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Numerical analysis of steel-concrete joint section shear transfer behavior

Jinzhi Wang 1,*, Junfeng Guo 2 and Xiaomin Mao 1

1 school of civil Engineering and Architectural, Wuhan University of Bioengineering Wuhan, China
2 Wuhan municipal engineering research and design institute CO.LTD, Wuhan, China

*Corresponding author e-mail: jinzhiwang2005@163.com

Abstract. The location, structural form, thickness and geometric dimensions of steel-concrete joint section and its shear connector form, shear connector layout are not the same, the mechanical properties of the joint section are not uniform. It is necessary to calculate and analyze the mechanical properties of the joint section. the part finite element simulation model joint section is established, considering most unfavorable load combination condition, mainly analyzed the steel section, the steel transition section, the concrete section and the concrete transition section. It is obtained that stress distribution, deformation trend, and larger stress value position, the stress horizontal, vertical and vertical distribution quantitatively in each maximum inner force working condition so as to offer reference for design and construction departments.

1. Introduction
Shear connectors were used in steel-concrete composite beams earlier, mostly in steel-concrete composite beams [1] with shear connectors, as well as in steel-concrete composite arch structures or other structural components [2, 3]. The composite structure of shear stud group is also widely used in various structures [4, 5], especially in recent years, innovatively used in some new structures [6]. Shear connectors are not only used in hybrid girder cable-stayed bridges, but also in steel-concrete composite girder bridges [7, 8], steel-concrete composite decks and steel-concrete composite arch bridges [9]. Shear connectors are important components in steel-concrete composite structures [10, 11]. The effect of shear connectors will be affected by the layout and geometric dimensions of shear connectors, the selection of material and other factors [12, 13]. It is particularly important to calculate the shear strength and stiffness of shear connectors.

2. Steel-concrete joint section structure
The section is made of partially filled concrete and back bearing plate. In order to make the steel beam and concrete beam transmit the force better, 120 mm thick compression plate is set on the steel-concrete interface to realize the axial force transmission. The inner and outer webs and the bearing plate diaphragm are welded by penetration welding, and the longitudinal ribs and the bearing plate diaphragm are polished and then welded. The U-shaped stiffening ribs of the steel box girder are adjusted to the plate-type closed box stiffening ribs near the joint section, and the grouting concrete is filled in the closed cavity of the plate-type stiffening ribs after the prestressed tendons are tensioned. Considering the structure of concrete box girder, in order to facilitate more direct and smooth force...
transfer between steel girder and concrete beam, four internal webs are added to the steel box girder, the thickness of the internal webs is 30 mm, the distance from the bridge center line is 1.95, 7.8 m, the internal webs are stiffened by plate stiffeners with the area of 360 mm x 32 mm on both sides.

Steel beams and concrete beams are connected by shear studs. The top and bottom slabs of steel beams extend into the concrete side 0.81 m, and the steel plate is outside the concrete beam. In order to prevent the relative slip between the steel plate and the concrete beam, a shear stud is arranged in the range, the longitudinal spacing of the shear studs is 220 mm. The bearing plate is connected with the concrete beam by a shear nail on the concrete side in order to vertical shear transfer. The shear nails are made of cylinder head shear nails of 22 mm in diameter and 200 mm in length. The material is ML15, the transverse spacing is 200 mm, and the vertical spacing is 220 mm.

3. Steel-concrete joint section numerical calculation model

3.1. Material parameters
The section is simulated by the finite element software Midas FEA. It has many load-bearing members and complicated load-transferring path. If the actual stress characteristics are strictly simulated, the constitutive model including rigid shell, shear nail, concrete beam and bond friction-slip relationship is established, the finite element model will be too large and complex. The calculation results are complex, the main contradiction is not outstanding, and the calculation results are difficult to be applied. Therefore, in the analysis of steel-concrete joint section, the shear studs are replaced by the equivalent elastic connection, concrete box girder and steel box girder are simulated by solid element, and prestressed strand is simulated by steel element.

3.2. Selection of joint section length
According to Saint Venant's principle, in order to ensure the accuracy of local analysis of steel-concrete joint section, the position of load and boundary conditions should be as far away from the joint as possible. Therefore, the length of finite element model of steel-concrete joint section should be large enough.

Generally speaking, when the length is chosen, the distance between the truncation points on each side and the interface is 1.5-2 times higher than the height or width of the main beam. At the same time, the corresponding position of the steel-concrete joint section in the overall structure should be considered as far as possible to facilitate the extraction of the load at both ends of the local analysis.

According to the design data of the bridge, considering the structural characteristics of concrete beams and the segmental division of steel beams, the length of the combined segment is concrete beam 34.25 m and steel beam 27.45 m. The model diagrams of joint section are shown in Figure 1. The grid diagram of joint section is shown in Figure 2.
3.3. Determination of joint section boundary condition

In the joint section analysis model, the boundary conditions are consistent with the structural constraints of the whole bridge. Consolidation constraints are imposed on the main girder at the pylon, while symmetrical constraints are imposed on the symmetrical plane of the central line of the bridge.

