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Parametric Study of Horizontally Curved Box Girders for Torsional Behavior and Stability

Ashish B Sarode, G R Vesmawala
Department of Applied Mechanics, S V National Institute of Technology, Surat, Gujarat, India.

Abstract:- The horizontally curved alignments for the urban interchanges or highway bridges are becoming more common and it is necessary to construct the structures curved in plan. Due to the effect of horizontal curvature of the box girders, torsional moments are predominant. Also the support reactions on the outer supports increase whereas on inner support decreases, which may leads the instability of the box girder. The outer web is longer than the inner web due to which the mid-span deflections are more at the outer web than the inner web. In this paper, the numerous models for curved box girders are analysed using LUSAS FEA software for different parameters such as span lengths, radii and loadings and the flexural and trosional behavior, stability and mid-span deflections of the curved box girders of various parameters are discussed.

Keywords:- Curved box girders; Torsional behavior; mid-span deflections; curved box girder stability; finite element method, LUSAS.

I. INTRODUCTION

The horizontally curved alignments for the urban interchanges or highway bridges are becoming more common and it is necessary to construct the structures curved in plan. Due to the requirements of more stringent route and high torsional stiffness as well as a desire for a greater sense of aesthetics, curved box girder bridges have become increasingly popular and have been an interesting subject of research [1].

Superstructures on the curved alignment can be constructed of steel or concrete I-girders in composite action with a concrete deck or constructed of box girder, Since, it is well known that I-girders are weak in torsion; Box girders are more popular due to its great torsional rigidity.

Analysis and design of the box girder can be divided into two parts i.e. longitudinal analysis (i.e. analysis along traffic direction) and transverse analysis (i.e. across traffic direction). The stresses and the deformations in the transverse analysis are dependent of the cross-sectional members' properties of the box girder. In Longitudinal direction the bending moment, shear and torsion of the curved box girders varies with the different spans lengths and radius.

There are several methods available for the analysis of box girder bridges. In each analysis method, the three-dimensional bridge structure is usually simplified by means of assumptions in the geometry, materials and the relationship between its components. The accuracy of the structural analysis is dependent upon the choice of a particular method and its assumptions. Available research works on some methods are grillage analogy method, orthotropic plate theory method, folded plate method, finite strip method, finite element method, computer programming and experimental studies. E.C. Hambly et al. [2] applied grillage analogy method to the multi-cell superstructure and R. Kissane et al. [3] to curved multi-spine box-girder bridges. M. S. Cheung et al. [4] dealt with the calculation of the longitudinal bending moment and transverse shear in multi-spine/web box-girder bridges using grillage analogy method and orthotropic plate theory method. A. C. Scordelis [5] developed an analytical procedure for determining longitudinal stresses, transverse moments and vertical deflections in folded plate structures by utilizing matrix algebra. M. S. Cheung M S et al. [6] applied finite strip method to analyze curved box girders. K. H. Chu et al. [7] developed a finite element approach for analyzing curved box girder bridges. C. P. Heins et al. [8] studied and analysed the Curved beam. C. P. Heins et al. [9] developed a program for the analysis simple or multi-span composite or non-composite steel box girder bridges.

In this paper, the numerous models are analysed for different parameters such as span length, radius of horizontally curved alignment of box girder and loadings. Due to the effect of horizontal curvature of the box girders, torsional moments are predominant. Also the support reactions on the outer supports increase whereas on inner support decreases, which may leads the instability of the box girder. The outer web is longer than the inner web due to which the mid-span deflections are more at the outer web than the inner web. Hence the flexural and trosional behavior, stability and mid-span deflections of the curved box girders of various parameters are discussed.

II. OBJECTIVE OF THE STUDY

In this paper, the three-dimensional finite element thick shell models are analysed for different parameters such as span length, radius of horizontally curved alignment, depth of box girders and loadings. The objectives of the study are as follows:

a) Compare the variation of bending moments, torsion and shear due to variation in curvature.

b) Variation in deflections at mid-span of inner and outer webs of the box girder.

c) Compare maximum and minimum reactions and check for stability against overturning. The parameters considered for modeling box girders are as follows:

i) Overall Span lengths - From 20m to 45m in multiples of 5m.

ii) Radius of curvature – 75m, 90m, 100m, 150m, 200m, 250m, 300m, 400m and 500m.

iii) Depth – Span to depth ratio of 16 is adopted. The depths for different spans are as follows:

Table-1: Depths corresponding to the lengths for L/D ratio of 16

L (m)	20	25	30	35	40	45
D (m)	1.25	1.5625	1.875	2.1875	2.5	2.8125

iv) Box type - Single-cell rectangular box girder having 7.5m 2-Lanes carriageway with overall deck width of 8.5m is considered.

v) Geometric considerations - The web thickness for the mid sections is kept 300mm and the at end section up to L/10 it is kept 500mm. The web is varied from 500mm to 300mm between L/10 to L/5. E.g. For 20m span, the web thickness of 500mm is kept 2m from end and varying web from 2m to 4 m.

