STIFFNESS & ARTICULATION OPTIMIZATION OF METRO RAIL STRUCTURES FOR RAIL STRUCTURE INTERACTION

A Dissertation Submitted
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF TECHNOLOGY

in
Structural Engineering
by

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CANDIDATE'S DECLARATION

I, **Dinesh Kumar**, M. Tech (Structural Engineering) student, having **Roll no: 2K21/STE/502**, hereby certify that the work which is being presented in the thesis entitled "**Stiffness & Articulation Optimization of Metro Rail Structures For Rail Structure Interaction**" in the partial fulfillment of the requirements of the award of the Degree **Master of Technology in Structural Engineering**, submitted in the **Department of Civil Engineering, Delhi Technological University** is an authentic record of my own work carried out during the period from **January 2024** to **May 2024** under the supervision of Dr. Shilpa Pal, Associate Professor, Department of Civil Engineering, Delhi Technological University, Delhi-110042 and Dr. Rajeev Goel, Chief Scientist, Bridge Engineering and Structures Division, CSIR- CRRI, New Delhi-110025.

The matter present in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

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This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

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Certified that **Dinesh Kumar (2K21/STE/502)** has carried out their search work presented in this thesis entitled "**Stiffness & Articulation Optimization of Metro Rail Structures For Rail Structure Interaction**" for the award of **Master of Technology in Structural Engineering** from the Department of Civil Engineering, Delhi Technological University, Delhi under our supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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Stiffness & Articulation Optimization of Metro Rail Structures for Rail Structure Interaction

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ABSTRACT

Long Welded Rail (LWR) is commonly used in elevated metro rail bridge structures, where the track is directly fixed on the concrete superstructure or deck. However, there is a significant difference between LWR on the ground and LWR on a bridge. The stiffness of a bridge is lower compared to that of LWR on the ground, leading to deformation under various loads and thermal effects.

The interaction between the track and the bridge structure plays a crucial role in determining the final deformations and stresses in the viaduct and track. This interaction, known as the Rail Structure Interaction (RSI) effect, involves force transfer between the rail track and various bridge components, including the superstructure, pier cap, pier, and pile cap. Vertical live loads from trains, braking or traction loads, and thermal effects contribute to this force transfer.

In this study, we investigate the stiffness and articulation optimization of metro rail structures for RSI analysis. The analysis follows guidelines from the UIC774-3R Code of Practice (International Union of Railways) and RDSO Guidelines for Rail Structure Interaction Studies on Metro Systems Ver 2. We consider multi-span bridges with different span configurations and superstructure types (such as I-girders and U-girders).

Key parameters include the axial stresses in the rail, relative displacement between the rail and superstructure, and support or bearing reactions transferred to the bridge components. The software used for analysis is Midas Civil. Our findings indicate that considering the stiffness of piles and piers can reduce axial stresses in the rail and forces at the bearing levels.

ACKNOWLEDGEMENT

I, **DINESH KUMAR,** would like to express my deepest gratitude to all those who have given unforgettable contributions to the successful contribution of this thesis.

I want to sincerely thank my supervisor, **Dr. Shilpa Pal,** Associate Professor, Delhi Technological University for giving me the chance to work in my area of interest. This thesis has really benefited from her tremendous advice, support, and encouragement during the whole research process. She has also provided intelligent suggestions, critical criticism, and unwavering encouragement.

I would like to express my profound appreciation to **Dr. Rajeev Goel**, CSIR-CRRI's HOD, for letting me collaborate with her. She gave me an introduction to the field of study. I was pleased by her love, enthusiasm, and inspiration for the students throughout the entire study process. Her knowledge, direction, encouragement, wise suggestions, constructive criticism, and unwavering drive were apparent the whole research project.

I am grateful to the PhD students, teachers, and staff at Delhi Technological University [DTU], particularly the Department of Civil Engineering, for their unwavering support and assistance whenever I have required it.

I also want to express my gratitude to all of my friends who supported me both directly and indirectly during the research project.

I want to express my sincere gratitude to my parents and the rest of my family for their steadfast support and patience during this trip. Their support, inspiration, and faith in my skills have been a never-ending source of strength.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATION	DESCRIPTION
RSI	Rail Structure Interaction
CWR	Continuous Welded Rail
LWR	Long Welded Rail
SWR	Short Welded Rail

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The railway has long been a significant mode of transportation for both people and products. In addition to serving the growing population, the expansion and modernization of the railway network coincide with other areas' growth and are crucial to the nation's economic development.

It entails building new railway lines, growing the new railway network, introducing high-speed trains, upgrading track structural technology, and placing a greater emphasis on computer technologies. The expansion of the metro rail system in both big and small cities in recent years has provided commuters with a quick way to get about.

In railway or metro bridges that use Continuous Welded Rail (CWR) or Long Welded Rail (LWR), a complicated phenomenon known as Rail Structure Interaction (RSI) takes place between the rail and the structure. Since CWRs are continuous rails, train loads (both vertical and longitudinal) and temperature variations affect every displacement that takes place on bridges and tracks. The following consequences could lead to safety issues on the rail during use, like buckling or fracture. The forces resulting from temperature changes causing the deck or rails to expand or contract, longitudinal displacement of the substructure under braking or tractive effects from the moving train, and vertical bending caused by the train's vertical live loads are some examples of these interaction effects. The bridge deck has less stiffness than the ground surface, which leads to a bigger displacement because of variations in loads or temperature effects. This is the difference between LWR or CWR on the ground surface and LWR or CWR on the bridge deck.

The railway track must adjust to these movements because it is supported on the bridge deck. However, the rails are continuous, preventing them from moving freely and producing loads within them. Owing to these loads, the entire railway track is shifted, releasing some of the weights before they are re-applied to the structure. This interaction, which is controlled by the stiffness of the bridge and the railway track, determines the final displacement and stresses in the viaduct and railway track. The RSI effect is the name given to this interaction between the railway track and the bridge construction.

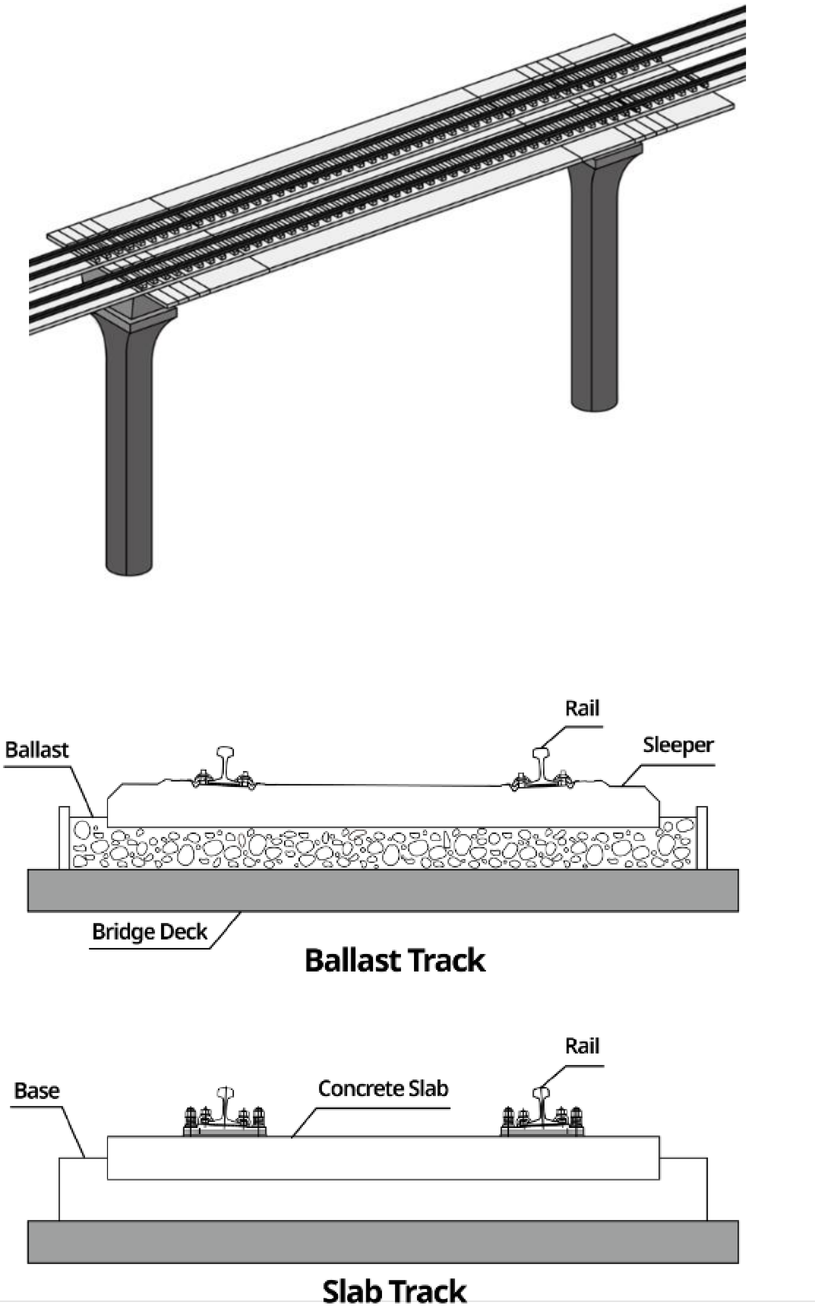


Photo 1.1. General Cross Section of Railway Bridge

1.2 TYPES OF WELDED RAILS

(i) **Short Welded Rails (SWR):-** Short welded rails are those that have the ability to expand and contract along their whole length as a result of heat influences. Three or ten rail lengths are welded together to create these kinds of rails.

