Curved Span PSC Box Girder Bridges: A Review

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Summary - This paper presents a literature review on the duration Curved Box PSC beam. The curvilinear nature of box girder bridges with their complex patterns of deformation and stress fields have led designers to adopt conservative methods for analysis and design. Recent literature on curved girder bridges to understand the complex behavior. In this study, an attempt was made to study the significance 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 due to the curvature. Comparative Study of the analysis and design of the PSC T-beam with the PSC box girder with the Staad software - pro, Normal and Skew Box Girder with different geometrical combinations has been included.

***Keywords* – Curved Bridges, Curved PSC Box, Structural Analysis & Design, Prestressing, Wrapping Stress, Torsion, Bridge Design, Shear Lag, etc…**

I. INTRODUCTION

The construction beam span curved bridges in the modern road network exchangers has become increasingly popular for economic and aesthetic reasons in many countries worldwide. Particularly in India especially in cities increasingly such alignment curve bridges were used in the design of the crowded urban areas where multilevel interchanges should be constructed with rigid geometric restrictions.

The box of the alignment beam bridges curve are very complicated analysis and design because of their complex behavior with respect to bridges straight bays. Treat bridges horizontally as curve right is that of the recommended way to simplify their analysis and design procedures according to some foreign codes, but these recommendations are not mentioned in the IRC code. The recommendations in foreign codes (AASHTO & CHBDC-LFRD) are underestimates the real structural behavior of curved beams scope of caissons.

Bridges curves can be constructed entirely of reinforced concrete, prestressed concrete, steel or composite deck concrete on steel I or caissons. concrete box girders are generally cast in situ or prefabricated in segments erected on shoring or a part of launching and prestressed. The platforms may be of steel, reinforced concrete or prestressed concrete. Curved composite box beams have a number of unique qualities that make them suitable for such applications, for example 1). Their structural efficiency allows designers to build long thin bridges have aesthetic appearance; and 2). composite housings are particularly high torsional and can be easily designed to withstand high torsional forces demands created by curvature of bridge and horizontal centrifugal vehicles. composite bridges curves boxes typically include one or more U-steel beams attached to a concrete deck by shear connectors. individual steel diaphragms link the channel beams periodically along the length to ensure that the bridge system behaves like a unit. The cross section of a flexible steel box (ie, can skew) in the transverse direction and must be stiffened with transverse frames which are installed between the membranes to prevent distortion. Web and the lower plate stiffeners are needed to improve the stability of relatively thin steel plates, which form the steel box. During construction, the overall stability and torsional stiffness of the beam are reinforced with high bracing elements. These bracing elements become irrelevant once the concrete hardens bridges, but are usually left in place anyway. Paper cover the references related to the development of the specifications guide charges, including the behavior of beams curve box, load distribution and codes of practice for bridges and box straight curves, dynamic response, Shear Lag & effect torsion and ultimate strength of these bridges.

II. LITERATURE REVIEW

Khaled M. Sennah & John B. Kennedy [1] conducted
(1) Elastic analysis and (2) experimental studies on the elastic response of box girder bridges. Elastic analysis, they represent the orthotropic method of the theory of the plate, the roasting method of analogy, the method of bent plate, finite element method, the theory of the curved beam to thin wall, etc.
The curvilinear nature of box girder bridges with their complex patterns of deformation and stress fields have led designers to adopt conservative and approximate methods for their analysis and design. Recent literature on the straight box bridges and curves dealt with analytical formulations to better understand the behavior of these complex structural systems. Few authors have undertaken experimental studies to investigate the accuracy of the existing method.
Kenneth W. Shushkewich [2] conducted approximate Concrete Box Girder Bridges Analysis. The actual behavior in three dimensions of a bridge girders box as predicted by a bent plate, finished strip or finite element analysis can be approximated using simple membrane equations in conjunction with planar frame analysis. This method is useful because almost al

