Third International Conference on Sustainable Construction Materials and Technologies http://www.claisse.info/Proceedings.htm

Examination of Load Distribution Factors for Various Bridge Types

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ABSTRACT

Distribution factors provided by AASHTO-LRFD for live load are excessively conservative. AASHTO presents number of methods to analyze bridges such as grillage analysis, finite element analysis, and load distribution factor. The finite element analysis is the most accurate method of analyses. In finite element analysis, the three-dimensional behavior of the bridge can be incorporated, however, with the load distribution factor method, the load factor shall be multiplied by results of one-dimensional analyses. There is a need to conduct finite element analyses of different bridge types to investigate the suitability of AASHTO distribution factors. The development of more suitable distribution factors will lead to more economical design. Steel and concrete I-girder and box-girder bridges were selected to be modeled and analyzed to address effect of important parameters such as number of spans, span length, and girder spacing. A set of recommendations are presented to guide the use of AASHTO distribution factors.

Keywords. Distribution Factors, AASHTO-LRFD, Bridge Live Load

BACKGROUND

The live load distribution factor for shear or moment is the ratio between the maximum shear or moment experienced by the bridge girder to the maximum shear or moment load that is calculated to be experienced by the whole bridge due to application of live load. The live load distribution factors calculated using the Association of State Highway and Transportation Officials load and resistance factor design (AASHTO-LRFD) for live load are reported as conservative (Huo et al., 2004; Khaloo and Mirzabozorg, 2003; Eom and Nowak, 2001; Barr et al., 2001; Chen and Aswad, 1996; Ebeido and Kennedy, 1995 and 1996; Zokaie et al., 1991). Also, it was found to be unconservative in some of the cases (Barr and Amin, 2006; Huo and Zhang, 2008). The use of conservative live load distribution factors would lead to uneconomical design. Although a number of studies have been conducted to examine the AASHTO distribution factors, there is not any studies examined the suitability of distribution factors for different types of bridges in the context of effect of various parameters.

This investigation targeted to examine the suitability of the use of AASHTO live load distribution factors for different bridge types and also to guide the use of these distribution factors. In this study, a wide range of three-dimensional finite element bridge models with different superstructure types, span lengths, number of spans, and girder spacing are investigated.

PROPERTIES OF BRIDGES

Three bridge types were considered including steel and concrete I-girder bridges and Box-beam bridges (Figure 1 through Figure 3). The steel I-girder bridge has 7 in. thick reinforced concrete (R/C) deck, six (6) steel plate girders with 50 ksi yield strength. The thickness of the bridge decks is 10 in. at hunch and at overhang locations. Inverted x-frames made up of L 4 x 4 x 5/16 are used in the bridge. The compressive strength of concrete (f'_c) used is 4000 psi. The benchmark bridge was altered to study various parameters. The bridges are 100 ft single span bridge, two-span bridge with 100 ft and 150 ft spans, and two-span bridge with 100 ft and 150 ft spans supported on only 4 girders. The R/C Box-beam bridge has 9 in. thick deck and 8 in. thick soffit and four (4) girders. The bridge has 3.5 ft wide end diaphragms and 5 ft wide diaphragm at bent location. The compressive strength of concrete (f'_c) used is 4000 psi. The box-beam bridges studied are 100 ft single span bridge, two 100 ft equal span bridge, two 150 ft equal span bridge, and two 150 ft equal span bridge supported on six (6) girders. The R/C I-girder bridge has 8 in. thick deck supported on five (5) Type I AASHTO girders. The bridge was examined with various spacings and spans.

