Development of Simplified Skew Correction Factor Equations for distribution of live load in Highway Multicell Box-Girder Bridge

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Abstract— The main objective of presented study is to evaluate the influence of skew on maximum bending moment of skewed continues concrete multicell box-girder bridges. the AASHTO LRFD specifications which widely used to bridge design in the most cases overestimates the moment distribution for external girder and underestimates that for internal girders by as much as 40% and 25%, respectively. The standard AASHTO of line live loads (distributing the wheel loads equally between all girders) bring about even more conservative results for distribution factor of both external and internal girder causes to uneconomic design. This study indicates that the grillage analysis can predict the maximum moment of external and internal girders more reliable than current codes. Using an expensive parametric study on a large number of prototype bridges, several modification factor expressions are proposed to enhance the accuracy of moment distribution of AASHTO LRFD specifications.

Keywords— Bridge, Truck, Skew Angle, Grillage Approach, Distribution Factor.

I. INTRODUCTION

MULTICELL box-girder bridges are one of the most common types of bridges in the United States. When the bridge superstructure is loaded longitudinally by a vehicle load, the deck and all the boxes will undergo both longitudinally and lateral bending moment and shear forces. The webs will twist along with the principle axis to keep the comprehensive stability of deflection at the slab and box-girder interfaces. The participatory effect of these box-girders will relate to the span length, girder spacing, stiffness of the slab and girders. The calculation of this participatory effect of various superstructure components is referred to as live load distribution factor which accepted by most practical bridge design codes[1-3]. These specifications recommended some technique to analyze bridges which include finite element technique, grillage approach, and empirical equations for live load distribution factors (LLDF). A large number of analytical and experimental studies [4-9] have been conducted to estimate accurate values for live load distribution of box-girder bridges under wheel loads [9]. In addition, the Association of State Highway and Transportation Officials Load Resistance Factor Design (AASHTO-LRFD) recommended the new equations for live load distribution factor of shear force and bending moment based on the results of the NCHRP project 12-26 [9]. Preliminary studies indicated that the proposed distribution factor formulas suggested by AASHTO-LRFD [10] may result in very conservative or unsafe values for shear and moment, respectively [11]. In addition, the accuracy of these equations may be more hazardous when the bridge constructed as skewed superstructure. However, the current LRFD specifications recommended skew correction factor expression to consider the effect of skewness on bridge responses, but the equations are very complex and need to estimate some bridge parameters in the first stage on bridge design. Therefore, the this study presented the results of investigation on four continuous two span multi-cell box-girder bridges to obtain the effect of main parameters on live load distribution factor of straight and skewed bridges. Correction factor expressions are derived based on the finding results from parametric study to improve the accuracy of AASHTO LRFD formulas in determining the moment and shear live load distribution factor of multicell box-girder bridges.

II. DESCRIPTION OF BRIDGE PROTOTYPES

Three real multicell box-girder bridges were selected for this study. Bridge No.1 is a three span bridge, located in the Buffat Mill Road in the United States. The bridge consist three span lengths of 91, 119 and 140 ft. The cross section and plan view of bridge No. 1 are shown in figure 1. The bridge has a skew angle of 28 degrees in all abutments and pies. The three other bridges are two span bridges which their properties are presented in Table 1. Previous investigations indicated that secondary properties such as parapet and barriers have an margin effect on live load distribution factor of shear and bending moment for skewed multicell box-girder bridges [5, 10]. Therefore, this study did not include these effects into bridge modeling. Moreover, the solid end diaphragms are installing in both abutments and piers and the continuity
Intermediate diaphragms are provided at spaces 30 ft (9.0 meter), as recommended by AASHTO specification.

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The finite element modeling in this study is validated by measurement results obtained by field testing on Tsing- Yi-South Bridges in Hong Kong [12, 13]. The comparisons of bending moment, first natural frequencies and strain indicated good compatibility between numerical modeling and Test. Based on this validation, the same final element modeling is provided to analyze the prototype bridge results.

### III. Numerical Finite Element Model

The CSIBRIDGE finite element computer program is used to simulate the bridge superstructure and vehicle loading conditions. The bridge are typically simulated with four-node shell element for both longitudinal and transverse members (diaphragms) to model an integrated superstructure. The applied shell elements consists the influences of biaxial bending, torsion, axial deformation, and biaxial shear deformations. A typical model of a skewed multicell box girder is presented in fig. 2.

