Analysis on steel-concrete joint section of hybrid girder cable-stayed bridge

Junfeng Guo 1,*

1Wuhan municipal engineering research and design institute CO.LTD, Wuhan, China

*Corresponding author e-mail: 429761683@qq.com

Abstract. Hybrid girder cable-stayed bridge has some advantages, such as structure mechanism performance and the low cost. In China, more and more cable-stayed bridge with hybrid girder appeared. The steel–concrete joint part is one of the key structures of large span cable-stayed bridge with hybrid girder, the static bearing capacity and fatigue performance of steel–concrete joint part structure is directly related to security and durability of the bridge. Through the finite element simulation calculation, the stress distribution is calculated, and the stress distribution of the steel structure top plate, steel structure baseplate, concrete top plate and concrete baseplate is analysed emphatically. Verify the bearing capacity and safety of the structural design of joint section.

1. Introduction

Steel-concrete joint section is an important component of hybrid girder cable-stayed bridge. There are two main reasons: the stiffness of steel beam and concrete beam is different, and the stiffness of the joint section between them should be smooth transition to avoid stress concentration due to sudden change of stiffness, so as to ensure structural safety, stability, durability and driving comfort; the main girder of cable-stayed bridge is under the great axial force due to the role of cable-stayed cable, the great axial force in steel and concrete beams must be transmitted through the joint section.

Its structure is complex and its stress distribution is extremely uneven. Researchers at home and abroad have studied the mechanical characteristics of the joint section of hybrid girder cable-stayed bridge from two aspects of theoretical calculation [1, 2, 3] and model test [4, 5, 6, 7].

Due to the steel–concrete joint part is particularity [8, 9] and complexity structure [10, 11, 12], despite a lot of research on the steel–concrete joint part, the mechanism performance [13], fatigue performance [14, 15], etc., need to be researched.

In this paper, the basic form, mechanical characteristics and reasonable structure of the joint section of the hybrid girder cable-stayed bridge are studied by finite element calculation, and the bearing capacity and safety of the structural design of the joint section of Wanzhou Third Bridge are verified.

2. Project profile

The longitudinal and cross sections of the steel-concrete joint section are shown in Figures 1 and 2 respectively.

3. Numerical analysis

Because of the complicated structure of the joint section, according to the composition of the structure and the distance from the steel-concrete interface, the four sections of the steel-concrete joint are
divided, which are the steel beam nearby the interface (0-3.15 m away from the bearing plate, negative near the concrete end, positive near the steel beam end, the same below), the transition section steel beam (3.15-8.85 m away from the compressive plate), the concrete beam nearby the interface (-2.5 to 0 m away from the bearing slab) and the transition section concrete beam (-8.75 to -2.5 m away from the bearing slab). The stress analysis of and were carried out respectively.

3.1. Stress analysis of the steel beam nearby the interface
According to the load combination of the steel-concrete interface, the stress results of the steel beam nearby the interface (0-3.15 m away from the bearing plate) are calculated.

Under the maximum axial force combination condition, the stress distribution of the steel beam nearby the interface is shown in Figure 3.

The calculation results show that, the steel beam nearby the interface under the maximum axial force:
(1) The von Mises stresses in most parts of the steel beam nearby the interface (0-3.15 m away from the bearing plate) are between 0-100 MPa. But the stresses of the joint between the stiffening rib and bearing plate, steel beam baseplate in the steel-concrete joint and the joint between the stiffener and the bearing plate are larger, the maximum value is 185.027 MPa, not more than 200 MPa.

(2) The principal compressive stress is between 0 and 97.5 MPa, the maximum value is 183.668 MPa, and the greater stress is occurred in the local areas, such as steel beam baseplate in the steel-concrete joint and the joint between the stiffener and the bearing plate. Because of the negative bending moment, the compressive stress of the top plate is obviously smaller than that of the baseplate, basically in 0-30 MPa.

(3) The principal tensile stress is basically within 30 MPa, and only the point-like stress concentration appears at the joint between the steel beam web and the bearing plate, but the area is very small.

(4) The shear stress level of the structure is not high because the shear force of this area is small, and it is less than 20 MPa.

Generally speaking, under the maximum axial load, the interface its vicinity steel beams are under compression, and the stress is basically less than 100 MPa.

