Behaviour of blind bolted connections to concrete filled hollow sections

Sean Ellison writes in conjunction with his supervisor, Dr Walid Tizani, about his undergraduate project at the University of Nottingham which was highly commended in the 2003 Model Analysis Award

The use of Structural Hollow Sections (SHS) as columns in multi-storey construction is attractive for architectural reasons and because of their high strength-to-weight ratio. However, their use is presently restricted by the problems associated with making connections to other members. Early attempts at overcoming the connection problem included fully welding the connection which, in countries such as the United Kingdom, is not an attractive solution. The use of standard bolts, the principal alternative to welding for open sections, is frequently impossible in the case of SHS as it requires access to the inside of the tube to facilitate tightening. The use of additional components, such as gusset plates and brackets, overcomes this problem but is not generally considered an acceptable solution for aesthetic reasons.

The need to make mechanical connections from one side only has arisen in a number of engineering fields and has resulted in the development of several types of so-called blind-bolts. In the context of structural engineering, the commercially available blind-bolts include Flowdrill, the Huck High Strength Blind Bolt, the Ajax Blind Bolt and the Lindapter Hollobolt.

Tests performed elsewhere[1] have already proved that it is possible to design nominally pinned connections (intended primarily to transfer vertical shear) to SHS columns using the Hollobolt and Flowdrill fasteners. The capacities of the bolts and the SHS face have been shown to be sufficient to withstand the shear load as well as the limited tensile loads arising from structural integrity requirements. Indeed, a guide for the design of connections of this sort has been available for a number of years[2]. However, the tests have also shown that such fasteners do not have sufficient stiffness to classify the connection as moment-resisting.

For this reason, ongoing research at the University of Nottingham has been developing a new blind-bolt suitable for moment resisting connections in steel framed buildings.

As part of this research, tests have been conducted using three types of blind-bolts. One of these is the Lindapter Hollobolt and the other two are modifications to the Hollobolt made by the researchers at Nottingham. The three types of blind-bolts are shown in Fig 1.

This article reports on the results of a testing programme looking into the performance of these three blind bolts compared with the standard dowel bolt when used in bolted connections to concrete-filled hollow sections.

Fig 1. (Right) Bolts used in tests
Fig 2. (Below) Testing arrangement T-stub to concrete filled SHS
Fig 3. (Bottom right) Sample ready for testing

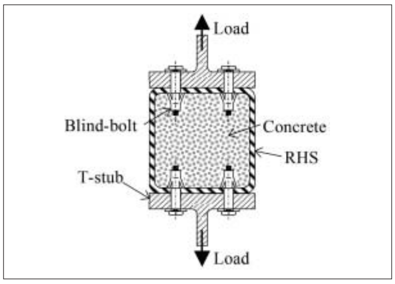


Table 1: Summary of test results of connection assemblies

Bolt Type	Ultimate load (kN)	Displacement at ultimate load (mm)	Failure mode
Standard	487.5	7.5	Bolt shank fracture
Hollobolt	536.3	10.5	Bolt shank fracture
RMH	535.6	8.5	Bolt pull-out
Extended Hollobolt	624.5	5.5	Bolt shank fracture

