

Study on the Pure Torsion Performance of I-Type Steel-Concrete Composite Bridge with Double Girders

H C Liu¹, S Wan¹ and Q J Liu¹

¹Department of Transportation, Si Pailou campus of Southeast University, Nanjing, Jiangsu, China

Abstract. At present, the study of the torsion performance of the steel-concrete composite bridge with open sections are usually simplified to study the torsion performance of single-girder steel-concrete composite bridge added the influence of transverse vehicle distribution. Due to the existence of transverse connections between the bridge girders, the overall torsion performance of double-girder composite bridge is different from that of single-girder composite bridge. Therefore, it is necessary to study the effect of different forms of the connections on the torsional properties of the double-girder composite bridge through experiments. In this paper, three double-girder steel-concrete composite model bridges are designed to study the effect of different forms of transverse connections and the effect of different shapes of steel webs on torsional properties of composite bridges.

1. Designing of the model bridges

This research contains three model bridges, and is respectively numbered SP1, SP2 and SP3. SP1 is a double-girder bridge with small beams connected to the vertical webs, SP2 is a double-girder bridge with trusses connected to the vertical web, and SP3 is a double-girder bridge with small beams connected to corrugated webs. The standard span of each model bridge is 2.4m, and the calculation span is 2.2m, the height is 0.374m, and the cross section size is shown in figure 1-figure 5.

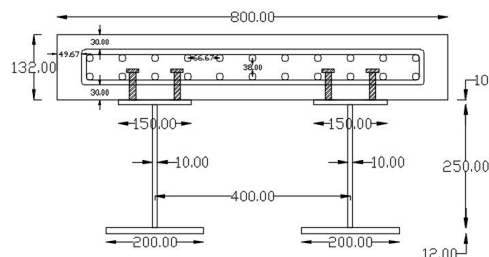


Figure 1. The cross-section of SP1 and SP2.

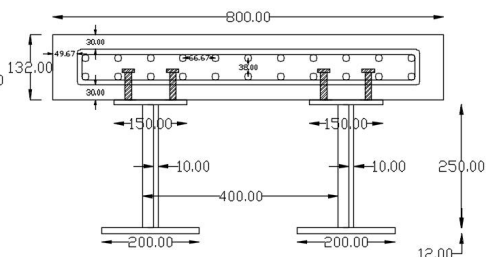


Figure 2. The cross-section of SP3.

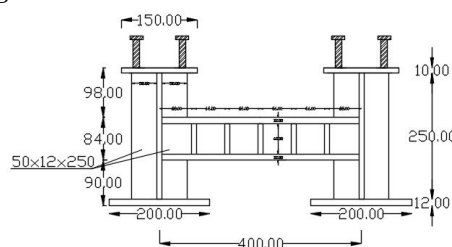


Figure 3. Connections between the webs of SP1.

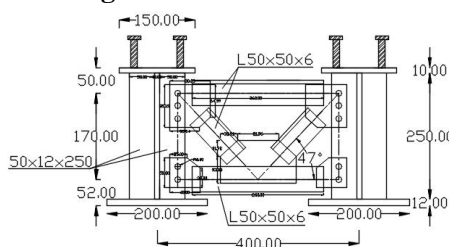


Figure 4. Connections between the webs of SP2.



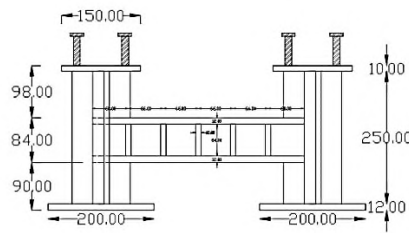


Figure 5. Connections between the webs of SP3.

The transverse connections are set at the end region and the mid-span position, as is shown in figure 6-8. The grade of the concrete used in this research is C50. The type of longitudinal steel and horizontal reinforcement steel used in the girder is R235. The type of steel used in corrugate webs is Q235. Studs are used to connect the steel webs and the concrete. The reinforcement of the model bridge and the fabrication of the corrugated steel web are shown in figure 9-10.

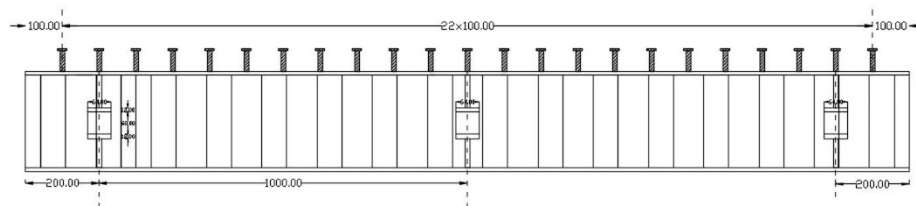


Figure 6. Elevation view of the beam connections of the girder with corrugated steel webs (mm).

