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Comparison of Design Forces for Metro Rail Structures

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Abstract—*This paper presents a comparative study of calculation of design forces using various codes for design of metro rail structures. Design forces were calculated for superstructure and substructure of metro rail bridges using Indian and other countries codes and a comparative study has been done between them. Structures were modeled using CSI-bridge software with the thin shell and beam elements and linear finite element analysis was performed to calculate the responses. From the study, it was found that design forces calculated using different code differ widely.*

Keywords*: Metro Rail Structures, Finite Element Analysis.*

1. INTRODUCTION

Metro bridges have two major elements: pier and prestressed box girder or beams. In almost all big cities of India metro construction work is going on but still at present nationwide guidelines are not available for the design of metro rail structure. Each metro organization in India has their own design specifications based on Indian Road Congress (IRC) or Indian Railway Standard (IRS) guidelines. The main objective of this study is to compare the design forces calculated for superstructure and substructures of metro rail bridges using IRC, IRS, Euro-code, California high-speed rail authority guidelines and other.

2. METHODOLOGY

For the study simply supported prestressed I (span 25m) and Box girder (span 40m) metro bridge were considered. Analysis of substructure and superstructure were carried out for all the static and dynamic (wind and seismic) loads as per various code and then a comparative study has been done between design forces.

2.1 Mathematical Modeling of Bridges

Cross section details of simply supported 25 m span prestressed I-girder and 40 m span Box-girder bridge are shown in Fig. 1 and Fig. 2 respectively. In I-girder bridge 5 equally spaced cross girder of thickness 0.5 m and depth 1.5 m were provided and in Box-girder three diaphragms (at support and mid-span) of thickness 1 m were provided. Mathematical modeling of both the structures were done in CSI-Bridge 2015 software. FEM model of I and Box girder bridge are shown in Fig. 3 and Fig. 4. Before modeling minimum sizes of each section elements were checked as per IRS-Concrete Bridge Code (CBC) [1]. For both the type of bridges M45 grade of concrete and Fe 415 grade steel were used. For post-tensioning, prestressing steel conforming to class 2 low relaxation uncoated stress relieved strands were used. Cable profiles were assumed to be parabolic.

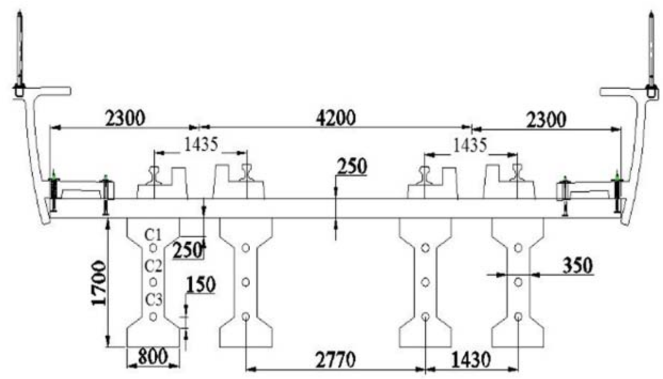

Fig. 1: Cross section of prestressed I-girder.

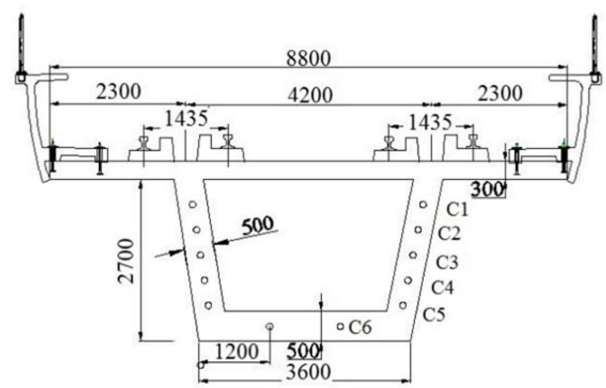

Fig. 2: Cross section of prestressed Box-girder.