(ii) **Long Welded Rails (LWR):-** These are the central portions, only the ends of which are impacted by temperature fluctuations, and the middle portions of which do not experience any longitudinal deformation. For broad gauge (BG), a minimum length of more than 200 metres will serve as LWR. In Indian conditions, the maximum length of LWR is one kilometre.

(iii) **Continuous Weleded Rails (CWR):-** CWR refers to the welded rails that are longer than one km and run from station to station with switch expansion joints.

1.3 LONG WELDED RAIL(LWR)

Long welded rail (LWR) or continuous welded rail (CWR) is a type of constant rail that is created by flash butt welding together around 20 to 25 metres of rails. It must be many kilometres long—let's say more than 2 km. Using CWR over jointed rail tracks has a number of benefits, which are detailed below:-

- This type of track has a lot of strength.
- Reduction of noise and vibration leads to a more comfortable ride.
- Requires minimal maintenance.
- Trains are able to go faster and with less resistance.

The benefits of CWRs have led to a recent expansion in their use, despite challenges with structural analysis during the design stage and problems with safety during the service stage.

Photo 1.2(a). Continuous Jointed Track

Photo 1.2(b). Continuous welded Rail (CWR)

1.4 NEED OF RAIL STRUCTURE INTERACTION (RSI) ANALYSIS

Because of train height, the braking/traction load impact, and temperature changes, CWR across a bridge structure usually sees a significant increase in longitudinal axial forces. This phenomenon is known as longitudinal rail-structure interaction, or track bridge interaction. RSI analysis focuses on the following key design actions:

(i) RAIL:-

- The forces drawn to the rail and the consequent increase in axial rail stresses as a result of the interplay between temperature, vertical, and braking/traction load.
- The longitudinal relative displacement between the rail and deck under these load impacts to maintain the bridge's ballast stability.

(ii) Bridge:-

The pier column, pile cap, and piles are among the substructure's forces and bending moments.

1.5 LOAD EFFECTS ON RAIL STRUCTURE INTERACTION (RSI)

(i) Thermal Expansion or Contraction:-

The load case with the biggest impact on the axial stress of the rail is thermal actions; however, since there is no displacement of the rail due to thermal change in the bridge section where the CWR is installed (the central zone of CWR), this load case is not taken into account in the interaction.

The expansion zone does grow and contract as a result of temperature variations, as seen in the below figure. Nevertheless, because of the ballast limits, this does not occur in the middle zone.

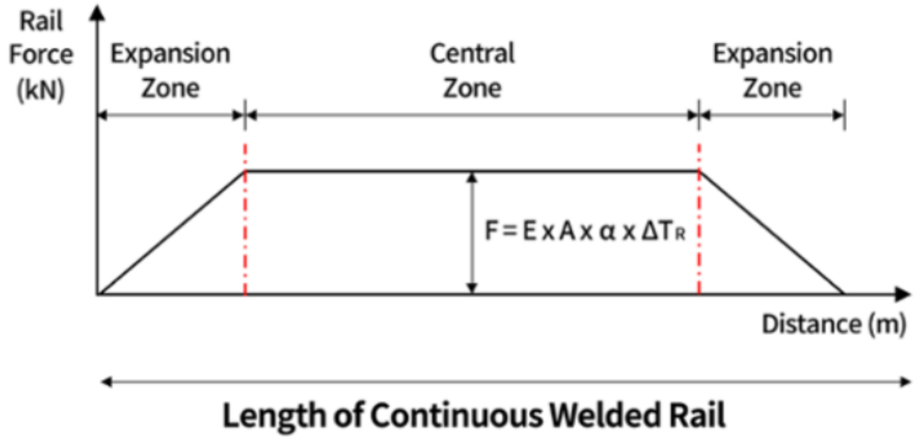


Fig 1.1 Behavior of CWR under the effects of temperature changes (UIC 774-3R Fig.1)

where, α: coefficient of thermal expansion

ΔT_R : change in rail temperature relative to the reference or laying temperature

E: Young's modulus for steel

A: combined cross-section of two rails

F: force in the track

While the deck of the bridge is not fixed, the longitudinal displacement of the rail is fixed by fasteners, sleepers, and ballast. As a result, as the below figure illustrates, temperature variations inside the bridge result in a relative displacement between the rail and the structure. Additionally, the track generates resistance to longitudinal displacements. Although the resistive force acts against the rail and structure, its magnitude remains the same.

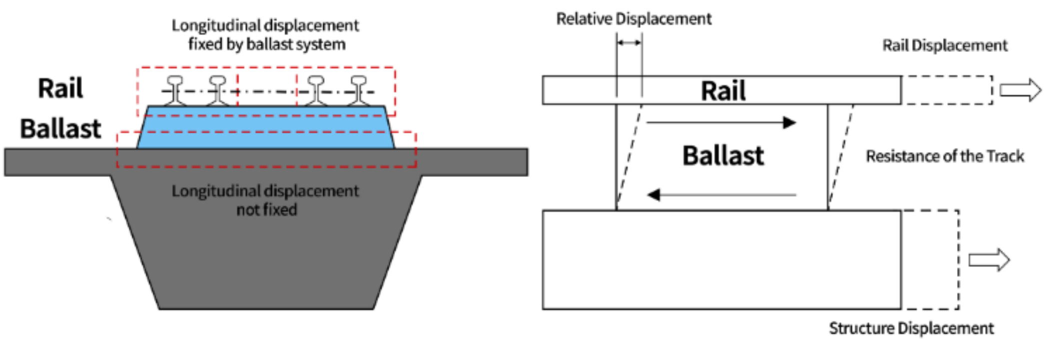


Fig 1.2 Resistance of the track to longitudinal displacement

The below figure illustrates the displacements caused by temperature changes on the bridge as well as longitudinal resisting force displacements on the rail. Additional axial stresses, such as compression or tension, are brought on by this movement in the rail.

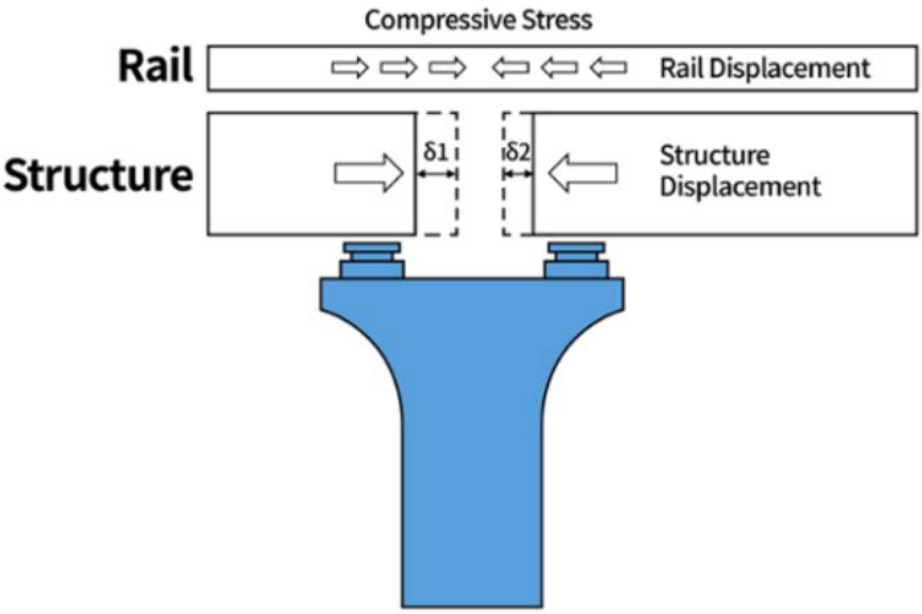


Fig 1.3 Interaction on bridges under temperature loads

(ii) Braking and Traction Forces:-

Similar to the changes brought about by heat action, braking and accelerating forces also cause the rail to move longitudinally, which creates longitudinal resistive forces. As seen in the image below, the two forces are acting in the opposing directions with regard to the train's direction of movement. Additional displacements happen in the same direction through the interaction if the load causes displacement in the rail in that direction.

