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LIVE LOAD DISTRIBUTION FACTORS FOR STEEL GIRDER INTEGRAL ABUTMENT BRIDGES

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ABSTRACT: This research examines the accuracy of both AASHTO Standard Specification and AASHTO LRFD girder distribution factors (GDF) for use with designing integral abutment bridges. To evaluate the GDFs, the integral abutment Scotch Road Bridge was modelled in the finite element software Abaqus/Cae. The model was verified using temperature-displacement data recorded from April, 2003 to May, 2006. Following the validation of the finite element model, three loading cases including one, two, and three lanes, were run in Abaqus. The stress data obtained from each case was used to calculate the GDF for each girder at the locations of maximum positive and negative moments. Lane one loading provided the most reasonable results for AASHTO LRFD, while the AASHTO standard equation was overly conservative in all cases. The positive and negative results yielded similar GDF ratios to each other for one lane loaded. The positive and negative Abaqus/Cae one lane loaded GDF values were 20% and 25% lower than AASHTO 2012 respectively, while being 50% lower than AASHTO 1996. Both AASHTO GDF equations were overly conservative for both two and three lanes loaded. The Abaqus calculated GDF was approximately 50% and 60% lower for two and three lanes loaded compared to AASHTO LRFD. A parametric study was conducted to investigate the effect of bridge skew, pile length, and pile spacing. We found that AASHTO 2012 better predicts the effect of skew in the calculated GDF, however, neither reducing the number of piles nor adjusting the pile length in a bridge creates a significant change in the GDF ratios when pile fixity is maintained.

KEYWORDS: Girder distribution factors; superstructure; vehicular live load; integral bridges.

1 INTRODUCTION

Expansion joints have been used in bridge construction, up until the 1960's (Arsoy, 1999). This was the best known method to account for the various material thermal movements of bridges. Inevitably, the joints incorporated into these bridges began to become ridged due to increased corrosion over time.

Even after joint failure, engineers observed that a bridge could still adequately perform without the use of expansion joints (Mourad, 1999). After discovering a bridge could function without a thermal movement joist the use of integral abutment bridges (IABs) has been growing rapidly among many states. In a survey conducted by the University of Illinois Champaign-Urbana (U of I), 39 responding states reported 9,000 fully integral and 4,000 semi-integral abutment bridges in service, and of these bridges two thirds have been built since 1995 (Olson, 2009). The survey not only highlights the increasing use of IAB but discusses the lack of national design standards between states. A West Virginia University (WVU) survey found IAB requirements vary from a maximum span length of 19.8 m to 91.4 m for fully integral steel girder bridges (Maruri, 2005). Similar ranges can be found for maximum skew, total length, and curvature of both steel and prestressed concrete girders (Maruri, 2005)

2 BRIDGE DESCRIPTION

The focus on this particular study was The Scotch Bridge located in Trenton, NJ. The Scotch Road Bridge was instrumented and monitored from April, 2003 to May, 2006 (Hassiotis, 2006). In order to better understand the effect of the vehicular live loading on the bridge a new Abaqus/CAE FEM was created and compared to the instrumented bridge temperature data. The bridge deck was two 45.45 m spans totaling 90.9 m long, 32.91 m wide, and had a 6.0 m approach slab with a 14.9^{o} skew. The Scotch Bridge lane, girder, pier, and abutment layout is as shown in Figs 1 and 2 below.

