Effect of Depth on Box Girder Bridges

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ABSTRACT: *This research paper deals with the performance of a single cell reinforced concrete box girder bridge under both the loads, i.e., dead load and IRC live loads, using finite element based software CSiBridge22. Linear analysis has been done on two box girder bridges (rectangular and trapezoidal) as per the Indian Road Congress (IRC) provision. An existing model is considered to validate the present results. A convergence study is performed to decide the optimum mesh size. The behaviour of rectangular box girder and trapezoidal box girder with uniform increments in Span/depth ratio has been discussed for various parameters such as deflection, bending moment, shear force, and torsion and comparison between the two box girders has been carried out. For the analysis, a simply supported two-lane bridge is considered and then analyzed for the combination of dead load and IRC loads, i.e. one Class 70R (tracked and wheeled) vehicle, one Class AA (tracked and wheeled) vehicle, and two Class A vehicles.*

Key Words: Box girder bridge, Linear analysis, Single-cell, IRC load, Finite element method.

1. Introduction

Box girder is a hollow box section type of bridge, which may be composed of reinforced concrete or pre-stressed concrete and structural steel and composite steel. This type of bridge is generally provided for a long span and wide deck, and it is more popular for its strength, torsional stiffness, and flexural stiffness in the modern road system. In these bridges, the main beams consist of a girder in the form of a hollow box section. It can be of a single-cell, multi-cell or multi spines with a rectangular, trapezoidal, or circular cross-section. The torsional rigidity of these types of bridges is high by virtue of this; a box girder can resist forces produced by the vehicular loading. The hollow section of these bridges can also be utilized for water supply pipes, telephone lines, electric supply cables, sewers, etc. The section has an additional advantage as being in the lightweight superstructure.

Some of the important literature which deals with the study of box-girder bridges are presented herein. T.Gupta and M Kumar[1] studied the flexural response of single-cell skew-curved box girder bridges. This study concludes that the presence of high skew angle in high curved bridges improves the flexural response of box-girder bridges. Khaloo and Mirzabozorg[2] analyzed the simply supported bridges having I-section concrete girders using ANSYS software. It is reported that the difference between the first and second systems increases, especially in decks with internal diaphragms perpendicular to the longitudinal girders when the skew angle increases. Menassa et al.[3] presented the effect of skewness on the maximum bending moment of RC box girder bridges under HS20 truck loading using the finite element method by varying the span length, slab width, and skew angle. It is reported that bridges with a skew angle less than or equal to 20° may be designed as straight (non-skewed) bridges, and when the skew angle is greater than 20°, then three-dimensional finite element analysis is to be performed. Khaloo and Kafimosavi[4] studied the flexural behaviour of pre-stressed (post-tensioned) curved box-girder bridges using a 3-D refined finite element method. In this study, the curvature is varied from 0 to 90°, keeping the bridge length, section geometry, and material properties the same. The results show that in curved bridges, the stress distribution is significantly different compared to straight bridges. Also, the level of stresses at some locations of section width is considerably higher. Sennah and Kennedy[5] "Literature review in Analysis of Box-girder Bridges". The literature study presented in this paper deals with elastics analysis and elastic response of box girder bridges. The study reported in their review paper that the finite element method is the most comprehensive and general technique for static and dynamic analysis, capturing all aspects affecting the structural response. Yuan-Hai Zhan, Li-Xia Lin[6] studied shear lag analysis of thin-walled box girders bridges. In this study shell element having 8 degrees of freedom is considered to analyze bridges with varying depth. The result of this study is that the deflection at mid-span of the three-span box girder model due to shear lag effect reaches 22.3% and 23.9% for concentrated and Udl loads, respectively, which is a serious case in engineering practice.

2. Validation

An existing model of Gupta and Kumar (Fig 1) is considered to validate the present study. A shell

element with four nodes and six degrees of freedom (three rotations and three translations) at every node is used to discretize the model with the mesh size of 20 cm in both longitudinal and transverse directions. The left interior support is restrained using pin support, and the rest three supports are provided by rollers, similar to that of the existing model. The span length=27.4; width=10.8m; overall depth=2.96 m. The material properties of concrete are: Poisson's ratio = 0.2; Characteristic strength = 25 MPa; Density = 25 kN/m3; and Modulus of elasticity = 2.5 × 107 MPa.

