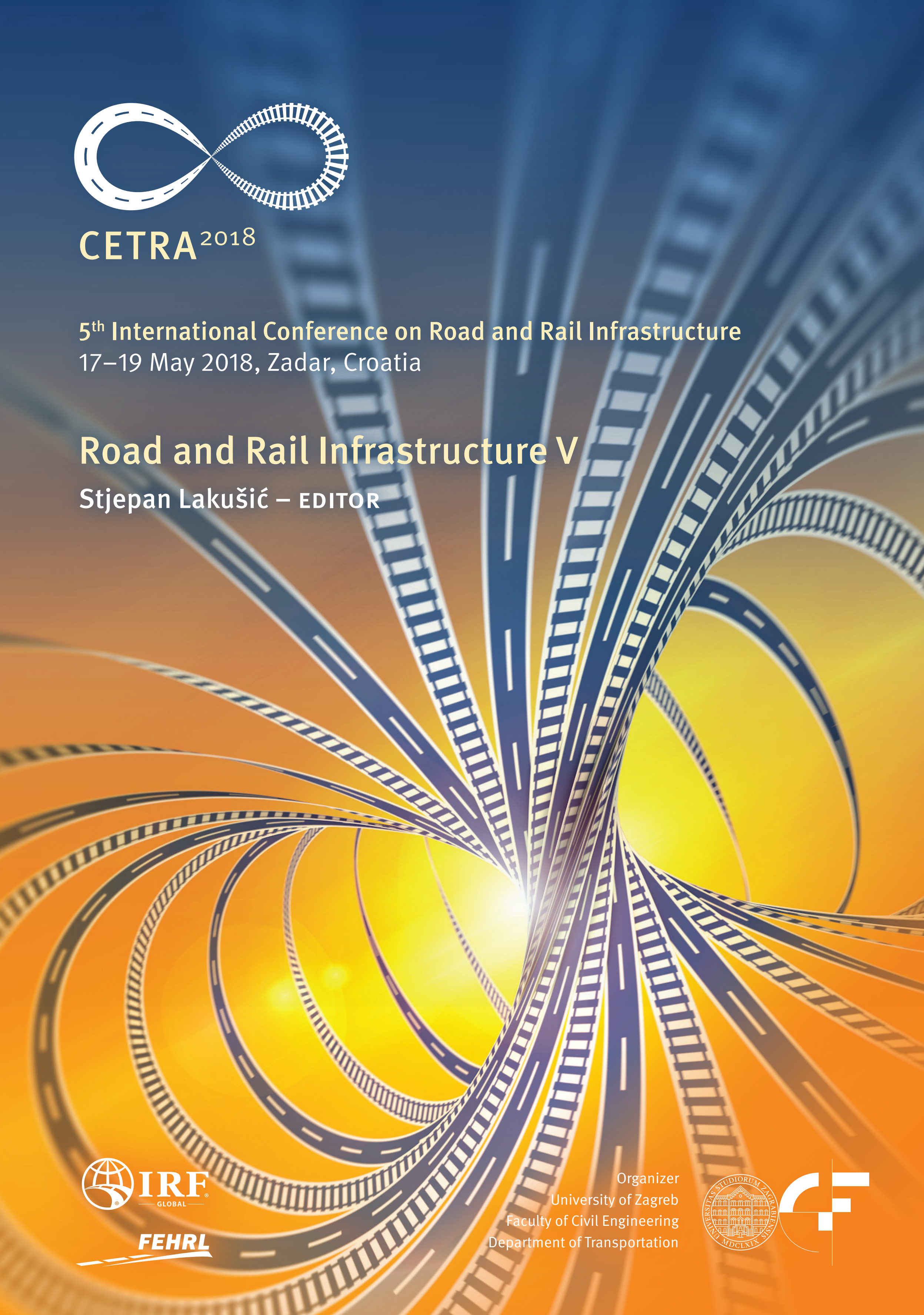
CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR



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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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CASE STUDY: RAIL STRUCTURE INTERACTION OF BRIDGE ACROSS BALRAM RIVER IN THE STATE OF GUJRAT, INDIA

