The Review on Load-bearing Capacity of Stud Shear Connectors

Tingjie ZHANG[1], Pengtao JIA[1], Lingyu HU[2]
[1]Department of civil engineering, Chongqing Jiaotong University, Chongqing 400074,CHINA
[2]Department of Civil Engineering, Anyang Institute of Technology, Henan Anyang 45500,CHINA

Abstract: It introduces the research status of the shear connector in different countries. There are several kinds of shear connectors are listed, and the experiment research is introduced, the mechanic characteristics and the influence factors to the bearing capacity of the shear connector are analyzed in this paper. The fitting formulas of the bearing capacity applied in different countries' are contrasted, and introduces the development trend of the stud shear connector and the study direction.

Keywords: Shear connectors; Push-out test; Construction form; Failure mode

1. Introduction

Steel-concrete composite structure is a new type of structure, which is based on the development of steel and reinforced concrete structure. It is composed of two or more than two kinds of materials, bear the load together and deformation compatibility. Steel and reinforced concrete can play their advantages respectively. However, the combination of the two materials needs to connect by the shear connectors.

2. Research Status of Shear Connectors

Shear connectors can transfer the shear force at the interface of steel beam and reinforced concrete slab. In addition, it can resist slippage and set off between them, which is crucial to ensure they work together. The scholars all over the world have done a lot of research on the shear connectors.

Stud shear connectors are influenced by several parameters according to previous researchers (Oehlers and Johnson 1987; An and Cederwall 1996), with major factors categorized into shank diameter, height and tensile strength of studs, compressive strength and elastic modulus of concrete, and reinforcement detailing. The different formulas of carrying capacity of the shear connectors in Euro4 are analyzed by Chinese's scholar (Hu Xiamin1996). The test results showed that the stud shear bearing capacity values of push-out tests were generally lower than those of beam tests, and the push-out test results were the lower limits of stud shear bearing capacity in composite beams (Slutter and Driscoll 1965). Present design methods in the codes for the calculation of the shear strength of studs are based on the push-out tests (Nie et al. 1996). The critical load of the stud was presented on the basis of push-out tests. In earlier studies on stud shear connectors, shear bearing capacity was suggested to be the load when stud load-slip curves became nonlinear, or the load corresponding to 0.762 mm of the residual slip (Viest 1956). At present, the stud shear bearing capacity generally depends on the ultimate shear bearing capacity, and the behavior of stud shear connectors has been broadly investigated by many researchers (Ollgaard et al. 1971; Gattesco et al.1997; Saari et al. 2004). A calculation model of stud shear bearing capacity was presented by Ollgaard et al. at Lehigh University based on push-out tests, and the model became the basis of the present design methods in the codes (Ollgaard et al. 1971). Push-out test results in normal and high strength concrete showed that concrete strength affected stud shear bearing capacity significantly. The increase of the transverse reinforcements had a negligible effect when high strength concrete was used and some effects when normal concrete was used, and a design formula taking into account the interaction between the studs and the surrounding concrete was suggested_ (An and Cederwall 1996). Push-out tests on studs 31.8 mm in diameter were conducted and the results showed that the ultimate shear bearing capacity could be safely determined using the equation given in the AASHTO LRFD Bridge Design Specification (AASHTO 2004) (Badie et al. 2002). Through push-out tests on studs 25, 27, and 30 mm in diameter, shear stiffness of the studs in an elastic range and trilinear load-slip curves were proposed. Ultimate slip capacity and shear bearing capacities were evaluated and the test results clearly showed the conservative values of design shear bearing capacity in Euro-code 4 (SSEDTA 2001) (Shim et al. 2004; Lee et al. 2005). A total of 24 push-out tests were performed at concrete ages ranging from 4 h to 28 days, and the results revealed that shear transfer was achieved at very early concrete ages and rate of stiffness gain of concrete was greater than that of strength (Topkaya et al.2004). After a standard push-out test procedure for composite beams with precast hollowcore slabs was proposed (Lam 2007), 72 full-scale push-out tests on headed studs in hollowcore slabs were performed and newly proposed design equations for calculating the stud shear bearing capacity for this form of composite beams was also given.

