EXPERIMENTAL STUDY ON BEHAVIOUR OF SHEAR CONNECTORS IN MOMENT RESISTANCE OF STEEL COMPOSITE JOINTS

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Abstract. This paper presents an experimental investigation on the behavior of steel stud connectors in steel composite joints with precast hollowcore slabs in resisting the static bending moment. An experimental program including 5 flexural tests was carried out, and the failure modes of the studs, as well as the shear capacity of stud connectors are investigated. Their contribution to the overall joint moment capacity were studied in depth. The pertinent design recommendation in shear stud design for enhance the moment capacity of the composite joints are also proposed. The testing results and design recommendations presented in this paper can provide basic for future design of composite joints using shear stud connectors with precast slabs

Keywords: Composite joints; Steel structures; longitudinal shear; Moment-rotation behaviour; Shear studs.

1. INTRODUCTION

Steel Composite structures are widely used in the bridges and buildings. It is widely known that, shear connectors play an important role in the behavior of the composite beams. Extensive experimental research on shear behavior of stud connectors under static loads [1], cyclic loads (Gattesco et al. [2]) and fatigue loads (Dogan et al. [3]) were carried out. The corresponding specifications of standard push-out tests in design codes such as Eurocode 4 [4]. Different factors affecting the behavior of the studs have been studied by various researchers. Badie et al. [5] and Shim et al. [6] investigated the diameter of studs. Valente et al. [7], Kim et al. [8] and Han et al. [9] investigated the fluence of concrete strength. Xu et al. [10]), investigated the biaxial loading effect on group studs the quantity of studs. Lin et al. [11] studied the influence of restrained conditions and loading conditions studs.

For a composite joint, the moment resistance is one of the important factors to be considered in the design. As reported by [12], The moment capacity is also affected by the behavior of the shear connectors. However, among above mentioned investigations, little work has been done toward the role and the behavior of the shear connectors in the moment resistance of a composite joint.

In this study, eight full scale tests have been tested under the bending moments, the behavior of the shear connectors and their influence on the moment resistance of a composite joint was investigated in detail.

2 TEST ARRANGEMENT

Eight full scale steel composite joints using precast hollowcore slabs were conducted for flexural tests in this research investigation. As it is introduced [13], all specimens were of cruciform arrangement as shown in Fig. 1 to simulate the internal beam–column joints in a semi-rigid composite frame. The specimen was assembled from two 3300 mm long; 457 × 191 × 89 kg/m; grade S275 universal beams and one 254 × 254 × 167 kg/m; grade S275 universal column to form the cruciform arrangement. The beams are connected to the column flanges using 10 mm thick flush endplates with two rows of M20 Grade 8.8 bolts. The steel connection is a typical connection currently used in UK practice for simple joints, this is to ensure that the enhanced performance of the composite joint is not provided by the bare steel connection. A single row of 19 mm diameter headed shear studs is pre-welded to the top flange of the steel beams.

Figure 1 Test arrangements

The primary goal in the eight full scale tests were to investigate the moment and rotation capacity of this type of composite joints. Different parameters which may affect the joint behavior were investigate. It can be seen from Table 1 that, different stud spacings, position of the first stud and the no of the shear studs/beam were selected in the experimental investigations. The eight tests were name as CJ1-8 accordingly. As only Test CJ4-CJ8 were dismantled after the test to observe the failure modes of the shear studs, therefore, only the results of test CJ4-CJ8 are presented in the paper.

Table 1 Test arrangement

Reference	**In situ concrete cube strength (N/mm^2)**	**Longitudinal bars section area (mm^2)**	**Precast Hollowcore slab thickness (mm)**	**Studs spacing (mm)**	**Position of first stud (mm)**	**No of shear studs/ beam**
CJ4	44	2T20(628)	200	400	510, 710	3
CJ5	41	2T20(628)	200	500	645	3
CJ6	37.3	4T16(800)	200	310	465	6
CJ7	40.2	2T16(400)	200	1200	900	2
CJ8	42.9	4T16(800)	250	450	705	4

2.1 Instrumentation and loading procedure

During the tests, the conventional instrumentation for flexural tests was used, which comprised of LVDTs, strain gauges to measure the deflection, rotation of the joints, strain in reinforcing bars, steel beams and bolts. It worth noting that, to monitor the behavior of the shear studs, the stain gauges were mounted to the two faces of the studs along the bending axis. This is designed to monitor the structural behavior of the studs during the bending.

2.2 Loading procedure

Load is applied by hydraulic jacks simultaneously to each ends of the steel beams as shown in Fig. 1 to produce the bending moment of the joints. The load was applied at 10 kN intervals and continued until failure occurred of the joints.

