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Effects of a New Method on Stress Amplitude and Fatigue Life of Orthotropic Steel Box Girder

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ABSTRACT

In this study, a new method of replaceable supporting member within orthotropic steel box girder is proposed in order to reduce stress amplitude and improve fatigue life of orthotropic steel box girder. The component model was established by ABAQUS, and the experiment was conducted to analyze stress amplitude of easily fatigue cracking areas of orthotropic steel box girder with and without the supporting member. In addition, the fatigue life was analyzed and predicted. The comparison results show that the finite element analytical results are in good agreement with the experimental results. The reduced proportion of stress amplitude of U rib, T rib grooves and mid-span of top plate of orthotropic steel box girder range from 40% to 60% and 20% to 40%, respectively. The analytical results show that the stress amplitude of orthotropic steel box girder can be reduced by the similar extent with the addition of the same supporting member under different loading pressure; The supporting member can improve the fatigue life of orthotropic steel box girder pertinently, which is simple in construction and low in cost, and can provide suggestions for solving fatigue problem of orthotropic steel box girder in engineering practice.

1. Introduction

Orthotropic steel box girders have been widely used in many countries due to its advantages of high load-carrying capacity, high material utilization and low structural height. However, with the increase of service time of bridges, the traffic volume increases rapidly, and the overload of vehicles are serious, which lead to the fatigue failure of orthotropic steel box girders. As a result, the bearing capacity and service life of the bridges decrease seriously (Kozy et al., 2011; Ya et al., 2011; Liu et al., 2018).

Some studies focused on the fatigue life by improving the pavement layer of orthotropic plate deck. It was found that CFRP reinforcement plate can effectively restore the overall strength and stiffness of damaged steel bridge, especially for the steel bridge seriously affected by corrosion, and the stiffness can be increased by 37% after repairing (Miller et al., 2001). Pan et al. (2016) proposed a composite deck system consisting of an orthotropic steel deck and an ultrathin reactive-powder concrete layer to solve the fatigue problem of orthotropic slabs. Jiang (2017) showed that the fatigue stress at each structural detail can be effectively reduced by increasing the thickness of bridge deck, and the fatigue life of the bridge deck can be improved by reducing the spacing of diaphragms. Yu et al. (2017) investigated that the fatigue life of orthotropic steel box girder can be effectively improved by carbon-glass hybrid fiber cloth reinforcement and crack welding reinforcement.

Other studies were devoted to optimizing the geometric parameters of orthotropic steel box girder to improve the fatigue life. Tong and Shen (1997, 2000) made a detailed study on the fatigue problem of orthotropic plate bridge deck. It was pointed out that the stress concentration at the slotted free edge of the diaphragm can be reduced by changing the geometric shape of the slotting. Ya et al. (2011) designed some fatigue specimens according to different welding penetration, and the optimal welding penetration of different fatigue details were obtained by experimental analysis in order to reduce the stress amplitude of fatigue prone parts of bridge deck and prolong its service life. Ding et al. (2011) conducted different cross partition construction experiments and showed that the stress amplitude at the welding

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hole can be effectively reduced by adding the built-in small partition to the longitudinal cross partition. Oh et al. (2011) studied the effects of different height, thickness, groove shape and other factors on stress in easily fatigue cracking areas of orthotropic plates, and proposed the optimal structural parameters. Wang et al. (2017a, 2017b) carried out the fatigue experiments of a full-scale model, measured and analyzed the fatigue stress of the real bridge under vehicle load, studied the fatigue resistance of the main fatigue details, and put forward some design suggestions to reduce the fatigue stress of the bridge deck slab structure details. Fu et al. (2018) considered the effects of amplitude, penetration rate, loading position, and steel strength on the fatigue life of a roof-U rib weld on orthotropic steel bridge decks, and a nominal stress of 70 MPa and a hot spot stress of 75 MPa were recommended for fatigue strength of roof-U rib welds under the manufacturing process.

For the previous methods to solve fatigue problems, many methods do not adjust the stress system of the structure after repairing the bridge, and the large stress amplitude may still lead to fatigue cracking of orthotropic steel deck. Some study results show that there are many factors affecting the fatigue life of orthotropic steel box girder, while the stress amplitude is the main factor (Xiang 2015; Zhao and Zheng, 2015).

In order to improve the fatigue life in easily fatigue cracking areas of orthotropic steel box girder, a new method of replaceable supporting member within orthotropic steel box girder is proposed in this paper. In addition, through the ABAQUS (2017) finite element analysis (FEA) and the reduced scale experiment, the variation of stress amplitude at U rib grooves, T rib grooves, top and bottom plates of orthotropic steel box girder with and without the supporting member were compared, and the effects of the addition of the supporting member on fatigue life of orthotropic steel box girder was analyzed and predicted. The new method proposed in this paper can provide reference to solve the fatigue problem of orthotropic steel box girder pertinently, which has the advantages of convenient construction, low cost and no impact on traffic operation.

2. Presentation of the New Method

In this paper, a new method of replaceable supporting member within orthotropic steel box girder is proposed. The schematic diagram of the method is shown in Fig. 1. The locking device is set up in the easily fatigue cracking areas and the bottom plate of the orthotropic steel box girder, and the supporting member is fixed through the locking device by thread occlusion. The locking device can be prefabricated in the factory and fixed to orthotropic steel box girder by high strength bolts, this connection involves no welding, as a result, the fatigue failure is not easy to occur.