The model is analyzed for both the loads, i.e., DL and LL (IRC Class-70R tracked vehicle load); the LL is considered here as concentrated load and placed at a distance of 1.2 m from the kerb. The absolute maximum bending moment in the girders is calculated for the model of Gupta and Kumar shown in Fig 1 and compared. The software results are come out to be very close to the Gupta and Kumar results (Table 1). Hence, the present approach can be accepted and extended for further study.

Table -1: Comparison of results of Gupta and Kumar, and Present Study

	Absolute Max dead load B.M (kN-mm)		Absolute max live load B.M. (kN-mm)	
	Outer girder	Inner girder	Outer girder	Inner girder
Gupta and Kumar results (2018)	7294	7294	3935	865
Present results	7315	7314	3928	855
% Variation	0.29	0.27	0.19	1.10

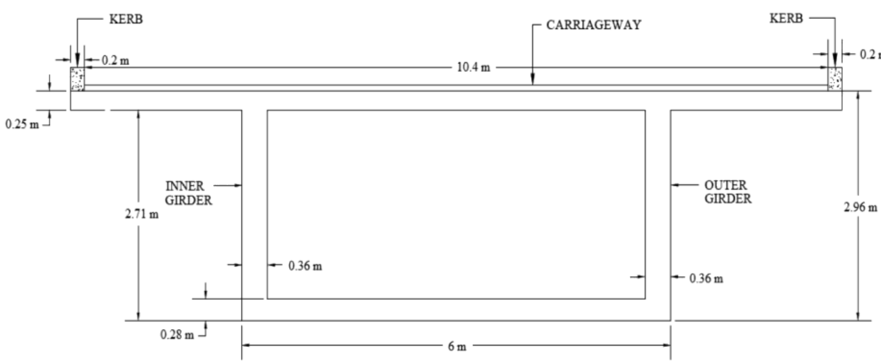

Fig -1: Cross-sectional details of the box girder (Gupta and Kumar model)

3. Methodology

In the present study, the modelling and analysis are carried out using a finite element-based software CSiBridge22.

1. Validation of present rectangular box girder results with the results published by Gupta and Kumar [Table 1].
2. Modelling and analysis of rectangular and trapezoidal box girders for dead load and IRC live loads [Class 70R (Tracked & Wheeled), IRC Class AA (Tracked & Wheeled), and two IRC Class A loading], using CSiBridge22 software.
3. Parametric study for deflection, bending moment, shear force and torsion for both the cross-sections of the box girder bridges.

4. Convergence study

For the convergence study, a straight single-cell reinforced concrete box-girder bridge Fig 1 is considered. For discretizing the bridge deck, four noded shell element having six degrees of freedom is used. The results converge at a mesh size of 10 cm and less. So, the mesh size of 10 cm is adopted in both the longitudinal and transverse directions. All the models of Reinforced Concrete Box Girder Bridge models are generated in CSiBridge22 software.

5. Analysis

Bridge girder details

The present study involves analysing two different cross-sections of reinforced concrete box girder bridges, i.e., rectangular and trapezoidal, using CSiBridge22 software. The straight box girder bridge's cross-section is taken based on the specifications mentioned in IRC:21-2000[7], which are mentioned below-

1. The span of the box girder bridge should not be less than 25m.
2. The minimum box girder thickness should be 300 mm.
3. Minimum thickness of bottom flange shall not be less than 200 mm or 1/20 of the clear span between the main girders, whichever s greater.
4. The cantilever arm length is equal to 0.45 times the distance between the webs.
5. The minimum clear height inside the box girder shall be 1.5m to facilitate inspection.
6. The thickness of the deck slab, including that at the tip of the cantilever, shall be 200 mm.
7. The thickness of the webs shall not be less than 250 mm.

The cross-section and details of the cross-section of the rectangular box girder bridge and trapezoidal box girder bridge are shown in Figs 2-3 and Table 2, respectively.