3 TEST RESULTS AND DISCUSSION

Table 2 summarizes the key test results for the eight tests.

Table 2 Test results

Reference	CJ4	CJ5	CJ6	CJ7	CJ8
Moment capacity (kN m)	368	363	425	274	439
Degree of shear connection (%)[b]	98	98	>100	>100	>100
Failure mode	CF	CF	RF	RF	RF

RF – reinforcement fracture; CF – connector fracture.

b Calculated using the ultimate strength of longitudinal steel bar.

3.1 Failure mode of the joints

It can be seen that, different degree of shear connection was used, which is the ratio between the total longitudinal shear force provided by the studs over the total ultimate tensile force provided in the longitudinal rebars. This is a key factor to determine whether a composite steel beam is full shear interaction or partial shear interaction. It can be seen that, for the partial shear interaction cases (CJ4 and CJ5), the shear connector failure is the failure mode of joints CJ4 and CJ5. For CJ6, CJ7 and CJ8 which are full shear interaction, the failure mode of the joints is the longitudinal bar failure.

3.2 Failure mode and behavior of the studs during bending

It is also worth investigating the failure modes and detailed behavior of the studs during the tests. The behavior of the studs in the five tests are further discussed in this section.

3.2.1 Test CJ4

In test CJ4, three studs were used in each side of the joints, however, the position of the first stud is different in each side with the distance of the first stud to the column flange are 710mm and 510mm at east side and west side respectively. During the test, when the applied moment reached 368 kNm, failure occurred on the east side where the first stud spacing of 710 mm was larger than the west side which was 510 mm.

Test CJ4 is partial shear interaction, as expected, it can be seen from Figure 4, the joints failed due to the shear connector failures. The specimen was not fully dismantled, however, from Figure 2, it can be seen that, separations can be observed at the joint location as well as the beam end location, so we can deduce that first and third stud are sheared off. A hole was drilled around the remaining connector which is not sheared off.

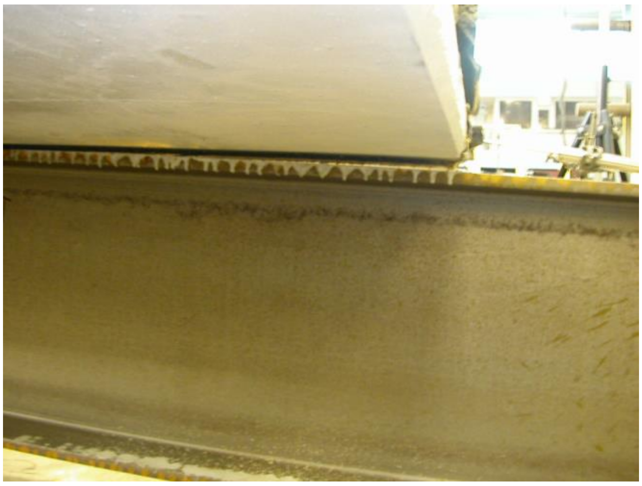

Fig 2 Separation of the slab and the steel beam at beam end

Fig. 3 gives the moment-strain curves of the shear studs in Test CJ4 at east side of the joints where ST11 and ST12 represents the reading of the two strain at front and back face of the stud along the bending axis of the joints, as it is explained in Figure 2. It is can be seen that, the strain at one face of the stud is in compression and in tension at another face, it shows that the stud shank is under the bending, this is due to curvature difference and the slip between the slab and the steel beam, so the studs are also in bending apart from longitudinal shear force.

