Proposed LRFD Single-Lane Live Load Distribution Factor Equations for Decked Bulb-Tee Girder Bridges

Zhongguo (John) Ma, *Associate Professor* and **Lungui Li**, *Graduate Research Assistant*
Department of Civil and Environmental Engineering
University of Tennessee Knoxville
223 Perkins Hall
Knoxville, TN 37996 – 2010

ABSTRACT

The live load distribution factor (DF) equations provided by AASHTO LRFD for the decked precast/prestressed concrete (DPPC) girder bridge system do not differentiate between a single or multilane loaded condition. This practice results in a single lane load rating penalty for DPPC girder bridges. The objective of this paper is to propose alternative DF equations which accurately predict the distribution factor of the DPPC girder bridge system when it is only subjected to single lane loading. Eight DPPC girder bridges were instrumented and calibrated grillage models were developed earlier. The calibrated grillage models were used to conduct a parametric study of the DPPC girder bridge system subjected to a single lane loaded condition in another study. Two sets of equations describing the single lane loaded distribution factor for both moment and shear forces are proposed here. The results of proposed DF equations and those of AASHTO LRFD equations are compared. It is shown that the current equations in AASHTO LRFD for the distribution factor of moment on interior girders will yield excessively conservative results for wide bridges. The proposed DF equations compare better with field testing results. Two detailed examples are given in the paper.

Keywords: Decked Bulb Tees, Load Distribution, Single Lane, LRFD Specifications, Field Tests

INTRODUCTION

Speed of construction, especially for the case of bridge replacement and repair projects, has become a critical issue more than ever. A strong momentum exists for the spread of precast construction for bridges with a push to expand the limits especially for the use in long-span bridges. One of the promising systems for precast bridge construction has used decked precast, prestressed concrete (DPPC) girders for superstructure, as shown in Figure 1. Despite several major benefits, the construction of this type of bridges has not shown the growth it deserves and has been mostly limited to the Pacific Northwest states of Alaska, Idaho, Oregon, and Washington. The reason is two-fold, one is because of the concerns and limitations in design and construction using DPPC girders, and the other is the lack of understanding due to limited research in this area. These issues include live load distribution, connections between adjacent units (Figure 2), and other factors.

