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Keynote Paper

Demountable Shear Connectors for Sustainable Composite Construction

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ABSTRACT

The UK Government has set an ambitious and legally binding target to reduce national greenhouse gas emissions by at least 80% by 2050 with an intermediate target of a 34% reduction by 2020, therefore it is important to consider the whole life cycle in composite construction. Composite flooring system formed by connecting the concrete slabs to the supporting steel beams has been widely used for many years throughout the world. Steel and concrete composite construction is well established as a cost-effective arrangement for floor systems in multi-storey steel frame building structures. Composite action between steel beams and concrete slabs through the use of shear connectors are responsible for a considerable increases in the load-bearing capacity and stiffness of the steel beams, which when utilized in design, can result in significant savings in steel weight and construction cost. However, shear connectors are welded through the steel decking and cast into the concrete; this made reuse of the steel components after deconstruction almost impossible. A demountable shear connector is developed and tested to assess its potential and suitability in term of replacing the traditional welded through headed shear studs. Test results shown that these shear connectors can be easily demounted after test and have a similar capacity and behaviour of the welded headed stud shear connectors.

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1. INTRODUCTION

Composite steel structures formed by connecting the concrete slabs to the supporting steel beams have been widely used for many years throughout the world. The use of composite action between steel and concrete is well established as a cost-effective arrangement for floor systems in multi-storey steel frame building structures. Composite action between steel beams and concrete slabs through the use of shear connectors is responsible for a considerable increase in the load-bearing capacity and stiffness of the steel beams, which when utilized in design, can result in significant savings in steel weight and construction cost. However, shear connectors are welded through the steel decking and cast into the concrete; this made deconstruction and reuse of the steel components almost impossible. In steel concrete composite construction, longitudinal shear force is transferred across the steel flange/concrete slab interface by mean of the mechanical action of the shear connectors. The capacity of the shear connection to transfer longitudinal shear forces depend on the strength and stiffness of the shear connectors and also the resistance of the concrete slab against longitudinal cracking induced by the high concentration of the load imposed by the dowel action.

Present knowledge on welded headed stud shear connector in solid slab is well illustrated by Mottram and Johnson (1990) and Menzies (1971). The shear connectors used in steel – concrete composite construction have primarily been this type of connectors. These connectors can be classified as flexible connectors, because under small shear forces, there will be relative movement or slip between the concrete slab and the steel beam at the interface. The research in demountable shear connector by Lam and Saveri (2012) shown in Fig. 1 is formed from the standard 19 mm diameter T.W. Nelson headed shear connector with a 16mm threaded end; and with or without a collar, a M16 Gr 8.8 nut is used to fasten the connector to the steel beam. Since the connector is manufactured from the standard headed stud shear connector, it has the same material properties of the standard welded headed studs. Although researches on bolted connectors have been carried out previously by Dallam (1968) and Marshall et al. (1971) on bolted connectors, their main emphasis was on the pre-tension behaviour of the shear connectors using high friction-grip bolts. More recently, research by Kwon et al. (2010) on bolted connectors was focused on the post-installed capacity for strengthening existing structures rather than the sustainable issues. Research on the sustainable issue for demountable shear connectors for composite construction is limited, the only other published research to date is carried out by Mirza et al (2010) using blind bolts as shear connectors. Although they performed reasonably adequate as shear connector, some of these blind bolts have a relatively brittle behaviour. The objective of this research is to investigate the behaviour of this form of demountable shear connectors embedded in normal-weight concrete when subjected to a static shear force. The results are used to be compared with those of the welded headed stud shear connectors to help to determine the feasibility of using this form of connectors in composite construction.

Fig. 1 Demountable shear connector

2. EXPERIMENTAL STUDY

A push off test specimen shown in Fig. 2 similar to the one described in Eurocode 4 (2004) was used. The test consisted of a short length of steel beam connected to two concrete slabs 300 × 300 × 150 mm in sizes. 2 pairs of shear connectors were used to connect the concrete slabs to the steel beam, vertical load is applied to the steel beam and slip between the steel beam and the slabs are measured against the load per connector. Both sides of the concrete slabs were cast horizontally using the same mix and poured at the same time. Once the slabs reached their required strength, the slabs were then connected to the steel beam before the test. The test program consisted of eight push off tests. The test parameters included the compressive strength of concrete and the sizes of the headed stud collar. Details of the test series and their results are shown in Table 1.