Anuj Asati, Vasanth Kumar Samyayya, Subir Das
L&T Construction, Chennai, Tamilnadu, India

Abstract

In long welded rails (LWR) considerable longitudinal forces may develop due to temperature variation, train loadings like braking and traction, deck end rotation due to vertical bending. Rail structure interaction (RSI) analysis is an important part of bridge design to evaluate the longitudinal stresses in LWR, longitudinal forces on the substructure and deflection/displacement of the structure. This paper presents the case study of an ongoing bridge project over Balram River, Gujrat India for Dedicated Freight Corridor Corporation (DFCC). Total length of the bridge is 195 m. The analysis is carried out by a finite element based software package and as per the endorsements given in the UIC 774-3 code. Stress developed in LWR largely depends on the stiffness of the girder and the substructure (pier and foundation). In general practice, the boundary condition is maintained as fixed on one abutment and free on the other with all the spans being simply supported having one end free and other end fixed. The large span of bridge and height of support increases the flexibility of structure and poses difficulty to satisfy the stress and displacement criteria mentioned in UIC & Indian Railway Standards (IRS) Codal provisions with these boundary conditions. Excessive displacement of deck can result in deconsolidation of ballast and track stability cannot be ensured. Use of expansion device in rail may require proper monitoring and demand for intensive maintenance. In present study different bearing articulations are tried and a parametric revision is done to arrive at the optimum/economical substructure and foundation stiffness which satisfy the stresses and displacement limits prescribed in UIC 774-3. It is found that the changed bearing arrangement with both the abutments fixed and center pier rendered to be free, keeping the structural dimensions unaltered, which yield the analysis results which satisfy the stress and displacement criteria as per relevent codal provisions and also arrive at an economical substructure design.

Keywords: Rail structure interaction; long welded rail; Track bridge interaction; simply-supported bridge.

1 Introduction

Ministry of Railways (MOR), Government of India has planned to construct a Dedicated Freight Corridor (DFC) covering about 3325 km on two corridors, Eastern and Western Corridors. The Western DFC Corridor streches from Jawaharlal Nehru Port, Mumbai to Tughlakabad/ Dadri near Delhi. This Western DFC corridor (WDFC) Project covers a length of 1,483 km (JNPT – Ahmadabad – Palanpur – Rewari – Asaoti – Dadri). The bridges and other structures will be designed to allow freight movement having 32.5 ton axle load, operating at maximum speed of up to 100 Km/hr. Balram River Bridge is part of the Western Dedicated Freight Corridor (WDFC).

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1.1 Rail – Structure Interaction (RSI)

Today Long Welded Rails (LWR) [9] are preferred for modern railway track structures for their safety, economical, comfortable and less maintenance due to following reasons:

- LWR tracks eliminate fish plated joints leading to safety.
- Fish plated joints are subjected to large dynamic forces. As a result fish plated joints exhibit large-scale rail wear and development of cracks from fish bolt holes and fractures. In some instances, premature rail renewal may have to be carried out due to excessive fractures. It has been estimated that there can be as much as 25 % to 33 % savings in the track repair and maintenance costs due to elimination of rail joints [9].
- Due to impact at rail joints, there is an added wear and tear of rolling stock wheels to an extent of 5 % and as the wheel has to negotiate the gap there is added fuel consumption to an extent of 7 % [9].
- Due to elimination of noise and vibrations at the rail joints passenger comfort is substantially increased.

