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Shear Lag Effect for PC Continuous Curved Box-section Girder Bridge under the Moving Vehicular Loads

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Abstract

In order to analyze the shear lag effect for pre-stressed concrete continuous curved box-shaped girder bridge under the moving vehicular load, bridge and vehicle are taken as two separate systems in this paper, which are connect by the conditions of geometric compatibility and force equilibrium on the contact point of wheels and bridge deck, and a quarter vehicle mode with six parameters and two degrees of freedom and a three-dimension physical finite element mode have been obtained. The analysis shows that the shear lag effect of different locations of box-girder curved bridge with four types of curvature radius subjected to three different traffic conditions, seven different driving eccentric and four different width-span radius. The results show that the impacts on the shear lag effect for the pre-stressed concrete continuous curved box-shaped girder bridge which is due to the variation of the curvature radius, width-span ratio, vehicle speed and driving eccentric.

Keywords: Curved Box-Section Girder Bridge; Pre-Stress; Moving Vehicular Loads; Shear Lag Effect

1 INTRODUCTION

The shear-lag effects for composite bridges is significant and a lot of research work has been done[1-4]. And now, the shear-lag effects of continuous curved box-section girder bridge is more and more be taken seriously. The shear lag theory of straight bridge is tended to be mature, however, due to curvature and the bending-tensional coupling effect, mechanics analysis of curved bridge becomes very complicated. Researching on the shear lag effect in curved bridge has its particularity. The shear lag effect in continuous box-girder curved bridge under static loads is studied[5], so it reaches that curvature radius and width-span ratio have a significant impact on the shear lag effect. The changing law of the shear lag effect in thin-walled structure under the triangle moving loads is discussed[6]. The shear lag effect in continuous box-girder curved bridge under symmetrical moving loads which is in different sizes and at different speeds is analyzed[7].

This thesis bases on the previous article and sets a three-span continuous beam as an example, and bridge and vehicle are taken as two separate systems in this thesis, which are connect by the conditions of geometric compatibility and force equilibrium, and a quarter vehicle mode with six parameters and two degree of freedom and a 3-D physical finite element mode is established by ANSYS finite element. Analysis the shear lag effect of different locations of box-girder curved bridge with four types of radius subjected to three different traffic conditions and seven different driving eccentric and four different width-span ratios.

2 THE ESTABLISHMENT of FINITE ELEMENT DYNAMIC ANALYSIS MODEL

When this thesis simulates car-bridge coupling dynamic analysis, car-bridge coupling system can be regarded as vehicle subsystem and bridge subsystem. Assuming that wheel and bridge deck always cling to each other during the

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process of vehicle running, and bridge and vehicle are taken as two separate systems, which are connect by the conditions of geometric compatibility and force equilibrium, so bridge and vehicle are made as an integrated system.

2.1 Vehicle Model

The main research, in car-bridge coupling dynamic analysis in this paper, is the shear lag effect in box-girder curved bridge under static loads and focuses on the dynamic response of the bridge structure more, so vehicle model be made as simple as possible. So as to reduce the complexity of the solution in car-bridge coupling system, vehicle system simplified simulation for a quarter of quality-spring-damping model.

Vehicle parameters: the upper quality m_1 is 1.8×104 kg, the under quality m_2 is 2.5×103 kg, the stiffness of suspension system k_1 is 6.5×106 N/m, the damping of suspension system c_1 is 4.0×104 N s/m, wheel stiffness k_2 is 8.5×106 N/m, wheel damping c2 is 0.5×104 N s/m, and vehicle model is shown in Fig. 1.

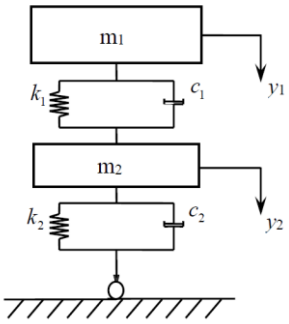


FIG. 1 SIX-PARAMETER VEHICLE MODEL

2.2 Bridge Model

This paper chooses a three-span single-room constant section of pre-stressed concrete curved box-girder in the interchange ramp bridge as research object, and the box-girder curved bridge with four types of radius, 50m, 75m, 150m and 300m. A series of curved box-girder bridge model with three kinds of different width-span ratio (they are 0.425, 0.34 and 0.28, respectively.) that width-span ratio in the same curvature radius is established by ANSYS software. The finite element model can be found in Fig. 2.

