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STUDY ON PARAMETRIC BEHAVIOUR OF SINGLE CELL BOX GIRDER UNDER DIFFERENT RADIUS OF CURVATURE

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Abstract: : 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 modelling 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. For the purpose of the parametric study, the five box girder bridges are modelled in SAP2000. The span length , cross-section and material property remains unchanged. The only parameter that changes is the radius of curvature. The cross section of the superstructure of the box girder bridge consists of single cell box. The curvature of the bridges varies only in horizontal direction. All the models are subjected to self weight and moving load of IRC class A tracked vehicle. A static analysis for dead load and moving load, and a modal analysis are performed. The longitudinal stress at top and bottom of cross sections, bending moment, torsion, deflection and fundamental frequency are recorded. The responses of a box girder bridge curved in plan are compared with that of a straight bridge. 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: *SAP 2000, Box Girder, Bending Moment, Torsion, Deflection*

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I.INTRODUCTION:

Bridges have historically served as vital infrastructure enabling connectivity and integration across diverse geographies. From ancient stone arches to modern cable-stayed and suspension structures, bridge engineering has evolved in response to increasing demands of functionality, safety, and efficiency. In the 20th and 21st centuries, the need for rapid urbanization, inter-regional transport corridors, and high-speed mobility has led to significant advancements in bridge design, particularly in superstructure configurations. Among the modern structural solutions, box girder bridges have become a favored choice, especially for medium to long spans. Their hallmark characteristic—a hollow box-shaped cross-section formed by top and bottom slabs connected through vertical or inclined webs—offers superior torsional stiffness, making them highly effective in resisting twisting forces. This resistance is crucial in applications where the bridge alignment is curved or when subjected to asymmetric loading conditions. The structural efficiency of box girders is further enhanced by their high strength-to-weight ratio. This makes them cost-effective over long spans, reducing the need for intermediate supports and allowing for greater navigational clearance in waterways or roadways beneath. Their aesthetic appeal—especially when designed with a slender deck profile—also contributes to their widespread use in urban settings where visual harmony with the environment is desirable. Box girders are also preferred due to their ease of maintenance and redundancy. Their enclosed nature allows for better protection of tendons in prestressed systems and provides safe internal access for inspections and retrofitting. With precast and segmental construction techniques, box girder bridges can be assembled rapidly, minimizing on-site labor and disruption. This adaptability suits projects in congested urban areas, difficult terrain, or places with strict environmental regulations. However, the structural analysis and design of box girder bridges become increasingly complex when the alignment of the bridge involves curvature in the horizontal plane. Horizontal curves are often necessitated by geometric constraints, topographical features, or alignment requirements in roadways and railways. Such curved bridges—frequently encountered in flyovers, interchanges, and viaducts—pose analytical challenges due to the interaction of flexural, torsional, and shear effects. In horizontally curved bridges, loads do not act in a simple vertical path. Instead, they generate a combination of bending moments, torsional moments, and shear forces, which interact and cause complex stress distributions within the girder. Moreover, the closed nature of box girders introduces additional behavior modes such as warping, shear lag, and distortion, particularly at locations of sudden curvature or cross-sectional variation.

II.OBJECTIVE

- The primary objective of this thesis is to investigate the parametric behavior of a single-cell box girder subjected to varying radii of curvature.
- The specific goals of the study are:To analyze the effect of horizontal curvature on the structural response of single-cell box girders.
- To examine the influence of curvature on bending moments, shear forces, torsional stresses, and deflections.To perform a comparative analysis of

different curvature cases using finite element modeling.

- To provide design recommendations based on the observed behavior for safer and more efficient box girder bridges.