3.4. Determination of joint section load

The maximum axial force, maximum shear force, maximum bending moment and maximum torque of six load combinations in each limit state are considered respectively. The vertical displacement value of the joint section under the maximum axial force is shown in Figure 3.

4. Numerical analysis of steel and concrete joint section

4.1. Stress distribution of the steel-concrete interface and steel beam nearby under maximum internal force condition

According to the calculation, the stress of the steel-concrete interface and steel beam nearby is the largest under the maximum axial force condition. Therefore, the transverse, longitudinal and vertical stress distribution characteristics of the steel beam under this condition are analyzed. The transverse distribution of the section longitudinal stress 0.12 m, 1.625 m and 3.15 m away from the steel-concrete interface are shown in Figure 4. The vertical stress distribution of steel webs at 1.95 m away from the central line of the bridge is shown in Figure 5. Longitudinal distributions of longitudinal stress of the top plate and baseplate at the sections of 0 m, 4.88 m and 11.2 m away from the center line of the bridge are respectively shown in Figures 6 and 7.
From Fig. 4 to Fig. 7, it can be seen that the stress of steel beam top plate in the steel-concrete interface varies greatly in transverse direction. The maximum is occurred near the center line of longitudinal bridge, and decreases gradually from the center line to the side box girder, forming a more obvious negative shear lag effect. The stress vertical distribution of steel web is basically transitional from the stress at the top of web to the stress at the bottom of web, there is no stress concentration on the steel webs. The top plate stress varies slightly along the longitudinal direction.
The farther away from the bridge center line, the smaller the height of the top plate due to the bridge transverse slope, under the combined action of axial force and bending moment, the longitudinal stress of the top plate decreases. The stress of the baseplate decreases gradually along the longitudinal direction, the farther away from the steel-concrete interface, the greater the bending moment at the section, the more uniform the stress change of the baseplate, there is no stress concentration on the baseplate.

Overall, the transverse, vertical and longitudinal stress in the steel-concrete interface transfer is normal, and there is no stress concentration, so the steel beams have good application effect.

4.2. Stress distribution of concrete beam in the steel-concrete interface under maximum internal force condition

According to analysis and calculation, the stress of concrete beam in the steel-concrete interface is the largest under the maximum axial force. Therefore, the stress distribution characteristics of concrete beam under this condition is analyzed. Longitudinal stress transverse distribution of the top plate in the sections 0 m, 1.25 m 2.5 m away from the steel-concrete interface is shown in Figure 8.

![Figure 8. Longitudinal stress transverse distribution of the top plate.](image)

It can be seen from Fig. 14 that the stress of concrete beam top plate decreases gradually from the middle line to the flange plate, and the stresses at the section 0 m and -2.5 m away from the steel-concrete interface tend to be consistent, but the fluctuation is large, mainly because the two ends are bearing plate and variable section concrete section, there is a certain stress concentration phenomenon. The stress distribution of the section -1.25 m away from the steel-concrete interface is relatively uniform, and only slightly decreases in the position of the flange plate.

Through the stress analysis, the stress magnitude and distribution of the concrete and steel structure can be obtained. There is a bond between the steel plate and the concrete interface. At the same time, the concrete under the steel plate and the bearing plate will expand due to the action of compressive stress and prestress. The bearing plate set on the steel-concrete interface is in close contact with concrete end section, while the steel plate is in close contact with concrete interface, so that the concrete and the steel structure can be formed as a whole more easily.

5. Conclusion

Through numerical analysis, the simulation analysis model of the steel-concrete joint section is established, and the stress analysis of the steel beam nearby the steel-concrete interface, the transition section steel beam, the concrete beam nearby steel-concrete interface and the transition section concrete beam under the most unfavorable load combination is analyzed. The following conclusions are obtained.

The structure and stress of the steel-concrete joint section is complex, the finite element analysis of the joint must be carried out to get the stress distribution in the joint quantitatively, which provides the basis for the design and construction.

Three-dimensional solid modeling was carried out, and the stress was calculated and analyzed under various operating conditions. The results show that the steel beam nearby the steel-concrete interface and the transition section steel beam are basically in compressive state under the most unfavorable load conditions, and the compressive stress is less than the allowable stress of Q345qD steel. The concrete beam is basically in compressive state under the conditions of maximum axial
force, maximum shear force, maximum bending moment and maximum torque under the most unfavorable load, and the compressive stress is small. Under the combined load of various working conditions, the relative deformation between the steel and concrete beam section in the steel-concrete interface is small and smooth, and the joint section has sufficient stiffness and smooth transition.

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