structural engineers have access to a plan under computer program, while many have neither access nor the desire to use more sophisticated programs. In particular, the method allows strengthening and prestressing be proportionate to transverse bending, and brackets to be assayed for the longitudinal shear and torsional simple unicellular prefabricated concrete segmental box girder bridges. The author considers the following to the explanations: (1) the webs may be inclined or vertical. (2) Self-weight, uniform load and load on the canvas can be considered relative to the transverse bending. (3) Both balanced (flexion) and expenses (twisting) anti-symmetric can be considered relative to the longitudinal shear and torsion. This document is particularly useful in the design of single-celled precast concrete bridge beam segmental box regardless of the shearing effect and leg torsional deformation. The author represents the three examples caisson bridges with different load cases and concluded that the results of an analysis of the folded plate that is believed to be accurate may be approximated closely using a simple equation using membrane together with a plane frame analysis.

K. Y. Cheung et al. [3] discussed curved bridge Box Girder based on the curvilinear coordinate system, the method of spline finite strip is extended to the elastic-static analysis. As the curvature effect can not be ignored, the souls of bridges must be treated as thin shells and flanges flat curved plates. The shape functions for description of the displacement field (radial, tangential and vertical) are given as a product of B-splines 3 in the direction and longitudinal piecewise polynomials in the other directions. The stress-strain matrices may then be formed as in the standard finite element method. Compared with the finite element method, this method provides considerable savings in terms of computer time and effort, because only a small number of unknowns are usually needed in the document shows three examples analysis.This box bridges beams of different geometric shapes in order to demonstrate the accuracy and versatility of the method. This method has been recently developed by Cheung et al. (1982) for analysis of the right straight plates and wells. It was later extended to oblique plates (Tham et al., 1986) and plates of arbitrary shape (Li et al., 1986).

Ricardo Gaspar & Reboucas Fernando Stucchi [4] presented Web Design Subwoofer concrete bridges. An experimental study was conducted in order to verify the validity of the approach developed recently. The following failure modes were considered: excessive plastic deformation of the brackets, the crushing of compressed struts and failure of the stirrups due to fatigue. The experimental results showed a good agreement with the results of the proposed approach. In addition, tests have revealed new aspects of behavior to fatigue failure of the bracket due to fatigue occurred in several stages, one at a time gradually. In any case, failure occurred near the connection between the band and the bottom edge. In this article, the approach of strengthening sum, the approach of Comparison of strengthening, Thürlimann approach, and the approach of stucchi is considered. newly developed approach: This new approach implies that the most realistic model is the one that considers the strength increment AT, due to the timing of transverse bending is balanced by both an increase in ΔTC of concrete compressive and a decrease in the tensile force ΔTtin the stirrup leg adjacent the compression brace. Therefore, AT = ΔTC + ATT. This proposal considers the two ideas in Thürlimann and application Roach stucchi. Similarly to Thürlimann of and Stucchi of this method propose that up to a certain level of time mmax1 transverse bending, balance is achieved by the eccentricity of the single spacer, the width of which should be limited by shear strength TRwdwithout the need for additional reinforcement. For higher values of the transverse bending moment, this model proposes that the AT increment force would increase the compression force and simultaneously reduce the tensile force T in the leg adjacent to the spacer stirrups. The equation for the moment of equilibrium is given by,