III.METHODOLOGY AND MODELLING APPROACH

3.1 METHODOLOGY

Five box girder bridge models are considered with constant span length and varying curvature. In order to validate the finite element modelling method, an example of box girder bridge is selected from literature to conduct a validation study. The example of box girder is modelled and analysed in SAP 2000 and the responses are found to be fairly matching. For the purpose of the parametric study, the five box girder bridges are modelled in SAP2000. The span length, cross-section and material property remains unchanged. The only parameter that changes is the radius of curvature in plan. The cross section of the superstructure of the box girder bridge consists of single cell box. All the models are subjected to self weight and moving load of IRC class A tracked vehicle. A static analysis for dead load and moving load, and a modal analysis are performed. The longitudinal stress at top and bottom of cross sections, bending moment, torsion, deflection and fundamental frequency are recorded. The responses of a box girder curved in plan and straight are compared. The ratio of responses is expressed in terms of a parameter.

3.2 MODELLING OF BOX GIRDER BRIDGES FOR PARAMETRIC STUDY

3.2.1 Curved girder bridge modelled in SAP2000

The curved Box Girder Model is made using Bridge module with shell elements of SAP2000 .The Horizontal alignment from Bridge Wizard is made curved by horizontally. Four curved bridges are modelled having radius of curvatures 205m, 210m, 220m and 306m. The curved bridge with radius of curvature of 205m is denoted as 205R. Similarly, 210R represents a curved bridge with radius 210m. Similar notation is followed for all the other cases. The Box Girders has Trapezoid in cross section. The Deck section was taken as per BMRC model and having a single span, of length 66m. The boundary condition is simply supported.

Table 3.1 Material properties.

Material Properties	Values
weight /unit volume	25000 N/m^3
Young's modulus (E)	32500 e^6 N/m^2
Poisson's ratio (υ)	0.15
Shear Modulus (G)	1.413 e 10 N/m^2
Coefficient of thermal expansion (A)	1.17 e $^{-5}$/°C
Specific compressive strength of concrete (fc')	45 e^6 N/m^2

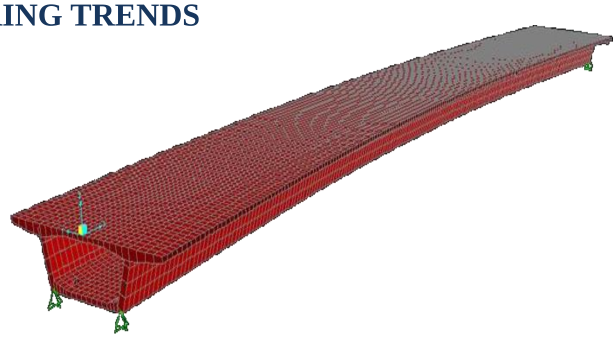
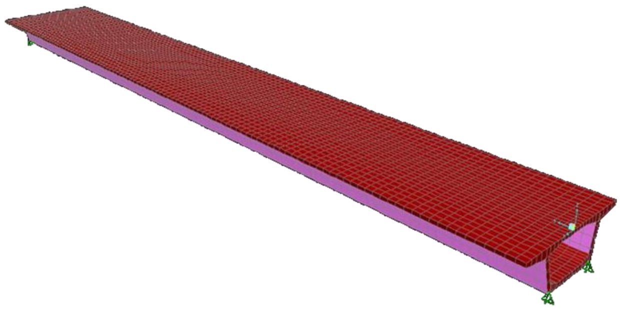


Figure 3.1 Curved Box Girder Modelled in SAP2000



3.2.2 Straight girder bridge modelled in SAP2000

The straight Box Girder Model is made using Bridge Wizard Commands with shell elements of SAP2000 .The Horizontal alignment from Bridge Wizard is made straight by horizontally. The Box Girders has Trapezoid in cross section. The Deck section was taken as per BMRC model and having a single span, of length 66m. The boundary condition is simply supported. The material property is same as for the curved models.