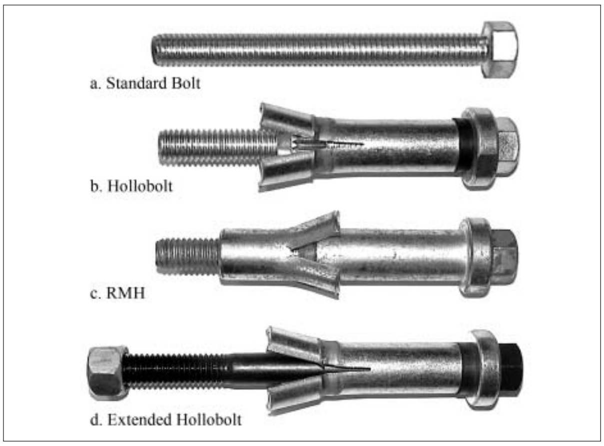
Testing programme and methodology

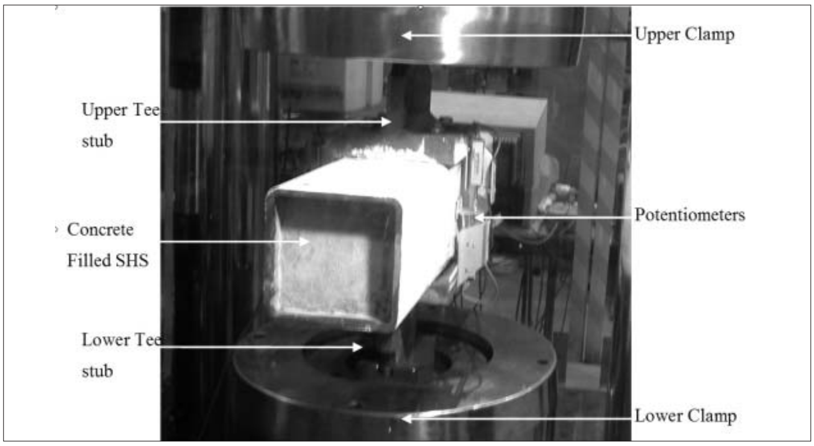
The test arrangement consisted of two T-stubs bolted to opposite sides of a 900mm length of a 200 × 200 × 10 SHS S355 (Fig 2 and 3). The T-stubs had 50mm thick endplates to eliminate the influence of the endplate bending on the behaviour of the connection. The bolt gauge was 120mm and the pitch was 100mm. The standard bolts would obviously not be used in practice in such a connection but were used here to provide a known benchmark for the other bolts. First the connections were bolted to the hollow section then the concrete infill was provided. The assemblies were left to cure for 7 days when their cube strengths, at the time of testing, varied between 54N/mm^2 and 57N/mm^2.

Four tests were conducted, one for each of the bolt types. The connected assemblies were placed in an Instron 8500 Universal testing machine with the webs of the T-stubs gripped in the jaws that apply tensile loading. Sensors were used to measure the separation of the T-stubs. Tensile load was applied at a constant displacement rate until ultimate load or excessive displacement was recorded. Bolts of the same batch as those used in the tests were separately tested to ascertain their tensile strengths. Load-displacement data and failure modes were recorded at the end of the tests.

Test results and analysis

The results are given in the form of load-displacement curves and failure modes. Table 1 shows the ultimate load and the associated displacement for each test type. The displacement was measured as the separation between the top and bottom T-stubs. Table 1 also gives the mode of failure. In the cases of the standard bolt, Hollobolt and Extended Hollobolt, the failure was by the tensile fracture of the bolt. However, the RMH connection failed by the collapse and





subsequent shearing of the legs of the expanding sleeve resulting in the bolts being pulled out of the section.

Table 2 provides the measured ultimate strengths for each of the bolt types. Because of the variability between the tensile properties of the bolts and to allow for direct comparisons between the tests, the load-displacement relationships were normalised using the ultimate load of the standard bolt as the reference. Figs 4 and 5 show the load-displacement curves for the raw data and the normalised data respectively.

Effect of concrete
The concrete confinement, as expected, has stiffened the tube wall against bending, and with the use of a stiff end-plate, the behaviour of the connection is dominated by the behaviour of the bolts. This was the intention of the testing programme so that direct comparisons between these bolts could be obtained. As a result the concrete filled tube had suffered very little deformation and the ultimate strengths of the bolts were attained. The results were also compared with previous tests carried out on unfilled hollow sections[3] where it was clear that the flexibility of the tube wall dominated the behaviour of the connection and the ultimate resistance of the bolts were not attained.

Table 2: Properties of bolt shanks, all fully threaded

Bolt type	Shank length (mm)	Nominal diameter (mm)	Theoretical ultimate tensile resistance (kN)	Actual ultimate tensile resistance (kN)
Standard bolt	120	16	125	126.3
Hollobolt	120	16	125	121.9
RMH	120	16	125	121.9
Extended Hollobolt	150	16	125	149.9

Comparison of ductility
The connection made with the Hollobolt exhibited the highest ductility – determined as the displacement capacity before failure. The RMH exhibited the next highest ductility capacity with 8mm displacement at ultimate load compared with 10mm for the Hollobolt. This can be explained by the flexibility offered by their fastening mechanisms. The standard bolt provided some ductility, with 7.5mm displacement, but as would be expected failed in a brittle manner. The Extended Hollobolt surprisingly exhibited even lower ductility than the standard bolt with 4.7mm displacement. The behaviour of the Extended Hollobolt is thought to be due to the anchoring nut that was provided at the tip of the bolt shank and partly due to the bolt characteristics as the bolt tensile test showed higher ultimate strength and less ductility than the standard bolt.

A full report on this project is available in the Institution library. The Model Analysis Award is an annual competition for experimental projects carried out by final year undergraduates and first year postgraduates. Applications are invited from March and papers have to be submitted by the end of June.

