STEEL TRUSS RAILWAY BRIDGE INTERACTION EFFECT WITH LWR TRACK

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

EARTHQUAKE ENGINEERING
(With Specialization in Structural Dynamics)

By

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CANDIDATE'S DECLARATION

It is certified that the work which is presented in the project report entitled **"STEEL TRUSS RAILWAY BRIDGE INTERACTION EFFECT WITH LWR TRACK"**, in partial fulfillment of the requirement for the award of the degree of **MASTER OF TECHNOLOGY** in **EARTHQUAKE ENGINEERING** with specialization **STRUCTURAL DYNAMICS** submitted to the Department of Earthquake Engineering at Indian Institute of Technology Roorkee, is an authentic record of my work carried out for a period from July 2012 to June 2013 under the supervision of **Mr. A. D. Pandey**, Associate Professor, Earthquake Engineering Department, IIT ROORKEE.

Place: Roorkee

Date: 14-6-2013

Vachhani Pratikkumar Arvindkumar

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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And lastly and most importantly, I feel eternally indebted to my parents for being patient with me through all the times and for their wisely advice.

Vachhani Pratikkumar Arvindkumar

Abstracts

In the present scenario most of railway lines go for long welded rail or continuous welded rail for higher level of comfort riding, safety and reduced track maintenances and also reduced total life cycle cost. LWR/CWR is more attractive for high speed railway lines, metro rail networks. Due to interaction between long welded rail track and bridge, there is a chance of variation in forces due to implementation of welded rail compare to conventional rail on railway bridges.

Problem in continuing LWR over Railway Bridge has been long debated topic. Through analysis of the bridges should be made after the conversion to LWR is made regarding the seismic safety. The analysis has been made with replacement of LWR track on the bridges. The type of analysis used, in this report confines to response spectrum with the type of soil condition as soft. However, time history analysis for a given earthquake (chi chi) has also been done for one of the bridge of 76.2 m span for 32.5 T route. The analysis results have been presented in the report and it is found that all the bridges are safe even after the replacement of LWR is done.

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INTRODUCTION

1.1 General Introduction

Railway is an important mode of transportation among all types of transportation networks. India has second largest rail network in the world, which proved that Railway is principal mode of transportation in India. Size of Railway network gauge wise in India (31.03.2011) as follows:

Table 1.1 Indian Railways Track Status [15]

Gauge	Route (kms.)	Running track (kms)	Total track (kms)
Broad Gauge (1676 mm)	55,188	77,347	1,02,680
Metre Gauge (1000 mm)	6,809	7,219	8,561
Narrow Gauge (762 & 610 mm)	2,463	2,474	2,753
Total	64,460	87,040	1,13,994

Bridges play an important role in the efficient functioning of railway transport. Today in India the total figure of existing bridges is about 127,154. Out of these, 731 bridges are important bridges, 10235 bridges are major bridges, and 116,188 bridges are minor bridges as per Indian railway in 2002 [15]. About 40 % of the railway bridges are more than 100 years old and they need to be checked for static as well as in dynamic loading.

Reliability against natural calamities like earthquake is serious concern for safety of passengers, goods, and employees. Bridges are life line structures and need to remain functional after considerable earthquake. Present study deals with seismic analysis of steel truss Railway Bridge with conventional rail and Long Welded Rail (LWR), a welded rail whose central part does not exhibit any longitudinal movement on account of temperature variation.

1.2 Development Of LWR

The development of welded rail has been necessitated due to economic consideration coupled with the technical advantages that a welded track possesses over a fish plated track. Welding of rails was started as early as in 1905. First long welded rail was implemented in Germany in 1924 and in U.S.A in 1930 and has become common on main lines since 1950. In 1936 rail length standards were increased in three major markets, U.S.A. increased from 30' to 39', England increased from 33' to 60', Germany increased from 90' to 100'. Also in that same year two Continuous Welded Rail (CWR) installations in U.S.A., 4,000' each, were laid in Tunnels on the Northern Pacific Railway in Montana [12]. On other hand German Federal Railway introduced CWR on concrete sleepers in 1952. In India, Railway Board has taken a policy decision in 1967 making LWR as the standard track structure on trunk routes and main lines as a part of modernisation of railway transport [8].

In India development of welded rail was done in last few decades, but at present condition about 70 % to 80 % of railway track have been converted in to long welded or continuous welded rails. As per first leaflet of LWR (1970) the minimum length of welded rail is 250 m for broad gauge and 500 m for metre gauge for a normally functional LWR [1, 9]. The maximum length of LWR under Indian conditions has been prescribed as one kilometre. But now in India the length of LWR is greater than 4 to 5 kilometre which is generally known as CWR (continuous welded rail). First manual of LWR regards to Girder Bridge that LWR shall not be continued over a girder bridge of single span of 13 m or multiple spans of overall length exceeding 18 m. The installation of welded rails on bridges poses several problems and restrictions have been imposed on the use of LWR on bridges as compared to the normal track. In 1996 Indian Railway published another leaflet of LWR regarding main concept of minimising interaction in between LWR and girder with the help of rail free fastening [8].

1.3 Objective of dissertation

With the modernisation of Indian railway conventional rails are being converted in to the LWR, to achieve better riding comfort and reduced maintenance cost of railway track. However, installation of welded rails on bridges poses several problems and restrictions have been imposed on the use of LWR on bridges as compared to the normal track. Introduction of LWR does not alter any effect on ground but there is a change expected over the railway bridge. Therefore a need of analysis of effect of LWR over the bridge is essential. Present study deals with the behaviour and feasibility of LWR over the steel truss railway bridge instead of conventional rail on already existing bridges with respect to seismic forces.

CHAPTER 2

LITERATURE SURVEY

2.1 Basic definitions [8]

1. **Short Welded Rail (SWR):** A rail which expands and contract through its length, length of SWR in BG is to be ≤ 39 m and in MG is to be ≤ 36 m is shown in Fig. 2.1

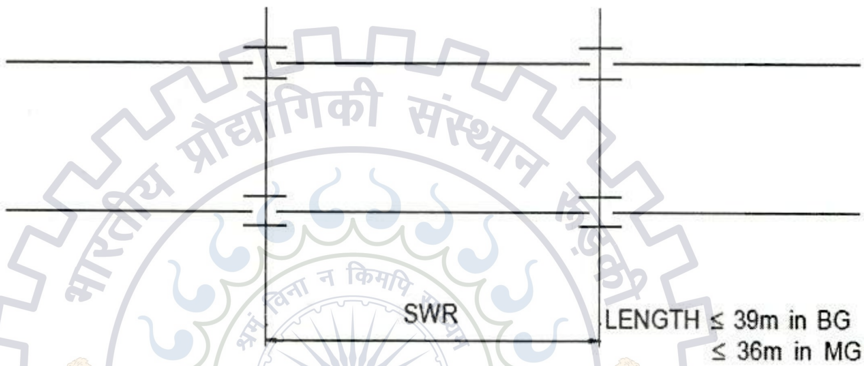


Fig. 2.1: Short Welded Rail [8]

2. **Long Welded Rail (LWR):** It is defined as a welded rail whose central part does not undergo any longitudinal movement due to temperature variation. The movement takes place on either side of the central portion which is called breathing length as shown in Fig. 2.2. The minimum length of a LWR should be 500 m in MG and 250 m in BG.

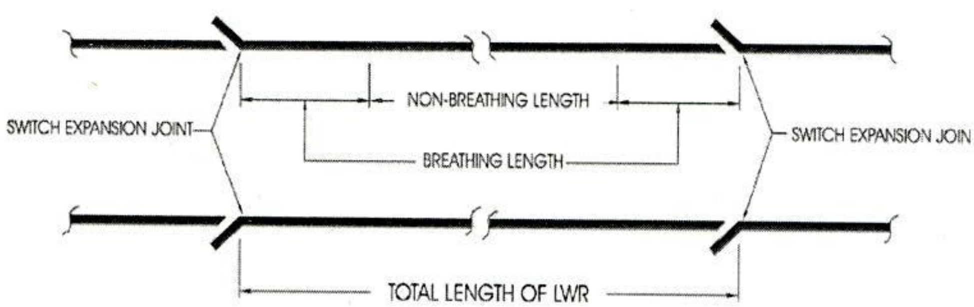


Fig. 2.2: Long welded rail [8]

3. **Continuous Welded Rail (CWR):** CWR is continuum of long welded rail through station yards including points and crossing is described as a Continuous Welded Rails.
4. **Breathing Length:** the length at the ends of a LWR on either side, which exhibit movement due to temperature variation is called the breathing length which is mentioned above in figure 2.2.
5. **Switch Expansion Joint (SEJ):** A physical device placed at the end of the breathing length of LWR to accommodate the expansion and contraction of the breathing length.

Fig. 2.3: switch expansion joint [15]

2.2 Need for Long Welded Rail

In conventional tracks (non-welded tracks) the rails are connected by fish plate joints to allow the change in length caused by temperature. Using this type of arrangement prevents the development of the axial forces and consequent risk of track buckling at high temperature. But main drawback of this joint arrangement is the maintenance of fish plate joint. In conventional rail problems are like, during the train passage rapid deterioration of vertical track geometry, rail cracks, plastic deformation of rail head, as well as damage to sleepers and fastening. The tracks with continuous welded rail do not possess these types of drawbacks. Joint less track geometry is better than conventional track and it reduces the total life cycle cost.

2.3 Advantages of LWR

Today, LWR is synonymous of Morden rail track because of wide spread popularity of LWR. The LWR makes train travel more comfortable, safe and economical. Reasons are as below [1, 6]:

1. LWR tracks eliminate fishplates, which is major worry for Indian railway in terms of maintenance and safety.
2. Fishplate joints are a source of large dynamic forces and also these exhibit a large scale of wear and development of cracks. Due to development of large dynamic forces at rail joints the track geometry at rail joints is disturbed frequently which increases the maintenance effort. After removing fishplate joints about 25 % to 33 % maintenance cost will reduce.
3. After eliminating fish plate joint chances of development of cracks at bolt hole and fracture will be less.
4. It decreases wear and tear of about 5 % of rolling stock.
5. Due to elimination of noise and vibration at the rail joint, passenger comfort substantially increases.
6. LWR is also used in a High Speed Rail (HSR) which contains speed up to 300 km/hr and reduced vibration and misalignment.

Main drawback of welded rail is buckling of the track. It only occurs due to improper distressing, jammed switch expansion joint, lifting of track for any reason, or when Stress Free temperature is quite low as compared with the prevailing temperature etc.

2.4 LWR on bridge

The problem in continuing LWR/CWR over bridges has been a long debated subject. However, installation of LWR on bridges poses several problems as compared to the normal track. The problem is interaction between track and bridge; due to the interaction forces and/or displacement, the rail generates forces and/or displacement in bridge and vice-versa. As per LWR manual, LWR/CWR may also be continued over a bridge with the provision of SEJ at the far end approach of the bridge using rail free fastenings over the bridge. However, due to provision of expansion device at the end of the bridge, the effect of dispersion of braking/traction forces to approaches will not be available and the existing substructures will be further stressed due to the non availability of this dispersion effect. In this study LWR has been installed over the bridge with help of SEJ at far end from bridge.

2.5 Problems and solutions to continue LWR/CWR on bridges

Interaction between track and bridge create alternating effect on each other via forces or displacement. Major problems are like thermal expansion of deck whenever rail expansion is present, horizontal and braking force, bending under vertical loads and many more, which do not create any major effect [11]. Some studies are presented as follows;

Indian railways [8]; Provision of LWR/CWR on the bridge is mainly concept of SEJ and rail free fastening. RDSO has developed a new design of SEJ for UIC 60 kg with 190 mm gap with continuation of LWR on longer bridge. To continue LWR over bridge the design of special PRC sleeper required for 300 mm gap SEJ has been developed. RDSO also gives some important points regarding SEJ;

a) *"Provisions of SEJ on pier to pier on each pier results in reduced dispersion of longitudinal force through discontinuity of LWR."*
b) *"Minimum 30 m approach length is needed for dispersion of longitudinal forces while the LWR manual provides SEJ at 10 m distance from abutment."*

South Korean railway [3]; Dang-san Bridge of Seoul subway number 2 was rebuilt for safety reason in 1996-1999. In this bridge Zero Longitudinal Restraint (ZLR) was provided for 120 m at south and 120 m at north approach to minimise interaction between track and bridge. This was adopted by Korean railway for first time.

German railway [10]; To minimise interaction between track and unballasted steel girder deck German railway has adopted a unique system. In this system a solid steel bar with a side groove is welded on the top of stringer. Bearing plates rest on this system and sleeper rests on those bearing plates. In this system relative movements are permitted in between sleeper and girder instead of rail and sleeper. In this design it is usual to provide SEJ after 400 m even though a length of 800 m on a bridge was provided without SEJ.

Bridge on high speed line Brussels-Lille (junction for Paris-London) [3]; here, the length of bridge is 438 m and it consists of 7 spans. Out of this length, main span is 120 m long which crosses the river Scheldt. Firstly they thought of providing expansion joint in high speed track on existing bridge but it is not attractive due to comfort, maintenance and safety aspect. After that effective solution is possibly to use ZLR fastening over some length of the track. This alternative gives considerable reduction of displacement and forces of track. This reduction depends upon the length of the fastening installed. Based on this combination of partial ZLR fastening and expansion device, CWR was designed on the bridge, which reduces the coast and fulfils the technical requirement also.

2.6 Support condition of bridge

In this analysis bridge support is considered as a rigid member. So stiffness of soil is directly transferred at the top of pier or abutment. To achieve same behaviour as of simply supported bridge, roller (allow rotation and translation) and fixed (allow rotation only) bearings are provided as a link element. For seismic response of soft soil on the bridge, stiffness of soft soil has been provided on basis of Gazetas (1991) stiffness coefficient. This stiffness coefficient depends on size of foundation *A*, Poisson's ratio *v*, and modulus of rigidity *G*. For soft soil some assumption have been taken and are given below;

Unit weight = 17.84 KN/m^3

Mass density = 1.784 x 10^3 Kg/m^3

Shear wave velocity (V_s) = 100 *m/s*

Poisson's ratio (v) = 0.45

Modulus of rigidity of soil, G is calculated from the relation,

$$G = \rho\,(V_s)^2$$

G = 1.784E+04 KN/m^2

Gazetas (1991) gave relation between surface foundation and embedded foundation in terms charts and equation both, for circular, rectangular, strip and arbitrary shape with surface, partially embedded, fully embedded or pile foundation. Equation of stiffness at different mode by Gazetas (1991) given below;

Table 2.1 Stiffness coefficient for surface and embedded foundation by Gazetas (1991) [7, 4].

Vibration mode	Surface stiffness co-efficient	Embedded stiffness coefficient
Vertical	$K_{z,S} = [2GL / (1-\nu)] (0.73+1.54\chi^{0.75})$	$K_{z,E} = K_{z,S} [1+(1/21)(D/B)(1+1.3\chi)] [1+0.2(A_w/A_b)^{2/3}]$
Lateral direction	$K_{y,S} = [2GL / (2-\nu)] (2+2.5 \chi^{0.85})$	$K_{y,E} = K_{y,S} [1+0.15(D/B)^{0.5}] \{1+0.52 [(h/B) (A_w/L^2)]^{0.4}\}$
Longitudinal direction	$K_{x,S} = K_{y,S} - [0.2 / (0.75-\nu)] GL [1-(B/L)]$	$K_{x,E} = K_{x,S} (K_{z,E} / K_{z,S})$
Rocking (R_x)	$K_{Rx,S} = [G/(1-\nu)] I_{bx}^{0.75} (L/B)^{0.25} [2.4+0.5(B/L)]$	$K_{Rx,E} = K_{Rx,S} [1+1.26(d/B) [1+(d/B) (d/D)^{-0.2} (B/L)^{0.5}]$
Rocking (R_y)	$K_{Ry,S} = [3G/(1-\nu)] I_{by}^{0.75} (L/B)^{0.15}$	$K_{Ry,E} = K_{Ry,S} [1+0.92 (d/L)^{0.6} \{1.5+(d/L)^{1.9} (d/L)^{-0.6}\}]$
Torsion (t)	$K_{t,S} = 3.5GI_{bz}^{0.75} (B/L)^{0.4} (I_{bz}/B^4)^{0.2}$	$K_{t,E} = K_{t,S}\, \Gamma_w\, \Gamma_{tre}$ $\Gamma_w = 1+0.4(D/d)^{0.5} (j_s/j_r) (B/D)^{0.6}$ $\Gamma_{tre} = 1+0.5(D/B)^{0.1} (B^4/I_{bz})^{0.13}$ $j_s = (4/3)\, d\, (B^3 + L^3) + 4BLd(L + B)$ $j_r = (4/3)\, BL\, (B^2+L^2)$

Where, G is shear modulus of soil, ν is Poisson's ratio of soil, L is length of foundation, B width of foundation, A_w is actual side wall soil contact area for constant effective contact height d, A_b is area of foundation, I_{bx}, I_{by} and I_{bz} are moment of inertia about x, y and z axis respectively, χ is ratio of B/L.

For this problem foundation data has been taken from Jeyanth B.K. (2009). The size of foundation is considered as length (L=12 m), width (B=7 m) and total depth of foundation (D=4.5 m) and the hysteretic damping to be 0.05, d is 3.5 m, A_b is 84 m^2, A_w is 133 m^2. As per Gazetas (1991) the value of support stiffness is as below;

Table 2.2 value of soil stiffness at the top of pier [7]

Types of stiffness	Embedded stiffness (*KN/m*)
Vertical, K_z	1.834E+06
Horizontal, K_x	1.403E+06
Horizontal, K_y	1.492E+06
Rocking, K_{xo}	1.499E+07
Rocking, K_{yo}	3.298E+07
Torsion, K_{zo}	4.084E+07

CHAPTER 3

ANALYTICAL MODELLING OF BRIDGES

In India, Railway Bridges are built to conform to the Indian Railway Standards laid down by Ministry of Indian Railways. Bridges are designed for standard specifications like span, live load and configuration. Steel bridges are more preferable for Railway bridges as compared to concrete bridges because, weight of super structure in steel bridge is lighter than concrete bridge and will facilitate faster construction. There are four types of routes namely,

1) MBG (Modified Broad Gauge)
2) HM (Heavy Minerals)
3) 25 Tons
4) 32.5 Tons

Seven different types of bridges have been defined for each type of route mentioned above. Types of bridges are as follows;

a) Three different spans of plate girder bridges are considered;
    1) Standard 12.2 m span
    2) Standard 18.3m span
    3) Standard 24.4 m span
b) Four different spans of truss bridge standard spans are considered;
    1) Standard 30.5 m span
    2) Standard 45.7 m span
    3) Standard 61.0 m span
    4) Standard 76.2 m span

3.1 Configuration of 30.5 m and 76.2 m steel truss bridge

30.5 m and 76.2 m span truss bridges are considered and data corresponding to truss bridge configuration and section details has been collected from RDSO, Lucknow. Modelling of present study is done in SAP2000.

