# Experimental Study on Stud Shear Connectors with Large Diameter and High Strength


Qian WANG
Department of Bridge Engineering
Tongji University
Shanghai, China
zl_bridge@163.com

Yuqing LIU
Department of Bridge Engineering
Tongji University
Shanghai, China
yql@tongji.edu.cn

Jie LUO
Department of Bridge Engineering
Tongji University
Shanghai, China
pidianer_7@163.com

Jean-Paul LEBET
ICOM, ENAC
Swiss Federal Institute of Technology
Lausanne, Switzerland
jean-paul.lebet@epfl.ch



***Abstract*—Studs with large diameter and high strength have been used in many composite structures, but the former research results were mainly based on middle or small diameter studs with normal strength. 12 push-out tests on stud connectors with different diameters and strengths were performed. The results show that the shear resistance and shear stiffness of studs with large diameter and high strength are all higher than the normal stud connectors used before. The experimental results were also compared with the calculated results based on the formulas from many countries' design codes. It seems that these formulas are all conservative and can be used to calculate the shear resistance of studs with large diameter and high strength.**



***Keywords-composite structure; studs; push-out tests; shear resistance; shear rigidity***


## I. INTRODUCTION

The stud shear connector is usually used in composite structures for its convenient construction and non-directional shear behavior [1]. Studs with large diameter and high strength have higher shear resistance than the typical stud connectors used in bridge engineering. The number of studs can be reduced when been used in the high shear zone, which can cut down the welding time and also reduce safety concerns for construction workers. For the composite bridges with prefabricated concrete slabs, stud connectors having higher capacity can provide a uniform distribution of shear pockets [2, 3]. The use of stud connectors with large diameter and high strength can simplify the structure, save the construction time and make steel and concrete work together better.

The research area of the former researchers for stud shear connectors is mainly on the middle and small diameter studs, and also the correlative formulas were performed mainly based on the push-out experiments of middle and small diameter studs [4]. For example, the equation given in Eurocode 4 to calculate the shear resistance of studs can only be used when the studs' diameters are between 16mm and 25mm, and the tensile strengths of studs are less than 500MPa[5], similar restriction condition exists also in other codes[6,7,8].

This research still uses the normal push-out experiments to study the shear behavior of studs with large diameters and high strengths. 12 push-out specimens were performed with different diameters and strengths. The results were analyzed and compared with the formula given in some common used design codes. The aim of the research is to have a better use of studs with large diameter and high strength, and to have more data of the mechanical behavior of studs.

## II. EXPERIMENTAL WORKS

### A. Test Specimens

The push-out specimens were designed according to the standard push-out test in Eurocode 4, 12 specimens were conducted by considering different diameters and different strengths of studs, and were divided into 4 groups, as shown in Tab.1. The length of all the studs was 200 mm, and the diameters were 22mm, 25mm and 30mm. Different strengths of studs were also considered to study the mechanical behavior of studs.

TABLE 1. PUSH-OUT SPECIMENS

| *Specimen* | *Number of Specimen* | *Shank Diameter (mm)* | *Length (mm)* | *Tensile Strength (MPa)* |
|---|---|---|---|---|
| SS-1 | 1 | 22 | 200 | 465 |
| | 2 | | | |
| | 3* | | | |
| SS-2 | 1 | 22 | 200 | 675 |
| | 2 | | | |
| | 3* | | | |
| SS-3 | 1 | 25 | 200 | 485 |
| | 2 | | | |
| | 3* | | | |
| SS-4 | 1 | 30 | 200 | 430 |
| | 2 | | | |
| | 3* | | | |

Note: the specimens with * are applied cyclic loads

Details of the push-out specimens are shown in Fig. 1. Two welded steel T-plates and two steel plates were combined together by high strength bolts, and there were two studs on each side. Both concrete slabs were cast in the horizontal position, as is done for composite beams in practice. Two layers transverse reinforcement were placed into the concrete slabs, as shown in Fig. 2. In order to get the pure shear resistant of studs, the bond at the interface between flanges of the steel


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parts and concrete slabs could be neglected by greasing the flange.

