Research on Force Design of Concrete Filled Steel Tube Structure with Open Hole and Stiffener

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Abstract: The built-in open-hole type stiffened rectangular steel tube concrete refers to a new combined structure formed by forming an open-hole steel plate in the longitudinal direction of the inner wall of the steel pipe and then filling the concrete. In order to study the function of the built-in open-hole stiffened joints, the design of the stiffened rectangular steel tube concrete was designed to analyze the influence of the mechanical properties of the steel-mixed interface. The results show that the vertical rib opening is formed, and the bearing capacity of the rectangular steel tube concrete interface is increased by 2.06 times under the limit state. The shear stiffness and shear capacity of the interface are improved by more than 4 times under normal use.

1. Introduction
The concrete-filled steel tubular structure has been widely used in long-span bridges, urban overpasses, subways and high-rise buildings due to its high bearing capacity, good plasticity and ductility, convenient construction and good fire resistance. It has achieved good economic and social benefits. China has built more than 300 concrete-filled steel tubular arch bridges. In order to study the mechanical properties of interface bond-slip of rectangular concrete filled steel tubes, experts and scholars such as Zhao Hongtie⁰, Liu Yongjian⁰, Morishita⁰ carried out push-out tests of rectangular concrete filled steel tubes, and obtained the constitutive relationship of steel-concrete interface bond-slip. For shear mechanical properties of built-in open-hole shear connectors in steel-mixed composite beams, Nie Jianguo⁰, Li Qiao⁰, Qiang Shizhong⁰, Hu Jianhua⁰ Experts and scholars have carried out a large number of launching experiments with built-in open-hole shear connectors. The construction requirements and design methods of Open type shear connectors are proposed without considering the influence of the thickness of the perforated steel plate and the adhesion of the steel-mixed interface.

2. Experimental study
In this paper, the launching test of the open-hole stiffened rectangular steel tube concrete is carried out. The design of a ribless rectangular steel tube concrete is designed based on whether the stiffeners, the stiffeners are opened, the opening pitch and the opening diameter are changed. Column test piece, a rectangular steel tube short column test piece with longitudinal ribs without opening steel plate and 10 PBL stiffened rectangular steel tube concrete short column test pieces to reveal the interface of the new combined structure of PBL stiffened rectangular steel tube concrete Mechanical properties.
2.1. experimental design

In this paper, the test pieces of the rectangular steel tube concrete test are divided into three categories: SC, LSC and PSC. Among them, the SC type refers to the ribless rectangular steel tube concrete, the LSC type refers to the rectangular steel tube concrete with the non-perforated steel plate stiffeners, and the PSC type refers to the rectangular steel tube concrete with the PBL stiffeners. In this paper, four sets of 12 openable-type stiffened rectangular steel tube concrete specimens were designed according to whether the stiffeners, the stiffeners are open, the apertures, the apertures and the coarse aggregate size are changed. See figure 1.

![Figure 1. Test piece construction](image)

(a) Specimen SC1  (b) Specimen LSC1  
(c) Specimen PSC (1-6)  (d) Specimen PSC (7-8)  (e) PSC (9-10)

The test piece SC1, the test piece LSC1 and the test piece PSC1 are used for comparative analysis of the interfacial adhesion properties of ordinary rectangular steel tube concrete, rectangular steel tube concrete without open-hole stiffeners and rectangular steel tube concrete with PBL stiffening. The test pieces PSC (1-2), PSC (3-4), and PSC (5-6) are PBL stiffened rectangular steel tube concrete members with coarse aggregate sizes of 5-15 mm, 5-20 mm, and 5-25 mm, respectively. The test specimens were used to compare and analyze the influence of different coarse aggregate sizes in concrete on the mechanical properties of PBL stiffened rectangular steel tube interface. The specimens PSC (1-2) and PSC (7-8) were used to compare and analyze the influence of the diameter of the opening on the shear bond strength of the rectangular steel tube concrete interface. The number of openings in the stiffeners of the single-opening steel plate of test piece LSC1, test piece PSC (1-2) and test piece PSC (9-10) are 0, 5 and 7 respectively, and the corresponding plate opening spacing is for none, 95mm and 130mm, the test piece was used to compare and analyze the influence of the number of openings of a single steel plate on the mechanical properties of the interface.

