

Contribution of Intermediate Diaphragms on LDFs of Straight and Skew Concrete Multicell Box-Girder Bridges

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Abstract. Current studies indicate that neglecting the effect of intermediate diaphragms might lead to highly conservative values for bending moment distribution factors and result in non-economic designs for skew bridges. This paper reports on a parametric study performed on 160 prototypes of straight and skew concrete multicell box-girder bridges. The obtained results were used to develop practical expressions to account for the diaphragm effects on American Association of State Highway and Transportation Officials formulas for live load distribution factors. It was observed that decks with internal transverse diaphragms perpendicular to the longitudinal webs are the best arrangement for load distribution in skew bridges.

Keywords: Box Bridges, Truck, Distribution Factor

1. Introduction

Li and Ma [1] carried out a field test on five decked Bulb-Tee bridges to investigate the contribution of IDs on LDFs. It was observed that Diaphragm details have an influence on the bending moment in the joint. However, the vertical shear in the joint is not affected by the diaphragm details and it is strongly affected by the location of the joint with respect to the location of the live load. The AASHTO standard specifications [2] recommend providing IDs at the point of maximum moment for spans exceeding 12 m but clear reasons for such requirements were not given. AASHTO LRFD [3] also suggests the use of internal transverse diaphragms in similar locations but while expanding the LDF formulas, the effects of the IDs were not considered. Samaan [4] concluded that the presence of diaphragms enhances the torsional stability of straight multiple steel-box bridges and that three concrete IDs, as well as top chords, are required to provide fairly uniform distribution of shear force. Park [5] developed a curved box beam finite element with nine degrees of freedom and proposed tentative design charts for adequate maximum spacing of IDs. Saber and Alaywan [6] performed the live load field tests with a comprehensive instrumentation plan provided a fundamental understanding of the load transfer mechanism through continuity diaphragms.

Celik and Bruneau [7,8] conducted experimental studies to quantitatively investigate the impact of diaphragms on seismic response of slab-on-girder bridges. The results confirmed that effective end-diaphragms constitute critical structural elements along the main seismic load path, and that they should be designed accordingly. Therefore, in new bridges, they should be designed to resist in an elastic manner the forces induced by the maximum credible earthquake. The focus of this study was to examine the effectiveness of IDs on LDFs for bending moment and shear force for simply and continuous skew MCB bridges

2. Geometric and Structural Properties

The structural properties of selected bridges are presented in Table 1. Fig. 1 shows the typical cross sectional symbols for bridges. Three different systems for ID arrangement were considered. In the first arrangement, no IDs were provided (S-1). In the second arrangement (Refer to Fig. 3a), IDs were parallel to the abutments (S-2). This system was consistent with the Louisiana bridge design manual, LADOTD [9], which recommends providing IDs at one-third and two-thirds of the span length. In the third arrangement, IDs were perpendicular to the longitudinal girders. For the third arrangement, three different cases were

considered. The first case of the third arrangement was based on AASHTO [2], in which IDs were placed at the mid-span of the bridges (S-3-1). In the second case of the third arrangement, the locations of IDs were according to the Louisiana bridge design manual (S-3-2) as shown in Fig. 2b. In the third case of the third arrangement, IDs were placed with a spacing of 7.50 m (S-3-3).

TABLE I: Structural Properties of Prototype Bridges (in meter)

set	L(m)	N _B	W(m)	N _L	d'	d''	θ
1	33, 38, 45, 60, 75, 90	2,3,4,	14	2,3,4	0.20	0.15	0,30,40,50
2	33, 38, 45, 60, 75, 90	3,4,5,6	17	2,3,4	0.20	0.15	0,30,40,50

