Proceedings of the 5th International Conference on Civil Engineering for Sustainable Development (ICCESD 2020), 7~9 February 2020, KUET, Khulna, Bangladesh (ISBN-978-984-34-8764-3)

LATERAL LIVE-LOAD DISTRIBUTION FACTORS OF A CURVED COMPOSITE BRIDGE

M. Hossain*[1], M. B. Zisan[2] and P. K. Das[2]

[1]Department of Civil Engineering, CUET, Bangladesh, email: mhossain.cuet@gmail.com
[2]Department of Civil Engineering, CUET, Bangladesh, email: basirzisan@gmail.com
[3]Department of Civil Engineering, CUET, Bangladesh

***Corresponding Author**

ABSTRACT

The live-load distribution factor is the key parameter in the design and construction of Highway Bridges. Numerous studies, as well as AASHTO and AASHTO-LRFD specification on live-load distribution, covered the conventional bridge only whereas the curved bridges yet remain hidden. The complexities in construction procedure and curvature provide in the curved bridge itself a unique feature. The objectives of the current study are investigating the effect of curvature, slab stiffness, girder stiffness and diaphragm spacing on live-load distribution. The numerical study consists of modeling and verification of an existing curved bridge model using ANSYS program. The analysis was performed using AASHTO HS20-44 design truck. This study shows that the live -load distribution factor of outer girder is increased about 38% for outer girder loading and 62% for inner girder loading with a decreasing radius of curvature. On the other hand, the distribution factor of inner girder is decreased about 78% and 36.5% for outer and inner girder loading respectively. The numerical analysis explored the live-load distribution for shear.

Keywords: *Live-Load Distribution Factor, Curved Composite Bridge, Curvature, ANSYS, AASHTO HS20-44 Truck*

1. INTRODUCTION

The use of horizontally curved bridges is increasing in complex and important highway interchanges and river crossing in urban and suburban regions to meet increasing traffic capacity demands. Usually, modernized curved bridges such as curve twin I-girder bridges (CTIGB), are becoming familiar for short and medium span highway bridges (Kim, Kawatani, & Hwang, 2004). The rationalize structures have advantages like simplicities for fabrication, design, and construction. Also, this type of construction gives a very economical performance, due to the less number of girders and secondary members (Awall, Hayashikawa, Matsumoto, & He, 2012). The American Association of State Highway and Transportation Officials (AASHTO) for highway bridges did not account the effect of curvature for curve bridges in live-load distribution factor (AASHTO (1994a), 1994). AASHTO gave Standard specification for straight bridges. Later in 1994, AASHTO LRFD gave a correction factor for skew bridge (AASHTO (1994b), 1994). But it did not mention any correction factor or specification considering the curvature effect. The distribution of load in a curve bridge is different than that of a normal straight bridge because of out-plane bending and excessive torsional effects (Brockenbrough, 1986). When the vehicular load is applied on the outer girder (with respect to origin of bridge curvature) of a twin I-girder curve bridge, uplift force will be induced in the inner girder support *(Zisan, Hayashikawa, Matsumoto, & He, 2015)*. But this is normally not happened in a straight bridge case. Hence, it is required to check the lateral live-load distribution in curved composite bridge

1.1 Live-Load Distribution Factors

The live-load distribution factor is the amount of the vehicular load carried by each girder. The live-load distribution factors for conventional bridges are given by the AASHTO Standard Specifications for Highway Bridges 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 (Barr, Eberhard, & Stanton, 2001). If a concrete bridge deck is constructed on prestressed concrete girders and carrying more than one lanes of traffic, the distribution factor (AASHTO 1996) is S/5.5, where S is the girder spacing in feet (AASHTO, 1996; Zokaie, 2000). The design moment will be the multiplication of this factor with the moment on a single girder, generated by one lane of wheel load. The changes in the code over the years have also created inconsistencies *(Zhang, Huang, & Wang, 2005)*. The objective of this study is to find out the live-load distribution factor of a composite bridge by finite element modeling and following the code specification for different bridge parameters. After that, the disparity between the live-load distributions factor obtained from the finite element analysis to the present practiced code is determined.