3.3 CONFIGURATION OF BOX GIRDER

3.3.1 Cross-sectional properties

The cross-sectional properties for the trapezoidal box girder like span length, width of bridge, depth of bridge, thickness of top flange, width of top flange, width of bottom flange etc. is shown in Figure 3.3 and Table 3.3 and the material properties like cross sectional area, moment of inertia, distance from bottom to centroidal axis etc. are given in Table 3.2

Figure 3.3 Details of cross-section at mid span

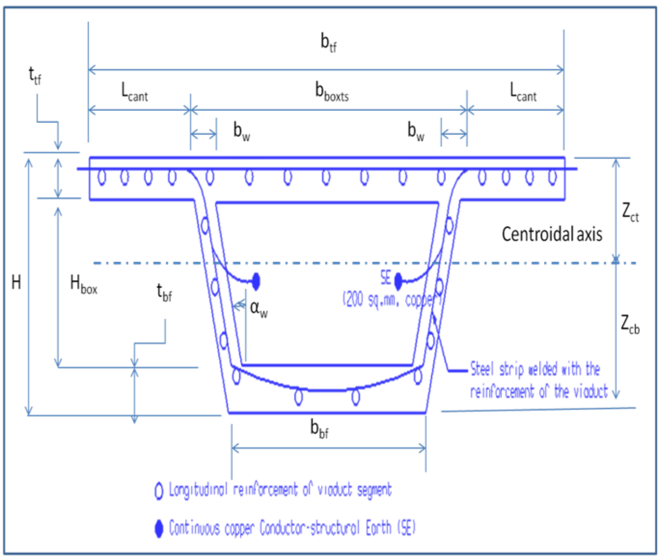


Table.3.2 Cross-sectional dimensions

IV.RESULT AND DISCUSSION

Parameters	Notation	(m)
Length span	L	66
Depth box girder	H	2.31
Width of top flange	b_{tf}	9.6
Thickness of top flange	t_{tf}	0.381
Width web	b_w	0.381
Width bottom flange	b_{bf}	4
Thickness bottom flange	t_{bf}	0.381
Width box top side	b_{boxts}	5.445
Cantilever lengthtop flange	L_{cant}	2.080
Depth webs	H_{box}	1.547

4.1RESPONSE OF BOX GIRDER BRIDGE WITH CURVATURE

Analyses of the curved and straight box girder bridge models are for dead load and moving load conducted. The responses such as torsion, bending moment, longitudinal stress, deflections are monitored in each analysis. The non-dimensional parameter (L/R) is considered to plot the variation of the maximum responses curvature of the bridges.
The effect of the ratio of span length to the radius of curvature is insignificant for straight bridges with L/R=0. However, for curved bridges the ratio increases with increase in span length for a constant radius of curvature; but, it decreases, if the bridge has constant span length and radius of curvature increases.

4.1.1Torsion

Torsion for all the bridge models is considered under dead load and moving load. The variation of torsion is plotted across the span length. A non-dimensional parameter α, is introduced here which represents the ratio of maximum torsion for curved bridge to that of straight from moving load analysis. The variation of α is considered with the non dimensional parameter (L/R) for plotting the graphs.

4.1.1.1.Torsion Due To Self Weight

The analysis is conducted for self weight for all the cases. The torsion along the span is monitored and a graph is plotted between torsion and the span length. Figure 3.6 shows the variation of torsion along the span for various models.
The straight beam (R =∞, curvature, 1/R =0) shows no torsion for dead loads. But as the curvature increases or (radius of curvature decreases) the torsion arises in the girder, and it varies across the span as shown in the Figure 3.6
The maximum value of the torsion in the cross section increases as the curvature increases. As the radius increases beyond 210m for the particular span considered, the box girder shows a double twist. This behaviour may not be a favourable one to the girder as the shear flow changes sign at that section.
A 33% decrease in maximum torsion is observed when the radius of curvature is increased from 205m to 210m, 210m to 220m and 220m to 306m.

