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EFFECT OF SKEWNESS ON LIVE LOAD DISTRIBUTION IN WEBS OF CONCRETE BOX-GIRDER BRIDGES

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The aim of the present paper is to study the effect of skewness on distribution of live load among the webs of the horizontally curved concrete box-girder bridges. In this paper, a 27.4 m long simply supported RC box-girder bridge has been considered to investigate the influence of skewness on box-girder with various curvatures. To this end, the central curvature angle of the bridge has been varied from 0° to 48° at an interval of 12° and the skew angle is swept from 0° to 50° at an interval of 10°. Using the three-dimensional Finite element analysis software CsiBridge, maximum vertical deflection under the webs of box-girder have been determined due to the IRC specified Class-70R tracked vehicular LL moving over the bridge at constant speed at maximum eccentricity specified by Indian Road Congress. Assuming the linear elastic behavior of the bridge, the live load has been distributed among the webs in the proportion of vertical deflections. The study revealed that the live load distribution among the webs is significantly affected by the skewness in conjunction with curvature. The results indicate that with increase in skewness, live load transferred to inner web decreases for almost all the curvature angles.

Keywords: Box-Girder, skew bridge, Load distribution, FEM, IRC loading.

Introduction

Bridges are the key elements in highways and flyovers for the smooth flow of traffic. For the smooth traffic flow in urban interchanges and highway, curved concrete bridges are inevitably used for economic and aesthetic considerations. However, due to eccentric vehicular loading and even due to self-weight due to curved geometry, the bridges curved in horizontal plan are subjected to high torsion in addition to longitudinal bending moment and shear force. Compared to several other cross-sections, box-sections are generally preferred in curved bridges because of their high torsional rigidity as well as due to economic and aesthetic considerations. Moreover, due to geometric and space constraints, sometimes it becomes necessary to provide skew supports for the horizontally curved bridges which results in a complex skew-curve geometry of the bridge deck. The structural response (support reactions, shear force, and bending moments) of box-girder bridges having right-, skewed- and curved- geometries is complex and it becomes more complex due to presence of skewness in conjunction with curvature. Moreover, because of eccentric loading and also due to complex geometry, distribution of traffic loads to the different webs is not uniform. The web closest to the vehicular load is expected to resist the largest portion of the load. The loads shared by the webs are commonly determined with the use of load distribution factors. At any section, the load distribution factor is calculated as the ratio of load shared by a web to the total load applied on bridge at that section. The load distribution factors may be used to distribute the live load shear as well as live load moment among the webs of the box-girder. The focus of this study is to investigate the effect of skewness on load distribution among the webs of skew bridges.

Several independent studies have been made to predict the structural behavior of skewed- and curved- bridges. Song et al. (2003) conducted a parameter study on curved box-girder bridges and indicated that the load distribution factors based on LRFD formulae are in well agreement with the distribution factors calculated from grillage analyses for the bridges with central angles up to 34°. Nutt et al. (2008) studied the limits of applicability for various methods of analyzing horizontally curved concrete box girder bridges. They identified that the in case of concrete box girder bridges with a central angle within single span of less than 12° has minor effect on response and hence the concluded that the bridges with central curvature 12° or less may be treated as straight bridges for the analysis. However, the bridges with high curvatures or unusual plan geometry (such as skewness) require a sophisticated three-dimensional computer analysis. Based on the findings of Song et al. and Nutt et al., AASHTO LRFD Bridge Design Specifications specifies that the structural behavior of box-girder bridges with small curvature with central angle up to 12° (L/R=0.2) is not significantly influenced by curvature and the bridge may be analyzed and designed for global forces using the simplified one-dimensional spine bridge modelling technique. Moreover, Khalafalla and Khaled [2014] carried out a study on curved box-girder bridges and concluded that, in general, curvature

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limitations specified in AASHTO-LRFD code underestimate the structural response of curved concrete bridge superstructure when treated as a straight one in design, yields unsafe design.