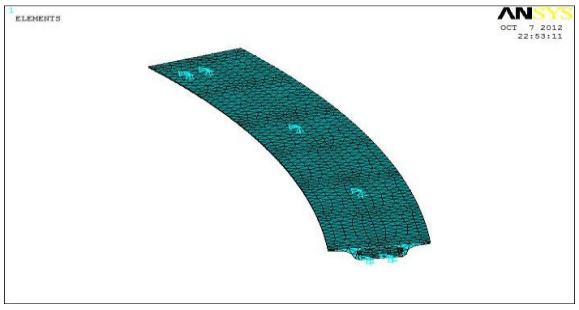


Fig. 2 FINITE ELEMENT MODEL OF CURVED BRIDGE

The beam uses C50 concrete, Modulus of elasticity is 345000MPa and Poisson's ratio μ is 0.3, 6φ15.2 mm low relaxation PC strand are symmetrical layout Inside and outside web, ultimate tensile strength of steel wires is 1860MPa, the tensioning stress σ is 1395 MPa, steel cable area s is 22cm^2, modulus of elasticity E is 195000MPa, Poisson's ratio μ is 0.3,and cross sectional dimensions shows in Fig. 3.

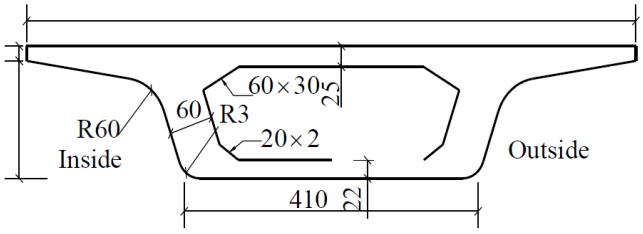


FIG. 3 SECTION SIZE OF CURVED BRIDGE

3 LONGITUDINAL DISTRIBUTION of the SHEAR LAG COEFFICIENT

The thesis chooses a three-span single-room constant section of continuous box-girder curved bridge, curvature radius is 150m, the top plate width of box girder is 8.5m, the width of bottom slab is 4.1m, the beam depth is 1.6m, the thickness of top plate is 0.25m, the thickness of top plate is 0.25m, the thickness of bottom slab is 0.22m, the web width is 0.6m, the length of cantilever wing plate is 2.2m, and specific section size is the same as simply supported curved box girder. Beam deck layout shows in Fig. 4. 1-1 is support section of bridge left end, 2-2 is the middle section of the middle span on the left side, 3-3 is single column pier bearing section, 4-4 is in the middle section of the middle span, 5-5 is the single column pier bearing section, 6-6 is the middle section of the middle span on the right side and 7-7 is support section of bridge right end.

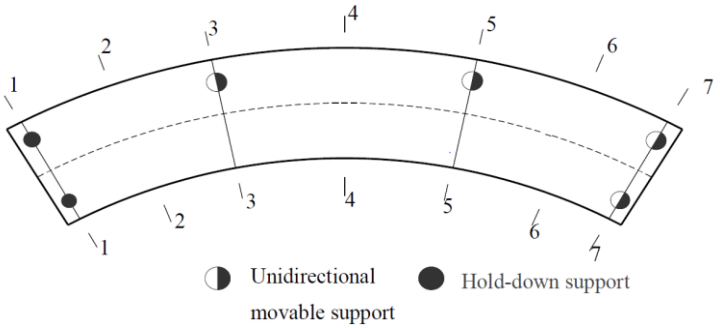


FIG. 4 THE LAYOUT OF THE CONTINUOUS BOX-GIRDER CURVED BRIDGE

In order to understand the changing rule that the shear lag effect in continuous box-girder curved bridge is along the bridge longitudinal direction, the radius of bridge model is selected as 150m. The vehicle's running speed is set as 54 km/h, and, when the vehicle moves to the section of 1-1, 2-2, 3-3, 4-4, 5-5, 6-6, 7-7, the shear lag coefficient distribution of the corresponding section of 1-1, 2-2, 3-3, 4-4, 5-5, 6-6, 7-7 are considered respectively. The shear lag coefficient distribution on the inside and outside web along the bridge longitudinal each section is given.