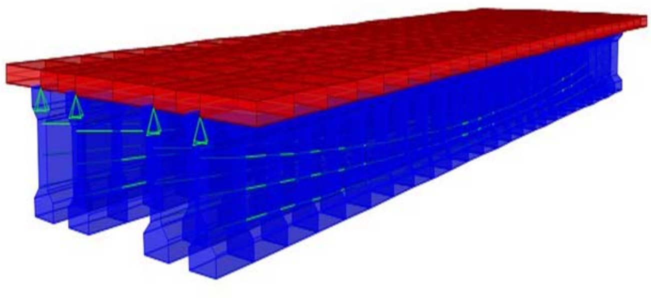

Fig. 3: Mathematical model of I-girder.

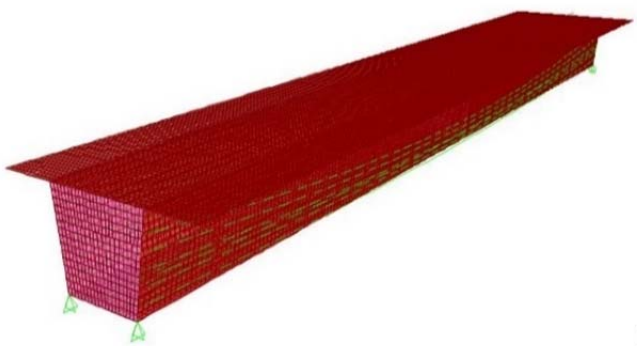

Fig. 4: Mathematical model of Box-girder.

2.2 Loading Specifications

Loading specification as per the various codes for all the static and dynamic (wind and seismic) loads are described below.

Both the Nagpur metro rail corporation Limited (NMRCL) design basis report (DBR) [2] and Hyderabad metro rail limited (HMRL) DBR [3] specify IRS Bridge Rules [4] for calculation of impact factor, longitudinal force, nosing force, force on parapet and footpath live load.

2.2.1 Super Imposed Dead Load (SIDL). SIDL is divided into two parts i.e. SIDL variable and SIDL fixed. Only parapet load comes under the fixed. SIDL load in kN/m is given in Table 1.

Table 1: SIDL for metro bridge in kN/m.

Item	Load kN/m	Item	Load kN/m
Rail + Pad	3	Miscellaneous	4
Cable + trays	0.8	Cable trays	0.1
Plinth	28	Hand rails	0.8
Light wt. drainage conc.	2.4	Cable duct cover	2
Cables through cell	7.4	Parapet (SIDL Fix)	32.6

2.2.2 Live Load. The live load considered as per NMRCL DBR, successive cars in a train is 6 with the length of each car is 21.8 m. Each car consists four axles and load of each axle is same i.e. 160 kN as shown in Fig. 5. To calculate maximum response moving load analysis were performed in CSI-bridge for both single and double track loadings. Impact factor for I and Box girder metro bridge was calculated as per IRS: Bridge rule, EN 1991-2 [5] and California high speed rail authority [6] which is given in Table 2.

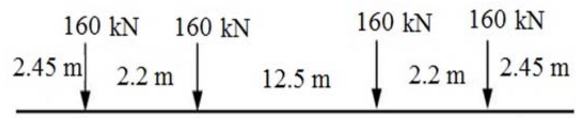

Fig. 5: Standard axle distances of Nagpur metro train.

Table 2: Impact factor for both the Bridges.

Code	Formula	CDA I-Girder	CDA Box-Girder
IRS Bridge Rules	$1+(0.15+\frac{8}{6+L})\geq 1.2$	1.4	1.32
EN1991-2	$\frac{2.16}{\sqrt{L}-0.2}+0.73\geq 1$	1.18	1.08
California high speed rail authority	$I=\frac{225}{\sqrt{L}}\%$ (12 to 38.7 m) I= 20% > 39m	1.24	1.2

2.2.3 Longitudinal Forces. Traction and braking forces were calculated for various codes which are given in Table 3, in which L' is live load on the deck

Table 3: Comparison of longitudinal force.