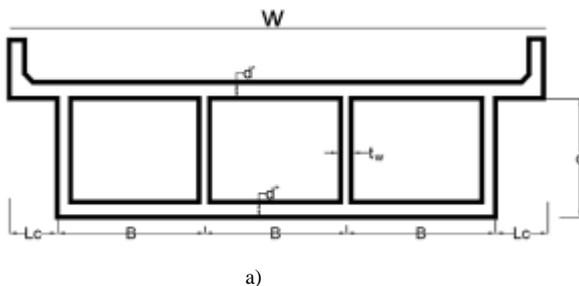


Fig. 1: Cross Section Symbols for three Box Bridge

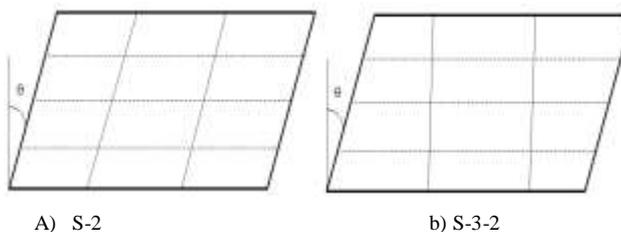


Fig. 2: Intermediate diaphragms arrangements

3. Loading Conditions

The bridge analyses were performed using the AASHTO LRFD live load, designated as HL 93, which includes truck design plus lane load design, or the tandem design plus lane load, whichever were govern. According to AASHTO LRFD [3], multiple presence factors of 1.00, 0.85 and 0.65 for two, three, and four lane loadings, respectively, were also applied to account for the effects of moving vehicles and the dynamic effects on the static responses of the bridges.

4. Discussion Of Parametric Study

A parametric study was carried out on ninety the prototype bridges to examine the effects of key parameters on the contribution of lateral transverse diaphragms (IDs) on LDFs for bending moment and shear force. These parameters were used to derive suitable correction factor expressions to take into account the effect of IDs in the AASHTO LRFD formulas for MCB bridges.

4.1 Effect of Span Length

The effect of span length on the effectiveness of IDs on the distribution of bending moment and shear force are plotted in Fig. 2. It can be observed that the presence of concrete continuous IDs significantly affects distribution of bending moment so that LDF is increased by almost 25% when the span length is enhanced from 30 m to 90 m. The graph also illustrate that providing IDs parallel to the skew supports result in an insignificant increases in LDF for bending moment for both external and internal girder by up to up to 3% and 5%, respectively. It can be observed with increasing the number of IDs, the DFm decreases by almost 10% differences between the S-3-1 and S-3-3 systems when the span length increases. The slight increase in distribution factor of the internal girder evidences that the effect of IDs on span length for internal girders could be neglected.

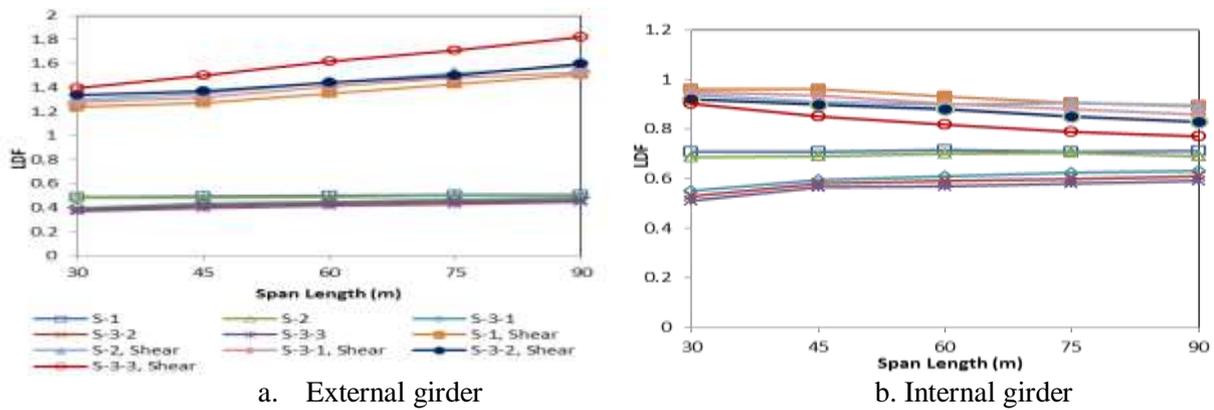


Fig. 3: Effect of Span Length on Live Load Distribution Factor of Bending Moment

4.2 Effect of skew angle

The relationship between the skew angle and LDFs of bending moment and shear forces are plotted in Fig.6. Results are shown for a single-span bridge with span length of 30 m and three lane loads with skew angle of 0° to 50° . From Fig. 4, it can be seen that the LDFs of bending moment decrease when the skew angle is increased by almost 45.5% and 50% for bridges with two IDs (Case S-3-2) and when IDs are located with a spacing of 7.5 m (Case S-3-3), respectively.