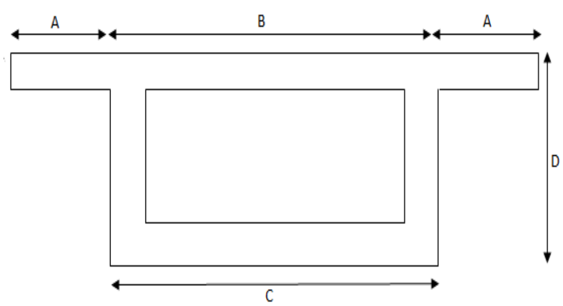

Fig -2: Cross-section of Rectangular box girder

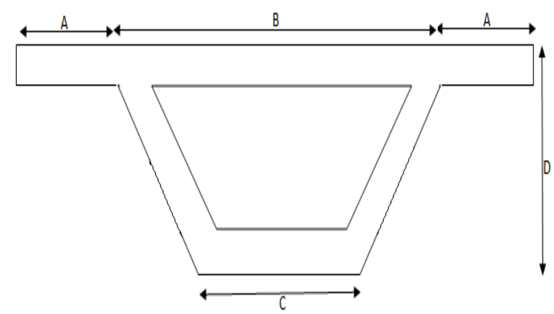

Fig -3: Cross-section of Trapezoidal box girder

Table -2: Dimensions of cross-sections of Rectangular and Trapezoidal Box Girder

L/D Ratio	Rectangular (m)			Trapezoidal (m)		
	A	B	C	A	B	C
10	2.75	6	6	1.7	8.9	5.80
12	2.75	6	6	1.6	8.3	5.76
14	2.75	6	6	1.8	7.9	5.78
16	2.75	6	6	1.9	7.7	5.90

A simply supported single-cell reinforced concrete box girder bridges with two lanes considered for analysis are such that the width of the bridge deck and the area of the cross-section are kept constant, and only the span/depth ratio is varied. Here Span/depth ratio greater than 18 is not considered because, according to IRC:21-2000, the minimum clear height inside the box girders shall be 1.5 m to facilitate inspection, and the case of L/D = 18 is not considered in this study because it is not in accordance with the provision of IRC: 21-2000. The bridge span is taken as 30 m and width as 11.5 m with a footpath of 1.5 m and a kerb of 500 mm on both sides for all box girder bridge sections. A constant thickness of 0.3 m is considered for all the elements of the bridge cross-section. The materials used are M-30 concrete and Fe-500 steel.

6. Parametric study

A parametric study is done to analyse Rectangular and Trapezoidal box girder bridges, varying the span/depth ratio (10, 12, 14 and 16). The live load is placed on the bridge decks as per IRC: 6-2000[8]. The parameters such as deflections, bending moment, shear force and torsion due to the combined effect of dead load and live load are compared.

Rectangular box girder

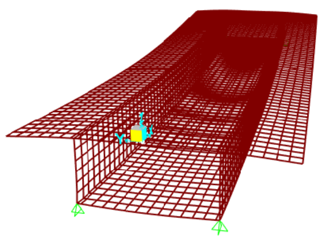

Fig -4: Shell element of rectangular box girder model

Comparison of the results under different live loads (IRC 70R Wheeled, IRC 70R Tracked, IRC Class A, IRC Class AA Tracked and IRC Class AA Wheeled) for rectangular box girder of different L/D ratios (10, 12, 14, 16) for the combined effect of dead load and live load are presented in Figs. 5- 8 respectively.

