Experimental Analysis of Single Cell Box Girder in a Metro Bridge under Various Radius of Curvature

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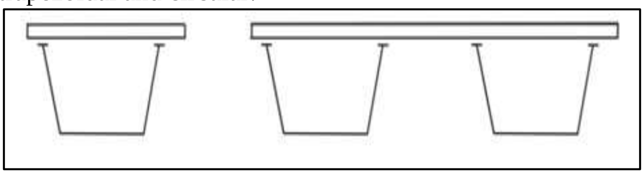
Abstract— Bhopal metropolis, the center of India, has experienced phenomenal growth in population in the last two decades. So, to meet the traffic demands, Metro Rail Transport started. Bhopal Metro Rail Corporation; is constructing some phase of Metro Rail to be of elevated one. There are different structural elements for a typical box girder bridge. The present study focus on the parametric study of single cell box girder bridges curved in plan. For the purpose of the parametric study, five box girder bridge models with constant span length and varying curvature. In order to validate the finite element modeling method, an example of box Girder Bridge is selected from literature to conduct a validation study. The example box girder is modelled and analysed in SAP 2000 and the responses are found to be fairly matching with the results reported in literature. The ratio of responses is expressed in terms of a parameter. From the responses it is found that; the parameters like torsion, bending moment, and deflection is increasing as curvature of the bridges increase.

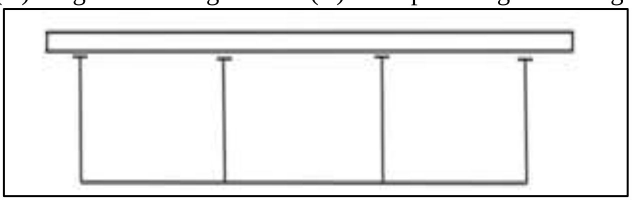
Keywords: Elevated Metro Structure, Box Girder Bridge, Direct Displacement Based Seismic Design, Performance Based Design, Force Based Design

I. INTRODUCTION

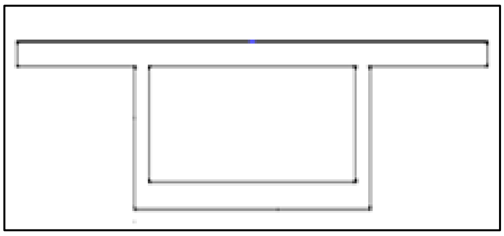
Box girders, have gained wide acceptance in freeway and bridge systems due to their structural efficiency, better stability, serviceability, economy of construction and pleasing aesthetics. Analysis and design of box-girder bridges are very complex because of its three dimensional behaviors consisting of torsion, distortion and bending in longitudinal and transverse directions. A typical box girder bridge constructed in Bhopal Metro Rail Project. Box girders can be classified in so many ways according to their method of construction, use, and shapes. Box girders can be constructed as single cell, double cell or multicell. It may be monolithically constructed with the deck, called closed box girder or the deck can be separately constructed afterwards called open box girder. Or box girders may be rectangular, trapezoidal and circular.



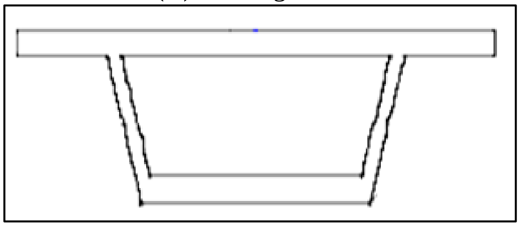
(A) Single-cell box grider (B) Multiple box grider bridge



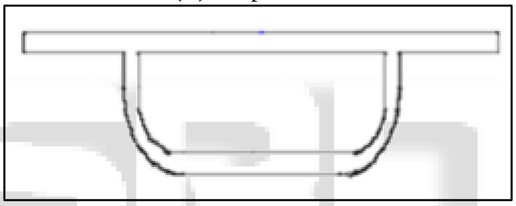
(C) Multi-cell grider bridge



(D) Rectangular c/s



(E) Trapezoidal



(F) Circular c/s

Fig. 1: Different types of box girder bridges

II. LITERATURE REVIEW

To provide a detailed review of literature related to Box Girder Metro Bridge in its entirety is too immense to address in this paper.

[Tung and Fountain (2010)] The finite element method of analysis is generally the most powerful, versatile and accurate analytical method of all the available methods and has rapidly become a very popular technique for the computer solution of complex problems in engineering. It is very effective in the analysis of complicated structures such as that of a box girder bridge with complex geometry, material properties and support conditions and subjected to a variety of loading conditions.

[Vlasov (2015)] Bridge Design Code has recommended the finite element method for all type of bridges. A large number of elements have been developed for use in the finite element technique that includes one-dimensional beam-type elements, two dimensional plate or shell elements or even three-dimensional solid elements.