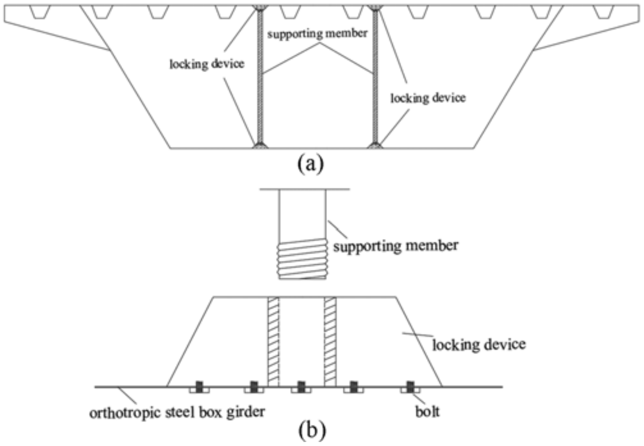


Fig. 1. Arrangement Diagram of Orthotropic Steel Box Girder with Supporting Members: (a) Arrangement of the Supporting Members, (b) Schematic Diagram of the Locking Device

In practice, the supporting member can be made as different materials and shapes according to the need, and the locking device can be made of steel. The supporting member can be selected according to the analytical results of FEA and reduced scale experiments. Compared with the traditional solutions of improving the fatigue life, the method of the replaceable supporting member proposed in this paper has the following advantages:

1. The manufacturing process of the supporting member is simple, the cost is low, it can be produced in batches in the factory and has good economy compared with other solutions.
2. The supporting member can be made as different shapes and materials according to the change of different shapes of steel box girder, which have good applicability for different kinds of steel box girder.
3. The installation process of the supporting member can be carried out after the construction of the bridge, and the installation can be operated manually and pertinently within the orthotropic steel box girder.
4. The supporting member transfers and share the large stress of top plate caused by the vehicle loads. If the supporting member is damaged, it can be replaced easily, which improves the durability of steel box girder.
5. The process of installing the supporting member is carried out inside the orthotropic steel box girder. The installation process is not only unaffected by the weather and other external factors, but also does not affect the normal traffic operation.

3. FEA and Verification

In order to study the effects of the addition of the supporting member on stress amplitude and stress distribution of easily fatigue cracking areas of orthotropic steel box girder, a 1/4 reduced scale component of orthotropic steel box girder was prefabricated according to a viaduct serviced in Jiangyin, the parameters of the reduced scale component were selected according to the real bridge, the stress amplitude and stress distribution in easily fatigue cracking areas of orthotropic steel box girder were analyzed by ABAQUS (2017).

Table 1. The Thickness of the Parts of the Component (m)

The parts	Top and bottom plate	Diaphragm	U/T rib	Web	Steel stiffener	Thickened gasket
Thickness	0.004	0.005	0.002	0.004	0.004	0.02

3.1 Parameter Selection

In this study, the steel material of the component is selected as Q235 according to the relevant specification (GB/T 714-2008, 2008). The length of the component is selected as 2 m, the width and height are selected as 0.82 m and 0.6 m, respectively. The diameter of steel supporting member selected in this paper is 5 cm. The thickness of the parts of the component are selected as shown in Table 1, and the geometric dimensions are shown in Fig. 2.

3.2 Finite Element Simulation

As shown in Fig. 2(a), the top plate of the component is set with 4 U ribs, the bottom plate is set with 4 T ribs, and each beam end is provided with a diaphragm. The cross section of steel box girder is symmetric longitudinally and transversely. Two longitudinal and transverse steel stiffeners are arranged on both webs of the steel box girder, and the head stiffener plates are set at the bottom of the longitudinal ends of the steel box girder, which is welding with the T ribs in order to prevent the local stress concentration at the supports.

As shown in Figs. 2(a) and 2(b), the supporting member is modeled by 3D solid element, and the other parts of the component are all modeled by 3D shell element (Cao and Shi, 2016). The supporting member is divided into grids by C3D8R, and the other parts of the component are divided by S4R. Based on the principle that the error of two FEA calculation results are not more than 2% (Cao and Shi, 2016), after debugging the model repeatedly, the mesh spacing of the U ribs, T ribs, diaphragms and stiffening plates are 0.02 m, the mesh spacing of top plate, bottom plate and webs are 0.05 m, and the mesh spacing of supporting member is 0.008 m.

As can be seen from Fig. 2(c), a rectangular of 0.2 m × 0.8 m is defined from the top plate of the finite element model as the loading area to avoid local buckling of the webs, a reference

