PARAMETRIC STUDY ON LIVE-LOAD DISTRIBUTION IN LATERAL DIRECTION OF A SKEW COMPOSITE BRIDGE

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ABSTRACT
Determination of Live-load distribution factors is an important step in the analysis of bridge structure. This paper describes a numerical study on live load distribution factor of a three dimensional (3-D) finite element model of a skew composite bridge which was developed by using commercial software ANSYS. The finite element model was developed from an existing work and then accuracy of the model was verified by comparing the numerical results to the existing experimental results. The bridge models investigated the effects of skew angle and different vehicle position on the live-load distribution factors for shear and moment. To evaluate the skew effect, the skew angle of the bridges was varied from 0° to 60°. Load distribution factors (LDFs) from finite element were compared with those calculated according to the American Association of State Highway and Transportation Officials (AASHTO) specifications. It is found that AASHTOs standard specification "S-over" equation is simple to use but this equation may under estimate the distribution factor for some bridges and over estimate for others. Though AASHTO LRFD formula considered more parameters such as skew correction continuity but it is complex to use.

Keywords: Load distribution factor; vehicle position; skew bridge; numerical study; ANSYS

INTRODUCTION
Nowadays skew bridges are very commonly used all over the world. The skew bridges are built to cross railways, waterways, roadways that are not perpendicular to the bridge at the intersection. The skew bridges can be defined as the bridge where the center line of the bridge is not perpendicular to the center line of the abutment and pier. Proper live-load distribution factor is important for bridge design. The American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges did not account for the effect of skew. The distribution of load in a skew bridge is different than a normal straight bridge because of skewness. Usually the load transfer in short direction more than the long direction. The load distribution factors in lateral direction for live load moment and shear is determined using the AASHTO *Load and Resistance Design Specifications* (AASHTO LRFD). The specification additionally require the application of skew correction factors (SCFs) to beams when the line of bridge support is skewed.

Live-Load Distribution Factors
Live load distribution is the proportion of the vehicular load carried by each girder. The AASHTO Standard Specifications for Highway Bridges have given live load distribution factors since 1931. The earlier approaches were based on the work done by Westergaard (1930) and Newmark (1938), but the factors were modified as new research results became available. To calculate the distribution factor, American Association of State Highway and Transportation Officials (AASHTO 2002) standard gave a simple "S-Over" equation. This "S-Over" equation is developed for straight bridges and the effect of skew angle and continuity are not considered in this code. Several investigation have been carried out to find the effect of skew angle on the live load distribution factor. Some researchers suggest new equations of live load distribution factor for moment and shear. In addition, AASHTO load and resistance factor design (AASHTO 2008) takes into account more bridge parameters such as girder spacing, girder stiffness, span length, continuity and the skew effect than the AASHTO standard

(AASHTO 2002). AASHTO LRFD presented skew correction factor for shear and moment distribution factor for skew bridge, however, the accuracy of those is still questionable (Huo et al., 2003; Zhang, 2008). According to Zokaie et al. (2000) study the LRFD code distribution factors lie within 5% of the distribution factors calculated with detailed finite-element models. The main objectives of this study are: (1) Development and verification of Finite Element Model of the skew bridge; (2) Disparity between the live-load distribution factor obtained from the finite element analysis to the present practiced code; (3) To figure out the effect of skew angle and vehicle position on live-load distribution factor; (4) Behavior of typical skew bridges; (5) To develop better design guidelines for bridge designers.

FINITE ELEMENT MODELING

Model Description

The finite element model developed for this study is taken from an existing work done by J. Meng et al. (2004) at the Federal Highway Administration Turner-Fairbank Highway Research Center. Here, approximately 1/6 reduced scale model was used for the finite element analysis. A two-span continuous bridge with a span length and deck width of 12 ft. and 7 ft., respectively was designed. The actual bridge would have a span of 72 ft. and width of 42 ft. The skew angle was selected based on practical skew angles used for real skew bridges. For most skew highway bridges, the skew angles fall in the range of 30°~60°. The existing model has a skew angle 36.87°.