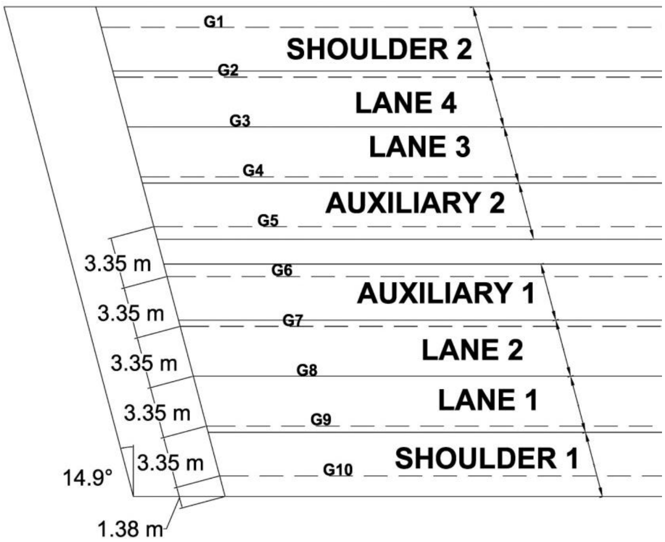

Figure 1. The Scotch Road Bridge deck layout and dimensions

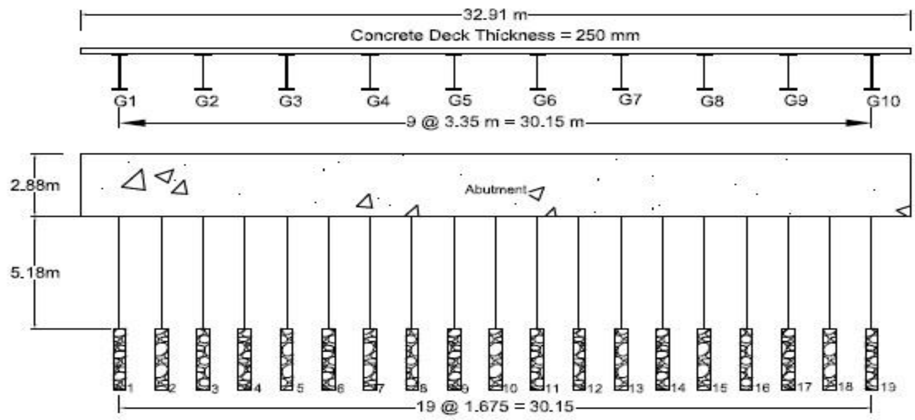

Figure 2. The cross-sectional layout of the Scotch Road Bridge

3 FINITE ELEMENT MODEL VALIDATION

In order to ensure the updated Scotch Road Bridge FEM behaved as anticipated, the temperature and displacement data was used from the originally monitored bridge (Hassiotis et al., 2006). The process of applying the same thermal load to the FEM as the field monitored bridge was iterated multiple times adjusting the spring coefficient of the Abaqus model for each iteration until the displacement obtained from the FEM closely matched those of the field data. The final selection was using a spring coefficient (k) = 10,000kN/m^2 (1,450psi) as shown in Figure 3.

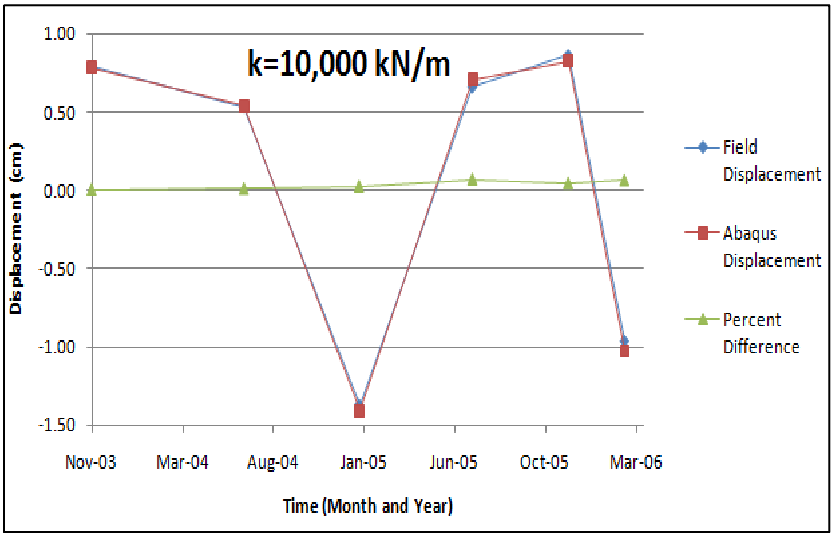

Figure 3. Abaqus field displacement comparison versus time

4 DISTRIBUTION FACTORS

The 1996 AASHTO Standard Specifications and the 2012 AASHTO LRFD Bridge Design Specifications were compared to the Abaqus calculated GDFs. The original AASHTO Standard equation was simple and neglected many factors associated with bridge design. The original GDF for one lane loaded is

$$GDF_{1\text{-lane}} = \frac{S}{4.27} \tag{1}$$

while two or more lanes loaded is

$$GDF_{multiple} = \frac{S}{3.36} \tag{2}$$

where S = the girder spacing (m).