As the rails are continuous over the structure, it will induce relative displacement in the structure and the track due to temperature variation of bridge deck and movement of train. Due to excessive displacement, additional stresses in rails may develop which may impact the stability of the track structure. So to ensure the stability of track and ballast, controlling the stresses and displacements are essential. To ensure safety of the structure & track, UIC 774 – 3R have stipulated following criteria to be met with regards to RSI analysis:

- The maximum permissible additional compressive rail stress due to temperature variation of the deck, braking/acceleration and deck-end rotation is 72 N/mm^2 ($\sigma_{rail} \le 72$ N/mm^2).
- The maximum permissible additional tensile rail stresses due to temperature variation of deck, braking/acceleration and deck-end rotation is 92 N/mm^2 ($\sigma_{rail} \le 92$ N/mm^2).
- The maximum permissible relative horizontal displacement between the deck and the rail due to braking/acceleration is 4 mm ($\delta_{rel} \le 4$ mm).
- The maximum permissible absolute horizontal displacement of the deck due to braking/acceleration is 5 mm ($\delta_{abs} \le 5$ mm).
- The maximum permissible displacement between the top of the deck-end and the embankment or between top of the consecutive deck-ends to vertical bending (including the dynamic factor) is 8 mm ($\delta_{(\theta H)} \le 8$ mm).

Based on the above criteria, following limitations in stresses are stipulated in IRS Bridge Rules:

- The maximum permissible additional compressive rail stress due to temperature variation of the deck, braking/acceleration and deck-end rotation is 60 N/mm^2 ($\sigma_{rail} \le 60$ N/mm^2).
- The maximum permissible additional tensile rail stresses due to temperature variation of deck, braking/acceleration and deck-end rotation is 75 N/mm^2 ($\sigma_{rail} \le 75$ N/mm^2).

The purpose of RSI analysis is to examine these additional 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 allowable limits mentioned above so that the track is safe under tension as well as compression.
In case the extra stresses in rails are beyond permissible limits, various options may be tried to bring the stresses within limits including alteration of the structural and articulation arrangements. The current study in Balram River Bridge aims to analyse the effect of these alterations/changes and presented in the subsequent sections.

1.2 General arrangement

This bridge over Balram River is multi-span simply-supported bridge (Figure 1 and 2) with cast in-situ deck slab and precast post-tensioned beams supported on spherical bearings placed over pier caps and abutment caps. The superstructure consist of precast post-tensioned "I"-girders with cast-in-situ deck slab. Total depth of superstructure including the deck slab is 3 m. Vertical forces are transferred to substructure through free spherical bearings whereas horizontal forces are transferred through guided spherical bearings. Twin pier system was adopted with height of pier being 25.75 m (Figure 3).