It can be seen from Fig. 5 that along bridge's longitudinal direction, when vehicles move to the middle of the side pan and the middle span, the shear lag coefficient in box-girder cross section is relatively large, which is the most unfavorable section of bridge, and the shear lag coefficient of the lateral web is grater than the medial web.

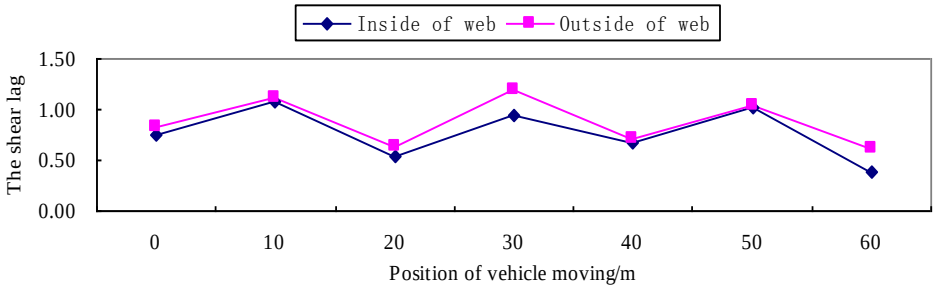


FIG. 5 THE DISTRIBUTION OF SHEAR LAG COEFFICIENT IN CONTINUOUS BOX-GIRDER CURVED BRIDGE

4 SHEAR LAG EFFECT of DIFFERENT PARAMETERS for CONTINUOUS BOX-GIRDER CURVED BRIDGE UNDER the MOVING VEHICULAR LOAD

Through the analysis of the previous content, the shear lag coefficient in the middle of the side pan and the middle span in continuous box-girder curved bridge is relatively large, that is, the side pan and the middle span are the most unfavorable section in continuous box-girder curved bridge. So, when the influence of the shear lag coefficient in continuous box-girder curved bridge is studied below, the middle section of both the side and the middle is analyzed.

4.1 Effects of the Curvature Radius

Analyzing the influence of different curvature radiuses to the shear lag effect in continuous box-girder curved bridge, the curvature radius is selected respectively as 50m, 75m, 150m and 300m now, and the running speed is 54km/h,

with driving along the center line of bridge and other parameters being hold. The results that four types of radius impact on the shear lag coefficient in a three-span continuous box-girder curved bridge are shown in Figs. 6 to 8.

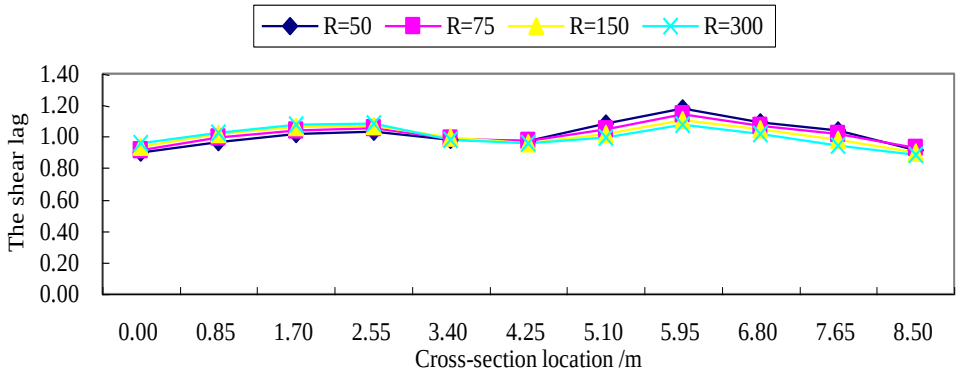


FIG. 6 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE LEFT SIDE SPAN

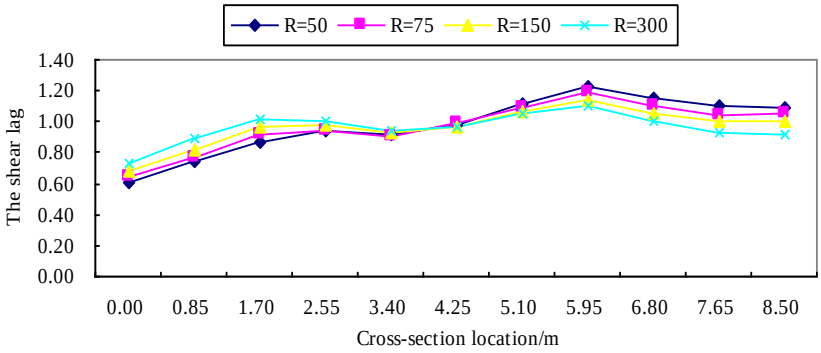


FIG. 7 THE DISTRIBUTION THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION