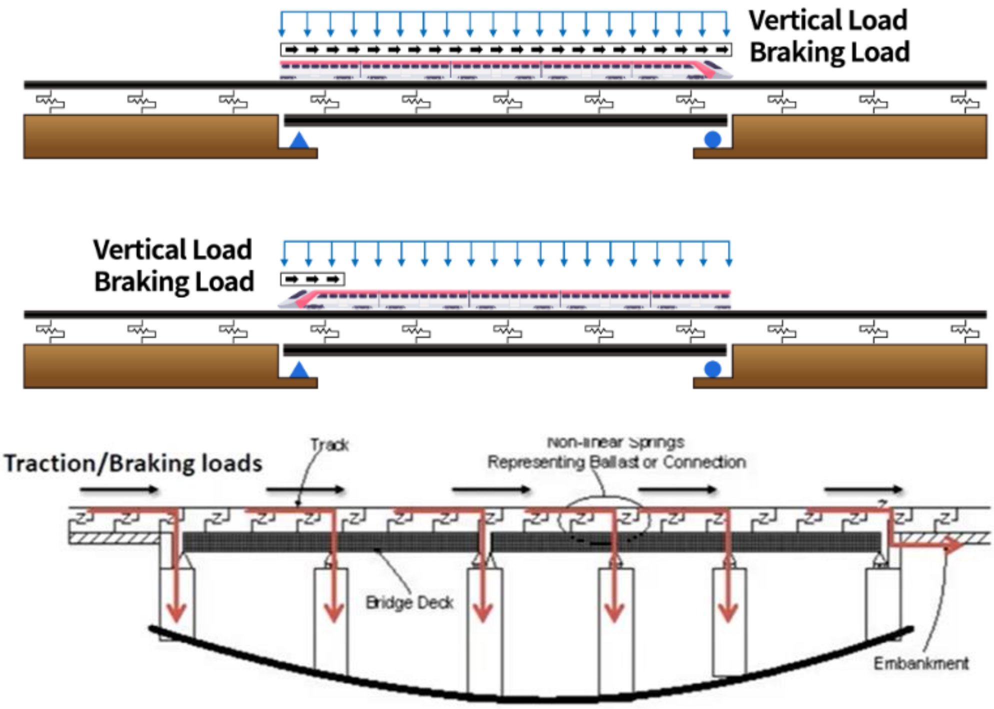


Fig 1.4 Braking and Traction Forces Action on the Bridge

(iii) Vertical Traffic Loads:-

Depending on what is being tested, vertical train loads should be loaded at the least advantageous position (e.g., stress occurring in rails or displacements occurring in bridges). As seen in the below figure, vertical train loads force the superstructure to flex and create end rotation between the upper end surface of the continuous deck and the upper edge of the deck end.

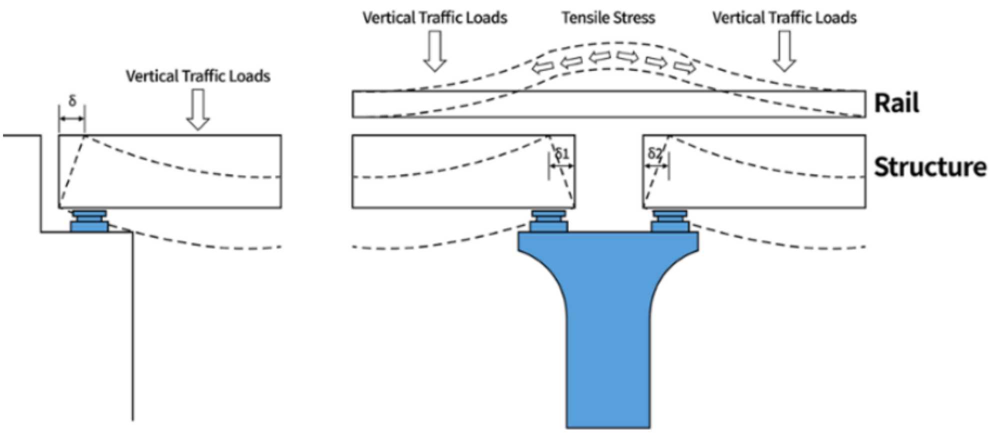


Fig 1.5 Displacement due to Deck Bending

1.6 PARAMETER AFFECTING THE RSI

The following variables have an impact on the interaction phenomenon:

- **<u>Change in Pier Stiffness</u>**
  - Integral Spans
  - Change in Bearing Arrangement
  - Extended Pier Caps
  - Change in soil conditions
- **<u>Change in Span Stiffness</u>**
  - Change in span length.
  - Change in girder type.
  - Steel Bridges
  - Composite Girders
- **<u>Change in Span Arrangement</u>**
  - Stations
  - Cross Over Locations

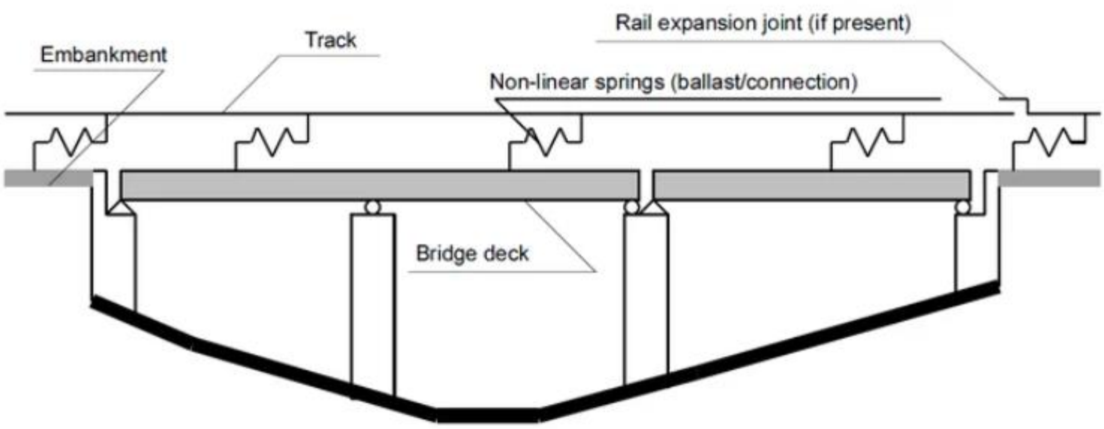


Fig 1.6 Structural diagram for the evaluation of RSI effect

1.7 NEED OF THE STUDY

The RDSO instructions for conducting the RSI studies on the metro system version 2 and UIC-774-3 are unclear about the following, necessitating more investigation:-

- Because there are insufficient standards for whether or not to include metro stations along the viaducts, RSI studies for metro viaducts are to be conducted for stretches.
- Impacts on the RSI as a result of the metro stations' extreme stiffness on the piers, piling caps, and other metro viaduct elements.
- To determine whether station modelling is adequate for RSI analysis, since the standard states that 100 metres of track must be taken into account beyond the structure in order to perform RSI.
- To compare the soil stiffness in the pile and open foundation, as well as the forces in substructures under various support circumstances at the pier bottom.

1.8 OBJECTIVES

The following are the objectives of the study in this thesis:-

(i) Study the influence of the stiffness of metro stations on the RSI of the viaduct.
  - To calculate the stresses in the rail over the viaduct.
  - Forces at the bearing level to be considered in the design of the substructure.

(ii) Study the influence of the stiffness of the viaducts on the RSI of the metro station.
  - To calculate the stresses in the rail over the elevated station.
  - Forces at the bearing level to be considered in the design of the substructure.

1.9 DIVISION OF THESIS

This chapter describes the rail structure interaction, the requirement for RSI analysis, how load affects RSI, and the parameters that have an impact on RSI. This chapter also outlines the necessity of the current investigation and the goals that were set.

CHAPTER-2 examines the different papers that were used to conduct the investigation. The project's foundation was created using the data from these studies.

CHAPTER-3 gives the step-by-step procedure followed in this study. The shape taken, adopted model etc are also discussed.

