The Influence of Common Closed Longitudinal Rib Sections on Stress Distribution of Orthotropic Decks

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Abstract. U shaped, V shaped, and trapezoidal sections are widely used as closed rib sections in orthotropic steel bridge decks. This paper calculated three full-scale models of section based on the finite element method, and analyzed the magnitude and distribution of extreme stress of the constituent members comparatively. Our research indicates that the V shaped section contributes the most advantageous distribution of stress for orthotropic steel bridge decks

Introduction

Orthotropic steel bridge decks refer to a structural system of perpendicular longitudinal and lateral stiffening ribs (longitudinal ribs and diaphragm plates) which, together with the decking cover plate, jointly carry the wheel loads. The longitudinal ribs act as continuous beams, with the crossbeams supporting each of the longitudinal ribs[1]. In the early stages, open shaped ribs were used for the longitudinal rib sections. This shape is simple and fabricating the connections is easy. Then, closed ribs were gradually developed, which have improved torsion and bending resistance, better buckling strength[2,3], and better economic performance. The closed rib sections for orthotropic are widely used in modern steel bridge design. However, this makes the structure more complex, and local peak stresses are related to the structural stiffness and the arrangement shapes of the component parts[4,5].

We explore the effect of the different shapes of the sections of longitudinal ribs on the mechanical behavior of the structural connection, based on a full-scale finite element model test of a steel bridge, by selecting several different shapes for the cross-section of the longitudinal ribs, and analyzing the stress distributions of the structural connections structure under wheel loads.

Influence of longitudinal rib section

Structural parameters of the model

In Fig. 1 we present the full-scale model of the specimen of orthotropic steel bridge deck of a large span bridge. The main structure of bridge deck is mainly composed of the decking cover plate, the longitudinal ribs and the transverse diaphragm plates welded together. For the longitudinal ribs, the diaphragm plates and lower flange use Q345B grade steel. To analyze the force in the diaphragm plates with the three different cross-sectional shapes of the closed longitudinal ribs, the U-shaped cross section (labeled as I), V-shaped cross section (II) and a trapezoidal cross-section (III) are designated respectively. The configuration and dimensions are shown in Figure 2.
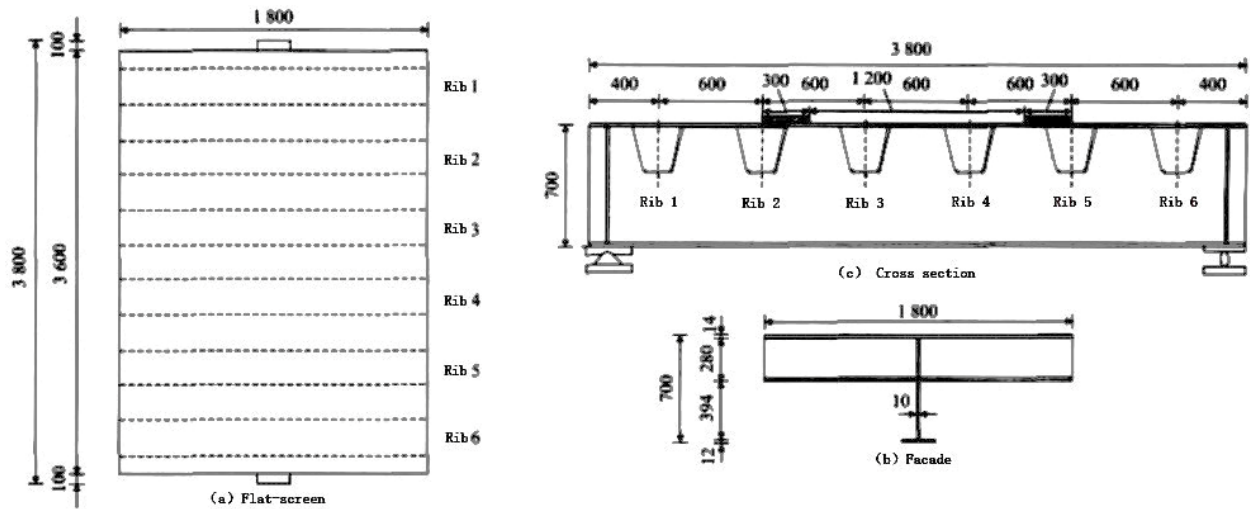
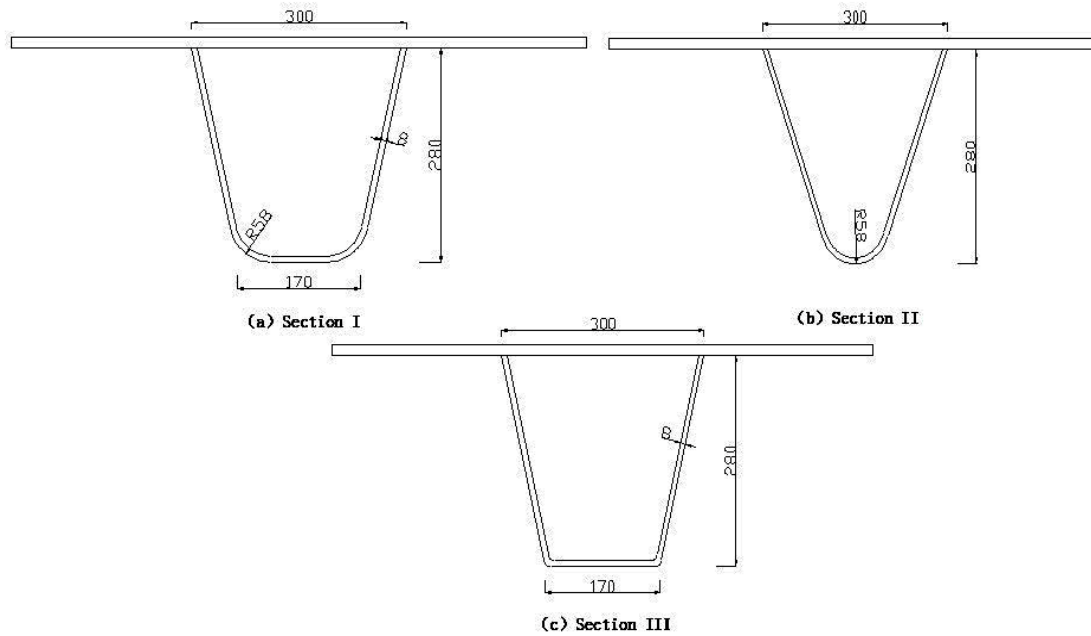Fig. 1 Dimensions of the Full-scale Test Model and the Stiffening Ribs [mm]

