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Study on Horizontal Curved Bridge – State of Art Literature Review

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Abstract - *Bridges are important and efficient structures which are comprised of variety of elements and substructures, namely the deck, abutment and foundation and possibly additional intermediate supports. Recently the horizontally curved beam bridge has become more desirable in modern motorway systems and massive cities. While numerous amounts of research are current to analyse and understand the behaviour of all kinds of box-girder bridges, the results from these different research projects are unevaluated and dispersed. Therefore, a transparent understanding of an accurate study on straight and curved box-girder bridges is required.*

In this paper, the analysis of horizontally curved prestressed concrete beam upper deck is studied by using three dimensional modeling and analysis. Section geometry and material properties are same altogether the models while its radius of curvature are different. Analysis is administered using the 70 R wheel IRC loading. The 3D Finite Element Models are prepared using CSi Bridge software. The results for shear force and bending moment are observed by keeping the identical material properties.

Key Words: *Curved beam bridge decks, prestress concrete, finite element model in csi bridge software, structural analysis, bending moment, shear force.*

1. INTRODUCTION

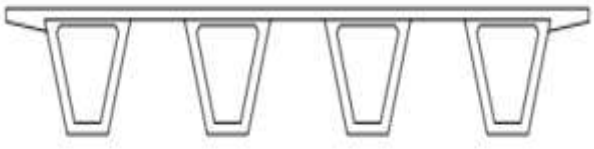
Prestressed curved box beam bridges are amongst the foremost common sorts of highway bridges. These bridges allow long spans to be achieved thanks to the prestress (as an economic solution), and are excellent in resisting torsion thanks to their 'closed' sectional nature. The look of those bridges has evolved over time, and therefore the design of prestressed bridges which are horizontally straight in form may be a well understood process. However, the client and/or engineer may be faced with the case where a horizontally curved deck solution is preferable. The traditional design consideration for prestressing is that the resistance of vertical load actions, hence prestressing cables are usually curved within the vertical plane to provide bending moments which oppose those produced by the loading (effectively causing an opposing 'equivalent' load). A horizontally curved bridge, by its geometric nature, would force the prestressing cable to follow the curve within the horizontal plane. This doesn't necessarily require the prestress to own deviation of horizontal distance from the section centroid which might otherwise cause prestressing moments within the horizontal plane. However, as curved bridges will suffer from torsion still as vertical loading effects, the presence of the prestress may prove beneficial in resisting any additional torsional effects, plus the sectional geometry of the beam.

1.1 Curved Bridge

Box girder cross sections may take the shape of single cell (one box), multi-spline (separate boxes) or multi-cells with a standard bottom flange. Box girders offer better resistance to torsion, which is especially of benefit if the bridge is curved in plan. because of the high torsional stiffness of the closed cross section of the box girders, which frequently ranges from 100 to 1000 times larger than the torsional stiffness of comparable I-shaped sections, the torsional moment induced by the curvature of the girder may be resisted by the box beam. The fabrication of the box beam is dearer compared to the I-shaped girder, but this extra cost is sometimes balanced by the reduction in sub structuring for the box beam, the highest of the box beam will work because the deck. Additionally, for long span bridges, where the segmental method of construction is chosen, prestressed concrete box girders have proved to be economical. The box beam comprises various sorts of geometries and forms, but the cross-section can generally be divided into single-cell, multi-cell or spread box beams as shown in figure 1

Single cell box girder

Multi cell box girder



Spread box girder
Fig-1: Types of cross sections

1.2 Analysis of curved girder

A curved girder with a horizontal radius of curvature of is taken into account. The girder is assumed to possess a hard and fast support at one end and a free support at the opposite end. This assumption for the boundary conditions doesn't hurt the generality of the matter. Also, it's assumed that the girder is under the uniform gravity load of. The length of the girder is and therefore the angle subtended by the girder is Θ.

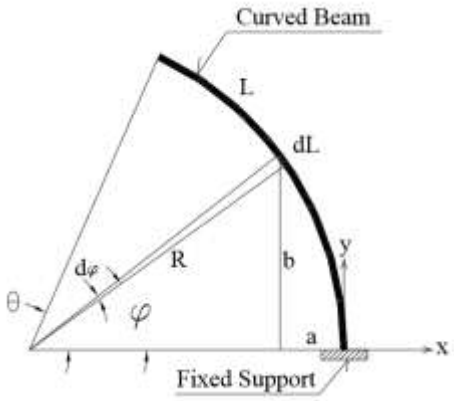


Fig-2: Plan View of a Curved Girder under Gravity Loads in z Direction

To find the support reactions, the equilibrium equations about the axes x, y and z are