CHAPTER-4 discusses the obtained results from simulation and graphs are plotted.

CHAPTER-5 deduces conclusions based on the collected data. Future directions for the research are also spoken about.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The current study's objectives were derived from the gaps found in previously published works. Papers pertaining to the research on railway constructions that deal with RSI analysis have been chosen for this project. Additionally, articles that address how the viaduct's stiffness affects the metro station building during RSI analysis, as well as how the station building's stiffness affects it at the viaduct's terminus. Included are the codes and standards that are used for validation.

2.2 PROVISIONS FROM CODE

The codes and standards are used in order to validate the models. UIC 774-3(R) [1] and RDSO guidelines [2] are used to limit the forces and displacements. The following are the main assumptions of UIC as follows:-

(i) The impact of the LWR over the bridges is investigated separately from the track's and the bridge's vertical bending.

(ii) It is assumed that the interaction between the track and the bridge is bilinear in order to simplify computations. The resistance rises with displacement up to tiny initial displacements of the track in relation to the bridge. After that, as the relative displacement increases further, the behaviour becomes more malleable and the resistance to displacement doesn't change. This link is depicted for several track types in Figure 2.1. The track structure and the load on the track determine the greatest resistive force that can be achieved.

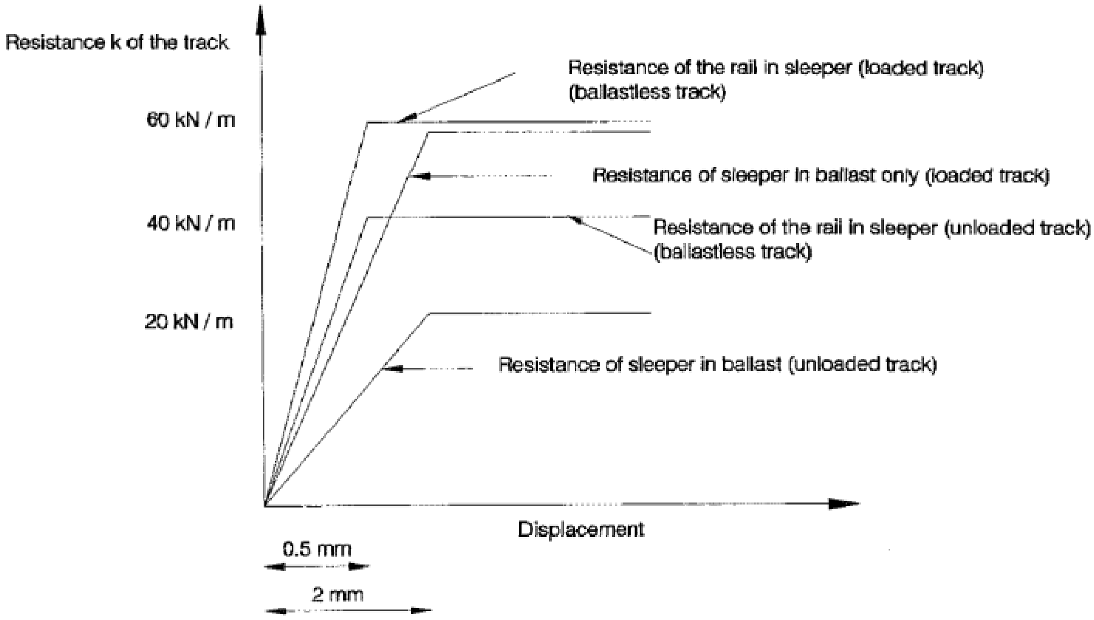


Fig 2.1 Resistance of the track as a function of longitudinal displacement of rail

(iii) To guarantee track stability, displacement limits are assigned for various scenarios since an exhaustive mathematical solution involving numerous case-specific factors would be excessively complicated.

- Under braking or accelerating forces, the maximum allowable relative displacement of the rail is 4 mm.
- The maximum absolute horizontal displacement of the deck is ±5 mm for the same forces.
- The maximum horizontal displacement of the deck under the same loads that is allowed for a CWR on ballasted track with expansion devices is 30 mm.
- The maximum displacement allowed by vertical bending for a CWR on ballasted track is 8 mm, either between the top of the deck end and the embankment or between the tops of two successive deck ends.

(iv) Because of the interaction, extra stresses of 72 N/mm^2 in compression and 92 N/mm^2 in tension are permitted in UIC 60 kg rails made of steel grade providing at least 900 N/mm^2 strength and a minimum curve radius of 1500 m.

(v) In the event of CWR without an expansion device, design charts are available for bridge spans up to 110 metres.

Computer analysis is recommended by the standards for both consecutive multi-span designs and longer spans. The UIC report's allowed values are those that are most commonly accepted for standard track components that are kept in good condition of repair. A railway may still apply the calculating methods even if it operates outside the scope of application for its own reasons by substituting new criteria based on its own observations and experience for the criteria included in the UIC report. The UIC's findings and the recommendations made by Eurocode EN 1991-2:2003 for the consequences of track-bridge interaction are likewise comparable. A set value of force is taken into consideration at the fixed support of the span for substructure design in the construction of contemporary elevated metro rail viaducts and stations in urban areas. The viaduct design by DMRC initially took LWR forces into account. Nonetheless, the following factors should be taken into account:

(i) For short piers (height less than six times the longitudinal dimension of the pier), the LWR forces for two tracks are 1.60 tonne/m.

(ii) For slender piers (height greater than ten times the longitudinal dimension of the pier), the LWR forces are 0.80 tonnes per metre for two tracks.

A feasible solution would be to fix the rail by using elastic fastenings to secure it to the bridge and to analyse the interaction effects. Therefore, the goal of this work is to create a computer model that has all the necessary features for interaction analysis and is easy to duplicate and modify as needed.

2.3 RESEARCH STUDIES

Wenshuo Liu, Gonglian Dai, Zhiwu Yu, Y. Frank Chen & Xuhui He. [3] found that the RSI during a seismic event has a major impact on the design and operation of railway bridges. They have developed a spatial model that incorporates rails, deck systems, braces, piers, foundations, major trusses, and cross beams with non-linear springs in order to reproduce the longitudinal resistance between the track and the bridge. The study's findings indicate that RSI raises the bridge's inherent frequencies and strengthens its structural stability. The Chinese code's ballast resistance specification generates a smaller reaction than the UIC code. Ignoring the friction of movable bearings will lead to underestimating the internal forces of some piers in the system and overestimating the rail stresses.

J.W. Kwark , E.S. Choi , Y.J. Kim , B.S. Kim & S.I. Kim. [4] research has been done to determine the dynamic behaviour of the bridges that the Korean high-speed train (KHST) crosses, using both theoretical and experimental methods. In comparison to static responses, this work has produced significantly enhanced dynamic reflexes of the bridge crossed by trains approaching the critical speed. Appropriate results are obtained for the dynamic behaviour analysis of bridges under fast-moving trains using the study's numerical approach technique. In the KHST scenario, the effects of train–bridge contact on the bridge's dynamic responsiveness appeared to be significant at all speeds.

Khanh Nguyen Gia, Felipe Gabaldón Castillo & José María Goicolea Ruigómez. [5] a numerical method is used to investigate how the mechanical characteristics of high-speed rail track components affect the dynamic response of the vehicle–track system. Specifically, the study examined the stiffness of the rail pad, ballast, and sub-grade layer as variables. A sensitivity analysis was performed to evaluate their impact on the dynamic response during vehicle–track contact. A two-dimensional simplified vehicle-track model that included several vehicle speeds, track imperfections, and non-linear wheel-rail contact was used for the analysis. Over 120 numerical simulations were run in total, each changing the parameter stiffness one at a time. After analysing the data, it was determined that while each parameter taken into account had some bearing, the one with the biggest impact was the stiffness of the rail pad. The process outlined is helpful in minimising the dynamic response and improving track design, it is concluded.

Tamilselvan. M, Koventhan. V & Sajal Nandy. [6] a case study of an ongoing metro bridge project in D.N. Nagar - Mandale, Mumbai, as well as an analysis of the rail structural interaction of a steel composite metro bridge. The entire length taken into consideration for this analysis is 743.43 metres, of which 260.43 metres is the steel composite bridge segment. The remaining length is made up of the superstructure spans of U-girder and PSC girder as a boundary condition. Using SOFiSTiK, a three-dimensional (3D) finite element analysis was performed. The current case study's findings are shown as axial rail stresses running the length of the bridge and are validated against the UIC 774-3R allowable limits.