![Fig. 1 cross section and plan view of bridge No.1](image)

**Fig. 1 cross section and plan view of bridge No.1**

The live load moment in prototype bridges are obtained subjected to AASHTO standard HS20-44 truck loading. The HS20-44 AASHTO truck is a three axle truck that front axle weight is 10 kip and weight of other axes is 40 kip. The distance between front and second axle is 4.30 meter and changes between 4.30 to 9 meter to obtain maximum responses. In the case of live load moment for non-skewed bridges, once the location of the maximum moment was found with one truck, the additional trucks are placed alongside the first. For the skewed bridges, the maximum bending moment is obtained when the trucks are exactly located at the mid span of each lane.

### IV. Loading Condition

The variation of bending moment distribution factor for both external and internal girder subjected to vehicle loading condition, versus span length of bridges are shown in fig. 3. The close agreement can be observed between finite element modeling method and two-dimensional grillage analysis [14]. The results indicates that the AASHTO Standard specification [1] and American Association of State Highway and Transportation officials load and resistance factor design [2] provide highly uneconomical LDF for moment in box external and internal webs of multicell box-girder bridges. In addition, for large span continues bridges, as can be seen in fig.3, the moment distribution factor calculated from AASHTO LRFD specification formulas provide so highly unsafe value for external girder.

![Graph showing Moment Distribution Factors](image)

**Graph showing Moment Distribution Factors**

**a. Interior girder**

**b. Interior girder**

150

VI. EFFECT OF SKEW ANGLE ON MOMENT DISTRIBUTION FACTORS

Fig. 4 indicates the effect of skewness on bridge responses for maximum bending moment distribution factor of external and internal girder of multicell box-girder bridges. The skew angle ranges from 0 to 60° to cover almost all possible range of skewness. By comparing the values of LDF from analytical and numerical methods, it can be seen that live load distribution factor of moment are determined highly conservative for exterior girders, since the AASHTO LRFD specifications [2] underestimated it in bridge with skew angle more than 30°.

VII. CORRECTION FACTORS FOR ESTIMATING MOMENT DISTRIBUTION FACTOR OF AASHTO LRFD

Two set modification factor expressions are derived to multiply the bending distribution factor formulas recommended in AASHTO LRFD [2] of multicell box-girder bridges.

A sensitive parametric study is done on 70 prototype multicell box-girder bridges. the Canadian Highway Bridge Design codes [14] are employed to obtain the properties and characteristics of prototype bridges. Then, a statistical analysis [15] based on the least squares technique and best analysis of nonlinear values are used to obtain the following expressions for exterior and interior modification factor (CFEX and CFIN) of AASHTO LRFD specifications:

- For interior beam:
  \[ \text{CF}_{\text{IN}} = 111.2 \frac{1}{L^{0.5}} \frac{1}{N_{C}^{0.8}} \]  
  \[ \text{MDF} = \left[ \frac{166}{N_{C}} \right]^{0.68} \left[ \frac{5}{5} \right]^{35} \left[ \frac{1}{L} \right]^{0.79} \]  

- For exterior girder
  \[ \text{CF}_{\text{EX}} = 10.30 \frac{1}{L^{0.56}} \frac{1}{N_{C}^{0.82}} \]  
  \[ \text{MDF} = 0.73 \left[ W_{e} \right]^{0.38} \left[ \frac{5}{5} \right]^{35} \left[ \frac{1}{L} \right]^{0.36} \]  

To verify the developed expression for skew correction factor and live load modification factor of multicell box-girder bridges, the finding results from analytical method are compared with corresponding results from other numerical and analytical methods including; finite element analysis, grillage methods and AASHTO and LRFD specifications. The fig. 5 shows a close agreement between proposed expressions and other methods for both interior and exterior girders.
VIII. CONCLUSION

Based on the results of a sensitive parametric study on four actual multicell box-girder bridges, it was observed that the span length, number of cells and skew angle of superstructure are the most critical parameters affecting the live load distribution of moment over bridge deck. The following conclusions also obtained from this study:

1. The AASHTO specifications calculate highly conservative values for both internal and external boxes.
2. The AASHTO LRFD specifications overestimate the maximum flexural moment for internal beams. While for external girder it calculates so conservative values for short span, the formulas underestimate LDF for medium and long span bridges.
3. The effect of skewness should be considered for bridge with skew angle more than 30°.

REFERENCES