Fig. 2 The Cross-Sectional Dimensions of the Longitudinal Stiffening Ribs [mm]

The boundary conditions and load cases

The boundary conditions are the simulated bridge bearings with areas of 200×300mm, where these distribute at the two end cross sections of the model under simply supported constraints.

The loads simulation uses double-point loading with the loads applied to the deck surface on two 200 × 300mm areas with a clear distance between them of 1200mm, to simulate a single tire wheel load transmitted through pavement. The loaded positions are symmetrical about the center line of the model, and that are located directly above the inside web plate of Rib 2 and Rib 5, as shown in Figure 1. By referring to full-scale steel panel fatigue testing for the Bronx Whitestone Bridge and the Guang'an Busan Bridge [6.8], in combination with finite element analysis results[7] of stress distribution of the steel bridge decks we determine a load of P=250kN.

A computational model is established using simulation software, as shown in figure 3. (Due to limited space, this paper only shows the finite element model for the U-shaped cross section).
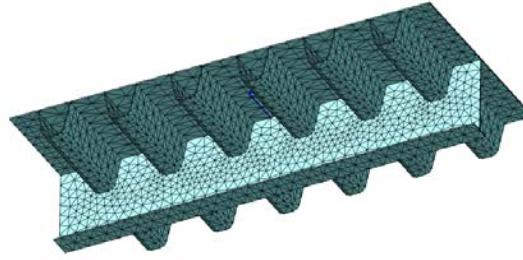
Fig. 3 Finite Element Model

Results and discussions

Table 1 shows the maximum stresses in the bridge deck, diaphragm beam and the longitudinal ribs from the results of each model. The data clearly shows that under all cases, the maximum stress of the diaphragm plates is much larger than that of other parts of the bridge.

Tab. 1 Extreme Stresses with Rib Stiffeners of Different Sectional Forms   [MPa]

Types of stress	section I			section II			section III		
	Bridge deck	Diaphragm	Rib	Bridge deck	Diaphragm	Rib	Bridge deck	Diaphragm	Rib
P_1	137.78	416.33	284.93	129.90	267.55	150.8	97.32	441.17	282.03
P_3	-286.97	-641.98	-376.23	-230.93	-521.5	-304.08	-279.67	-618.5	-561.97
$|\sigma_X|_{max}$	201.07	161.95	140.45	182.73	245.03	138.22	181.42	170.05	170.05
$|\sigma_Y|_{max}$	107.10	519.82	322.05	70.27	316.58	203.83	78.53	546.48	380.82