$R_x = R_y = 0$ EQ-1.2.1

$R_z = wL$ EQ-1.2.2

$M_x = \int_0^L dM_x$ EQ-1.2.3

$M_y = \int_0^L dM_y$ EQ-1.2.4

$M_z = 0$ EQ-1.2.5

In order to calculate the moment reaction about x and y directions, an infinitesimal element of the girder with the length of dl and location coordinates (a,b) is considered the position of the element in the polar coordinates can be written as,

$a = -R\,(1 - \cos\varphi)$ EQ-1.2.6

$b = R \sin\varphi$ EQ-1.2.7

The integrals are calculated as follows,

$$Mx = \int_0^L dM_x = \int_0^L (b)(w\,dl) = R^2 w\,(1 - \cos\theta)$$ EQ-1.2.7

$$My = \int_0^L dM_y = \int_0^L (a)(w\,dl) = R^2 w\,(\theta - \sin\theta)$$ EQ-1.2.7

The moment Mx is that the bending moment of the curved girder at the support and therefore the moment My is that the torsional moment developed within the cross section of the girder at support. The noticeable fact is creation of torsional moment because of just gravity load, like self weight, which is unheard within the case of straight girders. To verify the above equations, the values of Mx and My are evaluated for a special case of R=∞ which could be a straight girder,

$\lim_{R\to\infty} Mx = w \lim_{R\to\infty} R^2 (1-\cos\theta) = Wl^2/2$

$\lim_{R\to\infty} My = w \lim_{R\to\infty} R^2 (\theta - \sin\theta) = 0$

A curved girder with a horizontal radius of curvature of is taken into account. The girder is assumed to own a hard and fast support at one end and a free support at the opposite end. This assumption for the boundary conditions doesn't hurt the generality of the matter. Also, it's assumed that the girder is under the uniform gravity load of. The length of the girder is and therefore the angle subtended by the girder is Θ.

2. LITERATURE REVIEW

2.1 Review of selected Literature

1) **A. S. Khairmode and D. B. Kulkarni -**In this paper, the analysis of horizontally curved prestressed concrete beam upper deck is studied by using three dimensional modeling and analysis. Section geometry, material properties and radius of curvature are same all told the models while angle of curvature is varying from 0o to 90oand angle of curvature are kept constant as 30°,60° and 90° and its radius of curvature varying from 25 m to 50m.Analysis is disbursed using the IRC Class AA loading. The 3D Finite Element Models are prepared using SAP software. The results for stresses are observed by keeping the identical material properties.

2) **Pragya Soni and Dr. P.S. Bokare** Many studies are available on suitability of box beam bridges for various spans and effect of stresses for skewed box beam bridge. The curvilinear nature of box beam bridges together with their complex deformation patterns and stress fields have led designer adopt approximate and conservative methods for his or her analyses and style. Recent literature on straight and curved box beam bridges has prohibited analytical formulations to raised understand the behavior of those complex structural systems. It had been found that researchers have used finite element method for the analysis of box Beam Bridge. However, not much studies are available for the look of box beam bridge. Hence, this study emphasized on the look and analysis of box beam structure. The literature also indicates that the assorted researchers have used ANSYS, MIDAS and Stadd-Pro for the analysis of Pre-stressed Concrete Structures using FEM.

3) **Ashish B Sarode, G R Vesmawala -** The horizontally curved alignments for the urban interchanges or highway bridges are getting more common and it's necessary to construct the structures curved in plan. Because of 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 can leads the instability of the box beam. The outer web is longer than the inner web because of which the mid-span deflections are more at the outer web than the inner web. During this paper, the many models for curved box girders are analysed using LUSAS FEA software for various parameters like span lengths, radii and loadings and also the flexural and trosional behavior, stability and mid-span deflections of the curved box girders of assorted parameters are discussed.

4) **Syed Habibunnisa, Komma Hemanth Kumar Reddy and Mukkala Priyanka -** In this paper a parametric comparison was made between straight bridge and different curved bridges and skew bridges. Then these bridges were analyzed for dead, modal and moving load cases. This was tired order to review difference within the results obtained between straight, curved and skewed bridges for dead and moving load cases. The modeling a part of the both bridges was done by using SAP 2000 within which there's an option named bridge wizard by which modeling of the bridge can tired a sequential order. After analyzing for burden case unlike straight bridge there's torsion within the curved and skew bridges along the length of the bridge as there's unsymmetrical mass distribution in curved bridge about horizontal axis. Modal analysis showed the curved and skewed bridges have more initial torsional modes but whereas for straight bridge the initial modes were transverse and longitudinal. The amplifications in torsion were large compared to other parameters for curved and skewed bridges compared to straight bridge.