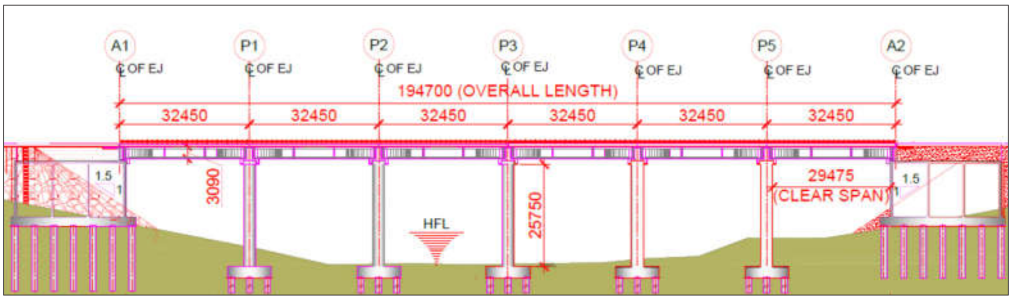

Figure 1 Elevation of the bridge

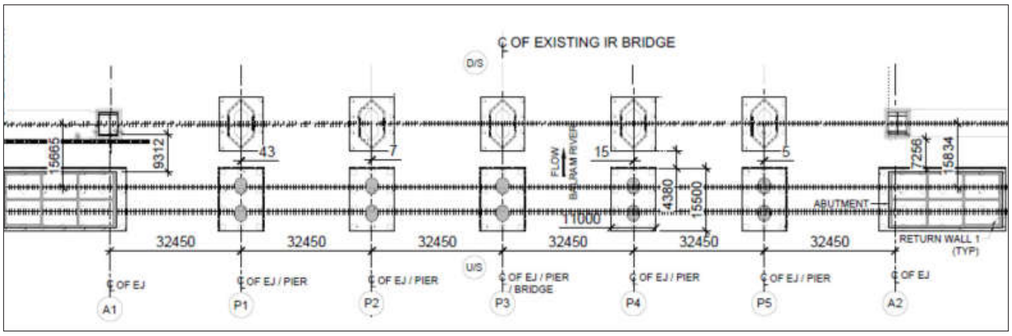

Figure 2 Plan View of the bridge

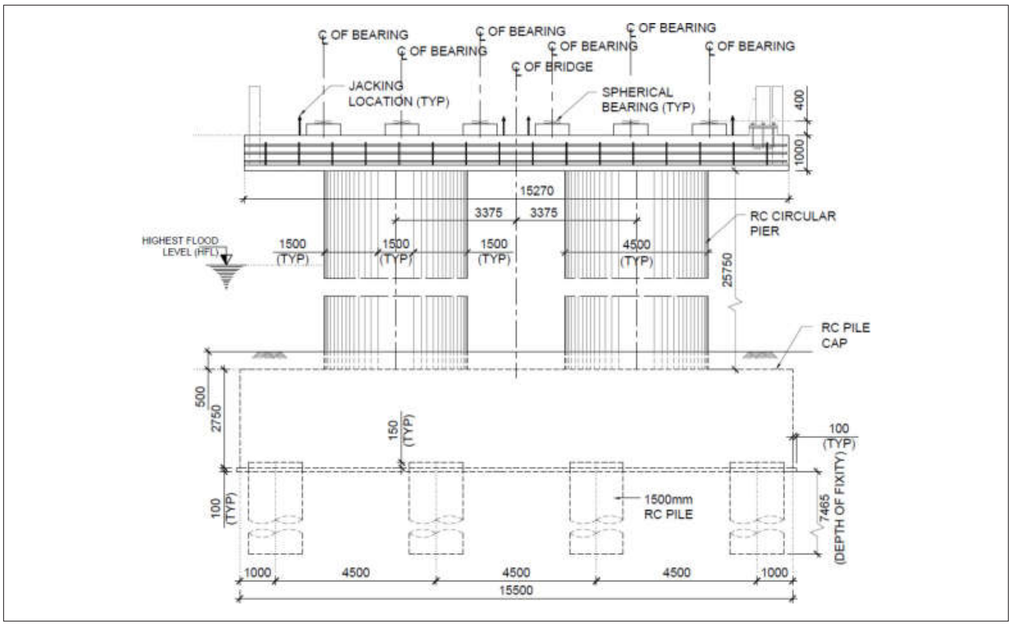

Figure 3 Section view of Pier (Across the Traffic/Track)

The Pier comprises of two recto-circular reinforced concrete (RC) columns of size 4.5 m × 3.0 m connected at top with common RC pier cap as portal structure.This portal pier supports the superstructure carrying tow tracks on top (Figure 3). Each of the RC abutments is a box type structure having arrangements shown in Figure 4. View of the existing Indian Railway Bridge is shown on Figure 5. Details of Existing and Proposed Bridge over Balram River is shown in table 1.