Table 3.1 Detailing of 30.5m span truss bridge

Type of Truss System	Standard Warren Truss
Clear Span (mm)	30500
Centre of Bearings (mm)	31926
No of Panels	6
Panel length (mm)	5321
Spacing between two trusses (mm)	5280
Height of Truss (mm)	7315

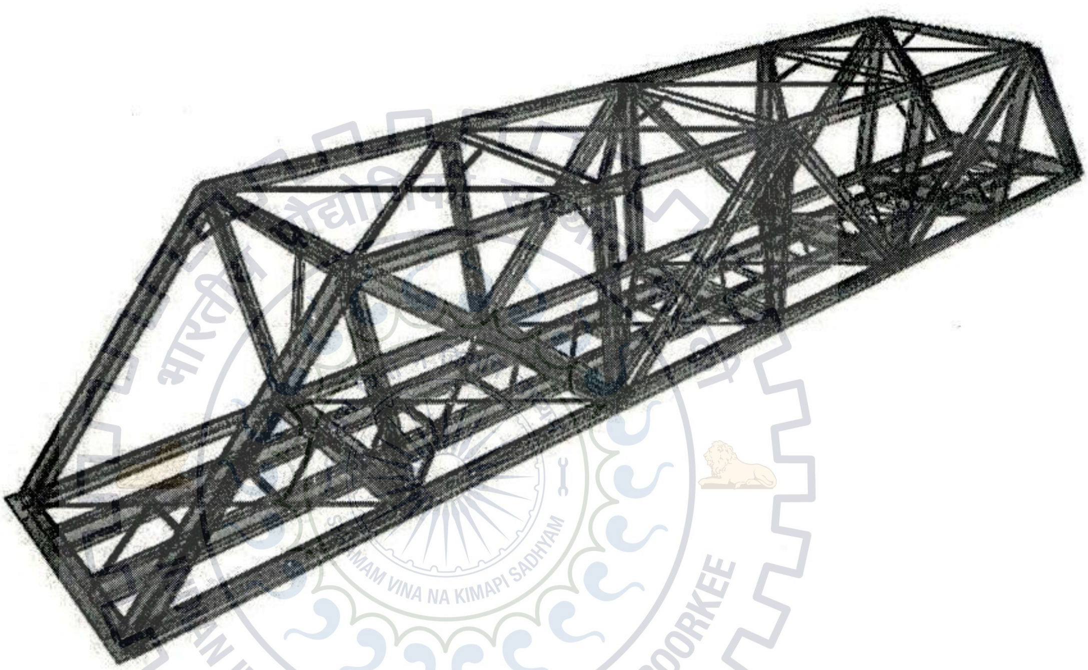


Fig. 3.1: Isometric view of 30.5 m truss bridge

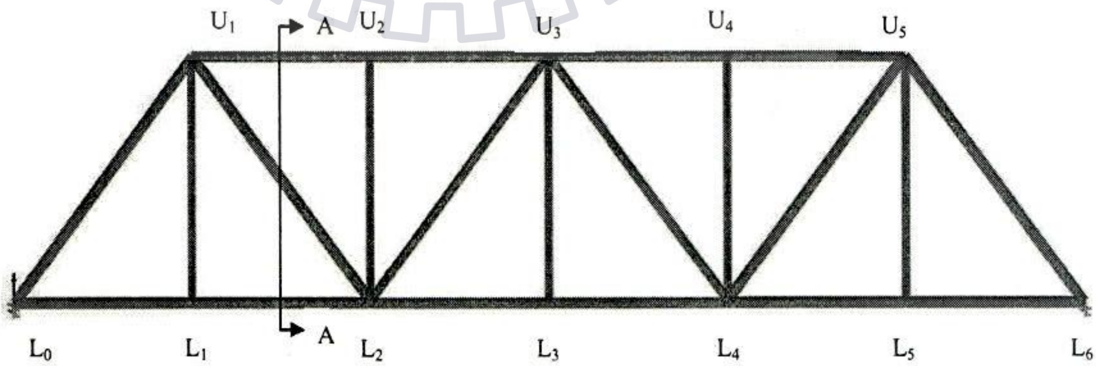


Fig. 3.2 Front view of 30.5 m truss bridge

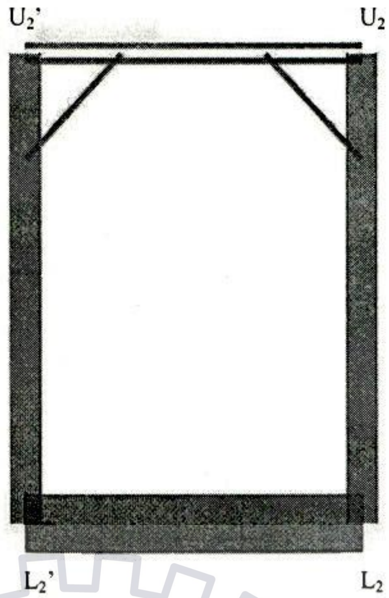


Fig 3.3 Section A-A of 30.5 m truss bridge

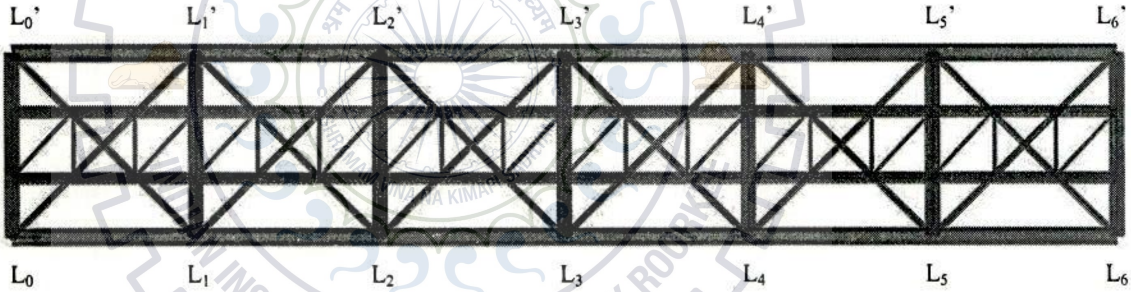


Fig. 3.4 bottom chord of 30.5 m truss bridge

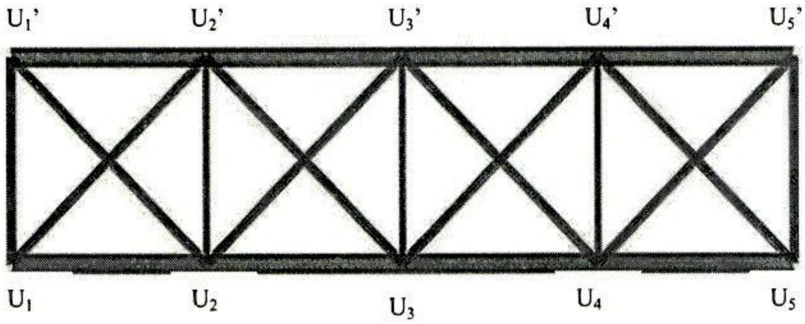
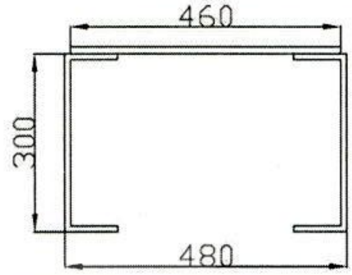
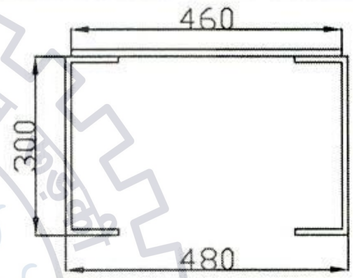
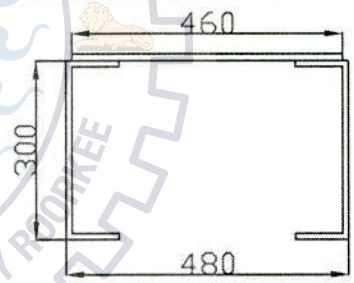
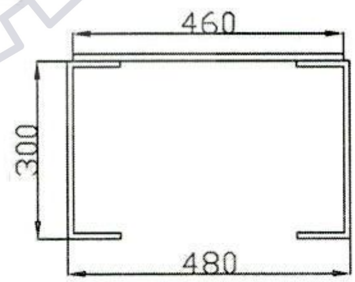
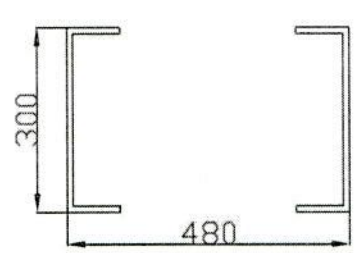
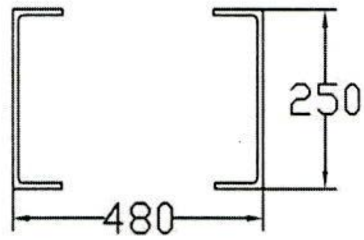
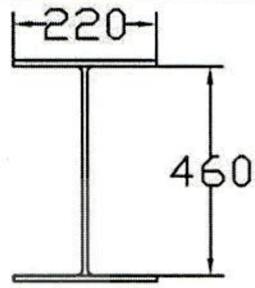
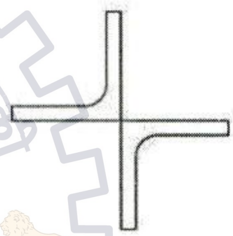
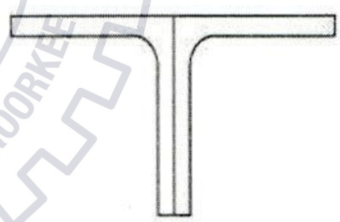
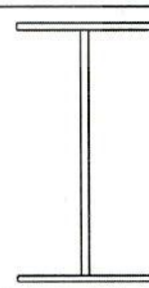


Fig. 3.5 top chord of 30.5 m truss bridge

Table 3.2 General Arrangement of 30.5 m span Railway Bridge (M.B.G)

Member	Description	Section
L_0-L_1, L_1-L_2, L_4-L_5, L_5-L_6	**Bottom Chord** 2 [s 300 x 90 1 Top plate 460 x 8 Batten @ bottom 10 mm thick	
L_2-L_3, L_3-L_4	**Bottom Chord** 2 [s 300 x 90 1 Top plate 460 x 12 Batten @ bottom 10 mm thick	
U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Chord** 2 [s 300 x 90 1 Top plate 460 x 8 Batten @ bottom 10 mm thick	
L_0-U_1, L_6-U_5	**Diagonal Member** 2 [s 300 x 90 1 Top plate 460 x 12 Batten @ bottom 8 mm thick	
L_2-U_1, L_4-U_5	**Diagonal Member** 2 [s 300 x 90 Batten @ top and bottom 10 mm thick	

L_2-U_3, L_4-U_3	**Diagonal Member** 2 [s 250 x 80 Batten @ top and bottom 10 mm thick	
U_1-L_1 U_2-L_2 U_3-L_3 U_4-L_4 U_5-L_5	**Verticals** Web plate 460 x 10 Top and bottom flange plate 220 x 10	
Panels L_0-L_1, L_1-L_2, L_2-L_3, L_3-L_4, L_4-L_5, L_5-L_6	**Bottom lateral Bracing** 2 L section 75 x75 x 10	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Lateral Bracing** 2 L section 100 x 100 x 8	
L_0-L'_0 L_1-L'_1 L_2-L'_2 L_3-L'_3 L_4-L'_4 L_5-L'_5 L_6-L'_6	**Cross Girder** Web plate 864 x 10 Top and bottom flange plate 410 x 18	

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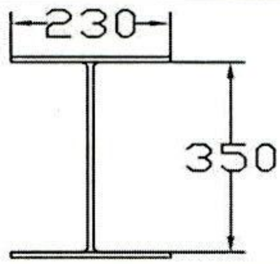
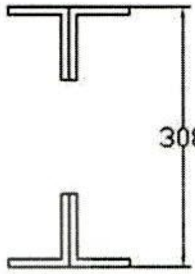
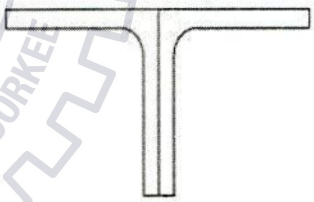
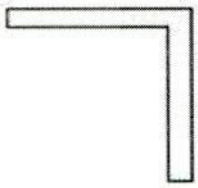
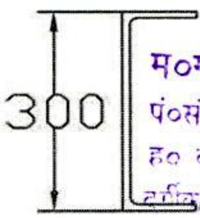
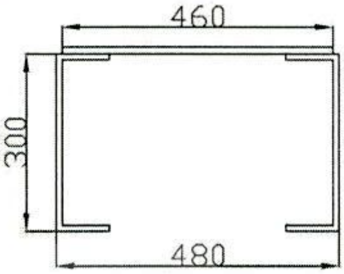
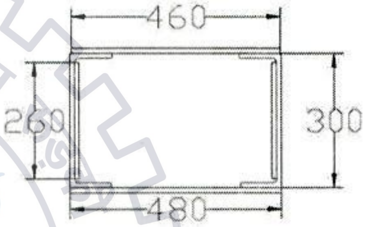
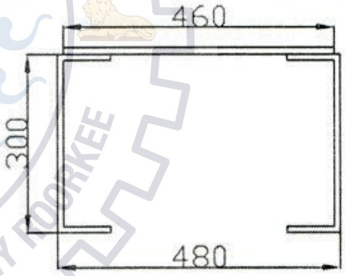
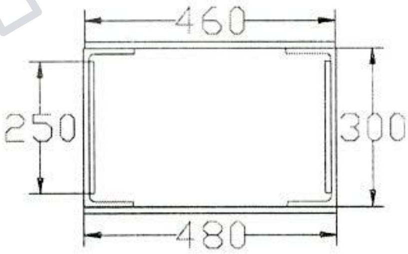
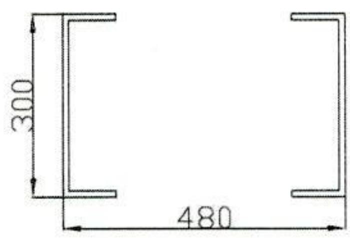
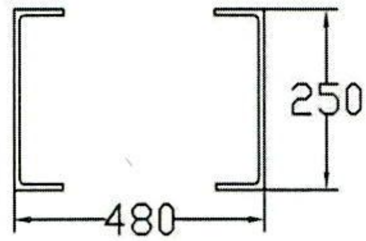
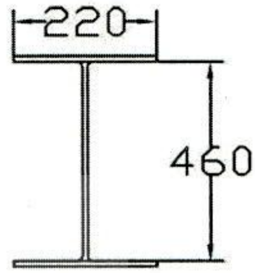
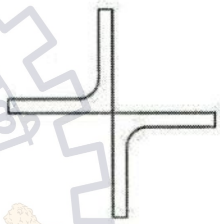
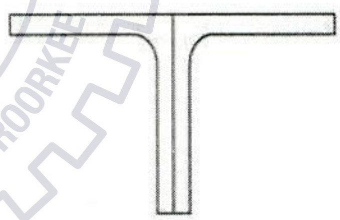
U_5-U'_5</td><td>Portal Girder
Web plate 350 x 8
Top and bottom flange plate
230 x 10</td><td>
</td></tr>
<tr><td>U_2-U'_2
U_3-U'_3
U_4-U'_4</td><td>Sway Girder
4 L section
75 x 75 x 10
Lacing flat
65 x 10</td><td>
</td></tr>
<tr><td colspan="2">Stringers
Web plate 718 x 10
Top and bottom flange plate 320 x 16</td><td></td></tr>
<tr><td colspan="2">All Sway and Portal Bracing
2 L section
75 x 75 x 10</td><td></td></tr>
<tr><td colspan="2">All stringer bracing
L section
75 x 75 x 10</td><td></td></tr>
<tr><td colspan="2">Diaphragm
Channel section
300 x 90</td><td>
</td></tr>
</table>

Table 3.3 General Arrangement of 30.5 m span Railway Bridge (H.M.)

