Shear Behavior of Stud-PBL Composite Shear Connector for Steel-Ceramsite Concrete Composite Structure

Zhu Hongbing[1], Fu Zhenghao[2], Li Yongcan[2] and Zhao Benlu[2]

[1]Professor,Wuhan University of Science and Technology
(No. 2, Huangjiahu West Road, Hongshan District, Wuhan City, Hubei Province)
E-mail: 519591225@qq.com
[2]Student,Wuhan University of Science and Technology
(No. 2, Huangjiahu West Road, Hongshan District, Wuhan City, Hubei Province)
E-mail: 206387159@qq.com

Abstract: Steel-concrete composite structures usually use flexible stud or rigid PBL shear connectors. In order to take advantage of these two types of shear connectors and improve the shear resistance of the steel-concrete interface in the composite structure, it is proposed to alternately arrange PBL and studs in the same plane to form a composite shear connectors. The composite structure formed by steel and polypropylene fiber ceramsite concrete of lightweight and high-strength was studied in order to reduce the weight of the structure. The static loading test of 5 polypropylene fiber ceramsite concrete composite shear connectors push-out specimens was carried out. The results show that the composite shear connectors has high shear bearing capacity, and the measured shear bearing capacity of the test is 18.4% higher than that of the PBL shear connectors, and 95.0% higher than that of the stud shear connectors, it has better deformability in the same time. The plastic phase in the measured load-slip curve is significantly longer than that of the PBL shear connectors.

Keywords: *bridge engineering, shear bearing capacity, push-out test, composite shear connector, ceramsite concrete, composite structure*

1. INTRODUCTION

Steel-concrete composite structure is a structure which combines the steel structure and the concrete structure to bear the common force together. It can give full play to the advantages of concrete structure and steel structure, and make the stress of the structure more reasonable[1]. The shear connector is a key element which makes steel and concrete structure can work together. At present, stud and Perfobond Leiste(PBL) shear connectors are mostly used in engineering. The stud connector resists longitudinal shear mainly through the nail bar and its large part resists the lifting force of the concrete slab. The PBL connector PBL is mainly composed of three parts: perfobond rib, concrete tenon and perforating rebar in order to resist longitudinal shear force and interface separation force. If PBL connector is arranged intermittently, the end of the perforated plate can also play a shear resistance.

Shear bearing capacity is an important performance index of shear connectors. It is very important to accurately evaluate the shear resistance of shear connectors and obtain a reliable calculation formula for shear bearing capacity. Through the static test of stud push-out specimens, Xue[2] put forward the formula of the load slip curve of the stud under shear and the calculation formula of the shear capacity considering the ratio of length to diameter of the stud;Through group studs push-out test, Xing[3] obtained the longitudinal stress distribution of the group studs, which is a saddle-shaped distribution with large ends and a small center; through finite element analysis, Zhou[4] found that the group studs effect could reduce the shear capacity of a single stud, and proposed the calculation formula of the shear bearing capacity of group studs considering the reduction factor of bearing capacity; Huang[5] carried out the push-out test of the group shear studs with outsourcing rubber. The results show that the Outsourcing rubber can reduce the shear stiffness of the group studs and make the shear bearing capacity of single stud tend to be uniform, then improve the shear bearing capacity of the group studs. The PBL shear connectors of composite beam are usually arranged in a continuous manner. Through the push-out test of PBL shear connectors, Hu[6] studied the influence of the diameter of perfobond rib's hole, perforating rebar's diameter, number and strength, concrete strength, stirrup strength, and the number of perfobond rib's hole on the shear bearing capacity, and proposed the calculation formula of shear bearing capacity; Zhao[7] proposed the calculation formula for the shear bearing capacity of the PBL shear connector based on the results of the push-out test and other scholars' tests; According to the push-out test's results of the PBL shear connector, Xiao[8] pointed out that when the perfobond rib is too thin, there will be a failure mode of the perfobond rib being sheared by the perforating rebars; Combining the push-out test results of PBL shear connectors and elastic foundation beam theory, Zheng[9] proposed the calculation formula for the shear bearing stiffness (stiffness is the slope of the secant line of the curve corresponding to the relative slip value of 0.2mm in the load slip curve)of PBL connectors; Through push-out test, Liu[10] studied the influence of the spacing of perfobond ribs on the shear stiffness of multi-row PBL shear connectors, and proposed the formula for calculating the shear stiffness of PBL connectors considering the effect of rib spacing. PBL shear connectors are intermittently arranged in the composite beam of the precast bridge deck. Through push-out test, Gu[11] and Yang[12] found that the compressive effect of the concrete at the end of the perfobond rib can significantly improve the shear bearing capacity of the PBL shear connector.