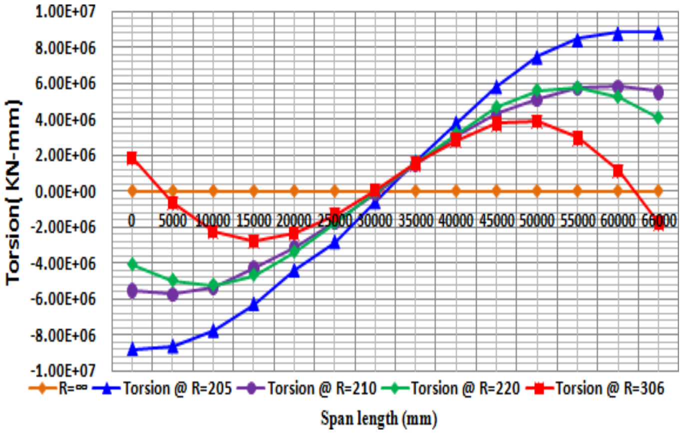


Figure.3.4 Variation of Torsion along the span under self weight

4.1.1.2Torsion due to moving load

The analysis is conducted for live load of IRC.6 class A Tracked vehicle load for all the cases. The torsion along the span is monitored and a graph is plotted between torsion and the span length. Figure 3.5 shows the variation of torsion along the span for various models.
The variation of torsion along the span length for the five models considered is shown in Figure 3.5. The straight bridge model experiences torsion due to lane loading; but, in comparison with the curved bridge models it is almost negligible In the curved bridges as the curvature increases torsion increases in general.
When the radius of curvature increased from 205m to 210m, the maximum torsion in the cross section decreased by 20.5%. An increase in maximum torsion of 7% is observed for in the increase in radius from 210m to 220m. When the radius of curvature increased from 220m to 306m, the maximum torsion is decreased by 16%.

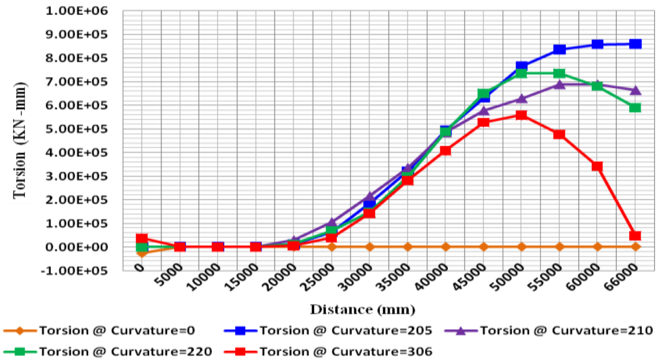


Figure 3.5 Variation of Torsion across the span under IRC class A loading

4.1.2Deflection of the box girder

The deflection is recorded both along transverse direction of the trapezoidal box girder and also along the longitudinal direction of box girder.

4.1.2.1Mid span vertical deflection along the width of box girder

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The vertical deflection of the girder is considered along the transverse direction of the single cell box girder. The variation of vertical displacement across the traverse direction is shown in Figure 3.6. It shows that the mid span vertical displacement is increasing as per the radius of curvature is increasing.
When the radius of curvature is increased from 205m to 210m, the maximum mid span deflection along the transverse direction is increased by 14%. For the radius of curvature increased from 210m to 220m, the maximum deflection increased by almost 12.5%. Also for the radius of curvature is increased from 220m to 306m, the maximum deflection is increases by 11.11%.

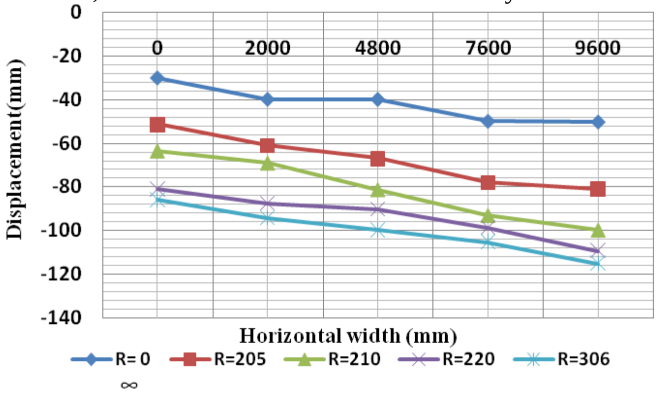


Figure.3.6.Mid-span vertical displacement along the width of box girder

4.1.3 Bending moment due to self-weight

Bending moment for the all the curved models are compared with the bending moment of the straight model, and it is plotted along the span of the bridge, refer Figure 3.7.
It shows the Bending moment diagram of five different radius of curvature models under self weight. As, it can be seen that, the 205R model shows maximum bending moment than that of other bridge models The bending moment decreases by almost 29% as the radius of curvature decreases from 205m to 210m, 210m to 220m, and 220m to 306m.