2.2. Material properties

Before the concrete strength loading test, the pre-stress test of the test block is carried out. During the loading process, the bearing surface is perpendicular to the top surface during molding, and the test machine and the test block are under pressure on the premise that the test block center is aligned with the center of the test machine pressure plate. Full contact. The standard value fc of the compressive strength of the concrete test block for each test piece is shown in Table 2. According to the experimental results, the ultimate compressive strength values of the test blocks were obtained, thereby converting the concrete axial compressive strength and elastic modulus [119], and the Ec was $2.83 \times 10^4$ MPa. The mechanical properties of the tested steel were: yield strength fy of 350 MPa, elastic modulus Es of $2.06 \times 105$ MPa, Poisson's ratio vs of 0.27.
2.3. loading method and measuring point arrangement

The transfer process of the load in the test is: launching the loaded steel block on the concrete surface of the test piece to transfer the load to the top surface of the concrete inside the pipe. The concrete top surface of the pipe transfers the load to the concrete concrete in the hole, and is transmitted to the stiffener through the action of the concrete concrete. The ribs are finally passed to the steel pipe. With the increase of load, the concrete in the hole of the perforated steel plate is crushed or sheared under the action of high stress, so that the relative slip between the core concrete and the steel pipe wall occurs, and the slip amount increases continuously until the test piece is destroyed. The loading of the launch test is shown in Figure 2.

![Figure 2. Shows the experimental force model](image)

3. results analysis

3.1. Whether the effect of stiffeners is set

In order to analyze the influence of longitudinal stiffeners on the bond behavior of rectangular steel tube concrete interface, the load-slip curve relationship between test piece SC1 and test piece LSC1 was extracted, as shown in Fig. 3. Table 1 lists the bearing capacity and shear stiffness test values for both. Referring to Fig. 3 and Table 1, it can be seen that the longitudinal rib or not, the bond slip of the rectangular steel tube concrete interface is basically the same as the load change; the ultimate displacement value of the longitudinal rib rectangular steel tube concrete interface is slightly larger than the rectangular steel tube concrete; The shear capacity and shear stiffness of the ribbed rectangular steel tube concrete are less improved than those of the ribbed rectangular steel tube concrete. After the longitudinal ribs are set in the rectangular steel tube concrete, the ultimate bearing capacity is increased by 2.6 times, and the shear resistance under normal use conditions is improved. The bearing capacity and shear stiffness are increased by 2.3 times.

![Figure 3. Comparison of load-relative slip curves with or without stiffening](image)

| Test piece number | Whether there is any stiffening | State bearing capacity /kN | Shear stiffness /kN/mm | Ultimate bearing capacity/kN |
|------------------|-------------------------------|--------------------------|------------------------|----------------------------|
| SC1              | yes                           | 40                       | 200                    | 228                        |
| LSC1             | no                            | 131                      | 655                    | 819                        |

Table1. Is the test result of the introduction of rectangular steel tube concrete without stiffening steel plate
3.2. Whether the stiffener has the effect of opening

In order to analyze the influence of the stiffener rib opening on the bearing capacity performance, the load-slip curve of the test piece LSC1 and the test piece PSC (1-2) was extracted, as shown in Fig. 4. Table 2 lists the bearing capacity and shear stiffness test values for both. It can be seen from Fig. 4 and Table 2 that the longitudinal rib opening or not, the variation of the bond slip amount of the rectangular steel tube concrete interface with the load varies; the longitudinal rib rectangular steel tube concrete after the ultimate load is reached, the load is slippery. The amount of shift increases and gradually decreases. After the ultimate load is reached, the load slip of the rectangular steel tube concrete remains basically unchanged. The rectangular steel tube concrete with open-hole longitudinal ribs has a great improvement on the shear capacity and shear stiffness of the rectangular steel tube concrete with non-opening longitudinal ribs. The ultimate bearing capacity of the ribbed rectangular steel tube longitudinal ribs is improved. 2.06 times, the shear capacity and shear stiffness increased by 4.56 times under normal use.