Member	Description	Section
L_0-L_1, L_1-L_2, L_4-L_5, L_5-L_6	**Bottom Chord** 2 [s 300 x 90 1 Top plate 460 x 10 Batten @ bottom 10 mm thick	
L_2-L_3, L_3-L_4	**Bottom Chord** 2 [s 300 x 90 1 Top plates 460 x 12 2 side plates 260 x10 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Chord** 2 [s 300 x 90 1 Top plate 460 x 12 Batten of 10 mm thick and Lacing L section 75 x 75 x 10 @ bottom	
L_0-U_1, L_6-U_5	**Diagonal Member** 2 [s 300 x 90 1 Top plate 460 x 12 2 side plates 250 x 10 Batten of 10 mm thick and Lacing L flats 65 x 10 @ bottom	
L_2-U_1, L_4-U_5	**Diagonal Member** 2 [s 300 x 90 Batten of 10 mm thick Lacing L flats 65 x 10 @ bottom	

L_2-U_3, L_4-U_3	**Diagonal Member** 2 [s 250 x 80 Batten of 10 mm thick and Lacing Flats 65 x 10 @ bottom	
U_1-L_1 U_2-L_2 U_3-L_3 U_4-L_4 U_5-L_5	**Verticals** Web plate 460 x 10 Top and bottom flange plate 220 x 10	
Panels L_0-L_1, L_1-L_2, L_2-L_3, L_3-L_4, L_4-L_5, L_5-L_6	**Top Lateral Bracing** ISST 200 x 165 x 8	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Lateral Bracing** 2 L section 100 x 100 x 8	
L_0-L'_0 L_1-L'_1 L_2-L'_2 L_3-L'_3 L_4-L'_4 L_5-L'_5 L_6-L'_6	**Cross Girder** Web plate 856x 12 Top and bottom flange plate 450 x 22	

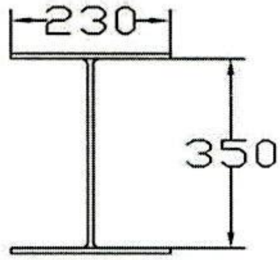
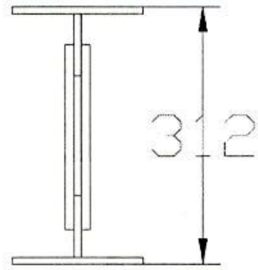
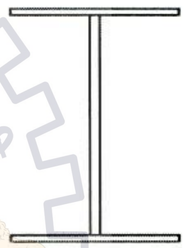
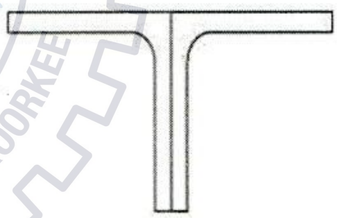
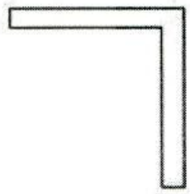
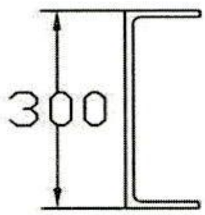
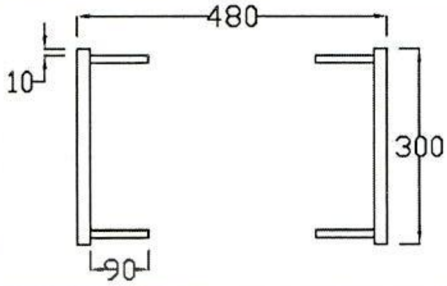
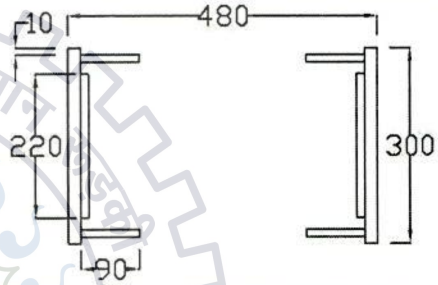
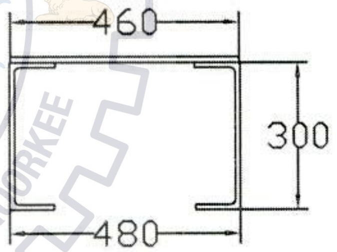
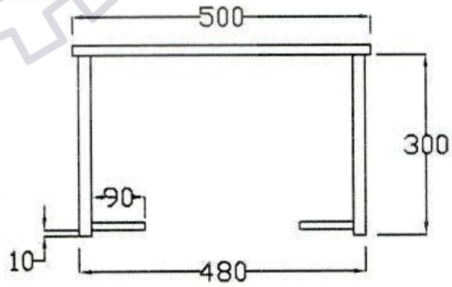
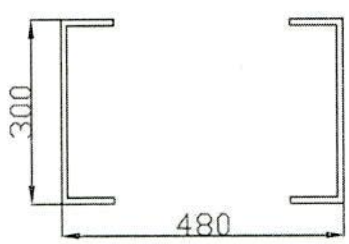
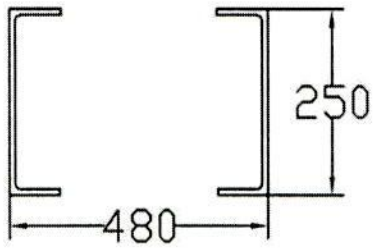
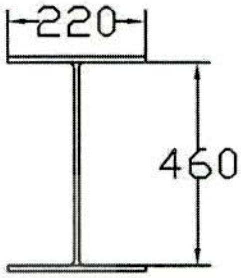
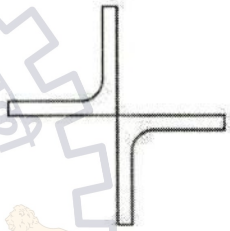
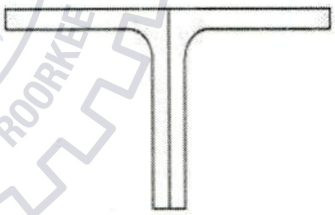
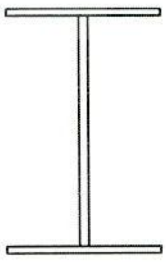
U_1-U'_1 U_5-U'_5	**Portal Girder** Web plate 350 x 8 Top and bottom flange plate 230 x 10	
U_2-U'_2 U_3-U'_3 U_4-U'_4	**Sway Girder** 4 L section 75 x 75 x 10 Lacing flat 65 x 10	
	Stringers Web plate 714 x 10 Top and bottom flange plate 320 x 18	
	All Sway and Portal Bracing 2 L section 75 x 75 x 10	
	All stringer bracing L section 75 x 75 x 10	
	Diaphragm Channel section 300 x 90	

Table 3.4 General Arrangement of 30.5 m span Railway Bridge (25 T)

Member	Description	Section
L_0-L_1, L_1-L_2, L_4-L_5, L_5-L_6	**Bottom Chord** 4 flange plates plate 90 x 12 2 side plates 300 x 20 Batten 10 mm thick @ bottom	
L_2-L_3, L_3-L_4	**Bottom Chord** 4 flange plates plate 90 x 12 2 side plates 300 x20 2 Additional side plates 220 x12 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Chord** 2 [s 300 x 90 1 Top plate 460 x8 Batten of 10 mm thick and Lacing L section 75 x 75 x 8 @ bottom	
L_0-U_1, L_6-U_5	**Diagonal Member** 1 Top plate 500 x 16 2 side plates 300 x 20 2 bottom flange plate 90 x 10 Batten of 10 mm thick and Lacing L flats 65 x 10 @ bottom	
L_2-U_1, L_4-U_5	**Diagonal Member** 2 [s 300 x 90 Batten of 10 mm thick	

L_2-U_3, L_4-U_3	**Diagonal Member** 2 [s 250 x 80 Batten @ top and bottom 10 mm thick	
U_1-L_1 U_2-L_2 U_3-L_3 U_4-L_4 U_5-L_5	**Verticals** Web plate 460 x 10 Top and bottom flange plate 220 x 10	
Panels L_0-L_1, L_1-L_2, L_2-L_3, L_3-L_4, L_4-L_5, L_5-L_6	**Bottom lateral Bracing** 2 L section 75 x75 x 10	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Lateral Bracing** 2 L section 100 x 100 x 8	
L_0-L'_0 L_1-L'_1 L_2-L'_2 L_3-L'_3 L_4-L'_4 L_5-L'_5 L_6-L'_6	**Cross Girder** Web plate 864 x 10 Top and bottom flange plate 410 x 18	

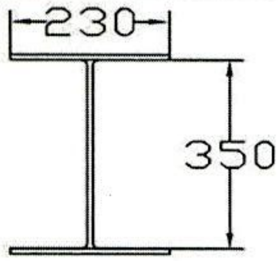
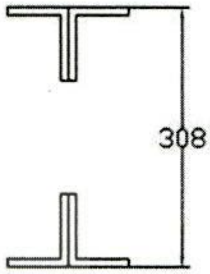
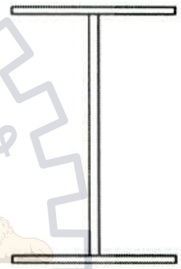
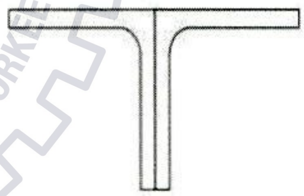
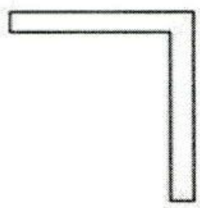
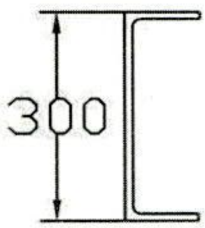
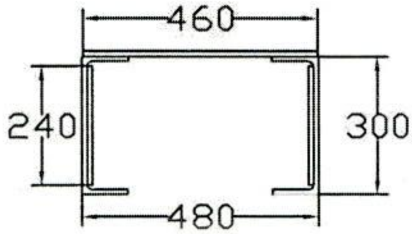
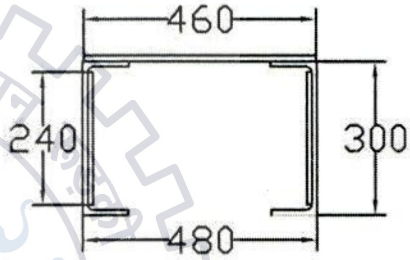
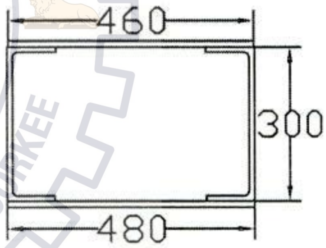
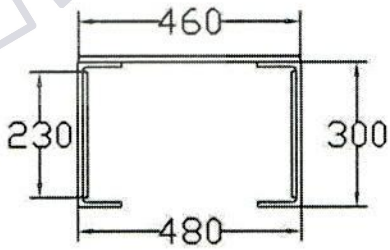
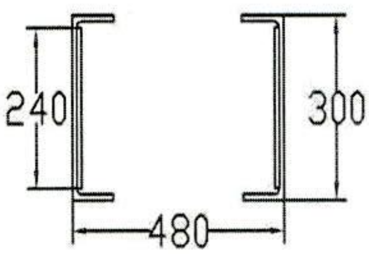
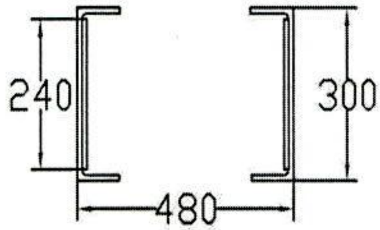
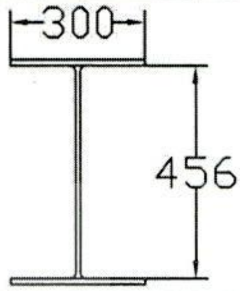
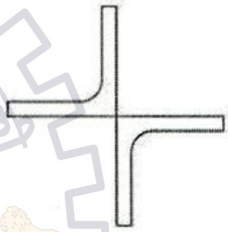
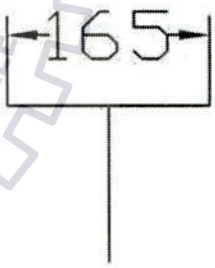
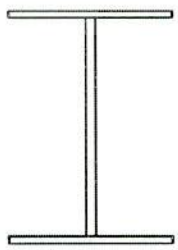
U_1-U'_1 U_5-U'_5	**Portal Girder** Web plate 350 x 10 Top and bottom flange plate 230 x 10	
U_2-U'_2 U_3-U'_3 U_4-U'_4	**Sway Girder** 4 L section 75 x 75 x 10 Lacing flat 65 x 10	
	Stringers Web plate 718 x 10 Top and bottom flange plate 320 x 16	
	All Sway and Portal Bracing 2 L section 75 x 75 x 10	
	All stringer bracing L section 75 x 75 x 10	
	Diaphragm Channel section 300 x 90	

Table 3.5 General Arrangement of 30.5 m span Railway Bridge (32.5 T)

Member	Description	Section
L_0-L_1, L_1-L_2, L_4-L_5, L_5-L_6	**Bottom Chord** 2 [s 300 x 90 1 Top plate 460 x 8 2 side plates 240 x8 Batten 10 mm thick @ bottom	
L_2-L_3, L_3-L_4	**Bottom Chord** 2 [s 300 x 90 1 Top plate 460 x 12 2 side plates 240 x10 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Chord** 2 [s 300 x 90 1 Top plate 460 x 10 Batten of 10 mm thick and Lacing L section 75 x 75 x 10 @ bottom	
L_0-U_1, L_6-U_5	**Diagonal Member** 2 [s 300 x 90 1 Top plate 460 x 22 2 side plates 230 x 12 Batten of 10 mm thick and Lacing L flats 65 x 10 @ bottom	
L_2-U_1, L_4-U_5	**Diagonal Member** 2 [s 300 x 90 2 side plates 240 x10 Batten of 10 mm thick Lacing L flats 65 x 10 @ bottom	

L_2-U_3, L_4-U_3	**Diagonal Member** 2 [s 300 x 90 2 side plates 240 x8 Batten of 10 mm thick and Lacing Flats 65 x 10 @ bottom	
U_1-L_1 U_2-L_2 U_3-L_3 U_4-L_4 U_5-L_5	**Verticals** Web plate 456 x 12 Top and bottom flange plate 300 x 12	
Panels L_0-L_1, L_1-L_2, L_2-L_3, L_3-L_4, L_4-L_5, L_5-L_6	**Bottom lateral Bracing** 2 L section 100 x 100 x 8	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5	**Top Lateral Bracing** ISST 200 x 165	
L_0-L'_0 L_1-L'_1 L_2-L'_2 L_3-L'_3 L_4-L'_4 L_5-L'_5 L_6-L'_6	**Cross Girder** Web plate 856x 20 Top and bottom flange plate 450 x 32	

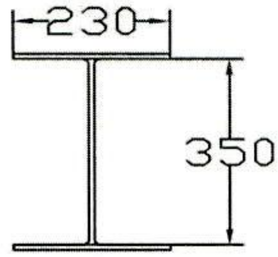
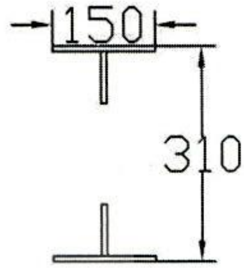
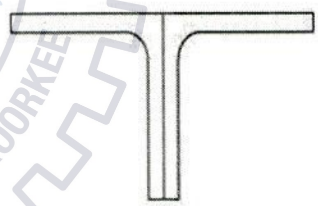
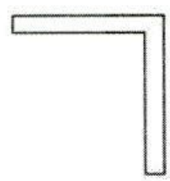
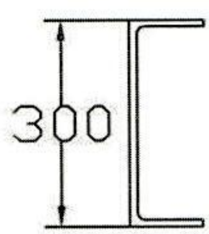
U_1-U'_1 U_5-U'_5	**Portal Girder** Web plate 350 x 8 Top and bottom flange plate 230 x 10	
U_2-U'_2 U_3-U'_3 U_4-U'_4	**Sway Girder** 2 ISHT 150 x 75 Lacing flat 65 x 10	
Stringers Web plate 716 x 10 Top and bottom flange plate 320 x 18 Stiff Ls 100 x 100 x 8		
All Sway and Portal Bracing 2 L section 75 x 75 x 10		
All stringer bracing L section 75 x 75 x 10		
Diaphragm Channel section 300 x 90		

Table 3.6 Detailing of 30.5m span truss bridge

Type of Truss System	Standard Warren Truss
Clear Span (mm)	76200
Centre of Bearings (mm)	78800
No of Panels	10
Panel length (mm)	7880
Spacing between two trusses (mm)	5500
Height of Truss (mm)	10315

Fig. 3.6 Isometric view of 76.2 m truss bridge

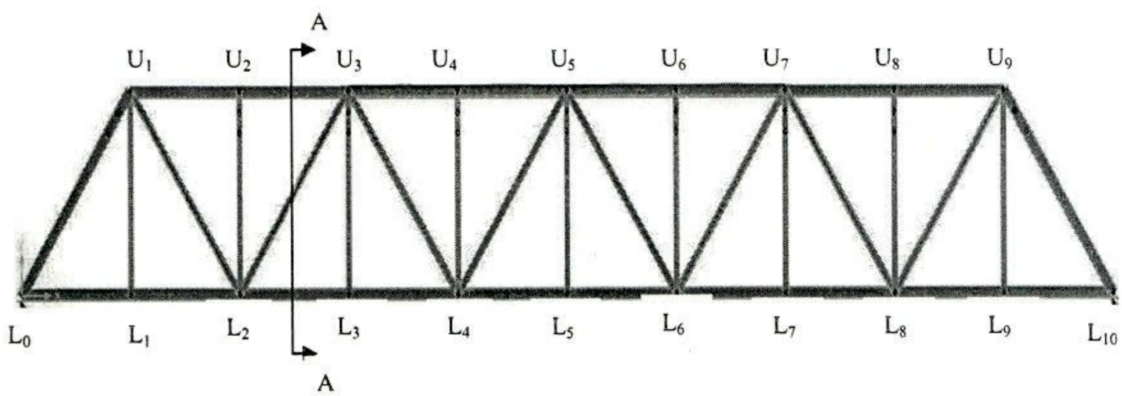


Fig 3.7 Front view of 76.2 m truss bridge

Fig 3.8 Section A-A of 76.2 m truss bridge

Fig. 3.9 bottom chord of 76.2 m truss bridge

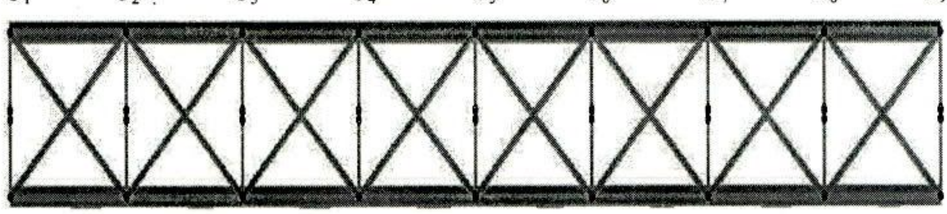
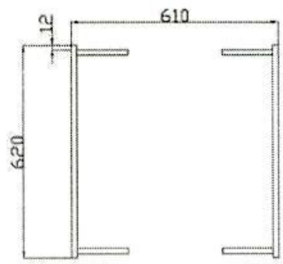
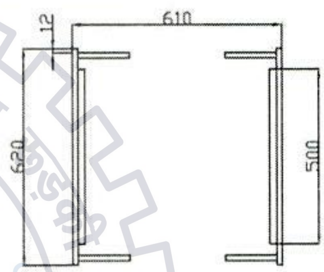
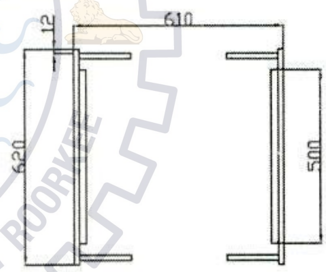
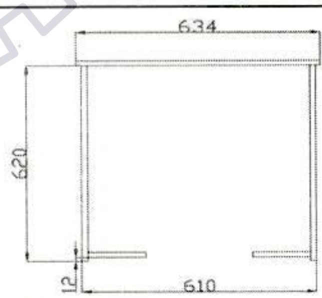
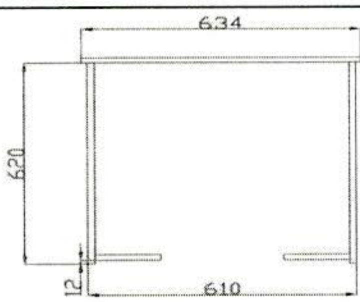
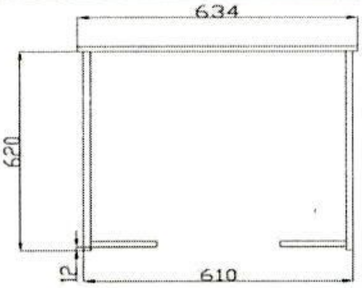
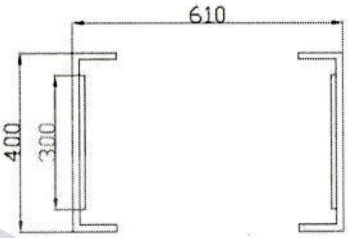
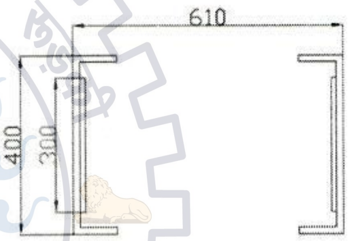
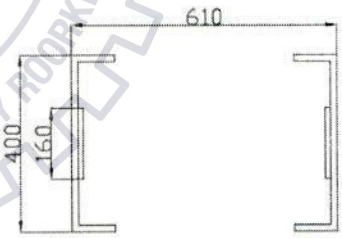
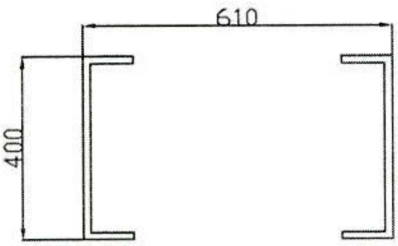
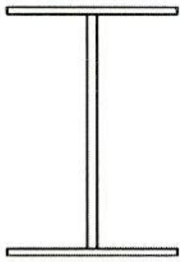
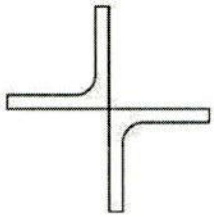
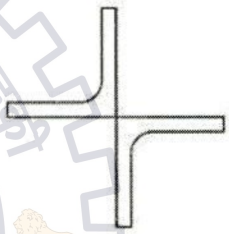
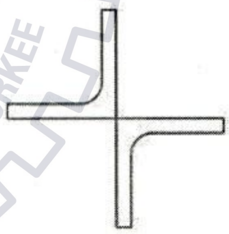
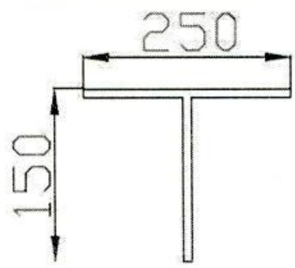