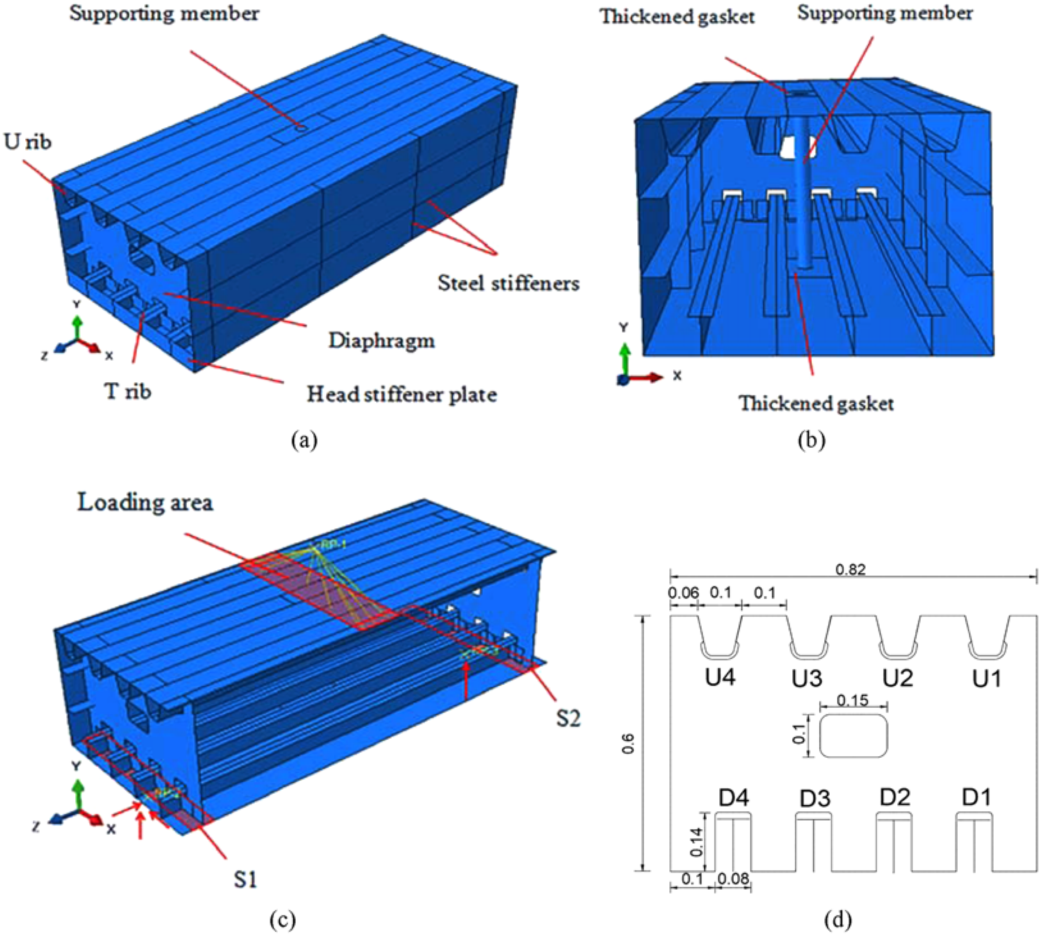


Fig. 2. Finite Element Model of the Component: (a) Facade of the Component, (b) Sectional View of the Component, (c) Loading Diagram of the Component, (d) The Dimensions and Number of U Rib and T Rib Grooves

point RP-1 is created above the loading area, the coupling interaction is established between the loading area and the reference point, and the concentrated load is applied to the reference point. The rectangular areas S1 and S2 of 0.1 m × 0.82 m are respectively defined from both ends of the bottom plate of the finite element model, two reference points RP-2 and RP-3 are created below the rectangular area, the coupling interaction are respectively established between the rectangular areas and the reference points, and the simple supported constraint is applied to the reference points.

As shown in Fig. 2(d), for the convenience of analysis, the U rib grooves on diaphragm are numbered from U1 to U4 in turn, and the T rib grooves on diaphragm are numbered from D1 to D4 in turn.

3.3 Positions of the Investigation

In this paper, the mid-span position of top and bottom plates, U1, U2, D1 and D2 of the steel box girder were selected for analysis due to the symmetry of the component. As shown in Fig. 3, longitudinal and transverse strain gauges are attached to the mid-span positions of top and bottom plates, strain rosettes are attached to U rib and T rib grooves, and all of them are numbered in turn.

As shown in Figs. 3(a) and 3(b), the distance of strain rosettes form the weld toe of top plate and U rib are 10 mm, the distance of strain rosettes from the weld toe of diaphragm and U rib are 10 mm, and the distance of strain rosettes from the scallop edge are 5 mm.

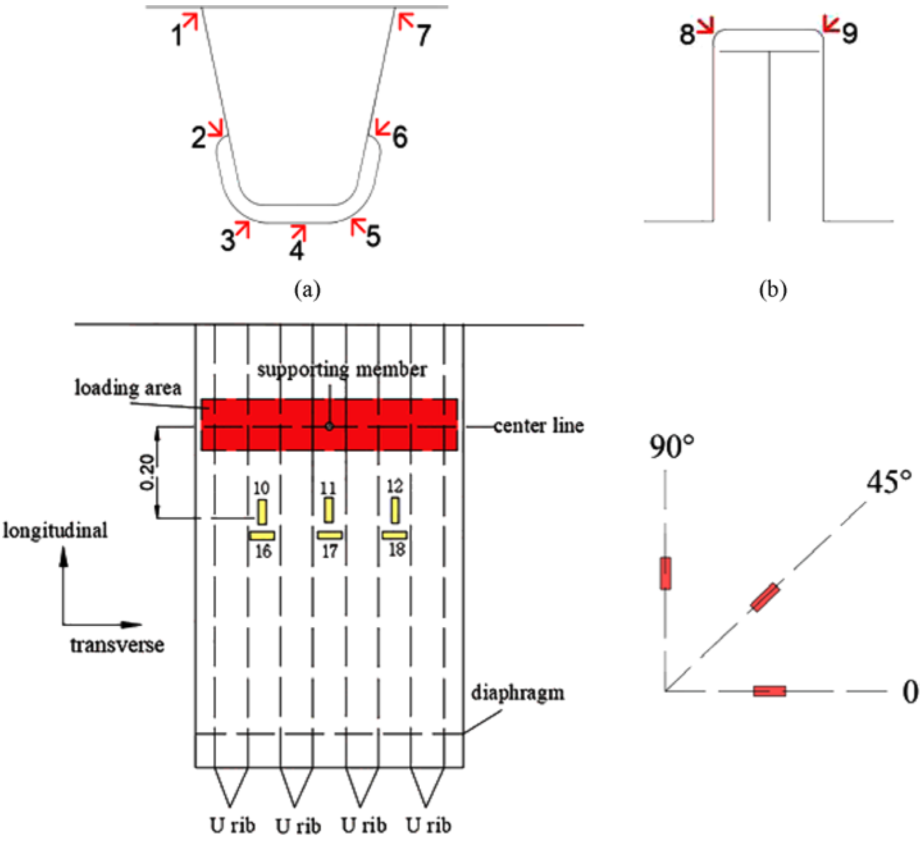
The positions of strain gauges sticking on top and bottom plates of orthotropic steel box girder are symmetrical, which are 0.20 m away from the center line of steel box girder. For the convenience of analysis, the longitudinal and transverse strain gauges of the bottom plate are numbered as 13, 14, 15 and 19, 20 and 21, respectively. As a result, strain gauge Numbers 13, 14, 15 and Numbers 10, 11, 12 are symmetrical one by one in position, strain gauge Numbers 19, 20, 21 and Numbers 16, 17, 18 are symmetrical one by one in position.