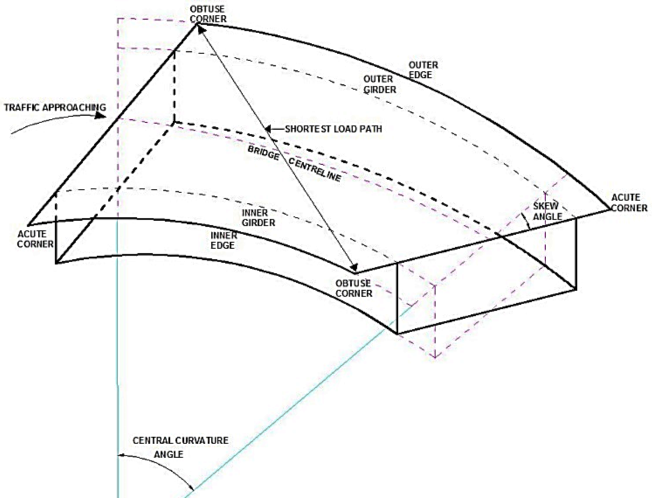


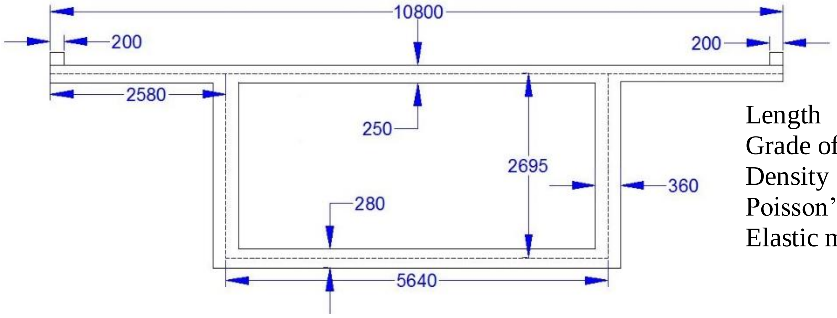
Figure 1: Schematic Diagram of skew-curved bridge showing shortest path for force transfer

In order to understand the structural response of skew bridges several studies have been made. Bakht (1988) pointed out that the bridges with small skew angle (< 20°), may be analyzed as a right bridge with span equal to the skew span. Moreover, they studied the structural response of the bridges with large curvature (> 12^o) and/or large skew angle (> 20°) and concluded that the structural response of these bridges significantly differs from right bridges since there exist substantial torsional deformations and they are susceptible for uplift at bearings, and therefore, the simplified one-dimensional spine bridge modelling technique is unable to predict the structural response of the skew- and curved- box-girder bridges. Therefore, it becomes necessary to use the sophisticated method such as finite element method to analyze the skew- and curved- bridges. It may be observed that studies have been made to predict the behavior of either skewed- or curved- bridges, however, no such studies have been made on the horizontally curved concrete box-girder bridges supported on skewed supports.

Present study focuses on capturing the structural response with regards to load distribution in outer and inner girder of single cell box-girder bridge for various combinations of curvature and skewness present in the bridge. In order to investigate the effect of skewness in conjunction to curvature on the live load distribution factors, a 10.8m wide box-girder and 28.6 m long simply box-girder has been considered where the central curvature angle is varied from 0° to 48° curvature angle, at an interval of 12° and the skew angle is swept from 0° to 50° at an interval of 10°. The finite element analysis is a well-established tool for analyzing box-girder bridges having complex geometries in more efficient way. In the present study linear elastic 3-D finite element analysis of the bridges has been performed using commercially available finite element software CsiBridge.

Numerical Investigation

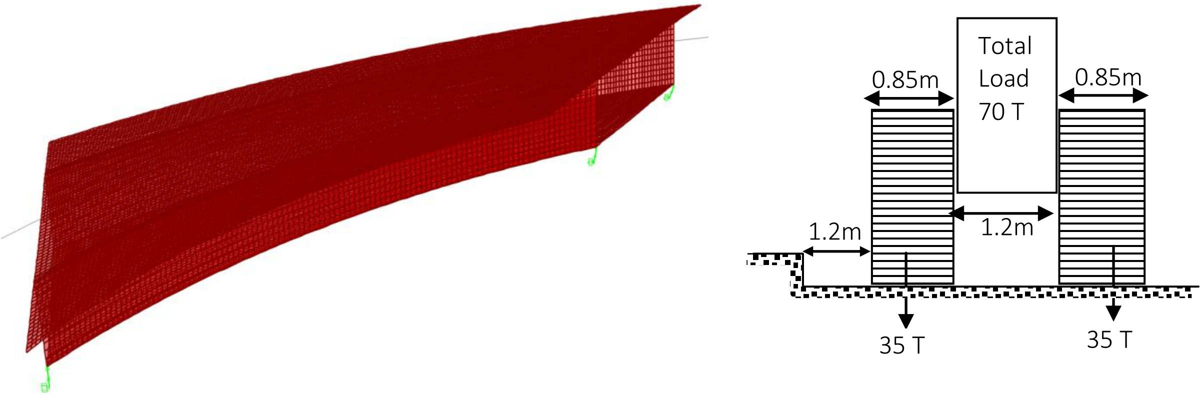
Present study considers the basic box-girder cross-section of Han-Jiang Bridge at Shayang located in Wuhan, China [Luo et al. (2003)]. The finite Element discretization of the problem has been done in CsiBridge using the 4 noded 3-D shell element which has six degrees of freedom at each node (3 translations + 3 rotational). Proper connectivity of top and bottom flange elements with the webs ensure the displacement compatibility of box components. For the linear elastic finite element analysis of skew-curved bridges, the 3-D finite element models of the bridges are generated and analyzed using CsiBridge.



