Experimental Study on Static Mechanical Behavior of Steel-Concrete Joint Section of Hybrid Girder Cable-Stayed Bridge

Dali Zhang, Yuwen Bao, Jianhui Gao, Xiaozhen Li, and Lin xiao

***Abstract*—According to the structural characteristics of steel-concrete joint section of WuSu Bridge, a 1:3 reduced scale test model was designed to study the static mechanical behavior of the steel-concrete joint section. The test model is loaded according to the serviceability limit state and ultimate limit state separately, the stress of each members of the control sections of the test model is obtained. As shown in the results, the load from steel is smoothly delivered to concrete through the steel-concrete joint section, the stress values of the test model are generally less than the permissible value of the material given by the standard. The load-stress curve shows that the structural materials are in the elastic stage when being loading. All these show the steel-concrete joint section of WUSU Bridge has sufficient security reserve, the design of the steel-concrete joint section meets the security requirements.**

***Index Terms*—Hybrid girder cable-stayed bridge, steel-concrete joint section, model test, static mechanical behavior.**

I. Introduction

Hybrid girder is a structure composite combined concrete section with steel section through steel-concrete joint in the length direction. Hybrid girder is widely used in cable-stayed bridges for its good mechanical and economic performance [1-3]. Because of the diversity of structure form, as well as the lack of code specification [4-5], model test become one of the effective means to research steel-concrete composite joint [6]. Based on model test, the static behavior of WuSu Bridge’s steel-concrete composite joint is studied in this paper.

II. Experiment Scheme

A. Engineering Background

The WuSu Bridge is a hybrid girder cable-stayed bridge with one pylon and single cable plane, the span arrangement of the bridge is 140m+140m. The girder is consolidated with tower and pier. The main beam of the bridge is steel box beam with long cantilever while the beam at the tower root is made of concrete with two steel-concrete joint sections set up on both sides of main tower. Axial force, bending moment and torque from steel box beam are delivered to concrete beam through the bearing plate and the shear studs in steel-concrete joint section. The layout of the steel-concrete joint section of WuSu Bridge is shown in Fig. 1.

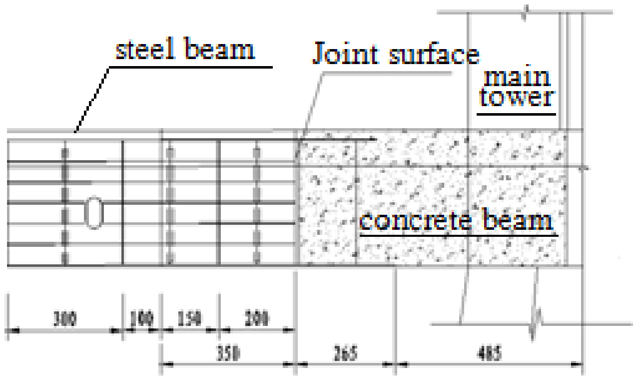

Fig. 1. Layout of the steel-concrete joint section of real bridge.

B. Design of Test Model

Considering the restrictions of loading equipment and model making, a 1:3 reduced scale test model of steel-concrete joint section was designed. The steel box beam and concrete beam are lengthened, because a sufficiently long arm of force is needed due to the moment loading requirement, and enough distance is required between studying position and loading position according to the Saint-Venant principle. Final dimension of test model is 1.1m in height, 0.916m in width; the test model is 8.368m in length with 4.668m in the length of steel box beam, 2.818m in the length of concrete beam and 0.882m in the length of steel-concrete joint section.

The materials of test model are as same as that of the real structure, the steel box beam is made of Q375qE steel, and the concrete beam is made of C55 concrete. Reinforcing steel type is HRB335 and the prestressed cable in the concrete beam used steel strand with the nominal diameter of 15.24mm. The similarity ratios of physical quantities of the test model are shown in Table I.

C. Loading and Testing Scheme

In order to study the stress distribution of the structure and

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to verify the structure safety, the model was loaded by 1.0 times and 1.7 times combined load respectively. The axial force was loaded by self-anchored prestressed steel strand, the bending moment and shear force was loaded by applying vertical force on the end of the cantilever beam, and the torque was loaded by applying a pair of equal and opposite forces on both sides of the steel beam. The loading scheme of the test model is shown in Fig. 2, the internal forces of working conditions are shown in Table II.

TABLE I: SIMILARITY RATIOS OF PHYSICAL QUANTITIES.