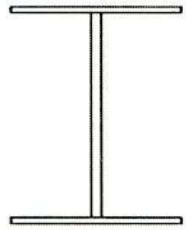
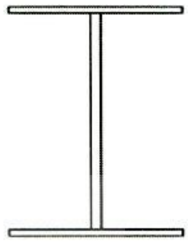
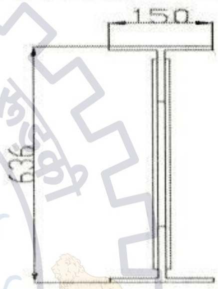
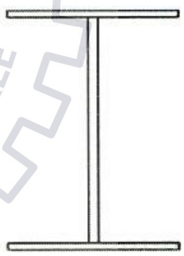
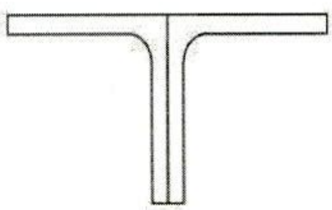
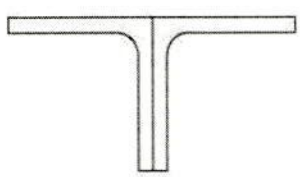
Fig. 3.10 top chord of 76.2 m truss bridge

Table 3.7 General Arrangement of 76.2 m span Railway Bridge (M.B.G)

Member	Description	Section
L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom Chord** 2 Side plates 620 x 12 4 Flange plate 150 x 16 Batten @ bottom 10 mm thick	
L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom Chord** 2 Side plates 620 x 16 4 Flange plate 150 x 16 2 Additional side plate 500 x 20 Batten @ bottom 10 mm thick	
L_4-L_5, L_5-L_6	**Bottom Chord** 2 Side plates 620 x 20 4 Flange plate 150 x 20 2 Additional side plate 500 x 20 Batten @ bottom 10 mm thick	
U_1-U_2, U_2-U_3, U_7-U_8, U_8-U_9	**Top Chord** 2 Side plates 620 x 12 2 Flange plate 150 x 12 1 Top plate 634 x 16 Batten @ bottom 10 mm thick	
U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7	**Top Chord** 2 Side plates 620 x 20 2 Flange plate 150 x 16 1 Top plate 634 x 16 Batten @ bottom 10 mm thick	

L_0-U_1, L_{10}-U_9	**Diagonal Member** 2 Side plates 620 x 20 2 Flange plate 150 x 20 1 Top plate 634 x 16 Batten @ bottom 10 mm thick	
L_2-U_1 L_8-U_9	**Diagonal Member** 2 [s 400 x100 2 Inner plate 300 x 12 Batten @ top and bottom 10 mm thick	
L_2-U_3, L_8-U_7	**Diagonal Member** 2 [s 400 x100 2 Inner plate 300 x 10 Batten @ top and bottom 10 mm thick	
L_4-U_3, L_6-U_7	**Diagonal Member** 2 [s 400 x100 2 Inner plate 160 x 10 Batten @ top and bottom 10 mm thick	
L_4-U_5, L_6-U_5	**Diagonal Member** 2 [s 400 x100 Batten @ top and bottom 10 mm thick	

U_1-L_1, U_2-L_2 U_3-L_3, U_4-L_4 U_5-L_5, U_6-L_6 U_7-L_7, U_8-L_8, U_9-L_9	**Verticals** Web plate 590 x 10 Top and bottom flange plate 280 x 10	
Panels L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom lateral Bracing** 2 L section 130 x130 x 10	
Panels L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom lateral Bracing** 2 L section 100 x 100 x 10	
Panels L_4-L_5, L_5-L_6,	**Bottom lateral Bracing** 2 L section 75 x75 x 10	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7, U_7-U_8, U_8-U_9	**Top Lateral Bracing** ISHT 150 x 250	

L_0-L'_0, L_1-L'_1 L_2-L'_2, L_3-L'_3 L_4-L'_4, L_5-L'_5 L_6-L'_6, L_7-L'_7 L_8-L'_8, L_9-L'_9 L_{10}-L'_{10}	**Cross Girder** Web plate 1360 x 10 Top and bottom flange plate 340 x 20	
U_1-U'_1 U_9-U'_9	**Portal Girder** Web plate 430 x 10 Top and bottom flange plate 200 x 10	
U_2-U'_2, U_3-U'_3 U_4-U'_4, U_5-U'_5 U_6-U'_6, U_7-U'_7 U_8-U'_8	**Sway Girder** 2 ISNT 150 x 150 x10 Lacing flat 65 x 10	
Stringers 1 Web plate 960 x 10 2 Flange Plate 340 x 20		
All Portal Bracing 2 L section 100 x 100 x 8		
All Sway Bracing 2 L Section 75 x 75 x 8		

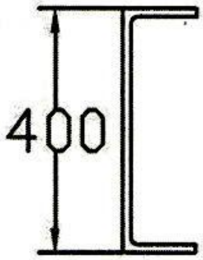
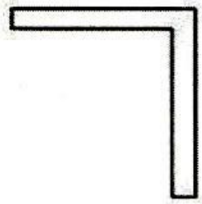
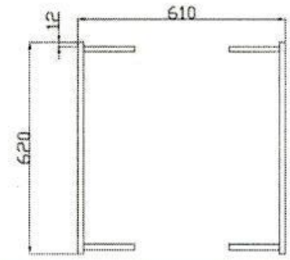
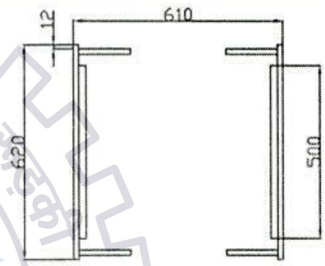
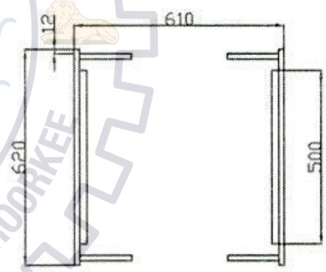
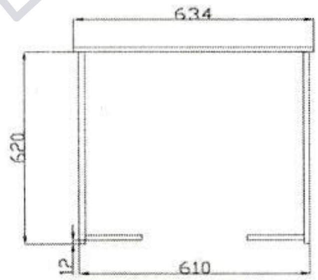
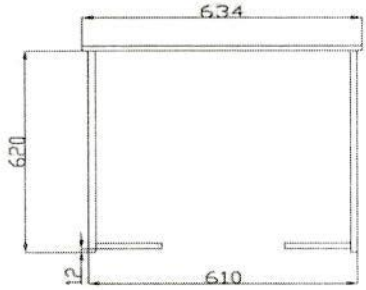
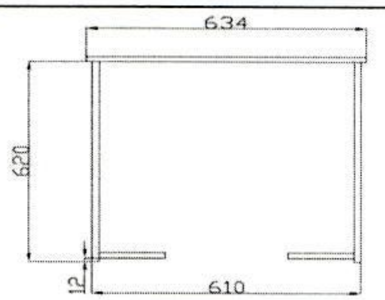
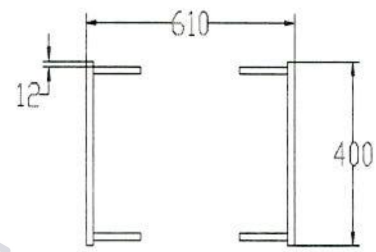
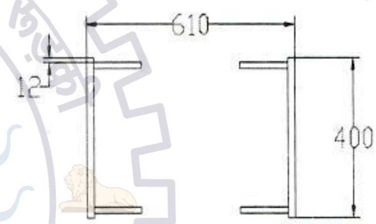
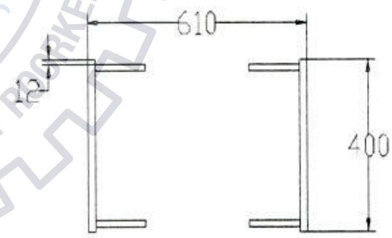
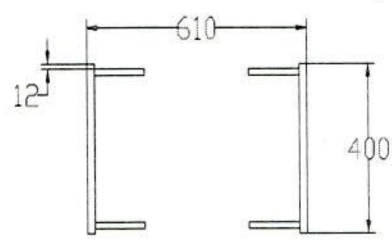
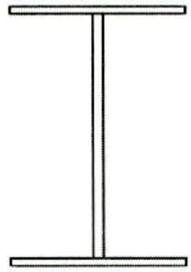
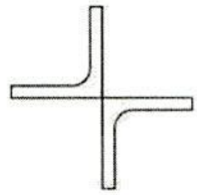
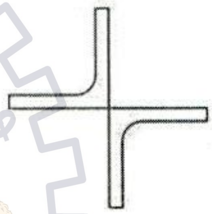
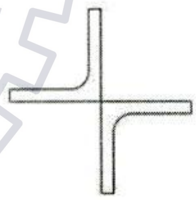
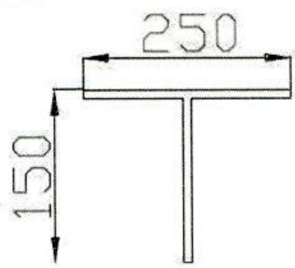
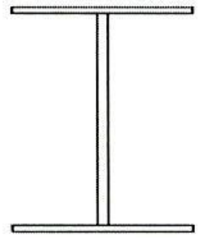
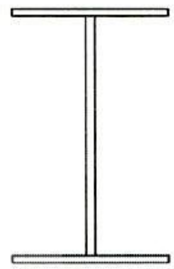
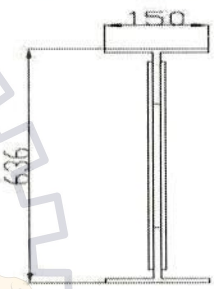
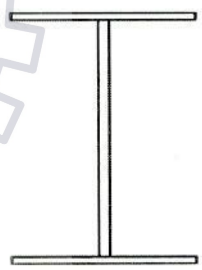
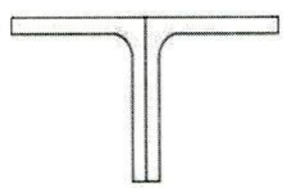
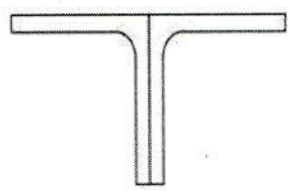
Diaphragm ISMC 400x10	
Stringer bracing L Section 100 x 100 x 10	

Table 3.8 General Arrangement of 76.2 m span Railway Bridge (H.M.)

Member	Description	Section
L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom Chord** 2 Side plates 620 x 20 4 Flange plate 150 x 20 Batten @ bottom 10 mm thick	
L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom Chord** 2 Side plates 620 x 25 4 Flange plate 150 x 25 2 Additional side plate 500 x 25 Batten 10 mm thick @ bottom	
L_4-L_5, L_5-L_6	**Bottom Chord** 2 Side plates 620 x 30 4 Flange plate 150 x 30 2 Additional side plate 500 x 25 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_7-U_8, U_8-U_9	**Top Chord** 2 Side plates 620 x 16 2 Flange plate 150 x 20 1 Top plate 634 x 16 Batten 10 mm thick @ bottom	
U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7	**Top Chord** 2 Side plates 620 x 28 2 Flange plate 150 x 28 1 Top plate 634 x 22 Batten 10 mm thick @ bottom	

L_0-U_1, L_{10}-U_9	**Diagonal Member** 2 Side plates 620 x 20 2 Flange plate 150 x 20 1 Top plate 634 x 20 Batten @ bottom 10 mm thick	
L_2-U_1 L_8-U_9	**Diagonal Member** 2 Side plates 400 x22 4 Flange plates 150 x 22 Batten 10 mm thick @ top and bottom	
L_2-U_3, L_8-U_7	**Diagonal Member** 2 Side plates 400 x20 4 Flange plates 150 x 16 Batten 10 mm thick @ top and bottom	
L_4-U_3, L_6-U_7	**Diagonal Member** 2 Side plates 400 x20 4Flange plates 150 x 10 Batten 10 mm thick @ top and bottom	
L_4-U_5, L_6-U_5	**Diagonal Member** 2 Side plates 400 x10 4Flange plates 150 x 10 Batten 10 mm thick @ top and bottom	

U_1-L_1, U_2-L_2 U_3-L_3, U_4-L_4 U_5-L_5, U_6-L_6 U_7-L_7, U_8-L_8, U_9-L_9	**Verticals** Web plate 590 x 10 Top and bottom flange plate 280 x 10	
Panels L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom lateral Bracing** 2 L section 130 x130 x 10	
Panels L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom lateral Bracing** 2 L section 100 x 100 x 10	
Panels L_4-L_5, L_5-L_6,	**Bottom lateral Bracing** 2 L section 75 x75 x 10	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7, U_7-U_8, U_8-U_9	**Top Lateral Bracing** ISHT 150 x 250	

L_0-L'_0, L_1-L'_1 L_2-L'_2, L_3-L'_3 L_4-L'_4, L_5-L'_5 L_6-L'_6, L_7-L'_7 L_8-L'_8, L_9-L'_9 L_{10}-L'_{10}	**Cross Girder** Web plate 1400 x 12 Top and bottom flange plate 400 x 20	
U_1-U'_1 U_9-U'_9	**Portal Girder** Web plate 430 x 10 Top and bottom flange plate 200 x 10	
U_2-U'_2, U_3-U'_3 U_4-U'_4, U_5-U'_5 U_6-U'_6, U_7-U'_7 U_8-U'_8	**Sway Girder** 2 ISNT 150 x 150 x10 Lacing flat 65 x 10	
	Stringers 1 Web plate 900 x 12 2 Flange Plate 450 x 20	
	All Portal Bracing 2 L section 100 x 100 x 10	
	All Sway Bracing 2 L Section 75 x 75 x 10	

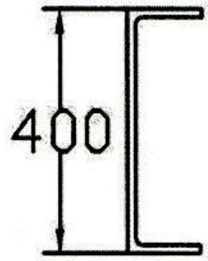
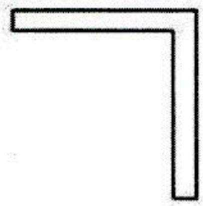
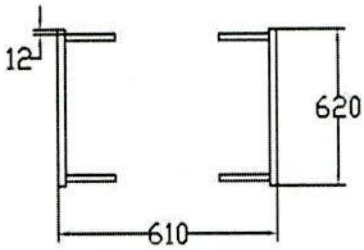
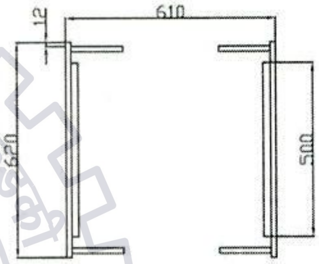
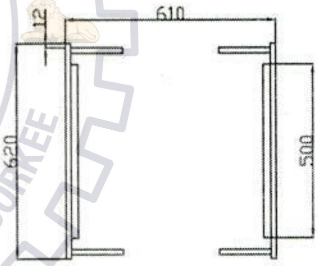
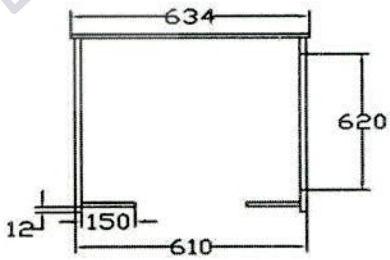
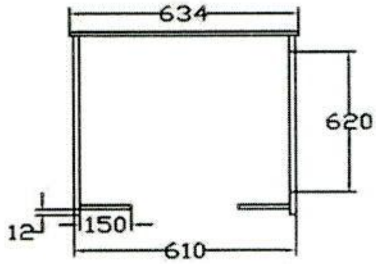
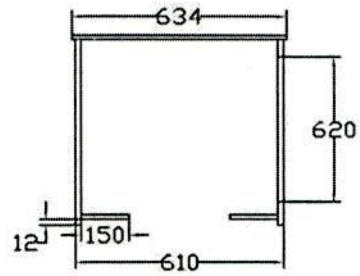
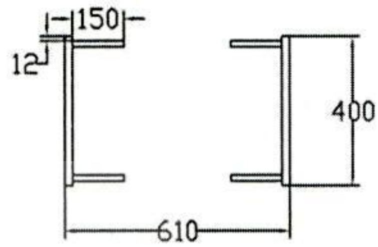
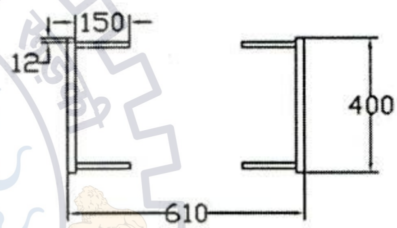
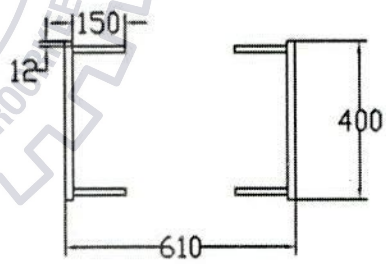
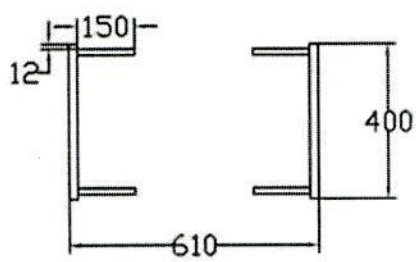
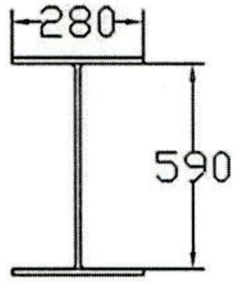
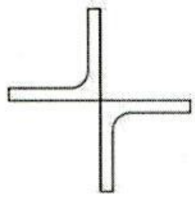
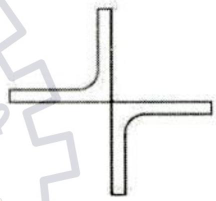
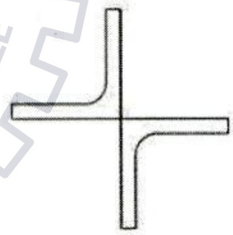
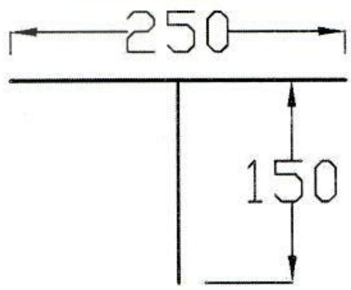
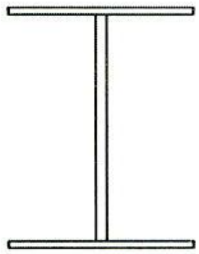
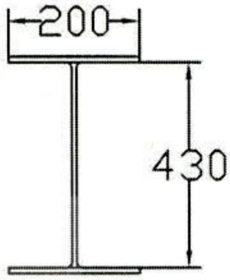
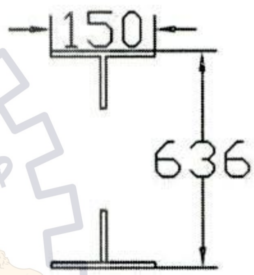
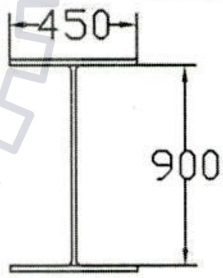
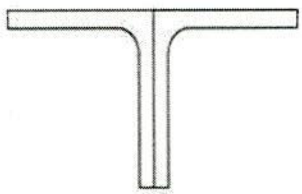
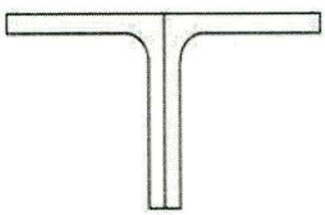
Diaphragm ISMC 400x10	
Stringer bracing L Section 100 x 100 x 10	

