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DEAD LOAD DISTRIBUTION IN SKEW CONCRETE SLAB-ON-PRECAST CONCRETE I-GIRDER BRIDGES

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Abstract: Using prefabricated elements has recently been more common in North America to improve the bridge construction. Fabricating different bridge elements off-site has many benefits including higher material quality and durability, more efficiency in time and cost, increased safety of the work zone, less environmental impacts and decreased traffic disruptions. Currently, the Canadian Highway Bridge Design Code (CHBDC) specifies empirical equation for shear distribution factor in skew slab-on-girder bridges subjected to dead load with skew parameters less than a certain value. However, there is no information available in the literature to verify the use of such equations for the design of the fully-precast Canadian Precast Prestressed Concrete Institute (CPCI) girder bridges. However, skew bridges are necessary in some conditions such as crossing an obstacle or highway interchange. Since CHBDC load distribution factors were determined for general slab-on-girder bridges with limited value of skew parameters, a parametric study is required to investigate the applicability of these factors for precast bridge systems and bridges with higher values of skew parameters. In this study, a finite element modelling (FEM) was used to obtain load distribution factors for such bridges under self-weight and superimposed dead load and then correlate them with those available in CHBDC. The results indicated that the skew factor identified by CHBDC is not applicable for shear distribution at obtuse corner of this type of bridge with skew angle larger than 20° and also considering a modification factor for distribution of longitudinal moment among girders is essential between 45° and 60° skew angles.

1 INTRODUCTION

Skew bridges are the bridges with longitudinal axis not at a right angle to the abutment. In modern transportation network, skew bridges are vital when space limitations, complex intersections and natural or manufactured obstacles prevent a perpendicular crossing. It was shown that the skew supports change the load path and loads transfer to the supports through their shortest path. As a result, smaller maximum moment in the girders and larger shear in the girder at the obtuse corner of a skew bridge are expected when compared to those obtained in a straight bridge of the same length and size. Hence, an additional factor needs to be considered to adjust load distribution factors of straight bridges when an engineer is designing or evaluating a skew bridge.

2 PREVIOUS STUDIES AND CURRENT BRIDGE CODE

2.1 Review of Previous Studies

There are limited studies that focused on dead load distribution factors of skew slab-on-concrete I-girder bridges. (Theoret and Massicotte 2011) produced an equation to calculate skew factor for shear distribution at obtuse corner of slab-on-steel I-girder bridge subjected to dead load for shored construction. Based on their study, this magnification factor needs to be measured to consider the effect of skew angle on shear distribution among girders. However, their equation is limited up to 45° skew angle and the applicability of this factor for bridges with concrete girders is not confirmed.

(Razzaq 2016) studied the influence of various parameters on the moment and shear distribution factors in slab-on-steel I-girder skew bridges subjected to dead load. As the result of the study, empirical formulas for moment and shear distribution factors of slab-on-steel I-girders subjected to dead load for shored and unshored construction were produced. It can be observed that based on the literature, the research study for considering the effect of skew angle on shear and moment distribution among girders for slab-on-precast concrete I-girder bridges is still unavailable in Canada.

2.2 Canadian Highway Bridge Design Code (CHBDC)

The Canadian Highway Bridge Design Code (CHBDC) introduces a magnification factor for considering the skew effect at the obtuse corner of slab-on-steel girder bridges subjected to dead load with shored construction only. CHBDC suggests that no consideration needs to be taken for skew effects in unshored construction. However, there are no recommendations about the skew effect on longitudinal shear and moment for slab-on-concrete I-girders bridges.

For shored construction or for superimposed dead loads, the skew factor, F_S shall be obtained by the equation presented in clause 5.6.6.2 of CHBDC (CSA 2014) as follows:

[1] $F_S = 1.2 - \frac{2}{(\varepsilon+10)}$

[2] $\varepsilon = \left(\frac{L}{S}\right)\tan\psi$ for $\psi \leq 45^{\circ}$

Where L is the length of the span and S is the spacing between girders. The value of F_S shall be applied from the line of supports to $0.25L_e$ for simply supported conditions or to the point of contra-flexure of dead loads for continuous support conditions. Moreover, F_S shall be equal to 1.0 for non-skewed bridges.