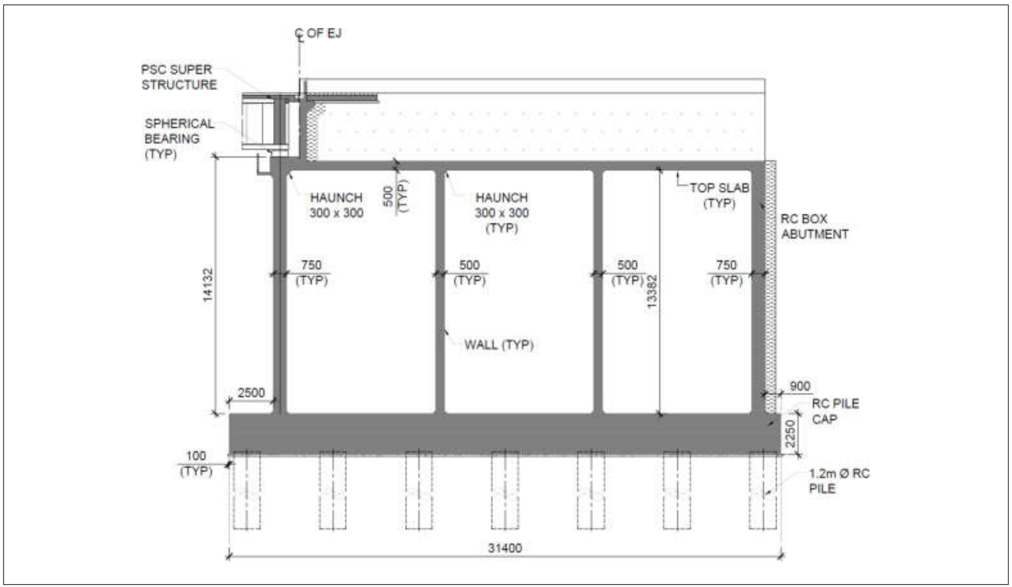

Figure 4 Section View of Box Type Abutment

Figure 5 View of the existing Indian Railway Bridge

Table 1 Details of Existing & Proposed Bridge over Balram River

Description	Existing Bridge No. 845	Propose Bridge No. 845
Chainage at center of bridge [km]	637/09-638/1	19+618.066
Span (Nos. × length) [m]	1x29.143+ 1x29.115 +	6x32.45 m
	1x29.143+ 1x29.135 +	
	1x29.170 + 1X29.290	
Standard of Loading	25T IR loading	32.5T DFC loading
Length of the Bridge [m]	191.496	194.7 m

2 Modelling

The design criteria adopted for rail structure interaction analysis as per UIC 774-3R and IRS Bridge Rules. The bridge structure is modelled using finite element based software to carry out rail structure interaction analysis, which aims to evaluate additional rail stresses, absolute and relative displacement of deck & rail and Support reaction at fixed support, Figure 6.

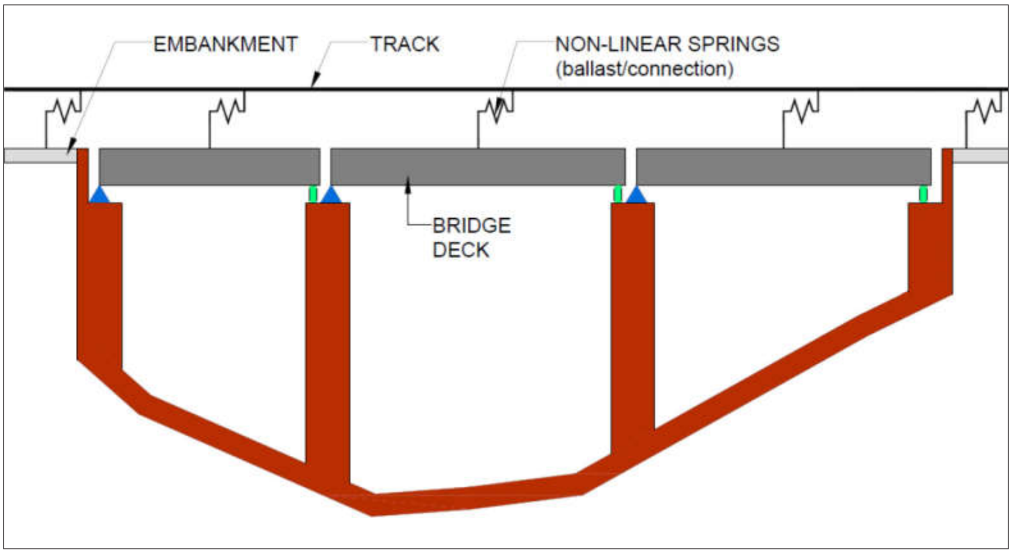

Figure 6 Representation of Analysis Model for IRS

The analysis model is done for the total bridge length of 194.7 m and embankment length of 300 m on either sides of bridge as per the recommendations given in UIC 774-3R. The substructure is connected to the top of bearing by elastic link. Rigid links connect bearing bottom to pier head, pier bottom to pile cap top and pile cap bottom to pile head, Figure 7.

