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INFLUENCE OF FLANGE WIDTH ON THE SHEAR-LAG EFFECT FOR PC SKEWED BOX-SECTION GIRDER BRIDGES

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Skewed box-section girder bridges are widely used in the proceeding of the road network construction. Ignoring the shear-lag effect will give rise to the instability and failure of bridges. The single-factor calculation theory of orthogonal box-section girder bridges cannot be applied to the calculation of the shear-lag effect of skewed box-section girder bridges. In this paper, simply-supported skew box-section girder bridge models with different widths of flanges were built by using the finite element software ANSYS. The distribution laws of shear-lag effect in the transverse and vertical of skewed box-section girder bridges were more obvious with an increase in the flange width.

Keywords: ANSYS, Flange width, Orthogonal box-section girder bridges, Shear-lag effect, Distribution law.

1 SHEAR-LAG EFFECT

Due to the torsioned and sheared deformation of up-and-down flanges, vertical displacement of a flange away from the rib lags behind displacement of the edge of the rib, which means bending-stress distribution within the flange becomes a curve. That is to say, the shear within a certain range plays into a limited role, resulting in uneven distribution of the normal stress (Qu 2003). Usually the shear-lag coefficient represents the uneven distribution of stress in order to determine the degree of shear-lag effect of skew-box girder bridges, the expression (Zhang et al. 1998) is:

$$\lambda = \frac{\sigma}{\overline{\sigma}} \tag{1}$$

where λ is the shear-lag coefficient, σ is the actual normal stress calculated by considering the shear-lag effect, and $\overline{\sigma}$ is the normal stress calculated by using elementary-girder theory. It is called "positive shear-lag effect" when the actual normal stress at the intersection of the flange and web is greater than the stress calculated by using elementary-girder theory. Conversely, it is called "negative shear-lag effect".

2 SETTING FE MODEL OF PRE-STRESSED SKEW BPX-SECTION GIRDER BRIDGE

ANSYS was used to set the FE model of the simply-supported pre-stressed skew box-section girder bridge with 30-degree gradients. The calculated span was 31.20 m, the form of girder bridge was a parallelogram rule skewed girder, its cross-section a single-cell box-uniform rectangular, and the parameters of the bridge with a 2.50 m flange width is shown in Figure 1. Its web spacing was 4.90 m.

The bridge was made up of C50 concrete with 7 shares of low-relaxation pre-stressed steel strand. Solid65 physical unit was used to simulate concrete, and link8 rod element used to simulate pre-stressed tendons in the FE models shown in Figure 2. The constraint-equation method was employed to couple the two materials. The density of bridge concrete was 2.5×10^3 kg/m^3, the elastic modulus E is 3.45×10^4 MPa. Six steel strands were distributed symmetrically in the web with diameter 15.24 mm. Both ends of the steel strand were subjected to 190 kN tensile force, with elastic modulus $E = 1.95\times10^5$ MPa. The Poisson ratio of steel strand and concrete were all expressed as $\mu = 0.3$.

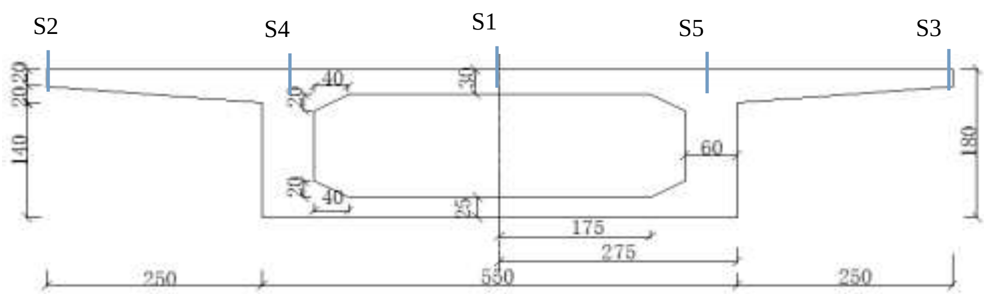

Figure 1. The cross-section dimensions of the skewed box-section girder bridge (Unit: cm).