[Zienkeiwicz (2007)] Since the structure is composed of several finite elements interconnected at nodal points, the individual element stiffness matrix, which approximates the behavior in the continuum, is assembled based on assumed displacement or stress patterns. Then, the nodal displacements and hence the internal stresses in the finite element are obtained by the overall equilibrium equations. By using adequate mesh refinement, results obtained from finite element model usually satisfy compatibility and equilibrium.

[Sisodiya,et.al (2014)] presented finite element analyses for single box girder skew bridges that were curved in plan. The bridge that could be analyzed by this method may be of varying width, curved in any shape, not just a circular shape and with any support conditions. They used rectangular elements for the webs and parallelogram or triangular elements for top and bottom flanges. Such an approach is impractical, especially for highly curved box bridges.

[Chapman,et al (2011)] conducted a finite element analysis on steel and concrete box girder bridges with different cross section shapes to investigate the effect of intermediate diaphragms on the warping and distortional stresses. They showed that curved steel boxes even with symmetrical load components gave rise to distortional stresses, and showed that the use of sloping webs resulted in an increase in distortional stresses.

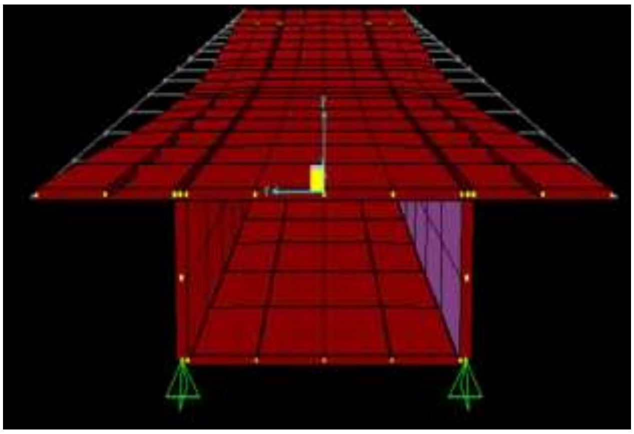
[Lim,et al. (2013)] developed an element that has a beam-like-in-plane displacement field which is trapezoidal in shape, and hence, can be used to analyze right, skew, or curved box-girder bridges with constant depth and width.

III. METHODOLOGY

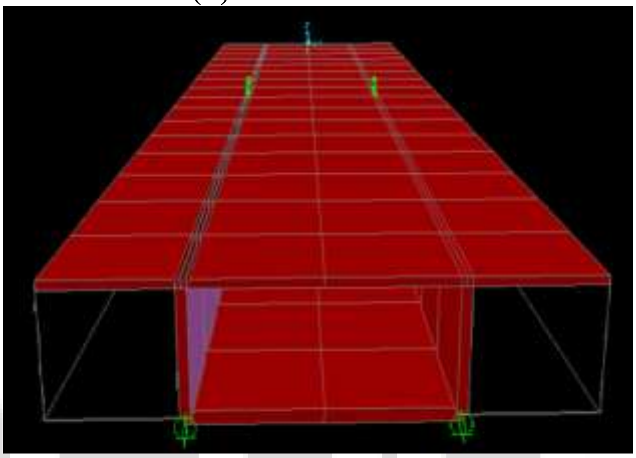
The method has become an important part of engineering analysis and design because nowadays finite element computer programs are used practically in all branches of engineering. A complex geometry, such as that of continuous curved steel box girder bridges, can be readily modeled using the finite element technique. The method is also capable of dealing with different material properties, relationships between structural components, boundary conditions, as well as statically or dynamically applied loads. The linear and nonlinear structural response of such bridges can be predicted with good accuracy using this method. In the current research, various structural elements are modelled using finite element method. Program SAP2000 that was utilized throughout this study for the structural modeling and analysis and finally the description of the models of the straight and curved box bridges is presented.

IV. FINITE ELEMENT MODEL

The cross section of the simply supported box beam bridge model used for the validation study. It is subjected to two equal concentrated load (P=2x800N) at the two webs of mid span. Length of Span is considered as 800mm, Modulus of elasticity (E) as 2.842GPa and Modulus of rigidity (G) as 1.015GPa. The model is Modelled in SAP refer Figure 3.2. The rectangular box girder is modelled with Bridge Wizard having Shell elements. The boundary condition is taken is simply supported. It is assigned with point loads along the negative Z direction. Static analysis is conducted for the model.



(A) Model without load



(B) Model with load

Fig. 2: Single cell rectangular box girder bridge modelled in SAP 2000

The bending moment, shear force and deflection at quarter span and mid span are monitored. The comparison of the values obtained and the values reported in literature, Gupta et. al (2010) are presented in the Table 3.1. The table shows that percentage error in the values obtained for BM, SF and deflections are very negligible. Hence the finite element model can be considered as validated. The same modelling approach is followed for further studies on modeling of straight and curved box girder bridges.