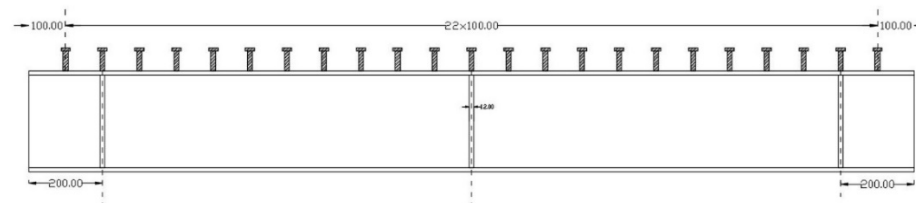


Figure 7. Elevation view of the truss connections of the girder with vertical steel webs (mm).

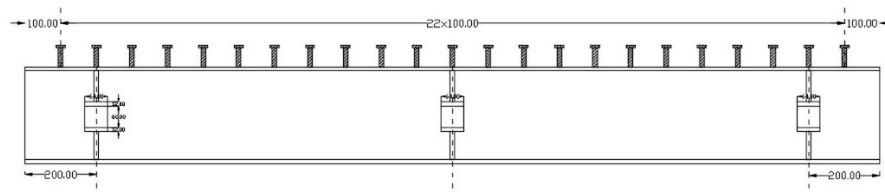


Figure 8. Elevation view of the beam connections of the girder with vertical steel webs (mm).

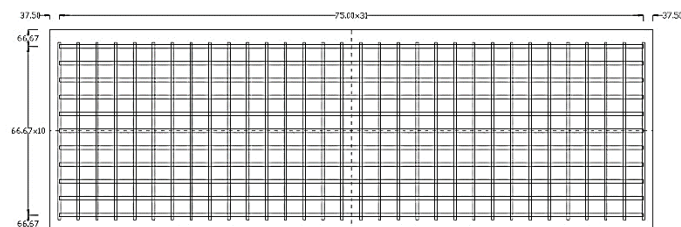


Figure 9. Top view of the reinforcement in the concrete plate.

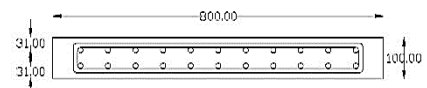


Figure 10. Side view of the reinforcement in the concrete plate.

2. Research Scheme of pure torsion performance of I-type steel-concrete composite bridge with double girders

2.1. Loading device of the research

The specimens are under pure torsion situation in this research. Eccentric loading is applied to the impose pure torque on the specimens. One end of the specimens is a fixed end and the other is a rotating end, which is rotated by the eccentric loading of the rotary hinge and the loading beam so that the specimens can be subjected to a pure torque load. The loaded arm of the torque is 1.35 m as shown in figure 11, and the eccentric load is applied by the hydraulic servo control jack.

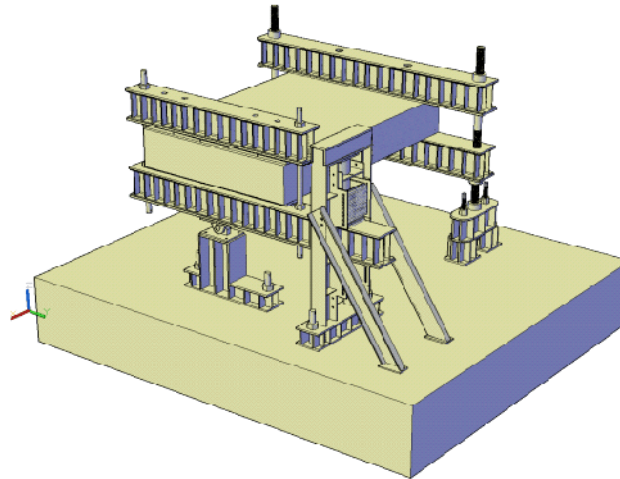


Figure 11. Loading equipment.

2.2. Research contents of the specimens and plant arrangement

The experimenting area of the research is shown in the picture below. The main contents of the experiment are the relative torsion angle of concrete flange and steel girder, the distribution and width of concrete crack in the area that is ± 0.75 m away from the middle.

The specific measurement scheme is shown in figure 12-13. The research data is collected automatically using IMP data acquisition system, and the collected data is directly saved into the computer, and is made into a text file. During the whole process of the experiment, the curve of load-inclination and load-midspan deflection of the specimen can be monitored on the monitor screen to observe and adjust the loading speed of the experiment.