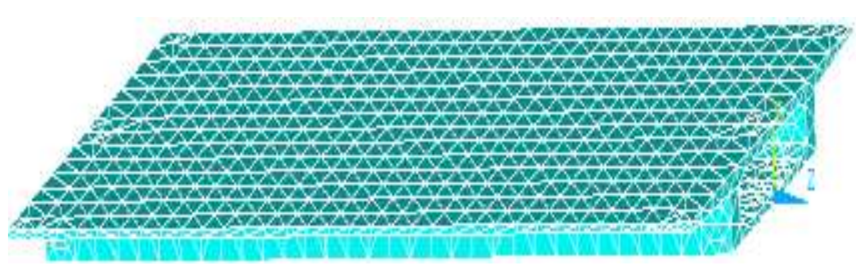

Figure 2. FE model of skewed box-section girder bridge.

3 SHEAR-LAG EFFECT OF PC SKEWED BOX-SECTION GIRDER BRIDGE

3.1 Deformation Analysis

The mechanical characteristics are very different between the orthogonal and skewed box-section girder bridges. The internal forces of the skew box-section girder bridges cannot be evaluated in accordance with elementary-beam theory (Ke et al. 2012), because the bridge is force-bended and torsioned with sheared coupling space effects. The strain will be generated at each point within the lane plane of the skew box-section girder bridges, and displacement will be produced at each support point when external factors, such as temperature changes, shrinkage of concrete, and creep, occur. As is known, flange-width changes will make the skew box-section girder bridges deform in different degrees. The flange width is smaller, and the torsional rigidity is bigger.

Under the self-weight and pre-stress, the maximum vertical displacement of the flange plate appeared in the mid-span, and with a smaller one at the ends of the bridge. Figure 3 and Figure 4 show the vertical deformation of the skewed box-section girder bridges whose flange plate width was 2 m and 3 m, respectively. As can be seen in the figures, the greater the flange width was, the greater the vertical displacement, and the deformed region was closer to the flange edge. In addition, the lateral displacement and torsion deformation appeared at the same time, but they did not vary with the flange width.

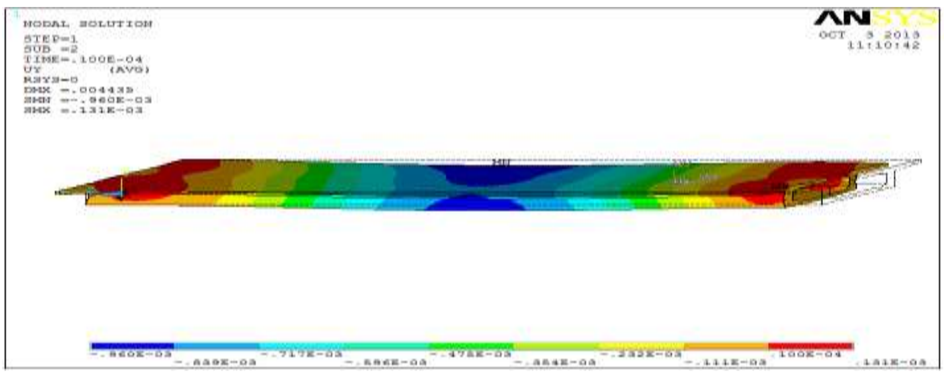

Figure 3. The bridge deformation for flange width of 2.00 m.

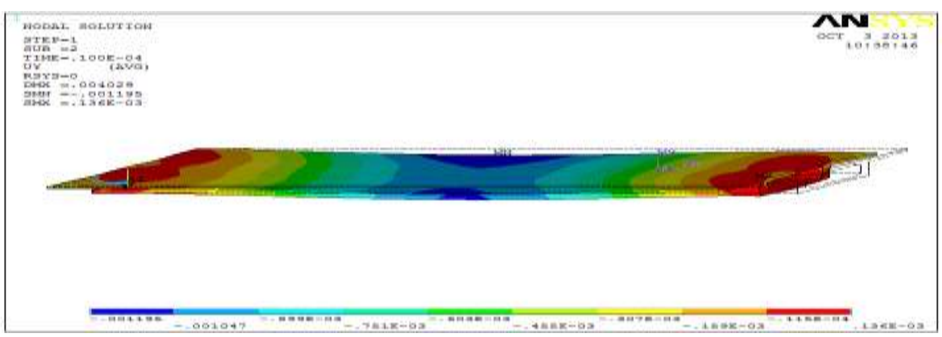

Figure 4. The bridge deformation for flange width of 3.00 m.