This paper proposes a composite shear connector formed by arranging alternately PBL shear connectors and stud shear connectors on the same plane. On the one hand, PBL arranged alternately can reduce the amount of steel used and increase the integrity of the concrete slab. The compressive effect of the end concrete can also improve the shear resistance of the shear connector; On the other hand, combining rigid PBL shear connector and flexible stud can complement the advantages of the two types of shear connector and make full use of concrete slab. Because the ceramsite concrete with the right amount of polypropylene fiber has the advantages of light weight, high strength, and good seismic performance[13], the influence of the type of shear connector (stud, PBL and composite connector) on the shear capacity of the specimen is studied through the push-out tests of 5 polypropylene fiber ceramsite concrete composite specimens.

2. EXPERIMENTAL DESIGEN

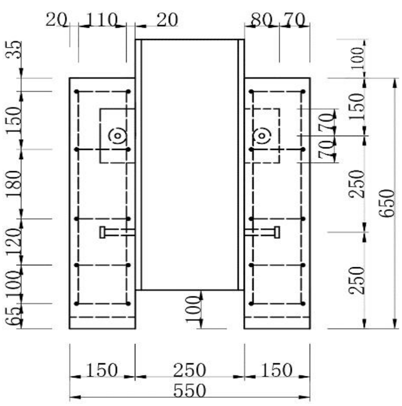
In order to study the shear resistance of arranging alternately stud and PBL in the same plane, 5 push-out specimens are designed according to Eurocode 4(EN 1994-2:2005, Eurocode 4). According to the shear connector type, it is divided into three groups, including LT-S group(This group has 1 specimen and there are only 8 stud shear connectors in this specimen.), LT-P group(This group has 1 specimen and there are only 8 PBL shear connectors in this specimen.) and LT-C group(This group has 3 specimens and each specimen contains 4 PBL shear connectors and 4 stud shear connectors . The shear connector formed by the combined arrangement of stud and PBL becomes a compesite shear connector.) .

Test adopt the 28th day cubic compressive strength of polypropylene fiber ceramsite concrete, and it is 52.3MPa. The content of polypropylene fiber is 0.9kg/m3(Volume content is 0.1%.); Perforating rebar model is HRB335. Its yield strength is measured to be 328MPa and ultimate tensile strength is 480MPa; Both H-beam and PBL perfobond rib are Q235 steel. Its yield strength is measured to be 330.9MPa and ultimate tensile strength is 440MPa; The stud material is ML15A1. Its yield strength is measured to be 360MPa and ultimate tensile strength is 400MPa.

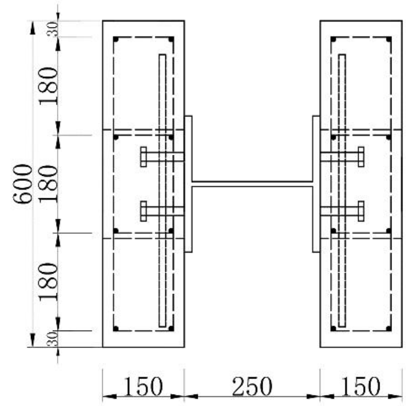
The structure of LT-C(composite shear connector) specimen is shown in Figure 1. Each specimen contains 4 PBL shear connectors and 4 stud shear connectors; replacing the PBL shear connectors on the upper layer of the LT-C specimen with studs, which becomes an LT-S specimen; replacing the studs in the lower layer of the LT-C specimen with the PBL shear connectors, which becomes the LT-P specimen. See table 1 for specific information.

As shown in Figure 2, a 2000kN electro-hydraulic servo pressure testing machine is used for loading. Preloading three times is carried out before formal loading, and then monotonous hierarchical loading is performed. The indicator of the percentage indicator is read after each level of loading is stable. Until the ultimate bearing capacity is reached, the development of cracks needs to be observed during the whole process. The whole loading process is not less than 45min.