$$m_{max2} = C\, e_{max} + \Delta T_C \,(e_{max} + \;) + \Delta T_t\, b_w$$

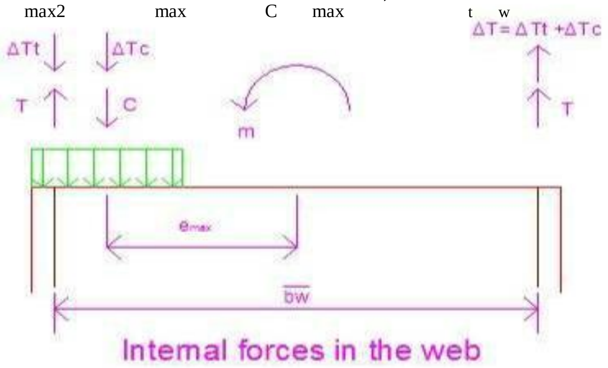

Figure:1 Newly Proposed Design Approach

Mr. Ayman Okeil & Sherif El Tawil [5] carried out detailed investigation of warping related stress in 18 composite steel-concrete beam bridges box. Bridges designs were adapted from existing bridges plans in the state of Florida and encompass a wide range of parameters, including the horizontal curvature, transverse properties, and the number of bays. Bridges after which the analysis are modeled prototypes were designed by different companies and built at different times and are considered representative of the practice of the current design. The forces are evaluated from analyzes that take into account the sequence of construction and deformation effect. Loading is considered under the provisions of AASHTO-LRFD 1998. The differences between the stresses obtained by taking into account the warpage and those calculated ignoring the warping are used to evaluate the effect of the deformation. The analysis results show that the distortion has little effect on both shear and normal in all decks.
Kurian Babu & Devdas Menon [6] conducted an estimate Reduce load single cells Concrete Bridges-box. The simplified equations available at this time to predict the collapse loads of concrete box girder bridges with unicellular ends simply supported are based

either on the analogy or collapse of space grillage mechanisms. Experimental studies by different researchers revealed that the two formulations available to predict the load of collapse, based on the mechanisms of collapse is more versatile and better suited to the sections of the box. As part of a bending mechanism of the pure collapse, the existing formulation was found to predict the load of collapse with a greater accuracy. However, in the presence of a distortion in cross-section, there are significant errors in the existing theoretical formulation. This paper attempts to solve this problem by proposing an amendment to the existing theory, incorporating an empirical expression for assessing the degree of formation of plastic hinge area under bending distortion collapse mechanism. The modified theoretical formulations are compared with experimental results available in the literature. New series of experiments are conducted to validate the modified theory proposed to estimate the burden of collapse. In any case, we see that the modified theory to predict closely the breaking load match with experimental results.

Pure of collapse bending mechanism:

The equation for collapse load $P = (\overline{F}_b h + 2 F_W h_1)$

F_b & F_W = Total yield force of the reinforcement provided in bottom flange and one web

h = distance from the c.g of bottom flange steel to centroidal axis of top flange