3. Classification of Shear Connectors

According to the form of the shear connectors, it can be divided into the following categories: the reinforced connector, high strength bolt connector, stud connector and perforated plate connector (PBL) (Fig.1).

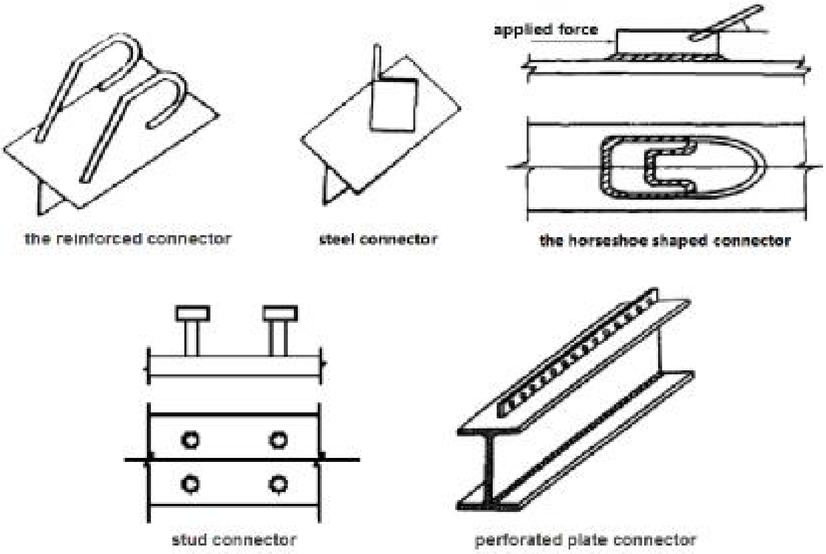

Figure 1. Shear Connectors

According to the shear stiffness, the shear connectors are conventionally divided into rigid shear connector and flexible shear connector. The load-slip curve of typical rigid shear connector and flexible shear connector was shown in Fig.2. The rigid shear connectors can't deformation when transfer the shear in the interface of steel beam and reinforced concrete. However, the flexible shear connectors have a good deformation capacity when transfer the shear at the interface of steel-concrete composite structure. Not only do the two types of shear connectors have different shear stiffness, but also they have different failure modes. Rigid connector is easy to cause high-stress concentration in the surrounding concrete, leads to the concrete were crushed or shear failure easily, even bring about weld failure between steel beam and shear connectors. Flexible connector, on the other hand, they will deformation because of the shear in contact surface, it's shear bearing capacity does not decrease when a certain slippage was created between steel beam and concrete slab.

The shear connector can be divided into ductile and non-ductile according to classification by ductility. There is no standard definition of the concept of ductility, slip capacity is generally the maximum displacement, which the shear connectors withstand the load reaches its shear bearing capacity of 90% and definition by the decline of the load-slip curve obtained from the push-out test. The definition of ductility of stud in equal width of flange section as shown in Fig.3. Most of the other shear connectors are considered to be non-ductile shear connectors. Since the maximum slippage of the push-out test is less than 3mm.

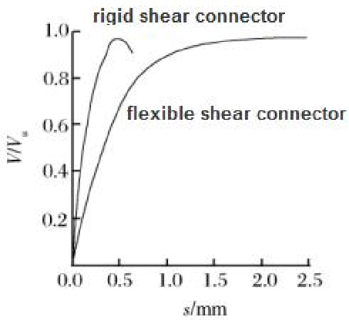

Figure 2. The load-slip curve of typical rigid shear connector and flexible shear connector

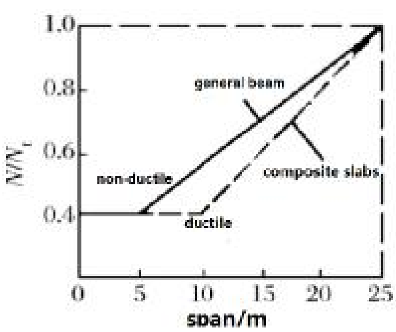

Figure 3. The definition of the stud connectors' ductility

4. Experimental Study on the Shear Connectors

Theoretical analysis about the mechanical behavior of shear connectors has not to be seen at home and abroad because of the complex mechanical behavior of shear connectors, is generally obtained by experiment. Test methods for determining the performance of the shear connectors are push-out test and beam test.