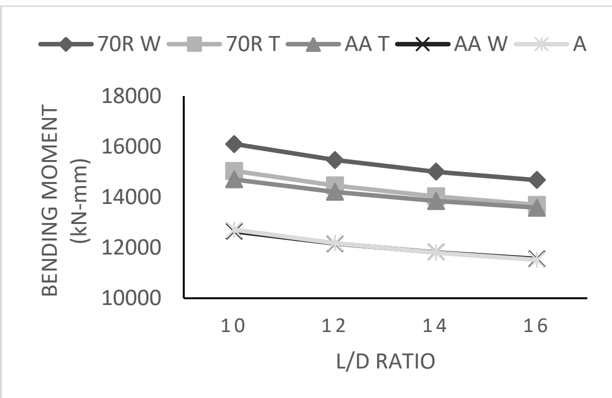

Fig -5: Maximum bending moment Vs L/D ratio

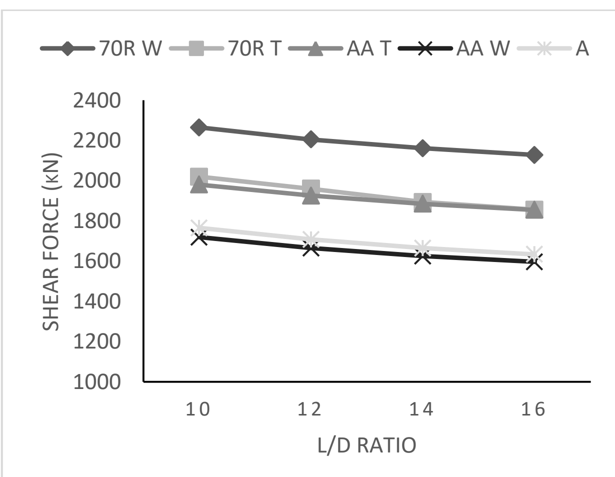

Fig -6: Maximum shear force Vs L/D ratio

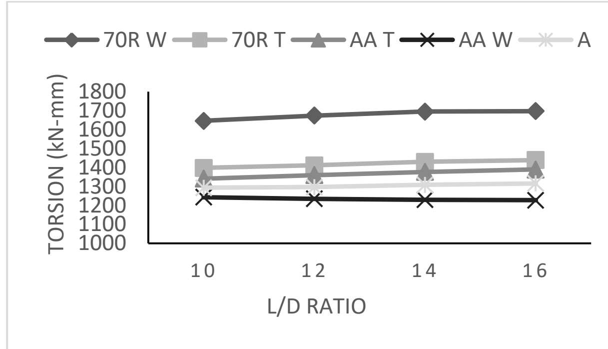

Fig -7: Maximum torsion Vs L/D ratio

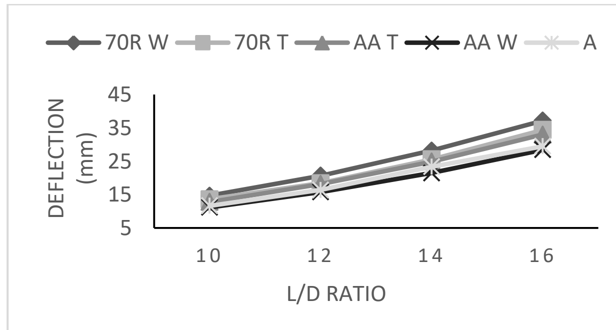

Fig -8: Maximum deflection Vs L/D ratio

The bending moment, shear force, torsion and deflection produced by Class 70R wheeled vehicle is largest. Hence, 70R wheeled load is considered for further study. The maximum bending moment and shear force decrease with the increase in span/depth ratio. The maximum deflection and torsion increase with the increase in span/depth ratio.

Trapezoidal box girder

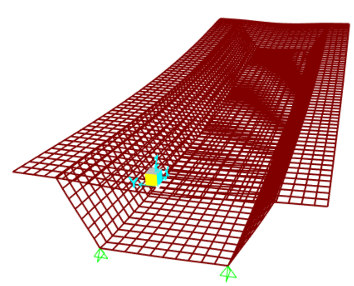

Fig -9: Shell element of trapezoidal box girder model

Comparison of the results under different live loads (IRC 70R Wheeled, IRC 70R Tracked, IRC Class A, IRC Class AA Tracked and IRC Class AA Wheeled) for trapezoidal box girder of different depths for dead load and live load placed centrally are presented in Figs 10-13 respectively.