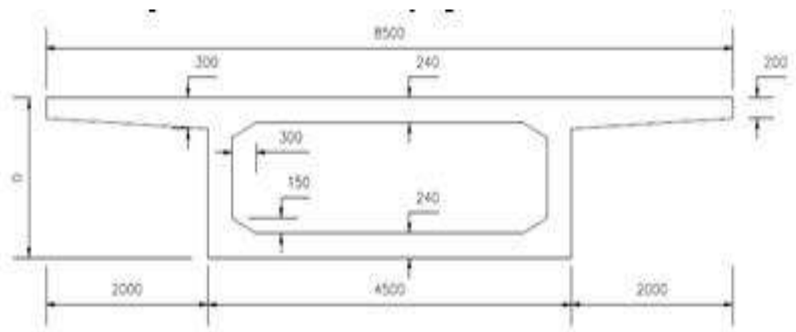

Fig-1: Cross-sectional dimensions of Rectangular Box Girder.

vi) The Loading considered in the analysis are -

a) Self weight (DL) of box girder

b) Super-imposed dead load (SIDL) form crash-barriers and wearing coat.

c) Live Load (LL) as per the IRC Loading such as 1-Lane Class 70R vehicle of 100ton or 2-Lanes Class A vehicles of 110.8 tons; whichever will create the worst effect. The appropriate impact factors as per IRC: 6-2010 [10] is applied to live load for different span lengths.

The analysis is carried out using the commercially available FEM software LUSAS Bridge Plus [11] for the above parameters.

III. FINITE ELEMENT MODELING AND ELEMENT DESCRIPTION

LUSAS is one of the world's leading structural analysis systems. The LUSAS system uses finite element analysis techniques to provide accurate solutions for all types of linear and nonlinear stress, dynamic, and thermal/field problems. The two main components of the system are LUSAS Modeller and LUSAS Solver. LUSAS Modeller is a fully interactive graphical user interface for model building and viewing of results from an analysis. LUSAS Solver is a powerful finite element analysis engine that carries out the analysis of the problem defined in LUSAS Modeller.

The components of the box girder are modeled with the thick shell surface geometry. Further the Surface geometry is discretise by generating mesh of elements which are defined by four nodes, thicknesses and the concrete material properties as per IRC: 18-2000 [12] and IRC: 21-2000 [13]. The model generated in the LUSAS is shown in the Figure2, 3, 4 below.