3 FINITE ELEMENT MODELING

The finite element analysis software SAP2000 (2017) was used in this study to determine the structural behavior of straight and skew bridges under dead load. This software is capable of analyzing structures in static and dynamic modes using the different type of elements that are available in the program. Slab deck, abutments and concrete I-girders were modeled using shell elements. One of the middle supports on the right end of the bridge was restrained against all possible translations (longitudinal, vertical and lateral). On the left side, one of the middle supports was restrained against vertical and lateral translations. However, the rest of supports at both ends were restrained against vertical translations only. In order to simplify the modeling, I-shaped girders were replaced with the rectangular girders using the same moment of inertia. A 225 mm thick concrete slab resting over concrete girders and abutments with a width equal to width of girder were considered in this modeling. The over-hanged slab length is equal to half the girder spacing. The modulus of elasticity of concrete material was taken 25 GPa with Poisson's ratio of 0.20. To improve the accuracy of the finite element modeling and to make the design more efficient and cost-effective, the aspect ratio of the shell elements was adjusted less than 2. The three-dimensional (3D) finite element model and the plan view of a bridge with 25 m length and 25° skew angle are shown in Figure 1 and Figure 2, respectively.

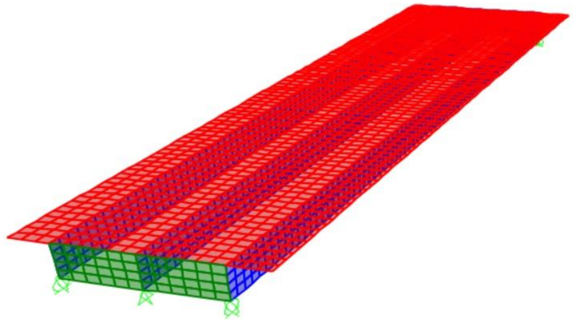

Figure 1: Three-dimensional finite element model of a skew bridge

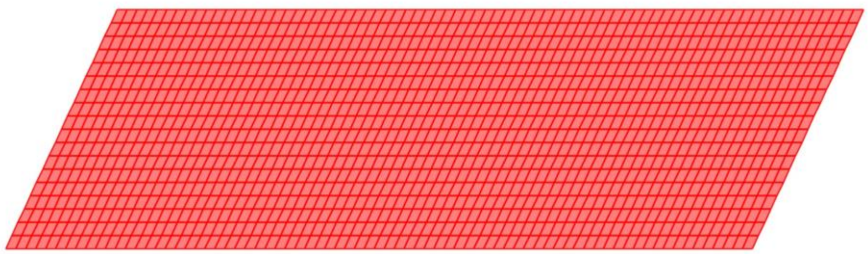

Figure 2: Plan view of a skew bridge

4 PARAMETRIC STUDY

To investigate the effect of different parameters on dead load distribution factors among girders, different configurations were considered. The bridge length range of 15 to 40 m with 5 m increment, the skew angle of 0° to 60° and the bridge width of 8, 11 and 13 m for 3 to 7 number of girders were considered in this study. Table 1 shows the corresponding cases that have been considered to investigate the effect of skew angle on longitudinal moment and vertical shear distribution of bridges subjected to dead load.

Table 1: Variables considered in the parametric study

Variables	Range
Length	15, 20, 25, 30, 35 and 40 m
Skew angles	0°, 10°, 20°, 25°, 30°, 40°, 50° and 60°
Number of girders	3, 4, 5, 6, 7
Width	8, 11 and 13 m

To find the skew factor based on 3D modeling, first the maximum flexural stress and the maximum vertical shear for the skew bridges from 3D modeling was calculated. Subsequently, the same values were evaluated using two-dimensional beam-line model (Barker and Puckett 1997). Thus, the skew factor of 3D modeling was defined as Equation 3.

[3] $\mathrm{F_{S\ model}} = \frac{\sigma_{3D}}{\sigma_{2D}}$ or $\frac{V_{3D}}{V_{2D}}$

Then, the ratio between the skew factor from 3D modeling and the skew factor based on the Canadian Highway Bridge Design Code was calculated to investigate the accuracy of equation suggested by the CHBDC for slab-on-precast concrete I-girder bridges.

4.1 Comparison of Skew Factor for Shear at Obtuse Corner Based on CHBDC and the Skew Factor based on this Study

To study the accuracy of the skew factor at obtuse corner defined by CHBDC for slab-on-precast concrete I-girder bridges, the ratio between the values from modeling and the values from CHBDC was utilized. The more this ratio is close to one, the more precise is the skew factor proposed by CHBDC to use for slab-on-precast concrete I-girder bridges. Figure 3 to Figure 8 show the variations of this ratio with skew angle for bridges with 8 and 13 m width. The number of girders changed to investigate the effect of girder spacing on skew factor.