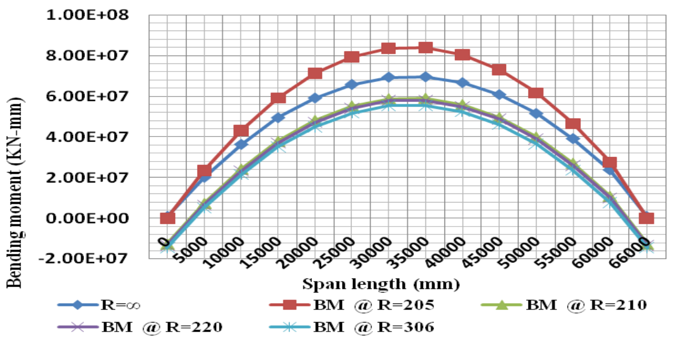
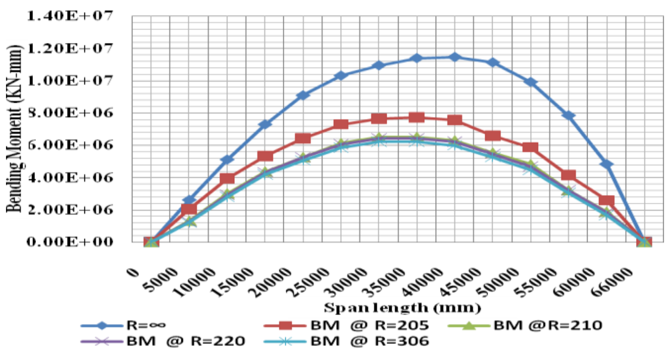


Figure.3.7 Bending Moment along the span of girder in their self weight

4.1.3.1Bending moment due to moving load

The models are loaded with rail load on one lane and the rail IRC class A tracked vehicle on the lane.
A moving load analysis is done in SAP2000. The results have been plotted and compared, as shown in Figure 3.8.



The Figure 3.8 shows that; there is decrease in bending moments as the radius of curvature increased
Figure 3.8, shows the Bending moment values under IRC Class A Tracked Vehicle loading. The 205 radius of curvature model shows higher bending moment values than that of straight and all other curved models shows almost close value that with straight one i.e. .horizontal radius of curvature more for 205 and for other model has less significance on bending moment values. The bending moment decreases by almost 18.75% as the radius of curvature decreases from 205m to 210m, 210m to 220m, and 220m to 306m.

4.1.4 FREQENCIES FOR THE BRIDGE MODELS

A modal analysis is performed for all the five box bridge models out of which one is straight and other four are curved in plan. All the five models have same span length and same material properties.
Table 4.1 Frequencies for the bridge models

Out put case	Frequency (Cycle/sec) R=205	Frequency (Cycle/sec) R=210	Frequency (Cycle/sec) R=220	Frequency (Cycle/sec) R=306	Frequency (Cycle/sec) R=0
Mode1	0.493	0.493	0.494	0.493	0.492
Mode2	0.963	0.964	0.971	1.006	0.998
Mode3	3.269	3.260	3.260	3.239	3.219
Mode4	3.771	3.772	3.803	3.829	3.798
Mode5	4.512	4.512	4.516	4.555	4.549
Mode6	7.644	7.640	7.646	7.698	7.642
Mode7	8.072	8.065	8.070	8.110	7.642