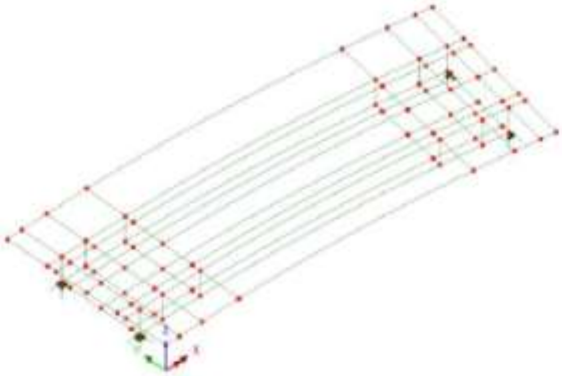

Fig-2: Curved Box girder model developed with LUSAS

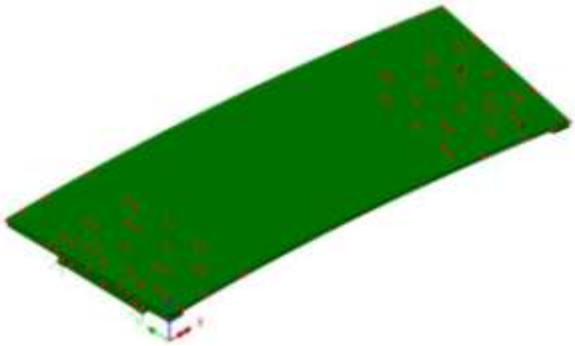

Fig-3: Model with member properties

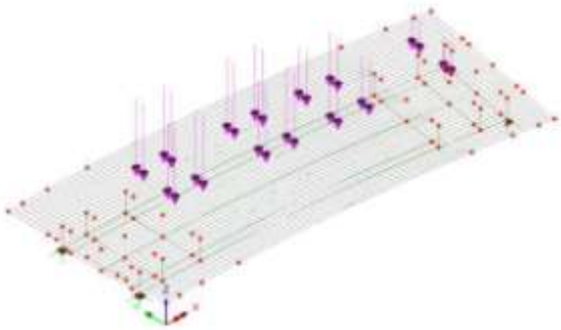

Fig-4: Model with load application

IV. RESULTS AND DISCUSSION

The horizontally curved box girders of 20 to 45m span lengths in combinations with radius of 75m, 90m, 100m, 150m, 200m, 250m, 300m, 400m and 500m totaling 54 models are analysed and the results for torsional moments, mid-span deflections and the reactions for Dead Load, Super-imposed Dead Load and Live Load are presented.

a) Variation in torsion, bending moments and shear against span radius

The maximum torsion, bending moments and shear forces for various span lengths and radii are compared. Figure 5, 6 and 7 shows the variations with the span radius.

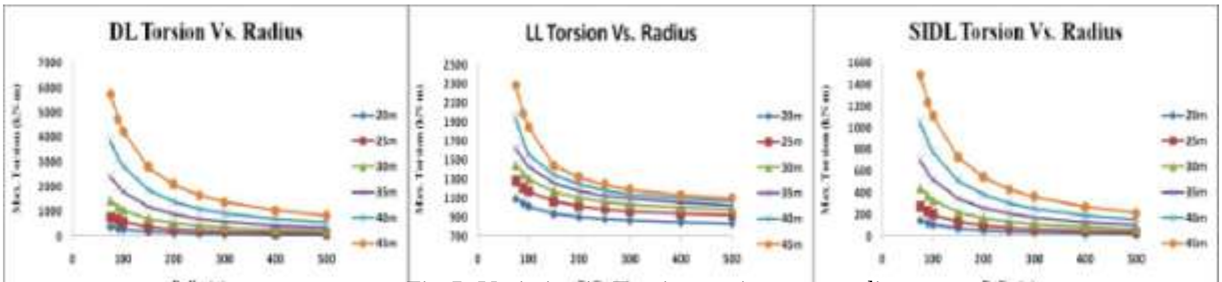

Fig-5: Variation in Torsion against span radius

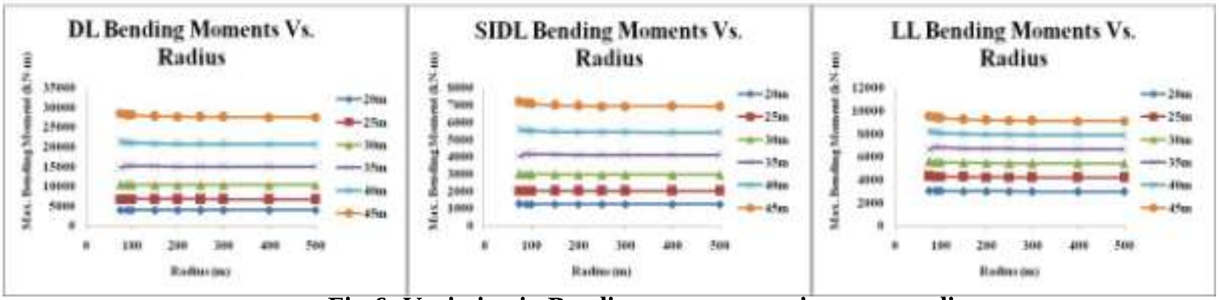

Fig-6: Variation in Bending moments against span radius

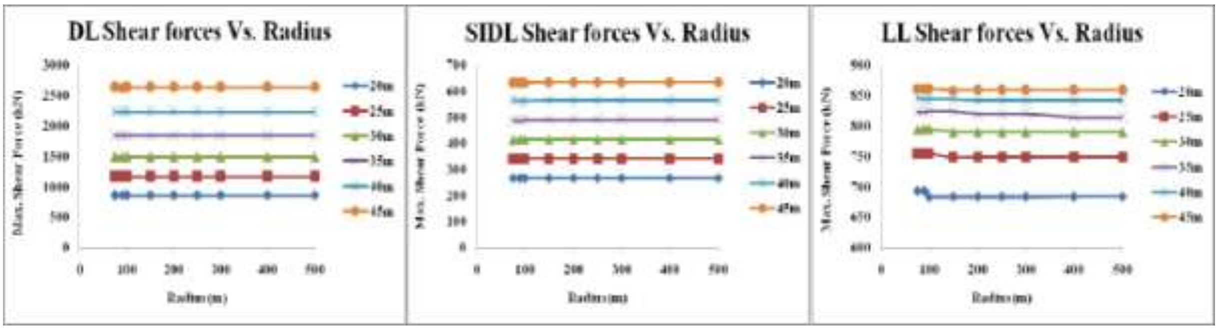

Fig-7: Variation in Shear against span radius

From the above figures, it is observed that there is no significant change in bending moments and shear forces for a span with different radii, but the torsional moments varies greatly due to the curvature effect. There is tremendous increase in torsion with decreasing span radius.