2. FINITE ELEMENT MODELING

2.1 Model Description

This study adopted a simply supported horizontal curved twin I-girder bridge of having a span length of 50 m. For model verification and validation an existing bridge model was chosen for this study from *Awall et al. (2012)*. The bridge model is consisting of two lanes for the vehicle along with two pedestrian lanes for cycling and walking. It has two main I-girders of 3 m deep and spaced transversely by 6 m. In this study, the radii of curvatures defined as the distance between the origin to the centerline of the circular arc. Thus, the length of the two main girders varies according to the bridge curvature, while the total mass of the bridge remains the same. The deck slab (10.5 m wide and 0.3m thick) is assumed to act compositely with steel girders. The two main girders are laterally interconnected by intermediate and end diaphragms at a uniform spacing of 5 m. The cross-sectional layout and geometric properties of the bridge are presented in Figure 2.1, and Table 1, respectively.

2.2 Bridge Model

In this study, the concrete and steel members were modeled by using SOLID45 and SHELL63 elements respectively. The SOLID 45 is a hexagonal 8-node element that has a large deflection and strain capability with three degrees of freedom at each node. Whereas the SHELL63 element is a quadrilateral

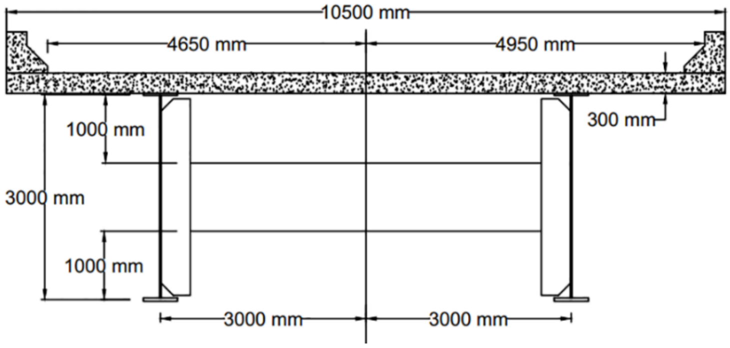


Figure 2.1: Cross-section of the bridge

Table 1: Geometric properties of the bridge (Awall et al., 2012)

Span length (m)	50
Deck thickness × width (m)	0.3 × 10.5
Dimensions of main girders (mm)	Upper FLG500×30, Lower FLG 500×50
Dimensions of intermediate cross-beams (mm)	WEB 1000×16, FLG 300×25
Dimensions of end cross-beams (mm)	WEB 3000×16, FLG 300×25

Table 2: Bridge boundary condition (Awall et al., 2012)

Type	U_1	U_2	U_3	θ_1	θ_2	θ_3
Hinged	Fix	Fix	Fix	Free	Free	Free
Movable	Fix	Free	Fix	Free	Free	Free

4-node element that has stress stiffening, bending, membrane, and large deflection capabilities with six degrees of freedom at each node. The main girders are supported by two types of support such as hinged support and roller support in the tangential direction as described in Table 2. The 3-D model of the curved bridge was created by taking advantage of the cylindrical coordinate system of ANSYS. Here, all the boundary conditions and elements are defined based on this system. For the material properties, the concrete has a modulus of elasticity, Poisson's ratio, and mass density of 28.57 GPa, 0.20, and 2,500 kg/m^3 respectively. A modulus of elasticity of 200 GPa, a mass density of 7,850 kg/m^3 and a Poisson's ratio of 0.30 was used for steel.

2.3 Model Verification

The verification of the bridge model was done by comparing the natural frequencies and mode shapes of this bridge with the existing bridge model. The existing bridge model was taken from *Awall et al. (2012),* where the natural frequencies of a numerical model of a two-span twin I-girder bridge are given. The cross-section, span number, boundary conditions, and other properties are same as the bridge adopted in this study. Therefore, the bridge is modeled with the same process using ANSYS, and natural-vibration analysis is performed to measure and compare it with existing data. Figure 2.2 shows Frequencies obtained from this analysis are similar to those obtained by Awall et al. (2012). Figure 2.3 shows the numerical natural vibration frequencies and mode shapes. Therefore, it can be concluded that the FE modeling technique for the bridge is appropriate.