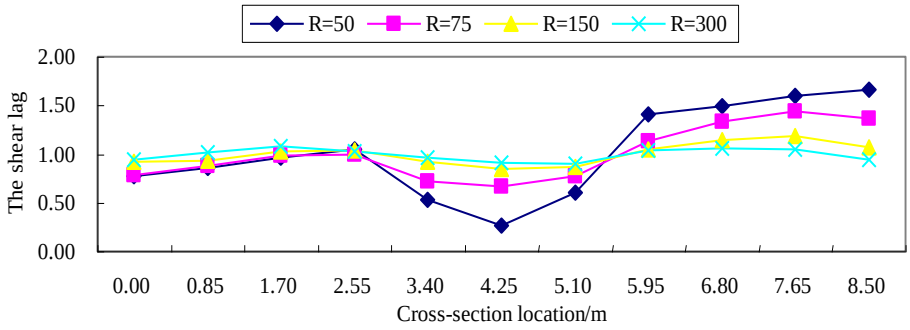


FIG. 8 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE RIGHT SIDE SPAN

From Figs. 6 to 8, the following observations can be induced.

(1) The shear lag coefficient of the inside and the outside web in the middle span section of the left side span is no different largely and changes gradually; The shear lag coefficient of the outside in the middle span section is greater than the inside web; The shear lag coefficients of the inside and the outside web in the middle span section of the right side differ from each other significantly, and the shear lag coefficient in the outside web is greater than the inside.

(2) In the middle span of the left side span, the shear lag coefficient has an increased trend with the curvature radius of the inside web added, while the outside reduces gradually. When the radius adds to 300m, the shear lag coefficients of the inside and the outside web are almost the same and the shear lag coefficient of the bridge midline with the change of the curvature radius is not obvious.

(3) In the middle span section, the regularity is the same as the middle span of the left side span, and the shear lag

coefficient of the bridge increases gradually with the increase of the curvature radius, but the outside reduces gradually.

(4) In the middle span section of the right side span, the change law of the shear lag coefficients on the inside and the outside web is the same as the middle span of the left side and the middle span, but on the bridge midline, the shear lag coefficient with the different changes of the curvature radius changes obviously, and the shear lag coefficient increases with the increase of the curvature radius.

4.2 Effects of the Driving Eccentric

The curvature radius is 150m in continuous box-girder curved bridge model is selected, and the running speed is 54km/h with other parameters being hold. Vehicles move along the inside web, the bridge midline and the outside web respectively, so the results of 3 kinds of different routes influence on the shear lag effect in a three-span continuous box-girder curved bridge is got. They are shown in Figs. 9 to 11.