Two dial indicators are placed on the front and back of the H-beam to measure the relative displacement of the H-beam and the bottom loading platform.



(a)



(b)

Fig.1 Details of Push-out Specimen（LT-C）(Unit: mm）:(a) Elevation,(b) Top view.

Table 1 Parameters of Push-out Test Specimen

Group	Number of studs per test piece/piece	Number of PBL shear connectors and openings per test piece/piece	Number of perforating steel bars per text piece/piece
LT-S	8	-	-
LT-P	-	8	4
LT-C	4	4	2

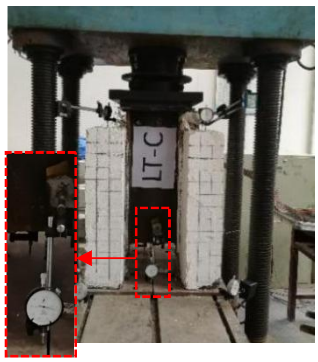
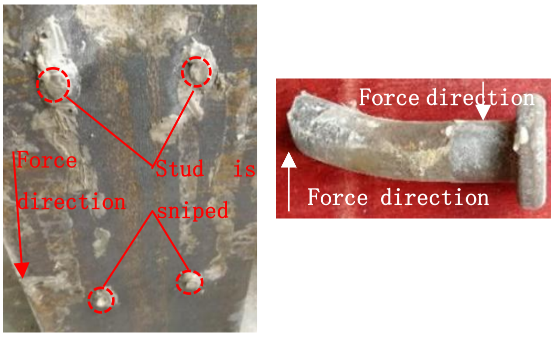


Fig.2 Sketch of Loading

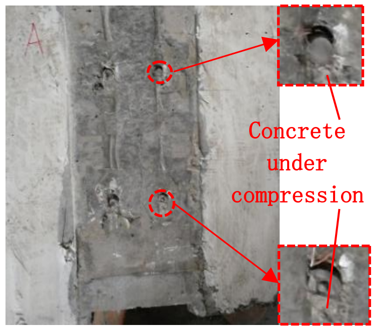
3. EXPERIMENTAL PHENOMENON

The experiment shows that the three types of shear connector specimens all contain three working stages: elasticity, plasticity and failure. At the beginning of loading, the relative displacement of H-beam and concrete slab is small, and the concrete slab is intact without cracks; Continue to load until failure, the three types of shear connector specimens show different damage phenomena.

Figure 3 shows the failure modes of push-out specimens. The studs on one side of the LT-S specimen are sheared from the root, and the studs on the other side show obvious plastic deformation. The concrete under the stud is compressed and plastically deformed. There are fine cracks at the bottom of the concrete slab; There is no obvious deformation of the perfobond rib when the LT-P specimen is damaged. The concrete tenon in the hole is crushed, and the perforating rebars yield. The bottom of the concrete slab is crushed; The studs of LT-C specimens are broken at the root of the nail rod (or large plastic deformation occurs). The concrete around the studs has obvious plastic deformation, and the concrete tenon is crushed. For Perforating rebars, plastic deformation occurs. The bottom of the concrete slab is crushed.



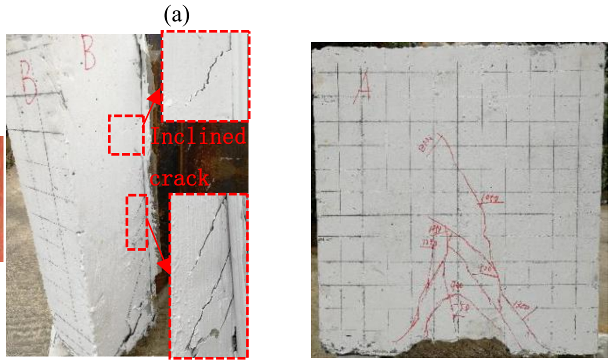
The stud is sniped



Plastic deformation of concrete under compression

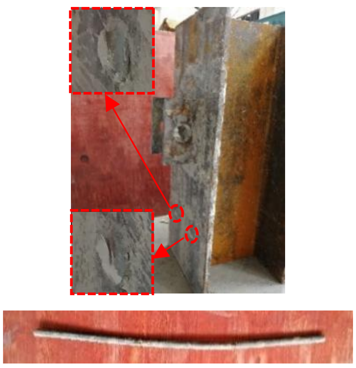
(a)