Code	Traction load	Braking load
IRS: Bridge Rules	0.2L'	0.18L'
EN1991-2	0.25L'	0.25L'
California high speed rail authority	0.25L	0.25L

2.2.4 Nosing force, force on parapet and footpath live load. Nosing force, force on parapet and footpath live load are compared in Table 4 for various codes.

Table 4: Comparison of other forces.

Code	Nosing Force (kN)	Force on parapet (kN/m)	Footpath live load (kN/m2)
IRS: Bridge Rules	100	1.5	4.9
EN1991-2	100	1.5	4
California high speed rail authority	98	1.5	4.8

2.2.5. Wind Load and Seismic Force. The wind and seismic forces were calculated as per the codal provisions of various codes which are given in Table 5. NMRCL suggests, for calculation of the wind and seismic forces IRS Bridge rules and RDSO guidelines for seismic design of railway bridges [7] shall be used. As per HMRL DBR both the dynamic forces to be calculated using IRC: 6 [8].

Table 5: Guidelines for calculation of the wind and seismic force.

Load	Seismic Force	Wind Force
IRS guidelines	IRS-Bridge rules clause 2.12	IRS-Bridge Rules , clause 2.11
IRC: 6	IRC: 6 clause 209	IRC: 6, clause 218
Euro-code	EN 1998-1 [9] EN 1998-2 [10]	EN 1991-1-4 [11]
California high speed rail authority	AASHTO LRFD [12] Clause 3.10	AASHTO LRFD With Caltrans Amendment Clause 3.8

3. ANALYSIS OF SUPER-STRUCTURE

Analysis of superstructure for both I and Box girder was carried out for DL, SIDL, prestressing load and live load. Variation of moment and shear force along the span for external and internal I-girder and Box girder are given in Table 7.

Table 7: Variation of moment (kNm) and shear force (kN) along span.

S.F. kN and B.M kNm	Exterior I-Girder		Interior I-Girder		Box girder	
	Support	**Mid span**	**Support**	**Mid span**	**Support**	**Mid span**
Dead Load						
B.M	0	3228	0	3155	0	35014
S.F.	474	0	424	0	3466	0
SIDL Fix						
B.M	0	773	0	497	0	6520
S.F.	231	0	35	0	636	0
SIDL Variable						
B.M	0	1187	0	1051	0	11570
S.F.	229	0	115	0	1128	0
Live Load						
B.M	0	1870	0	1724	0	14323
S.F.	392	130	279	108	1801	590

For the calculated moments required prestressing, the location of tendons were calculated. Details of prestressing cables for both I and Box girder bridges are shown in Table 8.

Table 8: Details of prestressing cable profile for I and Box girder.

Cable	Type	Position from Bottom at Support (mm)	Position from Bottom at Mid-span (mm)
Box-Girder			
C1	19K15	2280	1020
C2	19K15	1860	800
C3	19K15	1440	580
C4	19K15	1020	360
C5	19K15	600	140
C6	19K15	250	140
I-Girder			
C1	19K15	1300	500
C2	12K15	850	350
C3	19K15	400	150

All immediate and long-term prestressing losses were calculated as per IRS: CBC clause 16.8 and then max tensile and compressive stresses check at transfer and service stage were done. It was found that total prestressing losses for I-girder is 20.6% and for box girder is 21.4%. Stress check for both the bridges is given in Table 9.

Table 9: Compression and tensile stresses check at transfer and service stage.

Stresses at top and bottom	Exterior I girder	Box girder
Max/Min stresses at transfer stage (MPa)		
(P/A) - (P×e/Yt) + (M(DL+SIDL) / Zt)	9.47	6.87
< 0.5fci or 0.4fck (18 MPa)	Safe	Safe
(P/A) + (P×e/Yb) - (M(DL+SIDL)/Zb)	4.13	3.06
> 0 (no tension)	Safe	Safe
Max/Min stresses at service stage (MPa)		
(P/A) - (Pe/Yt) + (M(DL+SIDL+LL)/Zt)	11.62	9.07
< 0.4fck (18 MPa)	Safe	Safe
(P/A) + (P.e/Yb) - (M(DL+SIDL+LL)/Zb)	0.42	0.11
> 0 (no tension)	Safe	Safe