Table 3.9 General Arrangement of 76.2 m span Railway Bridge (25 T)

ember	Description	Section
L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom Chord** 2 Side plates 620 x 20 4 Flange plate 150 x 20 Batten @ bottom 10 mm thick	
L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom Chord** 2 Side plates 620 x 32 4 Flange plate 150 x 25 2 Additional side plate 500 x 16 Batten 10 mm thick @ bottom	
L_4-L_5, L_5-L_6	**Bottom Chord** 2 Side plates 620 x 40 4 Flange plate 150 x 30 2 Additional side plate 500 x 16 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_7-U_8, U_8-U_9	**Top Chord** 2 Side plates 620 x 16 2 Flange plate 150 x 20 1 Top plate 634 x 16 Batten 10 mm thick @ bottom	
U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7	**Top Chord** 2 Side plates 620 x 28 2 Flange plate 150 x 28 1 Top plate 634 x 22 Batten 10 mm thick @ bottom	

L_0-U_1, L_{10}-U_9	**Diagonal Member** 2 Side plates 620 x 20 2 Flange plate 150 x 20 1 Top plate 634 x 20 Batten 10 mm thick @ bottom	
L_2-U_1 L_8-U_9	**Diagonal Member** 2 Side plates 400 x20 4Flange plates 150 x 20 Batten 10 mm thick @ top and bottom	
L_2-U_3, L_8-U_7	**Diagonal Member** 2 Side plates 400 x20 4Flange plates 150 x 16 Batten 10 mm thick @ top and bottom	
L_4-U_3, L_6-U_7	**Diagonal Member** 2 Side plates 400 x16 4Flange plates 150 x 10 Batten 10 mm thick @ top and bottom	
L_4-U_5, L_6-U_5	**Diagonal Member** 2 Side plates 400 x10 4Flange plates 150 x 10 Batten 10 mm thick @ top and bottom	

U_1-L_1, U_2-L_2 U_3-L_3, U_4-L_4 U_5-L_5, U_6-L_6 U_7-L_7, U_8-L_8, U_9-L_9	**Verticals** Web plate 590 x 10 Top and bottom flange plate 280 x 10	
Panels L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom lateral Bracing** 2 L section 130 x130 x 12	
Panels L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom lateral Bracing** 2 L section 100 x 100 x 10	
Panels L_4-L_5, L_5-L_6,	**Bottom lateral Bracing** 2 L section 100 x 100 x 10	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7, U_7-U_8, U_8-U_9	**Top Lateral Bracing** ISHT 150 x 250	

L_0-L'_0, L_1-L'_1 L_2-L'_2, L_3-L'_3 L_4-L'_4, L_5-L'_5 L_6-L'_6, L_7-L'_7 L_8-L'_8, L_9-L'_9 L_{10}-L'_{10}	**Cross Girder** Web plate 1400 x 12 Top and bottom flange plate 400 x 20	
U_1-U'_1 U_9-U'_9	**Portal Girder** Web plate 430 x 10 Top and bottom flange plate 200 x 10	
U_2-U'_2, U_3-U'_3 U_4-U'_4, U_5-U'_5 U_6-U'_6, U_7-U'_7 U_8-U'_8	**Sway Girder** 2 ISNT 150 x 150 x10 Lacing flat 65 x 10	
Stringers 1 Web plate 900 x 12 2 Flange Plate 450 x 20		
All Portal Bracing 2 L section 100 x 100 x 10		
All Sway Bracing 2 L Section 75 x 75 x 10		

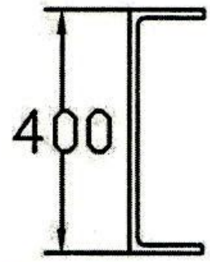
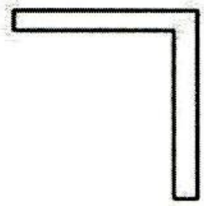
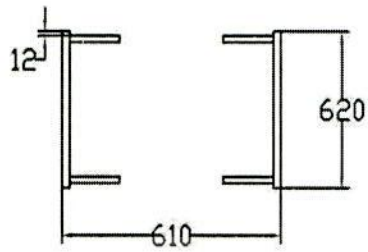
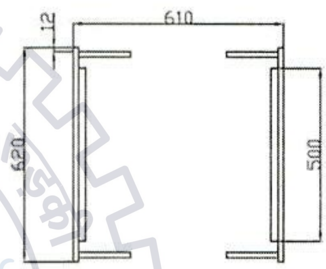
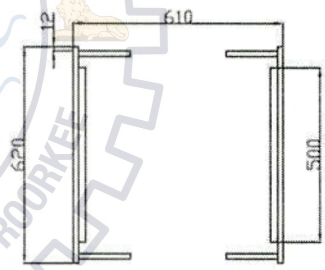
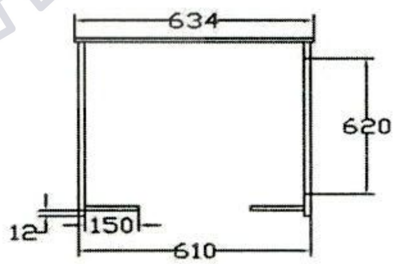
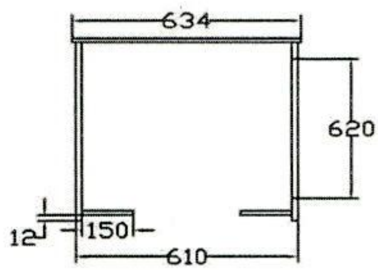
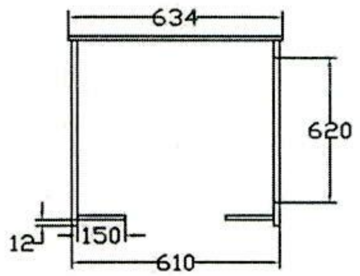
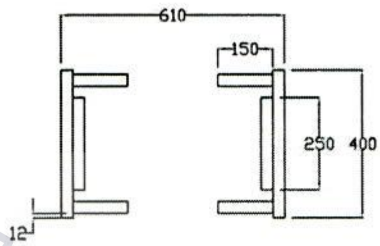
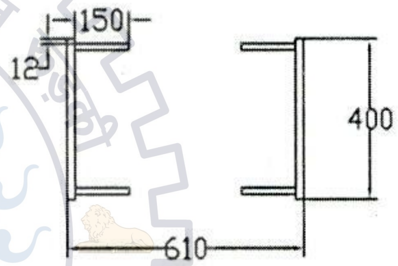
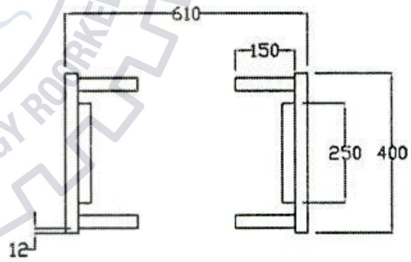
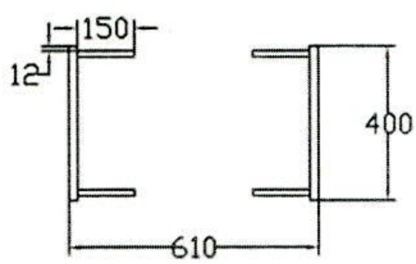
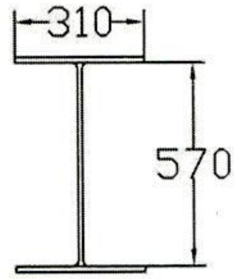
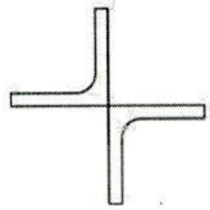
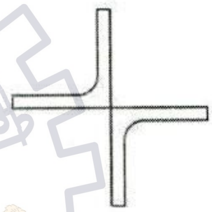
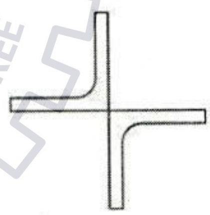
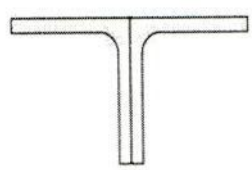
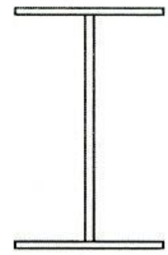
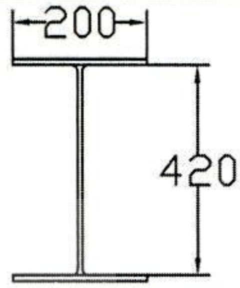
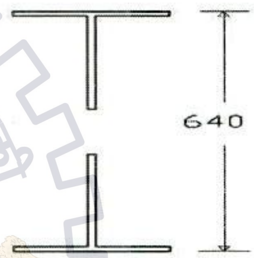
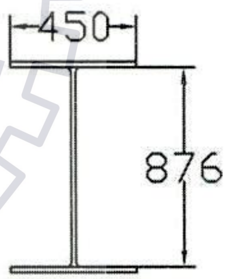
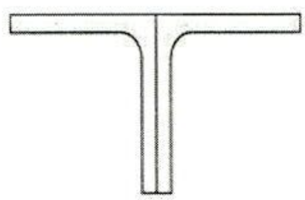
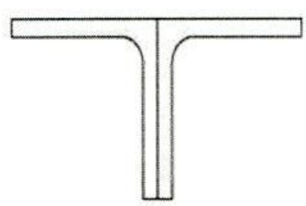
Diaphragm ISMC 400x100	
Stringer bracing L Section 100 x 100 x 10	

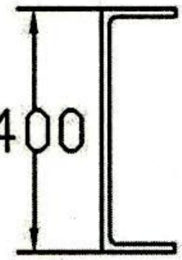
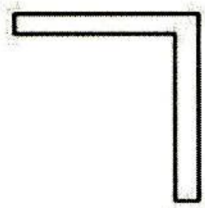
Table 3.10 General Arrangement of 76.2 m span Railway Bridge (32.5 T)

Member	Description	Section
L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom Chord** 2 Side plates 620 x 20 4 Flange plate 150 x 20 Batten 10 mm thick @ bottom	
L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom Chord** 2 Side plates 620 x 28 4 Flange plate 150 x 28 2 Additional side plate 500 x 28 Batten 10 mm thick @ bottom	
L_4-L_5, L_5-L_6	**Bottom Chord** 2 Side plates 620 x 32 4 Flange plate 150 x 32 2 Additional side plate 500 x 32 Batten 10 mm thick @ bottom	
U_1-U_2, U_2-U_3, U_7-U_8, U_8-U_9	**Top Chord** 2 Side plates 620 x22 2 Flange plate 150 x 22 1 Top plate 634 x 22 Batten 10 mm thick @ bottom	
U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7	**Top Chord** 2 Side plates 620 x 32 2 Flange plate 150 x 32 1 Top plate 634 x 32 Batten 10 mm thick @ bottom	

L_0-U_1, L_{10}-U_9	**Diagonal Member** 2 Side plates 620 x 28 2 Flange plate 150 x 28 1 Top plate 634 x 28 Batten 10 mm thick @ bottom	
L_2-U_1 L_8-U_9	**Diagonal Member** 2 Side plates 400 x32 4Flange plates 150 x 32 2 Additional side plate 250 x 36 Batten 10 mm thick @ top and bottom	
L_2-U_3, L_8-U_7	**Diagonal Member** 2 Side plates 400 x 32 4Flange plates 150 x 32 Batten 10 mm thick @ top and bottom	
L_4-U_3, L_6-U_7	**Diagonal Member** 2 Side plates 400 x32 4 Flange plates 150 x 32 2 Additional side plate 250 x 12 Batten 10 mm thick @ top and bottom	
L_4-U_5, L_6-U_5	**Diagonal Member** 2 Side plates 400 x32 4Flange plates 150 x 32 Batten 10 mm thick @ top and bottom	

U_1-L_1, U_2-L_2 U_3-L_3, U_4-L_4 U_5-L_5, U_6-L_6 U_7-L_7, U_8-L_8, U_9-L_9	**Verticals** Web plate 570 x 20 Top and bottom flange plate 310 x 20	
Panels L_0-L_1, L_1-L_2, L_8-L_9, L_9-L_{10}	**Bottom lateral Bracing** 2 L section 150 x150 x 12 Batten 10 mm thick	
Panels L_2-L_3, L_3-L_4, L_6-L_7, L_7-L_8	**Bottom lateral Bracing** 2 L section 130 x 130 x 10 Batten 10 mm thick	
Panels L_4-L_5, L_5-L_6,	**Bottom lateral Bracing** 2 L section 90 x 90 x 10 Batten 10 mm thick	
Panels U_1-U_2, U_2-U_3, U_3-U_4, U_4-U_5, U_5-U_6, U_6-U_7, U_7-U_8, U_8-U_9	**Top Lateral Bracing** 2 L section 130 x 130 x 12	

L_0-L'_0, L_1-L'_1 L_2-L'_2, L_3-L'_3 L_4-L'_4, L_5-L'_5 L_6-L'_6, L_7-L'_7 L_8-L'_8, L_9-L'_9 L_{10}-L'_{10}	**Cross Girder** Web plate 1364 x 16 Top and bottom flange plate 450 x 38	
U_1-U'_1 U_9-U'_9	**Portal Girder** Web plate 420 x 15 Top and bottom flange plate 200 x 15	
U_2-U'_2, U_3-U'_3 U_4-U'_4, U_5-U'_5 U_6-U'_6, U_7-U'_7 U_8-U'_8	**Sway Girder** 2 ISNT 150 x 250 Lacing flat 65 x 10	
	Stringers Web plate 876 x 14 Top and bottom flange plate 450 x 32	
	All Portal Bracing 2 L Section150 x 150 x 12	
	All Sway Bracing 2 L Section150 x 150 x 12	

Diaphragm ISMC 400x100	
Stringer bracing L Section 100 x 100 x 10	

3.2 LWR on truss bridge

In this problem length of LWR is taken as 495.056m on either side of the bridge. Truss bridge is placed exactly at centre of the span of LWR. So length of structure is 2*495.056+ (length of the bridge) in both the cases.

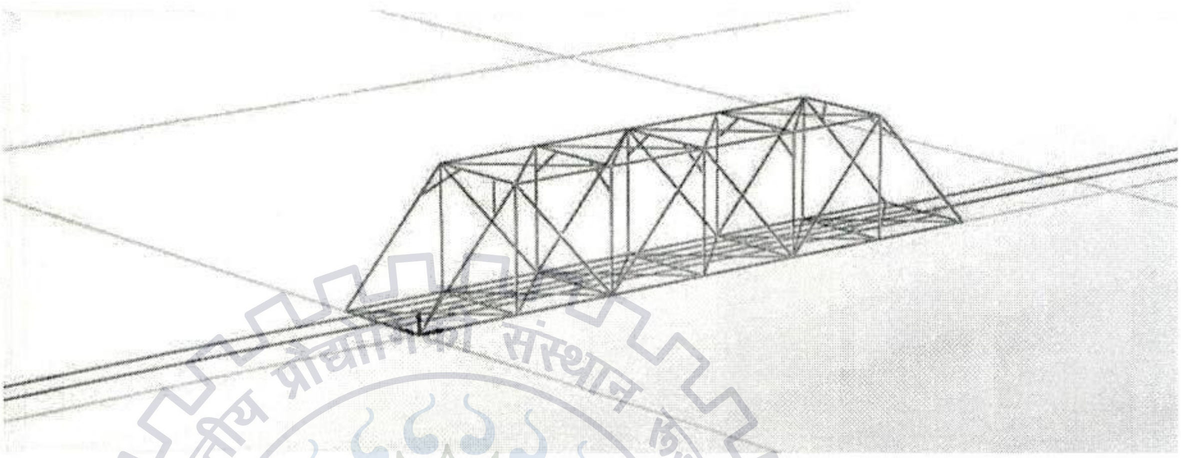


Fig 3.11 Isometric view of LWR on bridge

LWR is being connected on the bridge through a link element. The behaviour of this link element is same as that of ZLR rail fastening. This Link element can move only along the longitudinal direction and restrained in all other directions and in rotations in order to achieve equal displacement of girder and rail in vertical and transverse direction.

