = 3*19.05m = 57.15m

(iii) Therefore, Total length of deck/bridge with abutment = 457.15m

(iv) As per Para-4.2 of these guidelines, for 25 t load to be taken as:

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-∞
MBG Loading	182.95	104	47	22	0	34	13

(v) Longitudinal load intensity (TE) for (40-∞) = 0.00 kN/m. The span is only 19.775m and TE will govern single span as well as double span loaded conditions, **hence BF case not required to be run. For larger span both cases needs to be run separately.**

(vi) Location Increment for each Analysis = span/10 = 19.05/10 = 1.905m as per note 4 of para 4.2 of these guidelines.

(vii) Number of Track Loading Locations = (total length of bridge/location increment for each analysis)+1 = 31

For easy understanding, screenshot of LUSAS spreadsheet with data input is given below.

For Deck		Amount							
	Temperature	34							
For Rails	Temperature								
	Number of Track Loading Locations	31							
	Loading Type	Track Selection to be Loaded	Parametric Starting Position for Loadings	Parametric End Position for Loadings	Amount (per unit length)	Loaded Length	Starting Location of Loading for First Analysis	Finishing Location of Loading for Last Analysis	Location Increment for each Analysis
	Vertical1	1	188	200	182.95	12	0	57.15	1.905
	Vertical2	1	0	188	104	188	0	57.15	1.905
	Acceleration1	1	188	200	-47	12	0	57.15	1.905
	Acceleration2	1	160	188	-22	28	0	57.15	1.905

12.**Track stiffness to be considered:** As per Para 3.2.6 of the guidelines, the plastic resistance for ballasted track is:

Unloaded condition = 25kN/m/mm.

Loaded condition = 50kN/m/mm.

Limit for elastic deformation = 2 mm.

13.**Properties of rails to be considered:**

For 60 kg UIC rail, from LUSAS BRIDGE PLUS software modeling done and data collected.

A	Iyy	Izz	J	Asy	Asz	Eccentricity	Description
0.015440	0.0000614	0.011832	0.0118263	0.0127098	0.006599	0	Track with 2 UIC 60 kg Rails

E	ν	α	Description
210000	0.3	1.17E-05	60 kg Rails 90 UTS

14.**Eccentricity and other dimensions to be considered**:

Eccentricity between rail and slab = (height of NA of rail section+ height of sleeper at mid +ballast cushion+ wearing coat) = (0.086m+0.21m+0.35m+0.08m) = 0.726m.

Eccentricity between rail and deck section (Distance from Neutral Axis of rail to top of deck + Distance of neutral axis of girder from top) = 0.726 + 0.559 m = 1.285 m

15.**Results:** With above data input, the results obtained from LUSAS are summarized as follows. (It is seen that the bridge passes from RSI considerations.)

			Tempe-rature Only	**COMBINED (Temp. + Loading)**	**Only Train Loading**	**Permissible Value**	**Unit**	**OK or NOT**	**Reference For permissible value**
1	**MAX. Horizontal Displacement Of Deck (Under longitudinal loads**	**=**	**3.44**	**6.19**	**2.75**	**5.00**	**mm**	**OK**	UIC 774-3R, Cl.-1.7.2, No SEJ

	only)								
2	**Max. Relative Displacement Between Rail & Slab (Under longitudinal loads only)**	**=**	**3.225**	**4.175**	**0.95**	**4.00**	**mm**	**OK**	UIC 774-3R, Cl.-1.7.2
3	**Additional Tensile Axial Stress in Rail due to RSI Effects(MPa)**	**=**	**6.08**	**29.22**		**75.00**	**MPa**	**OK**	As Per IRC – Bridge Rules para 2.8.2.4.3, CS-45
4	**Additional Compressive Axial Stress in Rail due to RSI Effects(MPa)**	**=**	**4.43**	**31.95**		**60.00**	**MPa**	**OK**	As Per IRC – Bridge Rules para 2.8.2.4.3, CS-45
5	**Max. Deck End Rotation**	**=**	**1.46E-06**	**0.0002**	**2.021 E-04**		**m**		
6	**Height Of CG From Rail Level**	**=**	**1.285**				**m**		
7	**Max. Displacement Of Deck End Due To Rotation**	**=**			**0.26**	**8.00**	**mm**	**OK**	UIC 774-3R, Cl.-1.7.3
			Tempe-rature Only	**COMBINED (Temp. + Loading)**	**Only Train Loading**	**Permissible Value**	**Unit**	**OK or NOT**	**Reference For permissible value**
8	**Max Vertical Displacement Of Deck End**	=	**0.00**		mm	**3.00**	**mm**	**OK**	UIC 774-3R, Cl.-1.7.2, Permissible Value Not Given In IRS Bridge Rules. It is 3 mm as per para 3.3.2.4 of RSI guidelines
	Other Results Of Modelling								
9	**Max Relative Displacement Between Rail & Track**	**=**	**2.369**	**3.103**	**3.10**	**mm**			
10	**Bending Moment In Deck**	=	**7457.09**		**kN.m**				
11	**Peak Longitudinal Reaction On Abutment (N)**	=	**187.34**		**kN**				
12	**Max. Shear Force In Deck**	=	**1553.83**		**kN**				
13	**Max. Shear Force In Track**	=	**71.61**		**kN**				

-0-0-0-0-0-