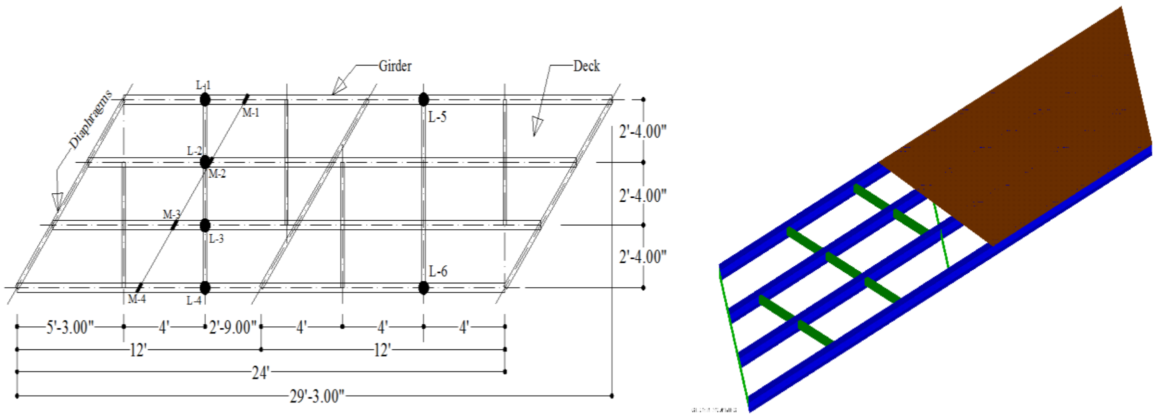
The girders and diaphragms were model using SHELL63 element. The girders were connected using diaphragms. Diaphragms are generally used to (1) transfer lateral wind loads to the deck and then to the bearings, (2) provide stability to the stringer or girder flanges during erection and placement of the deck, and (3) distribute laterally the vertical dead and live load from one stringer to other adjacent.

Bridge decks are used to carry the traffic load and to transfer the loading to the supporting girders and piers. Although most bridge decks are made of reinforced concrete, a 3/8 in. steel plate was used as the deck. Based on the theory of transformed section, this steel deck roughly simulated a 9 in. thick reinforced concrete Deck. Here the deck was modeled by using the SHELL63 element.

To simulate actual bridge bearings, pinned supports were provided at one end of the two span bridge and roller supports were provided to middle and other end of the bridge. The pin supports are designed to allow only the rotational movement about the pin and roller supports were designed to allow rotational movement plus translations along the length of the bridge.

Table 1 Basic geometric property of the bridge model

Span length	12 ft.
Width	7 ft.
Girder spacing	2 ft. 4 in.
Girder depth	6 in.
Web thickness	0.23 in.
Flange width	4 in.
Flange thickness	0.28 in.
Diaphragm cross-section	6 in. x 0.234 in.
Deck thickness	3/8 in.



(a) Plan View (J. Meng *et al*., 2004) (b) Finite element model (ANSYS)

Fig. 1: Bridge model

Model Verification by Incremental loading test

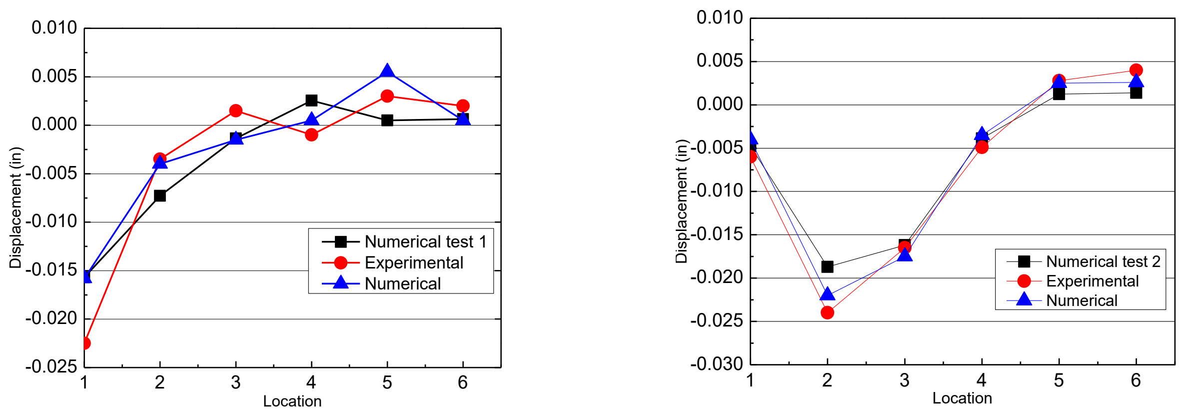
As a precursor to Live Load distribution factor calculation, two numerical incremental loading test was performed to verify the finite element model. For each numerical test, the load was applied in four increments of 200 lbs. each to a maximum of 800 lbs. The loading procedure is depicted in Table 2.

In the table 2, M1, M2, M3 and M4 refer to the load applied point in Fig. 1(a). Thus, for numerical test 1, load was applied to the model at only one location. However, for numerical test 2, loads were applied to two location. For each numerical test, displacement measurements were recorded at six location named L1, L2, L3, L4, L5 and L6 in Fig. 1 (a).

The value of the six displacement records from numerical analysis, experimental results (J. Meng et al., 2004) are shown in Fig. 2. The results obtained from finite element analysis are very similar to the experimental results which verified the model accuracy. Due to errors in measurements, instrumentation, uncertainty in support conditions, material properties and load placement, as well as approximations and assumptions used in any experimental test, it is difficult for the experimental and numerical values to compare to a high degree of accuracy.