h_1 = distance from the c.g of web steel to centroidal axis of top flange

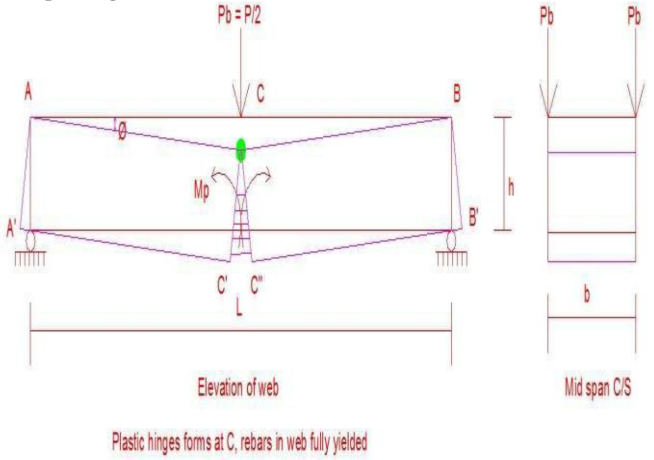

Figure: 2 Pure Bending Collapse Mechanism

Shi-Jun Zhou [7] conducted Shear Lag Analysis prestressed concrete Box GirdersThe delay shearing effect is one of very important mechanical characteristics of caissons. Many theoretical research efforts and the method of analysis of shear lag effect in thin-walled box beams have been made for many decades, and much progress has been made. Most studies on the shear lag effect in boxes are only concerned with concentrated loads and uniformly distributed loads. In this paper, a finite element method based on the variational principle is presented to analyze the effect of preloading on shear lag in boxes. The procedures and milestones are listed to demonstrate how to use the GEF project, which is verified by the method of analysis and numerical examples. The delay shearing effect in boxes with various types of pretensioned support conditions is analyzed in detail. The shear lag effect in prestressed caissons is more apparent than under uniform loads or concentrated loads vertical. Values and the distribution of shear lag coefficients are connected to the anchor points of the prestress and the distribution of internal forces along the beam under the uniformly distributed and the combined prestressing load. Among the findings of the study is that the negative shear lag under the uniformly distributed load and prestressing can occur to both the average length of a simply supported housing and the fixed end of a door box overhang beam.

Robert K. Dowell & Timothy P. Johnson [8] discussed shear flow Solution Bridges closed as in Twist box. To provide a desired rigidity and strength in torsion, super structures bridge are often built with a section made up of several cells that have thin walls relative to their overall size and resistance to Saint-Venant torsion shear flow (per unit strength length) that develops around the walls. For a single thin-walled cell subjected to torsion, the shear flow is constant along each of its wall while the shear stresses vary around the section according to changes in the wall thickness. When the section contains many cells they all contribute to the strength and torsion applied to the elastic continuity each cell must twist the same amount. With these considerations, the equilibrium and compatibility conditions permit simultaneous equations to be formed and solved for determining the shear rate for each cell. A second approach is the relaxation method that distributes the additional shear flow back and forth between the cells, thereby reducing errors of each dispensing cycle, until the final shear flows for all the cells are similar to correct values. A major advantage of this method is that it does not require setting up and solving simultaneous equations, which promotes situations where the calculation of the hand is desired. In this article, a closed form approach is introduced to determine exactly, both the torsion constant and any shearing of the multi-cell cross-sections under torsion stream; no simultaneous equations are needed and there is no need to distribute the shear flow back and forth between cells. Simple closed form equations are derived which give shear flow for cross-sections with a number of arbitrarily shaped cells.

Imad Eldin Khalafalla & Khaled M. Sennah [9] discussed Bend Limitations for Slab-on-I-Girder Bridges. In recent years, curved bridges horizontally have been widely used in congested urban areas, where the multi-level exchange structures are required for modern roads. In bridges with the light of curvature, the curvature effects on bending, shear and torsional stresses can be ignored if they are within an acceptable range. Treatment of horizontally curved bridges as straight bridges with limits is one of the ways to simplify the design process. Some specifications and bridge design codes indicated limits to treat horizontally curved bridge deck as law. However, these limitations do not differentiate cross the bridge the sectional configurations, in addition to being inaccurate to estimate the response of the structure. In addition, these specifications have been developed mainly for the calculation of bending moments of the beams. In this article, the author discusses the limitations of the Canadian curvature of the Road Bridge Design (CHBDC), AASHTO-LFRD Bridge Design Specification, and AASHTO Guide Specifications for Horizontally Curved Bridges. The AASHTO Guide Specifications Bridges curved Horizontally indicates that for I-girder bridges in composite steel, the curvature effect can be ignored in determining the vertical bending moment when the three following conditions are met: (1) beams are concentric; (2) carrying lines are not skewed more than 10 ° relative to the radial; and (3) the duration of the arc, divided by the duration of the beam, is less than 0.06 radians. AASHTO Guide specifies that the arc length L is the arc length of the beam in the case of single span bridges or 0.9 times the arc length of the beam to end spans of bridges continuous and 08 times the arc length of the beam to the inside length of continuous bridges. If these conditions are met, the AASHTO Guide specifies that the dead load applied to the composite bridge should be distributed uniformly to steel beams, and load balancing of living factors for bridges rights should be used. At the same time specify CHBDC for bridges that are curved in the plane and are built with the supported building, a simplified method of analysis can be applied by treating the bridge as a right, where both the following conditions exist: (1) there are at least two intermediate diaphragms per bay; and L2 / BR ≤ 0.5, where B is the width of the bridge, L is the curved center line span length, and R is the radius of the curvature. The curvature of boundary CHBDC equation does not include the effect of the continuity of the span length. Also, it does not differentiate between bridges with open and closed sections. However, the clause C10.13.30.2 Chapter 10 "steel structures" of CHBDC comment states tha t "for bridges over 90m radius of the longitudinal moments can be evaluated for a straight span. The third edition of the Highway Code deck Ontario Design (OHBDC), published by the Ministry of Transportation of Ontario, said the curvature effect can be neglected in the structural design considerations as that two conditions are met: (1) L2 / BR ≤ 0.5 (2) R> 90m. To investigate the accuracy of the codes above the limits of the curve, a series of horizontally curved, braced concrete slab-on steel I beams and slabs of concrete I girder bridges were analyzed by the author using three-dimensional modeling by finite elements, to study their death under load behavior. Parameters considered to longitudinal bending stresses beams, vertical deviation, vertical support reactions, and the bridge fundamental bending frequency for various degrees of curvature, span length, the bridge width, and the continuity of the length. Empirical equations for these force have been developed based on those of straight bridges. The provisions made in the bridge code to handle a curved bridge deck as a right were then correlated with the values obtained from the finite element modeling. Based on the author concluded that the curvature of limitations codified results were dangerous. And empirical expressions developed to determine these boundaries more accurately and reliably.