Through a collaboration of researchers the NCHRP Project 12-26 later developed GDF equations that were more representative of typical bridge design parameters (Eom et al., 2001). AASHTO later adopted the NCHRP equations adding additional factors to represent the true stiffness of a bridge. The equation developed for one lane loaded is

$$GDF = 0.06 + \left(\frac{S}{4.3}\right)^{0.4} \left(\frac{S}{L}\right)^{0.3} \left(\frac{K_g}{Lt_s{}^3}\right)^{0.1} \tag{3}$$

and for two or more lanes

$$GDF = 0.075 + \left(\frac{S}{2.9}\right)^{0.6} \left(\frac{S}{L}\right)^{0.2} \left(\frac{K_g}{Lt_s{}^3}\right)^{0.1} \tag{4}$$

with skew correction factor for both equations of

$$c_1 = 0.25 + \left(\frac{S}{L}\right)^{0.5} \left(\frac{K_g}{Lt_s{}^3}\right)^{0.25} \text{for } 30^o < \theta < 60^o \tag{5}$$

$$c_1 = 0 \text{ for } \theta < 30^o \tag{6}$$

where S = girder spacing (m), L = span length (m), t_s = slab thickness (m), K_g = longitudinal bridge stiffness = $n\left(I + Ae_g^2\right)$ (m^4), n = ratio of the beam to deck modulus of elasticity, I = moment of inertia of girder, A = girder area, and e_g = distance between the center of gravity of the deck and girder.

5 RESULTS

The Scotch Road Bridge was loaded with the standard AASHTO HS20-44 truck loading differing cases of one to three lanes loaded at a time. The stress data obtained from loading the bridge was collected at four integration points, two at the top and two at the bottom of each girder flange. The top and bottom points were then averaged respectively to obtain the axial stress at the top and bottom of the girder.

Figures 4 and 5 represent GDF ratios based on both positive and negative stresses for individual girders during the one lane loaded case. All graphs are represented as the FEM calculated GDF divided by both the AASHTO 1996 and AASHTO 2012 GDFs. The positive and negative results yielded similar GDF ratios to each other for one lane loaded. The positive and negative Abaqus one lane loaded GDF values were 20% and 25% lower than AASHTO 2012 respectively, while being 50% lower than AASHTO 1996.

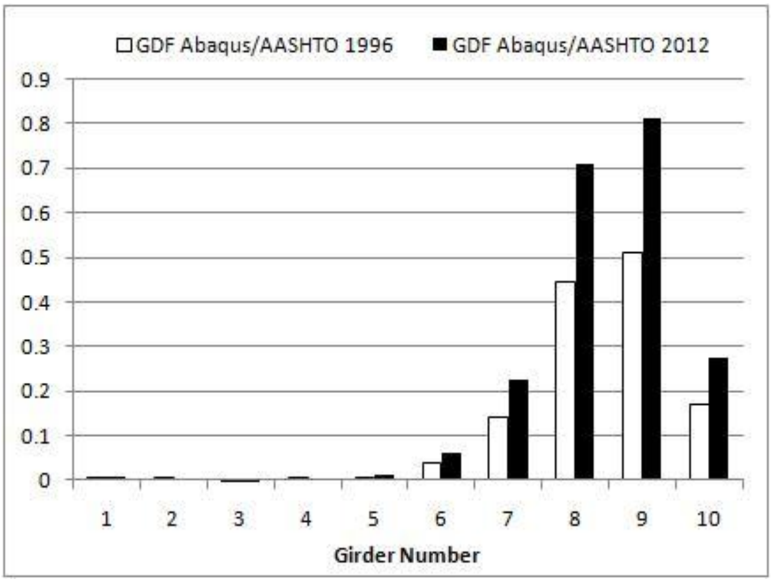

Figure 4. One truck loaded in lane one, the Scotch Road Bridge, positive stress

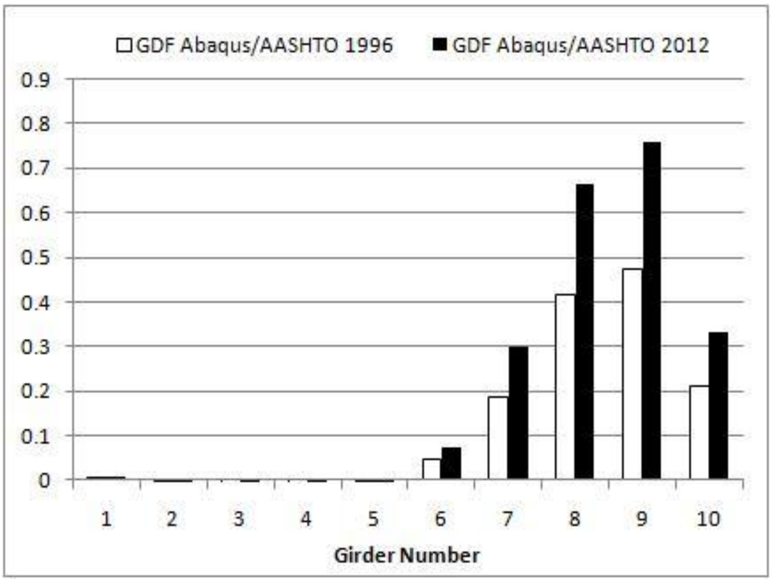

Figure 5. One truck loaded in lane one, the Scotch Road Bridge, negative stress

Figures 6 – 9 show results for the same Scotch Road Bridge positive and negative stress, but loaded in two and three lanes as indicated. The GDF ratios continued to correspond well whether positive or negative, but both the AASHTO 2012 and 1996 equations proved more conservative for multiple lanes loaded.