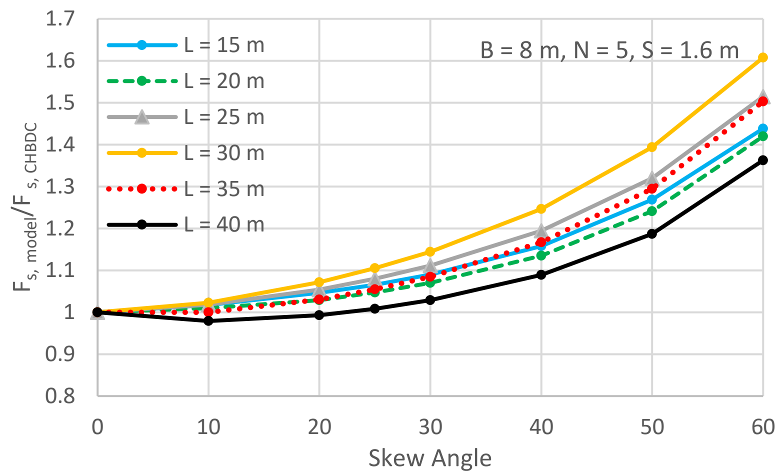

Figure 3: Skew angle effect on shear distribution at obtuse corner (width = 8 m and girder spacing = 1.6 m)

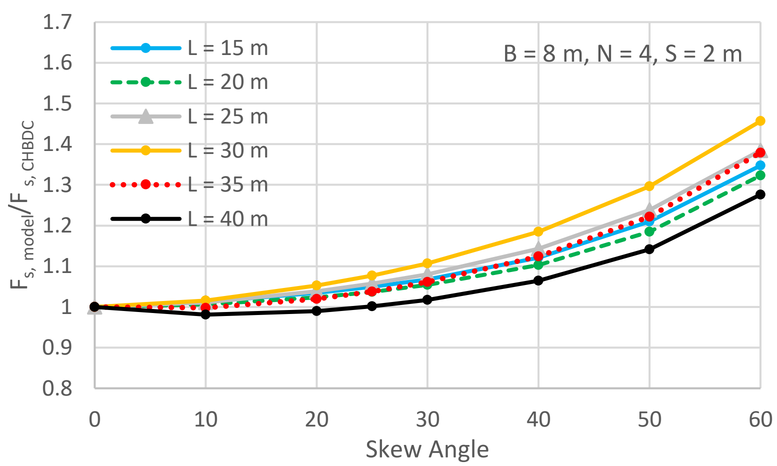

Figure 4: Skew angle effect on shear distribution at obtuse corner (width = 8 m and girder spacing = 2 m)

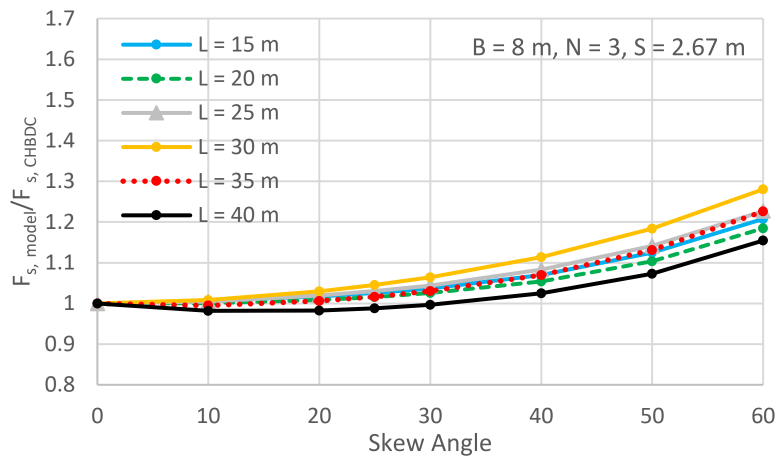

Figure 5: Skew angle effect on shear distribution at obtuse corner (width = 8 m and girder spacing = 2.67 m)

It was observed that for skew angles between 0° and 20° the skew factor proposed by the CHBDC can be used at obtuse corner of slab-on-precast concrete I-girder with a maximum of 8% error. However, for the skew angles between 20° and 60°, the accuracy of the skew factor at obtuse corner significantly decreases with the increase of skew angle. Moreover, the study showed that the increase in skew factor at obtuse corner of slab-on-precast concrete I-girder is more noticeable for bridges with smaller values of girder spacing.