2.4 Vehicle Parameters

The vehicle used in this study is an HS20-44 design truck, which is a major design vehicle for highway bridge design specified by AASHTO consisting of six wheels and three-axle tractor-trailer system. The front axle and rare axle load are 43KN and 145KN respectively. The distance between the axles is 4.3m and the width of the vehicle is 1.8m. In this study, vehicle transverse position used as only vehicle parameter. It is found that the vehicle transverse position has a significant effect on the live-load distribution factor

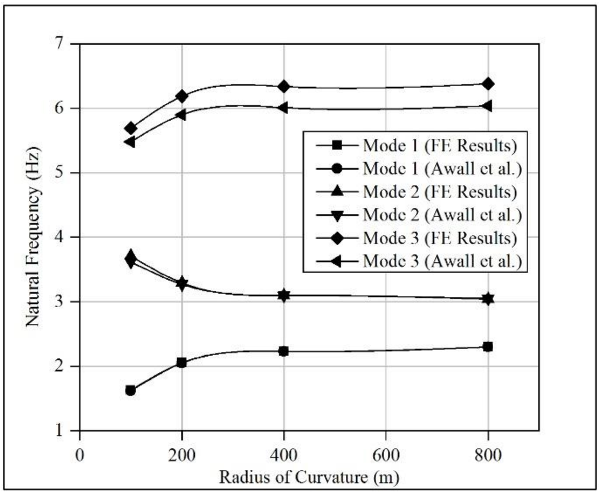
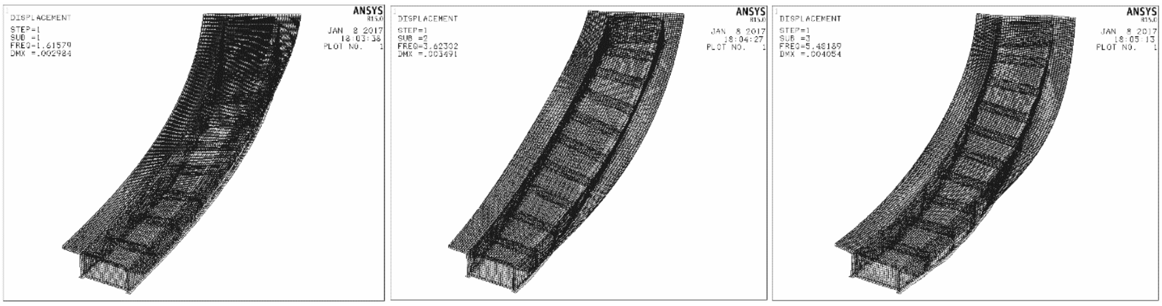


Figure 2.2: Comparison of Natural frequencies of the bridge with the existing model



1st Mode (1st bending) FE Analysis: 1.62 Hz	2nd Mode (1st torsion) FE Analysis: 3.62 Hz	3rd Mode (2nd bending and torsion) FE Analysis: 5.48 Hz

Figure 2.3: Different mode shapes and natural vibration frequencies

3. LIVE-LOAD DISTRIBUTION FACTOR

3.1 Effect of Curvature on Distribution Factor

Curvature has a significant effect on the live load distribution factor in a curve bridge. The ratio of distribution factor for curve bridge to straight bridge is used to describe the effect of curvature. A bridge with a small radius of curvature shows negative shear at inner girder support. In Figure 3.1, two locations were selected to apply vehicle load (HS20-44 truck) on the bridge named as Pi and Po. The girders are designated by Gi and Go for inner and outer girders respectively. Here, when the load applied at location Pi and measured distribution factor in girder Gi (Inner) than it is denoted by GiPi and similarly others.

Figure 3.2 shows the effect of the bridge radius on the LLDFs. For both girders, the distribution factors are changed up to 500 m radius of the curve than they remain straight. The AASHTO guide 1993 gives a highly conservative distribution factor. Whereas, lever rule gives a slightly conservative distribution factor.