Geometric parameters	Similarity ratio
Section width	1：6
Section height	1：3
Model length	1：3
Section area	1：18
Section moment of inertia	1：162

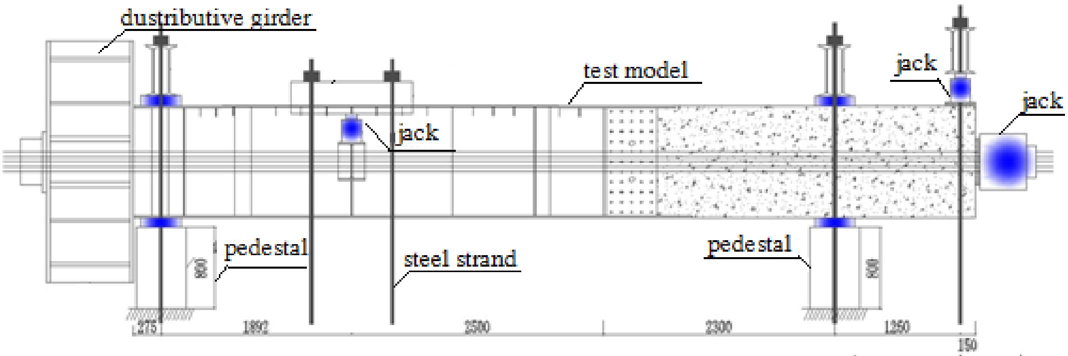


Fig. 2. Diagram of loading scheme.

TABLE II: INTERNAL FORCE OF TEST MODEL.

Load case	Axial force （kN）	Shear force （kN）	Bending moment（kN·m）	Torque (kN·m)
1.0 time axis force combined loads	4681	-240	-423	292
1.0 time negative bending moment combined	3389	-240	-435	292
1.7 times axis force combined loads	7957	-407	-719	497
1.7 times negative bending moment combined	5761	-407	-740	497

In order to know about the mechanical behavior of the steel-concrete joint section under the combined load, 10 representative sections are selected as testing sections, the position of testing sections are shown in Fig. 3. Layout of measuring points at testing sections is shown in Fig. 4.

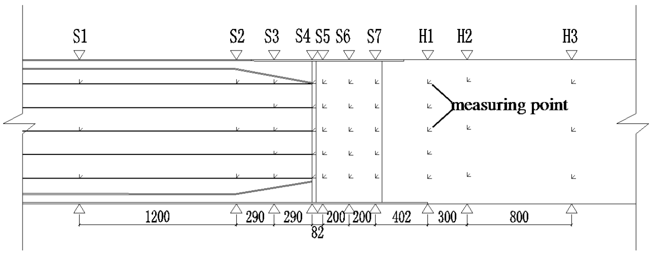


Fig. 3. Position of testing sections.

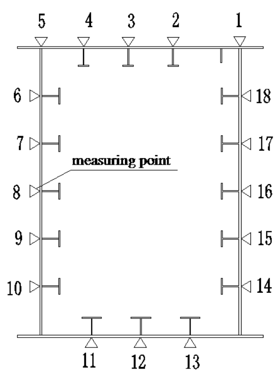


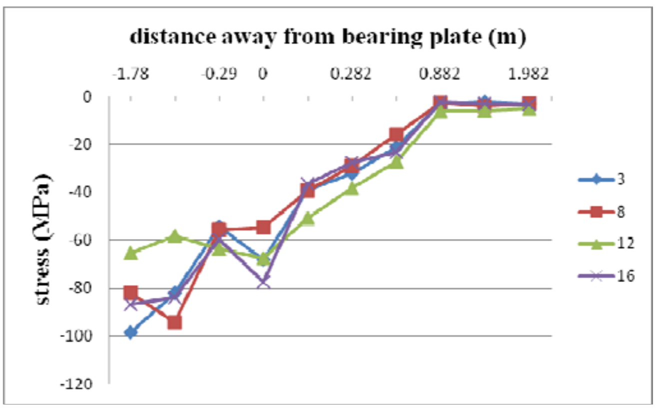
Fig. 4. Layout of measuring points at testing sections.

III. TESTING RESULTS AND ANALYSES

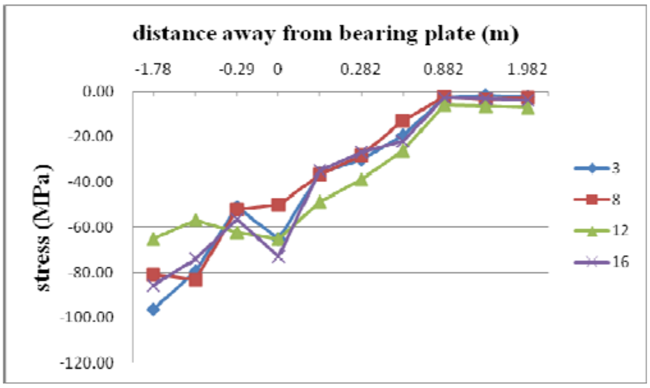
In describing of test results, origin of coordinate system is set as the spot of bearing plate and X-axis is set along the direction of bridge body, with positive direction towards the direction of concrete beam.

A. Analysis on Mechanical Behavior of Steel-Concrete Joint Section

In order to study the stress distribution of the structure under the combined loads, the test model was loaded by 1.0 time axial force combined loads and 1.0 time negative bending moment combined loads. The distribution of X-axis Stress on the structure is shown in Fig. 5.



