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Experimental study of flush end plate beam-to-column composite joints with precast slabs and deconstructable bolted shear connectors

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ABSTRACT

Composite steel-concrete floor systems represent a ubiquitous structural steel framing system for commercial and industrial buildings in the developed world, which exploit the strengths of reinforced concrete and structural steel both symbiotically and in a complementary fashion. However, as attention is being focused increasingly towards minimising emissions and maximising recycling, these composite systems are problematic for many reasons. This paper describes the results of tests on three full-scale sustainable flush end plate semi-rigid beam-to-column joints and three push-out tests with deconstructable tensioned bolted shear connectors, needed to establish the strength of the shear connection in order to design the joints. For this system, precast concrete slabs having a reduced content of ordinary Portland cement are attached compositely to the steel beam using post-tensioned high-strength friction-grip bolts that are unbolted readily at the life-cycle end of the building. This innovative connection system is proposed to circumvent the high-carbon attributes associated with the demolition of conventional steel-concrete composite framing systems. The push-out tests show that the behaviour of specimens with post-installed bolts in clearance holes is significantly different to that of members with stud shear connectors in slabs cast *in situ*, and the bolted connectors provide reliable and adequate shear connection to composite beams and joints with precast concrete slabs. The test results show that these composite joints have credible rotation and moment capacities within the recommendations of EC3 and EC4, and that fracture of the joint occurs after substantial rotational deformations had been achieved.

1. Introduction

Traditional flush end plate semi-rigid (FEPSR) composite connection is a popular and widely adopted choice for connecting a composite beam to a column in a frame, because it is economical and easily constructed on site. The rigidity of the connection allows for bending moments to be transmitted in the frame, and its ductility allows for bending moment redistribution at overload. These joints also have much higher initial stiffness, moment capacities and rotational capacities when compared with their bare steel counterparts, by virtue of the contribution of the reinforcing bars located in the slab. The tensile forces in the joint are resisted by the upper bolts and the reinforcing bars, and the compressive forces are resisted by the steel beam, creating a force couple that represents the bending moment transferred across the connection. In these composite joints, the reinforcing bars contribute significantly to the strength and stiffness of the connection [1].

Sustainable technologies in infrastructure design and construction relate to minimising carbon emissions and promoting product recycling in full life-cycle performance assessments, and in this regard traditional steel-concrete composite systems are problematic on a number of fronts. First, the composite action between the concrete slab and steel joist in a building frame is typically achieved using headed stud shear connectors that are welded automatically to the top flange of the steel beam to produce a robust shear connection, but their demolition necessarily is associated with much waste, considerable energy and environmental intrusion. Second, the slab is usually cast *in situ* onto profiled steel decking with conventional reinforcement being placed on site, which is time-consuming and labour intensive, and it is difficult to maintain the specified cover to the reinforcement. Third, these systems usually make use of concrete batched with ordinary Portland cement, whose manufacture is known to be one of the largest global sources of anthropogenic CO_2 emissions [2].

The deployment of precast concrete slabs batched from binders having up to a 65% reduction in the content of ordinary Portland cement ("green" concrete slabs) [3] with steel beams using deconstructable or demountable technologies has the potential to minimise the undesirable attributes of traditional composite framed systems when evaluated within paradigms related to sustainable infrastructure. The frame system proposed using precast green concrete (GC) slabs bolted to steel joists with high-strength friction-grip bolting procedures has components that are manufactured off-site, having the quality control that is associated with factory production. Importantly, the building system

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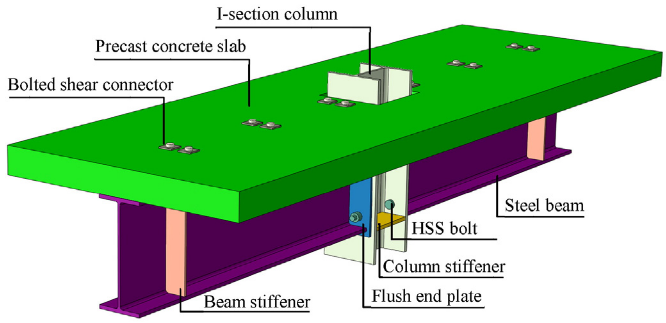

Fig. 1. Typical deconstructable flush end plate composite joint.

can be deconstructed at the end of its service life with a minimisation of waste and energy and a maximisation of recycling of the components. Central to the deconstructable composite frame system is the use of bolted shear connectors.