3.2. Stress analysis of the transition section steel beam
Because the steel beam in the steel-concrete interface is usually stiff, the stress is generally smaller than the adjacent beam section, and the larger stress is often occurred in the transition beam section near the interface. According to the maximum axial force, the maximum bending moment and the maximum shear force in the ultimate bearing capacity state, the stress state of the transition section of steel beam 3.15-8.85 m away from the compressive plate, is calculated and analyzed. The stress distribution in the transition section steel beam under the combined maximum axial force is shown in Figure 4.

![Figure 4. The stress distribution of the transition section steel beam.](image)

The calculation results show that under the condition of maximum axial force:

(1) The von Mises stress is between 0 and 150 MPa in most area of the transition section steel beam. The greater stress is occurred in the U-rib top of the top plate far away from the bearing plate.

(2) The principal compressive stress is basically between 0 and 150 MPa, and the greater stress is occurred in the U-rib top of the baseplate far from the bearing plate.

(3) The principal tensile stress is basically less than 30 MPa, and the greater stress is occurred in the discontinuous position between the U-rib and the stiffening rib of the baseplate.
(4) The shear stress of the transition section steel beam is basically less than 10 MPa, and the greater stress is occurred in the discontinuous position between the U-rib and the stiffening rib of the baseplate.

Generally speaking, the transition section steel beam under the combined action of the maximum axial load basically assumes a compressive state, and the tensile and compressive stress is within 150 MPa. The von Mises stress of steel beam decreases gradually from normal steel beam section, transition section steel beam to bearing plate.

3.3. Stress analysis of the concrete beam nearby the interface

According to the load combination of the interface, the stress of the concrete beam nearby the interface (-2.5 to 0 m away from the bearing slab) are calculated.

Under the maximum axial force combination, the stress distribution in the concrete beam nearby the interface is shown in Figure 5.

Figure 5. The stress distribution of the concrete beam nearby the interface

The calculation results show that under the condition of maximum axial force:

(1) The principal compressive stress of the concrete beam nearby the interface is between -14 MPa and 0 MPa, and the greater stress is occurred in the joint of concrete beam and the bearing plate and the concrete section varied position. The large tensile stress occurs around the hole in the side of transverse diaphragm in the interface. The stress is mostly less than 1 MPa. In addition, the principal compressive stress is larger near the local area around the hole in the side of transverse diaphragm.

(2) The principal tensile stress of top plate and baseplate in most parts of the concrete beam nearby the interface is between -1.5 and 1.5 MPa, but in a large area around the hole of transverse diaphragm in the interface, the stress range is between 2 and 8 MPa.

(3) Longitudinal stress of concrete beam is between -14.0 MPa and 1.4 MPa, and the tensile stress region mainly appears in the larger area around the hole of the transverse diaphragm. Because of the negative bending moment, the top plate compressive stress is relatively small, between -8 MPa and -6 MPa, and the baseplate compressive stress is relatively large, between -14 MPa and -10 MPa.
(4) The shear stress level of the concrete beam nearby the interface is between -2 MPa and 2 MPa, and the larger stress area is occurred in the local area around the hole of the transverse diaphragm.

Generally speaking, under the maximum axial force condition, the concrete beam nearby the interface is basically in the compressive state, but the tension stresses appears around the hole of the transverse diaphragm.

3.4. stress analysis of the transition section concrete beam

According to the load combination of the interface, the stress of the transition section concrete beam (-8.75 to -2.5 m away from the bearing slab) under maximum axial force, maximum shear force and maximum bending moment conditions are calculated.

Under the maximum axial force combination, the stress distribution of the transition section concrete beam is shown in Figure 6.

![Figure 6. The stress distribution of the transition section concrete beam.](image)

The calculation results show that under the condition of maximum axial force:

1. The principal compressive stress of the transition section concrete beam is between -20 MPa and 0 MPa, and the maximum stress is occurred in the thinnest section of the baseplate.
2. The principal tensile stress of most parts of baseplate and top plate is between -1.5 MPa and 1.5 MPa, and the stress of diaphragm is larger, and the stress range is between 1.5 and 3.5 MPa.
3. The longitudinal stress of the concrete beam is between -14 and 0 MPa, and the maximum stress is occurred in the thinnest section of the baseplate.
4. The shear stress level of the transition section concrete beam is between -2 MPa and 2 MPa, and the larger stress area is located in the local area where the anchorage section connects with the transverse diaphragm.

Generally speaking, under the condition of maximum axial force, the transition section concrete beam is basically in compressive state, the stress in the diaphragm is larger, and the principal tensile stress in the local area is larger.