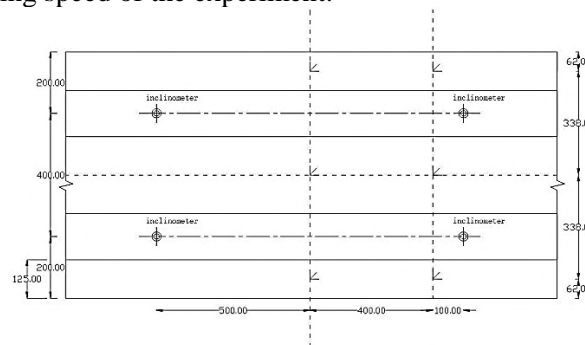


Figure 12. The strain gauges and inclinometers in the upper surface of the concrete flange.

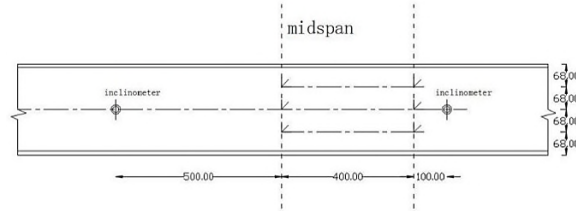


Figure 13. The strain gauges and inclinometers in the steel webs.

2.3. The loading process of the experiment

At the beginning of loading, 1.0kN is set as a segment, and graded loading is applied in order to observe and depict cracks and obtain the experimental data. When the applied torque is able to make

the first crack near the center of the concrete wing near the bearing happen, the cracking torque is recorded and the loading speed is slowed down to observe the degree of crack development. When penetrating cracks appear, the torque value is recorded and the change of the crack width is recorded. The loading continues until the value in the pressure sensor screen no longer increases, at this moment, the composite bridge has reached the torsion limit, and the limit torque is recorded. In the end, the loading is unloaded smoothly.

3. Results and analysis of the experiment

3.1. Failure characteristics of the composite bridges under pure torsion

The Experiment shows that the three specimens share similar damage patterns. The crack pattern of the pure torsion of composite girders is shown in figure 14-16. As can be clearly seen from the figure, almost every spiral crack goes through the entire concrete flange thoroughly, and the cracks are evenly distributed. Due to the restraint of the steel beam, the I-shape steel webs are still in the elastic stage when the concrete flange is damaged. The whole specimen can still bear some torque load. The development of the crack width is restricted and the reduction in bearing capacity is not obvious. By comparison, it is found that with the increase of stiffness of transverse connection, the number of diagonal cracks increases, and the width of cracks gets smaller.



Figure 14. The cracks on the side face of SP1.



Figure 15. The cracks on the end face of SP1.



Figure 16. The cracks on the top face of SP1.

Although there is a considerable torsion angle in the end, the torsional bearing capacity did not significantly decline. Due to the fact that these specimens are double-girder bridges, and are connected by different forms of transverse connections, the torsional bearing capacity of the concrete flange has been greatly improved. Compared with the single-girder bridge with same cross section, the ultimate torque resistance increases significantly. Finally, due to the emergence of one or several large-width cracks in the concrete flange, the whole composite specimen is damaged by torsion.

Comparing the final damage patterns of the double-girder specimens with different shapes of steel webs, the ultimate torsion angle and the ultimate torque of the corrugated-web specimen with small beam connections are larger than that of the vertical-web specimen with small beam connections. The torsional bearing capacity can be improved with the help of corrugated webs. But the corrugated webs cannot effectively restrict the deformation of the composite specimen. Comparing the final failure patterns of the double-girder vertical-web specimens with different transverse connections, it is found that the specimen with small beam connections has a small torsion angle, but a large ultimate torque.

Contrary to this, the specimen with truss connections has a large torsion angle, but a small ultimate torque. However, by comparing the torsion angle and the ultimate torque value of the two specimens, it is found that the difference between the specimens is minimal.

3.2. Main results of the experiment

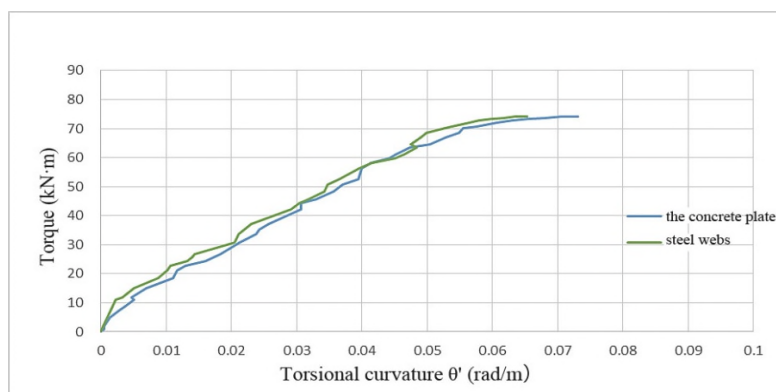
In table 1, T_{cr} represents the fracture torque of the specimen, which is characterized by the occurrence of the inclined crack in the concrete flange. T_u represents the ultimate torque of the specimen, which is characterized by the failure of applying higher forces. The θ'_{cr} and θ'_u respectively represents the ultimate torsional curvature and the cracking torsional curvature.