The IDs has different influence on distribution of shear force on MCB bridge rather than bending moment. Due to increase the shear and torsional stiffness of bridge decks, with increasing the number of IDs (refer to S-3-3), the shear distribution factor for external girder increases by up to 17.5% for bridge with span length of 90 m. From Fig. 5, other IDs arrangements have insignificant effects on LDF of shear force, for instance, this factor increased by up to 7% for bridge with two perpendicular IDs (S-3-2).

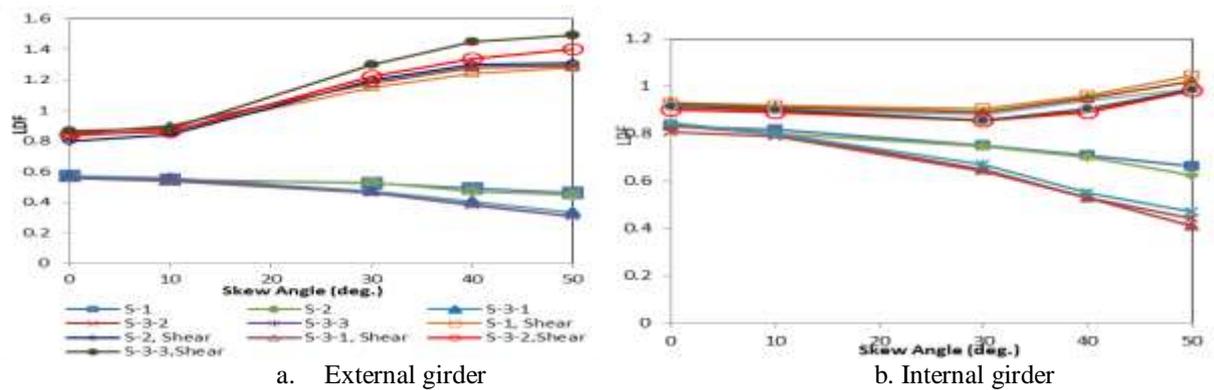
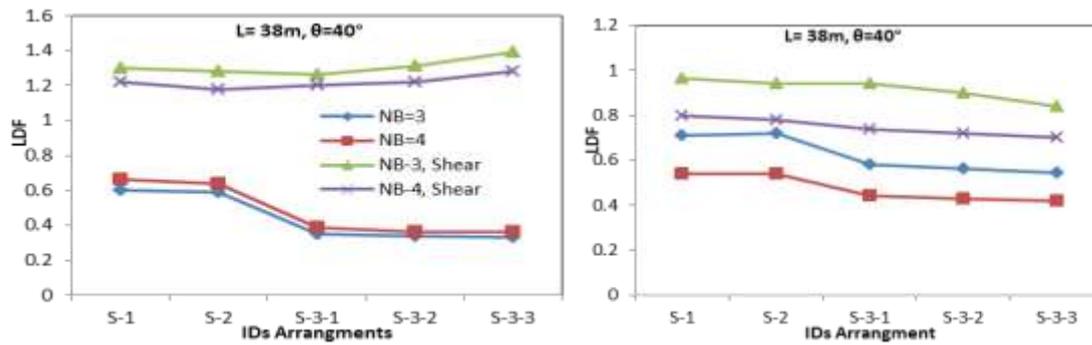


Fig. 4: Effect of Skew Angle on LDF of Bending Moment

4.3 Effect of intermediate diaphragm arrangement

The effect of ID arrangements on LDFs of bending moment and shear force for three and four box-girder bridges with a skew angle of 40° are shown in Fig.5. It can be seen that LDFs are not influenced significantly when concrete IDs are parallel to the abutments (Case S-2). For both external and internal girders, LDF for bending moment decreases by 19% when concrete IDs are perpendicular to longitudinal girders (Case S-3), which indicates that case S-3 is the most influential system for IDs arrangement in MCB bridges. It also observed that the number of diaphragms in the third type of arrangements (S-3-1 to S-3-3) has an insignificant influence on LDFs for bending moment



a. External Girder
b. Internal Girder
Fig. 5: Effect of various ID arrangements on moment distribution factor