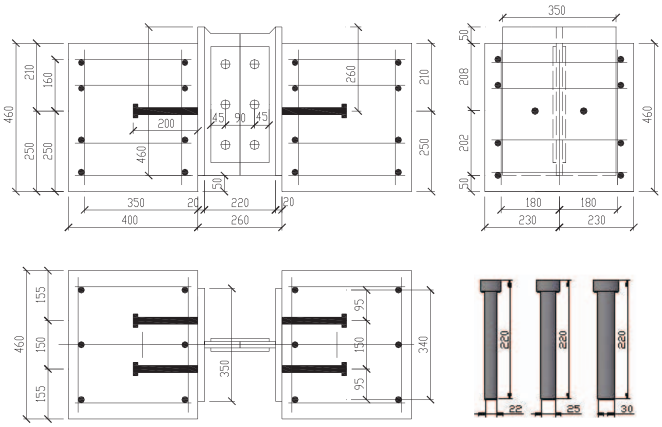



Figure 1. Details of the specimens

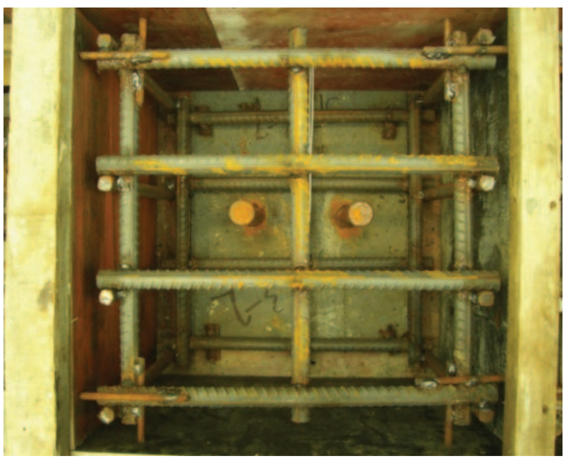


Figure 2. Construction of Concrete Formwork

## B. Material Property

The properties of concrete and steel are the same in all specimens, as shown in Tab. 2 and Tab. 3. Three cubic concrete blocks were casted at the same time with the specimens, and the tested average compressive strength was 70.3MPa after 28 days' air-cured. The steel plate and welding condition meet the criterion of GB/T10433-2002. The studs of each group are different not only in diameter but also in strength, as shown in Tab. 4.

TABLE 2. MATERIAL PROPERTIES OF CONCRETE

| ***Cubic Compressive strength*** ***$f_{cu}$ (MPa)*** | | ***Cylinder Compressive strength*** ***$f'_c$ (MPa)*** | ***Young's modulus*** ***$E_c$ (GPa)*** |
|---|---|---|---|
| 68.4 | 70.3 | 58.56 | 37.12 |
| 71.6 | | | |
| 70.9 | | | |

TABLE 3. MATERIAL PROPERTIES OF STEEL

| ***Steel specimen size (mm×mm×mm)*** | ***Yield strength (MPa)*** | ***Tensile strength (MPa)*** | ***Elongation (%)*** |
|---|---|---|---|
| 10×10×55 | 410 | 545 | 31.5 |

TABLE 4. MATERIAL PROPERTIES OF STUDS

| ***Specimen*** | ***Specification (mm×mm)*** | ***Yield strength $f_y$ (MPa)*** | ***Tensile strength $f_u$ (MPa)*** | ***Elongation (%)*** |
|---|---|---|---|---|
| SS-1 | 22×200 | 370 | 465 | 16 |
| SS-2 | 22×200 | 650 | 675 | 14 |
| SS-3 | 25×200 | 380 | 485 | 17 |
| SS-4 | 30×200 | 375 | 430 | 14 |

## C. Loading Procedure and Measurements

The specimens were tested with the hydraulic testing machine with a capacity of 2000kN. Fig. 3 shows the loading system. Two specimens in each group were tested under monotonic load, and the other one was tested under cyclic load. The load increment was 10% of the predicted bearing capacity for each cycle till 70% of the predicted bearing resistance, and then the load was increased monotonically up to failure of the specimen.

Four displacement transducers with high precision were installed at the same level of studs to measure the relative slip between the concrete and the steel plates. The magnitude of the load, the relative slip and the strain of the stud were measured by the data logger at each loading step.

Figure 3. Measurement System

# III. TEST RESULTS

## A. Failure Mode of the Specimens

With the high concrete compressive strength, the studs broke in shear in all push-out specimens. The concrete around the studs have no obvious cracks. Each specimen fractured in the shank of stud with smooth shear surface and obvious shear deformation, as shown in Fig.4.