3.3 LWR on the sub-grade soil

Same as the case of conventional track LWR rests on the same surface. In the present case LWR is resting on the sub grade soil on either side of the bridge upto a distance of 495.056m. The response of the track depends on the subgrade soil present below it. Depending on the dynamic characteristics, Indian soils are classified into three main categories, namely

1) Weak soils
2) Medium soil
3) Hard soil

All soils have different properties in different directions which play vital role on the response of the structure. Here, the analysis is done for of soft soil only. Stiffness of the soil is one of the most significant properties that affect the response between the bridge and the soil. The stiffness property of the soil depends on the type of the soil. The vertical stiffness of the soil K is defined as

$$K = C_u \times A$$

Where,

A = base area

C_u = coefficient of elastic uniform compression

The recommended design values for coefficient of elastic uniform compression C_u for Area equal to 10 m^2 as follow.

Table 3.11 Types of soil with coefficient of elastic uniform compression [14].

No.	Soil type	C_u in KN/m^3
1	Weak soils	Up to 3E+04
2	Medium soil	(3 - 5)E+04
3	Hard soil	(5-10)E+04

Here, only the stiffness of the soil is considered while as the stiffness of ballasted track should not be considered. To calculate stiffness of the soil, area under the track should be divided in terms of geometric progression to achieve more realistic behaviour. As per Indian railway the standard bottom width of the track is 4.44 m. Take an average value of C_u for calculating stiffness.

In geometric progression

n = 20

a = 2.2

r = 1.2

S_n = 495.056

Generally at the end of LWR, Switch Expansion Joint (SEJ) is provided, which gives some movement of LWR in longitudinal direction. To fulfil this situation, in this project the one end of LWR is hinged and the other one is roller to achieve longitudinal movement. Transverse direction of LWR can't move, so that translation of LWR in transverse direction is restrained at given point.

3.4 Equivalent rail section

As per Indian railway mainly two types of rail sections should be provided for long welded rail, 52 kg and 60 kg. In this study 52 kg rail has been used for LWR, and shape of rail is assumed as I section. Rail size and cross section properties are mention as below;

Table 3.12 Rail section (I section)

Width of top flange	67 mm
Thickness of top flange	35 mm
Width of bottom flange	136 mm
Thickness of bottom flange	20 mm
Height of web	101 mm
Thickness of web	15.5 mm
Weight	52.04 Kg

CHAPTER 4

ANALYSIS AND RESULTS

Here, two types of truss bridges of spans 30.5 m and 76.2 m are analysed for all type of routes, for conventional rail as well as long welded rail on soft soil. All the truss bridges in this study have been analysed under static as well as dynamic (seismic) loading. Out of all bridges under consideration linear time history has been done for one bridge of span 76.2 m, for 32.5 Tons route. For this study time history data of Chi-Chi earthquake has been collected from "(http://peer.berkeley.edu/)". Response spectra are convenient to linear analysis single degree of freedom as well as multi degree of freedom system. For complex and non linear structure system response spectra can't use directly. Therefore, given time history should be compatible with specified design spectrum. Figure 4.1(a) and 4.1(b) shows the plot of spectrum compatible time history for horizontal and vertical component of Chi-Chi ground motion. Seismo artif software has been used for making spectrum compatible time history.

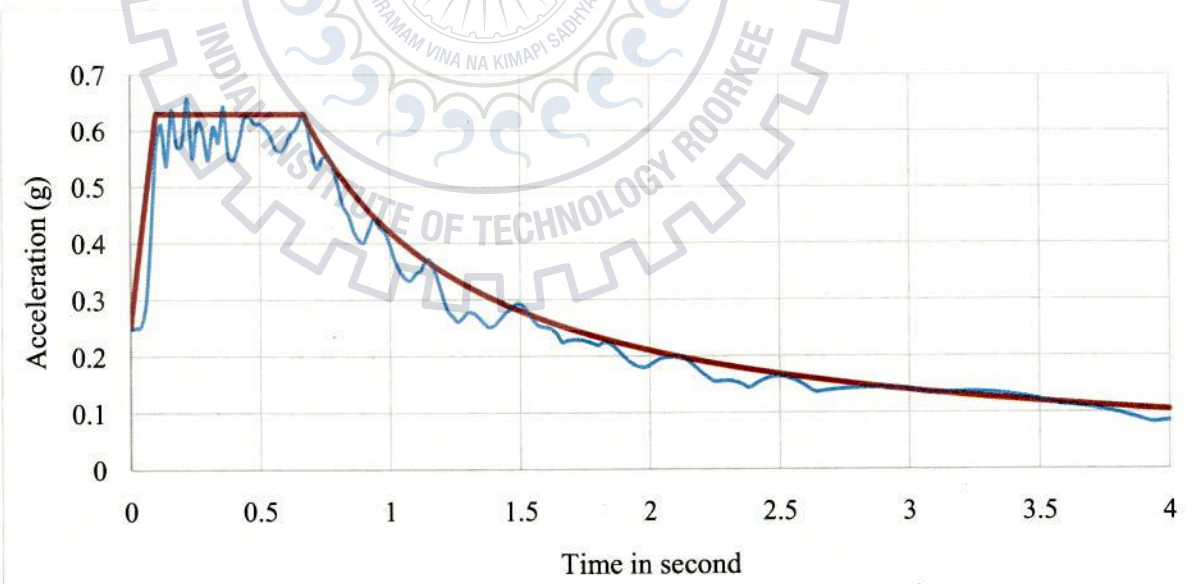


Fig. 4.1(a) compatible time history of horizontal component

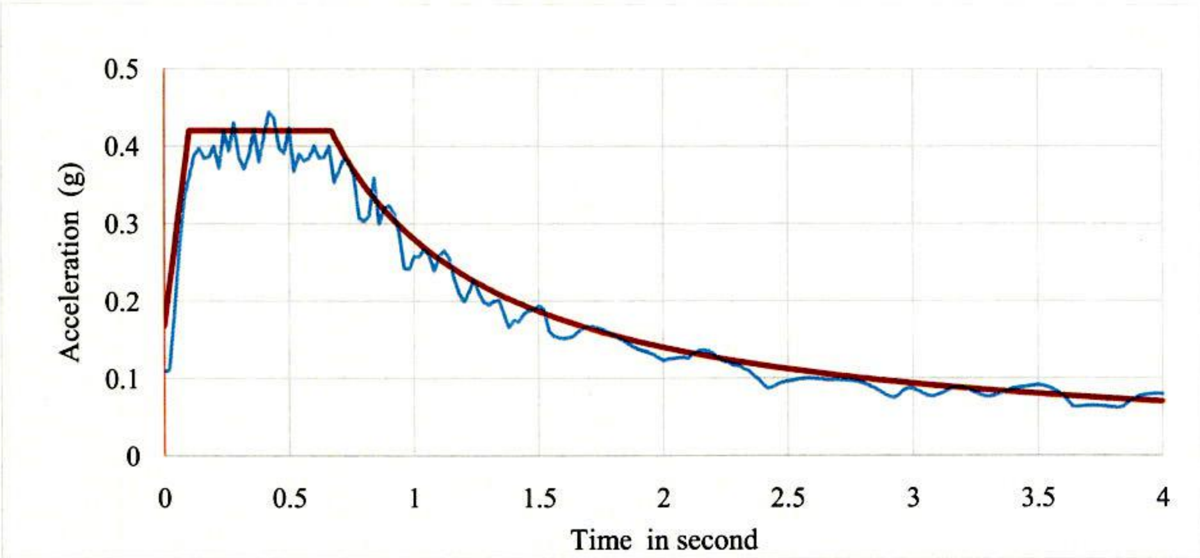


Fig. 4.1(b) compatible time history of vertical component

The forces that are induced in the truss bridge are the Earthquake forces according to the given response spectra as per IS 1893:2002 [2] and some guidelines on seismic design of railway bridges given by NICEE [5] like;

Response reduction factor R = 1

Importance factor I = 1.5

Material damping for steel β = 2 %.

Table 4.1 (a) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m MBG Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	57.14	56.83	0.543	-114.89	-114.67	0.191	-124.73	-124.32	0.329
Moment 2-2	-1.67	-1.66	0.599	-0.25	-0.24	4	-0.925	-0.913	1.297
Shear 3-3	-0.98	-0.98	0	-0.13	-0.13	0	-0.74	-0.735	0.676
Moment 3-3	0.98	0.99	-1.02	-0.46	-0.46	0	-6.88	-6.88	0
Shear 2-2	-1.94	-1.94	0	-1.97	-1.97	0	-3.85	-3.85	0

Table 4.1 (b) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m MBG Railway Bridge

Member	U7-L7 Vertical			L0-L0' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	-6.5	-6.5	0	-2.51	-2.55	-1.59	31.05	31.17	-0.39
Moment 2-2	-1.48	-1.48	0	16.74	16.72	0.119	0.135	0.126	6.667
Shear 3-3	-0.04	-0.04	0	15.96	16.05	-0.56	0.17	0.155	8.824
Moment 3-3	-0.21	-0.21	0	-10.44	-12.3	-17.8	6.28	6.5	-3.5
Shear 2-2	-0.05	-0.05	0	-10.37	-12.02	-15.9	-4.06	-3.51	13.55

Table 4.2 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m MBG Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	157.96	142.58	9.737	71.84	72.6	-1.06	68.92	69.71	-1.15
Moment 2-2	3.8	3.26	14.21	0.64	0.62	3.125	0.36	0.26	27.78
Shear 3-3	2.25	1.93	14.22	0.27	0.27	0	0.132	0.1	24.24
Moment 3-3	55.43	49.78	10.19	1.48	1.54	-4.05	35.51	31.61	10.98
Shear 2-2	12.94	11.62	10.2	0.7	0.69	1.429	4.5	3.92	12.89

Table 4.2 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m MBG Railway Bridge

Member	**U4-L4 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	4.34	4.42	-1.84	6.5	5.91	9.08	42.45	39	8.13
Moment 2-2	0.176	0.179	-1.7	41.3	36.2	12.3	0.9	0.51	43.3
Shear 3-3	0.142	0.13	8.45	39.33	34.72	11.7	0.57	0.305	46.5
Moment 3-3	2.385	2.33	2.31	2.78	3.68	-32.4	6.45	6.32	2.02
Shear 2-2	2.213	2.16	2.39	2.5	3.3	-32	1.67	1.68	-0.6

Table 4.3 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m MBG Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	18.54	17.75	4.26	94.29	90.29	4.24	125.35	125.43	-0.06
Moment 2-2	29.99	30.05	-0.2	7.38	7.68	-4.07	93.43	93.59	-0.17
Shear 3-3	8.43	8.45	-0.24	1.79	1.87	-4.47	19.22	19.25	-0.16
Moment 3-3	27.25	27.51	-0.95	3.76	1.2	68.1	17.72	17.88	-0.9
Shear 2-2	6.6	6.66	-0.91	0.81	0.51	37	2.63	2.65	-0.76

Table 4.3 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m MBG Railway Bridge

Member	**U1-L1 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	10.99	10.87	1.09	7.93	8.24	-3.91	71.57	72.29	-1.01
Moment 2-2	23.64	23.59	0.21	14.31	14.42	-0.77	0.97	0.87	10.3
Shear 3-3	9.176	9.16	0.17	10.1	10.17	-0.69	1.49	1.36	8.72
Moment 3-3	0.75	0.76	-1.33	7.92	7.8	1.52	4.77	4.3	9.85
Shear 2-2	0.22	0.22	0	2.93	2.72	7.17	0.715	0.74	-3.5

Table 4.4 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m MBG Railway Bridge

Member	L0-L1 Bottom Chord			U4-U5 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	53.3	56.29	-5.61	52.64	50.98	3.15	51.91	50.19	3.31
Moment 2-2	1.24	1.25	-0.81	0.25	0.27	-8	0.64	0.58	9.38
Shear 3-3	0.74	0.74	0	0.1	0.11	-10	0.48	0.38	20.8
Moment 3-3	22.96	23.5	-2.35	1.54	1.54	0	7.43	7.82	-5.25
Shear 2-2	5.37	5.5	-2.42	0.69	0.67	2.9	4.49	4.76	-6.01

Table 4.4 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m MBG Railway Bridge

Member	U4-L4 Vertical			L2-L2' Cross Girder			Stringer 4th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.54	3.37	4.8	4.8	5.1	-6.25	15.11	15.69	-3.84
Moment 2-2	0.136	0.13	4.41	3.66	3.5	4.37	0.41	0.27	34.1
Shear 3-3	0.22	0.12	45.5	3.96	3.82	3.54	0.29	0.18	37.9
Moment 3-3	1.2	1.3	-8.33	2.1	2.03	3.33	3.75	3.61	3.73
Shear 2-2	1.05	1.14	-8.57	7.1	6.9	2.82	1.73	1.55	10.4

Table 4.5 (a) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m MBG Railway Bridg

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	284.93	284.14	0.28	-609.66	-609.26	0.07	-622.12	-621.36	0.12
Moment 2-2	-9.54	-9.52	0.21	0.925	0.918	0.76	2.57	2.6	-1.17
Shear 3-3	-3.58	-3.58	0	0.212	0.21	0.94	0.55	0.56	-1.82
Moment 3-3	-0.81	-0.76	6.17	-33.56	-33.56	0	3.56	3.52	1.12
Shear 2-2	-6.16	-6.15	0.16	-14.03	-14.03	0	-8.78	-8.78	0

Table 4.5 (b) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m MBG Railway Bridge

Member	**U7-L7 Vertical**			**L0-L0' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	60.22	60.22	0	-12.95	-13.12	-1.31	157.2	157.72	-0.33
Moment 2-2	-5.88	-5.87	0.17	-54.15	-54.25	-0.18	0.58	0.566	2.41
Shear 3-3	-4.63	-4.62	0.22	-50.41	-50.84	-0.85	0.487	0.472	3.08
Moment 3-3	-0.66	-0.66	0	-14.75	-18.6	-26.1	21.53	21.93	-1.86
Shear 2-2	-0.126	-0.126	0	-14.24	-17.59	-23.5	-7.24	-6.49	10.4

Table 4.6 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m MBG Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	671.59	646.15	3.79	233.16	223.37	4.199	167.12	158.4	5.22
Moment 2-2	11.72	10.79	7.94	1.07	1.09	-1.87	0.64	0.68	-6.25
Shear 3-3	4.36	4	8.26	0.29	0.302	-4.14	0.136	0.15	-10.3
Moment 3-3	208.28	200.06	3.95	15.14	14.98	1.057	211.71	202.64	4.28
Shear 2-2	31.26	30.023	3.96	5	4.95	1	17.23	16.37	4.99

Table 4.6 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m MBG Railway Bridge

Member	U7-L7 Vertical			L0-L0' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	38.1	37.77	0.87	29.65	28.66	3.339	74.11	70.29	5.15
Moment 2-2	2.1	1.98	5.71	80.15	75.04	6.376	1.4	0.78	44.3
Shear 3-3	1.51	1.43	5.3	74.69	70.38	5.771	0.65	0.38	41.5
Moment 3-3	7.97	8.06	-1.13	6.81	8.26	-21.3	7.88	7.53	4.44
Shear 2-2	5.6	5.67	-1.25	6.26	7.55	-20.6	3.38	3.24	4.14

Table 4.7 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m MBG Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	601.12	601.34	-0.04	207.61	207.35	0.125	688.67	689.02	-0.05
Moment 2-2	293.98	294.07	-0.03	68.72	68.47	0.364	966.51	967.03	-0.05
Shear 3-3	48.11	48.14	-0.06	10.46	10.47	-0.1	144.56	144.64	-0.06
Moment 3-3	321.28	321.4	-0.04	71.54	71.55	-0.01	333.26	333.38	-0.04
Shear 2-2	51.05	51.07	-0.04	10.43	10.43	0	31.97	31.98	-0.03

Table 4.7 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m MBG Railway Bridge

Member	U1-L1 Vertical			L0-L0' Cross Girder			Stringer 1th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	9.73	9.65	0.82	10.42	11.9	-14.2	26.28	25.7	2.21
Moment 2-2	117.46	117.52	-0.05	17.28	17.38	-0.58	8.74	9.05	-3.55
Shear 3-3	27.27	27.29	-0.07	2.55	2.58	-1.18	1.27	1.14	10.2
Moment 3-3	3.15	3.156	-0.19	57.21	57.34	-0.23	0.29	0.25	13.8
Shear 2-2	0.61	0.61	0	21	20.9	0.476	0.615	0.56	8.94

Table 4.8 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m MBG Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	286.1	278.23	2.75	340.84	341.98	-0.33	310.9	311.6	-0.23
Moment 2-2	8	7.77	2.88	0.46	0.51	-10.9	0.987	1.07	-8.41
Shear 3-3	2.97	2.89	2.69	0.085	0.093	-9.41	0.2	0.22	-10
Moment 3-3	46.41	43.72	5.8	25.25	24.74	2.02	52.38	49.5	5.5
Shear 2-2	7.14	6.74	5.6	4.89	4.82	1.431	4.5	4.25	5.56

Table 4.8 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m MBG Railway Bridge

Member	U7-L7 Vertical			L4-L4' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	34.93	35.15	-0.63	23.4	23.28	0.513	109.24	108.78	0.42
Moment 2-2	2.86	2.88	-0.7	8.24	7.7	6.553	0.24	0.26	-8.33
Shear 3-3	2.37	2.34	1.27	8.1	7.58	6.42	0.206	0.25	-21.4
Moment 3-3	1.74	1.78	-2.3	3.24	3.26	-0.62	16.65	16.77	-0.72
Shear 2-2	1.25	1.28	-2.4	19.14	19.24	-0.52	3.07	3.04	0.98

Table 4.9 (a) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m HM Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	61.25	61	0.41	-127.24	-126.96	0.22	-150.21	-149.84	0.25
Moment 2-2	-1.76	-1.76	0	-0.39	-0.37	5.13	0.62	0.63	-1.61
Shear 3-3	-1.03	-1.02	0.97	0.14	-0.14	0	0.18	0.19	-5.56
Moment 3-3	1.62	1.63	-0.62	-5.18	-0.31	94.02	-0.87	-0.88	-1.15
Shear 2-2	-1.91	-1.91	0	-3.9	-2.07	46.92	-3.18	-3.18	0

Table 4.9 (b) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m HM Railway Bridge

Member	**U4-L4 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	-7.13	-7.13	0	-2.97	-3	-1.01	35.73	35.79	-0.17
Moment 2-2	-1.67	-1.67	0	21.87	21.81	0.27	1.36	1.33	2.21
Shear 3-3	-0.1	-0.1	0	20.42	20.48	-0.29	0.98	0.97	1.02
Moment 3-3	-0.25	-0.25	0	-11.49	-13.2	-14.9	-0.22	0.12	45.5
Shear 2-2	-0.07	-0.07	0	-11.68	-13.2	-13	-7.07	-6.43	9.05

Table 4.10 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m HM Railway Bridge