4.1.4.1Frequencies for the bridge models

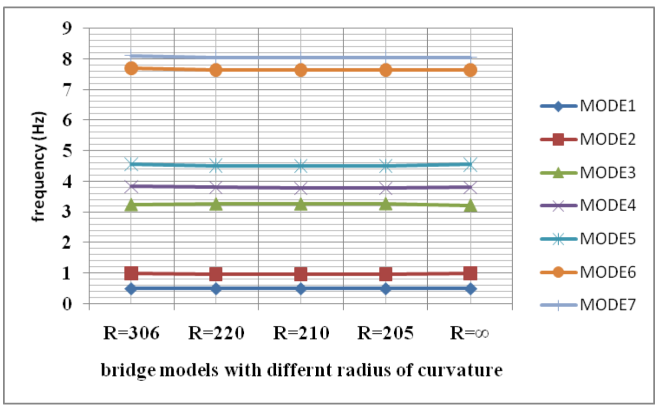


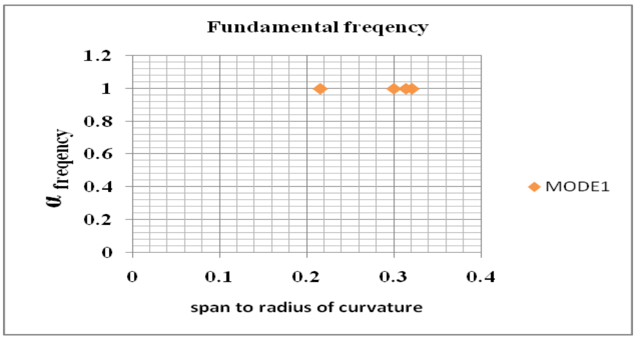
Figure 3.9 Various mode shapes with the different radius of curvature

Modal analysis is performed for all the five models. In result seven step frequencies taken. as shown in Figure 3.9.The Figure 3.9 shows there is no change in mode shapes for the curvatures considered in the present study. As the length and the material property is same for all the models so, the mass for all the five models are same; therefore there is no change in mode shapes.

4.1.4.2Fundamental frequency to L/R ratio

The ratio of fundamental frequency of curved to the fundamental frequency for straight is compared with span to radius of curvature for all the five models. As the mass remains same the α (fundamental frequency) remains unchanged with span to radius of curvature. So, there is no effect on fundamental frequency if curvature changes, refer

figure 3.10Figure 3.10 Fundamental mode frequencies to the L/R ratio



V.CONCLUSION

The conclusions are listed below

1. Under IRC Class A loading, it shows that; when the radius of curvature increased from 205m to 210m, the maximum mid span deflection along the transverse direction increases by 14%. For the radius of curvature increased to 220m, the maximum deflection increases by almost 12.5%. Also for the radius of curvature is increased from 220m to 306m, the maximum deflection is increases by 11.11%.

2.Under IRC Class A loading, it shows that; when the radius of curvature increased from 205m to 210m, the maximum mid span deflection along the span is decreased by 7.7%. As the radius of curvature is increased to 220m, the maximum deflection is decreased by almost 16.67%. Also, when the radius of curvature is increased from 220m to 306m, the maximum deflection is found to be decreased by 75%, which behaves more like a straight bridge.

3.Under dead load; it is recorded that, there is a 33% decrease in maximum torsion is observed when the radius of curvature is increased from 205m to 210m, 210m to 220m and 220m to 306m.

4.Under IRC class A loading; it shows that as radius of curvature is increased from 205m to 210m, the maximum torsion in the cross section decreased by 20.5%. An increase in maximum torsion of 7% is observed for in the increase in radius from 210m to 220m. When the radius of curvature increased from 220m to 306m, the maximum torsion is decreased by 16%.

5.For relation of torsional moment to the L/R ratio, it showed that with decrease in span to radius of curvature, the dimensionless value α for maximum torsion is increasing.

6.Under dead load, the bending moment decreases by almost 29% as the radius of curvature decreases from 205m to 210m, 210m to 220m, and 220m to 306m.

7.Under IRC Class A loading, the bending moment decreases by almost 18.75% as the radius of curvature decreases from 205m to 210m, 210m to 220m, and 220m to 306m

8.As the curvature increases the bending moment values also increases.

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