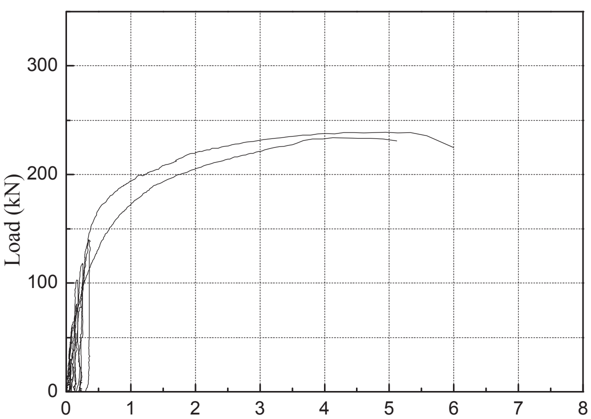
(a) Concrete Surface (b) Steel Surface

Figure 4. Details of the specimens

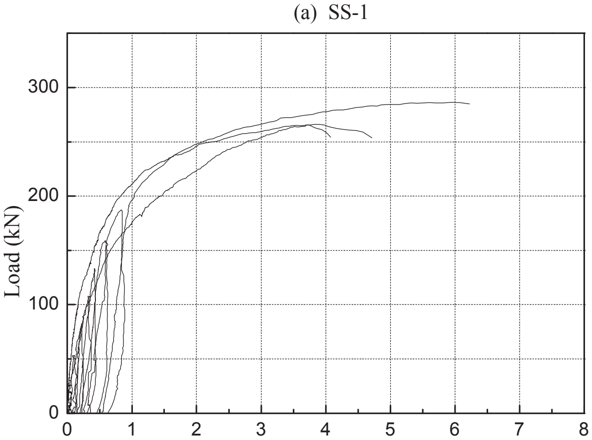
### *B. Analysis of the Test Results*

By analyzing of the data, the shear resistance, shear rigidity and the relationship curves between shear force and relative slip can be got. The load-slip curves of the push-out specimens are shown in Fig.5. The horizontal axis is the slip (the average value of four displacement transducers). The vertical axis is the load beard by one stud. SS-1-1 specimen had some problems when applying loads, so only the results of SS-1-2 and SS-1-3 in this group are listed.

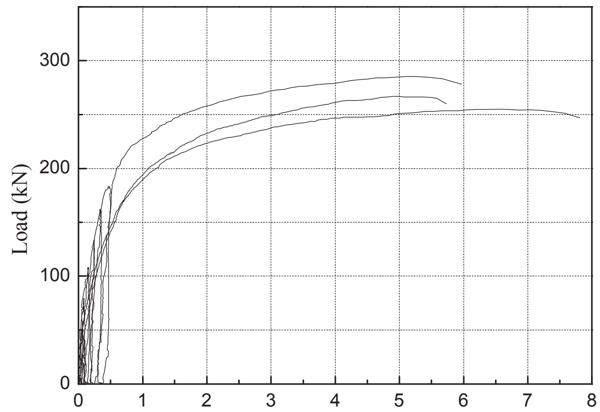
From the load-slip curves, we can know that specimens in each group have good repeatability, especially in elastic phase. The shear resistance of studs under cyclic loads in each group is not reduced.



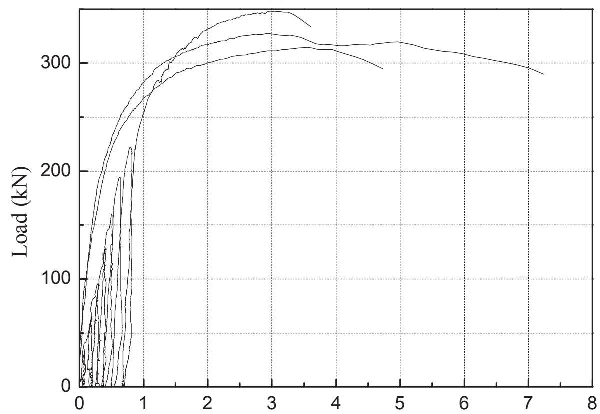

(a) SS-1




(b) SS-2




(c) SS-3




(d) SS-4

Figure 5. Load-Slip Curve

Tab. 5 indicates the average results of all push-out groups. We define the shear rigidity $K_{ss}$ is the secant slope of load-slip curve at 0.2mm slip. The maximal load is the shear resistance $V_u$, the ultimate slip $d_u$ is the relative slip at $V_u$.

The shear resistance and the shear rigidity increase as the diameter and the tensile strength of the studs become bigger. But the deformation capacity of the studs (the relative slip of the ultimate shearing capacity) has no regular pattern, which need more study.

TABLE 5. RESULTS OF THE PUSH-OUT SPECIMENS

| *Groups* | *Shear Rigidity $K_{ss}$ (kN/mm)* | *Shear Resistance $V_u$ (kN)* | *The Ultimate Slip $d_u$ (mm)* | *Failure Mode* |
|---|---|---|---|---|
| SS-1 | 399.7 | 236.5 | 4.54 | Shank failure |
| SS-2 | 462 | 272.7 | 4.53 | Shank failure |
| SS-3 | 421.2 | 269.0 | 5.59 | Shank failure |
| SS-4 | 728.1 | 330.1 | 3.17 | Shank failure |

The shear resistance of the studs with 675MPa tensile strength is about 15.3% higher than that of the studs with 465MPa. And the shear rigidity is about 15.6% higher.