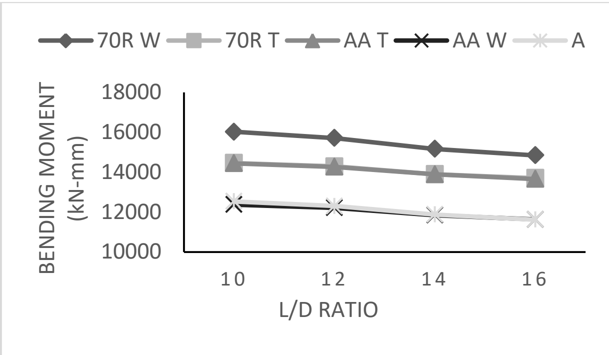

Fig -10: Maximum bending moment Vs L/D ratio

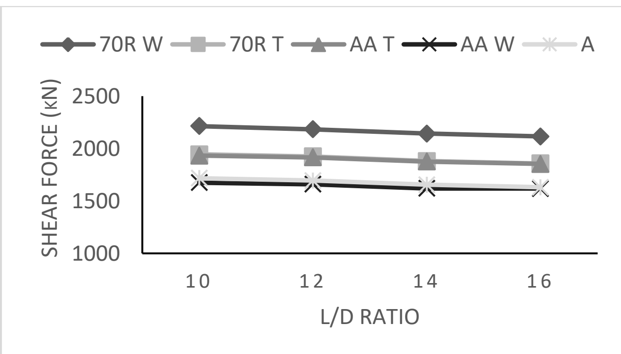

Fig -11: Maximum shear force Vs L/D ratio

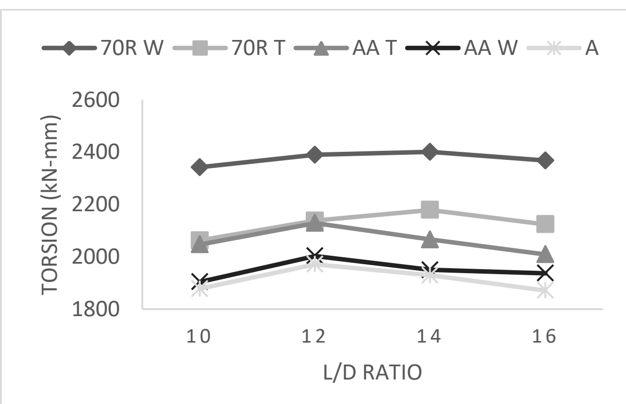

Fig -12: Maximum torsion Vs L/D ratio

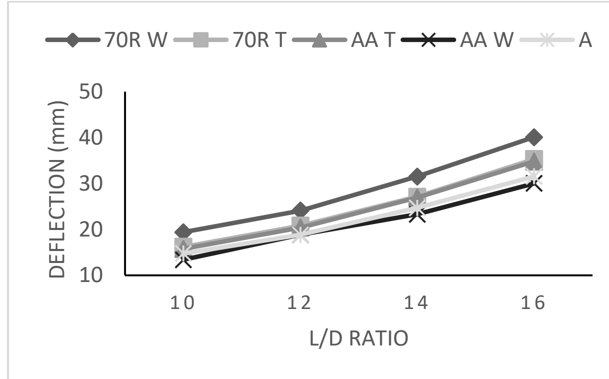

Fig -13: Maximum deflection Vs L/D ratio

The bending moment, shear force, torsion and deflection produced by Class 70R wheeled vehicle is largest. So, for 70R wheeled load, the maximum torsion and deflection at mid-span of the trapezoidal box girder due to combined effect of dead load and live load increases with the increase in span/depth ratio and the maximum bending moment and shear force decreases with the increase in span/depth ratio.

7. Comparison of Rectangular and Trapezoidal box girder

All IRC loads, i.e., Class 70R (tracked and wheeled), Class AA (tracked and wheeled) and Class A are considered to analyze both the girders but the obtained forces and deflection produced by Class 70R wheeled vehicle is largest, irrespective of the cross-section. Hence Class 70R wheeled load is considered for the comparison study of rectangular and trapezoidal sections. Following Figs, 14-17 show the comparison of Rectangular and Trapezoidal box girder bridges in terms of bending moment, shear force, torsion and deflection to span/depth ratio.