Parameters	Location	Present Study	Gupta et.al(2010)	% Error
Bending Moment (KN-m)	L/4th of span	0.16	0.16	0
	Mid span	0.32	0.32	0
Shear Force (KN)	L/4th of span	0.8	0.8	0
	Mid span	0.8	0.8	0
Deflection (mm)	Midspan	4.35	4.91	12.87

Table 1: Comparison of responses obtained in present study and Gupta et. al (2010)

Cross sectional parameter	Notation	Value
Cross-sectional area of concrete	Ac	6.375 m^2
Distance from bottom to centroidal axis	Z cb	1.47 m
Distance from top to centroidal axis	Z ct	0.83 m

Second moment of area of the concrete section	Ic	4.45 m^4
Section modulus bottom	W b 3	3 m^3
Section modulus top	W z	5.3m^3
Perimeter concrete box girder	u	22.66m

Table 2: Material Property of Trapezoidal Box Girder

Relation between maximum torsion to the ratio of span to radius of Curvature

From the relation, $T = \frac{G\theta I}{L}$

where,
T = Torsional Moment
G = Bulk Modulus
θ = Subtended angle
I = Polar Moment of Inertia
L = Span length

From the relation the graph from Figure 3.8 shows that as θ increases the Torsion increases. Thus with increase in θ, R will decrease for constant span. In comparison to straight model the curved models has much higher values of torsional moments.

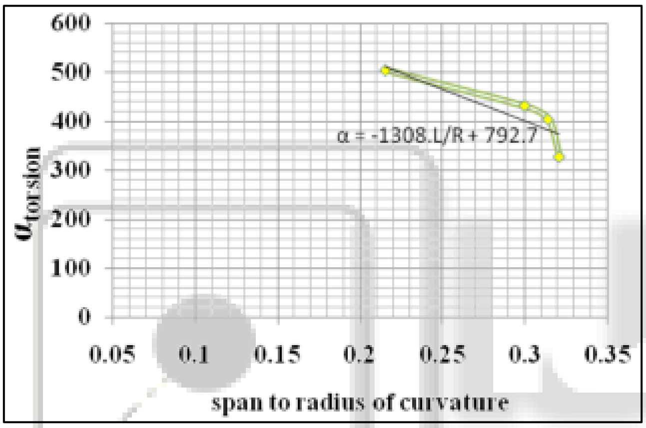


Fig. 3: Variation of αtorsion with the radius of curvature

Maximum Torsion can also be expressed in terms of L/R ratio by the following Linear Equation

$$\alpha\ torsion = -1308.L/R + 792.7$$

where,
α torsion = (max. torsion, curved/max. torsion, straight)
L/R = span to radius of curvature\

V. Conclusions

The major conclusions are listed below:

- Under IRC class A loading, for bottom face of left overhang part of girder, the longitudinal stress is increased by 12% as the radius of curvature is increased from 205m to 210m and it is increased by 17.5% as radius of curvature is increased from 210m to 220m radius of curvature, 5.2% when the radius of curvature is increased from 220m to 306m. For top face, the longitudinal stress for all the curved models increases about 6% from straight model
- Under IRC class A loading, the longitudinal stress increase of 12%, 25% and 1% are observed between the models 205R to 210R, 210R to 220R and 220R to 306R for the bottom face of central cross section. For top face the longitudinal stress for all the curved models increases fairly 6% from straight model.
- Under IRC class A loading, for bottom face of right overhang part of girder, the longitudinal stress is increased 16% from 205R to 210R and it is decreased by 28% both from 210R to 220R and 210R to 306R. For top face, longitudinal stress increases by 2% from 205R to 210R and by 33% from 210R to 220R and also from 210R to 306R.
- The fundamental mode is same for all the five models of bridges; as the mass and stiffness remains almost the same.

References

[1] AASHTO (2004) AASHTO LRFD "Bridge Design Specification" 2nd Editionwith Interims, American Association of State Highway and TransportationOfficials Washington D.C.
[2] Bhaskar Sengar (2005) "Load Distribution Factors for Composite Multi-Cell Box-Girder Bridges" Master in Engineering. Delhi College of Engineering.
[3] Cagri Ozgur (2007) "Behavior and Analysis of a Horizontally Curved and Skewed I-girder bridge" for MSc, School of Civil and Environmental Engineering
[4] Chu, K. J, and Pinjarkar, S. G. (2008) "Analysis of Horizontally Curved Box- Girder Bridges" Journal of the Structural Division ASCE 97(10), 2481–2501
[5] D. Linzell, D. Hall, and D. White (2004) "Historical Perspective on Horizontally Curved I Girder Bridge Design" Journal Bridge Engineering 9 (3), 218-229.
[6] Dabrowski, R. (2008). "Curved thin-walled girders, theory and analysis" Springer, New York.
[7] Dezi, L. (2015). ‘‘Aspects of the deformation of the cross-section in curved singlecell box beams.’’ Industria Italiana Del Cemento, 55(7–8), 500–808 (in Italian).