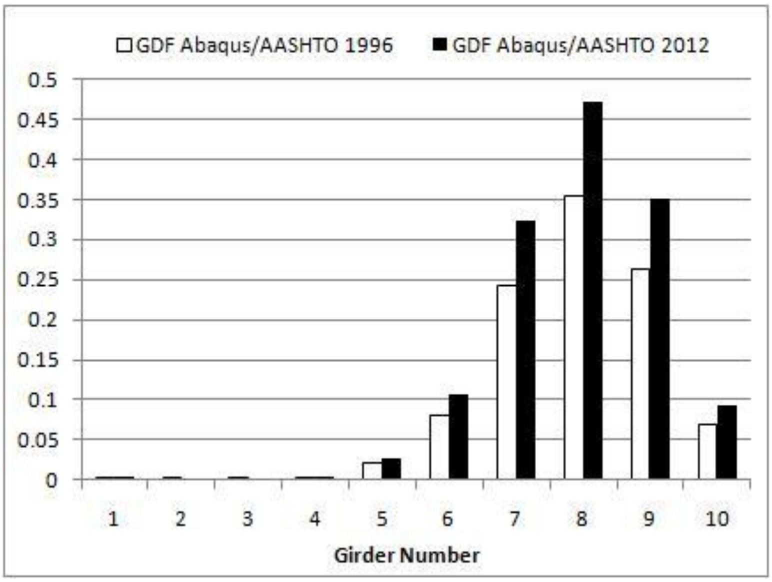

Figure 6. Two trucks in lanes one and two, the Scotch Road Bridge, positive stress

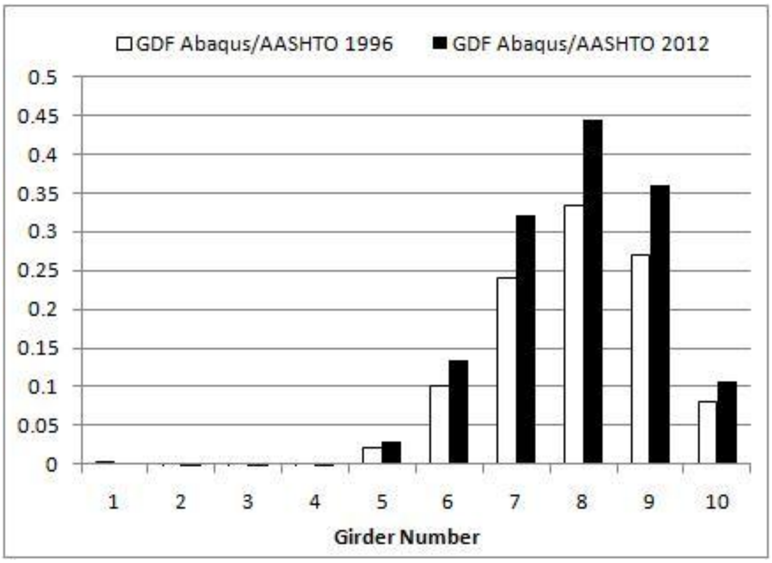

Figure 7. Two trucks in lanes one and two, the Scotch Road Bridge, negative stress