The push-out test is put a I-beam and two concrete slabs together by the studs that weld on the I-beam, and then put load on end of the beam, so the shear connectors buried in concrete slabs will be subjected to shearing action. We can get the load-slip curve of the shear connectors by measuring the relative slip between the steel beam and concrete slabs.

ECCS released a standard push-out specimen was widely used by researchers as shown in Fig.4. The standard push-out test obtain load-slip curves of shear connectors by measuring slippage between steel and concrete. This is done in order to get carrying capacity and shear stiffness of shear connectors under static load.

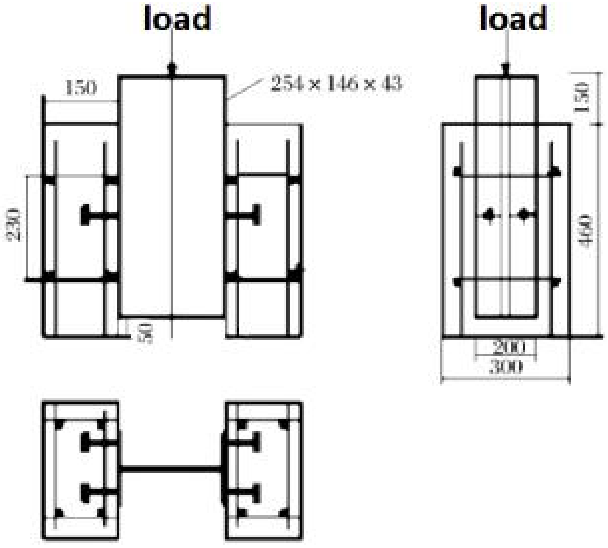

Figure 4. Push-out test of shear connector

The beam test is applied two symmetrical loads to simply supported composite beams, there is the horizontal shear at the interface of steel girder and concrete slab, longitudinal shear force increases with the increase of load until destruction. Beam test shown in Fig.5.

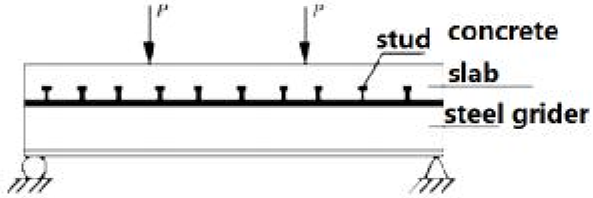

Figure 5. Beam test of shear connector

The test results show the result of push-out test is less than beam test. The main reason is the shear transfer of studs is mainly rely on local compression of concrete near the root, while the lateral compressive stress of concrete near the root of stud in beam test is larger than that in push-out test, the push-out test results are used as the basis of bearing capacity design at home and abroad, which is beneficial to improve the shear bearing capacity of shear connectors.

5. Factors and Failure Modes of Stud Connectors

Failure modes of shear connectors can be divided into two categories.

Tensile shear failure mode of shear connectors. It generally occurs in shear connector is weaker than the concrete, namely the higher concrete strength and damage showed some fragility. The shear bearing capacity has nothing to do with the concrete strength; it related to the type of shear connectors and materials.

The concrete failure near the shear connectors. It generally occurs in concrete strength is weaker than the shear connectors. Along the stress direction in front of the concrete will create a great compressive stress when shear connectors work, and concrete failure will occur. The ultimate shear bearing capacity increases with the increase of the concrete strength.