Member	L0-L1 Bottom Chord			U4-U5 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	152	140	7.89	62.28	63.1	-1.32	59.42	60	-0.98
Moment 2-2	3.54	3.14	11.3	0.53	0.52	1.88	0.28	0.25	10.7
Shear 3-3	2.07	1.83	11.6	0.24	0.24	0	0.1	0.095	5
Moment 3-3	53.92	49.42	8.35	1.37	1.42	-3.65	37.92	34.48	9.07
Shear 2-2	12.6	11.53	8.49	0.71	0.73	-2.82	4.63	4.14	10.6

Table 4.10 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m HM Railway Bridge

Member	U4-L4 Vertical			L0-L0' Cross Girder			Stringer 4th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.79	3.88	-2.37	6.8	6.26	7.94	37.83	40.17	-6.19
Moment 2-2	0.14	0.14	0	48.52	43.61	10.12	0.58	0.72	-24.1
Shear 3-3	0.09	0.09	0	45.27	40.9	9.65	0.43	0.53	-23.3
Moment 3-3	2.16	2.14	0.93	2.62	3.39	-29.4	0.38	0.5	-31.6
Shear 2-2	2	1.98	1	2.39	3.06	-28	3.12	3.06	1.92

Table 4.11 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m HM Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	18.31	17.98	1.8	83.17	83	0.20	112.75	112.8	-0.04
Moment 2-2	27.45	27.47	-0.07	10.29	10.35	-0.58	105.95	106.1	-0.14
Shear 3-3	8.1	8.1	0	2.46	2.48	-0.81	20.76	20.79	-0.14
Moment 3-3	21.95	22.08	-0.59	3.57	3.57	0	15.94	16.02	-0.5
Shear 2-2	5.29	5.32	-0.57	0.75	0.75	0	2.32	2.33	-0.43

Table 4.11 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m HM Railway Bridg

Member	**U1-L1 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	9.66	9.63	0.31	7.51	7.73	-2.93	56.46	56.87	-0.73
Moment 2-2	36.2	36.2	0	16.82	16.88	-0.36	1.54	1.51	1.95
Shear 3-3	7.39	7.39	0	11.25	11.27	-0.18	1.05	1.03	1.9
Moment 3-3	0.68	0.68	0	8.1	8.03	0.86	0.8	1.29	-61.3
Shear 2-2	0.18	0.18	0	3.04	2.92	3.95	0.92	1.28	-39.1

Table 4.12 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m HM Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	43.57	45.7	-4.89	52.21	51	2.32	52.4	51.27	2.16
Moment 2-2	1.01	1.01	0	0.16	0.17	-6.25	0.22	0.22	0
Shear 3-3	0.59	0.6	-1.69	0.075	0.08	-6.67	0.077	0.075	2.6
Moment 3-3	18.86	19.3	-2.33	1.51	1.51	0	13.05	13.28	-1.76
Shear 2-2	4.4	4.5	-2.27	0.71	0.72	-1.41	1.6	1.6	0

Table 4.12 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m HM Railway Bridge

Member	**U4-L4 Vertical**			**L2-L2' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.49	3.4	2.58	3.52	3.68	-4.55	14	14.32	-2.29
Moment 2-2	0.1	0.1	0	2.88	2.81	2.43	0.6	0.54	10
Shear 3-3	0.18	0.18	0	3.11	3.06	1.61	0.43	0.39	9.3
Moment 3-3	0.95	1.02	-7.37	1.68	1.66	1.19	0.67	0.73	-8.96
Shear 2-2	0.81	0.88	-8.64	6.87	6.76	1.6	2.85	2.7	5.26

Table 4.13 (a) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m HM Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	369.56	368.98	0.16	-785.56	-785.18	0.05	-779.8	-779	0.1
Moment 2-2	-11.75	-11.73	0.17	1.24	1.23	0.80	3.67	3.7	-0.82
Shear 3-3	-4.39	-4.38	0.23	0.29	0.29	0	0.83	0.83	0
Moment 3-3	-5.13	-5.08	0.97	-34.12	-34.12	0	8.15	8.1	0.61
Shear 2-2	-10.56	-10.54	0.19	-16.26	-16.26	0	-8.78	-8.79	-0.11

Table 4.13 (b) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m HM Railway Bridge

Member	U7-L7 Vertical			L0-L0' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	71.2	71.2	0	-12.26	-12.43	-1.39	200.12	200.23	-0.05
Moment 2-2	-5.97	-5.97	0	-67.72	-67.69	0.044	0.93	0.93	0
Shear 3-3	-4.41	-4.41	0	-64.51	-64.69	-0.28	0.73	0.73	0
Moment 3-3	-0.63	-0.63	0	-18.54	-22.05	-18.9	27.48	30.09	-9.5
Shear 2-2	-0.12	-0.12	0	-17.9	-21.02	-17.4	-6.7	-4.69	30

Table 4.14 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m HM Railway Bridge

Member	**L0-L1 Bottom Chord**			**U8-U9 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	872.98	846.27	3.06	294.77	285.27	3.223	205.67	197.56	3.94
Moment 2-2	14.07	13.19	6.25	1.2	1.2	0	1.06	1	5.66
Shear 3-3	5.21	4.87	6.53	0.33	0.33	0	0.23	0.215	6.52
Moment 3-3	291.76	282.25	3.26	17.51	17.38	0.742	237.43	229.17	3.48
Shear 2-2	44.03	42.58	3.29	5.62	5.59	0.534	20.22	19.41	4.01

Table 4.14 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m HM Railway Bridge

Member	**U7-L7 Vertical**			**L0-L0' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	47.62	47.41	0.44	27.91	27.17	2.651	90	85.89	4.57
Moment 2-2	2.14	2.07	3.27	100.77	95.62	5.111	1.23	1.22	0.81
Shear 3-3	1.34	1.28	4.48	96.1	91.39	4.901	0.59	0.63	-6.78
Moment 3-3	8.31	8.37	-0.72	6.97	8.13	-16.6	10.23	10.84	-5.96
Shear 2-2	5.84	5.88	-0.68	6.47	7.55	-16.7	3.34	2.65	20.7

Table 4.15 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m HM Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	667.92	668.14	-0.03	338.11	337.74	0.109	912.82	913.01	-0.02
Moment 2-2	468.2	468.41	-0.04	110.27	110.66	-0.35	1172.97	1173.4	-0.04
Shear 3-3	77.41	77.41	0	16.27	16.27	0	117.87	117.93	-0.05
Moment 3-3	428.15	428.24	-0.02	77.78	77.78	0	347.83	347.88	-0.01
Shear 2-2	68.58	68.6	-0.03	11.16	11.16	0	34.22	34.23	-0.03

Table 4.15 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m HM Railway Bridge

Member	U1-L1 Vertical			L0-L0' Cross Girder			Stringer 1th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	18.21	18.13	0.44	19.61	20.72	-5.66	43.65	43.08	1.31
Moment 2-2	137.97	138.03	-0.04	27.2	27.44	-0.88	25.88	25.92	-0.15
Shear 3-3	31.76	31.77	-0.03	5.97	5.74	3.853	1.11	1.07	3.6
Moment 3-3	2.88	2.89	-0.35	99.12	99.24	-0.12	0.38	0.42	-10.5
Shear 2-2	0.577	0.577	0	36.04	35.95	0.25	0.24	0.24	0

Table 4.16 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m HM Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	371.3	363.46	2.11	442.9	443.93	-0.23	398.32	398.86	-0.14
Moment 2-2	9.8	9.6	2.04	0.7	0.67	4.286	1.8	1.8	0
Shear 3-3	3.62	3.54	2.21	0.136	0.133	2.206	0.39	0.39	0
Moment 3-3	63.83	60.87	4.64	28.3	27.8	1.767	59.09	56.56	4.28
Shear 2-2	9.6	9.14	4.79	5.53	5.46	1.266	5.15	4.91	4.66

Table 4.16 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m HM Railway Bridge

Member	**U7-L7 Vertical**			**L4-L4' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	41.78	41.9	-0.29	23.32	23.23	0.386	138.97	138.2	0.55
Moment 2-2	3.02	3.02	0	9.73	9.28	4.625	0.42	0.56	-33.3
Shear 3-3	2.32	2.33	-0.43	9.76	9.31	4.611	0.38	0.45	-18.4
Moment 3-3	1.67	1.67	0	3.74	3.74	0	21.51	23.39	-8.74
Shear 2-2	1.22	1.21	0.82	23.48	23.54	-0.26	2.44	1.42	41.8

Table 4.17 (a) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m 25 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	66.32	66.04	0.42	-122.57	-122.37	0.163	-133.58	-133.22	0.27
Moment 2-2	-1.73	-1.72	0.58	-0.24	-0.24	0	-0.6	-0.59	1.67
Shear 3-3	-0.975	-0.97	0.51	-0.11	-0.11	0	-0.58	-0.57	1.72
Moment 3-3	1.39	1.4	-0.72	0.058	0.05	13.79	-9.183	-9.183	0
Shear 2-2	-2.36	-2.36	0	-1.58	-1.58	0	-5.55	-5.55	0

Table 4.17 (b) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m 25 T Railway Bridge

Member	**U4-L4 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	-6	-6	0	-2.34	-2.39	-2.14	26.7	26.82	-0.45
Moment 2-2	-1.51	-1.51	0	14.27	14.27	0	0.11	0.1	9.09
Shear 3-3	0.02	0.02	0	13.61	13.7	-0.66	0.138	0.126	8.7
Moment 3-3	-0.26	-0.26	0	-9.96	-11.64	-16.9	6.33	6.56	-3.63
Shear 2-2	-0.07	-0.07	0	-9.95	-11.43	-14.9	-4.1	-3.54	13.7

Table 4.18 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m 25 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	187.06	171.71	8.21	68.95	70.49	-2.23	65.54	66.73	-1.82
Moment 2-2	4.31	3.76	12.8	0.66	0.64	3.03	0.43	0.36	16.3
Shear 3-3	2.46	2.14	13	0.28	0.28	0	0.16	0.137	14.4
Moment 3-3	54.69	49.9	8.76	1.55	1.6	-3.23	48.78	44.1	9.59
Shear 2-2	12.89	11.76	8.77	0.84	0.85	-1.19	5.75	5.11	11.1

Table 4.18 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m 25 T Railway Bridge

Member	**U4-L4 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.89	4.03	-3.6	6.26	5.77	7.827	37.81	35.11	7.14
Moment 2-2	0.17	0.17	0	37.93	33.66	11.26	1.04	0.63	39.4
Shear 3-3	0.14	0.146	-4.29	36.12	32.28	10.63	0.68	0.4	41.2
Moment 3-3	2.46	2.43	1.22	2.59	3.46	-33.6	5.88	5.88	0
Shear 2-2	2.27	2.24	1.32	2.34	3.1	-32.5	1.48	1.51	-2.03

Table 4.19 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m 25 T Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	26.39	26.05	1.29	92.38	91.9	0.52	125.87	126	-0.1
Moment 2-2	41.69	41.77	-0.19	11.63	11.77	-1.2	124.84	125.07	-0.18
Shear 3-3	11.44	11.46	-0.17	2.77	2.81	-1.44	24.28	24.32	-0.16
Moment 3-3	19.56	19.77	-1.07	3.69	3.71	-0.54	18.3	18.5	-1.09
Shear 2-2	4.74	4.79	-1.05	0.81	0.81	0	2.64	2.7	-2.27

Table 4.19 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m 25 T Railway Bridge

Member	U1-L1 Vertical			L0-L0' Cross Girder			Stringer 4th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	11.51	11.5	0.09	7.74	8.24	-6.46	55.89	56.53	-1.15
Moment 2-2	19.22	19.2	0.1	11.46	11.54	-0.7	0.98	0.92	6.12
Shear 3-3	7.94	7.93	0.13	8.12	8.16	-0.49	1.53	1.45	5.23
Moment 3-3	0.67	0.68	-1.49	7.05	6.94	1.56	3.98	3.66	8.04
Shear 2-2	0.19	0.2	-5.26	2.65	2.56	3.396	0.55	0.97	-76.4

Table 4.20 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m 25 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	51.37	54.38	-5.86	58.16	56.54	2.785	58.47	56.9	2.69
Moment 2-2	1.17	1.17	0	0.21	0.24	-14.3	0.37	0.35	5.41
Shear 3-3	0.67	0.67	0	0.09	0.1	-11.1	0.13	0.12	7.69
Moment 3-3	18.85	19.52	-3.55	1.73	1.74	-0.58	16.63	17.07	-2.65
Shear 2-2	4.44	4.59	-3.38	0.84	0.84	0	2	2	0

Table 4.20 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m 25 T Railway Bridge

Member	**U4-L4 Vertical**			**L2-L2' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.5	3.42	2.29	3.51	3.7	-5.41	12.17	12.44	-2.22
Moment 2-2	0.15	0.15	0	3.03	2.87	5.281	0.38	0.26	31.6
Shear 3-3	0.26	0.26	0	3.17	3.01	5.047	0.27	0.2	25.9
Moment 3-3	1.1	1.2	-9.09	2.1	2.06	1.905	4.03	4.03	0
Shear 2-2	0.93	1.03	-10.8	7.1	6.95	2.113	1.81	1.7	6.08

Table 4.21 (a) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m 25 T Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	366.82	366.2	0.17	-788.97	-788.6	0.047	-784.59	-783.86	0.09
Moment 2-2	-12.01	-12	0.08	1.13	1.13	0	3.69	3.72	-0.81
Shear 3-3	-4.48	-4.48	0	0.27	0.27	0	0.83	0.83	0
Moment 3-3	-5.06	-5.01	0.99	-36.99	-36.99	0	8.5	8.45	0.59
Shear 2-2	-10.35	-10.33	0.19	-16.95	-16.95	0	-8.67	-8.67	0

Table 4.21 (b) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m 25 T Railway Bridge

Member	U7-L7 Vertical			L0-L0' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	74.11	74.11	0	-14.3	-14.4	-0.7	201.79	202	-0.1
Moment 2-2	-6.1	-6.1	0	-68.84	-68.87	-0.04	0.9	0.89	1.11
Shear 3-3	-4.43	-4.43	0	-65.59	-65.82	-0.35	0.71	0.7	1.41
Moment 3-3	-0.67	-0.67	0	-18.63	-22.21	-19.2	28.47	28.86	-1.37
Shear 2-2	-0.12	-0.12	0	-18.03	-21.17	-17.4	-7.4	-6.66	10

Table 4.22 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m 25 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	872.3	845.3	3.1	223.33	214.12	4.124	199.2	191.51	3.86
Moment 2-2	14.62	13.71	6.22	0.91	0.94	-3.3	1.02	0.96	5.88
Shear 3-3	5.4	5.05	6.48	0.23	0.24	-4.35	0.22	0.21	4.55
Moment 3-3	294.47	284.78	3.29	74.2	72.65	2.089	239.3	230.8	3.55
Shear 2-2	44.39	42.92	3.31	11.91	11.7	1.763	20.3	19.47	4.09

Table 4.22 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m 25 T Railway Bridge

Member	**U7-L7 Vertical**			**L0-L0' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	47.47	47.28	0.4	32.91	31.99	2.79	91.49	87.37	4.5
Moment 2-2	2.1	2.02	3.81	103.06	97.82	5.08	1.34	1.2	10.4
Shear 3-3	1.3	1.23	5.38	98.29	93.58	4.79	0.63	0.62	1.59
Moment 3-3	8.31	8.37	-0.72	7.38	8.8	-19.2	10.38	10	3.66
Shear 2-2	5.85	5.89	-0.68	6.89	8.15	-18.3	3.34	3.23	3.29

Table 4.23 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m 25 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	663.4	663.7	-0.05	341.42	341.2	0.064	906.25	906.63	-0.04
Moment 2-2	437.85	437.96	-0.03	113.85	113.9	-0.04	1150.4	1150.9	-0.04
Shear 3-3	72.75	72.78	-0.04	16.78	16.79	-0.06	174.3	174.4	-0.06
Moment 3-3	427.7	427.88	-0.04	76.87	76.89	-0.03	346.82	346.95	-0.04
Shear 2-2	68.39	68.42	-0.04	10.82	10.82	0	33.97	33.98	-0.03

Table 4.23 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m 25 T Railway Bridge

Member	**U1-L1 Vertical**			**L0-L0' Cross Girder**			**Stringer 1th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	18.2	18.1	0.55	17.11	18.24	-6.6	43.4	42.9	1.15
Moment 2-2	137.81	137.88	-0.05	30.87	31.04	-0.55	22.29	22.51	-0.99
Shear 3-3	31.71	31.73	-0.06	5.64	5.75	-1.95	1.04	1.12	-7.69
Moment 3-3	2.94	2.94	0	99.3	99.44	-0.14	0.38	0.41	-7.89
Shear 2-2	0.58	0.586	-1.03	36.15	36.05	0.27	0.32	0.315	1.56

Table 4.24 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m 25 T Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	362.3	354.75	2.08	445.92	446.94	-0.23	402.12	402.66	-0.13
Moment 2-2	9.93	9.73	2.01	0.66	0.64	3.03	1.81	1.82	-0.55
Shear 3-3	3.66	3.59	1.91	0.13	0.13	0	0.39	0.39	0
Moment 3-3	61.46	58.57	4.7	28.87	28.38	1.69	57.37	54.92	4.27
Shear 2-2	9.32	8.89	4.61	5.77	5,7	1.21	5.06	4.83	4.55

Table 4.24 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m 25 T Railway Bridge

Member	U7-L7 Vertical			L4-L4' Cross Girder			Stringer 6th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	43.96	44.12	-0.36	23.78	23.69	0.37	139.87	138.18	1.21
Moment 2-2	3.1	3.1	0	9.18	8.73	4.90	0.39	0.5	-28.2
Shear 3-3	2.32	2.33	-0.43	9.2	8.76	4.78	0.36	0.41	-13.9
Moment 3-3	2.11	2.15	-1.9	3.58	3.58	0	22.21	22.32	-0.5
Shear 2-2	1.49	1.51	-1.34	23.77	23.86	-0.38	2.87	2.83	1.39

Table 4.25 (a) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m 32.5 T Railway Bridge

Member	L0-L1 Bottom Chord			U4-U5 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	71.94	71.68	0.36	-149.97	-149.76	0.14	-178.85	-178.44	0.23
Moment 2-2	-2.1	-2.1	0	-0.482	-0.48	0.415	-0.6	-0.61	-1.67
Shear 3-3	-1.26	-1.25	0.79	-0.211	-0.21	0.474	0.17	0.173	-1.76
Moment 3-3	1.953	1.96	-0.36	-0.046	-0.04	13.04	-1.18	-1.18	0
Shear 2-2	-2.32	-2.32	0	-1.86	-1.86	0	4.08	4.08	0

Table 4.25 (b) comparisons of forces between conventional rail and LWR, for static case, in 30.5 m 32.5 T Railway Bridge