3.4 Verification

In order to verify the effectiveness of the method proposed in this paper, the stress amplitude and stress distribution of easily fatigue cracking areas of orthotropic steel box girder with and without the supporting member were analyzed separately by finite element method.

3.4.1 Stress Amplitude

The stress amplitude of orthotropic steel box girder at the same position is defined as the value when the loading pressure is the



(a) (b)

(c) (d)

Fig. 3. The Numbers of Strain Rosettes and Gauges: (a) Strain Rosettes at U1 and U2, (b) Strain Rosettes at D1 and D2, (c) Strain Gauges at Top Plate (m), (d) The Direction of Strain Rosettes

maximum minus the stress value when unloading is considered (also called the initial state and the stress is defined as 0 in this paper) (Xiang, 2015). The difference value of stress amplitude is defined as the stress amplitude with the supporting member minus the stress amplitude without the supporting member. The following stress amplitude values of strain rosettes are Mises stress (calculated by the Fourth strength theory), the stress amplitude values of strain gauges are longitudinal and transverse stress.

The FEA results show that the variation law of stress amplitude at the same positions are similar when the concentrated load is 1t, 2t, 3t, 4t and 5t, respectively, as a result, the results of FEA were analyzed shown in Fig. 4 when the concentrated load is 5t.

It can be seen from Figs. 4(a) and 4(b) that the stress amplitude at groove positions of orthotropic steel box girder with the supporting member is smaller than that without the supporting member, and the stress amplitude at U1 and U2 decrease a little more than that at D1 and D2. Fig. 4(a) shows that the stress amplitude of number 2 at U1 is about 80.64 MPa without the supporting member, while the stress amplitude is about 49.75 MPa with the supporting member, the stress amplitude is decreased by 30.89 MPa; The same rule applies to Fig. 4(b), it shows that the stress amplitude of number 2 is decreased by 41.82 MPa after the addition of the supporting member.

From Figs. 4(c) and 4(d), it is obvious that the stress amplitude of the top plate is much larger than that of the bottom plate. After the addition of the supporting member, the stress amplitude of the top plate shows a decreasing trend, while the stress amplitude of the bottom plate shows a small increasing trend. It can be seen from Fig. 4(c) that the longitudinal stress amplitude of top plate at number 11 decreases larger than that at numbers 10 and 12, about 16.87 MPa; The longitudinal stress amplitude of bottom plate at numbers 13 and 15 increases larger than that at number 14, about 2.89 MPa. It can be seen from Fig. 4(d) that the variation of transverse stress is similar to that in Fig. 4(c).

Therefore, the stress amplitude of easily fatigue cracking areas decrease obviously after the orthotropic steel box girder is installed with the supporting member.

3.4.2 Stress Distribution

The stress distribution of steel box girder without and with the supporting member when the concentrated load is 5t are shown in Fig. 5.

As can be seen from Figs. 5(a) and 5(b), compared with the steel box girder before the addition of the supporting member, the stress at top plate and U ribs decrease with the addition of the supporting member, the stress of bottom plate increase slightly, which is similar to the law of stress amplitude. As a result, the addition of the supporting member transfers and share the large stress of the top plate.

It is known that the fatigue failure of orthotropic steel box girder mainly occurs in the welding positions such as bridge deck, diaphragm and groove positions, the bottom plate does not bear vehicle load directly and the stress amplitude level is low. Therefore, the slightly increase of the stress amplitude of the bottom plate will not cause the fatigue failure.

As the stress of U rib grooves are larger than that of the other parts under experimental load, the stress distribution of U1 and U2 are selected as the analytical object. Fig. 6 shows the detailed stress distribution of numbers 1 to 7 at U1 and U2 when the concentrated load is 5t. As can be seen from Fig. 6 that the stress at numbers 2 and 6 are larger than that of the other numbers, which are similar to the law of stress amplitude analyzed above.