3.2 Transverse Shear-lag Analysis

Figure 5 shows the shear-lag coefficients when the web spacing was 4.90 m, and the width of the flange plates were 2.00 m, 2.25 m, 2.50 m, 2.75 m and 3.00 m, respectively. The thirteen calculation points were distributed along the transverse uniformly.

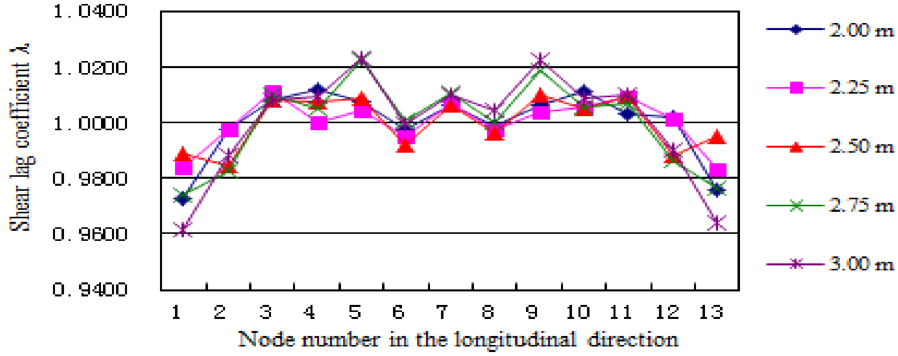

Figure 5. The shear-lag coefficients of the mid-span cross-section for different flange width.

The distribution rules of the transverse shear-lag coefficients for the skewed box-section girder bridge with different flange width can be obtained from Figure 5. The distribution of shear-lag was symmetrical about the axis of the bridge, and the shear-lag coefficient on the central axis was not affected by the width of the flange plate. When the calculated span is certain, the width of the flange plate is greater, and the difference between minimum and maximum shear-lag coefficient is greater. The most appropriate flange width is about half of the bridge web spacing. In that case, the shear-lag effect of the skewed box-section girder-bridge roof is relatively flat, and its influence to the bridge is smaller.

3.3 Longitudinal Shear-lag Analysis

Shear-lag coefficients of five selected sections along the longitude of the PC-skewed box-section girder bridge with flange width of 2.50 m were calculated and plotted in Figure 6. The five typical sections were selected (Figure 1): S1 was the longitudinal axis section, S2 the left flange edge, S3 the right flange edge, S4 the intersection of the left web and bridge roof, and S5 the intersection of the right web and bridge roof, respectively. S2 and S3 were symmetrical about the central axis, as were S4 and S5. The nine calculation points were distributed along the bridge span longitude uniformly.

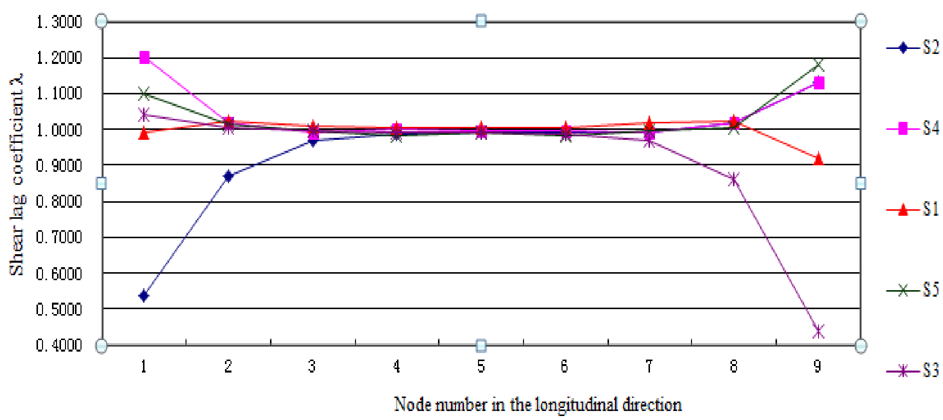

Figure 6. Shear-lag coefficients of five typical sections along the longitude.

The following observations can be made based on Figure 6: The maximum shear-lag coefficients occurred at the intersections of the web and bridge roof, and the minimum values occurred at flange edges. The distribution of the shear-lag coefficients of the PC skewed bridge was not symmetric about the longitudinal axis, but the distribution was symmetric about the cross-section at the mid-span. The shear-lag coefficients at both ends of the bridge varied significantly, and the acute angle affected the shear-lag coefficient distributions significantly.