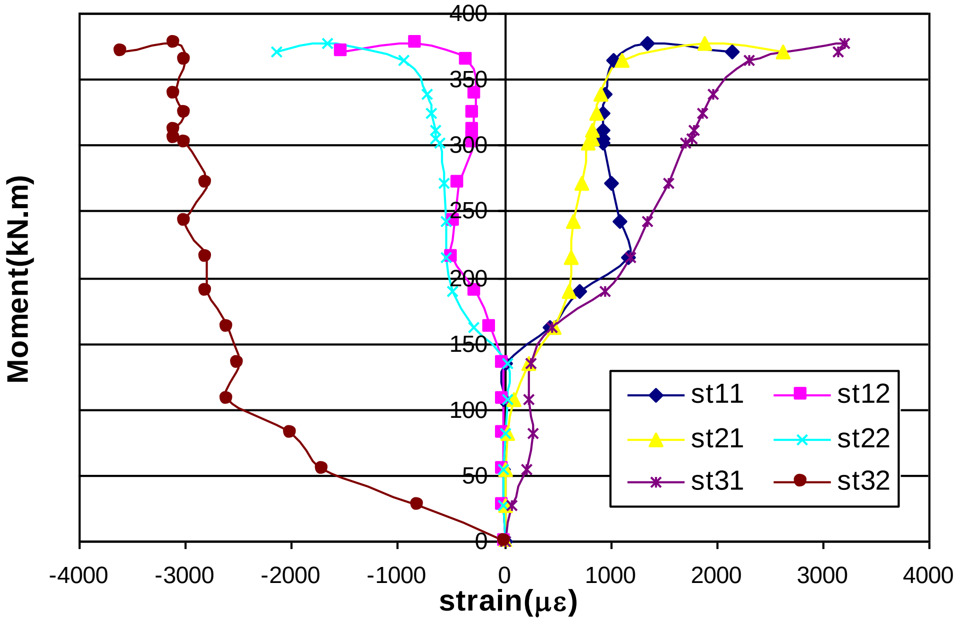

Fig 3 Moment vs. stud strain curves of Test CJ4 at east side of the joints

3.2.2 Test CJ5

Test CJ5 is also partial shear interaction. At a load of 125.14kN (362.9 kNm), the specimen failed on the east side. The result of Test CJ5 is almost identical to that of Test CJ4. The ultimate moment achieved is 362.9 kNm Failure was caused by fracture of the shear studs as shown in Fig. 4, where two of the studs were sheared off on the east side, which shear stud 5 remained intact.

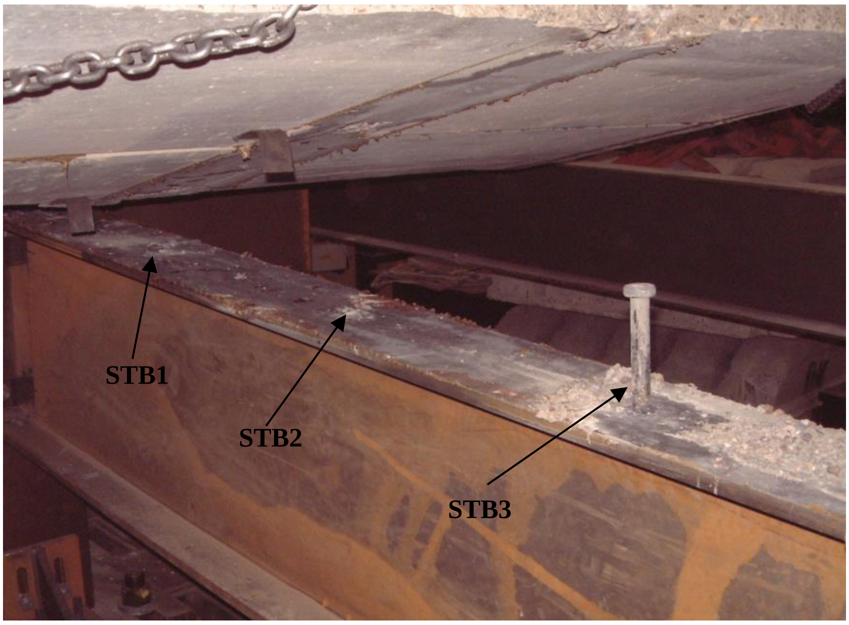

Fig 4 Stud condition after the test CJ5

3.2.3 Test CJ6

Test CJ6 is full shear interaction case. Figure 5 shows the status of the shear studs after dismantling. It can be seen that, all the studs are remaining intact, but deformation can be observed for all the studs. More severe deformation can be observed in the first stud, and its stud head was squashed. No obvious squash were observed for the remaining 3 studs.

Fig 5 Steel beam after dismantling for CJ6

3.2.4 Test CJ7

Test CJ7 is also full shear interaction case. Figure 6 shows the status of the shear studs after dismantling. It can be seen that, the studs are remaining intact.

Fig 6 Condition of headed stud after dismantling CJ7

3.2.5 Test CJ8

Test CJ8 is also full shear interaction case. The shear studs after dismantling show that all the studs are remaining intact, the shear stud head was also squashed for the first stud.