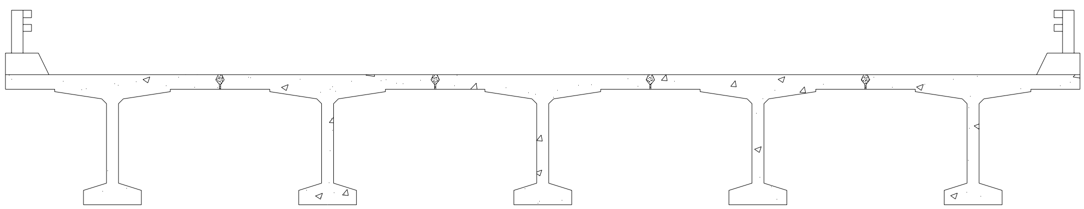

Figure 1 Cross Section of DPPC Bridge System

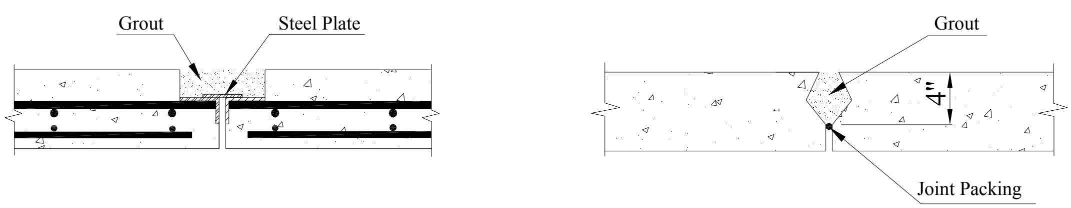

Figure 2 Typical Connection Details of DPPC Adjacent Units

The latest research on the DPPC girder bridge system was in 1986 when the University of Washington published a new set of DF equations in NCHRP Report 287 (Stanton and Mattock 1986). That research focused on understanding the distribution of stemmed multi-beam bridge systems to include the decked bulb-tee cross-section. The objective of that study was to modify the existing distribution factor equations so that they could be used for multi-beam bridges with stemmed cross-sections. The University of Washington study is the furthest the equations for the DPPC girder bridge system has been developed. Since that study the design community has identified many shortcomings in the S/D formulas ("S" and "D" are defined in the next section). In 1991 in NCHRP Report 12-26, the research team of Zokaie et al. reconstructed the equations governing most other bridge systems not including the DPPC girder bridge system (Zokaie et al 1991). The report provided new equations which specify a distinct distribution factor equation for interior and exterior girders, moment and shear forces, and also single and multilane loading conditions. The research conducted in the University of Washington only focused on the moment distribution for design purposes. It only considered multilane loaded cases and did not focus on the distribution of a single lane loaded case for the purpose of bridge rating. Therefore, AASHTO-LRFD presents only one equation for both single and multilane loaded conditions for DPPC girder bridges.

CURRENT AASHTO-LRFD SPECIFICATIONS

The current AASHTO LRFD (AASHTO 2004) wheel load DF equations governing the DPPC girder bridge system for both the single lane loading condition and the multilane loading condition are as follows:

Moment DF on Interior girders

$$DF = \frac{S}{D}$$

$$D = (5.75 - 0.5N_L) + (0.7N_L)(1 - 0.3C)^2 \qquad \text{for} \qquad C \leq 5$$

$$D = 5.75 - 0.5N_L \qquad \text{for} \qquad C > 5$$

$$C = K\frac{W}{L}$$

$$K = \sqrt{\frac{E \cdot I}{2 \cdot G \cdot J}}$$

where

- S = width of the precast member
- N_L = number of lanes
- W = overall width of the bridge in feet
- L = span length of the bridge in feet
- E = modulus of elasticity of the concrete
- I = area moment of inertia of the girder
- G = shear modulus of the concrete
- J = Saint-Venant's torsional stiffness constant

For moment DF on exterior girders, shear DF on interior girders, shear DF on exterior girders, AASHTO-LRFD recommends the "Level Rule" be used to determine distribution factors. The "Level Rule" is the simple distribution of the wheel loads on to neighboring girders.

EXPERIMENTAL PROGRAM

Field load testing gives a realistic determination of the results. Figure 3 shows the field load testing conducted on the tested bridge. Table 1 shows the tested eight bridges in Anchorage, Alaska. In selecting the bridges to instrument, researchers considered the following factors (Ma et al 2003):

- They are all located in or near Anchorage, Alaska.
- Traffic can be closed during late night hours for all these bridges.
- They are all accessible to instrument.
- They represent different geometry of the DPPC girder bridges in Alaska in terms of skew angle and aspect ratio (length/width).

The research team decided to test paired structures to provide verification of the instrumentation and modeling procedures.

Table 1 Field Tested Bridges

Name		Bridge Geometry				Girder	
		Span (ft)	Width (ft)	Skew(^{o})	Aspect Ratio	Spacing (in.)	Depth (in.)
Set 1	W100th NB	116.0	37.0	0	0.32	88.4	54.0
	W100th SB						
Set 2	Diamond Rd	110.0	107.0	0	0.97	90.6	54.0
	Dowling Rd						
Set 3	Campbell NB	139.0	37.0	4.3	0.27	88.4	65.0
	Campbell SB						
Set 4	Huffman NB	128.0	37.0	27.5	0.29	72.0	54.5
	Huffman SB						

Figure 3 Field Load Testing

PROPOSED SIMPLIFIED DISTRIBUTION FACTOR EQUATIONS

Based on the field testing data and a parametric study of the DPPC girder bridge system subjected to a single lane loaded condition, DF equations for the single lane distribution factor of the decked bulb-tee bridge system were developed by Millam and Ma (Millam and Ma 2005). The development and verification of DF equations are discussed in Millam and Ma (2005). In the developed DF equations, three parameters were considered: girder spacing, girder span length and girder's stiffness. Two sets of simplified equations for moment and shear distribution on the exterior and interior girders were provided. The first set equations are only a function of the girder spacing. The second set equations are function of girder spacing, girder span length and the girder's cross section moment of inertia.