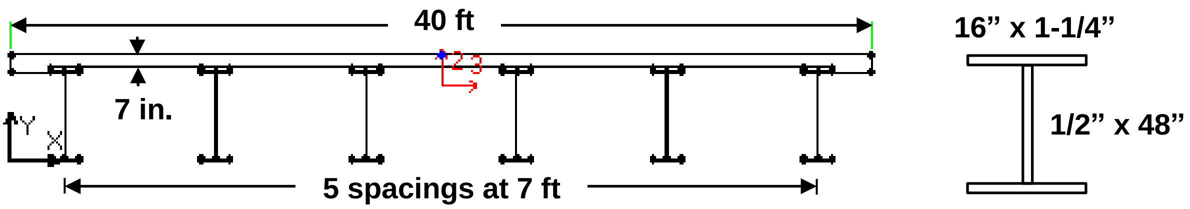


Figure 1. Benchmark steel I-girder bridge

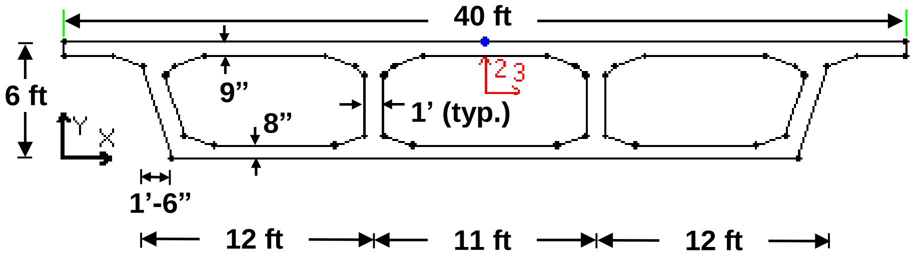


Figure 2. Benchmark box-beam bridge

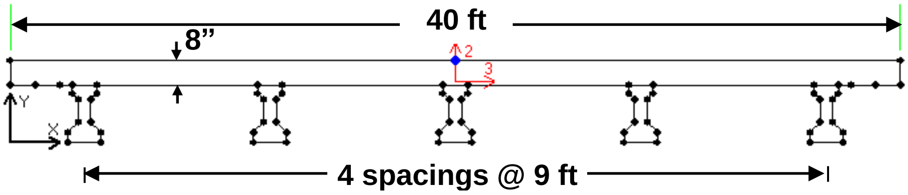


Figure 3. Benchmark R/C I-girder bridge

MODELING AND ANALYSIS

As mentioned earlier, three bridge types are considered in this study. Three-dimentional finite element models of bridges developed to include various parameters such as span length, number of spans, and girder spacings were developed. The bridge deck and girders were modeled using shell elements. To study the adequacy of the mesh used, a bridge model with finer mesh was developed. The results of analysing that bridge were compared to those of the bridge with a typical mesh used. AASHTO-LRFD HL-93 live load which is the larger of HS-20 and 0.64 kip/ft uniform load and tandem load and 0.64 kip/ft was applied to all of the bridge models under study. It is noted that an impact factor of 33% was applied to both of HS-20 truck and tandem load. Also, the bridges were divided to the proper number of lanes. The cases, where an exterior lane is loaded solely, the central lane is loaded solely, two adjacent lanes loaded, and all of the lanes are loaded, were all considered in order to arrive at the critical distribution factors for exterior and interior girders for both of shear and moment. It is important to note that live load was moved along the length of the bridge in order to maximize shear or moment in the bridge and girders. The critical distribution factor is the largest distribution factor, for each of moment and shear, of those associated with all of lane(s) loading cases described before.