Length	27.4m
Grade of Concrete	M25
Density	$25 kN/m^3$
Poisson's ratio	0.2
Elastic modulus	2.958×10^7 kN/m^2

Figure 2: Cross-section of Han-Jiang Bridge [18] (dimensions in mm)

The chosen two lane straight bridge is having a length of 27.4m which is made simply supported at its end. A kerb of 0.2m at both extreme of cross-section width is adopted along the span length. A linear elastic analysis is performed for each skew/curved/skew-curved case to monitor Vertical deflections obtained under bridge girder under dead and live load conditions. Dead load in form of gravity loading is activated on the bridge and further for live loads upon the structure IRC class 70R vehicle (weighing 70 tons) is considered at maximum eccentricity of 1.2 m on outer lane as point load with an impact factor of 15% (as per IRC6 (2017) only one lane should be loaded with this vehicle for a two-lane bridge) to generate worst torsional effect in the bridge. The recommendations of Indian Road Congress (IRC) are used to place the vehicular live load in transverse directions. However, it is not possible to place the vehicular load in longitudinal direction to develop maximum displacement directly since the rolling load concept can be used only for normal bridges. To mitigate this problem, in the present study, vehicle load is considered to run through-out the span at an average speed of 1m/s, for which the results of vertical support reactions are captured at an interval of 0.1 second. Thus, at every 0.1m interval output are gathered and finally all such outputs are compared for finding out the worst condition in all cases.



(a) 3D FEM model

(b) IRC Class 70R Tracked Vehicle

Figure 3: (a) 3D FEM model of a typical skew-curved bridge model generated in CsiBridge IRC Class 70R Tracked Vehicle considered as Live Load

For considering simply supported modelling conditions, one end is given pin support constraining all translational degrees of freedom but allowing moments to pass throw, while other end is given a roller support. The same base cross-section is used for all parametric variations of bridge which are modelled for above mentioned skew and curve cases.

Results and Discussions

In order to study the influence of skewness on the Dead Load (DL) and Live Load (LL) distribution in straight (right) and curved bridges, the skew angle has been varied from 0° to 50° at the interval of 10° while the angle of central curvature has been varied from 0° to 48° at the interval of 12°. In the linear elastic analysis, the load may be assumed proportional to load, therefore, in the present study the loads shared by the webs of the box-girder are considered proportional to deflections under the webs. The influence of skewness in the right and curved bridges is presented in terms of Relative Load Factor (RLF) defined as the ratio of load (i.e. deflection) at any point in the web of box-girder under consideration to the load (i.e. deflection) at the same point in the straight non-skew box-girder bridge under the same loading.

Figure 4 and 5 shows the effect of skewness on straight and curved bridges on the magnitude of maximum load in the outer and inner webs for DL and LL respectively. It may be observed from the Figure 4 that up to 10°skewness irrespective of curvature, there is no effect of skewness on load distribution in outer as well as inner webs. Moreover, with increase in skewness, the RLF in outer as well as in inner webs decreases with increase in skewness for all the curvature angles considered. Furthermore, the rate of decreasing the RLF increases with increase in curvature and consequently a combination of higher skewness in conjunction with higher curvature decreases the DL shared by outer as well as inner web with respect to straight non-skew bridge. Figure 4 indicates that for the 50° skewness and 48° curvature the loads in outer and inner webs reduces up to 35%.