Marshall *et al.* [4] appear to be the first researchers to have reported the use of bolted shear connection, but the context of the usage is not clear, although 3 years earlier, Dallam [5] undertook twelve push-out tests using high strength bolts as shear connectors, but they were embedded in the concrete and so did not have clearance holes in the slab. These bolted shear connectors were tensioned by the turn-of-nut method after the concrete had reached 28 days' strength, and it was pointed out that the strength of the push-out specimens was about twice that of counterpart specimens with stud shear connectors. Six

Table 1
Details of push-out test specimens.

Specimen	Beam section $h_b \times b_{fb} \times t_f \times t_w$ (mm)	Shear connector	H_{cs} (mm)	H_{sb} (mm)	C_1 (mm)	C_2 (mm)	P_b (kN)	f_c (MPa)	N_c
PT1		M20	24	22	2	1	145	59.5	4
PT2	460UB 82.1 (460 × 191 × 16 × 9.9)	M16	20	18	2	1	95	59.5	4
PT3		M20	24	22	2	1	145	59.5	4

Note: H_{cs} = hole diameter in slab; H_{sb} = hole diameter in steel; C_1 = clearance between bolt and hole in slab; C_2 = clearance between bolt and hole in beam; P_b = applied bolt pretension; f_c = average compressive cylinder strength of concrete slab; N_c = no. of connectors, h_b = beam height, b_{fb} = flange width, t_w = web thickness, t_f = flange thickness.

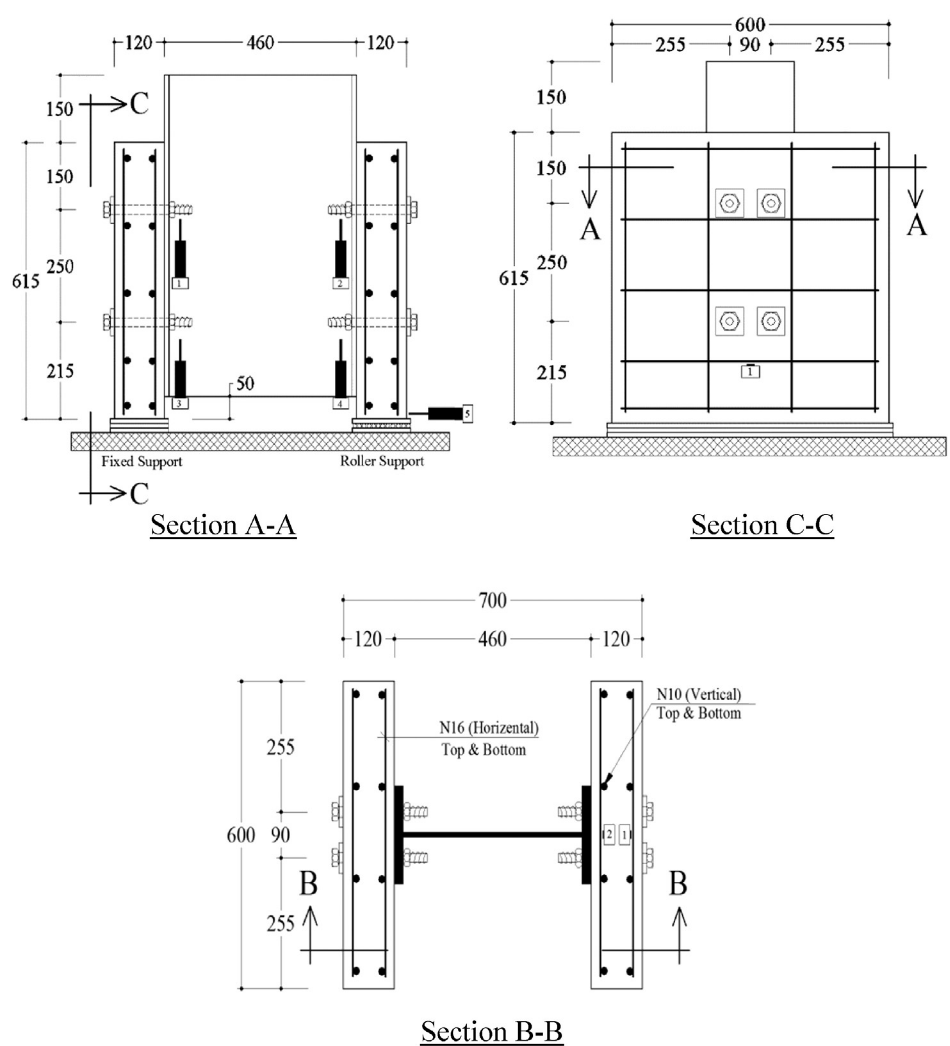

Fig. 2. Details of push-out test specimens.