Dereck J. Hodson et al. [10] evaluated the load distribution factors live bending to cast in place box girder bridges. The typical live load test response was recorded during a live static load test. This test involved driving two trucks heavily loaded through the instrumented bridge on selected roads. The instruments used to record the response of the bridge were strain gauges, displacement sensors, and tilt sensors. The measured data were then used to calibrate a modeling system FEA using solid elements. From this finite element model, the load distribution factors in theoretical and live load capacity for the test deck were determined and compared with the factors and assessments provided in the AASHTO-LFRD specifications. A parametric study of cast in place, bridge caissons with the modeling system calibrated finite element was then used to study how various parameters such as the span length, spacing of beams, parapets, skew, and the thickness of the platform affects the distribution of the load directly to the bending factor. Based on the results of a parametric study, a new equation that predicts more accurately the external beam distribution factor is proposed.

Alok Bhowmick [11] presented constructive provisions of IRC: 112-2011 Compared to previous codes (IRC: IRC 21 &: 18) Part 2: Detail Requirement Structural Detailing for members and ductile seismic resistance (section 16 and 17 IRC: 112). The unified code of concrete (IRC: 112), published by the Indian Road Congress (IRC) in November 2011 combining the code for the reinforced concrete and prestressed concrete structures. The new unified concrete Code (IRC 112) represents a significant difference from the previous practice of Indian IRC: IRC & 21: 18. The code is less prescriptive and offer a wider choice of design and detailing methods with the scientific reasoning. This new generation of code, when used with a full understanding, will bring benefits to all sectors of our society as it will eventually lead to the construction safer to make a tangible contribution to a sustainable society. The current situation in the industry is that most consulting agents are struggling to understand this code, which is not so easy to use. Since the designer is difficult to time pressure, the majority of consultants are unfortunately spend their precious time in compliance with the prescribed code of rules, acting as technical lawyer, with little understanding.

The new code covers retailer in much more detail than previous codes. There are three sections on the details in the new code (namely Article 15, 16 and 17). General rules retailer are covered in Article 15. In addition, the article covers the specific rules detailing for beams, columns, walls, brackets, cornices and areas below bearing etc. Article 17 covers ductile details seismic review. The purpose of this document is to provide an explanation of various clauses of Article 16 and 17 of the IRC 112 and provide a comparative analysis with the previous codes. This document is following a part-1 published in the journal IRC covering article 15 of the code.