In developing the DF equations, the following assumptions were made:

- The girders are typical decked bulb-tee girders.
- The girder height is between 36 inches and 66 inches.
- The deck thickness is between 4 and 8 inches.
- The number of girders of the bridge is greater than or equal to 4.
- The bridge has no skew.
- The span length of the bridge is between 40 and 180 ft.
- The girder spacing is between 4 and 9 ft.
- The bridge is loaded by a single lane of traffic.

The first set of DF(S) equations are:

Moment over Interior Girder (MI): $DF_{MI} = \frac{S}{13}$

Moment over Exterior Girder (ME): $DF_{ME} = \frac{S}{11}$

Shear over Interior Girder (SI): $DF_{SI} = \frac{S}{11}$

Shear over Exterior Girder (SE): $DF_{SE} = \frac{S}{10}$

The second set of DF(S, L, I) equations are:

Moment over Interior Girder (MI): $DF_{MI} = \frac{S}{12.5} + \frac{I}{300} - \frac{L}{10}\left(\frac{S-3}{200}\right)$

Moment over Exterior Girder (ME): $DF_{ME} = \frac{S}{10} + \frac{I}{300} - \frac{L}{10}\left(\frac{S-1}{300}\right)$

Shear over Interior Girder (SI): $DF_{SI} = \frac{S}{12.5} + \frac{I}{250} - \frac{L}{100}\left(\frac{S}{100}\right)$

Shear over Exterior Girder (SE): $DF_{SE} = \frac{S}{12} + \frac{I}{400} - \frac{L}{100}\left(\frac{S-3}{100}\right) + 0.07$

where

S : girder spacing in feet,

L : span length in feet,

I : The cross section moment of inertia of one girder with 6-inch deck in ft^4.

DETAILED EXAMPLES

Detailed examples are given to illustrate the calculation of DFs of the field tested bridges according to the current AASHTO LRFD Specifications and the proposed DF equations.

<u>Calculating DFs for bridges located at 100th based on AASHTO LRFD</u>

Moment distribution factor for interior girder:

I_x=364478 in^4, I_y=412395 in^4, $I_p = I_x + I_y = 776873$ in^4, A=1088.5 in^2, μ=0.2, W=37 ft, L=113.75 ft, $S = \frac{88.4}{12} = 7.367$ ft

$$J = \frac{A^4}{40I_p} = \frac{1088.5^4}{40 \times 776873} = 45176 \text{ in}^4$$

$$K = \sqrt{\frac{(1+\mu)I_x}{J}} = \sqrt{\frac{(1+0.2)\times 364478}{45176}} = 3.112$$

$C = K\dfrac{W}{L} = 3.112 \times \dfrac{37}{113.75} = 1.012 \prec K = 3.112$ OK.

$N_L = \dfrac{37}{12} = 3.08 = 3$

$D = 11.5 - N_L + 1.4N_L(1-0.2C)^2 = 11.5 - 3 + 1.4 \times 3 \times (1 - 0.2 \times 1.012)^2 = 11.172$

$DF_{MI} = \dfrac{S}{D} = \dfrac{7.367}{11.172} = 0.66$

Shear distribution factor for interior girder:
Level rule for determining shear distribution factor.
Distance of wheel to middle of outside girder $D_o = 53.125$ in

$DF_{SI} = \dfrac{D_o}{S} = \dfrac{53.125}{7.367 \times 12} = 0.60$

For both shear and moment in exterior girder, the LRFD specifications use level rule to calculate distribution factors.
Distance of left wheel to middle of second girder $D_l = 103.0625$ in
Distance of right wheel to middle of second girder $D_r = 31.0625$ in