Table 2. Test results of whether the stiffened steel plate is open

| Test piece number | Whether there is any stiffening | State bearing capacity/kN | Shear stiffness/kN/mm | Ultimate bearing capacity/kN |
|-------------------|--------------------------------|---------------------------|----------------------|----------------------------|
| LSC1              | no                             | 131                       | 655                  | 819                        |
| PSC1              | yes                            | 724                       | 3487                 | 2512                       |
| PSC2              | yes                            | 678                       | 3390                 | 2525                       |

3.3. Influence of open hole diameter

In order to analyze the influence of the aperture diameter on the bearing capacity performance, the load-slip curves of the test piece PSC (1-2) and the test piece PSC (7-8) were extracted, as shown in Fig. 5. Table 3 lists the bearing capacity and shear stiffness test values for both. Referring to Fig. 5 and Table 3, the test piece is pushed out vertically. With the increase of the aperture of the opening, the ultimate load of the open-hole type stiffened rectangular steel tube concrete specimen is larger, and the corresponding limit slip value is smaller. The aperture of the opening is increased from 35mm to 45mm, the bearing capacity and shear stiffness of the component are increased by 25.2%, and the ultimate bearing capacity is increased by 16.4%.

Figure 4. Vertical ribs whether the opening is compared

Figure 5. different opening diameter comparison
Table 3. Test results of pore diameter change

| Test piece number | Whether there is any stiffening/mm | State bearing capacity/kN | Shear stiffness/kN/mm | Ultimate bearing capacity/kN |
|-------------------|-----------------------------------|--------------------------|----------------------|----------------------------|
| PSC(1-2)          | 35                                | 724                      | 3487                 | 2512                       |
| PSC(7-8)          | 45                                | 907                      | 4537                 | 2924                       |

3.4. Influence of opening pitch

In order to analyze the influence of the hole spacing on the bearing capacity performance, the load-slip curves of the test piece PSC (1-2) and the test piece PSC (9-10) were extracted, as shown in Fig. 6. Table 4 lists the bearing capacity and shear stiffness test values for both. On the basis of Fig. 6, in order to ensure the same number of holes, the test piece PSC (1-2) and the test piece PSC (9-10) are simply superimposed to obtain the load-slip curve of the single hole. As shown in Figure 7. It can be seen from Fig. 7 and Table 4 that the larger the opening pitch, the larger the ultimate load of the test piece, and the greater the bearing capacity and shear rigidity of the normal use state.

Table 4. Single hole bearing capacity and stiffness value with varying opening spacing

| Test piece number | Opening spacing/mm | State bearing capacity/kN | Shear stiffness/kN/mm | Ultimate bearing capacity/kN |
|-------------------|--------------------|--------------------------|----------------------|----------------------------|
| PSC(1-2)          | 95                 | 25.5                     | 125                  | 89.7                       |
| PSC(9-10)         | 140                | 33.2                     | 160                  | 102.7                      |

Figure 6. with different opening spacings  
Figure 7. Load-slip curves converted to single holes

4. Conclusion

When the longitudinal rib opens, a stiffening rib with an opening is formed, the interface bond performance of rectangular concrete filled steel tube can be improved by setting the longitudinal rib. The shear capacity and stiffness of concrete filled rectangular steel tube interface have been greatly improved. The ultimate bearing capacity of concrete filled rectangular steel tubular with longitudinal ribs is increased by 2.06 times, and the shear stiffness and shear bearing capacity of concrete filled rectangular steel tubular with longitudinal ribs are increased by 4.56 times in normal service. With the increase of aperture, the area of shear section of concrete tenon increases, which effectively improves the shear capacity of its interface. Of course, a single steel plate is not the bigger the hole is, the better the diameter of the hole is. Further finite element analysis or theoretical analysis is needed to determine the optimum diameter of the hole.

About the Author:

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