b) Mid-span deflections

For straight spans, all the webs are of same lengths hence there is no variation in the mid-span deflections below webs. But in curved box girders the length of the outer web is greater than the inner web and the load contribution for the outer web is more due to curvature effect which creates the torsion in the box girder hence the deflections below the outer web are more than that of inner web. The Figure shows the Mid-span deformation shape for the box girder.

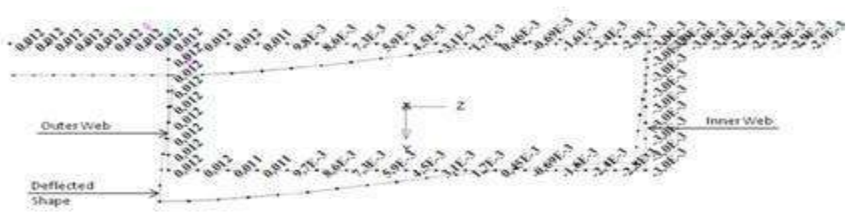

Fig-8: Mid-span deformation shape for the box girder.

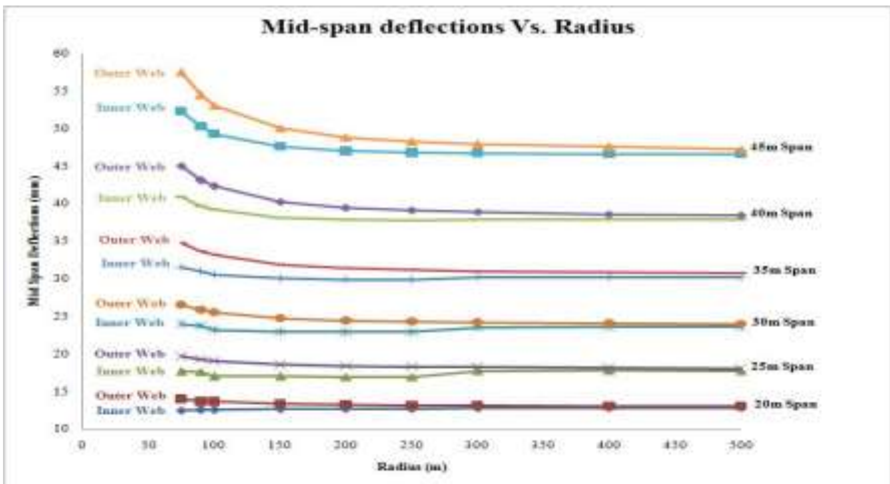

Fig-9: Variation in the mid-span deflections for inner and outer webs.

From the above Fig-9, it is observed that the mid-span deflections for the greater radius is nearly equal for a span, but the variation in the deflections is significant for the span radius below 200m.

c) Maximum and minimum reactions and stability against overturning

The curvature effect gives the maximum reaction on the outer support and minimum reaction at inner support of the box girder. The maximum and minimum reactions due to combined dead load, SIDL, live load, and centrifugal force for the box girder models worked out and the variation in the reactions on the inner and outer bearings for the above results is as shown in the Figure 10 below. The Max R indicates the maximum reaction on the outer support whereas Min R is the minimum reaction on the inner support.

