Research on Shear Lag Effect of Three-span Continuous Curved Steel Box Girder Bridge

Kongliang Chen1,*, Liankun Wang1 and Wenzhi Zhang1
1School of Civil and Architectural Engineering, Wuyi University, Jiangmen, Guangdong, 529000

*Corresponding author

Abstract. The normal stress of box-section beam under symmetrical load is the non-uniform characteristic called shear lag effect. Based on actual engineering project, the plate-beam finite element method is used to study the shear lag effect of the three-span continuous-curve steel box-girder bridge under the variety conditions of the curve radius, and the width span ratio, and the distribution of the shear lag effect in the longitudinal and horizontal direction under the symmetrical load are summarized in this paper, providing references for design of steel box-girder bridge. The results show that the shear lags of steel box girders are all positive shear lags under symmetrical loads. Under the conditions of three parameters, the curve radius and the width-span ratio have a great influence on the shear lag effect of steel box girders, and the high-span ratio change has no obvious effect on the shear lag effect, and the shear lag effect of bottom plate is far less severe than the top plate.

Keywords: steel box girder; shear lag effect; curvature radius.

1. Introduction
Box section is a commonly used section form in bridge design. Under the action of symmetrical bending load, considering the shear deformation of box girder, the distribution of the normal stress shows unevenness along the lateral direction, which is called shear lag effect [1-6]. In the structural design, the neglect of the shear lag effect will underestimate the deflection and stress at the joint between the web and the wing of the box girder, resulting in unsafe structural design. Several foreign countries have not considered the "shear lag effect" and caused the instability of the structure or a partial damage accident. At present, as the rapid development of steel structure technology, the use of steel box girder bridges is more and more extensive. Due to its advantages of light weight, high bending stiffness and torsional stiffness, good integrity and quick installation, steel box girder bridges are widely used in overpass bridges and long-span bridges. Some workers have been working on steel box girder bridges. The research work on the shear lag is carried out [7]. The shear lag effect of box girder is analyzed by constructing the warping displacement mode of cross section, and the energy variation method is based on the principle of minimum potential energy in paper [8]. Based on the deformation coordination and equilibrium conditions of the composite wing plate micro-element, the normal stress differential equation of the cross-section wing is established, and the shear lag coefficient of the composite box girder wing is derived in paper [9]. Through the calculation and analysis of the shear lag effect of curved box girder bridges with different parameters, the shear lag effect variation law of curved box girder continuous bridge with various influencing factors is summarized in paper [10], but the research results of the shear lag effect of the curved continuous steel box girder bridge still need further research.
2. The Shear Lag Effect of Curved Steel Box Girder Bridge

The curved continuous beam bridge generates torque under load. The "bending and torsion coupling" phenomenon is very important in the curved beam bridge, which will cause the structural stress of the curved bridge to be inconsistent with the force of the linear bridge. Therefore, the inner and outer forces of the curved bridge are inconsistent with the deformation and deformation under the action of the symmetrical load, leading to the difference of the shear lag between the inner and outer sides of the curved beam bridge.

\[
\Pi = \int (M(x) + M'(x)) \left( \frac{d^2w}{dx^2} \right)^2 dx + \frac{1}{2} \int EI_u \left( \frac{d^2w}{dx^2} \right)^2 dx + \frac{1}{2} \int t_h (E \varepsilon_{sh}^2 + G \gamma_{sh}^2) dx dy \\
+ \frac{1}{2} \int t_h (E \varepsilon_{sh}^2 + G \gamma_{sh}^2) dx dy + \frac{1}{2} \int (GK_{t}K_{p}^2 + EI_{s}K_{p}^2) dz \\
= \int (M(x) + M'(x)) \left( \frac{d^2w}{dx^2} \right)^2 dx + \frac{1}{2} \int EI_u \left( \frac{d^2w}{dx^2} \right)^2 dx + \frac{1}{2} \int E \left\{ \left( w'' \right)^2 + \frac{3}{2} w''u' + \frac{9}{14} (u')^2 \right\} + \frac{9Gu''}{5b^2} \right\} dx \\
+ \frac{1}{2} \int (GK_{t}K_{p}^2 + EI_{s}K_{p}^2) dz
\]

(1)

Where:

\[
I_{su} = 2t_b h_u^2 + 2ab t_u h_u^2 \quad I_{sb} = 2t_b h_b^2 \quad I_s = I_{su} + I_{sb}
\]

Figure 1. Shear stagnation point arrangement

Figure 2. Loading diagram

From the above curve steel box beam elastic control differential equation, it can be seen that the influencing factors of the curved steel box girder have an important relationship between the radius curvature, the high span ratio and the width span ratio, which will be discussed for steel in this paper.

