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Torsional Behavior and Constancy of Curved Box Girder Superstructures

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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 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. 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. The resultant bending moments, shear and the torsional moments of the various curved box girders are compared. Also the feasibility and stability of the curved box girder of various span length and radius considering support reactions are discussed.**

Keywords: **Curved Box Girder, Stability of Box Girder, Torsional Behavior, Flexural Behavior**

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 finite element models are analysed for different parameters such as span length, radius of horizontally curved alignment of box girder and loadings. The bending moments, shear and torsional moments are compared. Also the feasibility and stability of the curved box girder of various span length and radius considering support reactions 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 parameters considered 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 are considered.

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

Table I 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.

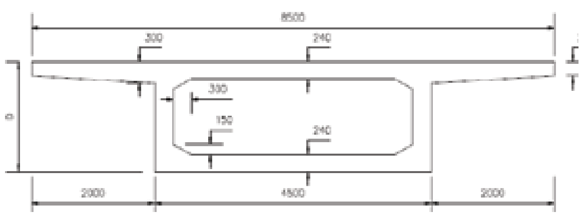

Fig. 1 Cross-sectional dimensions of Rectangular Box Girder

v) Geometric considerations - The web thickness for the mid sections is kept 300 mm 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.

vi) The Loading considered in the analysis are -

a) Self weight of box girder

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

c) Live Load as per the IRC Loading such as 1-Lane Class 70R vehicle of 100 ton or 2-Lanes Class A vehicles of 110.8 tons; which will create the most 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. The variations in the bending moments, shear and torsions for the various spans are compared. The maximum and minimum reactions are considered for the stability of the curved box girders.

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 models generated in the LUSAS are shown in the Figure 2, 3, 4 below.

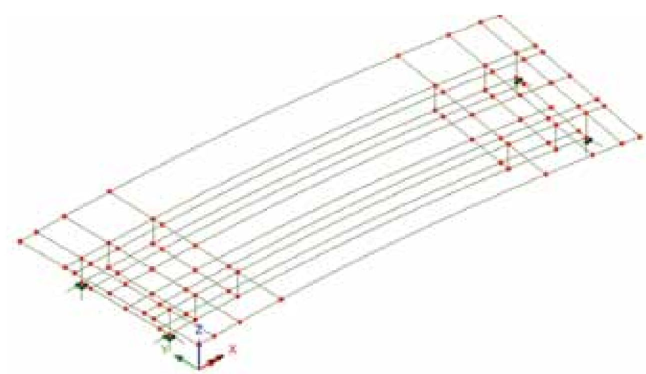

Fig. 2 Curved Box girder model developed with LUSAS

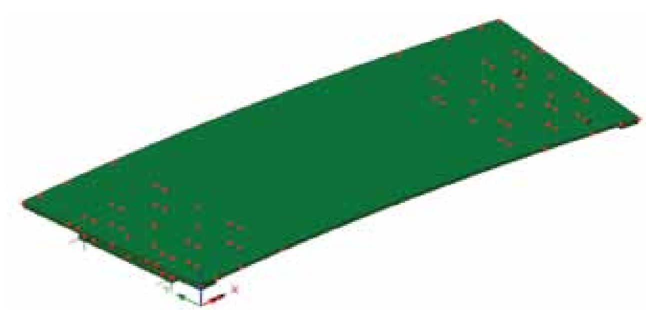

Fig. 3 Model with member properties

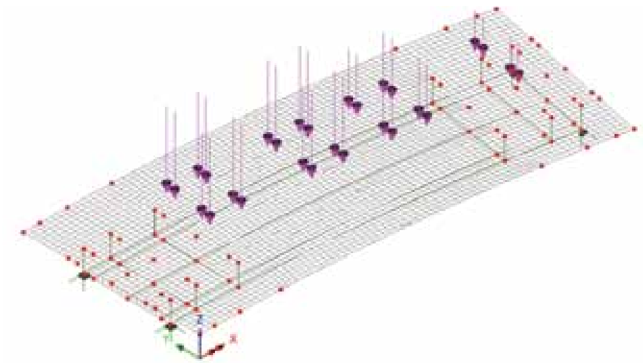

Fig. 4 Model with load application

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 bending moment, shear and torsion results for combined Dead Load, Super-imposed Dead Load and LiveLoad are presented.