Khaled M. Sennah & John B. Kennedy [12] discussed various topics such as (1) the different configuration of the bridge box girder; (2) issue of the construction; (3) platform design; distribution (4) load; (5) deflecting and camber; (6) the requirement bracing; (7) of the end diaphragms; (8) the thermal effects; (9) vibration characteristics; (10) the impact factors; (11) the seismic response; (12) ultimate load carrying capacity; (13) buckling of the individual element forming the box sections; (14) fatigue; (15) the curvature limits provided by a curved bridge processing codes in a straight line. The objective of this study is to provide the most important reference highlights linked to the development of the current guide specification for the design of bridges and curves straight box. Construction of box girder bridges curves in the modern road network exchangers has become increasingly popular for economic and aesthetic reasons. Box beam section may take the form of a single cell, multi-vertebral column, or multi-cell with a common bottom flange.

T. Vishwanathan [13] explained in section 8 of the IRC: 112 ultimate limit states of linear elements for bending analysis covering the bending beams. It covers the basic principles, different blocks of stress and also design rectangular beams, T-beams and doubly reinforced beams. The uses of the horizontal leg and inclined leg stress strain diagrams for steel were also explained. An example of beams design and verification of the beams were covered in detail. The code describes three types of stress blocks to calculate the ultimate moment of resistance which, as shown in the figure below.

The εcu3 value εcu2, εc3, εc2 can be obtained from Table 6.5 of the IRC 112 and the λ value and η can be obtained from section 2.9 of annexure A2. Designer can use any of the stress blocks, but the most common are the parabolic stress block and rectangular stress block. The design value of concrete compressive strength fcd =

$\frac{.}{\quad} = \frac{.}{.} = 0.446$ fck. For accidental

combination = 1.2

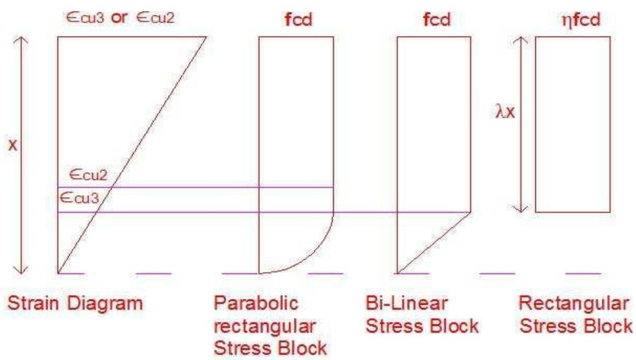

Figure: 3 Stress Blocks

The parabolic-rectangular stress block will be converted in to equivalent rectangular stress block having uniform compressive strain spread to neutral axis giving the same total compression force. The diagram of the center of gravity will be maintained identical to that of the parabola strain rectangular block. For design, it will become very easy to manipulate the rectangular bounding box. When the parabolic rectangular bounding box is converted to equivalent rectangular stress block, obviously the average stress far will work out to be less than fcd. First, we must work out the equivalent stress factor to reach fav for different concrete qualities of the value fcd as shown in Fig.

The rectangular bounding box which is relatively easier stress block may also be converted to constraint average concept of block diagram. The CG of the equivalent stress block must be maintained at the same distance from the original stress block to be unchanged when the capacity. η and are defined in Equation A2-33, 34, 35 and 36 of Annex A2 of the IRC: 112. As the stress block is distributed over a greater depth relative to the actual stress block to have the same strength, outside the stress of the fiber must be reduced to achieve fav, compared to ηfcd.