$DF_{ME} = DF_{SE} = \dfrac{D_l + D_r}{2S} = \dfrac{103.0625 + 31.0625}{2 \times 7.367 \times 12} = 0.76$

<u>Calculating DFs for bridges located at 100th based on proposed equations</u>

Bridge parameters: $S = \dfrac{88.4}{12} = 7.367$, $L = 113.75$, $I = \dfrac{364478}{12^4} = 17.577$

Moment over interior girder:

$\dfrac{S}{13} = 0.57$

$\dfrac{S}{12.5} + \dfrac{I}{300} - \dfrac{L}{10}\left(\dfrac{S-3}{200}\right) = 0.40$

Moment over exterior girder:

$\dfrac{S}{11} = 0.67$

$\dfrac{S}{10} + \dfrac{I}{300} - \dfrac{L}{10}\left(\dfrac{S-1}{300}\right) = 0.55$

Shear over interior girder:

$\dfrac{S}{11} = 0.67$

$\dfrac{S}{12.5} + \dfrac{I}{250} - \dfrac{L}{100}\left(\dfrac{S}{100}\right) = 0.58$

Shear over exterior girder:

$$\frac{S}{10} = 0.74$$

$$\frac{S}{12} + \frac{I}{400} - \frac{L}{100}\left(\frac{S-3}{100}\right) + 0.07 = 0.68$$

<u>Calculating DFs for bridges located at Diamond/Dowling based on AASHTO LRFD</u>

Moment distribution factor for interior girder:

I_x=279224 in^4, I_y=362787 in^4, $I_p = I_x + I_y = 642011$ in^4, A=1026 in^2, μ=0.2, W=108 ft, L=110 ft, $S = \frac{90.6}{12} = 7.55$ ft

$$J = \frac{A^4}{40 I_p} = \frac{1026^4}{40 \times 642011} = 43151 \text{ in}^4$$

$$K = \sqrt{\frac{(1+\mu)I_x}{J}} = \sqrt{\frac{(1+0.2)\times 279224}{43151}} = 2.787$$

$$C = K\frac{W}{L} = 2.787 \times \frac{108}{110} = 2.736 \prec K = 2.787 \qquad \text{OK.}$$

$$N_L = \frac{108}{12} = 9$$

$$D = 11.5 - N_L + 1.4 N_L (1 - 0.2C)^2 = 11.5 - 9 + 1.4 \times 9 \times (1 - 0.2 \times 2.736)^2 = 5.083$$

$$DF_{MI} = \frac{S}{D} = \frac{7.55}{5.083} = 1.49$$

Shear distribution factor for interior girder:
Level rule for determining shear distribution factor.
Distance of wheel to middle of outside girder $D_o = S - 3ft = 4.55ft$

$$DF_{SI} = \frac{D_o}{S} = \frac{4.55}{7.55} = 0.60$$

For both shear and moment in exterior girder, the LRFD specifications use level rule to calculate distribution factors.
Distance of left wheel to middle of second girder $D_l = 1.5 \times S - 2.5ft = 8.825ft$
Distance of right wheel to middle of second girder $D_r = D_l - 6ft = 2.825ft$

$$DF_{ME} = DF_{SE} = \frac{D_l + D_r}{2S} = \frac{8.825 + 2.825}{2 \times 7.55} = 0.77$$

<u>Calculating DFs for bridges located at Diamond/Dowling based on proposed equations</u>

Bridge parameters: $S = \frac{90.4}{12} = 7.55$, $L = 110$, $I = \frac{279224}{12^4} = 13.466$

Moment over interior girder:

$$\frac{S}{13} = 0.58$$

$$\frac{S}{12.5} + \frac{I}{300} - \frac{L}{10}\left(\frac{S-3}{200}\right) = 0.40$$

Moment over exterior girder:

$$\frac{S}{11} = 0.69$$

$$\frac{S}{10} + \frac{I}{300} - \frac{L}{10}\left(\frac{S-1}{300}\right) = 0.56$$