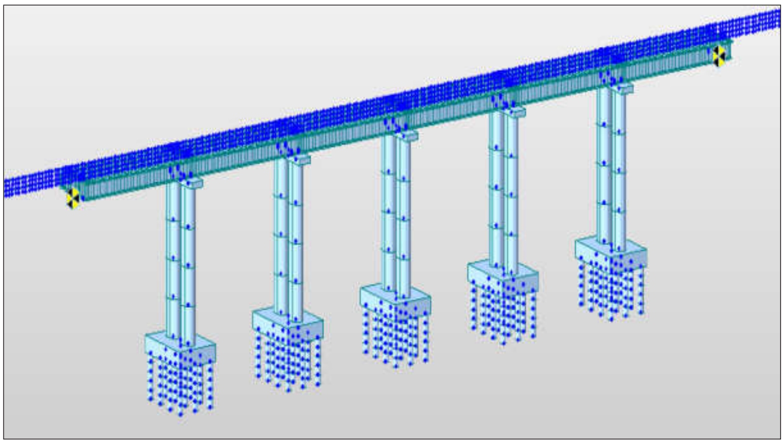

Figure 7 Complete Model for Analysis

2.1 Assumptions for analysis model

1) Track and deck are modelled as discrete elements with maximum element length of 1.0 m to generate more accurate results.
2) Nonlinear springs are used to connect track and deck to represent the actual behaviour of ballast rail fastening system and stiffness of ballast are applied for these springs.
3) For this analysis, pile is modelled up to the depth of fixity and given fixed supports at the fixity point.

2.2 Track properties

The resistance of the track to longitudinal displacement is a function of the displacement of the rail relative to its supporting structure. The resistance increases rapidly while the displacement remains low, but remains virtually constant once the displacement has reached a certain magnitude. The graph representing the bilinear behaviour of the track as per UIC 774-3 is shown in Figure 8:

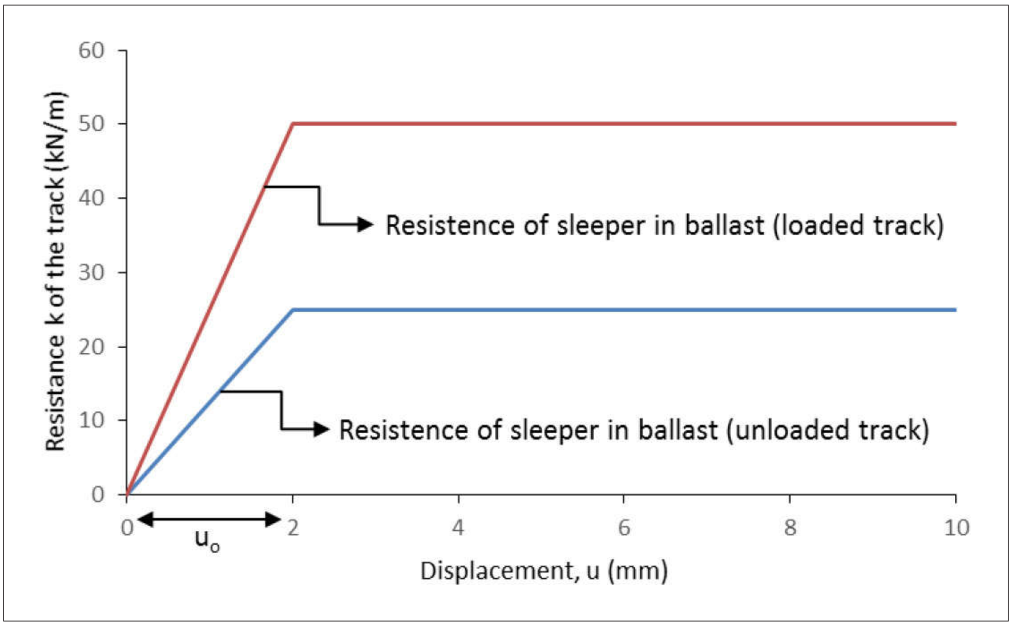

Figure 8 Resistance of the track per unit length as a function of the longitudinal displacement u of the rails

The graph shows that the displacement between the plastic and elastic zone is 2 mm. The value of track resistance for computations is taken as 25 kN/m for unloaded condition and 50 kN/m for loaded condition of the track.