Figure. 3.3 shows the variation of distribution factor with L/R ratio, where L and R named as span length and radius of curvature respectively. When the truckload applied on the outer girder (Po), the distribution factor of inner girder (GiPo) is decreasing with the decrease of radius of curvature and the distribution factor of outer girder (GoPo) is uniformly increased with the decrease of radius of curvature. The distribution factor of outer girder (GoPo) is 0.68 and 0.32 for inner girder (GiPo) when the bridge is nearly straight (radius of curvature is above 1000m). Though the distribution factor of outer girder (GoPo) is increased to 0.94 with a decreasing radius of curvature (radius of curvature is 100m), whereas it rapidly decreased to 0.07 for inner girder (GiPo).

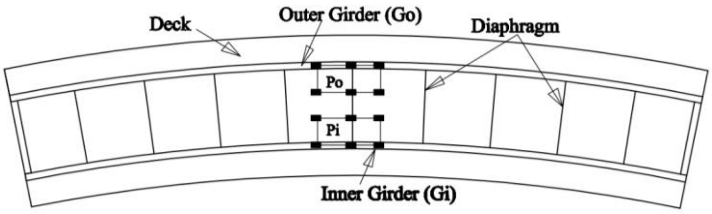


Figure 3.1: Plan view of the curved bridge

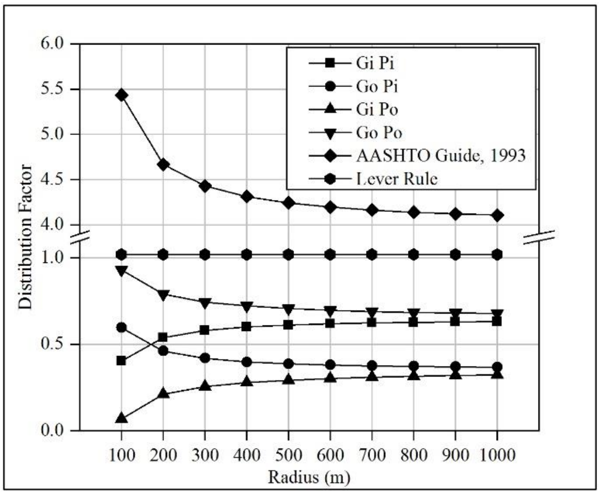
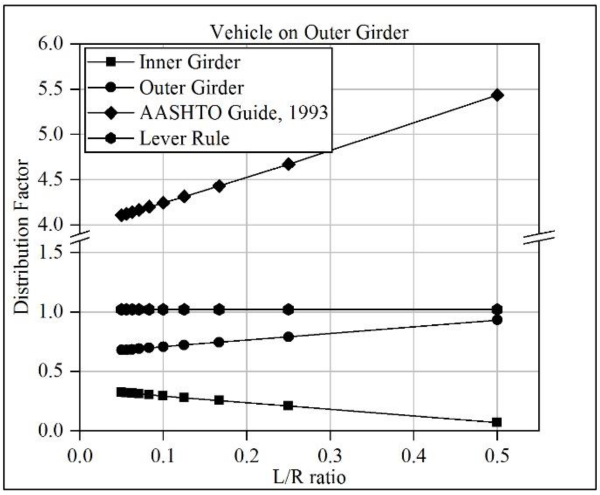


Figure 3.2: Effect of bridge radius on distribution factor



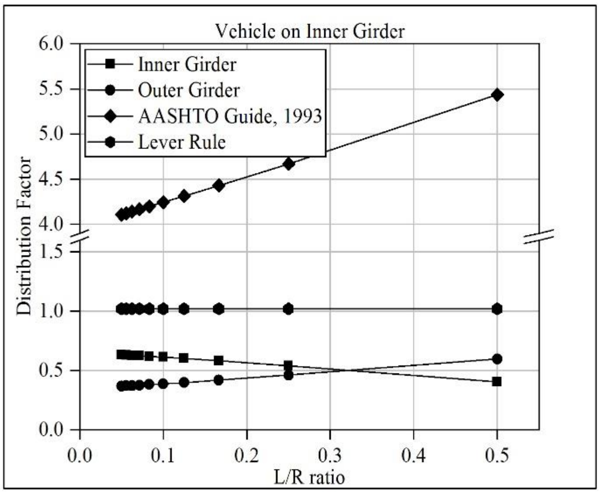


Figure 3.3: Effect of bridge curvature on distribution factor [Vehicle on outer girder (P_o)]