Fig. 2 Push off test specimen

Table 1: Push test program and results

Ref.	Concrete Cube Strength, f_{cu} (MPa)	Stud Type	Max. Load per stud (kN)	Slip at Max. Load (mm)	Mode of Failure
POT 1	19.85	16mm	75.0	8.75	Stud fracture
POT 2	21.45	17mm collar	93.5	7.94	Stud fracture
POT 3	20.10	18mm collar	71.9	22.03	Concrete crushing
POT 4	25.20	18mm collar	81.5	10.02	Concrete crushing
POT 5	29.90	18mm collar	90.0	20.25	Concrete crushing
POT 6	61.38	18mm collar	107.5	22.03	Stud fracture
POT 7	20.10	19mm welded	71.6	5.2	Concrete crushing
POT 8	29.90	19mm welded	92.7	9.0	Concrete crushing

For specimens with demountable headed stud shear connectors, two types of failure mechanism were observed; fracture of the shear connectors near the threaded end or failure by concrete crushing and splitting. The load – slip curves of the two specimens representing these two types of failure are shown in Fig. 3. It can be seen that the load – slip curve associated with stud fracture, although quite ductile, end abruptly. Concrete crushing – splitting type of failure provides considerable warning as the load carrying capacity decreases slowly. The fracturing of the shear connectors is shown in Fig. 4 while concrete crushing and splitting failure is illustrated in Fig. 5. For the specimen failed by concrete crushing, the slabs were demounted from the steel beam and examined carefully, there was no damage occurred to the threaded portion of the demountable stud and the slabs were easily detached from the steel beam.

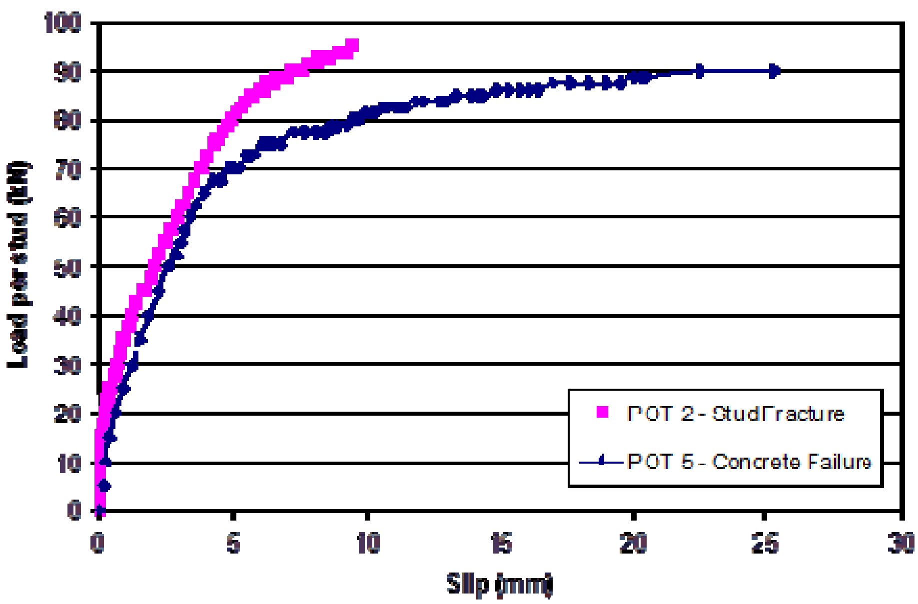

Fig. 3 Load – slip curves of demountable stud POT2 and POT 5

Fig. 4 Stud fracture

Fig. 5 Concrete crushing – splitting

A comparison of load – slip curves of push test with welded headed studs and push test with demountable connectors are shown in Fig. 6, the results showed that with similar concrete strength and mode of failure, the demountable connector appears to be more ductile than the welded connector but achieving the similar capacity. However, the welded connectors showed a much higher initial stiffness when compared with the demountable studs. In addition, at 6 mm slip, the shear capacity of the demountable connector is 16% lower than the welded connector. However, although these connectors have a lower shear capacity, this might not has significance influence to the ultimate and serviceability limited state of composite beams in bending.