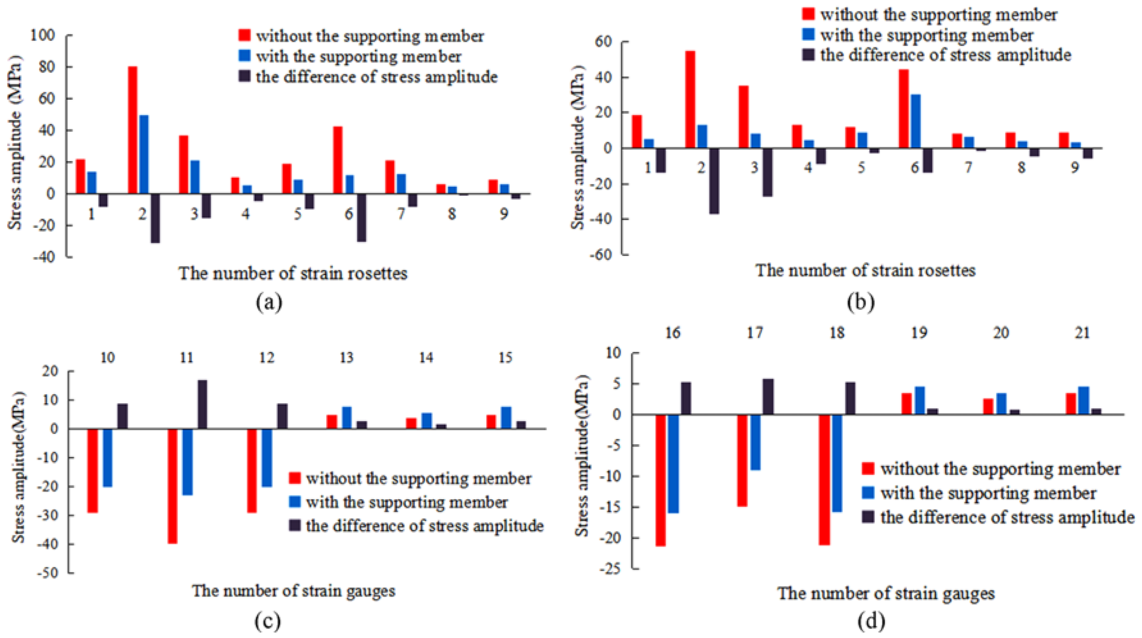
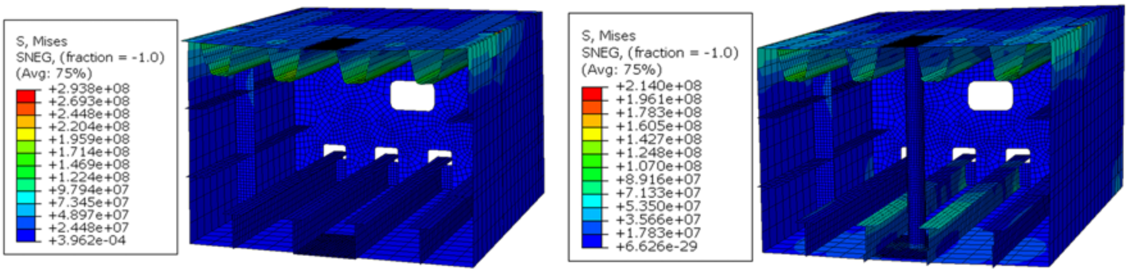


Fig. 4. Stress Amplitude of the Component: (a) Stress Amplitude at U1 and D1, (b) Stress Amplitude at U2 and D2, (c) Longitudinal Stress Amplitude at Mid-Span Position of Top and Bottom Plates, (d) Transverse Stress Amplitude at Mid-Span Position of Top and Bottom Plate



(a) (b)

Fig. 5. Stress Distribution of the Steel Box Girder: (a) Stress Distribution of Steel Box Girder without Supporting Member, (b) Stress Distribution of Steel Box Girder with Supporting Member

Through the comparison of Figs. 6(a) and 6(b), it can be seen that the stress distribution of every objective point decreases after the supporting member is added, and there exists no stress concentration, the stress distribution of the objective points are relatively small and uniform, which have little influence on the structure whether the supporting member is added or not.

The results of FEA show that the stress amplitude of top plate, U rib and T rib grooves are effectively reduced by the addition of the supporting member, which proves the effectiveness of the method proposed in this paper.

4. Experiment and Comparative Analysis

4.1 The Experiment

The layout of the loading device of the experiment is shown in Fig. 7. The TDS 303 made in Japan was used as strain tester in the experiment.

As shown in Fig. 7(a), the numbers 1 to 7 represent rigid pier, experimental steel box girder, rigid cushion beam, hydraulic jack, pressure sensor, rigid cushion plate and reaction frame, respectively.

As shown in Fig. 7, the bottom dimension of the rigid cushion beam is chosen as 0.2 m × 0.8 m, which is consistent with the FEA model. The experimental steel box girder was initially pre-loaded for 1t, after unloading, the supporting member was screwed up to top plate by the screw rotation, and the steel box girder was loaded to 5t one by one. After unloading, the supporting member was removed and then reloaded the hydraulic jack to 5t one by one. The loading process is as the following two steps:

a. 0t→1t→0t→1t→2t→3t→4t→5t→0t
(with the supporting member);
b. 0t→1t→2t→3t→4t→5t
(without the supporting member).

At the same time, the stress data with and without the supporting member were recorded by TDS 303, respectively. As a result, the experimental steel box girder is proved in elastic state during the whole experiment process when the load is less than 5t.

As shown in Fig. 7(b), in order to conveniently measure the stress amplitude of steel box girder with and without the supporting member in the experiment process, the bottom of the supporting member is designed as threaded, and the bottom of the supporting member is screwed with the bottom of the steel box girder and the thickened gasket.

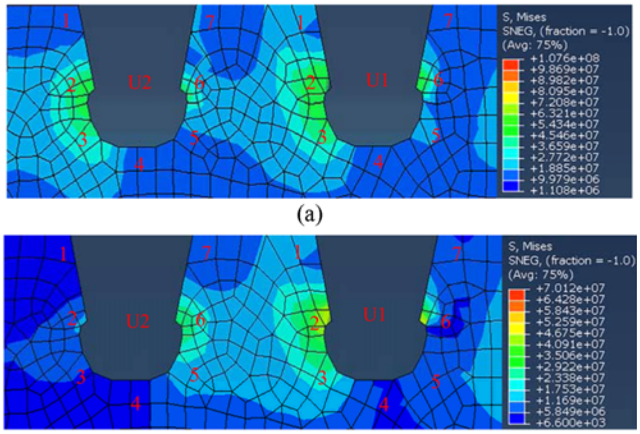
As shown in Figs. 7(c) and 7(d), the position of strain gauges and strain rosettes are the same as that selected positions in finite element model.

