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Push-off tests on pin-connected shear studs with composite steel–concrete beams

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ABSTRACT

A new stud system fastened with high strength pins was investigated experimentally in this paper. This system is reported to be the fastest and the most economical method for installing studs to steel roof and floor decking in composite construction. It is 5–10 times faster than welding, screwing, or using powder actuated tools, which will directly reduce the fastening cost. These advantages would make significant contribution to the popularity of composite construction. The shear capacity of headed studs in composite steel–concrete beams has been determined experimentally in seven full-scale push-off tests. The tests were used to study the strength and ductility of the proposed stud system. Maximum resistances from the experimental tests are compared with the predictions of EC 4 and results from other researchers. The capacity of the stud is reduced due to fracture of the pins that occur before the shear stud had yielded. The proposed stud system can be improved further by increasing the size and the strength of the pins and base plate.

1. Introduction

The advantage of using composite construction in buildings has known to increase the loading capacity and stiffness of the composite beam due to the composite action. In steel-to-concrete composite construction longitudinal shear forces are transferred across the steel–concrete interface by the mechanical action of shear connectors, such as headed studs welded to the flanges of steel beams [1]. Research on shear connectors were carried out by Boksun et al. [2] based on numerical analysis. The study focused on the effect of the crack width on concrete slab and ratio of rebar in concrete slab to the performance of the shear connectors by comparing the experimental and numerical results. The study by Boksun showed that the maximum concrete crack width decreased as the longitudinal rebar ratio increased. Lam et al. [1] carried out 12 full-scale push-off tests on headed studs in precast concrete hollow-cored slab construction. The effect of the size of the gap between the ends of the precast slabs, and the amount of tie steel placed transversely across the joint, and the strength of concrete infill were studied. The work then was further extended by Lam and El-Lobody [3] who model the headed stud in a finite element analysis to validate the computed value with the existing experimental results. The comparison showed a good relationship between the finite element model and the experimental results.

The use of composite construction resulting in significant savings in steel weight and construction depth; however, more savings can be achieved by using a new method of fastening the shear stud, as shown in Fig. 1, by means of high strength pin connector, as proposed in this paper. In the proposed method, each stud is connected to a base plate that has two circular holes specially designed to locate fastening pins. The pin was fired into the steel section with a pneumatic pinning machine fad by an air compressor, with a pressure of 1200 kN/m^2 under normal operating conditions. The use of compressed air-actuated steel fasteners was introduced by Pneutek in 1976 [4,5]. Tests on the stud system were conducted to check the penetration ability of the fasteners, resistance to pull-out and uplift forces for steel decks ranged from 0.64–1.29 mm. The fasteners used by Pneutek were later tested for cyclic loading on a roof deck [6]. The results concluded that Pneutek fasteners perform adequately in cyclic loading provided that they are not installed with an excessive force which may damage the surface of the roof deck. The research was continued on the strength characteristics of Pneutek pins subjected to direct shear, tensile, and full scale diaphragm shear tests on steel deck [7]. It was reported that the strength in direct shear tests was limited by contact area over the pin diameter and the sheet thickness. For tensile tests, the axial tension is very much dependent on the materials and the driving conditions. For the full-scale diaphragm tests, a slight reduction in strength was recorded compared with the predicted strength due to difficulties in driving the pins. The Pneutek pins system was further tested on steel decks for roof construction for securing steel roof decking to structural steel supports [8]. The test results indicated that the Pneutek air actuated fasteners were able to meet the design requirements. The objective of this paper is to present the results of seven full-scale push-off tests using the Pneutek stud system with composite steel–concrete beams. The aims of the tests are to determine the shear strength, ductility, and failure modes of the proposed shear fasteners.

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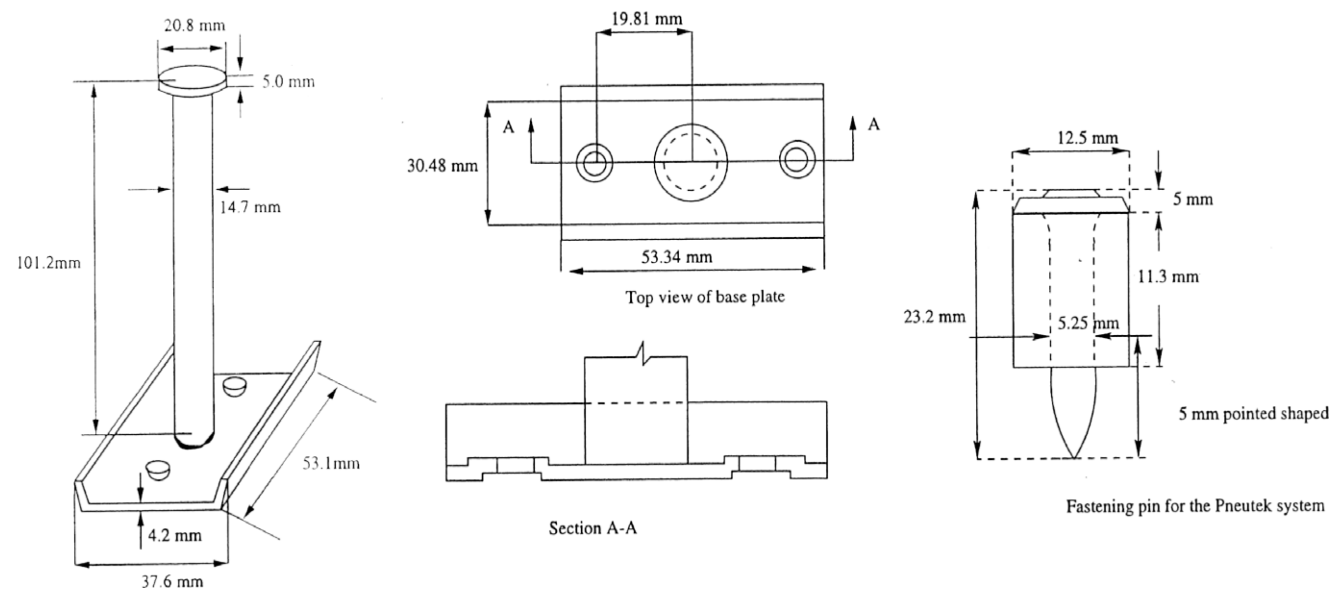