4. COMPARISON OF DESIGN FORCES FOR SUPER-STRUCTURE

For this study, following load combination are used to get design moment and shear force.

i. IRS: CBC and NMRCL DBR Load comb. 1
$1.4DL + 2SIDL_{(fix + variable)} + 2Live\ load$

ii. HMRCL DBR Load comb.1
$1.25DL + 2SIDL_{(variable)} + 1.25SIDL_{(fix)} + 1.75LL$

iii. EN 1990 [13] Load Comb. 1
$1.35DL + 1.5SIDL_{(variable)} + 1.35SIDL_{(fix)} + 1.45LL$

iv. California high speed rail authority Load comb.1 (Strength 1 Basic load combination)

$$1.25DL + 1.5SIDL_{(variable)} + 1.25SIDL_{(fix)} + 1.75LL$$

Comparison of maximum design moment calculated using Indian and other countries codes for external and internal girder of I-girder bridge are shown in Fig. 6 and Fig. 7 and for Box-girder shown in Fig. 8.

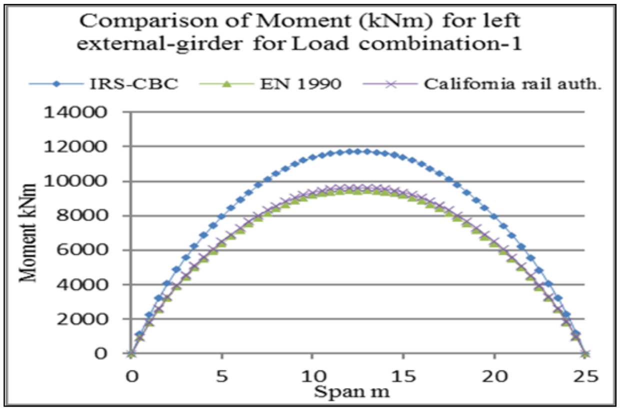

Fig. 6: Comparison of Moment (kNm) for left external girder for load combination -1

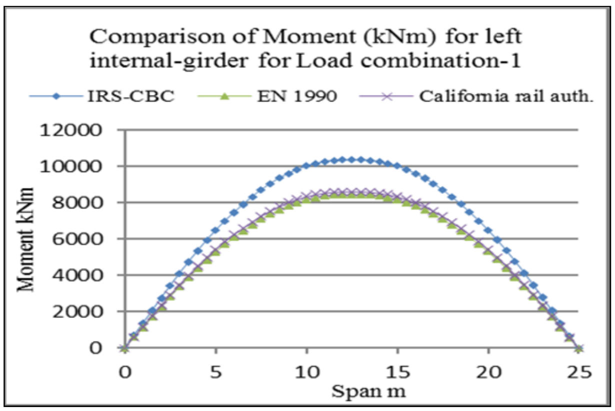

Fig. 7: Comparison of Moment (kNm) for left internal girder for load combination -1

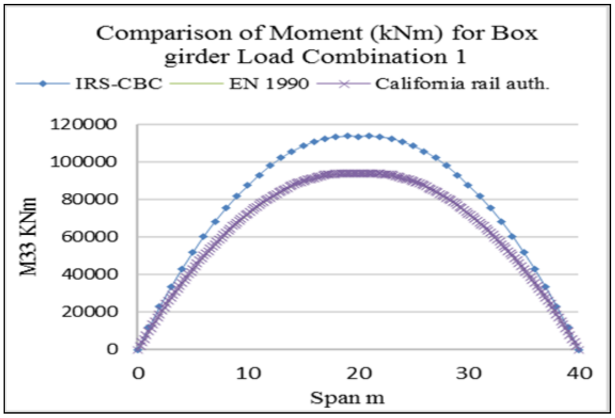

Fig. 8: Comparison of Moment (kNm) for Box- girder for load combination -1

Comparison of maximum shear force calculated using Indian and other countries codes for I-girder and Box-girder bridge are shown in Table 10.