2.4 LIMITATIONS

The literature review and codal provisions note that RSI studies for metro viaducts are to be carried out for portions because there are insufficient requirements for whether or not to consider metro stations along the viaducts. effects on the RSI due to the extremely rigid metro stations on the piers, piling tops, and other parts of the metro viaduct. to ascertain if the station modelling is sufficient for the RSI study, given that the recommendations require that the 100-meter track be taken into account in addition to the structure in order to do the RSI. to compare the forces in substructures under different support conditions at the pier bottom with the soil stiffness in the pile and open foundation.

The optimisation of Metro Rail Structures' stiffness and articulation for rail structure interaction analysis is the focus of this work. The axial stresses in rail, the relative displacement between rail and superstructure, and the support or bearing reactions transferred to the bridge components are calculated based on the span and stiffnesses of the pile, pile cap, and pier. The RSI analysis is carried out in accordance with the guidelines provided in UIC774-3R [7] Code of Practice (International Union of Railways) and RDSO Guidelines for carrying out Rail Structure Interaction Studies on Metro Systems Ver 2. Midas Civil is the programme utilised in the analysis. Based on the research, we can conclude that taking into account the stiffness of piles and piers minimises the axial stresses in the rail and the forces at the bearing levels.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

This study mainly aims at the RSI analysis of the metro viaduct and station using MIDAS Civil software on the live load of the metro as per the DMRC Outline design section. This chapter includes the step-by-step process involved in the completion of the analysis part.

Consider the span arrangement and geometry of the super and sub structure for the RSI

↓

Consider the material properties

↓

Decide the type of bearings

↓

Prepared the Midas Model as per the above configuration

↓

Applied the vertical load of the train, thermal and traction/ braking loads on the structure

↓

Calculate the stresses in the model and check whether it is in limit or not

Fig 3.1. Flowchart depicting workflow

3.2 ASSUME DATA FOR THE ANALYSIS

- Consider the 30 viaduct spans between the two stations.
- Types of the superstructure are U-girder(U-G) and I-girder(I-G) decided based on the span length and curve.
- Two numbers of tracks.
- Grade of Concrete:- U-girder and I-girder - M50

  Pile & Pile cap - M35

  Pier - M40
- The shape of the Viaduct pier and pile is circular with a diameter of 1m.
- For various span arrangements, the piers range in height from 8 to 12 meters from top of pile cap to top of rail level.
- The strata of soil is assumed to be medium sand. The stiffness of the soil will be calculated as per IS2911.
- The shape and dimension of pier cap are shown below along with the dimensions and shape of U- girder and I-girder.

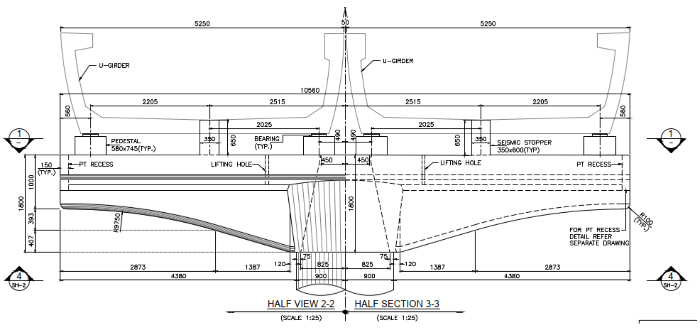


Fig 3.2. Typical Cross section of Pier Cap U-girder

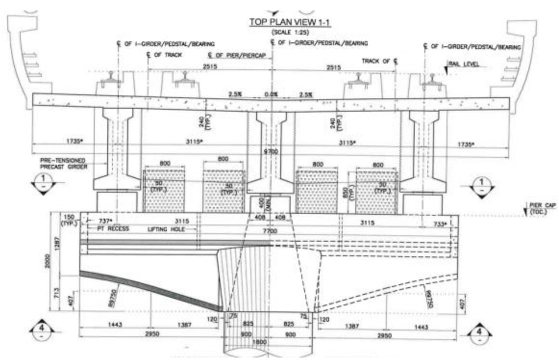


Fig 3.3. Typical Cross section of Pier Cap I-girder

- Dimensions and properties of rails:-

  Modulus of elasticity - 2e+5 N/mm^2

  Thermal Coefficient - 1.2e-5 1/ °C

  Weight Density – 78.5 kN/m^3

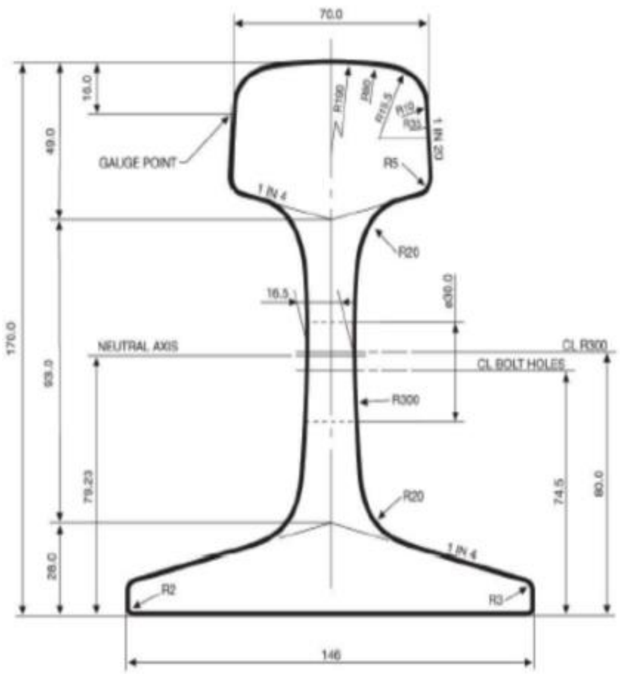


Fig 3.4. Typical Cross section of rail

- There are 8 numbers of spans each of 17.5m considered for the RSI study of the station.
- There are a total of 3 levels in the elevated station (considering the platform level for modelling).
- There are 4 numbers of axles in 1 bogie of metro and for the RSI study 6 bogies with the speed of 80kmph.
- To calculate the stresses in the rail over the viaduct and elevated station.
- Forces at the bearing level to be considered in the design of the substructure.

3.3 LOAD CALCULATION

(i) Vertical Load of the train bogie:-

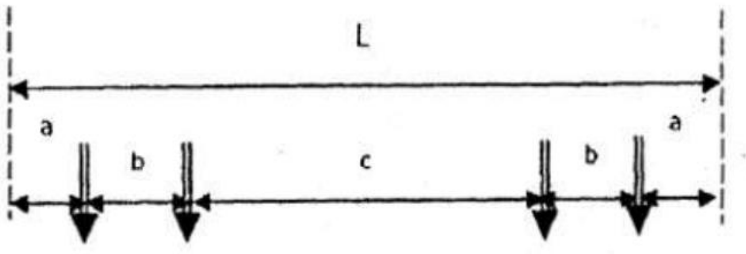


Fig 3.5. Train Bogie

- All the Axle loads = 17 tons
- There are total 6 numbers of successive cars.
- In above fig 3.5, L= 22.1m (Length of the car)

  a = 2.25m (overhang)

  b = 2.5m (wheelbase in a bogie)

  c = 12.6m (Distance between Axle-2 and Axle-3 in the car)

(ii) Braking and Traction load:-

Braking load is taken as 18% of the unfactored Axle load

Braking load = 0.18 x 17 = 3.06 tons = 30.02 kN

Traction load is taken as 20% of the unfactored Axle load.

Traction load = 0.20 x 17 = 3.40 tons = 33.35 kN

(iii) Thermal load:-

Thermal expansion of the deck = +37.5 °C

Thermal contraction of the deck = -37.5 °C

In case of CWR, the temperature variation in case of rail is assumed to be zero, as it does not effect the interaction effects and +37.5/-37.5 °C will be considered in the deck only for deck heating and deck cooling case.

3.4 BOUNDARY CONDITION

- The base of the pier is considered to be fixed by assuming as the open foundation.