3 Loading

Following are the loads considered for the analysis as per UIC 774-3R:
1) Temperature loads
2) Horizontal braking and acceleration forces due to Train loading
3) Vertical loads due to train loading

3.1 Temperature loads

A uniform temperature variation of 35 degree Celsius is applied in the deck. Maximum uniform variation of temperature of 50 degree Celsius in the rail is considered. However, in case of LWR a variation in temperature of the track does not cause a displacement of track and thus there is no interaction effect due to variation in the temperature of the track.

3.2 Live loads

Various possible combinations of live load are provided in IRS Bridge Rules and the most critical load case is considered for the analysis. The vertical loads due to live loads are further enhanced using the coefficient of dynamic augment.

4 Analysis

Since the bridge is straight with simply-supported spans with lesser span length, simplified separate analysis is carried out. Results are summarized separately for thermal variations, braking/traction and vertical bending, which are finally combined and compared with the allowable stresses. Instead of doing moving load analysis, various static load cases are considered by placing the train load at different support locations in forward as well as reverse direction. The total train length is assumed to be 500m. In the first load case the train load starts from left embankment and ends at abutment A1. Similarly, other load cases are formed ending at other support locations.

5 Case Study

Following three cases, each having different bearing arrangements are considered for analysis.

Case 1
In this case the bearing arrangements are adopted in such a way that one abutment is fixed and other abutment is free with all spans fixed at one end and free on the other end (refer Table 2).

Case 2
In this case the bearing arrangements are adopted such that the up track is fixed and the down track is free at A1 and the up track is free and down track is fixed at A2 (refer Table 2).

Case 3
In this case bearing arrangement is adopted such that both the abutments A1 and A2 were kept fixed with centre pier P3 completely free and all the spans fixed at one end and free on the other (refer Table 2).

Table 2 Bearing arrangement considered for different cases

Cases	Track	A1	P1		P2		P3		P4		P5		A2
1	up	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free
	down	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free
2	up	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free
	down	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed	Free	Fixed
3	up	Fixed	Free	Fixed	Free	Fixed	Free	Free	Fixed	Free	Fixed	Free	Fixed
	down	Fixed	Free	Fixed	Free	Fixed	Free	Free	Fixed	Free	Fixed	Free	Fixed

6 Results

As it can be seen from the charts that for case 1 and case 2, rail stress is exceeding the recommended value as per IRS Bridge rules. With the arrangement in case 2 there was a reduction in stress due to temperature variation but the stress due to breaking and traction was found to be increasing which resulting in overall stresses crossing the permissible limit. Stress comparison for different cases at support location is shown on Figure 9. The absolute maximum displacement of the deck is greater than limiting value of 5 mm as prescribed in UIC 774-3R. The relative displacement between the deck and the rail was found to be within limits for all the three cases. Only in case 3, with fixed abutments and free centre pier, both strength as well as the serviceability criteria are satisfied. Subsequently, same articulation arrangement (case 3) is adopted for final design. Comparison for stresses and displacement for different cases at support locations is shown on Figure 10.