Table 10: Comparison of shear force for load comb.-1

EN 1990		**IRS CBC**		**California high rail authority**	
Span (m)					
Support	Mid-span	Support	Mid-span	Support	Mid span
Shear force at Exterior I-Girder (kN)					
1863	188	2369	263	1910	227
Shear force at Internal I-Girder (kN)					
1197	157	1311	214	1234	189
Shear force Box Girder (kN)					
9841	856	11982	1319	9971	1032

From Fig. 7-9 and Table 10, it can be seen that design moment and shear force calculated as per IRS: CBC are more compared to other codes. Responses calculated as per EN 1990 are approximately equal to calculated by California guidelines. Comparing maximum moment and shear force it is observed that inner girder of I-girder bridge gives lower result than the outer girder.

5. ANALYSIS OF SUB-STRUCTURE

Analysis of substructure was done for the simply supported box girder bridge. Horizontal and vertical reactions were calculated on the pier due all static and dynamic loads (wind and seismic). General elevation diagram of Box girder bridge is shown in Fig. 9. The height of solid parapet is 1.5 m and height of train considered is 3.9 m. Sectional and material properties of the column are given in Table 11.

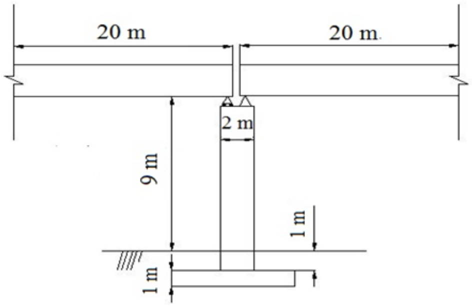

Fig. 9: Elevation Box-girder bridge

Table 11: Material and sectional properties of the pier.

Properties	Value	Properties	Value
Fck (MPa)	M40	Height (m)	10
Dia. (m)	2	I (mm4)	0.785
K (kN/m)	74510	Location	Nagpur

6. COMPARISON OF DESIGN FORCES FOR SUB-STRUCTURE

Vertical and horizontal reactions on top of the pier due all the static and dynamic (wind and seismic) loads were calculated. Horizontal and vertical reaction due to DL, SIDL, live load are given in Table 12, where H_L and H_T are the horizontal force in the longitudinal and transverse directions, Z_L and Z_T are lever arm from bottom of the footing in the longitudinal and traverse directions.

Table 12: Reactions on the pier due to Static load.

Load Cases	Forces		
	V (kN)	HL kN	ZL (m)
DL	6930	-	-
SIDL Fix	1304	-	-
SIDLVar	2296	-	-
Live Load	2688	-	-
Braking and traction	44.7	426	11

6.1 Comparison of Reactions Due to Seismic Force

Base shear due to seismic force were calculated for the pier as per IRC: 6, IRS- Bridge rules and RDSO guidelines for seismic design of railway bridges for all the three type of soils. Comparative study for base shear is shown in Table 13.

Table 13: Comparison of base shear.

Load Cases	Base shear and lever arm			
	HL (kN)	ZL (m)	HT kN	ZT (m)
Seismic force as per IRS-Bridge Rules For I = 1.5				
Hard soil	355	12.72	334	11
Medium soil	426	12.72	402	11
Soft Soil	532	12.72	502	11
As per RDSO guidelines (I =1.5 and R = 4)				
Hard soil	285	12.72	269	11
Medium soil	388	12.72	366	11
Soft Soil	476	12.72	450	11
As per IRC: 6 (I = 1.5 and R = 4)				
Hard soil	277	12.72	269	11
Medium soil	377	12.72	366	11
Soft Soil	463	12.72	450	11

From Table 13 it is seen that for the particular case base shear calculated using IRS: Bridge Rule code is higher as compared to other Indian guidelines. Base shear calculated as per RDSO guidelines is same in the longitudinal direction and more in the transverse direction as compared to IRC: 6. It may be because as per IRC: 6, 20% live load is considered in transverse direction and as per RDSO guidelines 50% live load is considered.