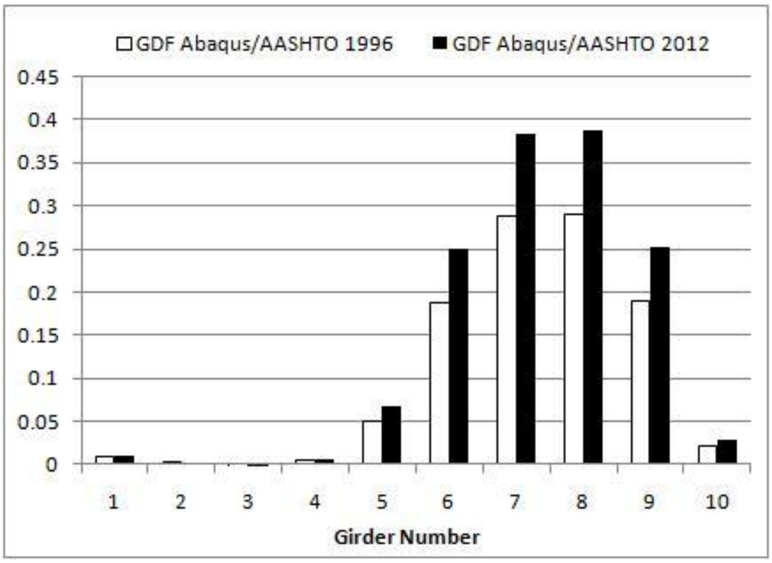

Figure 8. Three trucks in lanes one, two, and auxiliary, the Scotch Road Bridge, positive stress

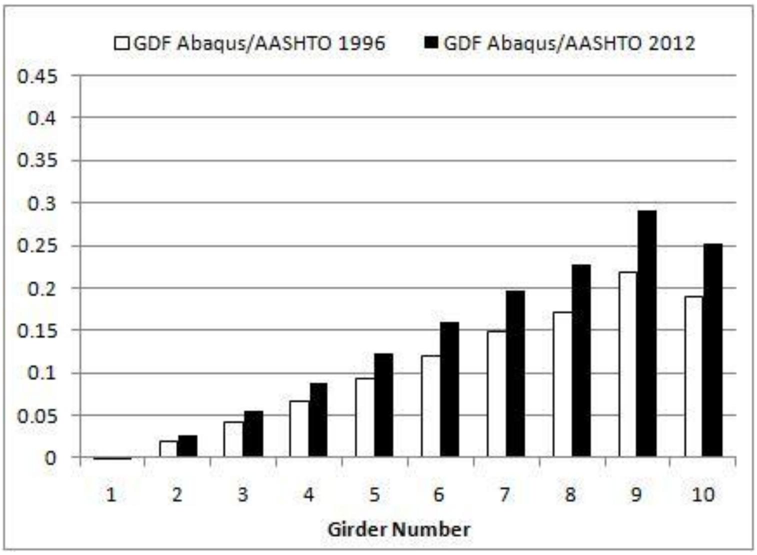

Figure 9. Three trucks in lanes one, two, and auxiliary, the Scotch Road Bridge, negative stress

After comparing the Scotch Road Bridge to the 1996 and 2012 AASHTO specifications, a parametric study was conducted to study the effect of crucial design parameters on the calculation of GDFs. The first parameter analyzed was the effect of changing bridge skew. As with the previous results both the positive and negative stresses were used with a varying number of lanes loaded. The primary trend variation when comparing the effects of skew is the "jump" in the GDF ratios from 25^{o} to 35$^{o.}$ This variation in the GDF ratio is consistent for all loading cases and for both AASHTO–LRFD and the AASHTO standard specifications, Figures 10 – 13. Though still containing a "jump" in results, AASHTO-LRFD has developed a correction factor for GDF equations with skews over 30^{o}, while the 1996 AASHTO standard specification has not. Both the positive stress GDF ratios have a similar 10% drop from 14.9^{o} to 25^{o} followed by a 10% increase from 25^{o} to 35^{o} for one lane loaded. The AASHTO-LRFD skew correction factor, while improving GDF values, does not create significant consistency when designing a bridge around the 30^{o} skew. Moreover, a better single skew correction factor or multiple correction factors defining smaller ranges of skew would be an improvement to the consistency of the 2012 AASHTO-LRFD skew correction factor. The positive and negative stress GDF ratios for the 1996 and 2012 AASHTO followed similar trends, both the 1996 AASHTO and negative stress ratios prove more conservative than the equivalent 2012 AASHTO-LRFD.

In addition to skew, effects of pile length and spacing were investigated. The Scotch Road Bridge model was adjusted to ten piles spaced at 3.35 m, opposed to the original nineteen piles spaced at 1.675 m. All loading cases yielded similar results to the full model analysis with one truck in lane one being the most accurate and 2 and 3 trucks being overly conservative. There was no significant change caused by varying pile spacing.