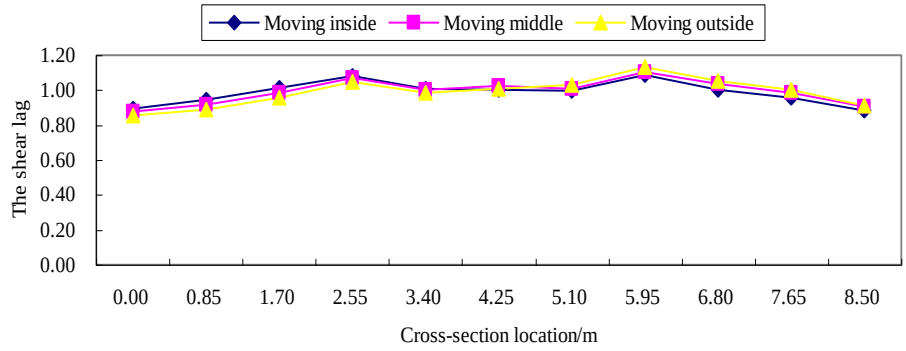


FIG. 9 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE LEFT SIDE SPAN

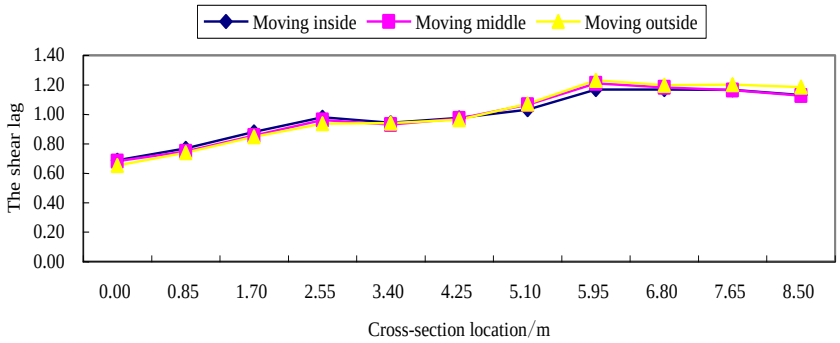


FIG. 10 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION

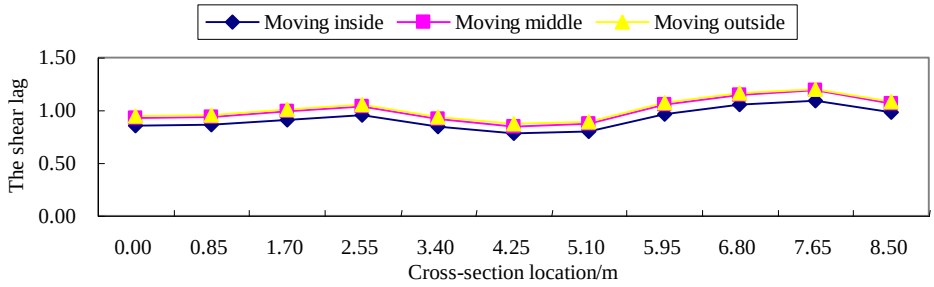


FIG. 11 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE RIGHT SIDE SPAN

The following observations are made from Figs. 9 to 11:

(1) The shear lag coefficients of the inside and the outside web in the middle span section of the left side span are almost the same. The shear lag coefficients of the inside and the outside web in the middle span section differ from each other significantly. The differences of the shear lag coefficient that driving both on the midline and the outside of the right side span are not obviously, but it becomes much smaller when vehicles drive on the inside.

(2) In the middle span section of the left side span, the shear lag coefficient of the inside web decreases with the increase of driving eccentricity, but that of the outside web increases and the shear lag coefficient of the bridge midline with the change of driving eccentricity doesn't change obviously.

(3) In the middle span section, the existing regularity is the same as the middle span of the left side.

(4) In the middle span section of the right side span, the shear lag coefficient of the inside and outside web, the bridge midline as well, increases with the increase of driving eccentricity.

4.3 Effects of the Running Speed

The curvature radius is 150m in continuous box-girder curved bridge model is selected, and with other parameters being hold, the running speed is 108km/h, 90km/h, 72km/h, 54km/h, 36km/h, 18km/h and vehicles drive along the bridge midline. So the results of six different driving speeds influence on the shear lag effect in a three-span continuous box-girder curved bridge is got, which are shown in Figs. 12 to 14.

A general law of the shear lag coefficient is influenced by driving speeds can be obtained from Figs. 12 to 14, which are as follows.