Table 2 Loading procedure (units: lbs., 1 lb. = 4.45 N)

		M1	M2	M3	M4
Numerical test 1	Step 1	-200	-	-	-
	Step 2	-400	-	-	-
	Step 3	-600	-	-	-
	Step 4	-800	-	-	-
Numerical test 2	Step 1	-	-200	-200	-
	Step 2	-	-400	-400	-
	Step 3	-	-600	-600	-
	Step 4	-	-800	-800	-



(a) (b)

Fig. 2. Displacement comparison. (a) Numerical test 1; (b) Numerical test 2;

LIVE-LOAD DISTRIBUTION FACTOR

Shear Distribution Factor

Skew angle has significant effect on live load distribution factor. The ratio of distribution factor at any skew angle to the distribution factor at zero skew shows the effect of skew (Barr et al., 2001). For a bridge with skew, the shear at the obtuse corner has been found to be higher than that at the acute corner. As a result, the presence of skew can significantly increase the exterior girder shear and reduce the interior girder shear.

In Fig. 3, there are four location was selected to apply vehicle load on the bridge named as P1, P2, P3 and P4. The girders are designated by G1, G2, G3 and G4. Here, when load applied at location P1 and measured distribution factor in girder G1 (Exterior) than it is denoted by G1 P1 and similarly others. Since this research is carried using a scaled bridge model, to similitude with bridge model a scaled vehicle (HS20-44 truck) load were used.

The effect of skew was investigated by performing a finite element analysis with skew angle varies from 0° to 60° and at different position of the vehicle load. The FE results for different skew angle under the single-lane loading on exterior and interior girder shown in Fig. 4. The live-load distribution factor by AASHTO standard specification (S-over equation) is very much conservative for both exterior and interior girder shown in Fig. 4(a). In finite element analysis, curve G1P1 and G1P3 shows that the distribution factor of the loaded girder is decreased with the increase of skew angle up to 45^0 and then for 60°, the distribution factor increased slightly when the load was applied at acute corner. In contrast, curve G4P2 and G4P4 shows that the distribution factor increased with the increase

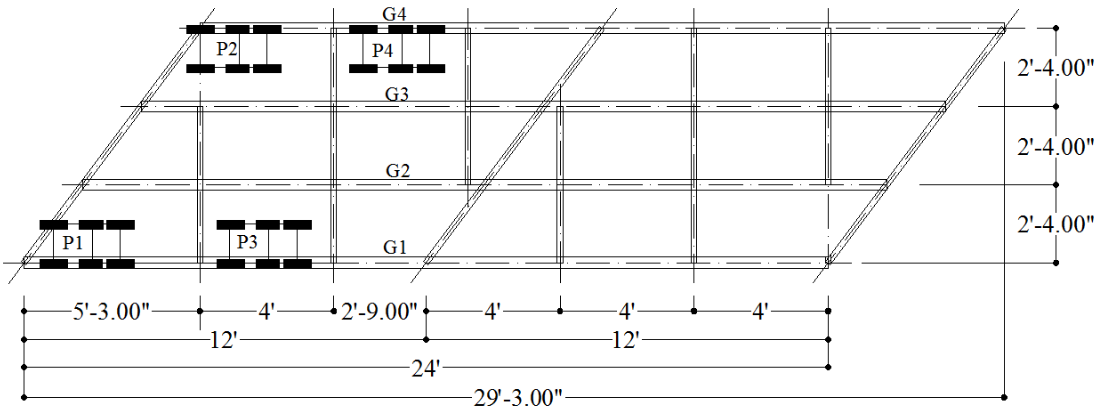
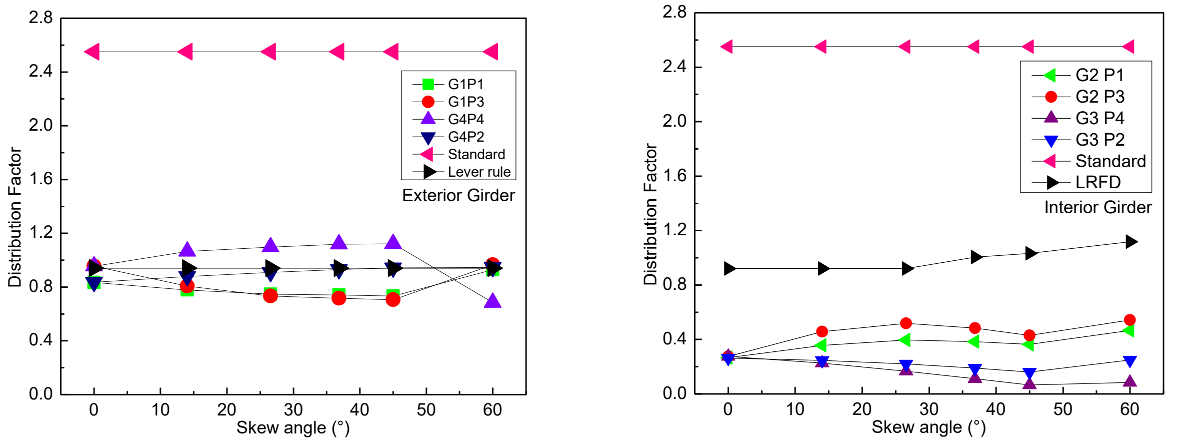