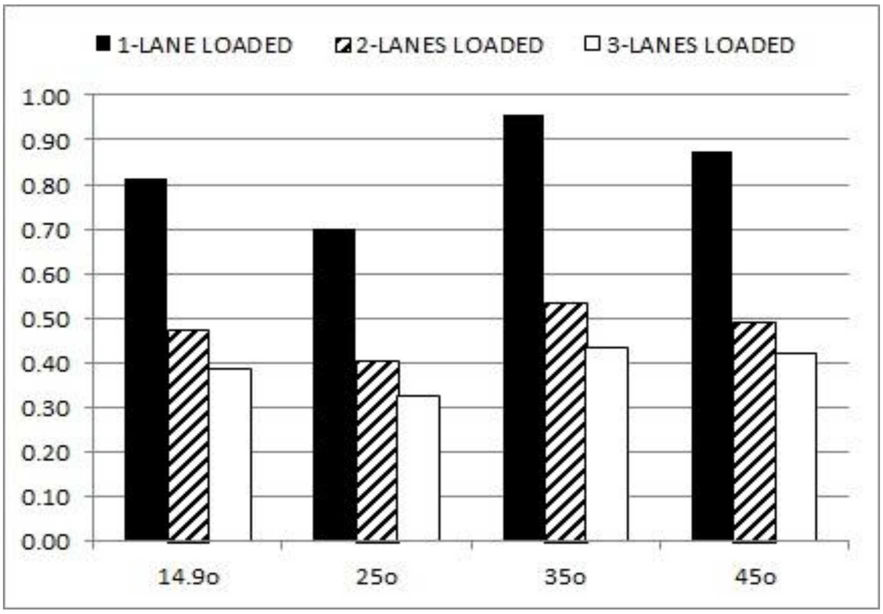

Figure 10. Ratio of Abaqus GDF/2012 AASHTO-LRFD GDF for different skews and loading cases, positive stress

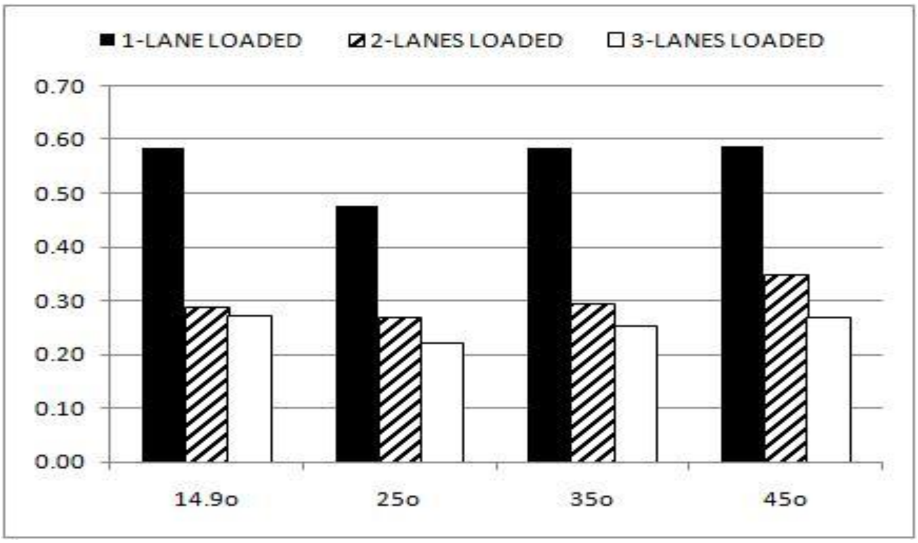

Figure 11. Ratio of Abaqus GDF/2012 AASHTO-LRFD GDF for different skews and loading cases, negative stress

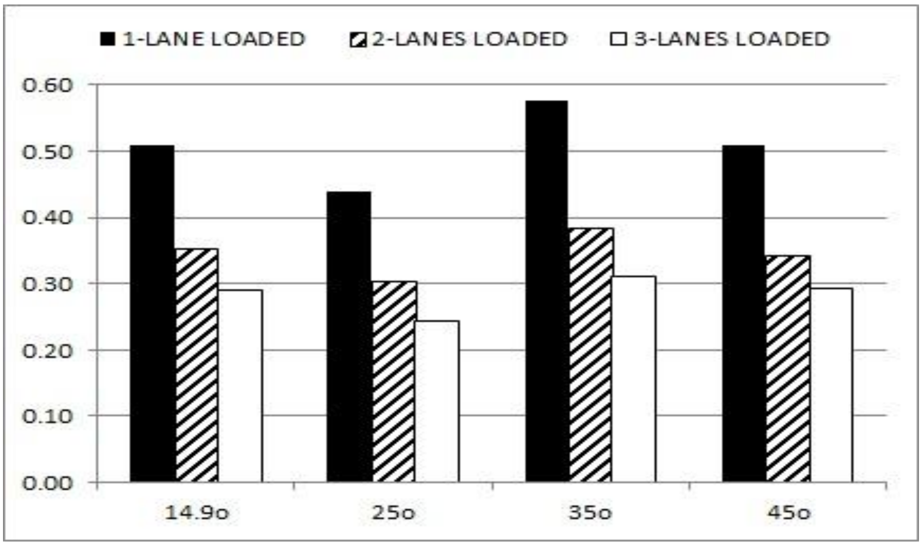

Figure 12. Ratio of Abaqus GDF/1996 AASHTO GDF, for different skews and loading cases, positive stress

