Study on the influence of flat plates for stiffening on the force transmission of frame cross bracing

Dafang Mei1, Ming Li2

1 School of Highway, Chang’an University, Xi’an, Shaanxi Province, 710064, P.R. China
2 General Contracting Branch of CCCC Third Highway Engineering CO., LTD, Beijing, 100009, P.R. China
*Corresponding author’s e-mail: 2018121054@chd.edu.cn

Abstract. The main girders of the I-section steel-concrete composite twin girder bridge is usually connected together by frame cross bracing. When the cross girder is connected with the main girders by welding, the flat plates for stiffening can be used to strengthen the connection to ensure the effective transfer of connection forces between the two. In this paper, the finite element simulation method is used to study the influence of flat plates. The results show that, compared with the twin girder structure without flat plates for stiffening, when the same load acts on the cross girder: the stress peak value of the cross girder of the twin girder structure with flat plates is obviously reduced, and the stress peak value of the main girders is increased; the bending stress of the web of T-shaped connection stiffeners diffuses faster from the welding part to the end; the peak value of the axial stress on the web of T-shaped connection stiffeners decreases obviously, and the position of the peak value changes from the side near the cross girder to the side near the web of main girder. The above results show that it is necessary to set the flat plates for stiffening in the twin girder bridge to ensure the transfer of forces between the main girders and cross girder.

1. Introduction
Steel-composite plate girder bridge is mainly composed of concrete bridge deck, steel main girder, transverse connection system, longitudinal connection system and shear connector.

The composite steel plate girder bridge with duplex shaped steel has become the mainstream of new medium and small span bridges. Because it can reduce the workload and cost of steel structure manufacturing [1]. Generally, two I-beams need to be connected together by cross bracings. The cross bracing fulfills three basic functions: 1) prevent deformation of the bridge cross section. 2) distribute the load to make the stress of each main beam more even. 3) the main beams, the horizontal plan bracing, and the cross bracing form the spatial truss structure to resist horizontal load. Twin girder structure generally adopts frame cross bracing, because it needs less working hours [2].

2. Connection structure of frame cross bracing and main girder
Frame cross bracing comprises a cross girder rigidly connected to uprights that also have the function of vertical web stiffeners for the main beams [3]. The cross girders are generally rolled H or I sections, which are connected with the uprights (the vertical web stiffeners for the main beams) through welding or bolt connection [4].
For welded connection, the main girder and cross girder are generally connected by T-shaped cross-section stiffeners (the uprights), which are welded on the web of the I-section steel main girder. The T-shaped stiffeners are called "connection stiffeners". When the slip form construction platform needs to move on the lower flange of the steel girder, the flange of the T-shaped connection stiffener should be at least 100 mm away from the lower flange edge of main girder [5], as shown in Figure 1.

![Figure 1. Examples of a welded frame cross bracing.](image)

In order to ensure the transfer of connection forces between the cross girder and main girder, the connection between them are normally stiffened by using flat plates. The flat plates for stiffening are like extended cross girder flanges, as shown in Figure 2.

![Figure 2. Examples of details for a welded frame cross bracing.](image)

In this paper, two local finite element models of twin girder bridge are established, the only difference is whether to set flat plates for stiffening the connection between the cross girder and main girders. By comparing the stress distribution of the two models under same load, the influence of stiffening plates is studied.

### 3. Finite element simulation calculation

#### 3.1. Study on influence of the position of cross girder

In this paper, before studying the influence of setting flat plates for stiffening, considering that the position of cross girder may become the interference item of the comparative test, the position of cross girder relative to the height of the main girder is taken as the variable to analyze its influence on the structure stress. The cross section of a typical 35m span steel plate composite beam with two main beams are shown in Figure 3. Figures 4 to 6 show the segmental model of the double girder structure with the cross girder at three height positions.
In this section, the stress results of the top plate, web and bottom plate of main girder in the three models are extracted, and the stress extraction path is the axis direction of the plate, and the two main girders are numbered as 1# and 2#. The stress distribution of the bottom plate of the main girder is shown in Figure 7: (1) In the case of three height positions of the beam, the stress on the bottom plate axis of the 1# girder is higher than that of the 2#, which is due to the eccentric load acting on the top of the 1# main girder. (2) The results show that the stress curves of 1# main girder (or 2#) in three cases coincide very high, which indicates that the position change of cross girder has no obvious influence on the stress distribution law of the main girder bottom plate. (3) Under the action of eccentric load, the load is transferred from the 1# girder to 2# through cross girder, but the stress level of the bottom plate of the 2# in the three models is same, which shows that position change of cross girder has no obvious influence on the load transfer. From Figure 8 and Figure 9, it can be seen that the stress distribution of the top plate and web of the main beam also shows the same law.
To sum up, the position of cross girder in the height direction has no obvious influence on the stress distribution of the main girder of the double girder structure, so this parameter analysis will not be repeated in the subsequent analysis.

3.2. Establishment of contrast model
In this paper, two groups of models with the same size parameters are established, and whether or not to set up flat plates is the only variable of the two models. The connection stiffeners in model 1 has no stiffener plates, as shown in Figure 11. Model 2 has stiffener plates, as shown in Figure 12. A uniform load of 100 kN/m is applied to cross girder in the segment model.