Shear over interior girder:

$$\frac{S}{11} = 0.69$$

$$\frac{S}{12.5} + \frac{I}{250} - \frac{L}{100}\left(\frac{S}{100}\right) = 0.57$$

Shear over exterior girder:

$$\frac{S}{10} = 0.76$$

$$\frac{S}{12} + \frac{I}{400} - \frac{L}{100}\left(\frac{S-3}{100}\right) + 0.07 = 0.68$$

COMPARISON OF RESULTS

Tables 2 to 4 give the distribution factor values from the experimental data, LRFD method and proposed equations from different bridges.

Table 2 Distribution Factors of 100th Bridge

	Experimental Data	LRFD	DF(S)	DF(S,L,I)
MI	0.35	0.66	0.57	0.40
ME	0.45	0.76	0.67	0.55
SI	0.43	0.60	0.67	0.58
SE	0.66	0.76	0.74	0.68

Table 3 Distribution Factors of Campbell Bridge

	Experimental Data	LRFD	DF(S)	DF(S,L,I)
MI	0.34	0.66	0.57	0.39
ME	0.53	0.76	0.67	0.54
SI	0.50	0.60	0.67	0.61
SE	0.71	0.76	0.74	0.70

Table 4 Distribution Factors of Diamond/Dowling Bridge

	Experimental Data	LRFD	DF(S)	DF(S,L,I)
MI	0.32	1.49	0.58	0.40
ME	0.46	0.77	0.69	0.56
SI	0.55	0.60	0.69	0.57
SE	0.60	0.77	0.76	0.68

where

MI: moment of interior girder;
ME: moment of exterior girder;
SI: shear of interior girder;
SE: shear of exterior girder.

Figures 4 to 6 show the comparison of the distribution factor values from the LRFD method, proposed equations and experimental data.