3. Project Background

Figure 3. A steel box girder bridge of some Expressway

Figure 4. R=160m steel box girder model

A continuous curved steel box girder of Guang-Zhong-Jiang Expressway is taken as the research object. The bridge span is 28m+52m+26m, and the upper structure is a single-chamber steel box girder with curvature radius R=160m, and the width of bridge deck is 10.5m, and the beam height is 2.5m, and there is a horizontal slope on the inner side of the main beam, shown in Figure 3. In addition to the
two-way 3m spacing stiffeners in the span, and the rest are strongly and weak stiffened every 2m along the longitudinal direction. In this paper, the Midas finite element program is used to establish the spatial plate beam combination model. The top plate, bottom plate, wing plate, web and diaphragm of the box girder are simulated by the plate element, and the longitudinal stiffeners are simulated by the beam element. Figure 4 shows the radius of curvature $R = 160m$ calculation model.

4. Analysis of Shear Lag Effect

Figure 5 is the main section of the main beam, and the points 1 and 9 of the top plate are located on the inner side and the outer side of the cross section respectively, and the points 1 and 4 on the bottom plate are located on the inner side and the outer side of the cross section respectively. The type of load is the full-span symmetric uniform load $q=10kN/m$ is mainly considered in the calculation.

![Figure 5. Shear stagnation point arrangement](image)

![Figure 6. Loading diagram](image)

Figure 7. The structure displacement of symmetric load

Figure 8. The plate stress of symmetric load

4.1. Analysis of Shear Lag Effect of Steel Box Girder

The shear lag results of the $R=160m$ model under symmetric load are shown in Figures 9-11. Figure 9 is the shear lag effect of the roof with uniform load, and the Figure 10 is the shear of the bottom plate, and Figure 11 is the longitudinal shear lag effect, from which can lead to the following conclusions:

1) Under the action of symmetric load, the shear lag curve of the roof is similar, and both are positive shear lag effect, and the shear lag coefficient of the inner and outer sides of the roof is different, and the shear lag effect of the shear lag is inconsistent.

2) There is also shear lag in the steel box girder bottom plate, but the shear lag coefficient is smaller than the top plate. The bending and torsion effect of the curved bridge leads to inconsistent shear lag in the inner and outer sides of the bridge.

3) It can be known from the longitudinal shear lag of the graph that as the radius of curvature becomes smaller, the longitudinal shear force hysteresis effect of the curved steel box girder increases, but the increase is about 20%; The load is still concentrated, and there is no negative shear lag in any section along the longitudinal section of the bridge span. This may be due to the strong stiffening and weak stiffening in the longitudinal direction; the shear lag effect near the support is better than the rest.

![Figure 9. The shear lag of the Roof](image)
4.2. The Parameter Variation of The Shear Lag

For the curvature radius R=80, 160m, 240m, R=0 four different curvature radius of bridge, and The width span ratio is defined as the ratio of bridge deck width to the length of the beam axis (2b/L). Keep the width of the section unchanged, while the span L changes, the ratio of 2b/L is 0.1, 0.2, and 0.3 respectively. The variation law of shear lag is summarized.

1) As can be seen from figures 12-13, the peak value of the shear lag coefficient of the outer web across the mid-span and the fulcrum section is smaller than the peak value of the shear lag coefficient of the inner web. This is due to the inconsistent shear lag of the inner and outer sides caused by the combination of bending and torsion of the steel box girder. The peak value of shear lag coefficient increases with the decrease of curvature radius. When the curvature radius is 160m<R<240m, the shear lag curve is closer; when the curvature radius is much larger than 240m, the curved steel box beam can be The shear lag coefficient is calculated approximately as a straight line beam without a large error. Under the action of symmetric load, the shear lag coefficient of the steel box girder bottom plate is a downward concave curve. Under the conditions of curvature radius, the shear lag curve of the bottom plate is not obvious, which also indicates that the shear lag effect of the bottom plate is far from the top plate.

2) It can be seen from the data in Table 1 and Figure 14 that the law of shear lag is a quadratic parabola with increasing width-to-span ratio. The width-to-span ratio has a greater influence on the shear lag coefficient. As the width-to-span ratio increases, the shear lag effect increases, but the degree of aggravation gradually decreases.