Figure 3.4: Effect of bridge curvature on distribution factor [Vehicle on inner girder (P_i)]

Figure 3.4 shows that when the load applied to the inner girder the distribution factor is increasing for outer girder (G_oP_i) and decreasing for inner girder (G_iP_i) with decreasing radius of curvature. When the bridge is nearly straight, the maximum load will be carried by the inner girder and the distribution factor is 0.63 whereas 0.37 for outer girder. As the bridge getting curved (small radius of curvature), the distribution factor is increased to 0.60 for outer girder and decreased to 0.40 for inner girder. The distribution factor for outer and inner girder is intersecting when the radius of curvature is approximately 150m.

3.2 Effect of Slab Thickness on Distribution Factor

Figures 3.5 & 3.6 shows that slab thickness has little effect on the live-load distribution factor. Here, the slab thickness varies from 0.25 to 1 m. When the vehicle on the outer-girder, live-load distribution factor of the outer girder is increasing with an increasing slab stiffness. Whereas, the distribution factor for inner girder is decreasing. This variation in distribution factor occurs due to increasing slab stiffness. On the other hand, when the vehicle position on inner-girder, the distribution factor is nearly similar for both inner and outer girders. But this time the loaded girder distribution factor is not increased like outer girder vehicle position. From the figure, it can be noted that the AASHTO standard specification gave a highly conservative distribution factor for both inner and outer girders. But the lever rule gives a close distribution factor for outer girder loading and a slightly conservative for inner girder loading.

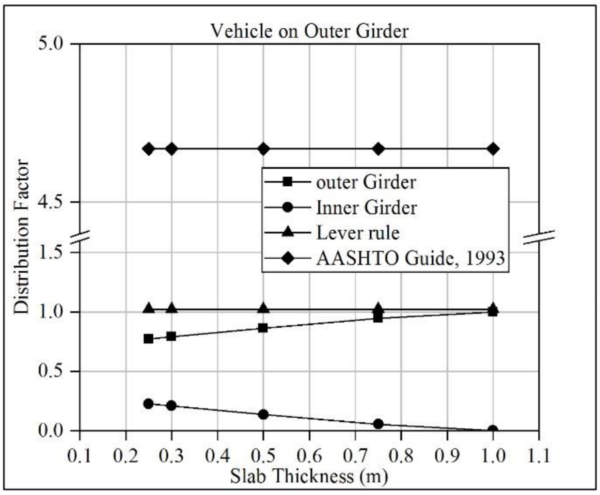


Figure 3.5: Effect of slab thickness on distribution factor [Vehicle on outer girder (P_o)]

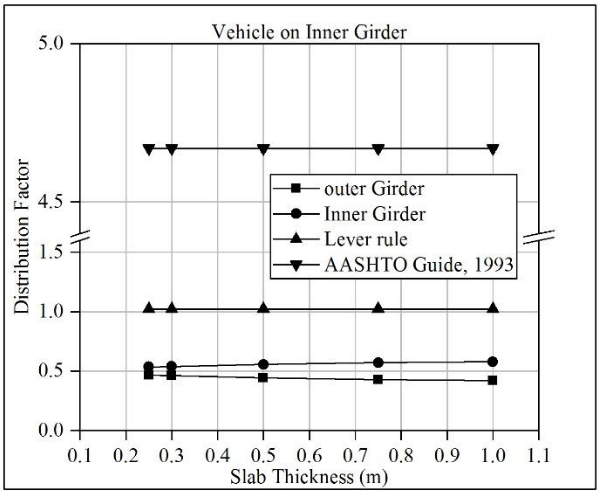


Figure 3.6: Effect of slab thickness on distribution factor [Vehicle on inner girder (P_i)]