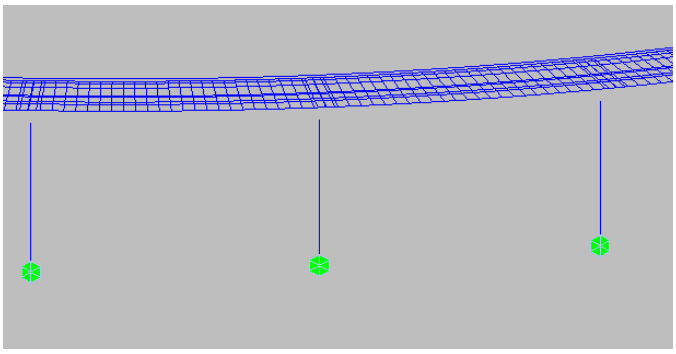


Fig 3.6. View of pier base fixed in the Midas Model

3.5 MODELLING

Midas Model :-

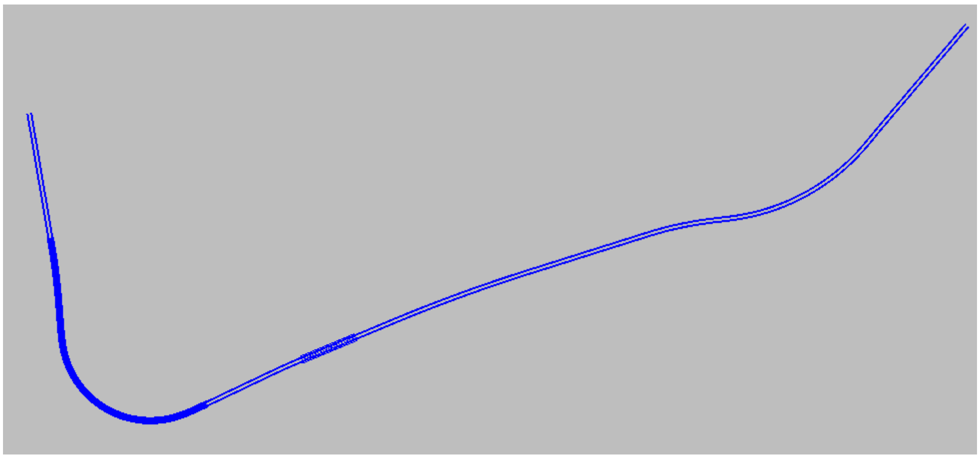


Fig 3.7. Plan view of Viaduct Stretch between two stations

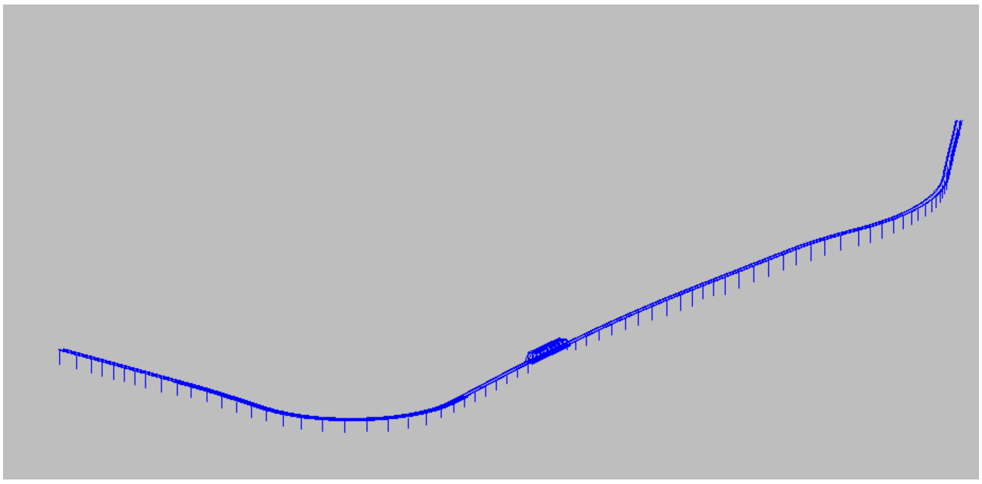


Fig 3.8. 3D view of Viaduct Stretch between two stations

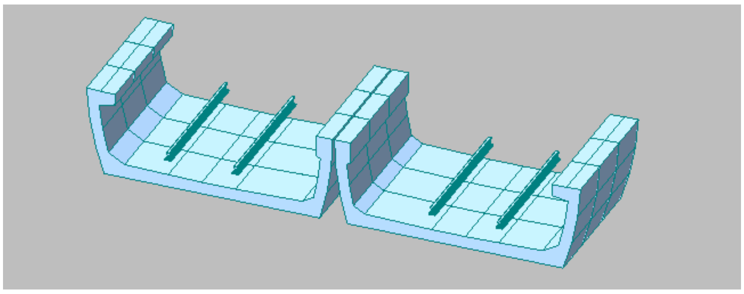


Fig 3.9. 3D Rendering view of U-girder Superstructure with rails

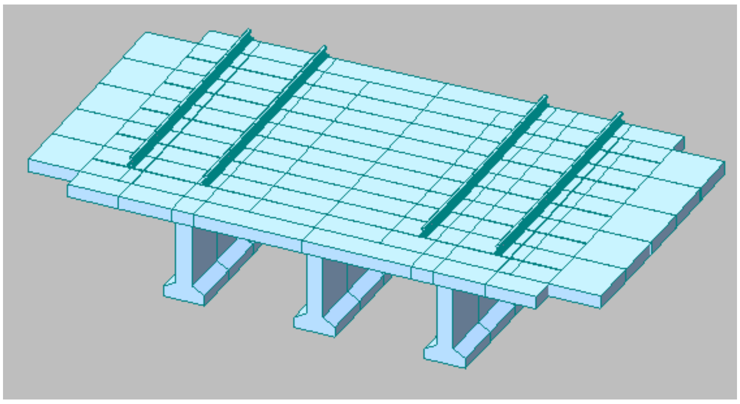
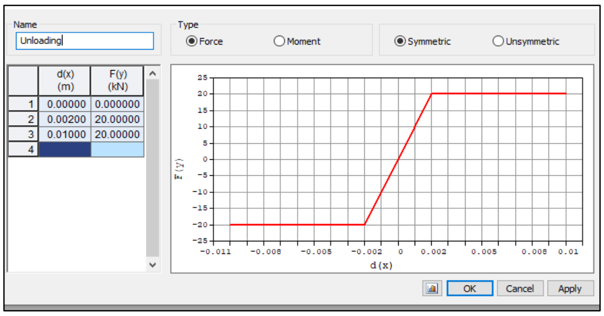
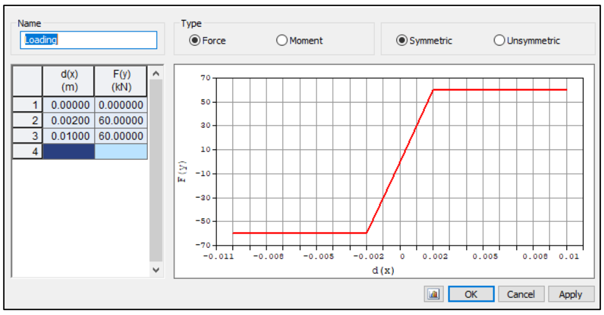


Fig 3.10. 3D Rendering view of I-girder Superstructure with rails



(a)



(b)

Fig 3.11. Multilinear elastic links which are used to connect deck and rail and provide stiffness in longitudinal direction (a) Unloading Condition, (b) Loading Condition

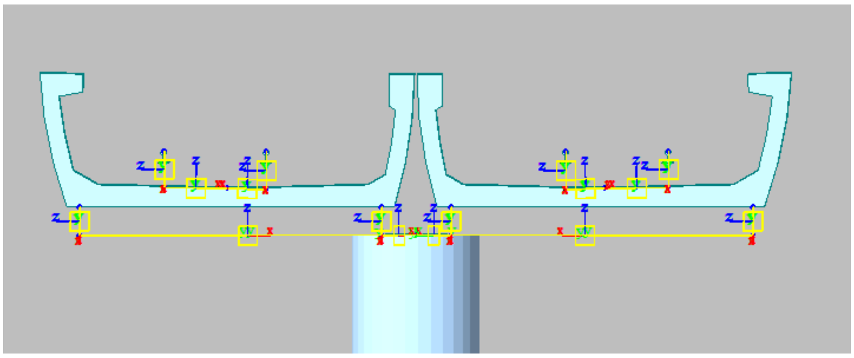


Fig 3.12. Elastic link connection between rail, U-girder and pier

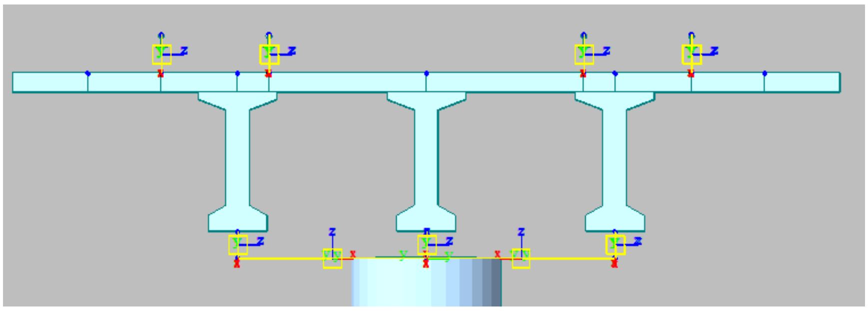


Fig 3.13. Elastic link connection between rail, I-girder and pier

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter discusses results from the models, so as to determine the axial stress and displacement at the rail and forces at the pier top. The variation of axial stress along the span isolated is discussed in this chapter.