The shear resistance of the studs with 25mm diameter is 13.8% higher than that of the studs with 22mm diameters, and the shear rigidity is 5.4% higher. The shear resistance of the studs with 30mm diameter is 39.6% higher than that of the studs with 22mm diameters, and the shear rigidity is 82.2% higher.

## IV. Comparison with Design Codes

We compare the experimenal results with the ultimate shear resistance calcuted from some common used design codes.

Eurocode-4[5] specifies the design strength of stud shear connectors which are welded automatically, as (1a) and (1b).

$$P_{Rd} = 0.8 f_u (\pi d^2 / 4) / \gamma_v \quad (1a)$$

$$P_{Rd} = 0.29 \alpha d^2 \sqrt{(f_{ck} E_{cm})} / \gamma_v \quad (1b)$$

Whichever is smaller, with: α=1.0, for $h_{sc}/d > 4$ in the specimens of this paper, and the partial factor $\gamma_v$ should take one when compared to test results.

The design code of United State, AASHTO LRFD[6], gives another way to get the ultimate shear resistance of studs embedded in concrete slabs as (2).

$$Q_r = 0.5 A_s \sqrt{E_c f_c^{'}} \le A_s F_u \quad (2)$$

Formula in Bridge Standards and Procedures Manual of Canada, Supplement to CHBDC S6-00[7], is shown as (3).

$$Q_d = 0.5 A_s \sqrt{E_c f_c^{'}} \le 448 A_s \quad (3)$$

According to Chinese Design Code for Steel Structures (GB50017-2003) [8], the ultimate shear resistance of studs can be calculated in (4)

$$N_v^c = 0.43 A_s \sqrt{E_c f_c} \le 0.7 A_s \gamma f \quad (4)$$

Where, $E_{cm}$ , $E_c$ is the elastic modulus of concrete; $d$ is the diameter of the shank of studs; $A_s$ is the area of the shank section of studs; $f_u$ , $f$ is the tensile strength of the material of the stud; $f_c^{'}$ , $f_{ck}$ is the characteristic cylinder compressive strength of the concrete; $f_c$ is the characteristic prism compressive strength of the concrete; α=1.0 in (1b); $\gamma_v$ =1.0 in (1 a,b) and $\gamma$ =1.0 in (4).

The condition of test groups of SS-1 and SS-3 are covered by all the above equation, but for the diameter and the tensile strength of studs, SS-2 and SS-4 are out of the validity domain of some equations. Tab.6 shows the comparison between the experimental results and the calulated results based on (1-4). For all experimental results, the calculated results are conservative. In the case of Eurocode 4, the calculated result of SS-2 which with higher tensile strength is 27.5% lower of the experimental results, and the The calculated result of SS-4 with large diameter is 35.8% lower of the experimental results.

TABLE 6. Compare thr Results with Eurocode 4

| ***Specimens*** | ***SS-1*** | ***SS-2*** | ***SS-3*** | ***SS-4*** |
|---|---|---|---|---|
| ***Experimental Results*** (kN) | 236.5 | 272.7 | 269.0 | 330.1 |
| ***Results of (1)*** (kN) | 141.4 | 205.3 | 190.5 | 243.2 |
| ***Results of (2)*** (kN) | 140.6 | 247.1 | 186.5 | 265.1 |
| ***Results of (3)*** (kN) | 170.3 | 170．3 | 219.9 | 316.7 |
| ***Results of (4)*** (kN) | 155.3 | 186.3 | 212.5 | 244.0 |

The formulas in all the above design codes are conservative and can still be used to calucate the shear resistance of studs with large diameter and high strength.

## V. Conclusion

12 push-out test specimens of stud shear connectors with large diameter and high strength were performed, the results were analyzed and compared with the some common used design codes, and the following results can be gained:

- The use of studs with large diameter and high strength can simplify the composite structure, save the construction time and make the steel and the concrete work together better. It will be commonly used in the future composite structures.
- The load-slip curves of specimens under monotone load and cyclic load in each group have very good repeatability, especially the elastic phase.
- The shear resistance and shear rigidity of studs with large diameter and high strength are all higher than the normal studs used in composite structures and can be better used in bridge structures.
- The formulas specified in some common design codes are conservative and can still be used to calculate the shear resistance of studs with large diameter and high strength.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