A. Bending Moments, Shear And Torsion Results

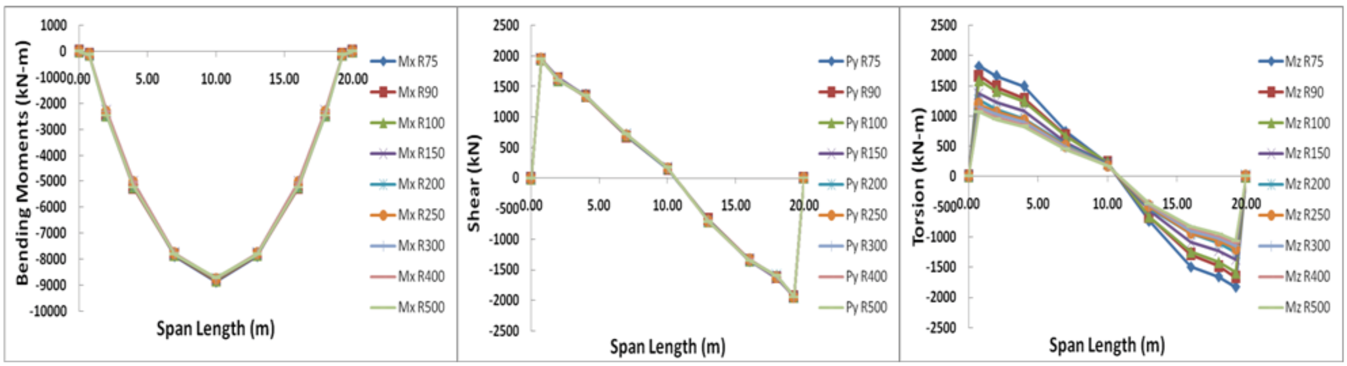

Fig. 5 20m Span bending moments, shear and torsion for various radii

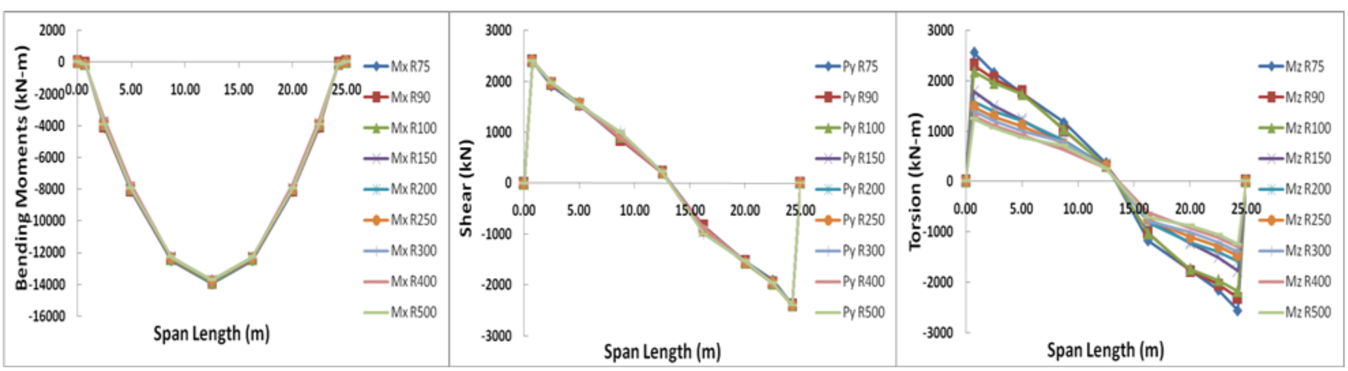

Fig. 6 25m Span bending moments, shear and torsion for various radii

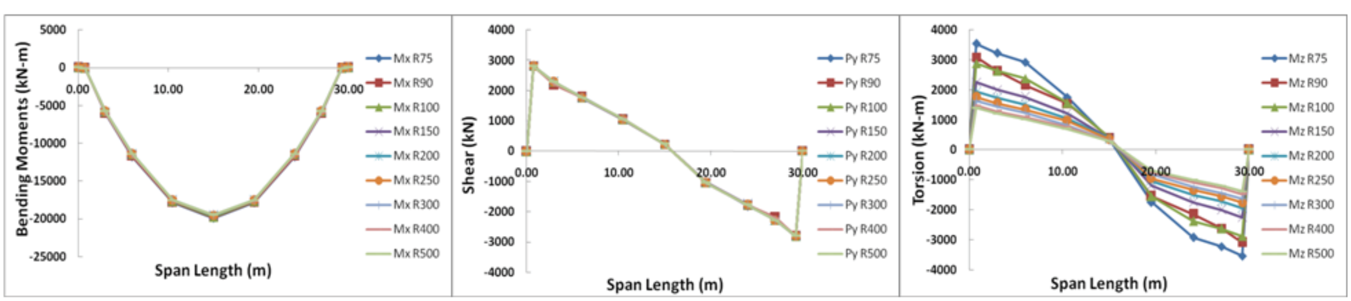

Fig. 7 30m Span bending moments, shear and torsion for various radii

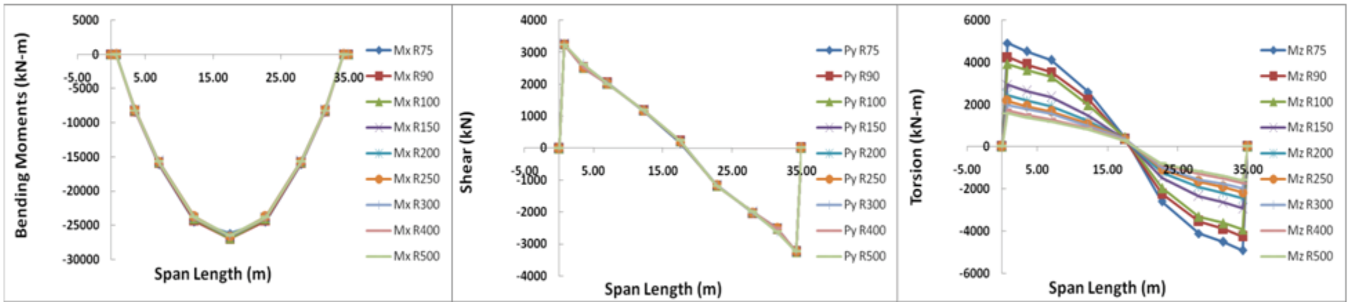

Fig. 8 35m Span bending moments, shear and torsion for various radii

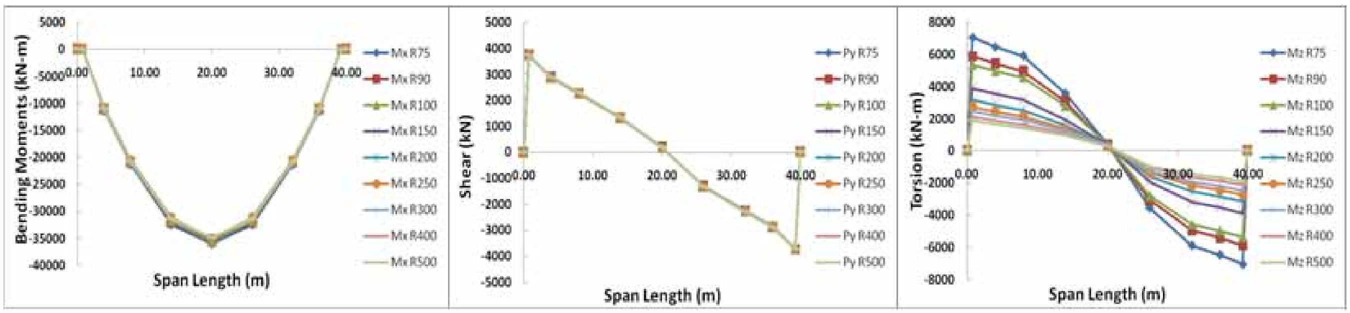

Fig. 9 40m Span bending moments, shear and torsion for various radii