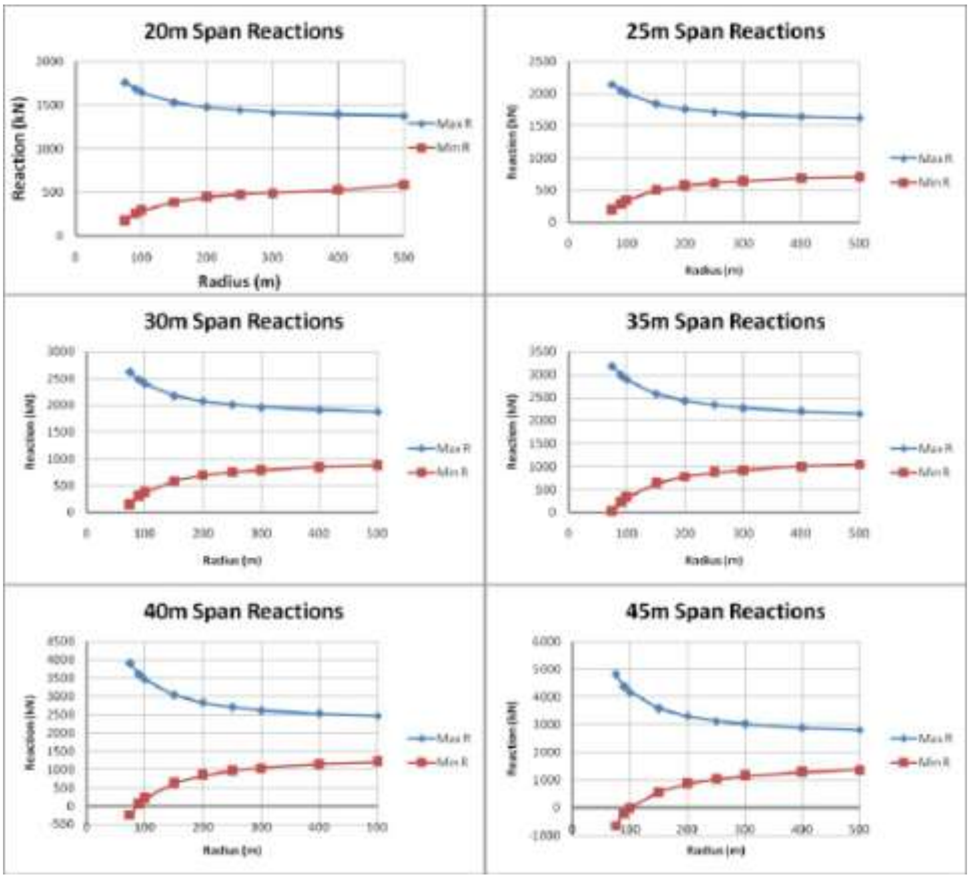

Fig-10: The variation in the reactions on the inner and outer bearings

There are some negative reactions which indicate that the box girders are not stable. Since overturning effects due to other factors such as wind load, seismic forces etc are not considered in the study, the stability of the box girders may be checked by considering the factor of safety against overturning of 1.5. Hence, the factor of safety against overturning of the box girders are worked out considering the ratio of stabilizing moments to the overturning moments as tabulated below.

Table-2: Factor of Safety against overturning for the box girders

Span (m)	Radius (m)								
	75	90	100	150	200	250	300	400	500
20	1.5	1.9	2.2	3.2	4.2	5.1	5.8	7.2	17.1
25	1.5	2.0	2.2	3.5	4.5	5.6	6.5	8.1	9.5
30	**1.4**	1.9	2.2	3.6	4.9	6.1	7.1	9.0	10.6
35	**1.0**	1.6	1.9	3.5	5.0	6.3	7.5	9.7	11.5
40	**0.6**	**1.2**	1.5	3.2	4.9	6.3	7.7	10.2	12.3
45	**0.0**	**0.6**	**1.0**	2.8	4.6	6.2	7.7	10.4	12.8

From the above table, it is observed that the box girders having the factor of safety against overturning less than 1.5 are not feasible or the sharp radius shall be avoided. If such sharp curves are unavoidable then the structural changes to the cross-sectional dimensions are made to stabilize or hold-downs or tension bearings are introduced to stabilize the box girders.

V. CONCLUSIONS

In this paper numerous curved box girder superstructure models are analysed for the various parameters such as span lengths, radius of curvature and loading are carried out using LUSAS Finite Element analysis software to access the more accurate bending moments, shear, torsion, mid-span deflections and support reactions. The conclusions made in this study are as follows:

1. It is observed that there is no significant variation in the bending moments and the shear forces for DL, SIDL and LL for the specific span length with different radii.

2. The torsional moments increase greatly with the decrease of the span radius of the box girder. There is more variation in torsion with span radius below 200m, whereas less variation for span radius above 300m.

3. The mid-span deflections at the soffit of the outer and inner webs vary significantly with radius of curvature of the box girder. For radius less than 200m there is considerable variation in the deflections. Such variation in mid-span deflection shall be accounted while achieving the required superelevations of the deck.

3. From the reactions, it is observed that the box girders having the factor of safety against overturning less than 1.5 are not feasible. The sharp radius below 100m shall be avoided. If such sharp curves are unavoidable then it may require structural changes to the cross-sectional dimensions to stabilize or hold-downs or tension bearings are introduced to stabilize the box girders which may increase the construction cost.

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