4. Conclusion

Through the finite element simulation calculation, the stress distribution of the joint section is calculated, and the stress distribution of the steel structure top plate, steel structure baseplate, concrete top plate and concrete baseplate is analyses emphatically.

In all, under the condition of the most unfavorable load, the steel beam nearby the interface, the transition section steel beam, the concrete beam nearby the interface and the transition section concrete beam are basically in compressive state, the stress in the diaphragm is larger, and the principal tensile stress in the local area is larger. The stress of the joint section is smaller than the material allowable value, and the strength of the joint section meets the requirements.
References

[1] Glib Vatulia, Maryna Rezunenko, Dmytro Petrenko, Sergii Rezunenko. Evaluation of the Carrying Capacity of Rectangular Steel-Concrete Columns [J]. Civil and Environmental Engineering, 2018.01: 76-83.

[2] Lowe D, Das R, Clifton C. Characterization of the splitting behavior of steel-concrete composite beams with shear stud connection [J]. Procedia Materials Science, 2014, 3: 2174-2179.

[3] Qureshi J, Lam D, Ye J. The influence of profiled sheeting thickness and shear connector’s position on strength and ductility of headed shear connector [J]. Engineering Structures, 2011, 33 (5): 1643-1656.

[4] Pavlović M, Marković Z, Veljković M, et al. Bolted shear connectors vs. headed studs behaviour in push-out tests [J]. Journal of Constructional Steel Research. 2013, 88: 134-149.

[5] Bartosz Grzeszykowski, Magdalena Szadkowska, Elżbieta Szmitowska. Analysis of Stress in Steel and Concrete in Cfst Push-Out Test Samples [J]. Civil and Environmental Engineering Reports, 2017.03: 145-159.

[6] Fei Yang, Yuqing Liu, Zhibo Jiang, Haohui Xin. Shear performance of a novel demountable steel-concrete bolted connector under static push-out tests [J]. Engineering Structures, 2018.01: 133-146.

[7] Qinghua Han, Yihong Wang, Jie Xu, Ying Xing, Guang Yang. Numerical analysis on shear stud push-in test with crumb rubber concrete [J]. Journal of Constructional Steel Research, 2016.12: 148-158.

[8] Guilherme Alencar, Abilio M.P. de Jesus, Rui A.B. Calçada, José Guilherme S. da Silva. Fatigue life evaluation of a composite steel-concrete roadway bridge through the hot-spot stress method considering progressive pavement deterioration [J]. Engineering Structures, 2018.02: 46-61.

[9] Shao Hua He, Aymen S. Mosallam, Zhi Fang, Chao Zou, Wenzheng Feng, Jie Su. Experimental study on CFSC encased shear connectors in steel-concrete composite joints with UHPC grout [J]. Construction and Building Materials, 2018.04: 638-649.

[10] Jianwen Zhong, Yuande Zhou, Qichang Bao, Enzhi Wang, Qingbin Li. Strengthening mechanism of channel steel plate for notched concrete beams against fracture: Test and numerical study [J]. Engineering Fracture Mechanics, 2017.05: 132-147.

[11] Abdolreza Ataei, Mark A. Bradford, Hamid R. Valipour. Finite element analysis of HSS semi-rigid composite joints with precast concrete slabs and demountable bolted shear connectors [J]. Finite Elements in Analysis & Design, 2016.08: 16-38.

[12] Claudio Amadio, Chiara Bedon, Marco Fasan, Maria Rosa Pecce. Refined numerical modelling for the structural assessment of steel-concrete composite beam-to-column joints under seismic loads [J]. Engineering Structures, 2017.02: 394-409.

[13] Huang Z, Burgess I W, Plank R J. The influence of shear connectors on the behaviour of composite steel-framed buildings in fire[J]. Journal of Constructional Steel Research, 1999, 51 (3): 219-237.

[14] OKUBO Nobuhito, KURITA Akimitsu, KOMATSU Keichi, NAKAJIMA Seika. Analytical study on mechanical characteristics of steel-concrete composite girder with grouped stud shear connectors[J]. Kou kouzou rombunshuu, 2002, 9 (34): 67-75.

[15] Okamoto Y, Nakamura S. Static and seismic studies on steel-concrete hybrid towers for multi-span cable-stayed bridges [J]. Journal of Constructional Steel Research, 2010, 58 (8) : 203-210.