5) **Vraj J. Shah** - This paper present a literature review associated with Curved span PSC beam. The curvilinear nature of beam bridges with their complex deformation patterns and stress fields have led designers adopt conservative methods for analysis & design. Recent literature on curved girder bridges to know the complex behavior. Within the present study a trial has been made to review the importance of PSC Box Girders & Type, Curvature effect of span, superload effect, wrapping stress in curved beam, Shear Lag & Torsion effect thanks to curvature. Comparative study of study & design of PSC T-girder with PSC beam using software Staad - pro, Normal & Skew beam with different geometrical combination has been included.

6) **M K Harish, V R Chethan and B T Ashwini** – The design of a Highway bridge is critically conditional standards and criteria for the protection, quality and overall cost of the project. beam bridges are terribly unremarkably used. The box girder ordinarily includes of pre-stressed concrete, steel or steel concrete. Various software's is used for the Analysis and style of bridges which is able to be far better and fewer time consuming compared to manual calculations. This project discusses the Analysis of beam bridges under AASHTO loading of two differing types Single1cell and Multi cell with AASHTO standard codes followed superstructures subjected to load of heavy vehicles to grasp its structural behaviour and to come to a decision which section is healthier when comparing the ends up in determining the economical section all told aspects for the assumed problem statement. Also to grasp about the modelling pattern using CSi bridge and to grasp the structural behaviour1considering the bridge object responses and horizontal moments of both single cell and multi cell box girders under AASHTO loading conditions.

7) **Rishabh Jain and Mr. Ajit Singh -** This paper presents a literature review on the duration Curved Box PSC beam. The curvilinear nature of beam bridges with their complex patterns of deformation and stress fields have led designers to adopt conservative methods for analysis and style. Recent literature on curved girder bridges to know the complex behavior. during this study, an endeavor was made to review the importance of the PSC Box Girders & Type, the wide curvature effect, the effect of the payload, packaging stress in curved girder

Box, Shear Lag & Torsion effect because of the curvature. Comparative Study of the analysis and style of the PSC T-beam with the PSC beam with the Staad software - pro, Normal and Skew beam with different geometrical combinations has been included.

8) **Kiran Kumar Bhagwat, Dr. D. K. Kulkarni and Prateek Cholappanavar -** Box girder bridges are the widely used upper deck systems thanks to cost effective and artistic solutions for over passage, under passage, separation structure and viaducts found in today's modern highway systems. The behaviour of beam bridges is complex in nature thanks to the non-uniform distribution of stresses in longitudinal and transverse directions. Recent literature on beam bridges suggests that finite element method is suitable and effective in analyzing box sections. During this study linear analysis of three box girders (Rectangular, Trapezoidal and Circular) has been meted out using finite element software CSi Bridge 2017 as per Indian Road Congress (IRC) provisions. The behavior of box girders with uniform increments full has been discussed. Detailed study is conducted for various parameters like deflection and longitudinal stress. The validity and accuracy of this work has been also accessed by comparing the software results with manually calculated results.

9) **Mulesh k. Pathak -** In this paper, various behaviours like bending, shear, axial & torsion are presented for horizontally curved RCC box bridges considering 3-D FEM using SAP software. FEM models are prepared for four different span lengths keeping the identical material properties with varying degree of curvature from 0° to 90° for various load conditions & combinations to induce multiplication factor for various actions like BM, SF, AF & TM w.r.t to straight bridge to multiply the required parameters of straight bridge to induce that for curved bridge. This approach simplifies analysis & the preliminary design of curved bridge section.

10) **Anurag Deshpande, H M Jagadisha and Aravind Galagali-** The bridge model considered for the project consisted of two spans each of 50m, with abutments at both ends and piers at mid section. 2 columns of 1.5m diameter were considered at mid section. during this project beam bridge and that i girder bridge are compared with horizontal curvature being (R= inf, 150m, 250m) and column skewness with (0, 15, 25 degrees) variation. The results of the study like modal results and pushover results were tabulated and compared with other bridge models. The software used for the study is CSI Bridge 2016 v18 subjected to seismic load subjected to code of 1893 2002 and IRC 6 for vehicle loading.

3. CONCLUSIONS

From review of above papers, following findings are observed.

1. With increase in the radius of curvature and angle of curvature, the stresses at the top of the prestressed curved bridges increases while stresses at the bottom of the bridges decreases. As the radius of curvature and angle of curvature of prestressed concrete curved bridge increases the midspan vertical deflection goes on decreasing. [1]

2. After going through the existing literature on analysis of RCC box girder it was found that many researchers have studied the comparison between various section of box girder bridge and from the study it was found that rectangular box girder section is economical and hold good strength for torsional,warping stresses.[2]

3. Deflection increases with increase in curvature almost linearly and with skew angle it does not follow a regular pattern it might decrease or increase on the skew angle.[3]

4. The literature deals with: - (1) elastic analysis and (2) experimental studies on the elastic response of box girder bridges. In elastic analysis the author represents the orthotropic plate theory method, grillage analogy method, folded plate method, finite element method, thin-walled curved beam theory etc [5]

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