4.2 Comparative Analysis

In order to compare and analyze the experimental and FEA results, the reduced proportion of stress amplitude is defined as follows:

$$\frac{\text{stress amplitude without the supporting member} \atop -\text{stress amplitude with the supporting member}}{\text{stress amplitude without the supporing member}}\times 100\% \tag{1}$$

When the result of Eq. (1) is positive, it shows that the stress amplitude of steel box girder decreases with the addition of the supporting member, while when the Eq. (1) is negative, it shows that the local stress amplitude of steel box girder increases with



(a)

(b)

Fig. 6. Detailed Stress Distribution of U1 and U2: (a) With No Supporting Member, (b) With a Supporting Member

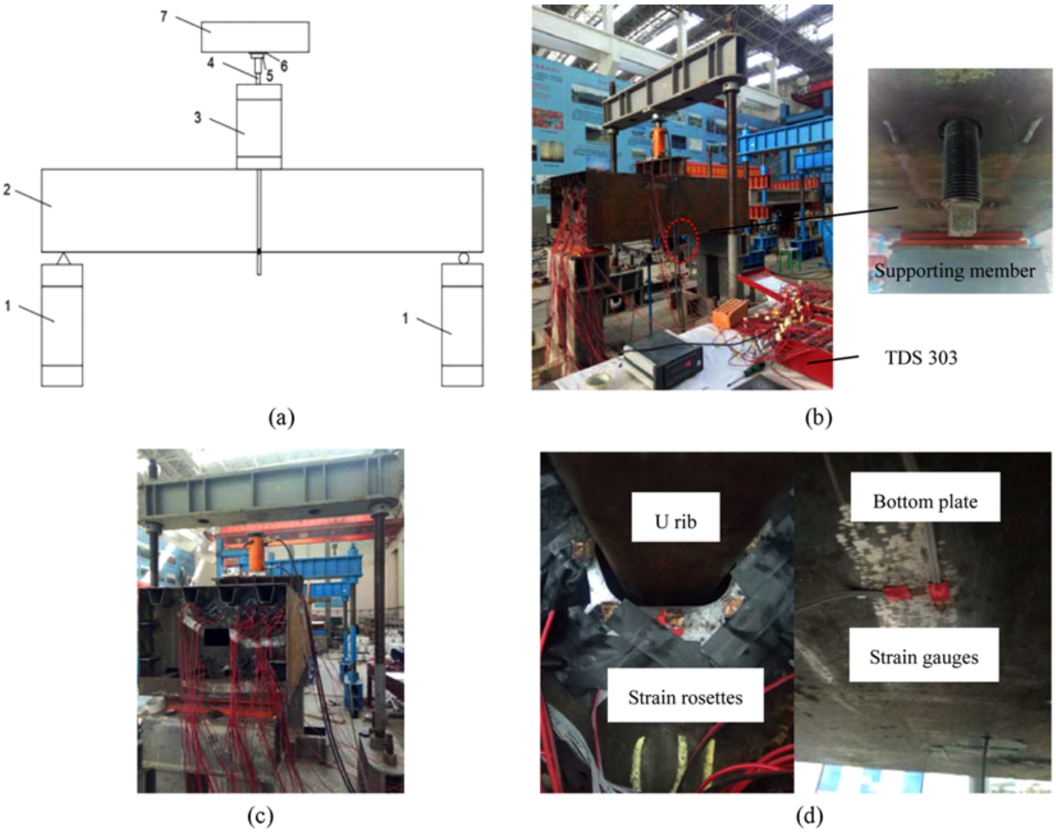


Fig. 7. Devices of the Experiment: (a) Schematic Diagram of Experiment Device, (b) Elevation of the Experimental Steel Box Girder, (c) Side View of the Experimental Steel Box Girder, (d) Strain Rosettes and Gauges of U1 and Bottom Plate

the addition of supporting member.

The equation for calculating the principal stress of strain rosettes is shown as follows (Sun et al., 2001):

$$\sigma = \frac{E}{1-\mu}\left[\frac{1+\mu}{2}(\varepsilon_{0^\circ}+\varepsilon_{90^\circ}) \pm \frac{1+\mu}{\sqrt{2}}\sqrt{(\varepsilon_{0^\circ}+\varepsilon_{45^\circ})+(\varepsilon_{45^\circ}-\varepsilon_{90^\circ})^2}\right] \quad (2)$$

Where E denotes the steel elastic modulus of Q235, μ denotes the poisson ratio, and the $\varepsilon_{0^\circ}, \varepsilon_{45^\circ}, \varepsilon_{90^\circ}$ denote the micro-strains measured in horizontal direction, 45 degree direction and vertical direction, respectively.

The comparison results are summarized shown in Fig. 8 after calculation.

It can be seen from Fig. 8 that the relative errors of the reduced proportion of stress amplitude are about 10% between the FEA results and the experimental results, which verify the accuracy of the FEA results and the feasibility of the proposed method.

Figure 8(a) shows that the reduced proportion of stress amplitude of number 6 at U1 is the largest from number 1 to number 9, about 70.84%, the number 8 is the smallest, about 19.04%, and the reduced proportion of stress amplitude at other positions are mostly range from 40% to 60%. As shown in Fig. 8(b), the largest reduced proportion of stress amplitude at U2 is number 2, about 75.35%, the smallest is number 7, about 18.11%, and the other positions are between 50% and 60%.

As shown in Figs. 8(c) and 8(d), the reduced proportion of the longitudinal and transverse stress amplitude of top plate range from 20% to 40%, and the increased proportion of the longitudinal and transverse stress amplitude of bottom plates are about 50% and 30%, respectively.

It is also known from Fig. 8 that the stress amplitude at U rib grooves can be reduced to the greatest extent by adding the supporting member, followed by the stress amplitude at T rib grooves and top plate. In addition, the reduced proportion of stress amplitude at U rib and T rib grooves are related to their positions, the closer to the supporting member, the larger the reduced proportion.

As the stress amplitude is the most important factor that affects the fatigue life of orthotropic steel box girder, the reduction of stress amplitude in easily cracking areas proves that the effects of adding the supporting member is obvious.