5. Development of R_d Equations for AASHTO LRFD Specification

To take into account the effectiveness of IDs on LDFs of LRFD formulas, a statistical analysis based on the best minimum least squares fit of data [10] was employed on the data collected from parametric studies. Accordingly, the correction factor the live load distribution of AASHTO LRFD with IDs effectiveness is expressed as following:

$$DF_{LRFD} = CF \times DF_{FEA} \quad (1)$$

The correction factor, CF, is assumed to have the following form:

$$CF = a \times f(L) \times f(\tan\theta) \times f(W_e) \quad (2)$$

Where a is scale factor and W_e is the half the width of bridge and total width of overhang. Regression analysis is then required to find the best function to match variation of live load distribution factor with each parameter. Obtained results from finite element analysis and AASHTO LRFD formulas are used for the regression analysis. For each parameter, linear function, exponential function, and polynomial function are compared and the one with squared correction coefficient closet to unity is accepted to be the best function. Accordingly, the following equations were derived to calculate the LDF for bending moment for MCB bridges:

$$DF_{in} = (0.243 \times L^{0.25} - \frac{A \times B}{100}) \times LLDF_{in} \quad \theta \geq 20^\circ \quad (3)$$

$$DF_{ex} = (0.75 - \frac{C \times D}{100}) \times (1.30 - 0.033 \times W_e) \times LLDF_{ex} \quad (4)$$

In the proposed equations, subscript 'ex' and 'in' stand for the external and internal girders, respectively. The parameters A, B, C and D are described as follows:

$$A = 26.14 \times L - 0.148 \times L^{1.25} \quad (5)$$

$$B = 0.320 \times \tan\theta - 0.017 \quad (6)$$

$$C = 18.90 - 1.55 \times L \quad (7)$$

$$D = 0.80 \times \tan\theta - 0.028 \quad (8)$$

It should be mentioned that the proposed equations are practical only in the range of applicability defined by the AASHTO LRFD (2007) specifications.

6. Verification of Proposed Equations

The results of the verification analysis for the proposed R_d equations are shown Fig.6, for LRFD-based equation. It can be observed that the coefficient of determination R^2 , for all proposed equations is higher or slightly lower than 0.90, which is excellent and indicates a low variety of the finite element analysis results. It is also concluded that the effectiveness of IDs is more significant on internal girders. This is due to the transverse position of the truck load on the internal girders. The external girder is subjected to torsional moment due to the eccentricity of truck loading and the external girder.

The standard deviation (SD.), average (AVG.) and coefficient of variation are presented in Table 2 for each set of ratios between equations and finite element analysis results (Equation/FEM). It can be observed that the average values for both external and internal girders were very close to unity, which is excellent. From Table 2, the standard deviations of 0.035 to 0.100 reveal that the distribution factor of bending moments are sufficiently close to mean values.

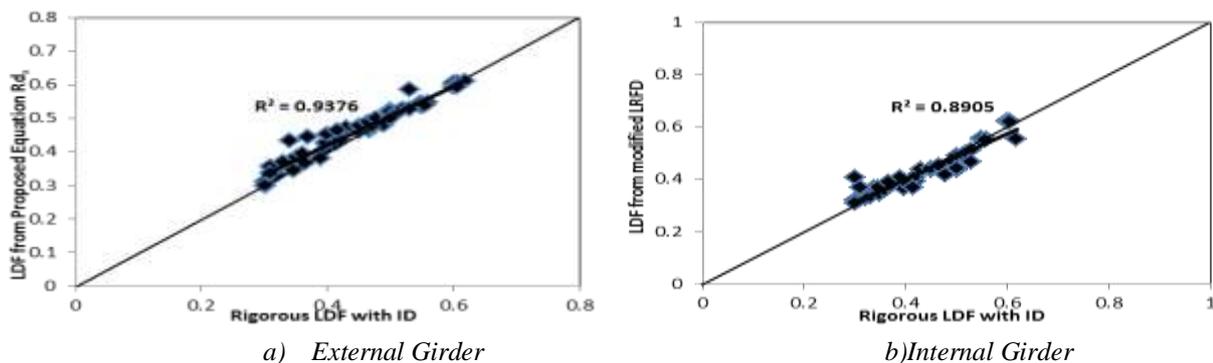


Fig.6 Live load distribution factor for bending moment from modified LRFD equations vs. Rigorous analysis

TABLE II: Comparative Statistics of Empirical Equations

Distribution factor	Girder	AVG.	SD.	COV.
LRFD Based Equations	External	0.992	0.0795	0.0766
	Internal	1.060	0.1080	0.1018

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