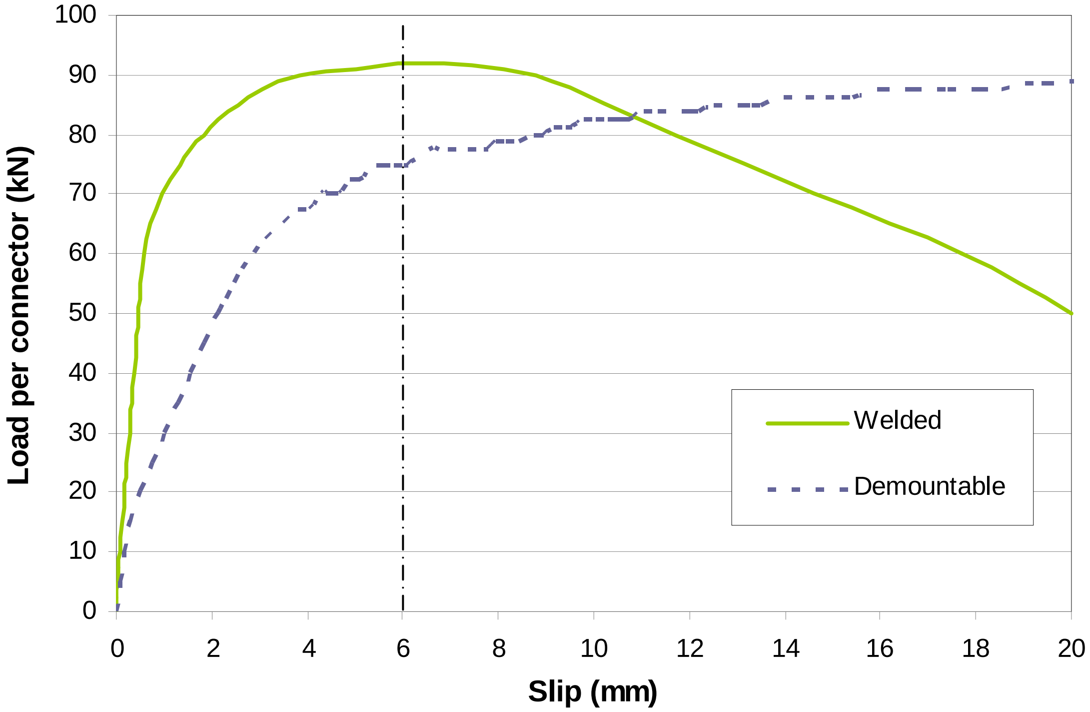

Fig. 6 Welded vs. demountable connectors in C30 concrete

3. FINITE ELEMENT MODEL

A finite element (FE) model of the steel-concrete composite beams are built using ABAQUS (2011) to investigate the load-slip behaviour of these demountable shear connectors to the ultimate and serviceability limited state of the composite beams in bending. A 12m span simply supported beam is built with solid elements with four points loading. Fig. 7 shows the 3-D FE model of composite beams with solid concrete slabs. Combination of three dimensional eight-node brick (C3D8R) and six-node wedge (C3D6R) reduced integration elements are used to model the concrete slab and the steel beam. The reduced integration approach eliminates shear locking and ensures computational efficiency of the analysis.

A 457 × 152 × 52 UB S355 is used for the steel section and a 150mm thick solid concrete slab with concrete cube strength of 30 N/mm2 and shear connectors at 300 c/c is modelled. Two points loading is applied at the one-third point. The load-slip characteristic of the shear connectors obtained from the push test experiments is represented by the spring elements in the FE model. The results of the moment vs. mid-span deflection with welded shear connectors and demountable shear connectors are shown in Fig. 8. Results showed that although the shear capacity of the demountable shear connector is 16 % lower than that of the welded connector, the effect to the bending moment capacity of the 12m composite beam is less than 5%. In addition, the low initial stiffness of the demountable shear connectors to the welded shear connectors did not have significant effect to the initial stiffness of the composite beams.