3) It can be seen from the Figures 15-17 that the shear lag curve is basically bonded when the high-span ratio changes, indicating that the high-span ratio change has no obvious effect on the shear lag coefficient of the top and bottom plates.
Figure 13. The shear lag of bottom plate with curvature radius

Figure 14. The shear lag effect with width span ratio

Figure 15. The shear lag of the roof with high span ratio (1)

Figure 16. The shear lag of the roof with high span ratio (2)

Figure 17. The shear lag of bottom plate with high span ratio

Table 1. Shear lag coefficient of No. 3 point on the top plate

| section          | radius | width span ratio | Fitting formula                  |
|------------------|--------|------------------|----------------------------------|
| Side-span        | 160m   | 0.1, 0.2, 0.3    | $y = 2.5223x^2 + 0.3388x + 1.2413$ |
| Near the pivot   | 160m   | 0.1, 0.2, 0.3    | $y = 1.9245x^2 + 0.3378x + 1.1155$ |
| Mid-span         | 160m   | 0.1, 0.2, 0.3    | $y = 6.0834x^2 - 1.7417x + 1.365$  |
5. Conclusion
Through the above calculation and analysis, the variation law of shear lag effect of continuous curved steel box girder bridge under symmetric load is summarized:

1) Under the action of symmetrical load, the shear lag of steel box girder is positive shear lag, and the curve radius and width span ratio have relatively large influence on the shear lag effect of steel box girder, the variation law of shear lag curve increases with the width span ratio and is similar to the quadratic parabola with irregularity, and the high-span ratio change has no obvious effect on the shear lag effect.

2) Under the action of symmetric load, the shear lag coefficient at the boundary between the inner and outer webs of the steel box girder and the roof is the peak, and the variation of the shear lag coefficient of the bottom plate is the downward concave curve, and the shear lag effect is far less severe than the shear lag of the top plate.

3) The curvature radius is an important parameter for the analysis of shear lag effect of continuous curved steel box girder bridge. Due to the different inner and outer radii of curvature, the shear lag coefficient of the inner and outer sides of the steel box girder is inconsistent.

4) Under the action of symmetrical load, there is no negative shear lag in the longitudinal direction of the bridge. This may be due to the strong stiffening and weak stiffening in the longitudinal direction.

Acknowledgements
The paper supported by the Special Funds of the National Natural Science Foundation of China (11502172) and Guangdong Science and Technology Department Project (2016A040403125).

References
[1] Zhang Yuan-hai, Su Yan-dong, Lin Li-xia.2010.Finite Beam Element Analysis on Shear Lag Effect of Skewly Supported Continuous Box Girder. Journal of the China Railway Society.pp 44-50.
[2] Li Yun-sheng, Zhang yan-ling, Fan Jian-sheng. 2010. Shear lag effect study of cracked steel-concrete continuous beams.Journal of Building Srtuctures. pp 390-397.
[3] Li Xia-yuan, Wan Shui, Chen Jian-bing, Mo Yi-lung. 2018. Analysis on shear lag effect in thin-walled box girders based on modified warping displacement function.Journal of Southeast University.pp 851-856.
[4] Stuart S Chen, Amjad J. Aref, Methee Chiewanichakorn, Il-Sang Ahn. 2007. Proposed Effective Width Criteria for Composite Bridge Girders. Journal of Bridge Engineering. pp 325-338.
[5] Aref Amjad J, Methee Chiewanichakorn, Chen Stuart S. 2007.Ahn Il-Sang. Effective slab width definition for negativemoment regions of composite bridges. 2003. Journal of Bridge Engineering.pp425-426.
[6] Li Li-feng, Shao Xu-dong, Yi Wei-jian, Zhang Xin.2007. Model Test on local stability of flat steel box girder. China Journal of Highway and Transport. pp 60-65.
[7] Zhang Yuan-hai, Li Lli-xia. 2013. Initial parameter method for analyzing shear lag effect of thin-walled box girders. Engineering Mechanics. pp 205-211.
[8] Luo Qi-zhi, Wu You-ming, Liu Guang-dong. Shear lag of the thin-wall box girder with varying depths[J]. Journal of the China Railway Society.pp 81–87.
[9] Luo Qi-zhi. 1998. Analysis of the shear lag effect on continuous box girder bridges with variable depth[J]. China Journal of Highway and Transport, pp 63–70.
[10] Chen Yu-ji, Luo Qi-zhi. 2007. The analysis of large deflection of curved box girders in considering three shear lag functions. China Railway Science, pp13–18.