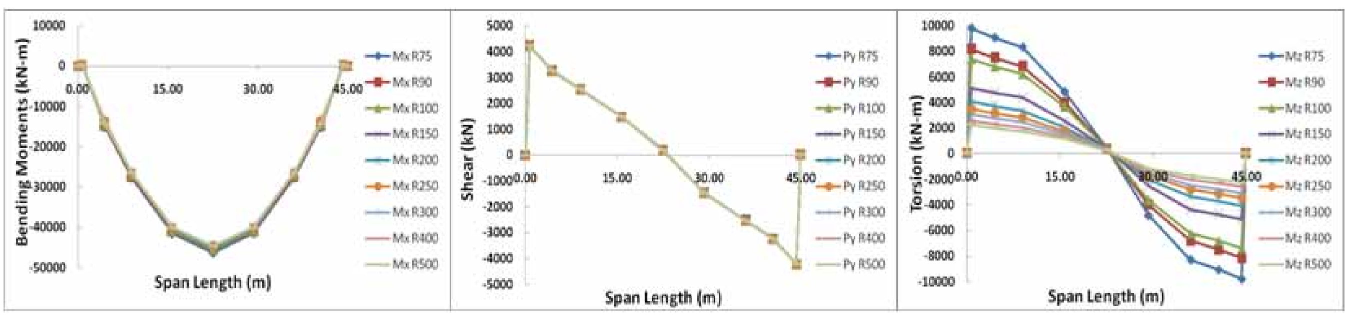

Fig. 10 45m Span bending moments, shear and torsion for various radii

From the above results, it is observed that the there is no significant variation in the bending moments and shear forces for different radii for a span. But the Torsional moments varies greatly due to the curvature effect.

B. Variation of Torsion Against Radius of Curvature of Span

The dead load, SIDL and Live load torsions against various radii for various spans are considered to assess the variation. The torsion increases greatly with the decrease in span radius. Figure 9 below shows the variation of torsion due to dead load, super-imposed dead load and live load against the radius of curvature of span.

Observing the Figure 9 to figure 11, the radius below 200m shows the tremendous increase in the torsional moments where as for radius more than 400m the variation is not significant.

C. Maximum and Minimum Reactions and Stability of Box Girders

The curvature effect gives the maximum reaction on the outer support and minimum reaction at inner support of the box girder. In the models, two bearings spaced at 4m centers on each end of the span are considered. The centrifugal force is also considered as per the IRC:6-2010, Cl. 202.