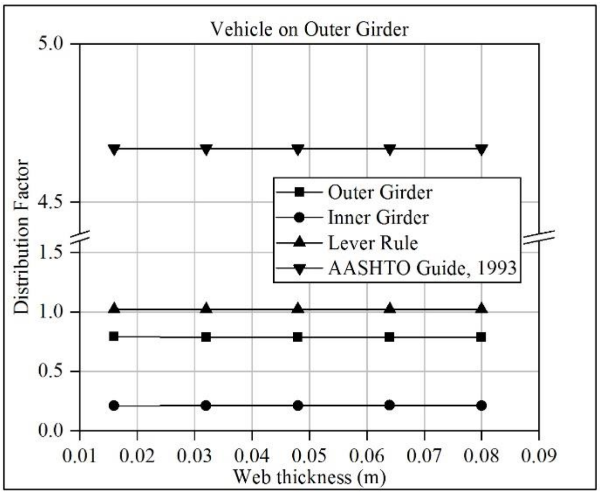


Figure 3.7: Effect of web thickness on distribution factor [Vehicle on outer girder (P_o)]

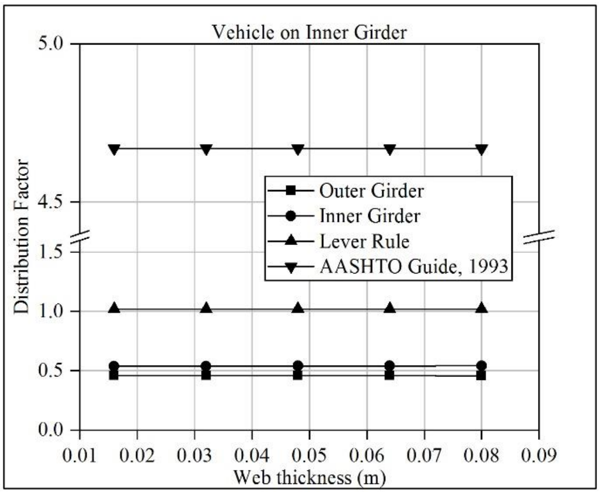


Figure 3.8: Effect of web thickness on distribution factor [Vehicle on inner girder (P_i)]

3.3 Effect of Girder Stiffness on Distribution Factor

In this study, the effect of girder stiffness on the distribution factor has been evaluated. Figures 3.7 & 3.8 show that the girder stiffness doesn't have any effect on the distribution factor in curve bridge.

3.4 Effect of Diaphragm spacing on Distribution Factor

Figures 3.9 & 3.10 show that the diaphragm spacing has no influence on the live-load distribution factor at all. Here, the distribution factor for different diaphragm spacing has been evaluated. The diaphragm spacing ranges from 5 to 25 m. The FE results show no effect on the distribution factor. It can be observed that AASHTO standard specification gives a highly conservative distribution factor whereas lever rule provides slightly conservative results.

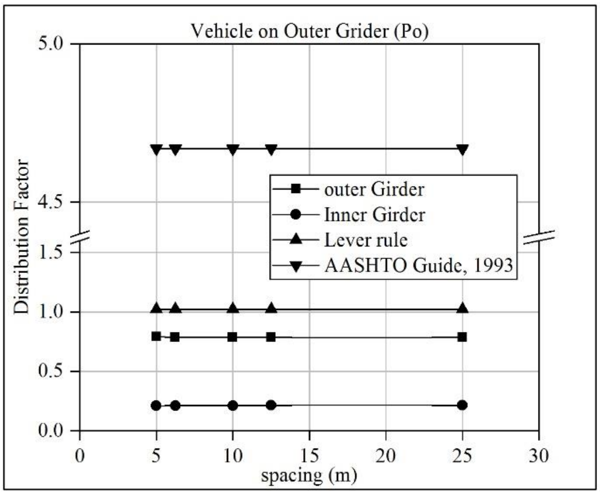


Figure 3.9: Effect of diaphragm spacing on distribution factor [Vehicle on outer girder (P_o)]