6.2 Comparison of Reactions Due to Wind Force

Reactions due to wind force were calculated on the pier as per Indian and other countries codes and a comparative study has been done between them which is shown in Table 14.

Table 14: Comparison of wind forces on top of the pier

Load Cases	Reaction due to wind forces			
	HL kN	ZL m	HT kN	ZT m
Wind force as per IRS Bridge Rules				
Unloaded deck	66	11	265	13.25
Loaded deck	71	11	285	14.45
Pier	-	-	15	6.5
Wind force as per IRC: 6				
unloaded deck	123	11	492	13.25
Loaded deck	175	11	702	14.05
pier	-	-	18	6.5
Wind forces as per EN: 1991-1.4				
Unloaded deck	105	11	421	13.25
Loaded deck	160	11	640	14.45
Pier	-	-	9.2	6.5
Wind forces as per California high speed rail auth.				
Unloaded deck	114	11	457	13.25
Loaded deck	169	11	685	14.45
Pier	-	-	14	6.5

From Table 14 it is observed that Wind forces calculated for superstructure using IRS Bridge Rule are less compared to other codes. It may be because pressure coefficient method is used in IRS Bridge rules code where as in other codes guest factor method is used. Wind forces calculated as per IRC: 6, EN: 1991-1.4 and California high speed rail authority are comparable with each other.

7. CONCLUSION

The following are broad conclusions.

1. IRS: CBC suggests higher partial safety factors for dead load, SIDL and live load in load combinations. Therefore, moment, shear force calculated as per IRS: CBC at superstructure are larger as compared to Euro-code and California high speed rail authority guidelines.
2. Seismic forces calculated on the pier as per RDSO guidelines for seismic design of railway bridges, are same in the longitudinal direction and more in the transverse direction as compared to IRC: 6.
3. Wind forces calculated at superstructure using IRS-Bridge rules is less as compared to other guidelines.

This paper shows that various codes for metro bridges give different design forces. Hence there is a need of nationwide guidelines for the design of metro rail structures.

REFERENCES

[1] IRS: Concrete Bridge Code (1997), “Code of practice for plain reinforced and prestressed concrete for general bridge construction”, Research Designs and Standards Organisation, Lucknow, India.

[2] NMRCL DBR (2015), Design basis report for viaduct, (revised draft), Nagpur Metro Rail Corporation Limited, Nagpur, India.

[3] HMRL DBR (2012), Design basis report for viaduct, (section 2), Hyderabad Metro Rail Limited, Hyderabad, India.
[4] IRS: Bridge Rules (2008), "Rules specifying the loads for design of super-structure and sub-structure of bridge and for assessment of the strength of existing bridge (second revision)", Research Designs and Standards Organisation, Lucknow, India.
[5] EN 1991-2 (2003), "Eurocode 1: Action on structures- Part 2: traffic loads on bridges", European Committee for Standardization, Brussels.
[6] HSR 13-06 (2012), "California high-speed train project design criteria", California High-Speed Rail Authority, California.
[7] RDSO (2015), "RDSO guidelines on seismic design of railway bridges", Research Designs and Standards Organisation, Lucknow, India.
[8] IRC: 6 (2010), "Standard Specification and code of practice for Road Bridges, section II load and stresses", Indian Road Congress, New Delhi, India.
[9] EN 1998-1 (2004), "Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic action and rules for buildings", European Committee for Standardization, Brussels.
[10] EN 1998-2 (2005), "Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges", European Committee for Standardization, Brussels.
[11] EN 1991-1-4 (2005), "Eurocode 1: Action on structures- Part 1-4: General action – wind actions", European Committee for Standardization, Brussels.
[12] AASHTO (2012), "AASHTO LRFD Design Specifications (6th edition)", American Association of State and Highway Transportation Officials, Washington D.C.
[13] EN 1990 (2002), "Eurocode – Basis of structural design", European Committee for Standardization, Brussels.