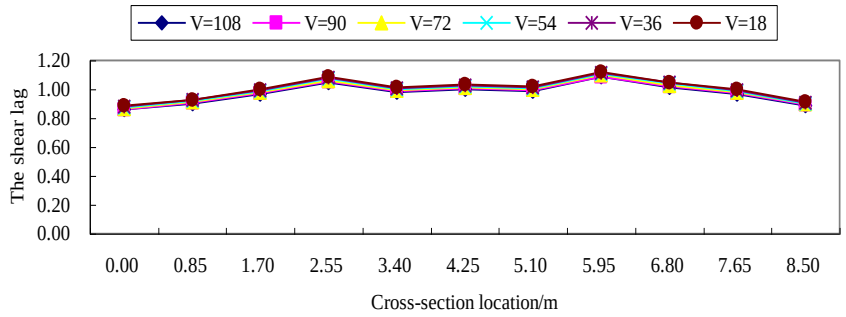


FIG. 12 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE LEFT SIDE SPAN

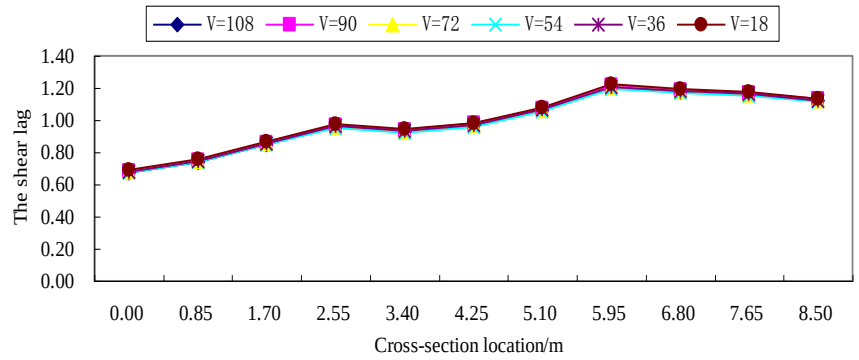


FIG. 13 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION

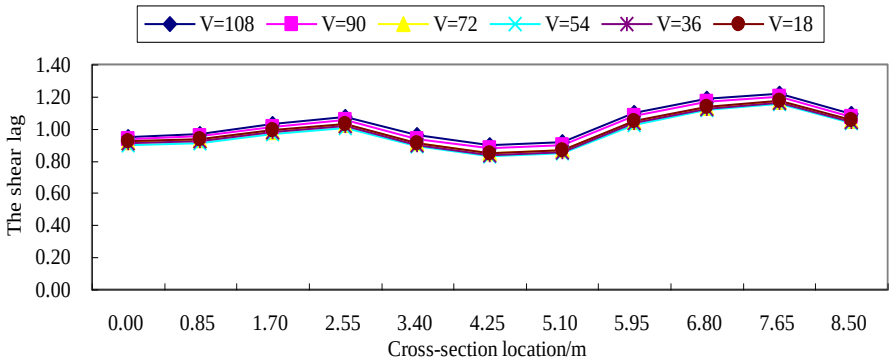


FIG. 14 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE LEFT SIDE SPAN

(1) The shear lag coefficient in the middle span section of the left side span and the middle span doesn't change obviously with the speed changing, but the shear lag coefficient of the right side span changes more obviously.

(2) The shear lag coefficient of the inside in the middle span section of the left side span is almost the same as the outside web and changes gradually. The shear lag coefficient of the outside web in the middle span section is greater than the inside web, and the shear lag coefficients of the inside and the outside web in the middle span section of the right side span is also greater than the inside web, but they don't differ from each other significantly.

(3) In the middle span section of the left side span, the shear lag coefficient of the cross-section all decreases with the increase of the speed. However, with the speeds increasing, the shear lag coefficient in the middle span section of the right side span and the middle span decreases firstly, and then increases. When the speed is 54km/h, it gets the minimum.

4.4 Effects of the Width-Span Ratio

The definition of width-span ratio is also the same as simply supported box-girder curved bridge. In order to analysis that the shear lag effect in continuous box-girder curved bridge is influenced by different width-span ratio, that the span of single-span is 20m, 25m and 30m is selected, which the corresponding width-span ratio is 0.425, 0.34 and 0.28, the curvature radius is 150m, with other parameters being hold. The results of three different width-span ratio influences on the shear lag effect in a three-span continuous box-girder curved bridge is got, which show in Figs. 15 to 17.

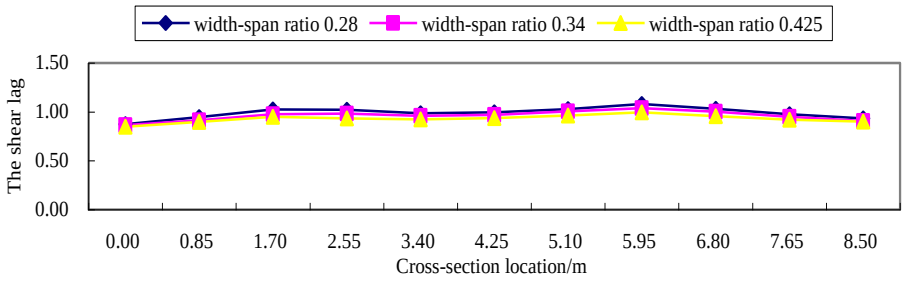


FIG. 15 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION OF THE LEFT SIDE SPAN