(a) 1.0 time axial force combined loads



(b)1.0 time negative bending moment combined loads

Fig. 5. Distribution of x-axis stress on structure.

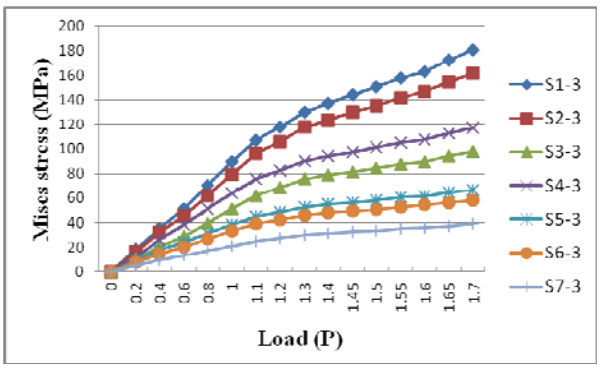
As shown in the results, the stress distribution of the structure shows a stepladder distribution. Stress in the standard segment of the steel box beam is comparatively high, and is reduced rapidly in the transition segment because of the increase cross-sectional area; There is a stress concentration phenomenon in the position of bearing plate, but it is not obvious; The stress level in the steel-concrete joint section decreases significantly, showing that the load from steel box beam has been delivered to concrete gradually; The load from steel is smoothly delivered to concrete through the transition segment of the steel beam and the steel-concrete joint section, so the stress in the concrete beam is very low.

B. *Analysis on Security of Steel-Concrete Joint Section*

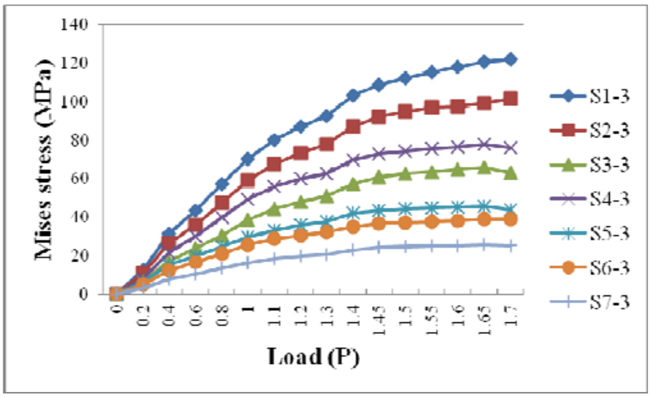
In order to study the security of the structure under the combined loads, the test model was loaded by 1.7 times axial force combined loads and 1.7 times negative bending moment combined loads. The maximum VonMises stress in the steel beam and the maximum principal stress in the concrete beam are shown in Table III. The load-VonMises stress curves of part of the measuring points are shown in Fig. 6.

TABLE III: MAXIMUM COMPOSITE STRESS ON TEST MODEL (MPA).

Load case	Steel box beam	Concrete beam	
	Mises stress	Principal stress	Principal tensile stress
1.7 times axial force combined loads	180.79	1.45	-13.64
1.7 times negative bending moment combined loads	124.16	1.98	-11.21



(a) 1.7 times axial force combined loads



(b)1.7 times negative bending moment combined loads

Fig. 6. Load-mises stress curve of measuring points.

Concrete crack and steel plate buckling was not observed during the test. As shown in the results, when the test model is loaded by 1.7 times axial force combined loads, the maximum VonMises stress in the steel beam is 180.79MPa, and the maximum principal tensile stress of the concrete beam is 1.45MPa while the maximum principal stress is -13.64MPa. When the test model is loaded by 1.7 times negative bending moment combined loads, the maximum VonMises stress in the steel beam is 123.46MPa and the maximum principal tensile stress of the concrete beam is 1.98MPa while the maximum principal stress is -11.21MPa. All the maximum composite stresses meet the requirements of standard. The stress of the measuring points presents a tendency of linear increase as the loads increase, showing that the structure is in elastic state when it was loaded by 1.7 times combined loads. All the analyses show that the steel-concrete joint section has a good performance in mechanical behavior, and the structure meets the security requirements.

IV. CONCLUSIONS

1) When the structure is loaded according to the serviceability limit state, the load from the steel is smoothly delivered to concrete through the transition segment and steel-concrete joint section. The stress decreases gradually during the test process, it indicates that the steel-concrete joint section of WuSu Bridge is reasonably designed.
2) When the structure is loaded according to the ultimate limit state the maximum VonMises stress in the steel box beam, the maximum principal tensile stress and the maximum principal stress meets the requirements of standard, it indicates the steel-concrete joint section of WuSu Bridge meets the reliability requirements.
3) When the structure is loaded according to the ultimate limit state the stress of the steel beam presents a tendency of linear increase as the loads increase, indicating that the structure is in elastic state and the design of the steel-concrete joint section of WuSu Bridge meets the security requirements.

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