4 TEST RESULTS DISCUSSION

From the tests results it can be seen that, the shear studs play an important role in the moment resistance. The behavior of the studs is not exactly identical to the push-out tests. It is widely known that the EC4 uses below formula to determine the ultimate resistance of stud connectors, which is taken the less of

$$P_R = 0.8 f_u \frac{\pi d^2}{4} \qquad (1)$$

$$P_R = 0.29 \partial d^2 \sqrt{f_{ck} E_c} \qquad (2)$$

Where

(1) representing the shear connector failure
(2) representing the concrete failure

Where,

d stands for the diameter of stud,
f_{ck} refers to the characteristic value of cylinder compressive strength of concrete,
E_c is the elastic modulus of concrete
f_u is the actual tensile strength of steel stud

It can be seen that, formula (1) is primary taken the tensile capacity of the shear studs according to its cross-sectional area of its shank and multiple by it is tensile strength. So, it is derived with the assumption that the whole stud is in tension. Though, it uses a deduction factor of 0.8 reduce further reduce its capacity in the design for the sake of safety, when in the real loading scenarios such as the composite beam is in bending, that studs are not in pure tension as we discovered from the test observations. In addition, as this formula is derived primarily based on the push-out tests. the status of the studs under bending is slightly different to that under the push-out test case. Therefore, we recommend a further reduction factor which is smaller than 0.8 should be used for formula (1).

From the results observation of the five tests, it can be seen that, for the partial shear interaction cases, test CJ4,5, the fracture of the first studs were observed. For test CJ6 and CJ8, though no studs were fractured, large defamation or shear head squash was observed for the first stud. We can also conclude that, the first stud which is closer to the joint will be more likely to be damaged due to the larger bending moment at the joint region, especially for the partial shear interaction case.

For test CJ4, the joints failed at the east side where large first stud to the flange distance,710mm, was adopted, so we can also conclude that it will be beneficial to put the shear studs closer to the joints.

5 CONCLUSIONS

Below conclusions can be made from above investigations:

1. When the joints are under bending, the studs are under bending as well as longitudinal shear, so, further deduction of the shear connector capacity with a smaller reduction factor in calculating the ultimate shear capacity of the studs is recommended in real design, especially for partial shear interaction design of the composite beams;
2. The larger the distance of the first stud to the joints, the more vulnerable the joints under bending moment;
3. Although the degree of shear connection determines the failure mode of the joints, place more shear studs in the location near the joints zone will be beneficial to the capacity of the joints under bending.

REFERENCES

[1]. D Lam, E El-Lobody, Behavior of headed stud shear connectors in composite beam,Journal of Structural Engineering 131 (1), 96-107

[2]. N. Gattesco, E. Giuriani Experimental study on stud shear connectors subjected to cyclic loading J. Constr. Steel Res., 38 (1) (1996), pp. 1-21

[3]. O. Dogan, T.M. Roberts Fatigue performance and stiffness variation of stud connectors in steel-concrete-steel sandwich systems J. Constr. Steel Res., 70 (2012), pp. 86-92

[4]. Eurocode 4 Design of Composite Steel and Concrete Structures, Part 1-1: General Rules and Rules for Buildings CEN-European Committee for Standardization, Brussels (2004)

[5]. S.S. Badie, M.K. Tadros, H.F. Kakish, et al. Large shear studs for composite action in steel bridge girders J. Bridge. Eng., 7 (3) (2002), pp. 195-203

[6]. C.S. Shim, P.G. Lee, T.Y. Yoon Static behavior of large stud shear connectors Eng. Struct., 26 (2004), pp. 1853-1860

[7]. I.B. Valente, P.J.S. Cruz , Experimental analysis of shear connection between steel and lightweight concrete J. Constr. Steel Res., 65 (2009), pp. 1954-1963
[8]. J.S. Kim, J. Kwark, C. Joh, et al. Headed stud shear connector for thin ultrahigh-performance concrete bridge deck J. Constr. Steel Res., 108 (2015), pp. 23-30
[9]. Q.H. Han, Y.H. Wang, J. Xu, et al. Numerical analysis on shear stud in push-out test with crumb rubber concrete J. Constr. Steel Res., 130 (2017), pp. 148-158
[10]. C. Xu, K. Sugiura, H. Masuya, et al.Experimental study on the biaxial loading effect on group stud shear connectors of steel-concrete composite bridges J. Bridg. Eng., 20 (10) (2015)
[11]. Z.F. Lin, Y.Q. Liu, J. HeBehavior of stud connectors under combined shear and tension loads, Eng. Struct., 81 (2014), pp. 362-376
[12]. CAN/CSA-S16-01Limit State Design of Steel Structures, Canadian Standard Association, Mississauga (2005)
[13]. F. Fu, D. Lam, Experimental study on semi-rigid composite joints with steel beams and precast hollow-core slabs, Journal of Constructional Steel Research 62 (2006) 771–782