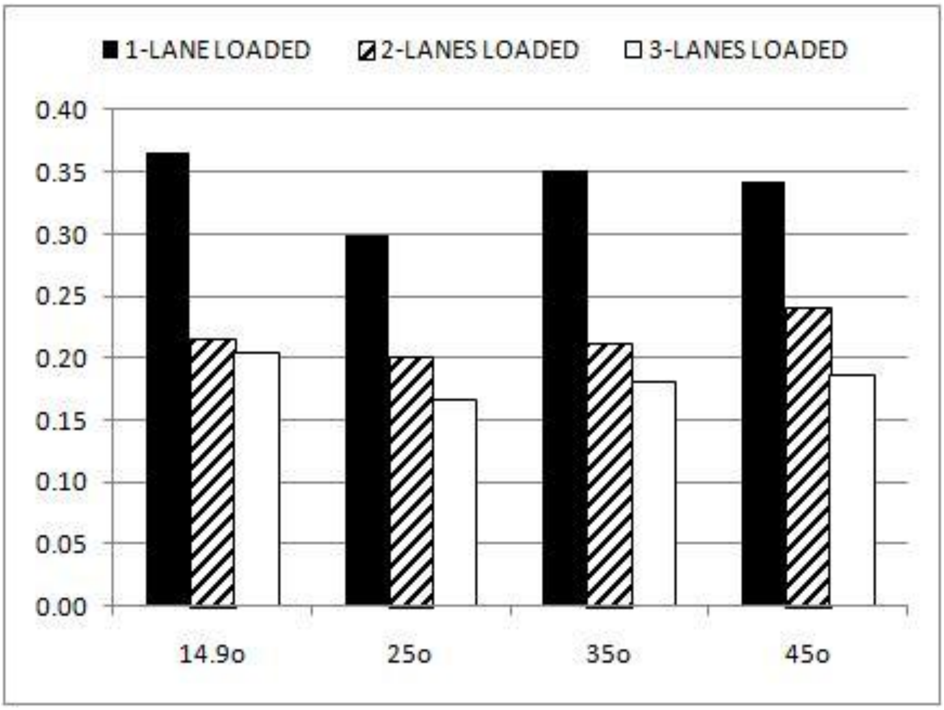

Figure 13. Ratio of Abaqus GDF/1996 AASHTO GDF, for different skews and loading cases, negative stress

Additionally, the effects of the pile length were analyzed and are shown in Figures 14 and 15. The critical component of pile lengths is the minimum length required for pile fixity. In addition to being design and constructed at a 5.18 m depth, the piles were placed in pre-augured holes and filled with concrete below the 5.18 m depth. The previously described figure 2 above shows the cross sectional dimensions of the Scotch Road Bridge and shows details of the abutment pile layout including the concrete encased piles.

The parametric pile study extended the piles beyond the original 5.18 m to 7.5 m, and 10 m to ensure the piles would accurately behave as fixed in the field as they were design in the Abaus/Cae model. The pile length had a 10% difference between the maximum GDF ratio and the minimum GDF ratio when comparing each loading case for both positive and negative stresses.

Both the pile length and pile spacing comparisons validate the absence of a pile parameter in the AASHTO-LRFD girder distribution factor. Though pile length had some effect on the GDFs, the effect was minimal and did not create as large of a change as other analyzed parameters.