4.2 TYPICAL STRESS CHECKS IN RAIL ()

The below table is the result summary of Stress check extracted from the RSI analysis results for the Metro Loading as per clause 1.5.2 of UIC774-3.

Table:- 4.1 Summary of Stress Check in Rails

		Rail stress (MPa)		
	Description	**Design**	**Allowable**	**Status**
Temperature load	**Compressive stress**	-34.10	-92	PASS
	Tensile stress	29.50	92	PASS
Temp. + Braking/traction + Vertical	**Compressive stress**	-56.20	-92	PASS
	Tensile stress	43.47	92	PASS

4.3 TYPICAL DISPLACEMENT CHECKS IN RAIL

The below table is the result summary of the displacement checks extracted from the RSI analysis results for the Metro Loading as per clause 1.5.3 & 4 of UIC774-3.

Table:- 4.2 Summary of Displacement Check in Rails

Load case	Description	Design(mm)	Allowable(mm)	Status
Braking and traction load	**Long. Displacement in Deck**	3.29	5.0	PASS
	Rel. long. Disp. in Deck	2.10	4.0	PASS
Train vertical load	**Long. Displacement in Deck**	2.06	8.0	PASS
	Relative Vertical Displacement in Deck	1.06	2.0	PASS

4.4 PIER LONGITUDINAL FORCES AT THE BEARING LEVEL

The below table represents the LWR forces due to the rail structure analysis which is critical while designing the substructure.

Table:- 4.3 Summary of longitudinal forces at the bearing levels

Location of pier/abutment	Shear Force (in kN) due to		Design Shear Force in Pier (in kN)
	Temperature Load	Train Live Load	
Pier 1	437.99	944.0	1382.0
Pier 2	194.39	1088.3	1282.6
Pier 3	149.71	1014.1	1163.8
Pier 4	59.53	895.4	954.9
Pier 5	171.42	1011.5	1182.9
Pier 6	8.11	1841.6	1849.7
Pier 7	27.79	895.4	923.2
Pier 8	301.78	1115.8	1417.6
Pier 9	121.05	1255.1	1376.2
Pier 10	36.34	1267.9	1304.2
Pier 11	55.92	1521.5	1577.4
Pier 12	88.93	1521.5	1610.4
Pier 13	133.07	731.5	864.6
Pier 14	62.72	919.4	982.1
Pier 15	83.35	1118.3	1201.6
Pier 16	83.79	971.3	1055.1
Pier 17	136.37	811.1	947.5

Pier 18	147.68	882.9	1030.6
Pier 19	95.51	1249.1	1344.6
Pier 20	85.03	1293.0	1378.0
Pier 21	41.44	1232.3	1273.8
Pier 22	41.56	1256.2	1297.8
Pier 23	128.71	1126.1	1254.8
Pier 24	182.36	1161.5	1343.8
Pier 25	314.64	823.1	1137.7
Pier 26	101.03	826.1	927.1
Pier 27	84.77	1355.8	1440.6
Pier 28	225.53	1271.9	1497.4
Pier 29	1068.23	1436.2	2504.4
Pier 30	481.26	1414.7	1896.0