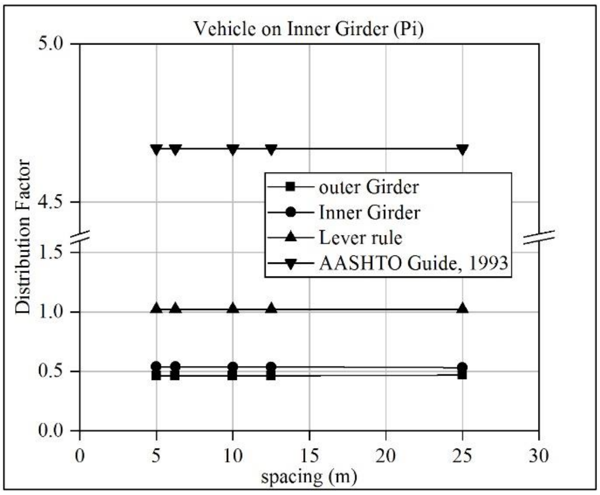


Figure 3.10: Effect of diaphragm spacing on distribution factor [Vehicle on inner girder (P_i)]

4. CONCLUSIONS

The accurate estimations of distribution factors for live-load is very important to bridge design. If the distribution factors are underestimated, the bridge members may be under-designed and will experience serviceability problems. On the contrary, if distribution factors are overestimated, the bridge members will be over-designed and the cost of the bridge construction will increase unnecessarily. Based on the FE study and result of the curve bridge, the following conclusions are made: (1) curvature has a significant effect on live-load distribution in a Curved twin I-girder bridge; (2) the distribution factor of inner girder is decreased for both loading condition with decreasing radius of curvature. It is decreased 78% and 36.5% for outer and inner girder loading respectively; (3) the distribution factor of outer girder is increased for both loading conditions with decreasing radius of curvature. It is increased 38% for outer girder loading and 62% for inner girder loading; (4) AASHTO Guide, 1993 gives a highly conservative distribution factor. However, lever rule method gives a fairly conservative distribution factor; and (5) the finite element results also show that the slab stiffness has considerable effect. Whereas, the girder stiffness and diaphragm spacing have no effect on the distribution factor. Considering this curvature effect some correction factor needs to be added to the standard specification.

REFERENCES

AASHTO. (1996). *Standard specifications for highway bridges* (16th Ed.). Washington, DC.

AASHTO (1994a). (1994). *LRFD Bridge Design Specifications* (1st Ed.). Washington, DC.

AASHTO (1994b). (1994). *LRFD Bridge Design Specifications* (2nd Ed.). Washington, DC.

Awall, R., Hayashikawa, T., Matsumoto, T., & He, X. (2012). Effects of bottom bracings on torsional dynamic characteristics of horizontally curved twin I-girder bridges with different curvatures. *Journal of Earthquake Engineering and Engineering Vibration*, *11*(2), 149–162. https://doi.org/10.1007/s11803-012-0106-4

Barr, P. J., Eberhard, M. O., & Stanton, J. F. (2001). LIVE-LOAD DISTRIBUTION FACTORS IN PRESTRESSED CONCRETE GIRDER BRIDGES. *Journal of Bridge Engineering*, *6*(5), 298–306.

Brockenbrough, R. L. (1986). Distribution factors for curved I-girder bridges. *Journal of Structural Engineering (United States)*, *112*(10), 2200–2215. https://doi.org/10.1061/(ASCE)0733-9445(1986)112:10(2200)

Kim, C. W., Kawatani, M., & Hwang, W. S. (2004). Reduction of traffic-induced vibration of two-girder steel bridge seated on elastomeric bearings. *Engineering Structures*, *26*(14), 2185–2195.

Zhang, H., Huang, D., & Wang, T.-L. (2005). Lateral Load Distribution in Curved Steel I-Girder Bridges. *Journal of Bionic Engineering*, *10*(3), 281–290. https://doi.org/10.1061/(ASCE)1084-0702(2005)10:3(281)

Zisan, B., Hayashikawa, T., Matsumoto, T., & He, X. (2015). Dynamic response and distortion-stress in curved multi-girder bridges subjected to high-speed moving vehicles. *Journal of Structural Engineering*, *61A*.

Zokaie, B. T. (2000). AASHTO-LRFD LIVE LOAD DISTRIBUTION SPECIFICATIONS. *Journal of Bridge Engineering*, *5*(2), 131–138.