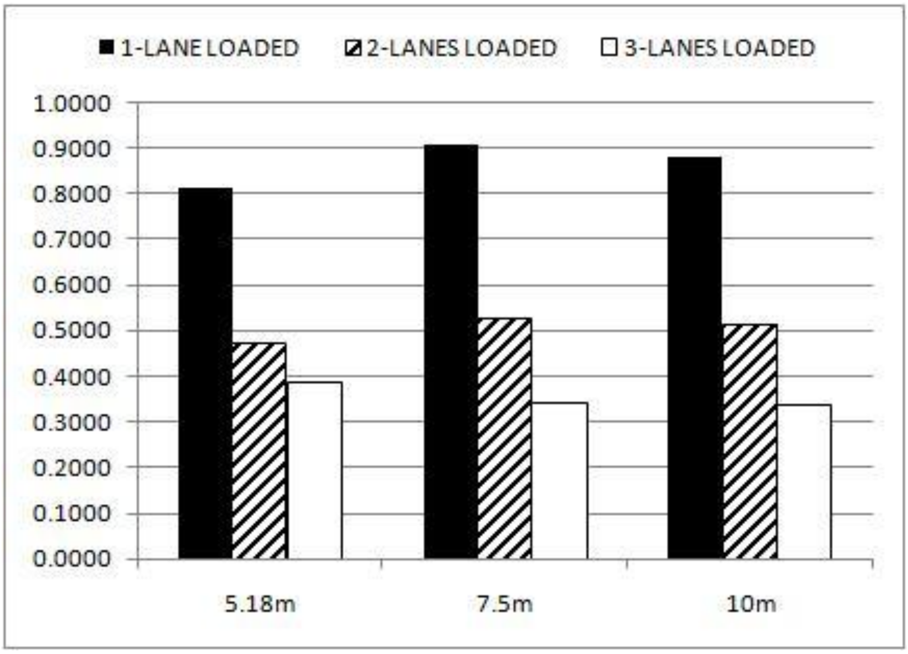

Figure 14. Ratio of Abaqus GDF/2012 AASHTO-LRFD GDF, for different pile lengths, positive stress

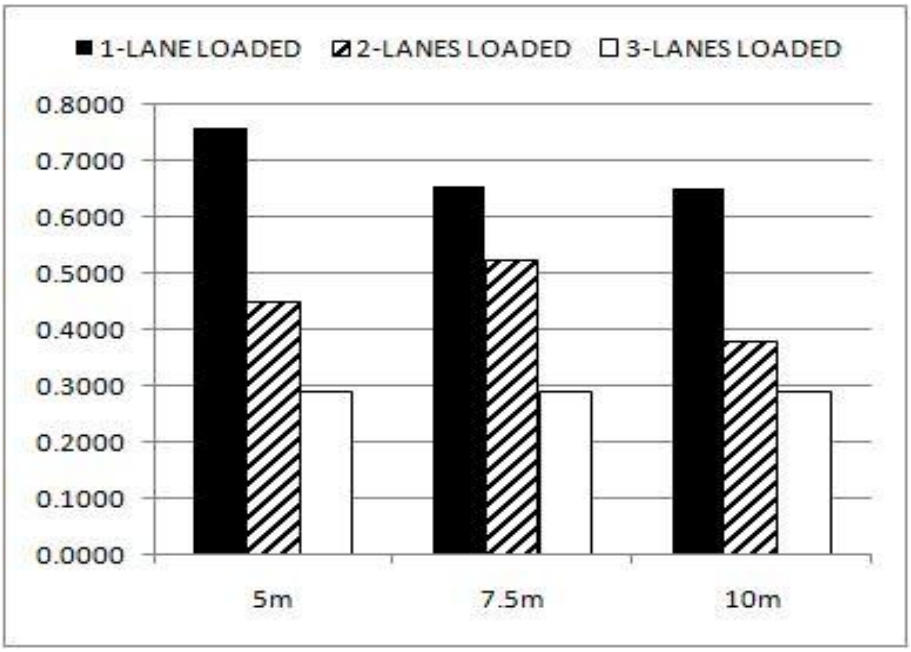

Figure 15. Ratio of Abaqus GDF/2012 AASHTO-LRFD GDF, for different pile lengths, negative stress

6 CONCLUSIONS

The results of the Scotch Road Bridge compared to both AASHTO specifications and the parametric are as follows:

- The 1996 AASHTO standard specifications GDF values are significantly more conservative than current 2012 AASHTO-LRFD Bridge Design Specifications in all loading cases and parametric analyses.
- The GDF values calculated from the negative stress locations can be used to calculate GDFs, but the values are more conservative than that of the positive stress GDF values.
- GDFs for the 2012 AASHTO-LRFD Bridge Design Specifications are reasonable for one lane loaded, while overly conservative for multiple lanes loaded.
- Neither reducing the number of piles nor adjusting the pile length in a bridge creates a significant change in the GDF ratios when pile fixity is maintained.
- Skew effects were adequately accounted for in AASHTO-LRFD for both positive and negative stress calculated GDFs for one lane loaded at higher skews.
- GDF ratios for positive and negative stress values were overly conservative for two and three lanes loaded.
- Both AASHTO-LRFD with two or more lanes loaded and all AASHTO standard cases provided overly conservative GDF ratios with regards to changes in skew.
- Investigation into providing either a better single skew correction factor or multiple correction factors defining smaller ranges of skew could improve the consistency of the 2012 AASHTO-LRFD skew correction factor.

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