Fig. 3: Vehicle location and girder numbering



(a) (b)

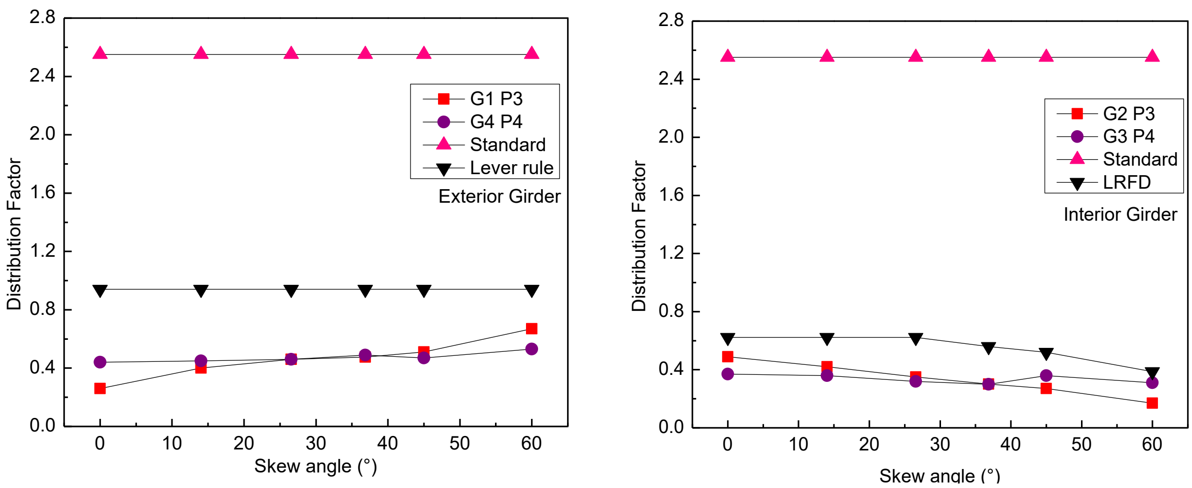
Fig.4: Comparison of LLDFs for shear with code

of skew angle up to 45^0 and then for 60°, the distribution factor decreased slightly when the load was applied at obtuse corner. Here the distribution factor by lever rule method for exterior (loaded) girder is slightly unconservative for load applied at obtuse corner and conservative for acute corner.

For interior girder both AASHTO standard and LRFD gave conservative distribution factor. In Fig. 4 (b) curve G3P4 and G3P2 shows that for the interior girder there was nearly a linear decrease in the distribution factor for skew angles up to 45° and then above 45°, the distribution factor increased slightly when load applied at obtuse corner. Curve G2P1 and G2P3 shows a slight up and down in distribution factor when load applied at acute corner.

Moment Distribution Factor

Fig. 5(a) shows a variation of moment distribution factor in exterior girder with increasing skew angle. Also it shows the difference in between the codes to finite element distribution factor. AASHTO specification gave highly conservative moment distribution factor for both exterior and interior girder. Curve G1P3 and G4P4 shows a gradual increase in distribution factor for exterior girder. Due to the skew angle, the moment at the acute corner has been found to be higher than that at the obtuse corner. Here, curve G2P3 and G3P4 shows a slight decrease with increase in distribution factor.



(a) (b)

Fig. 5: Comparison of LLDFs for moment with code

CONCLUSIONS

Based on this FE study and result, the following conclusion are made: (1) the shear distribution factor for exterior girder increasing and decreasing depending upon the position of vehicle with increasing skew angle. (2) For interior girder both AASHTO LRFD and standard equation overestimate the shear distribution factor and (3) Also for interior and exterior girder AASHTO gives higher value for moment distribution factor. Here the study shows that the lever rule method can very well predict the shear distribution factor for exterior girder. In the authors' opinion, the lever rule method with skew correction factor can be used to obtain fairly well live-load distribution factor for skew bridge. It is also recommended that more research should be performed to quantify a good distribution factor for skew bridge design.

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