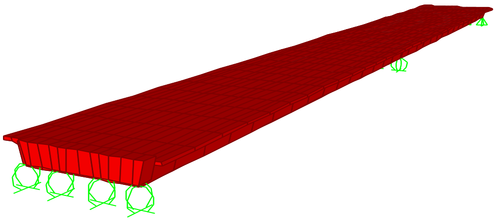


Figure 4. Box-Beam bridge model

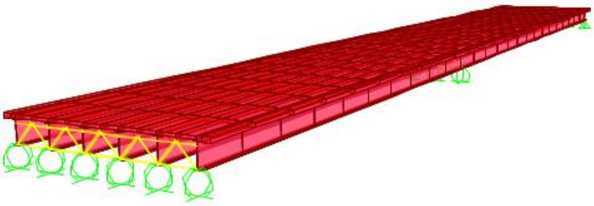


Figure 5. Steel I-girder bridge model

RESULTS AND DISCUSSIONS

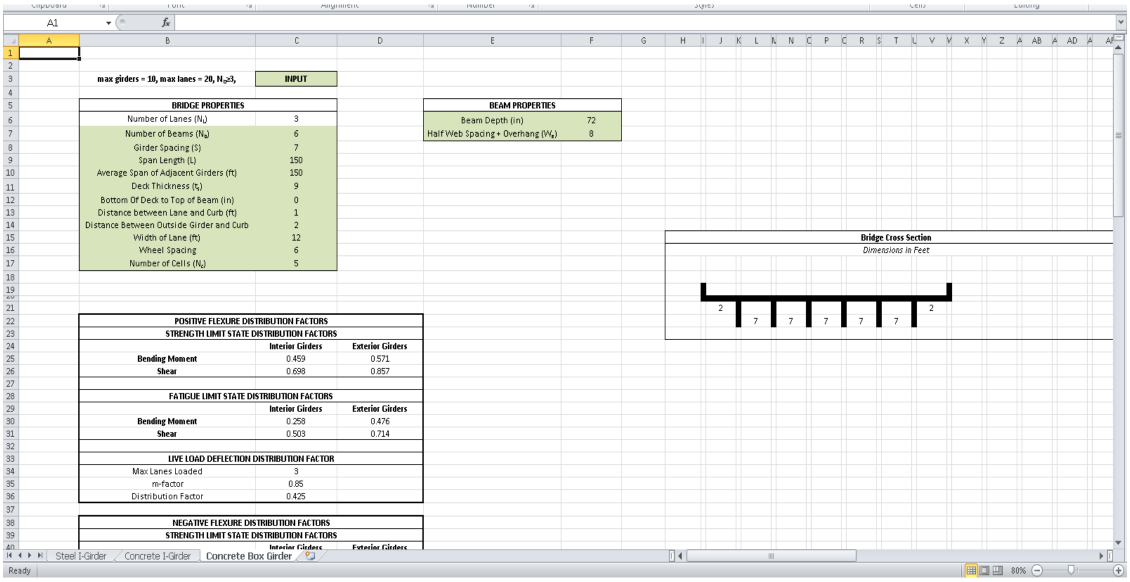
To examine the adequacy of the mesh used to develop the three-dimensional finite element models used to assess the live load distribution factors in bridges under study, a bridge model with finer mesh was developed and analyzed. The distribution factors for different lane loading cases namely, eccentric one lane loaded, concentric one lane loaded, two lane loaded, and three lane loaded, for shear and moment were calculated using the two cases of mesh distribution and presented in Table 1. For shear distribution factors, the difference between results of using the typical mesh and a finer mesh was about 1.6% for the exterior girder and 0% for the interior girder. For the positive moment distribution factor, the difference was about 4% for the exterior girder and 0% for the interior girder. The results of using either of the typical mesh or a finer mesh were identical for both of the exterior and interior girder when the negative moment distribution factor was calculated. Therefore, the mesh that is used was verified to be accurate.

Table 1. Results of using a finer mesh

Girder		Shear distribution factor	Positive moment distribution factor	Negative moment distribution factor
Typical mesh	Exterior girder	0.61	0.25	0.30
	Interior girder	0.47	0.32	0.33
Finer mesh	Exterior girder	0.62	0.24	0.30
	Interior girder	0.47	0.32	0.33

The primary objective of this study is to compare live load distribution factors calculated using AASHTO-LRFD equations and lever rule to those determined from analysis of three-dimensional finite element bridge models in order to guide the use of AASHTO-LRFD distribution factors. Therefore, Excel spreadsheet (Figure 6) was developed incorporating AASHTO-LRFD equations and lever rule, which is used in certain cases as per AASHTO tables, to facilitate the calculation of AASHTO-LRFD. The AASHTO distribution factor were calculated for either shear or moment for all of the bridge cases considered in this investigation. The spreadsheet was general enough to accommodate all of the bridge types considered and also a large number of girders and lanes.

Figure 7 shows a comparison between the distribution factors calculated using AASHTO-LRFD and analytical distribution factors. It is clear that AASHTO-LRFD distribution factors are over conservative when they are compared with analytical ones. This conclusion can be generalized for both shear and moment. Also, it is applicable regardless of the type of superstructure.



max girders = 10, max lanes = 20, $N_b \geq 3$, INPUT

BRIDGE PROPERTIES	
Number of Lanes (N_L)	3
Number of Beams (N_b)	6
Girder Spacing (S)	7
Span Length (L)	150
Average Span of Adjacent Girders (ft)	150
Deck Thickness (t_s)	9
Bottom Of Deck to Top of Beam (in)	0
Distance between Lane and Curb (ft)	1
Distance Between Outside Girder and Curb	2
Width of Lane (ft)	12
Wheel Spacing	6
Number of Cells (N_c)	5