Note: P_1 represents the maximum principal stress;P_3 represents the minimum principal stress;$|\sigma_X|_{max}$ represents the maximum value of the absolute value of the stress in the X direction;$|\sigma_Y|_{max}$ represents the maximum value of the absolute value of the stress in the Y direction.
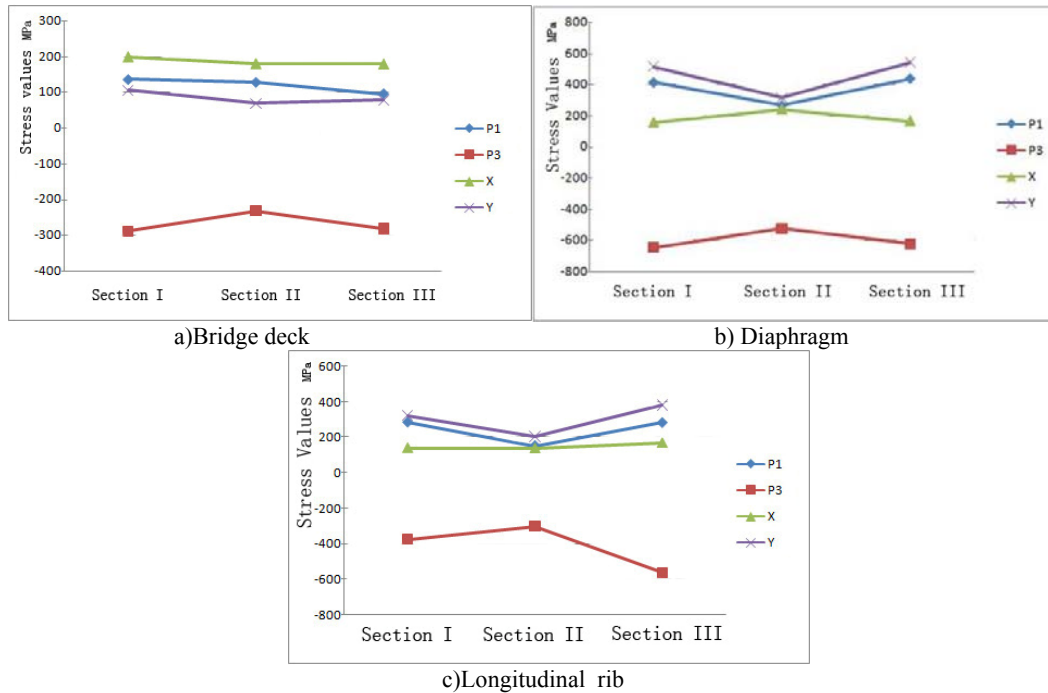

a)Bridge deck

b) Diaphragm

c)Longitudinal rib

Fig. 4 Comparison of Extreme Stresses

It can be seen in Fig.4 that the maximum stresses for Section II are smaller than those for the other two sections, which indicates section II is the best cross-sectional shape. It can be also concluded that the type of longitudinal rib has a direct influence on the inner force transference of orthotropic steel bridge decks, and thus has an impact on the stress distribution of diaphragm and longitudinal rib as well. The jump in stress P_3 for Section III in Fig.4-c is caused by the unsmoothed corner of the trapezoid section, which leads to a stress concentration at the corner of the section. The maximum stress of bridge deck is insensitive to section form because it directly bears the wheel load. Figure 5

shows that the maximum stresses in the diaphragm were mainly found in the parts with the bending and shear connections.

a)Principal stress nephogram of diaphragm with section Ⅰ   b)Principal stress nephogram of diaphragm with section Ⅱ

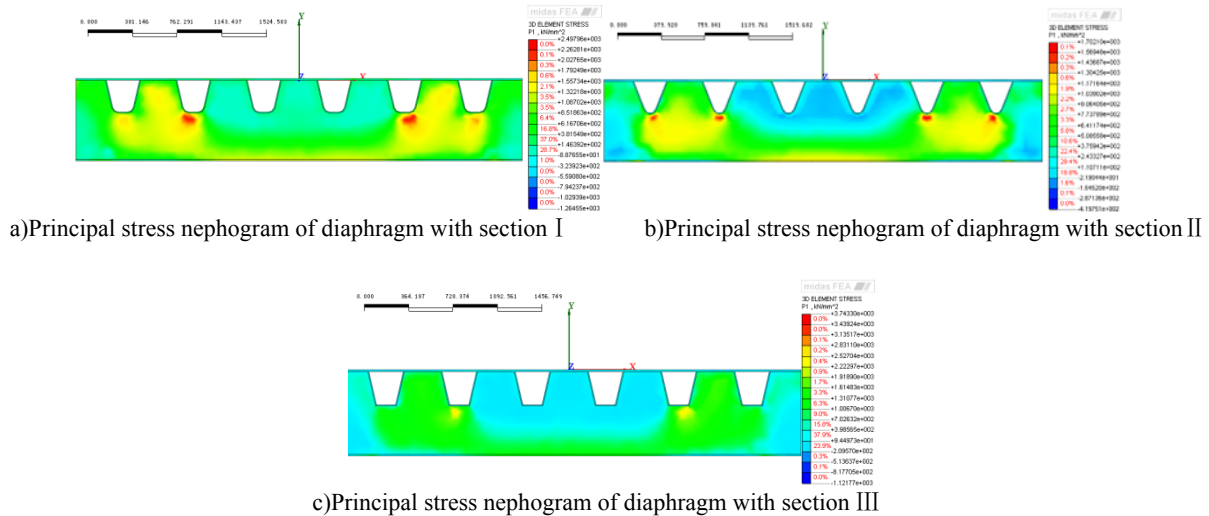c)Principal stress nephogram of diaphragm with section Ⅲ

Fig. 5 Stress Nephograms of Diaphragm for the three types of cross-section.

Conclusions

According to the above analysis, the following conclusions can be drawn:

a)Among the three types of section, the V shaped section performed the best, in regard to inner force transference and stress distribution.

b)The areas around the corners of the trapezoid section are susceptible to stress concentrations, requiring additional structural measures.

c)The maximum stresses were mainly found in the shear and bending connections of the components.

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