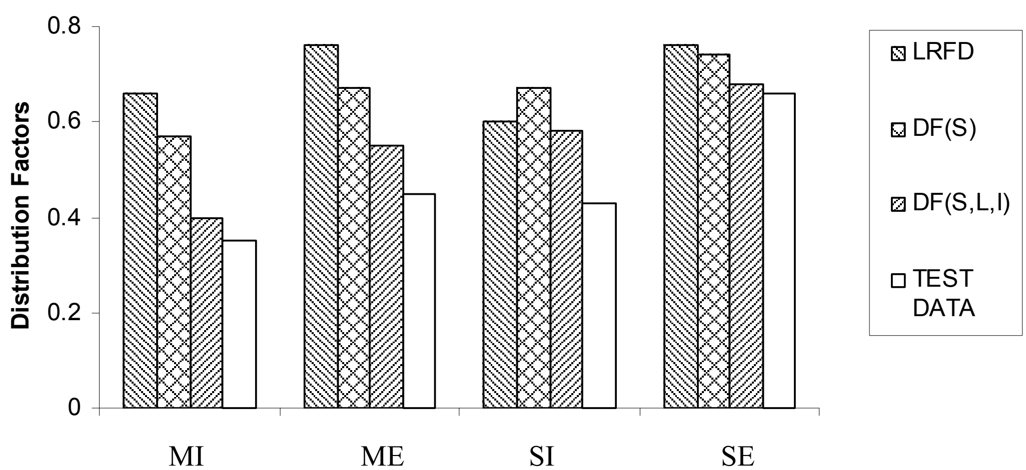

Figure 4 Distribution Factors of 100th Bridge

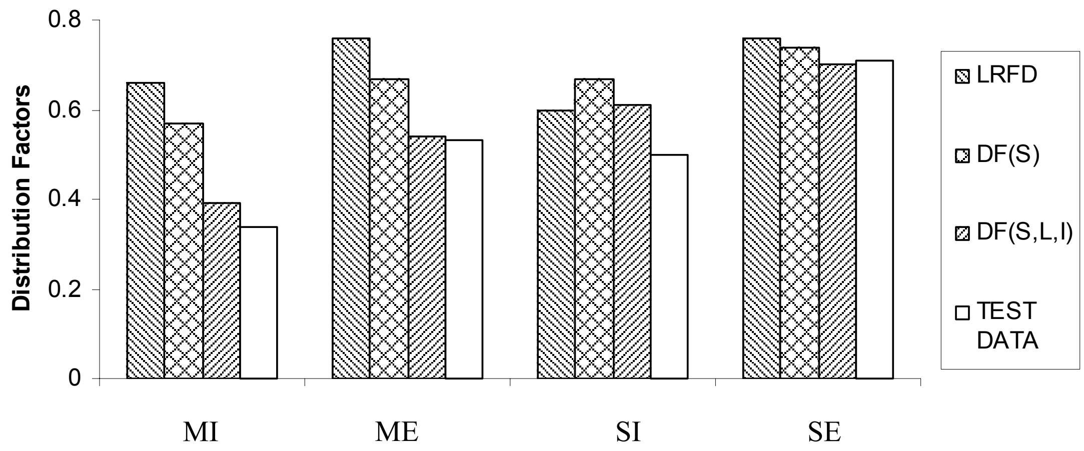

Figure 5 Distribution Factors of Campbell Bridge

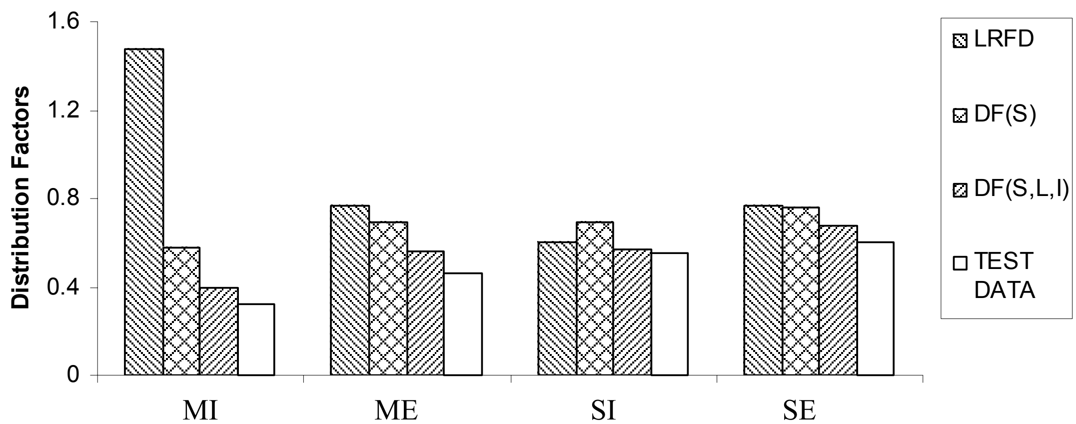

Figure 6 Distribution Factors of Diamond/Dowling Bridge

The current equations in the LRFD for the distribution factor of moment on interior girders include the aspect ratio as one of its parameters. For wide bridges, such as Diamond/Dowling Bridge whose aspect ratio is 0.982, the distribution factor of moment on interior girders is 1.49 according to the equations in the AASHTO LRFD Specifications. However, the distribution factor from the field tests is only 0.32. The LRFD prediction is over conservative and not reasonable. On the other hand, the proposed DF equations compare much better with the testing results.

CONCLUSIONS

By comparing the existing LRFD distribution factor equations to the testing results of field tested bridges, it appears that the existing equations in the LRFD for the distribution factor of moment on interior girders includes the aspect ratio as one of its parameters are not reasonable and will yield excessively conservative result for wide bridges when applied to a single lane loaded condition. The proposed DF equations are simple to use, more reasonable and more accurate than the current distribution factor equations in the LRFD Specification. The proposed equations are recommended to be the DF equations governing the live load distribution factor of bridges with decked bulb tee girders connected only enough to prevent relative vertical displacement at the interface for the single lane loaded condition in the future AASHTO LRFD Specifications.

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