Fig. 1. Geometrical characteristics of the proposed shear stud connector (test nos. 1–6).

2. Design equations for the proposed stud system

In Eurocode 4 (EC 4) [9] the resistance per stud, P_u is defined in Eq. (6.4) of the code, as:

$$P_u = 0.7 f_u \left(\frac{\pi \times d^2}{4} \right) \tag{1}$$

where f_u is the ultimate tensile strength (UTS) of the headed stud material, taken as 450 N/mm^2 in this paper and d is the shank diameter.

This equation is based on the connections in solid concrete slabs. The failure load may be influenced by the grade of concrete, type of decking, number of stud, and the method of stud connection. However, the pin fasteners can also influence the failure modes and the ultimate resistance of the stud system.

An extra shear resistance may exist due to the base plate of the stud system. This can be calculated by taking the length and thickness of the base plate multiplied by the cube strength of the concrete, which is:

$$P_{UP} = ltf_{cu} \tag{2}$$

where l is the length of the base plate in mm, t is the thickness of the base plate in mm and f_{cu} is the average concrete cube strength.

The maximum shear resistance of the proposed stud system can be calculated by summing up Eqs. (1) and (2).

3. Composite floor construction

3.1. Specimens arrangements and configurations

The experiments were divided into two parts, with each having different shear stud characteristics. The first part comprised five tests, with three specimens cast in solid reinforced concrete (RC) slab and two specimens cast in profiled metal decking slab. All five specimens used the same size of fastening pins. The second part comprised two tests with all specimens cast in solid RC slab. The geometric configurations of all seven tests are shown in Table 1. The layout of the proposed specimens is shown in Fig. 2 for solid RC slab and Fig. 3 for cold-formed metal decking slab. The basic configurations of all specimens were in accordance with the recommendation in EC 4 [9]. All specimens were cast with in situ concrete designed to Grade 30 (C30). The concrete mixture was designed by adopting the method proposed by Kong and Evant [10]. Ordinary Portland Cement (OPC) was used for the normal weight concrete mix together with coarse aggregates (around 10 mm) and fine aggregates (graded as medium sand) for the infill concrete.

Each specimen had two slabs, namely slab A and slab B, where slab A was cast 1 day earlier than slab B. Both slabs were cast horizontally and compacted using a 25 mm diameter vibrating poker, to eliminate air pockets around the studs. Seven batches of concrete were prepared for each set of slab to be cast. Two numbers of cubes (100 mm $\times$ 100 mm $\times$ 100 mm) were cast from each batch of concrete to determine the cube strength on the day of testing. Three additional cubes were prepared to determine the time needed before the strength was in the desired range of 30–35 N/mm^2. All specimens and cubes were cured under wet hessian after casting.

In each slab (except test no. 1), one layer of 6 mm diameter steel mesh with the spacing of 200 mm $\times$ 200 mm, labelled as A142 was placed as the slab reinforcement with a 15 mm thick concrete cover. Test no. 1 has two layers of reinforcement as shown in Fig. 2. Test nos. 1–4 had the base plate of the connectors parallel to the web of the steel beam, so that the fastening pins would be fully embedded into the web of the steel section. Test nos. 5–7 had the base plate orientation perpendicular to the web as described in Table 1. In the case of test no. 5 the base plate had to be positioned perpendicular to the web because the shape of the profiled metal decking prevented them from being placed parallel. In test no. 4, a 30 mm lateral spacing (as shown in Fig. 3) for the centre stud in slab A was necessary due to the shape of the profiled decking. Details of the geometry for the profiled metal decking (CF51 and CF70) are shown in Fig. 4.

3.2. Pneutek stud system

Studs were delivered with the base plate welded to one end of the shank of the stud. Dimensions for the connectors used in the specimens are given in Fig. 1 (for test nos. 1–6) and Fig. 5 (for test no. 7). The diameter of the stud was measured to be 14.7 mm and the height to be 101 mm (from the top to the face of the base plate) for test nos. 1–6. The base plate has two holes designed to allow the two fastening pins penetrate into the section. The two holes were specially designed with an upward protrusion to allow