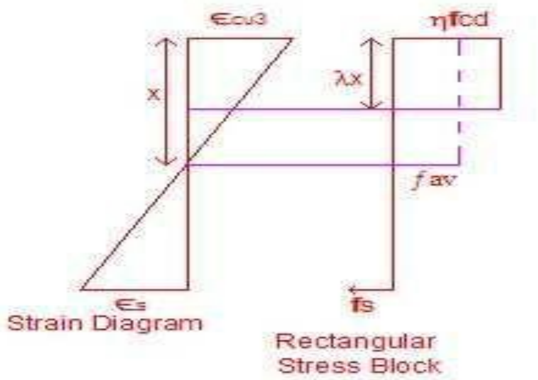

Figure: 4 Stress Strain Diagram for Rectangular Stress Block

In Hwan Yang [14] proposed a method for uncertainty analysis and analysis of creep effects of sensitivity and removal in prestressed concrete (PSC) box girder bridges. In addition, a method for reducing the uncertainty of the long-term prediction of the effect over time due to creep and shrinkage of concrete is developed. The study focuses on the uncertainties in the prediction of long-term creep and shrinkage effects using the sampling method. partial rank correlation coefficient and rank standardized regression coefficient calculated based on the observations of the ranks are examined to quantify the sensitivity of outputs to each of the input variables. update of the long-term forecast up is achieved using Bayesian inference. The theory is applied to the long-term prediction of the prestressing force of a box PSC girders real bridges. Numerical results indicate that the uncertainty factor creep model and relative humidity seem to be the most dominant factors with regard to the uncertainty of the model output. The present study shows that the width of mean ± two standard deviation for prior prediction of prestress forces. Therefore, the adoption of an approach developed in this study would reduce the uncertainties of prediction of time-dependent effects due to creep and improve greatly the long-term serviceability of PSC box girder bridges. to the other two types, while the other two types show almost the same stiffness. The amount of ultimate resistance for chevron bracing is around 50% higher than the X bracing. This means that using the same value for response modification factor of all types of concentric bracing does not seem appropriate, and the design codes needs some revision in this regard.

III. CONCLUSION

[1] 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.[1]

[2] Transverse flexure, Moment due to self weight, uniform load & load over webs have a uniform distribution in longitudinal direction, and this distribution is completely independent of the span length..[2]

[3] Reinforcement & Prestressing to be proportioned for transverse flexure, Stirrups to be propositioned for longitudinal shear & tortional..[2]

[4] As the curvature effect cannot be ignored, the webs of the bridges have to betreated as thin shells and the flanges as flat curved plates..[3]

[5] Vertical displacements continued to increase with the transverse bending load application, even though the shear force was kept constant, indicating decrease of the beam stiffness. [4]

[6] Warping calculation is complicated & time consuming, its effect is very small so it can be ignored in design calculation [5]

[7] The simplified equations available at present to predict the collapse load of concrete box-girder bridges have been reviewed in this paper. The errors were found to be in the wide range −21 – +51% in comparison with the experimental result.

[6]

[8] The shear lag effect in box girders under prestressing is more apparent than that under uniformly distributed loads or vertical concentrated loads. The values and distribution of shear lag coefficients are related to the anchorage locations of prestressing and the distribution of internal forces along the girder under the combined uniformly distributed load and prestressing.[7]

[9] For a single thin-walled cell subject to torsion, shear flow is constant along each of its walls while shear stresses vary around the section based upon changes in wall thickness. [8]

[10] Two sets of empirical expressions for curvature limitations were developed steel I-girder bridges & concrete I- Girder Bridges considering 5 and 10% underestimation in design, respectively. [9]

[11] Cast-in-in place, box girder bridges using the calibrated finite element modeling scheme was then used to investigate how various parameters such as span length, girder spacing, parapets, skew, and deck thickness affect the flexural live load distribution factor. [10]

[12] The article gives the fundamentals, average stress concept, design and checking of rectangular, beams, use of upper branch of stress-strain diagram of steel, doubly reinforced beams and T beams. [13]

[13] The most influential factors in the long-term prediction of structural response in PSC box girder bridges and the results indicate that the creep modeling uncertainty factor and the variability of relative humidity are two most significant factors on time-dependent effects. [14]

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