Curved perforating rebar

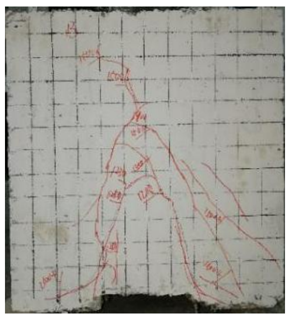


Concrete slab cracking

(b)



The stud is sniped and perforating rebar bending



Concrete slab cracking

(c)

Fig.3 Typical Failure Model of Push-out Test Specimens:(a) LT-S specimen,(b) LT-P specimen,(c) LT-C specimen

4. TEST RESULITS

Table 2 lists the shear capacity of the specimens. It can be seen from Table 2 that the measured shear capacity of the specimens LT-S and LT-P respectively are 197.3kN and 325.0kN. It is found by superposing the bearing capacity of a single stud and a single PBL (Pu, LT-S+Pu, LT-P)/2=261.2kN is less than the average value of the shear capacity of the specimen LT-C (384.7kN), and the shear capacity of the specimen LT-C is 18.4% higher than that of the specimen LT-P. The reason is that the strength of the PBL shear connector is high, and the concrete at the bottom of the perforated plate is in a concentrated stress state during the stress process, which is easy to crack, which reduces the effective stress area of the concrete slab and weakens the shear capacity of the specimen; This also shows that the shear connector composed of studs and PBL can be better combined with the concrete slab, giving full play to the performance of both the shear connector and the concrete slab.

Figure 4 shows the load slip-curve measured by the test. Due to equipment limitations, only the load-slip curves of the specimen in the elastic and plastic working stages are obtained. In the elastic stage, the load on the specimen is in a linear relationship with the slip; in the plastic stage, adding a small amount of load will greatly increase the amount of slip. The plastic stage of the LT-S specimen is the longest, followed by the LT-C specimen, and the plastic stage of the LT-P specimen is the shortest. This shows that under the condition of certain concrete strength, replacing the perforated plate of the lower layer with studs can improve the deformation performance of the push-out specimen.

Table 2 Results of Push-out Test

Specimen number	Test measurement P_u / kN
LT-S	197.3
LT-P	325.0
LT-C-1	404.0
LT-C-2	375.1
LT-C-3	375.1
LT-C average value	384.7

Note: P_u in the table is 1/4 of the shear bearing capacity of the push-out specimen. That is, the specimen LT-S contains 2 studs, the specimen LT-P contains 2 PBLs, and the specimen LT-C contains 1 stud and 1 PBL.

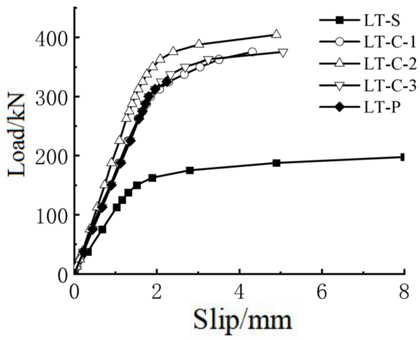


Fig.4 Load-slip Curves of Push-out Test

5. CONCLUSIONS

Aiming at the shear resistance test of the bonding interface of the steel-polypropylene fiber ceramsite concrete composite structure, the following main conclusions are obtained:

(1) Through the push-out test of 1 stud shear key (LT-S), 1 PBL shear key (LT-P), 3 stud-PBL combined shear connectors (LT-C), it can be known that the composite shear connector has excellent shear resistance, and its shear bearing capacity is 18.4% higher than that of the PBL shear connector, and 95.0% higher than that of the stud shear connector; the plastic deformation performance of the composite shear connctor is obviously better

than that of the PBL shear connector.

(2)The experiments, numerical simulation conclusions and calculation formulas in this paper have a certain promotion effect on further reducing the self-weight of the composite structure and improving the shear resistance of the composite structure interface. However, the number of push-out specimen is too small. In the future, further experimental research will be carried out, and further discussion will be carried out on the shear resistance and shear bearing capacity calculation method of the stud-PBL composite shear connector.

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