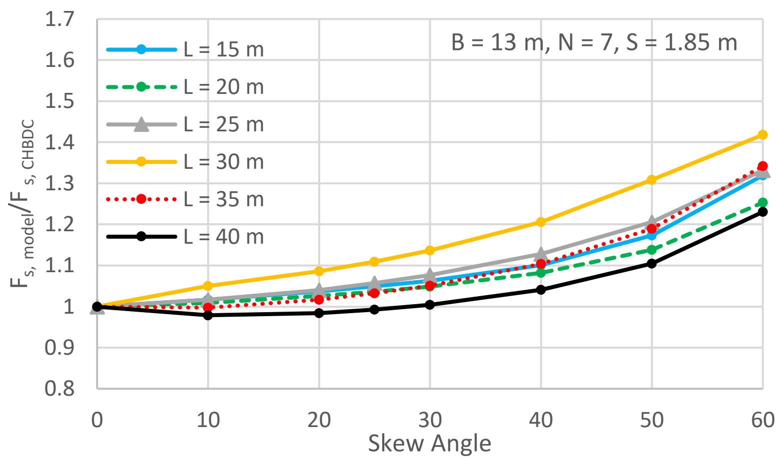

Figure 6: Skew angle effect on shear distribution at obtuse corner (width = 13 m and girder spacing = 1.85 m)

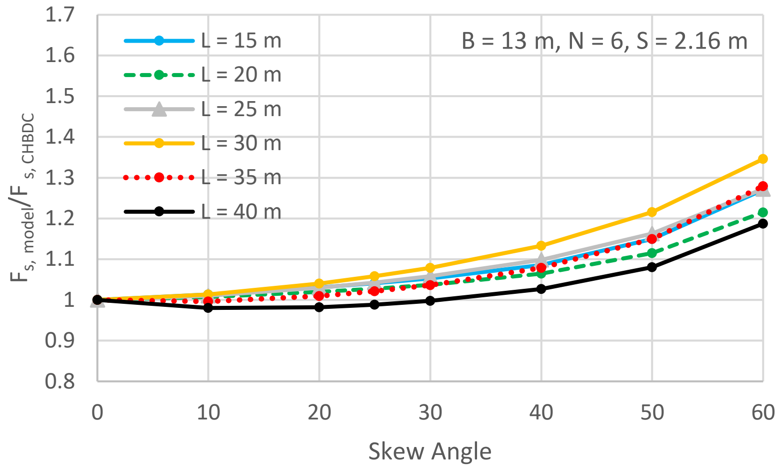

Figure 7: Skew angle effect on shear distribution at obtuse corner (width = 13 m and girder spacing = 2.16 m)

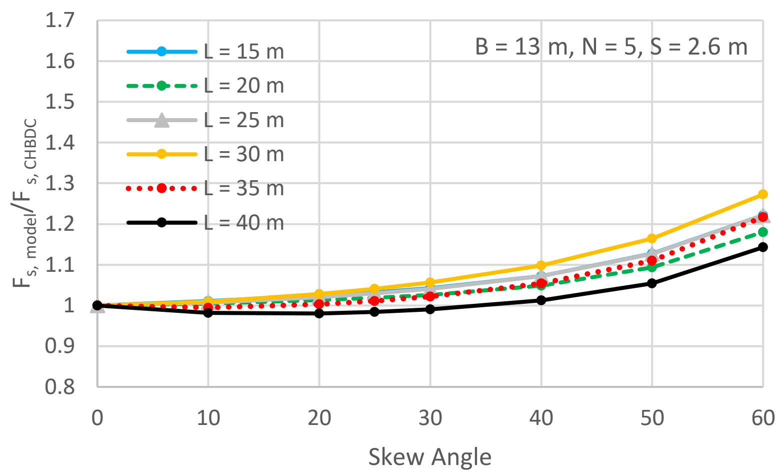

Figure 8: Skew angle effect on shear distribution at obtuse corner (width = 13 m and girder spacing = 2.6 m)

4.2 Effect of Skew Angle on Longitudinal Moment

Although the presence of skew angle can change the distribution of longitudinal moment between girders, the current edition of Canadian Highway Bridge Design Code does not have any recommendations to consider this effect for slab-on-precast concrete I-girder bridges. In this study, the maximum flexural stress in the girders of skew bridges was evaluated from modeling. Then, the skew factor, $F_{s\,model}$ based on Equation 3 was proposed to investigate the effect of skew angle on distribution of longitudinal moment between girders. Figure 9 to Figure 11 show the variation of skew factor, $F_{s\,model}$ for exterior girder of bridges with 8, 11 and 13 m width, 30 m length and different number of girders.

It was observed that skew angle has no significant effect on the distribution of longitudinal moment between girder for angles between 0° and 45°. For skew angles between 45° and 60°, exterior girders showed a decrease of F_s with the increase of angle. Moreover, it was revealed that using a greater number of girders for a specific width of the bridge, results in a more significant reduction of F_s .