Table 1. Measured values of feature load and torsional curvature of the specimens under pure torsion.

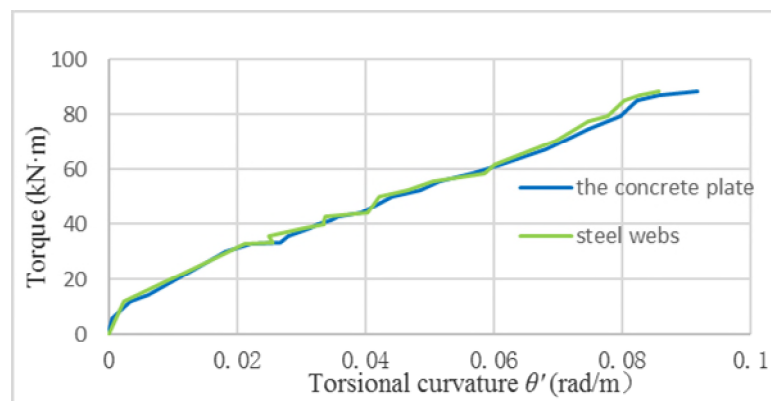
Specimens	SP1	SP2	SP3
T_{cr} (kN·m)	10.95	10.9	10.80
T_u (kN·m)	82.20	83.59	83.97
T_{cr} / T_u	0.133	0.130	0.129
θ'_{cr} (10^{-3} rad/m)	2.26	2.09	2.79
θ'_u (10^{-3} rad/m)	83.0	91.6	46.3
θ'_{cr} / θ'_u	2.72%	2.28%	6.03%

3.3. Analysis on torsional deformation

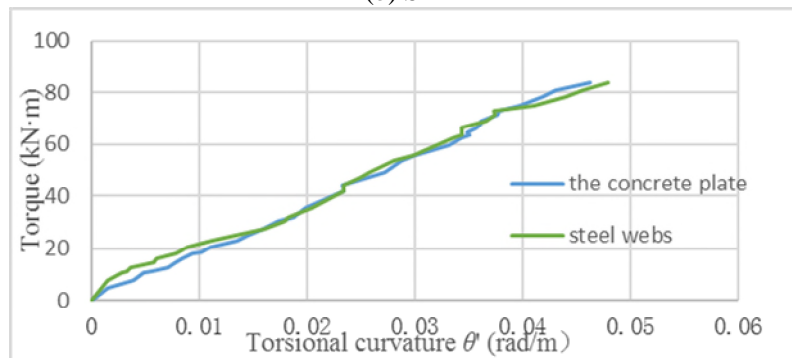
3.3.1. Relationship between the torsional deformation of concrete flange and the steel web. As can be seen from the relationship curve of $T-\theta'$ shown in figure 17, the torsion of steel webs and concrete flange is well coordinated and basically synchronized in the elastic stage. After the cracking torque is reached, the torsional curvature of steel webs and concrete flange begins to have dissimilarities. When the ultimate torque is reached, the torsional curvature of the concrete is larger than that of the steel webs, but the difference between them is not big. At the same time, it is considered that the loading device has a great effect on the concrete flange. During the loading process, there are no signs of destruction of connectors. And after the concrete is smashed, no signs of significant deformation of the pegs are found, so it can be assumed that in the entire process of torsion loading, the concrete flange and steel webs are well coordinated and basically synchronized.



(a) SP1



(b) SP2



(c) SP3

Figure 17. Relationship between torque and torsional curvature of concrete flange and steel webs.

This result provides a basis for the assumption in the torsional analysis that the torsional curvature of concrete flange and the steel web are equal in values. After the specimens are cracked, the torsional curvature of the concrete flange is slightly larger than that of the steel webs, and the difference rate between them is about 10%, which may be caused by the decrease of the torsional rigidity after the cracking of the concrete happens. So the torsional curvature of concrete flange can be adopted as the torsional curvature of the composite girder for safety purpose.

4. Conclusion

(1) In the entire process of the torsion loading, the concrete flange and steel webs are well coordinated and basically synchronized. This result provides a basis for the assumption in the torsional analysis that the torsional curvature of concrete flange and the steel web are equal in values. And the torsional curvature of concrete flange can be adopted as the torsional curvature of the composite girder for safety purpose.

(2) The effect of the shape of steel webs on the torsional resistance of composite girders is that the torsional bearing capacity can be improved by the usage of corrugated webs, but the influence of the usage of corrugated webs on constraint of deformation is not obvious.

(3) The effect of the forms of transverse connection between the double girders on the torsional resistance of composite girders is that the contribution of the small beams connections to the torsional stiffness of the composite girders is greater than that of the truss connections, and the ultimate torsion angle is smaller with small beam connections, but the improvement on torsional bearing capacity is not obvious.

References

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