4. Numerical simulation results
4.1. Comparison of structural stress peaks
In model 1, the stress results show that the Mises stress peak of the cross girder is 247.4 MPa, which is located at the connection of the upper flange plate of the cross girder and the flange plate of the T-shaped connection stiffeners; the peak stress of the main beam is 127.6 MPa, which is located at the connection between the web of the main beam and the web of T-shaped stiffener. In model 2, the maximum stresses of cross girder and main girder is 163.2 MPa and 136.1 MPa. The position of peak stress is the same as that of model 1. The Mises stress nephogram of model 1 and model 2 are shown in Figure 13 and Figure 14.
The above results show that the stress peak positions in the two models are the same. However, compared with model 1, the peak stress of cross girder in model 2 is reduced by 34%, and peak stress of main girder is increased by 6.7%. The above results show that, under the same load, the setting of stiffened plate of connection stiffeners does not change the overall stress distribution law of the twin girder bridge, but changes the stress distribution ratio of the structure: the maximum stress level of the main girder is increased, the maximum stress level of the beam is reduced, and the external load of the beam is more efficiently transferred to the main girder through the connection stiffeners.

4.2. Comparison of bending stress distribution

The bending stress nephogram of T-shaped connection stiffeners’s web of the two groups of models are shown in Figure 15 and Figure 16.

In order to compare the diffusion and distribution of bending stress on T-shaped connection stiffeners’s web in the two groups of models, the stress values at several same positions of the webs in the two groups of models are extracted and drawn into a broken line diagram. The extraction path of bending stress is shown in Figure 17. The upper side of the web as shown in Figure 17 is the side near the cross girder, and the lower side of the web is the side close to the web of the main girder.
As shown in Figure 18, the stress changes in model 1 and model 2 have the same characteristics: the maximum stress of T-shaped stiffeners’s web occurs in the central region of the length direction of the web, that is, the part where T-shaped stiffeners connects with the end of cross girder. From the center to both ends of the web, the bending stress decreases rapidly and tends to be stable. It is difficult to directly compare the bending stress change trend from Figure 18. Therefore, the data are processed as follows: the stress at each point is expressed as $\sigma_i$, and the peak stress of each group of data is $\sigma_{imax}$. Take $|\sigma_i|/\sigma_{imax}$ as the ordinate label to draw a broken line diagram, as shown in Figure 19, to compare the stress diffusion degree of the two groups of models. The smaller $|\sigma_i|/\sigma_{imax}$ is, the more the stress value at this point decreases relative to the stress peak value, which can be regarded as the higher degree of diffusion when the stress is transferred to the point.

As shown in Figure 19, the stress diffusion degree of webs in the two models is similar in the connection area between T-shaped stiffener and cross girder. In the region near the two ends of the web, the degree of bending stress diffusion in model 2 is higher than that in model 1, which is 25% higher on average.

### 4.3. Comparison of axial stress distribution

The axial stress nephogram of T-shaped stiffeners’s web is shown in Figure 20 and Figure 21. In the figure, the upper side of the web is the side near the cross girder, and the lower side is the side close to the main girder web.
In model 1, the maximum stress on the web of T-connection stiffener is 126 MPa, which is located on the side of the web near the small beam; in model 2, the maximum stress of the web is 58 MPa, which is significantly reduced compared with the results of model 1, and the peak stress is located on the side of the web near the main beam web.

From the above results, it can be seen that the axial stress level of T-shaped stiffener in model 1 is higher, which is the main load-bearing member, and the steel girder is less involved in the stress; the stress level of T-shaped stiffener in model 2 is significantly lower than that in model 1, and the peak position of stress is close to web of main girder, which indicates that the main girder can participate in the stress better.

5. Conclusions

The results show that, compared with the twin girder structure without flat plates for stiffening, when the same load acts on the cross girder:

The stress peak value of the cross girder of the twin girder structure with flat plates is obviously reduced, and the stress peak value of the main girders is increased. It shows that the load on cross girder is more transferred to the main girder through T-shaped stiffener. It can be seen that the setting of flat plates for stiffening enhances the connection stiffness between main girders and cross girder.

The bending stress of the web of T-shaped connection stiffeners diffuses faster from the welding part to the end. The reduced stress on the web of connection stiffener due to diffusion is transferred to main girder. It shows that the setting of flat plates for stiffening can improve the stress diffusion efficiency of the web and improve the force transfer efficiency from cross girder to main girder.

The peak value of the axial stress on the web of T-shaped connection stiffeners decreases obviously, and the position of the peak value changes from the side near the cross girder to the side near the web of main girder.

Based on the above conclusions, in the I-section steel-concrete composite twin girder bridge with frame cross bracing, the setting of flat plates for stiffening can ensure the effective transmission of force between the cross girder and main girders.

References

[1] Liu, Y. J., Gao, Y. M., Zhou, X. H., et al. (2017). Technical and Economic Analysis in Steel-concrete Composite Girder Bridge with Small and Medium Span. China Journal of Highway and Transport, 30(3):1-13.

[2] Shi, X. F., Ma, H. Y., Liu, C. (2018). Parametric Study and Optimization on Behavior of Twin-I Girder Composite Bridges. Journal of Tongji University, (nature Science), 46(4), 444-451.

[3] Zhang, K. (2016). Research on the Accelerated Construction Technology and the Application of Composite Steel Plate Girder Bridge with Medium-small Span. Xi’an, Chang’ an University.

[4] Lebet J P, Hirt M A. (2013). Steel Bridges: Conceptual and structural design of steel and steel-concrete composite bridges. Lausanne: EPFL press.

[5] Ministry of Transport of the People’s Republic of China. Specifications for design of highway steel bridge: JTG D64-2015. Beijing: China Communications Press, 2015.