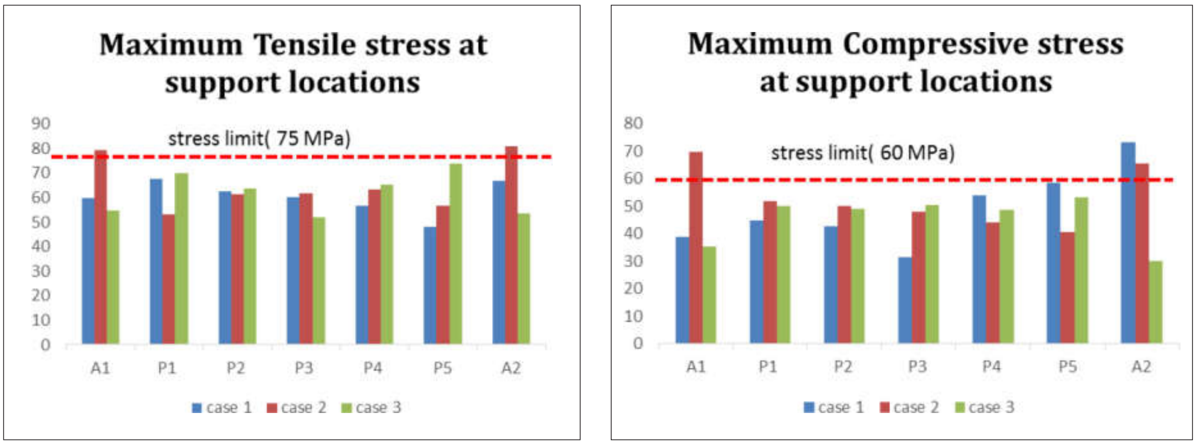

Figure 9 Stress comparison for different cases at support location

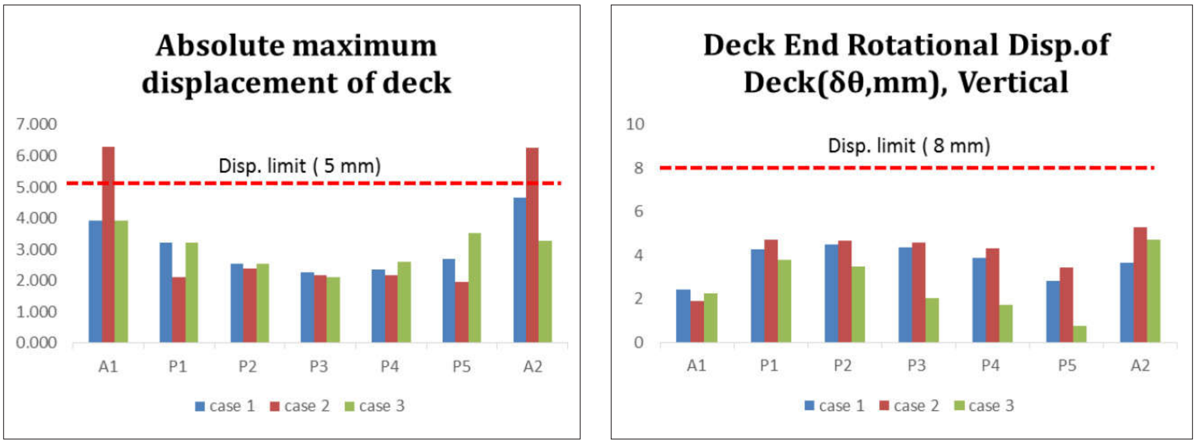

Figure 10 Comparison for stresses and displacement for different cases at support locations

7 Conclusion

With the requirement of LWR, the present study is carried out with three different cases which lead to the following conclusion:

- In case of multi-span long bridges if the rail stresses exceed permissible limits, change in the bearing arrangement can be tried before going for any dimensional change in structure or using expansion device for rails.
- As both the abutments are fixed a tensile stress is generated in the rails at both the abutment locations due to vertical bending which negates the compressive stress developed due to braking and traction.
- Due to fixity at both the ends the rail stress due to temperature variation is guided towards the free pier at the centre. Hence, the maximum stress due to temperature and live load do not occur at the same location in the rails resulting in reduction in overall stress.

The current study is aimed to find a way out to mitigate the rail stresses due to IRS and may reasonably yield similar conclusion for bridges having similar number of spans/length. However, for bridges with large number of spans, similar studies need to be carried out to ascertain the effects which would help the designer to take decisionson structural dimensions and/or articulations of the bridges.

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