To analyze the flange-width effect on the shear-lag coefficients, Figures 7 to 11 give shear-lag coefficients of the above five sections for different flange widths: 2.00 m, 2.25 m, 2.50 m, 2.75 m, and 3.00 m, respectively. The following observations can be made: The shear-lag coefficients on both of the flange edges were decreased with the increase of the flange width, but their variation was not obvious in the middle part of the bridge. The shear-lag coefficients of the intersection between the webs and bridge roof were bigger than 1.0, increasing with the increase of the flange width, and their variation was not obvious in the middle part of the bridge. The shear-lag coefficients of the longitudinal axis increased slightly with the increase of the flange width, and varied gently in the middle of the bridge.

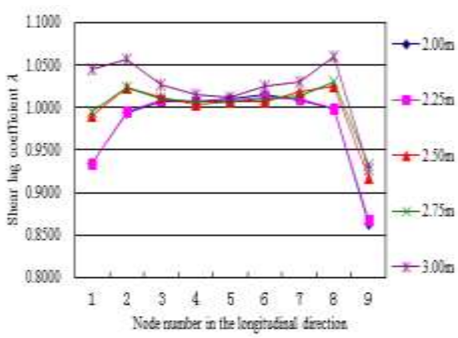

Figure 7. Shear-lag coefficient at S1 section.

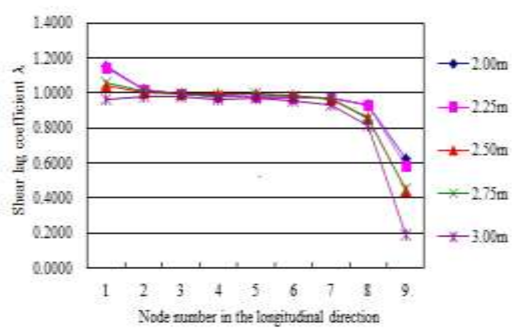

Figure 9. Shear-lag coefficient at S3 section.

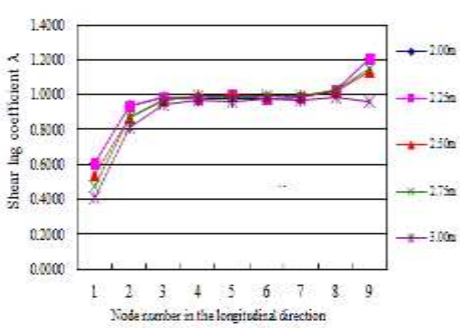

Figure 8. Shear-lag coefficient at S2 section.

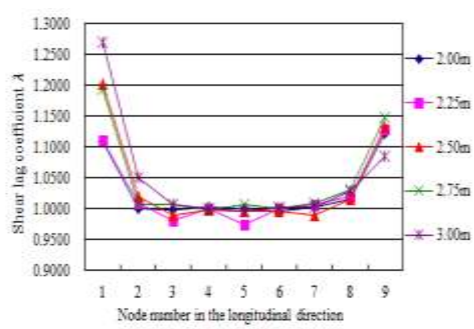

Figure 10. Shear-lag coefficient at S4 section.

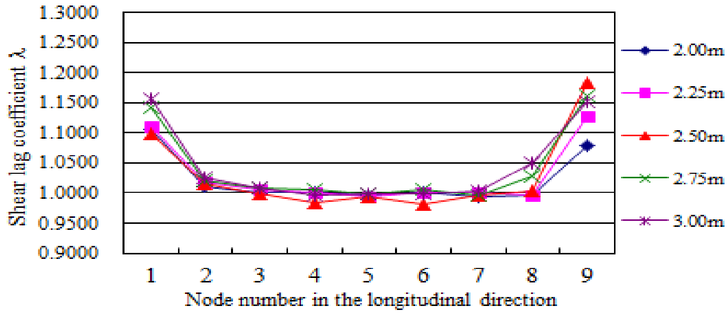

Figure 11. Shear-lag coefficient at S5 section.

4 CONCLUSIONS

(1) The flange width has an influence on the shear-lag and deformation of the PC skewed box-section girder bridge.
(2) The flange width affects the shear-lag of the PC skewed box-section girder bridge differently in longitudinal and transverse directions, and the influence is coupled with the acute-angle effect.
(3) The distribution of the shear lag and deformation in longitudinal and transverse directions of the shear-lag coefficients is not symmetric because of the acute angle.
(4) The most appropriate flange width is about half of the bridge web spacing.

Acknowledgements

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