4.5 VARIATION OF RAIL STRESSES

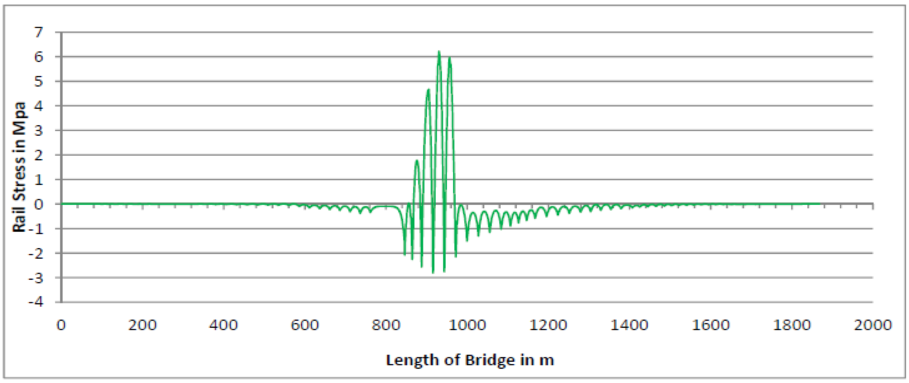


Fig 4.1. Rail Stresses due to Vertical load

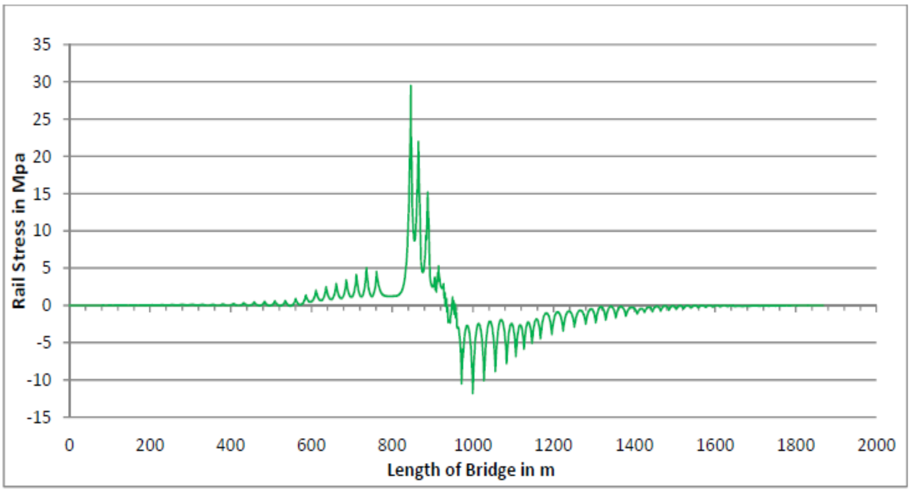


Fig 4.2. Rail Stresses due to Braking and Traction

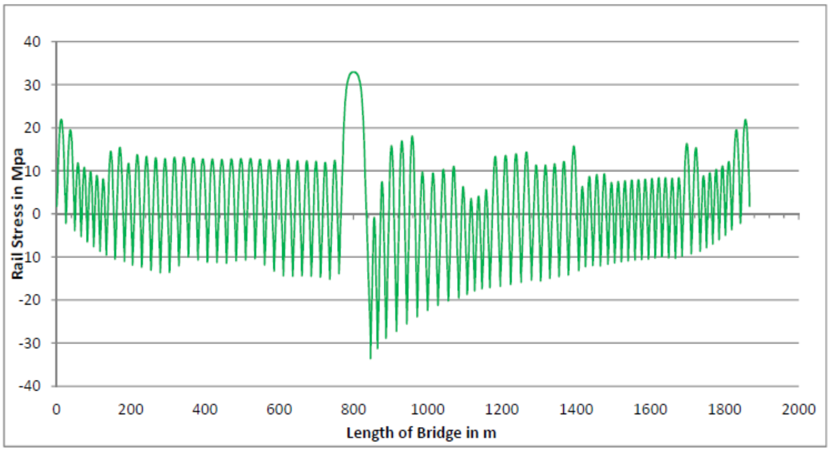


Fig 4.3. Rail Stresses due to Temperature Rise

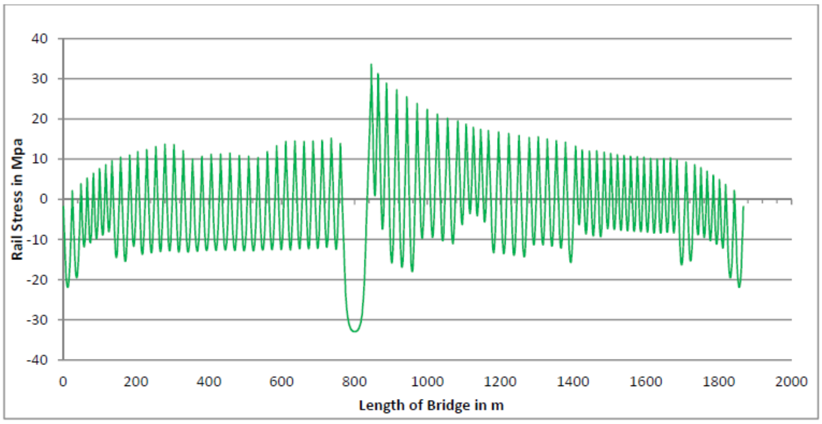


Fig 4.4. Rail Stresses due to Temperature Fall

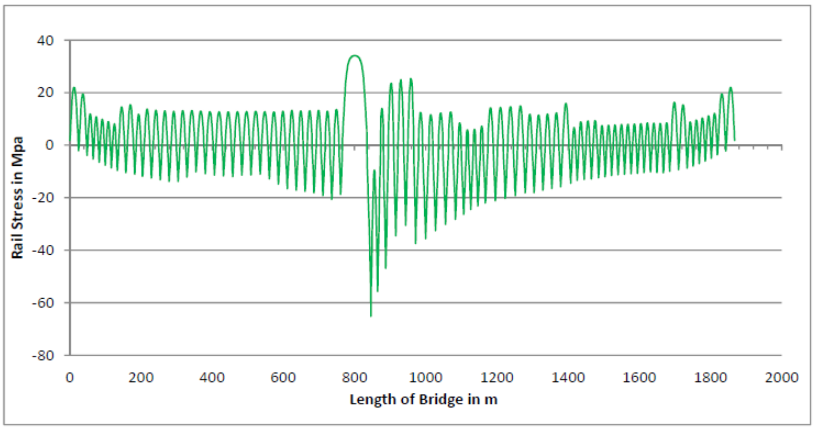


Fig 4.5. Rail Stresses due to Combine loads(with Temperature Rise)

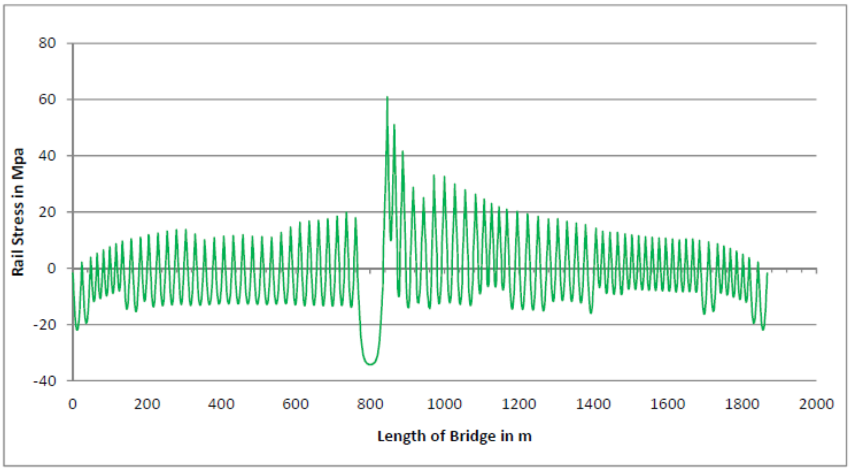


Fig 4.6. Rail Stresses due to Combine loads(with Temperature Fall)

4.6 LWR FORCE AT THE PIER BASE

LWR force at the pier base due to temperature rise/fall (ΔT girder =± 37.5°C) with vertical live load.

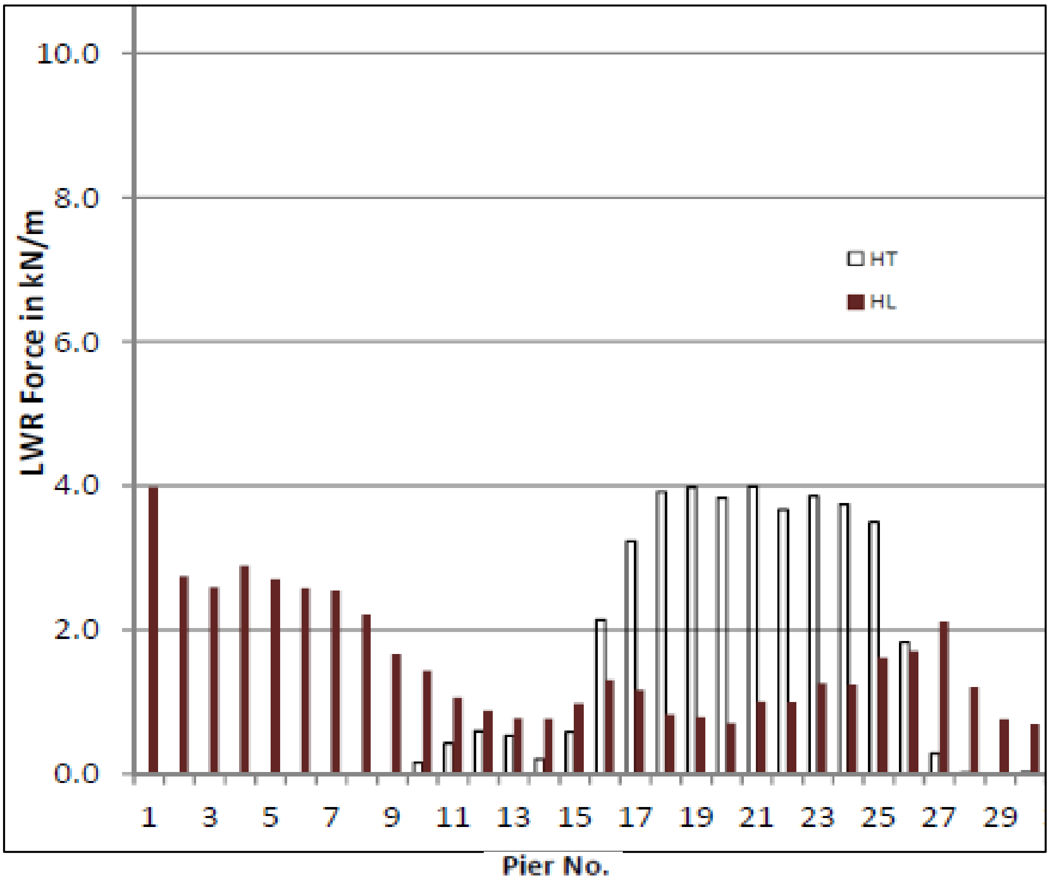


Fig 4.7. Variation of LWR Force at the Pier base

Table:- 4.4 Summary of longitudinal and transverse forces at the bearing levels

Sr. No	**Span with Radius ≥ (m)**	**Force in Transverse direction (kN/m)**	**Force in Longitudinal direction (kN/m)**
	Superstructure with "I-Girder Spans"		
1	900	0.60	1.80
2	127	4.00	1.70
	Superstructure with "U-Girder Spans"		
3	1050	0.50	4.0
4	500	1.30	3.00
5	300	2.80	1.80

From the above, it is noted that the maximum value of the LWR force is 4.0 kN/m which is lesser than the value suggested in the OUTLINE DESIGN SPECIFICATIONS DMRC Clause 6.5.3(f) is 1.6 t/m or 16 kN/m.

CHAPTER 5

CONCLUSIONS

The simulation results have been presented through graphs and tables. The data has been interpreted and the following conclusions are obtained:

- The compressive and tensile stresses in the rail are within limit as per the UIC 774-3(R) [1].
- The displacement check in the deck is within the limit as per the UIC 774-3(R) [1].
- The maximum compressive stress in the rail due to temperature load is 34.1 MPa.
- The maximum tensile stress in the rail due to temperature load is 29.5 MPa.
- The maximum compressive stress in the rail due to temperature + braking/traction + vertical load is 56.2 MPa.
- The maximum tensile stress in the rail due to temperature + braking/traction + vertical load is 43.47 MPa.
- The maximum longitudinal displacement in the deck is 3.29 mm and the relative longitudinal displacement in the deck is 2.1 mm for the temperature load.
- The maximum longitudinal displacement in the deck is 2.06 mm and the relative longitudinal displacement in the deck is 1.06 mm for the temperature + braking/traction + vertical load.
- The maximum LWR force at the bearing level is 4.0 kN/m.

From this RSI study, it is concluded that the maximum force at the bearing level is 4.0 kN/m which is less than the value recommended in the ODS DMRC Phase IV which is 16 kN/m. Hence, by doing the RSI study on the viaduct and stations we can reduce the forces on the pier which automatically reduce the reinforcement and cost of the construction.

FUTURE SCOPE OF THE WORK

- To investigate how earthquakes affect the interaction between rails and structures.
- To investigate how vehicle vibration affects the interaction between rails and structures.

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