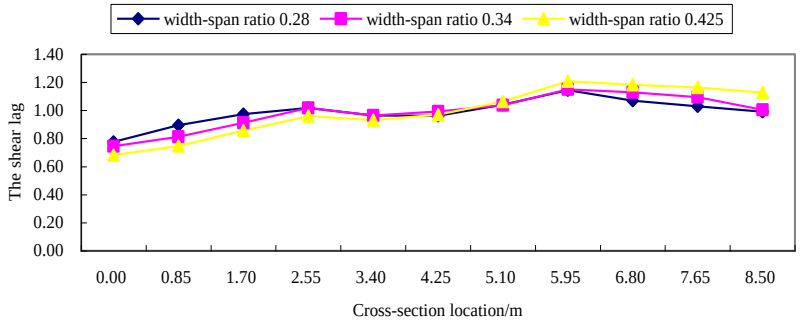


FIG. 16 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION

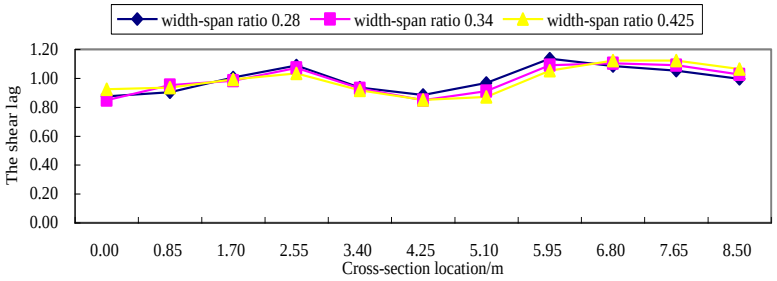


FIG. 17 THE DISTRIBUTION OF THE SHEAR LAG COEFFICIENT IN THE MIDDLE SPAN SECTION

Figs. 15 to 17 exhibit the following observations:

(1) The shear lag coefficient of the middle span section of the left side span changes gradually, and the shear lag coefficient of the inside and the outside web doesn't differ from each other significantly. The non-uniformity of the shear lag coefficient in the middle span of the middle span and the right side span is relatively obvious;

(2) In the middle span section of the left side span, the shear lag coefficient of the inside web and the outside web all increases with the width-span ratio decreasing, but this tendency on the bridge midline is not very obviously;

(3) In the middle span, the shear lag coefficient of the inside web increases with the width-span ratio decreasing, yet the shear lag coefficient of the outside web decreases with the width-span ratio decreasing, and this tendency on the bridge midline isn't also very obviously;

(4) In the middle span of the right side span, the shear lag coefficient of both the inside web and the outside web increases with the width-span ratio decreasing, the bridge midline as well, but an opposite tendency of the inside and outside cantilever plate appears.

5 CONCLUSIONS

According to the analysis of the shear lag effect in pre-stressed concrete continuous box-girder curved bridge under moving vehicular load, the following conclusions are got.

(1) In the aspect of curvature radius, the existing regularity is almost similar in the middle span section of the right side span, the left side span and the middle span. The shear lag coefficient has an increased trend with the curvature radius increasing, and the shear lag coefficient on the outside web decreases with the curvature radius increasing.

(2) In the aspect of the routes, the shear lag coefficient on the inside web decreases with the increase of driving eccentricity in the middle span of the right side span and the middle span, and the shear lag coefficient on the outside web increases yet. But the shear lag coefficient on the inside and outside web and the bridge midline increases with the increase of driving eccentricity in the middle span of the right side span.

(3) In the aspect of the running speed, the shear-lag coefficient decreases gradually with the increase of the speed in the middle span section of the left side span. With the speeds increasing, the shear lag coefficient in the middle span section of the right side span and the middle span decreases firstly, and then increases. When the speed is 54km/h, it gets the minimum.

(4) In the aspect of width-span ratio, the shear lag coefficient on the inside web and the outside web all increases with the width-span ratio decreasing in the middle span section of the left side span. In the middle span, the shear lag coefficient on the inside web increases with the width-span ratio decreasing, yet the shear lag coefficient of the outside web decreases. In the middle span of the right side span, the shear lag coefficient of both the inside web and the outside web increases with the width-span ratio decreasing, the bridge midline as well, but an opposite tendency of the inside and outside cantilever plate appears.

ACKNOWLEDGMENT

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Pros. Bu is a peer review experts of National Natural Science Foundation of China. He obtained third prize of natural science of Hebei province in 2011, and won second prize of China construction of science and technology in 2012. From now, he has published over 50 papers and 1 works.



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