4.3 Parameter Study

In order to study the effects of the diameter of supporting member on the reduced proportion of stress amplitude of orthotropic steel box girder, the position of number 2 at U2, which has the largest reduced proportion of stress amplitude in Fig. 8, was selected as the research object, and ABAQUS (2017) was used to analyze the stress amplitude. The results are shown in Fig. 9.

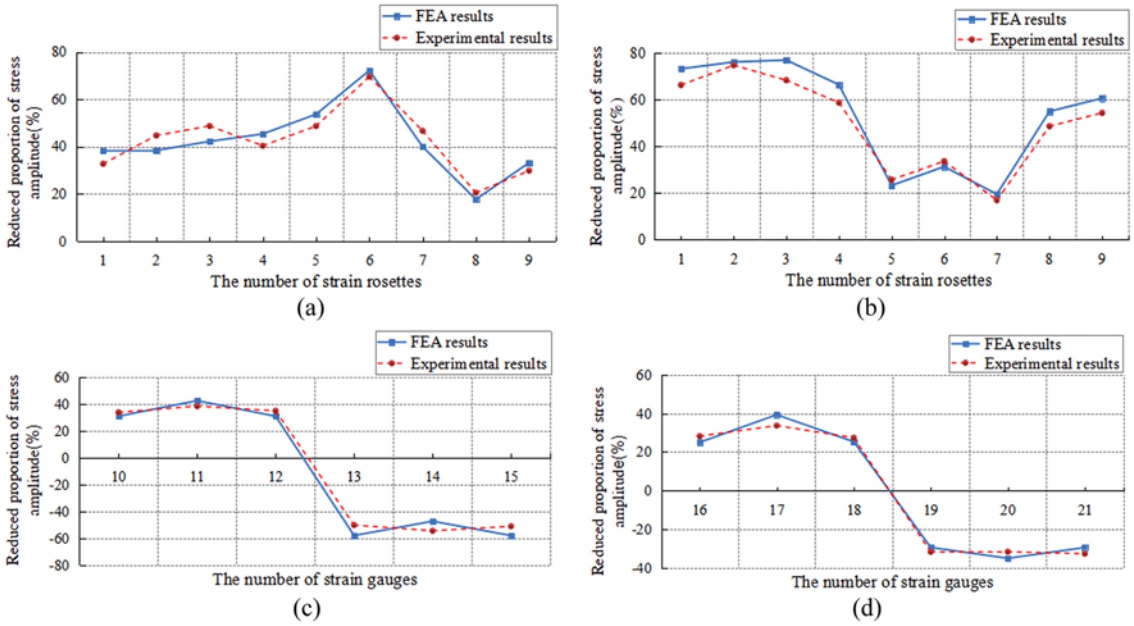


Fig. 8. Reduced Proportion of Stress Amplitude of the Component: (a) Reduced Proportion of Stress Amplitude at U1 and D1, (b) Reduced Proportion of Stress Amplitude at U2 and D2, (c) Reduced Proportion of Longitudinal Stress Amplitude at Mid-Span Position of Top and Bottom Plates, (d) Reduced Proportion of Transverse Stress Amplitude at Mid-Span Position of Top and Bottom Plates

Figure 9 shows that when the diameter of the supporting member is 2 cm, the stress amplitude at the position of number 2 at U2 decreases by 73.05%. With the increase of the diameter of the supporting member, the reduced proportion of the stress amplitude increases gradually. When the diameter of the supporting member is 5 cm, the reduced proportion of stress amplitude is 76.02%. When the diameter of the supporting member increases larger than 5 cm, the increasing tendency of the reduced proportion stress amplitude decreases.

In this paper, the selected supporting member with the diameter of 5 cm can reduce the stress amplitude to a large extent. In practical engineering application, the supporting member should be reasonably calculated and selected according to the need.

In the process of solving the fatigue problem of orthotropic steel box girder bridge in practice, the optimal diameter of the supporting member can be selected by finite element simulation and reduced scale experiment in the laboratory.

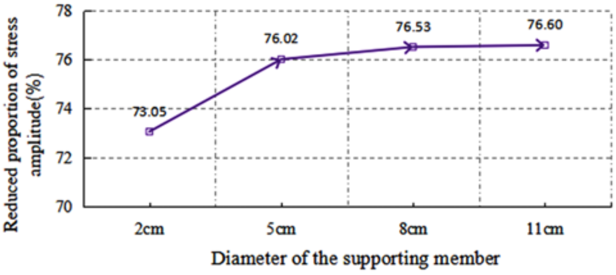


Fig. 9. The Effects of Diameter of Supporting Member on the Reduced Proportion of Stress Amplitude

5. The Effects of the Supporting Member on Fatigue Life

5.1 The Effects on the Component

In order to predict and analyze the effects of the supporting member on fatigue life of the component, as the areas where the stress amplitude decreases most obviously after the addition of the supporting member, the positions of the number 1 and the number 2 at U2 were selected to calculate the fatigue life.

The fatigue resistance equations at positions of number 1 and number 2 are shown as follows according to the basic form of component connection and the category of fatigue allowable stress amplitude, respectively (TB 10091-2017, 2017):

$$\lg N + 3\lg\Delta\sigma_i = 11.64 \tag{3}$$

$$\lg N + 3\lg\Delta\sigma_i = 11.26 \tag{4}$$

where N denotes the fatigue life, $\Delta\sigma_i$ denotes the stress amplitude.

The calculation results show that the fatigue life $N = 6.309 \times 10^7$ for the position of number 1 before the addition of the supporting member, while $N = 3.303 \times 10^9$ after the addition of the supporting member. For the position of number 2, the fatigue life before and after the addition of the supporting member are 1.091×10^6 and 7.943×10^7, respectively.