BEAM PROPERTIES	
Beam Depth (in)	72
Half Web Spacing + Overhang (W_e)	8

POSITIVE FLEXURE DISTRIBUTION FACTORS

STRENGTH LIMIT STATE DISTRIBUTION FACTORS

	Interior Girders	Exterior Girders
Bending Moment	0.459	0.571
Shear	0.698	0.857

FATIGUE LIMIT STATE DISTRIBUTION FACTORS

	Interior Girders	Exterior Girders
Bending Moment	0.258	0.476
Shear	0.503	0.714

LIVE LOAD DEFLECTION DISTRIBUTION FACTOR

Max Lanes Loaded	3
m-factor	0.85
Distribution Factor	0.425

NEGATIVE FLEXURE DISTRIBUTION FACTORS

STRENGTH LIMIT STATE DISTRIBUTION FACTORS

	Interior Girders	Exterior Girders

Figure 6. Screenshot of spreadsheet

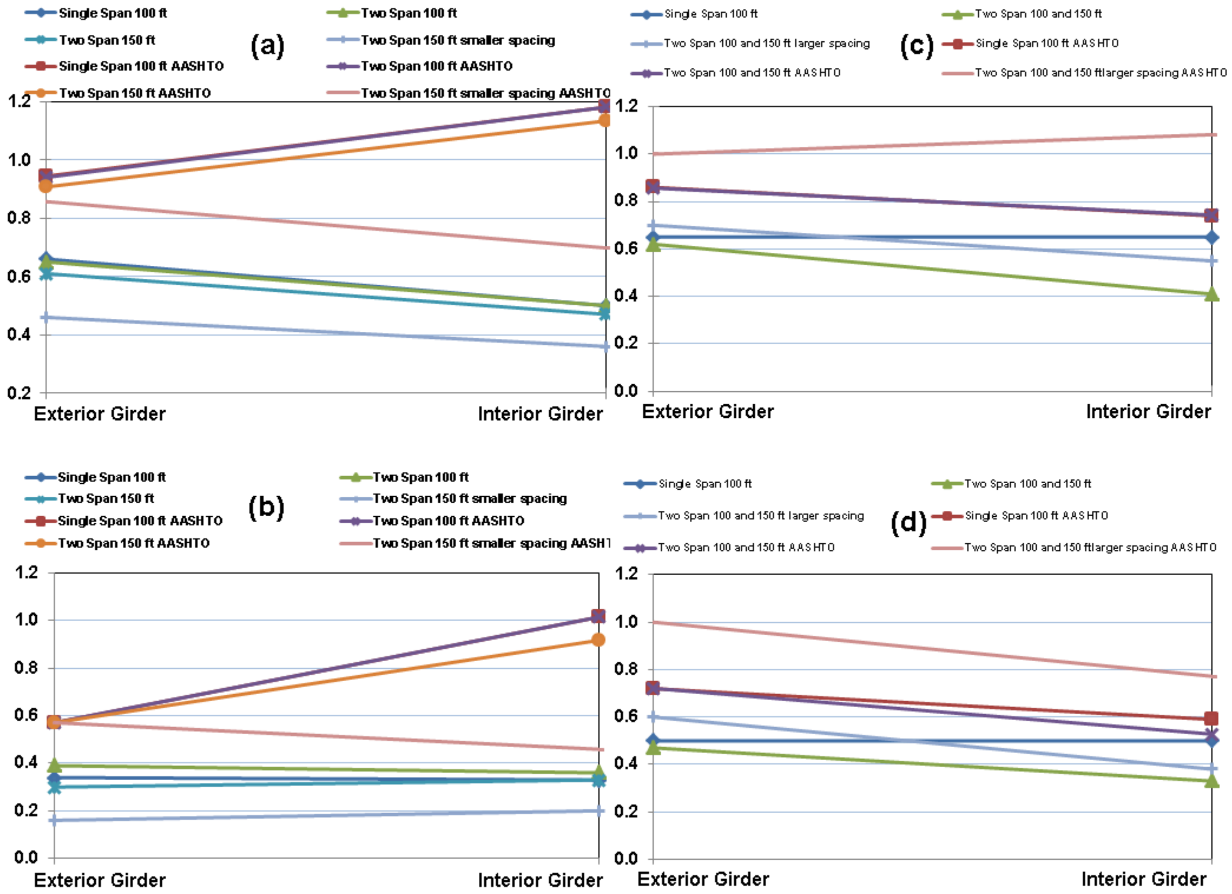


Figure 7. Comparison between analytical distribution factors and AASHTO distribution factors (a) Shear – Box-Girder bridge, (b) Moment – Box-Girder bridge, (c) Shear – Steel I-girder bridge, and (d) Moment – Steel I-girder bridge

CONCLUSIONS

This study evaluated the use of current AASHTO-LRFD methods to determine the live load distribution factors. Three bridge types including box-beam bridge, steel I-girder, and RC I-girder bridges were examined. Various parameters were studied such as span length, number of spans, and spacing between girders. Benchmark bridges selected were altered to study the parameters mentioned earlier. Three-dimensional finite element models of all of bridge types included in the study we developed. Based on the study performed, the finite element mesh used was proven to be accurate. Therefore, it can be used to develop the bridges used in this study and other bridges if needed. Also, this study proved that AASHTO-LRFD current methods to determine the live load distribution factors are overly conservative. There is a need to adjust the current design method in order to achieve a close agreement between the actual live distribution factors expected and the ones determined using AASHTO-LRFD. The live distribution factors determined from finite elements analyses are the most accurate factors therefore they were used to evaluate the accuracy of AASHTO-LRFD current methods to determine live load distribution factors. This investigation should be expanded through including more bridges and more parameters. Making the investigation more comprehensive will assist to ensure the validity of the conclusion for any types of bridges and for any expected conditions. Also, it will help to propose set of equations or set of adjustment factors to be used to improve the accuracy of current AASHTO-LRFD methods to calculate live distribution factors.

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