Comparison of stiffness
The ductility of a connection would normally be provided by guarding against bolt failure modes. Bolt ductility, although beneficial, would not normally be a factor considered in the connection behaviour. The stiffness characteristic, on the other hand, is the deciding factor when assessing the rotational behaviour of such connections. Fig 4 shows that the connection made with standard bolts had the highest stiffness. Such behaviour can lead to rigid connection behaviour when used with the appropriately sized beam and column. This level of stiffness was treated as the benchmark for the other types of connections. The RMH and Extended Hollobolt connections displayed very similar stiffness characteristics to those of the standard bolt whereas the Hollobolt displayed much lower stiffness. In the case of the Extended Hollobolt the additional anchorage, offered by the extended shank length and the anchorage nut, significantly improved the stiffness characteristics of the connection. Therefore, such connections are judged to be capable of exhibiting rigid behaviour when using the RMH or the Extended Hollobolt whereas those using the Hollobolt can at best exhibit semi-rigid behaviour.

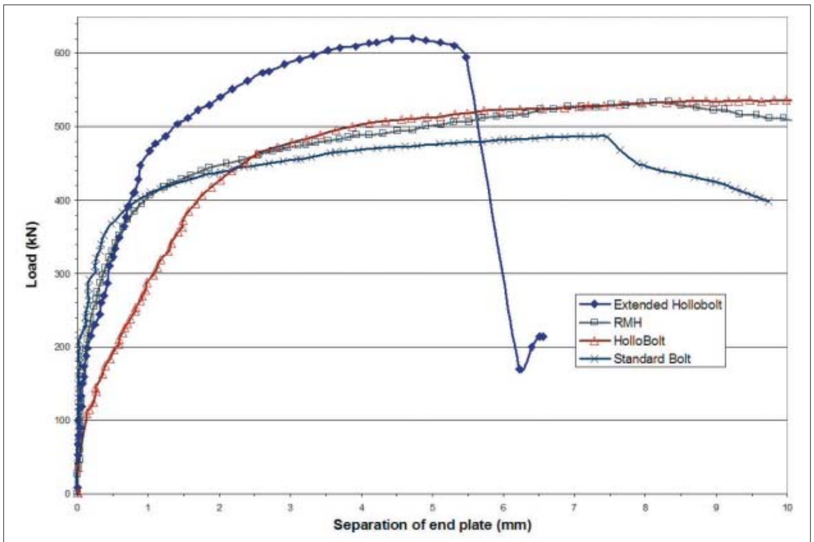


Fig 4. Load–displacement relationships, raw data

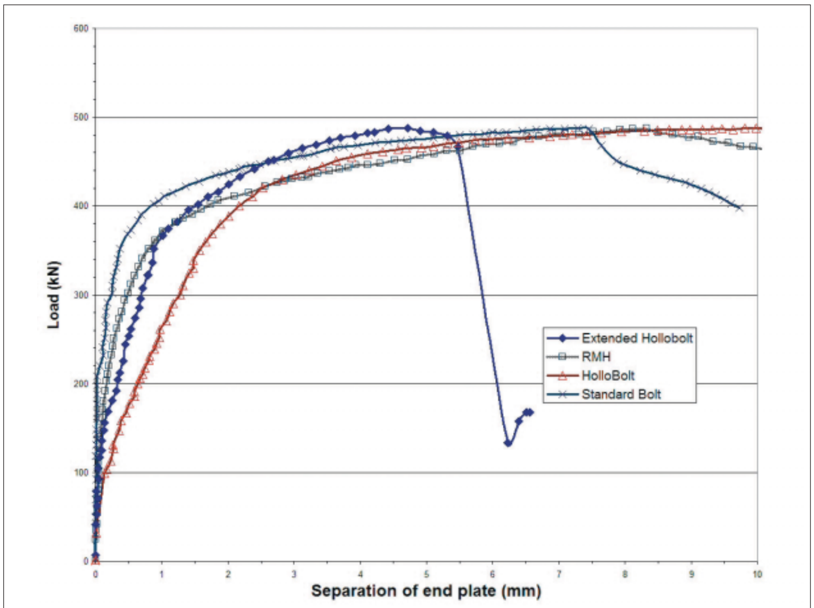


Fig 5. Load–displacement relationships, normalised for ultimate load of standard bolt

Conclusions

The results of this exploratory testing programme indicated that rigid connections to hollow sections could be achieved using blind-bolts. The tests used modified Hollobolt connectors and concrete filled hollow sections. These are preliminary results; the assembly was not tested with the bolts subjected to combined shear and tension, as would be expected when moment is applied. However, the results do clearly indicate that moment-resisting connections to hollow sections are feasible and could replace the more expensive and cumbersome welded connections. se

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