As a result, with the addition of the supporting member, the fatigue life of easily cracking areas of the component increases obviously, which verifies the effectiveness of the method proposed in this paper.

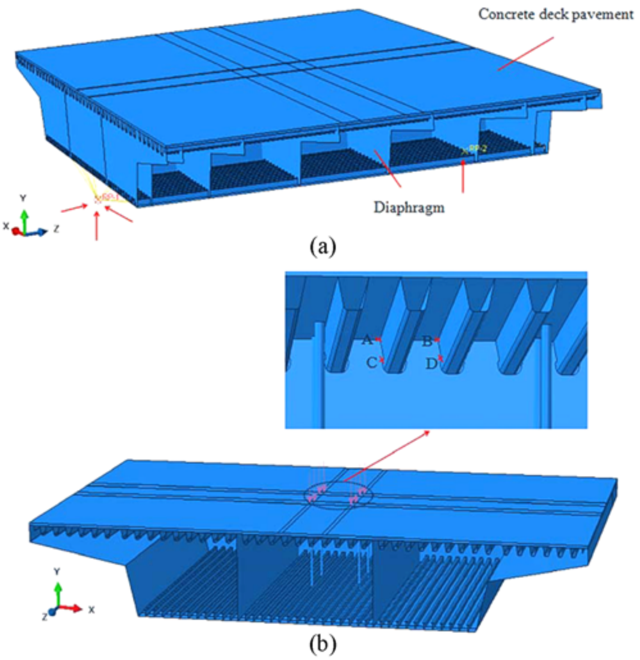


Fig. 10. Segmental Finite Element Model of the Real Bridge: (a) Supporting Method and Member Name, (b) Loading Form and Objective Points

5.2 The Effects on the Real Bridge

Taking the orthotropic steel box girder of a serviced viaduct in Jiangyin as an example, as shown in Fig. 10, the segmental finite element model of the real bridge was established using ABAQUS (2017).

As shown in Fig. 10, The length of the real bridge is selected as 14m, the thickness of concrete deck pavement is 0.08 m. According to the actual bridge, the number of diaphragms is 5, the number of U ribs is 40, the number of T ribs is 37, and the dimensions of these parts are the same as the serviced bridge.

As shown in Fig. 10(a), the vehicle loads were applied on the top plate of the steel box girder according to the JTG D60-2015 (JTG D60-2015, 2015), four loading areas are all selected as 0.2 m × 0.6 m, the maximum loading pressure is 1×10^6 Pa, and the minimum is 0.

Two rectangular regions with a width of 0.5 m are respectively defined from both ends of the bottom plate of the finite element model, two reference points RP-1 and RP-2 are created below the rectangular area, the coupling interaction are respectively established between the rectangular areas and the reference points, and the simple supported constraint is applied to the reference points, which is the same as Fig. 2(c).

As shown in Fig. 10(b), four solid cylindrical supporting members with the diameter of 10 cm are set within the orthotropic plate of the steel box girder. As is shown, Four easily fatigue cracking joints were selected as the analytical object, the selected welding points of U rib and top plate were numbered as position A and position B, the selected welding points of U rib and diaphragm were numbered as position C and position D.

For the convenience of comparison and safety calculation, according to the basic form of component connection and the category of fatigue allowable stress amplitude (TB 10091-2017, 2017), the effects of the supporting member on the fatigue life of the easily fatigue cracking areas of the bridge was analyzed based on the fatigue resistance equations. The calculation results are shown in Table 2.

Table 2 shows that the stress amplitude of the easily fatigue cracking areas of orthotropic plate can be reduced by the addition of the supporting members, and the fatigue life of the real bridge increased by about 16% – 26%.

It shows that the proposed method of the addition of the supporting member within the orthotropic steel box girder can effectively improve its fatigue life. In addition, the above results show that the fatigue life of the easily cracking areas of orthotropic steel box girder can be improved in different degrees with the addition of different sizes and numbers of supporting members.

6. Conclusions

In this study, the stress amplitude of orthotropic steel box girder after the addition of the supporting member was analyzed by finite element method and experiment, and the effects of the supporting member on fatigue life of easily fatigue cracking areas of orthotropic steel box girder was analyzed and predicted. The following conclusions can be drawn from this study:

1. The stress amplitude of top plate, U rib and T rib grooves of orthotropic steel box girder can be effectively reduced by the addition of the supporting member. The reduced proportion of stress amplitude can reach from about 30% to 60%, which proves the feasibility and effectiveness of the new proposed method.
2. The stress amplitude at U rib grooves can be reduced to the greatest extent by the addition of the supporting member, followed by the T rib grooves and the top plate.
3. For the same orthotropic steel box girder, with the increase of the diameter of the supporting member, the fatigue life

Table 2. Fatigue Life of Segment of the Real Bridge

The easily fatigue cracking areas		Position A	Position B	Position C	Position D
Without the supporting member	Stress amplitude (MPa)	19.60	42.70	2.04	4.67
	Fatigue life	5.753×10^7	5.597×10^6	2.138×10^{10}	1.786×10^9
With the supporting member	Stress amplitude (MPa)	18.71	39.82	1.89	4.43
	Fatigue life	6.668×10^7	6.902×10^6	2.697×10^{10}	2.094×10^9

of the objective points increase, but the increasing extent gradually decreases.

4. The further the objective points from the supporting member is, the less the fatigue life is improved.
5. The stress amplitude of orthotropic steel box girder can be reduced by the similar extent with the addition of the same supporting member under different loading pressure.

In conclusion, the new method of the addition of the supporting member within the orthotropic steel box girder proposed in this paper can effectively improve the fatigue life of the easily fatigue cracking areas of orthotropic steel box girder, which does not affect the traffic, and is simple in construction and low in cost, and can provide reference value for solving fatigue problems in engineering practice.

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