Member	U4-L4 Vertical			L0-L0' Cross Girder			Stringer 4th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	-6.85	-6.85	0	-4.09	-4.13	-0.98	45.98	46.04	-0.13
Moment 2-2	-1.96	-1.96	0	28.04	27.96	0.285	0.18	0.17	5.56
Shear 3-3	-0.356	-0.356	0	25.65	25.66	-0.04	0.22	0.21	4.55
Moment 3-3	-0.55	-0.55	0	-13.85	-15.57	-12.4	5.07	5.31	-4.73
Shear 2-2	-0.146	-0.146	0	-14.67	-16.23	-10.6	-4.44	-3.87	12.8

Table 4.26 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m 32.5 T Railway Bridge

Member	L0-L1 Bottom Chord			U4-U5 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	207.32	193.4	6.71	89.79	91.05	-1.4	86.83	87.47	-0.74
Moment 2-2	4.534	4.14	8.69	0.62	0.61	1.613	0.42	0.38	9.52
Shear 3-3	2.74	2.48	9.49	0.29	0.29	0	0.136	0.124	8.82
Moment 3-3	69.17	64.22	7.16	1.796	1.846	-2.78	54.48	50.16	7.93
Shear 2-2	16.55	15.37	7.13	0.9	0.91	-1.11	6.61	5.95	9.98

Table 4.26 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 30.5 m 32.5 T Railway Bridge

Member	U4-L4 Vertical			L0-L0' Cross Girder			Stringer 4th from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	4.56	4.71	-3.29	10.54	9.81	6.93	62.63	58.99	5.81
Moment 2-2	0.25	0.25	0	70.22	64.19	8.59	0.283	0.09	68.2
Shear 3-3	0.138	0.129	6.52	64.15	58.91	8.17	0.14	0.1	28.6
Moment 3-3	2.81	2.71	3.56	2.57	3.59	-39.7	5.73	5.62	1.92
Shear 2-2	2.74	2.64	3.65	2.35	3.27	-39.1	1.76	1.76	0

Table 4.27 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m 32.5 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	23.57	22.51	4.49	119.55	119.16	0.326	159	159.22	-0.138
Moment 2-2	45.97	46.05	-0.17	13.82	14	-1.3	143.2	143.35	-0.1
Shear 3-3	13.62	13.54	0.58	3.36	3.4	-1.19	27.64	27.66	-0.07
Moment 3-3	29.96	30.23	-0.9	4.5	4.43	1.55	24.59	24.8	-0.85
Shear 2-2	7.42	7.5	-1.08	0.97	0.94	3.1	3.61	3.65	-1.11

Table 4.27 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 30.5 m 32.5 T Railway Bridge

Member	**U1-L1 Vertical**			**L0-L0' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	17.18	17.23	-0.29	8.3	9.34	-12.5	73.76	74.53	-1.04
Moment 2-2	25.86	25.78	0.31	29.05	29.24	-0.65	0.851	0.81	4.82
Shear 3-3	11.84	11.8	0.34	18.41	18.5	-0.49	1.45	1.39	4.14
Moment 3-3	2.156	2.18	-1.11	17.34	17.2	0.807	4.16	3.62	13
Shear 2-2	0.612	0.62	-1.31	6.47	6.31	2.473	0.642	0.933	-45.3

Table 4.28 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m 32.5 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U4-U5 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	62.79	65.42	-4.18	71.04	69.48	2.196	70.97	69.28	2.38
Moment 2-2	1.34	1.37	-2.24	0.193	0.2	-3.62	0.24	0.11	54.16
Shear 3-3	0.81	0.81	0	0.1	0.095	5	0.08	0.038	52.5
Moment 3-3	25.98	26.57	-2.27	1.96	1.95	0.51	20.32	20.63	-1.53
Shear 2-2	6.23	6.37	-2.25	0.915	0.91	0.54	2.52	2.52	0

Table 4.28 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 30.5 m 32.5 T Railway Bridge

Member	**U4-L4 Vertical**			**L2-L2' Cross Girder**			**Stringer 4th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	3.8	3.76	1.05	4.82	5.01	-3.94	21.34	21.71	-1.73
Moment 2-2	0.2	0.195	2.5	4.28	4.22	1.402	0.16	0.096	40
Shear 3-3	0.04	0.243	-508	4.61	4.58	0.651	0.136	0.093	31.6
Moment 3-3	1.464	1.53	-4.51	2.18	2.18	0	2.83	2.94	-3.89
Shear 2-2	1.22	1.29	-5.74	8.28	8.19	1.087	1.96	1.86	5.1

Table 4.29 (a) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m 32.5 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	475.55	474.96	0.12	-1168.65	-1168.2	0.039	-1150	-1150	0
Moment 2-2	-22.69	-22.66	0.13	2.95	2.95	0	6.67	6.7	-0.45
Shear 3-3	-8.51	-8.5	0.12	0.6	0.6	0	1.55	1.55	0
Moment 3-3	-5.32	-5.29	0.56	-31.37	-31.37	0	9.73	9.69	0.41
Shear 2-2	-11.01	-11	0.09	-19.04	-19.04	0	-12.8	-12.81	-0.08

Table 4.29 (b) comparisons of forces between conventional rail and LWR, for static case, in 76.2 m 32.5 T Railway Bridge

Member	**U7-L7 Vertical**			**L0-L0' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	96.5	96.5	0	-28.16	-28.29	-0.46	435.04	435.17	-0.03
Moment 2-2	-11.32	-11.32	0	-170.4	-170.32	0.047	1.86	1.84	1.08
Shear 3-3	-9.76	-9.76	0	-156.17	-156.4	-0.15	1.37	1.36	0.73
Moment 3-3	-1.36	-1.36	0	-28.72	-32.1	-11.8	25.23	25.66	-1.7
Shear 2-2	-0.26	-0.26	0	-28.99	-32.1	-10.7	-12.88	-12.11	5.98

Table 4.30 (a) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m 32.5 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U8-U9 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	1153.42	1133.1	1.76	476.3	463.72	2.641	371.11	362.23	2.39
Moment 2-2	25.28	24.42	3.4	2.07	2.1	-1.45	2.78	2.66	4.32
Shear 3-3	9.4	9.08	3.4	0.547	0.55	-0.55	0.58	0.55	5.17
Moment 3-3	370.87	364.2	1.8	24.35	24.21	0.575	422.19	414	1.94
Shear 2-2	57.04	56	1.82	7.54	7.51	0.398	37.14	36.34	2.15

Table 4.30 (b) comparisons of forces between conventional rail and LWR, for EQx case, in 76.2 m 32.5 T Railway Bridge

Member	**U7-L7 Vertical**			**L0-L0' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	56.82	55.96	1.51	63.33	62.26	1.69	191.28	185.84	2.84
Moment 2-2	4.64	4.51	2.8	263.5	256.8	2.543	4.4	5.02	-14.1
Shear 3-3	3.88	3.75	3.35	241.8	236.03	2.386	2.54	2.54	0
Moment 3-3	15.06	15.1	-0.27	8.92	10.53	-18	10.23	9.97	2.54
Shear 2-2	10.6	10.65	-0.47	9.04	10.52	-16.4	5.8	5.62	3.1

Table 4.31 (a) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m 32.5 T Railway Bridge

Member	L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	944.1	944.45	-0.04	476.03	475.8	0.048	1423.84	1424.2	-0.03
Moment 2-2	600.52	600.6	-0.01	200.02	200.1	-0.04	1726.68	1727.1	-0.02
Shear 3-3	106.17	106.2	-0.03	28.99	28.99	0	265.63	265.71	-0.03
Moment 3-3	529.7	529.8	-0.02	135.3	135.3	0	601.07	601.2	-0.02
Shear 2-2	86.48	86.5	-0.02	20.8	20.8	0	59.82	59.83	-0.02

Table 4.31 (b) comparisons of forces between conventional rail and LWR, for EQy case, in 76.2 m 32.5 T Railway Bridge

Member	U1-L1 Vertical			L0-L0' Cross Girder			Stringer 1[th] from left support		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	33.32	33.4	-0.24	33.76	35.25	-4.41	122.02	121.53	0.4
Moment 2-2	270.44	270.52	-0.03	140.61	140.8	-0.14	54.25	54.4	-0.28
Shear 3-3	61.5	61.52	-0.03	49.5	49.85	-0.71	5.61	5.7	-1.6
Moment 3-3	8.68	8.68	0	231.74	231.98	-0.1	2.59	2.38	8.11
Shear 2-2	1.73	1.73	0	83.81	83.79	0.024	1.14	1.2	-5.26

Table 4.32 (a) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m 32.5 T Railway Bridge

Member	**L0-L1 Bottom Chord**			**U1-U2 Top Chord**			**L0-U1 Diagonal**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	524.62	516.47	1.55	650.45	652.23	-0.27	578.52	579.72	-0.21
Moment 2-2	19.11	18.86	1.31	1.52	1.51	0.658	3.61	3.61	0
Shear 3-3	7.1	7.01	1.27	0.26	0.26	0	0.79	0.79	0
Moment 3-3	96.57	93.68	2.99	41.68	41.02	1.583	118.82	115.4	2.88
Shear 2-2	14.52	14.1	2.89	7.86	7.76	1.272	10.22	9.9	3.13

Table 4.32 (b) comparisons of forces between conventional rail and LWR, for EQz case, in 76.2 m 32.5 T Railway Bridge

Member	**U7-L7 Vertical**			**L4-L4' Cross Girder**			**Stringer 6th from left support**		
Component	conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	55	55.21	-0.38	32.25	32.18	0.217	300.3	299.5	0.27
Moment 2-2	5.95	5.97	-0.34	16.23	15.96	1.664	2.03	2.17	-6.9
Shear 3-3	5.34	5.36	-0.37	15.67	15.42	1.595	1.27	1.32	-3.94
Moment 3-3	3.4	3.4	0	3.74	3.78	-1.07	19.53	19.64	-0.56
Shear 2-2	2.52	2.5	0.79	29.83	29.95	-0.4	5.55	5.52	0.54

Time history analysis

Table 4.33 (a) comparisons of forces between conventional rail and LWR, for time history analysis in x direction, in 76.2 m 32.5 T Railway Bridge

Member		L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	1062.27	1066.35	-0.38	374.27	353.81	5.47	330.93	314.35	5.01
	Min.	-1135.96	-1106.1	2.63	-368.02	-352.6	4.19	-329.52	-314.92	4.43
Moment 2-2	Max.	26.67	25.91	2.85	2.27	2.28	-0.44	2.58	2.49	3.49
	Min.	-23.96	-23.83	0.54	-2.1	-2.09	0.48	-3.1	-2.81	9.35
Shear 3-3	Max.	9.96	9.66	3.01	0.546	0.531	2.75	0.53	0.51	3.77
	Min.	-8.9	-8.86	0.45	-0.48	-0.47	2.08	-0.6	-0.55	8.33
Moment 3-3	Max.	327.8	327.45	0.11	112.56	108.54	3.57	374.9	374.33	0.15
	Min.	-377.5	-362.06	4.09	-103.64	-104.14	-0.48	-429.31	-411.55	4.14
Shear 2-2	Max.	50.3	50.25	0.1	18.06	17.42	3.54	32.81	32.7	0.34
	Min.	-58.14	-55.76	4.09	-17	-17.12	-0.71	-37.98	-36.36	4.27

Table 4.33 (b) comparisons of forces between conventional rail and LWR, for time history analysis in x direction, in 76.2 m 32.5 T Railway Bridge

Member		U7-L7 Vertical			L0-L0' Cross Girder			Stringer 6th from left support		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	46.31	44.34	4.25	62.26	61.06	1.93	166.79	165.82	0.58
	Min.	-58.76	-56.33	4.14	-58.42	-58.75	-0.56	-214.54	-208.99	2.59
Moment 2-2	Max.	4.75	4.51	5.05	268.29	262.6	2.12	4	4.58	-14.5
	Min.	-4.16	-4.04	2.88	-246.62	-246.8	-0.07	-4.07	-4.57	-12.3
Shear 3-3	Max.	3.84	3.63	5.47	246.15	241.3	1.97	2.087	2.37	-13.6
	Min.	-3.51	-3.43	2.28	-226.26	-226.8	-0.24	-2.06	-2.36	-14.6
Moment 3-3	Max.	13.19	12.87	2.43	8.24	10.12	-22.8	9.1	8.96	1.54
	Min.	-15.18	-14.86	2.11	-8.3	-9.91	-19.4	-10	-9.72	2.8
Shear 2-2	Max.	9.26	9.18	0.86	8.44	10.19	-20.7	6.06	5.72	5.61
	Min.	-10.67	-10.45	2.06	-8.46	-9.98	-18	-5.2	-4.92	5.38

Table 4.34 (a) comparisons of forces between conventional rail and LWR, for time history analysis in y direction, in 76.2 m 32.5 T Railway Bridge

Member		L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	1010.15	1009.7	0.04	441.59	441.17	0.1	1257.61	1258.42	-0.06
	Min.	-914.64	-914.18	0.05	-462.93	-462.41	0.11	-1423	-1421.8	0.08
Moment 2-2	Max.	590.36	589.88	0.08	200.2	200.1	0.05	1732.06	1730.4	0.1
	Min.	-627.44	-627.07	0.06	-184.23	-184.31	-0.04	-1659.6	-1659.6	0
Shear 3-3	max.	104.41	104.33	0.08	29.0	29.0	0	266.52	266.25	0.1
	Min.	-110.98	-110.93	0.05	-27.17	-27.17	0	-255.3	-255.3	0
Moment 3-3	Max.	534.82	534.65	0.03	133.2	133.2	0	611.1	610.8	0.05
	Min.	-525.6	-525.2	0.08	-139.26	-139.26	0	-595.6	-595.08	0.09
Shear 2-2	Max.	87.18	87.15	0.03	20.32	20.32	0	60.8	60.8	0
	Min.	-85.85	-85.79	0.07	-21.65	-21.65	0	-59.3	-59.24	0.1

Table 4.34 (b) comparisons of forces between conventional rail and LWR, for time history analysis in y direction, in 76.2 m 32.5 T Railway Bridge

Member		U1-L1 Vertical			L0-L0' Cross Girder			Stringer 1st from left support		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	35.34	35.03	0.88	34.02	37.92	-11.5	122.93	122.22	0.58
	Min.	-32.16	31.89	0.84	-36.1	-39.16	-8.48	-121.18	-120.5	0.56
Moment 2-2	Max.	257.7	257.73	-0.01	139.68	139.74	-0.04	53.29	53.33	-0.08
	Min.	-271.25	-271.08	0.06	-140.2	-140.34	-0.1	-58.16	-58.25	-0.15
Shear 3-3	max.	58.56	58.56	0	49.28	49.58	-0.61	6.2	6.3	-1.61
	Min.	-61.7	-61.66	0.06	-45.45	-45.78	-0.73	-6.55	-6.67	-1.83
Moment 3-3	Max.	8.64	8.63	0.12	209.72	209.83	-0.05	2.61	2.38	8.81
	Min.	-8.56	-8.56	0	-228.36	-228.36	0	-2.57	-2.37	7.78
Shear 2-2	Max.	1.72	1.72	0	75.87	75.92	-0.07	1.03	1.12	-8.32
	Min.	-1.7	-1.7	0	-82.58	-82.27	0.38	-1.13	-1.18	-4.42

Table 4.35 (a) comparisons of forces between conventional rail and LWR, for time history analysis in z direction, in 76.2 m 32.5 T Railway Bridge

Member		L0-L1 Bottom Chord			U1-U2 Top Chord			L0-U1 Diagonal		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	513.72	516.24	-0.49	575.8	572.34	0.6	520.6	519.51	0.21
	Min.	-452.1	-456.51	-0.98	-520.19	-520.27	-0.02	-465.5	-465.92	-0.09
Moment 2-2	Max.	15.66	15.4	1.66	1.28	1.25	2.34	2.6	2.95	-13.5
	Min.	-17.23	-17.25	-0.12	-1.44	-1.32	8.33	-2.97	-2.99	-0.67
Shear 3-3	max.	5.79	5.7	1.55	0.24	0.23	4.17	0.64	0.63	1.56
	Min.	-6.39	-6.39	0	-0.28	-0.25	10.7	-0.67	-0.65	2.99
Moment 3-3	Max.	104.17	102.89	1.23	36.64	37.79	-3.14	127.47	126.51	0.75
	Min.	-87.12	-89.4	-2.62	-42.04	-41.79	0.59	-107.54	-107.5	0.04
Shear 2-2	Max.	15.7	15.5	1.27	6.77	7.01	-3.55	11.03	10.97	0.54
	Min.	-13.14	-13.6	-3.5	-7.69	-7.68	0.13	-9.23	-9.45	-2.38

Table 4.35 (b) comparisons of forces between conventional rail and LWR, for time history analysis in z direction, in 76.2 m 32.5 T Railway Bridge

Member		U7-L7 Vertical			L4-L4' Cross Girder			Stringer 6th from left support		
Component		conventional rail	LWR	% variation	conventional rail	LWR	% variation	conventional rail	LWR	% variation
Axial	Max	44.27	44.59	-0.72	25.23	25.35	-0.48	243.02	243.1	-0.03
	Min.	-49.43	-49.41	0.04	-26.33	-26.43	-0.38	-236.93	-238.07	-0.48
Moment 2-2	Max.	5.19	5.14	0.96	15.15	14.62	3.5	2.01	2.2	-9.45
	Min.	-4.77	-4.78	-0.21	-13.68	-13.43	1.83	-1.77	-1.96	-10.7
Shear 3-3	max.	4.61	4.56	1.08	14.69	14.17	3.54	1.19	1.28	-7.56
	Min.	-4.31	-4.31	0	-13.34	-13.09	1.87	-1.05	-1.14	-8.57
Moment 3-3	Max.	2.87	2.81	2.09	3.14	3.17	-0.96	15.35	15.46	-0.72
	Min.	-2.56	-2.54	0.78	-2.77	-2.78	-0.36	-15.94	-16	-0.38
Shear 2-2	Max.	2.31	2.31	0	24.9	24.99	-0.36	4.83	4.71	2.48
	Min.	-2.03	-2.03	0	-23.03	-23.08	-0.22	-4.41	-4.23	4.08

CHAPTER 5

CONCLUSION

In this study, static, response spectrum and time history analysis have been conducted for M.B.G., H.M., 25 T, 32.5 T routes. to consider the feasibility of replacement of conventional track by LWR from seismic consideration. And on the basis of the obtained results the following conclusion emerge;

- In static analysis, member forces are more or less same in case of conventional track bridge and long welded rail track bridge.
- When earthquake loading is applied in longitudinal direction, forces are reduced due to provision of rail free fastening in LWR track. There is considerable reduction of forces in bottom members of all truss bridges. When earthquake loading is applied in transverse and vertical direction, the variation in forces and moments is increased in isolated member only due to additional stiffness of long welded rail. But increment of forces and moments is very marginal.
- In time history analysis conducted for 76.2 m span of 32.5 T Bridge, this also corroborates the results of the response spectrum analysis.

It can therefore be concluded that the conventional track may be replaced by LWR on existing steel railway bridges, from seismic consideration. However other aspects of design may need further investigation.

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