Moreover, for evaluating the effect of live load on load distribution, IRC class 70 R tracked vehicle is considered to ply over the outer girder. Figure 5 indicates that up to 12° curvatures, for all the skewness angles considered the RLF for outer web remains almost unity which indicates that for low skew angle straight as well as curved bridges behaves similar to right bridge. On the other hand, the load transferred to inner web significantly decreases as compared to non-skew straight bridge. Figure 5 indicates that the effect of skewness becomes predominant rather than curvature. For 0° and 12° curvatures the RLF is found to reduced up to approximately 0.63 and 0.68 respectively while increasing the skewness from 0° to 50°.

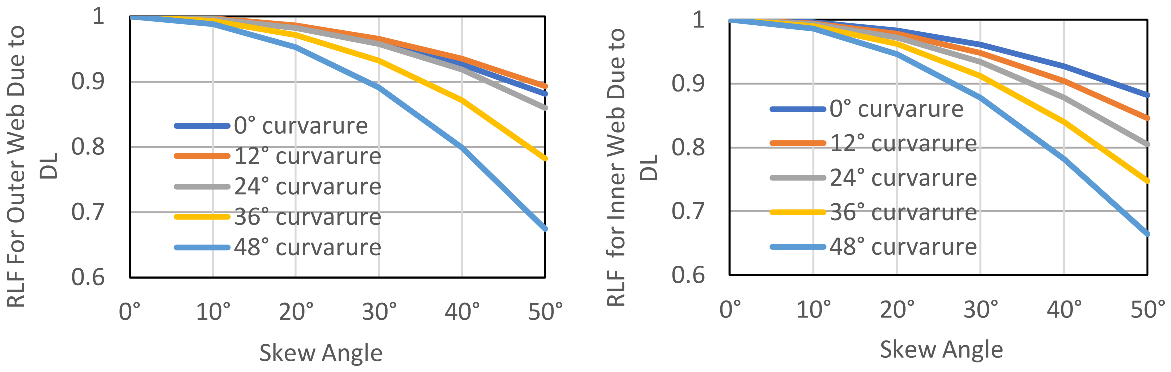


Figure 4: Relative Load Factor (RLF) for Outer and Inner Web due to Dead Load (DL)

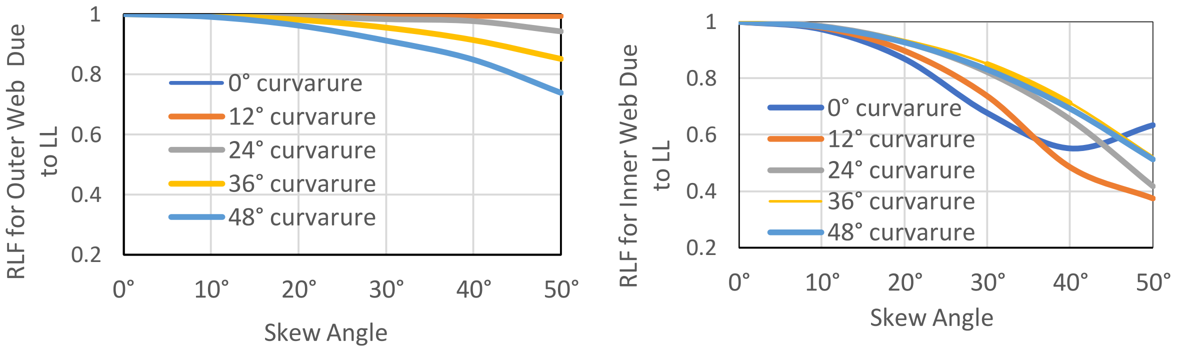


Figure 5: Relative Load Factor (RLF) for Outer and Inner Web due to Dead Load (LL)

Conclusions

In order to investigate the effect of skewness on Dead and Live load distribution among the webs of the concrete box-girder bridge, a 27.4m (90 ft) span simply supported concrete box-girder bridge has been considered and a parametric study has been performed where the central curvature angle is varied from 0° to 48° and the skew angle is changed from 0° to 50°. Based on the three-dimensional (3D) finite element analysis of the box-girder bridges with different curvature and skewness combinations, following conclusions have been drawn:

- For small skewness (≤ 10°) irrespective of curvature, there is no effect of skewness on load distribution in outer as well as inner webs.
- Inclusion of curvature in the bridges geometry reduces the load on inner as well as outer web as compared to straight non-skew bridge for DL as well as LL case.
- For a given curvature, load on outer web reduces with increase in skewness as compared to straight non-skew bridge for outer as well as inner webs for DL as well as LL case.
- The reduction in load transferred to outer web is more significant for DL case as compared to LL, however, for inner web the reduction in load is found more for LL case as compared to DL.

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