For stud shear connectors, the above two kinds of failure modes are possible occurrence. This is related to the strength of concrete, elastic modulus, strength and size of the stud. In addition, studies show that the layout and structure of stud have a great impact on the shear bearing capacity of the shear connectors.

6. Stud Shear Bearing Capacity

According to the different failure forms and influencing factors, the shear connectors for each form have its own unlike calculation formula of shear bearing capacity. For stud shear connectors, The specifications of the different countries have adopted different calculation formulas, with no—pressure plate as an example, compare the following:

The calculation formula for the stud shear bearing capacity was derived based on AISC(1969) of America, and the expression is

$$Q_{ua} = 37.45 A_{sa} \sqrt{f_{ca}^{'}} \quad (1)$$

Where Q_{ua} = stud shear bearing capacity; A_{sa} =cross-sectional area of a stud shear connector; $f_{ca}^{'}$ = compressive strength of concrete cylinders.

There is a new specification of composite structures, which was published in 2005. The shear bearing capacity of shear connectors has been modified, and the expression is

$$Q_d = 0.5A_s\sqrt{E_c f_c^{'}} \le A_s f_u \qquad (2)$$

Where Q_d = the nominal strength of one stud shear connector; A_s =cross-sectional area of a stud shear connector; E_c =elastic modulus of concrete; $f_c^{'}$ = compressive strength of concrete cylinders; f_u = ultimate tensile strength of the stud.

The formula of Canadian standard adopted.

$$Q_d = 0.5 j_{sc} A_s\sqrt{E_c f_c^{'}} \le j_{sc} A_s f_u \qquad (3)$$

Where j_{sc} = coefficient of shear bearing capacity, take as 0.8, the rest of the symbolic significance as above.

Eurocode 4 specified the design strength of stud shear connectors which are welded automatically, as Eq. (4).

$$P_u = \min(0.8 f_u (p d^2/4)/g_v, 0.29 a d^2\sqrt{f_c^{'} E_c}/g_v) \qquad (4)$$

Where d =diameter of the studs; f_u =ultimate tensile strength of stud; $f_c^{'}$ =compressive strength of concrete cylinders; E_c =elastic modulus of concrete; g_v = partial safety factor (=1.25); a =0.2(H/d +1) ≤ 1;and H =height of the studs.

For the calculation of shear bearing capacity of the stud shear connectors, specifications of different countries consider different influencing factors. They have different forms and calculation results.

7. Research Trends

In recent years, the steel-concrete composite structure and high strength concrete structure develop quickly in china. The steel-concrete composite beam organically formed of steel beam and concrete by stud shear connectors, which has a broad application prospect in the field of bridge and building structures.

Because of the studs in the complex stress state, the calculation formulas of the bearing capacity are obtained by fitting test date. However, test is a press with a strong random element, and the date of large size and irregular connectors rarely, so there is an urgent need for data of large-scale and more perfect theory.

References

[1] Candido-Martins J, Costa-Neves L F, Vellasco P D S . Experimental evaluation of the structural response of Perfobond shear connectors［J］. Engineering Structures, 2010, 32 (8) :1976-1985

[2] Valente I, Cruz P J. Experimental analysis of Perfobond shear connection between steel and lightweight concrete［J］. Journal of Constructional Steel Research, 2004 , 60 (3):465-479

[3] Zhang Qinghua, Li Qiao, Bu Yizhi. Load transmission mechanism of PBL shear connector group (Ⅰ)-theoretical model [J]. China Civil Engineering Journal, 2011, 44(4):71-77

[4] Zhang Qinghua, Li Qiao, Bu Yizhi. Load transmission mechanism of PBL shear connector groups Ⅱ:load capacity [J]. China Civil Engineering Journal, 2011, 44(5):101-108

[5] Xiao Lin, Li Xiaozhen, Wei Xing. Research on the static load mechanical properties of PBL shear connectors push-out test [J]. China Railway Science, 2010, 31(3):15-21

[6] EN 1994 Eurocode 4: Design of composite steel and concrete structures [S]. Brussels, Belgium: European Committee for Standardization, 2005