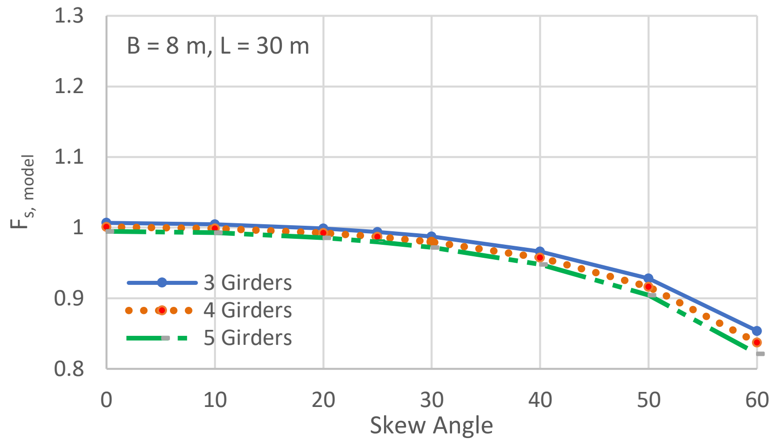

Figure 9: Skew angle effect on longitudinal moment (width = 8 m)

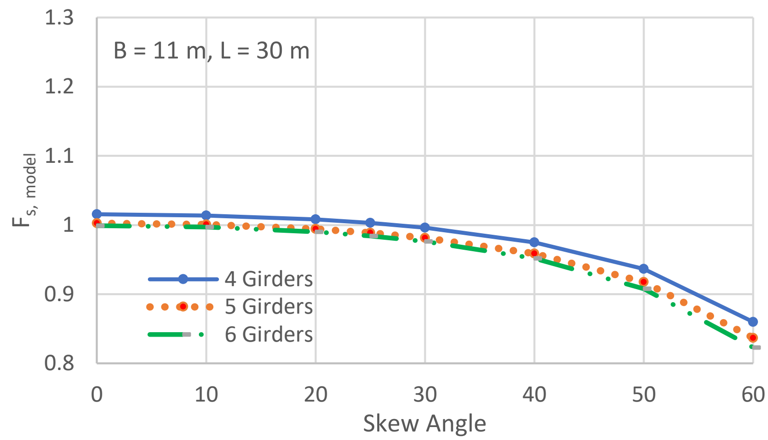

Figure 10: Skew angle effect on longitudinal moment (width = 11 m)

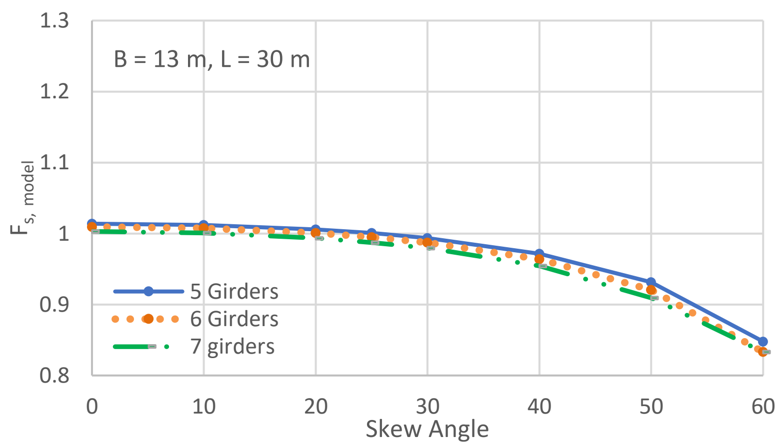

Figure 11: Skew angle effect on longitudinal moment (width = 13 m)

5 CONCLUSIONS

Based on the results of parametric study conducted on slab-on-precast concrete I-girders subjected to dead load, the following conclusions can be drawn:

- Although the skew factor of CHBDC can be used at obtuse corner of slab-on-precast concrete I-girder bridges up to 20°, utilization this factor for larger skew angles will be resulted in underestimation of the effect of skew angle on the obtuse corner of such bridges.
- The value of skew factor at the obtuse corner of slab-on-precast concrete I-girder bridges increases as the girder spacing decreases for a specific width of bridge.
- The distribution of longitudinal moment between girders for slab-on-precast concrete I-girder bridges does not change significantly for skew angles up to 45°.
- The skew factor for longitudinal moment decreases for bridges with skew angle between 45° and 60°.
- Utilization of a greater number of girders results in a more significant reduction of skew factor for longitudinal moment

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