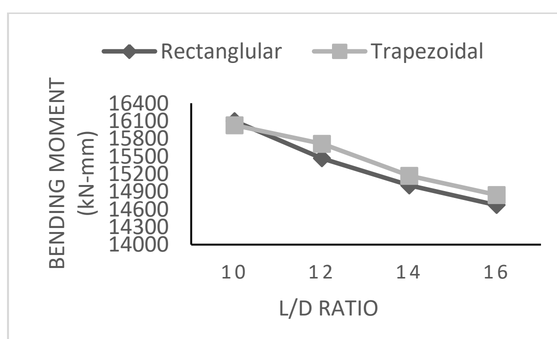

Fig -14: Bending moment VS L/D ratio

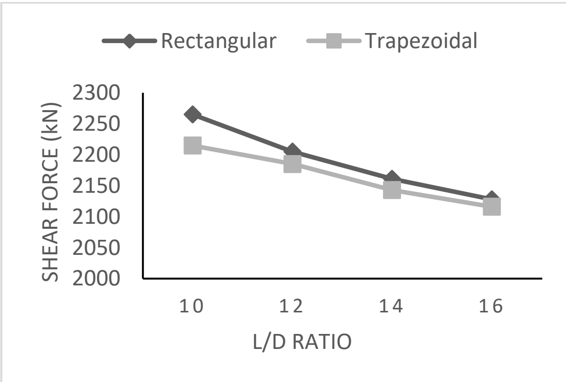

Fig -15: Shear force Vs L/D ratio

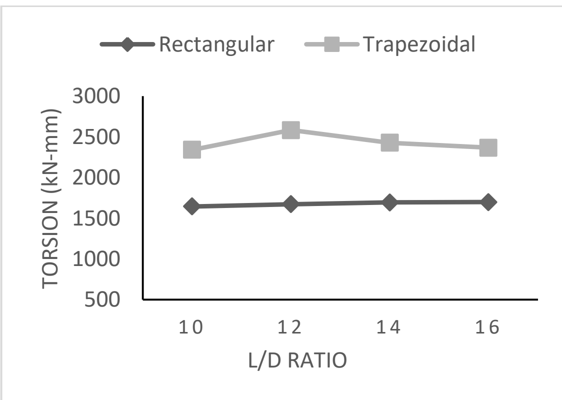

Fig -16: Torsion Vs L/D ratio

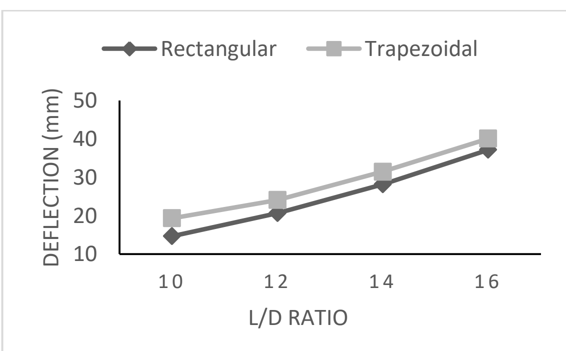

Fig -17: Deflection Vs L/D ratio

The maximum deflection due to the combined effect of dead load and live load in the rectangular section for the span/depth ratio 10, 12, 14, and 16 is lower by 31.7%, 16.4%, 11.4% and 7.7%, respectively, in comparison to those in the trapezoidal section and the maximum bending moment due to combined effect of dead load and live load in the rectangular section for span/depth ratio 10,12,14, and 16 is lower around 2-5% in comparison to trapezoidal section. The maximum shear force is more in the rectangular section, and the maximum torsion is more in the trapezoidal section. Hence, the rectangular section is stiffer than the trapezoidal section.

8. Conclusions

The conclusions that are drawn from the present study:

1. The deflection and torsion increase while the bending moment and shear force decrease when the span/depth of the box girder increases.

2. The Bending moment, shear force, torsion and deflection produced by the Class 70R wheeled vehicle are largest, irrespective of the cross-section.

3. The deflection and bending moment are lower in rectangular sections and higher in trapezoidal sections; hence, the rectangular section is stronger than the trapezoidal sections.

9. References

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