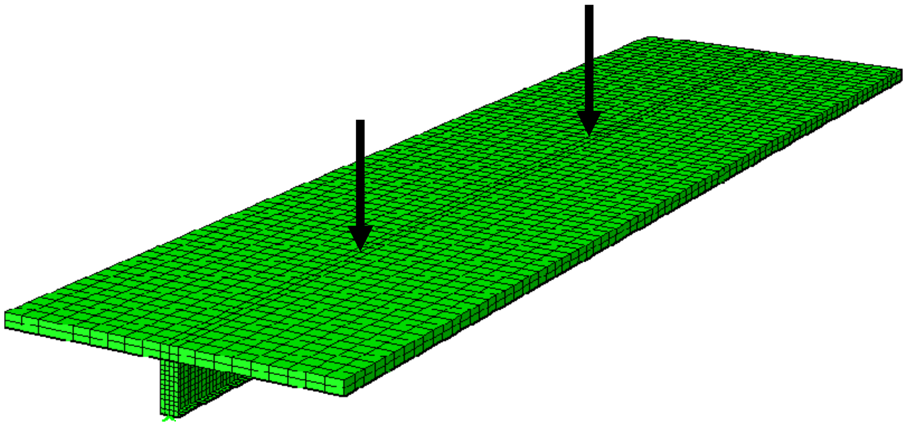

Fig. 7 FE model of 12m span simply supported composite beam

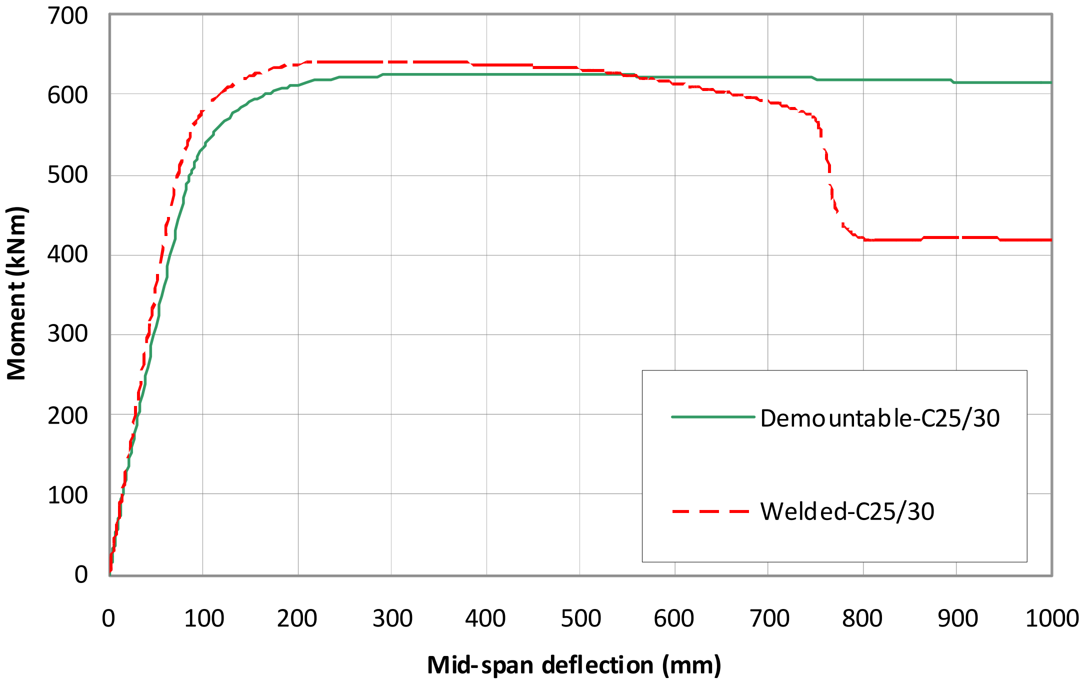

Fig.8 Moment vs. mid-span deflection of the composite beams

4. CONCLUSIONS

A demountable shear connector is developed in the form of headed stud shear connectors. A series of the push off tests have been carried out to assess its potential and suitability. Test results shown that these shear connectors can be easily demounted during the working load stage and after the test. They have a similar behaviour and shear capacity to the welded headed studs. In addition, test results showed that the new demountable shear connectors process high ductility in comparison with the welded shear connectors but relatively lower initial stiffness. A FE model is built to investigate the load slip behaviour of these demountable shear connectors to the moment capacity of the composite beams. Results showed that although the shear capacity of the demountable shear connector is 16 % lower than that of the welded connector, the effect to the moment capacity of the 12m composite beam is less than 5%. In addition, the lower initial stiffness of the demountable shear connectors did not affect the initial stiffness of the composite beam. Full-scale beam tests with this type of demountable shear connectors is currently being planned and further research on this form of demountable shear connectors with metal deck profile composite slabs is on-going.

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