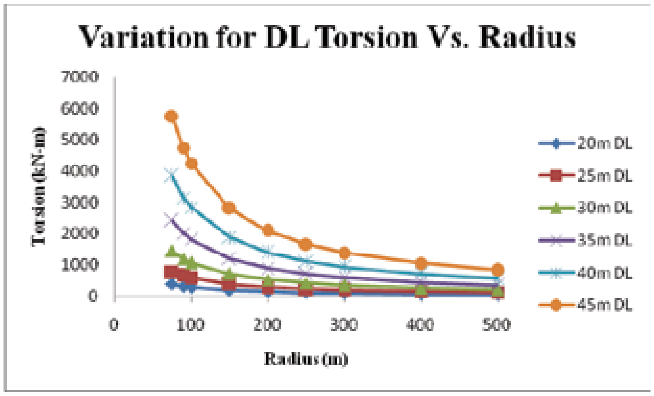

Fig. 11 Variation of Dead load torsion against radius of curvature of span

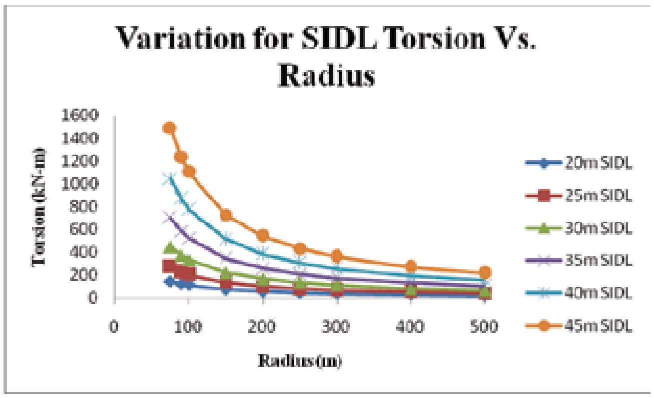

Fig.12 Variation of Super-imposed Dead load torsion against radius of curvature of span

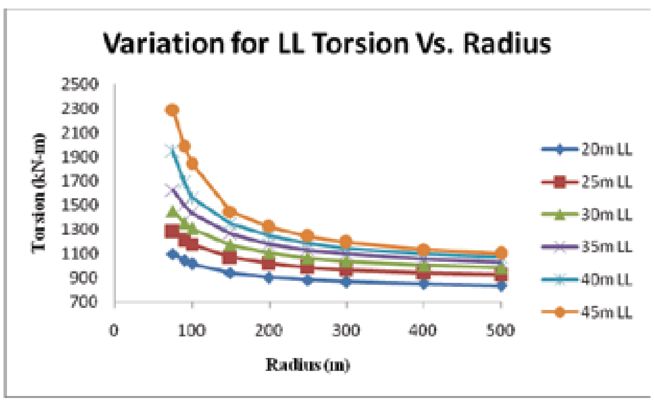

Fig.13 Variation of Super-imposed Dead load torsion against radius of curvature of span

The negative values in the Table II show the complete instability of the box girders.

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.

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.

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 and support reactions. The main conclusions madein 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 radius.
2. The torsional moments increase significantly 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 400m.
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.

TABLE II MAXIMUM REACTIONS AT OUTER SUPPORT AND MINIMUM REACTIONS AT INNER SUPPORT OF BOX GIRDER

Span (m)	Reactions (kN)	Radius (m)								
		75	90	100	150	200	250	300	400	500
20	Max R	1760.65	1690.80	1645.58	1530.56	1478.22	1444.16	1414.26	1393.76	1377.12
	Min R	174.06	254.17	289.72	391.77	447.40	479.14	492.63	526.29	589.98
25	Max R	2146.42	2052.55	2000.68	1839.41	1762.82	1716.68	1677.99	1647.15	1624.19
	Min R	195.20	300.91	350.69	501.73	570.92	619.11	641.42	685.38	707.32
30	Max R	2613.57	2471.39	2398.83	2180.98	2073.84	2010.25	1960.17	1914.01	1882.14
	Min R	149.99	303.99	375.10	586.36	690.80	752.82	787.03	846.51	877.55
35	Max R	3178.35	2984.11	2885.10	2577.52	2427.13	2338.38	2274.23	2196.86	2152.29
	Min R	22.27	231.00	329.87	636.42	784.47	872.44	921.20	1004.20	1047.84
40	Max R	3902.75	3602.80	3463.37	3044.87	2833.56	2710.95	2622.22	2530.95	2467.16
	Min R	-232.34	74.80	212.98	634.36	846.57	969.88	1044.15	1150.61	1214.50
45	Max R	4808.98	4374.72	4171.83	3588.19	3303.96	3136.99	3026.14	2891.45	2805.38
	Min R	-648.51	-209.18	-0.90	577.78	867.35	1036.96	1149.52	1286.15	1373.21

TABLE III FACTOR OF SAFETY AGAINST OVERTURNING FOR VARIOUS 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

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