The performance of a new blind-bolt for moment-resisting connections

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ABSTRACT: The paper introduces the principal findings of a testing programme carried out to assess the performance of a newly developed blind-bolt. The blind-bolt, an evolution of the Lindapter-Hollobolt, is intended for use when making moment-resisting connections to Rectangular Hollow Sections. To date, the testing programme has concentrated on ascertaining the tensile strength and axial stiffness of the bolt, with tests subjecting the blind-bolt to a predominantly tensile load in a representation of the tensile region of such a connection. The results of the initial tests have shown the new blind-bolt to possess sufficient stiffness to classify the connection as moment-resisting but a lower tensile strength than standard bolts. However, the addition of a concrete infill to the tube in later tests has resulted in a tensile strength equivalent to standard bolts together with axial stiffness sufficient to classify the connection as rigid.

1 INTRODUCTION

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 for on-site fabrication. The use of standard dowel 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 fasteners. 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 (e.g. Banks 1997 and France et al. 1999) have already proven 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 (British Steel, 1997). However, the tests have also shown that such fasteners do not have sufficient stiffness, relative to that of the connecting beam to classify the connection as moment-resisting.

For this reason, ongoing research at the University of Nottingham has been concerned developing a new blind-bolt suitable for moment resisting connections in steel framed buildings. The research, funded by DETR (Department for the Environment Transport and the Regions, UK) has resulted in a modification of the commercially available Hollobolt with an ability to allow sufficient clamping force to generate the required stiffness for a moment-resisting connection. The research is also concerned with developing a fundamental understanding of the behaviour of the SHS face when subjected to moments from a connection fastened using a blind-bolt capable of such clamping action.

This paper introduces the new blind bolt, know as the Reverse Mechanism Hollobolt (RMH), and presents the principal results of tests carried out to compare its performance with the commercially available Hollobolt and standard bolts.

2 REVERSE MECHANISM HOLLOBOLT

The Lindapter Hollobolt (Figure 1b) performs well for shear-connections, but does not generate sufficient clamping force to prevent axial deformation at high tensile loads. For this reason, connections made with Hollobolts cannot, for most configurations, be classified as moment-resisting. Recent research at the University of Nottingham (Barnett et al. 2000) has resulted in a modification of this bolt, known as the Reverse Mechanism Hollobolt (RMH) for which the expanding part is inverted. The RMH was developed in an attempt to form a blind connection with comparable performance in clamping (and hence stiffness) and tensile strength to equivalent connections made with standard bolts.

The RMH (Figure 1a) consists of three separate sections: a standard set screw, a mild steel tapered plug, and a threaded, slotted, mild steel sleeve. Upon tightening of the bolt head, the sleeve grips the tapered plug, resulting in subsequent tightening causing expansion of the sleeve through flaring of its legs. The expanding sleeve of the RMH flares directly against the underside of the connection (Figure 2) producing more effective clamping of the connected plies than that provided by the Hollobolt.

3 OVERVIEW OF TESTING PROGRAMME

To develop and evaluate the performance of the RMH, three main test series were carried out: T-stub to t-stub (Figure 3); t-stub to SHS (Figure 4); and t-stub to concrete filled SHS (Figure 5). In all of the tests, a relatively rigid t-stub (50 mm thick) was employed in order to eliminate the influence of end-plate bending and result in connection behaviour being dependent on the behaviour of the bolts and the interaction between the bolts and the SHS.

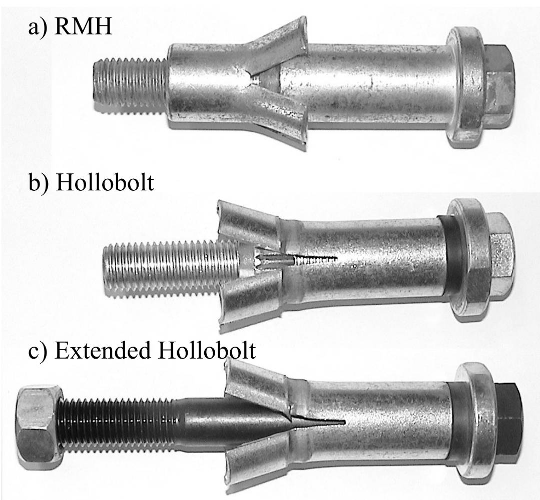

Figure 1. Blind bolts (expanded)

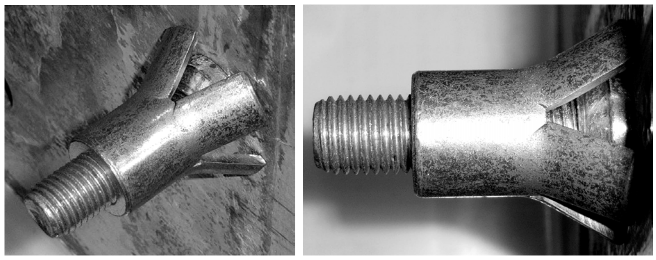

Figure 2. Clamping action of the inverted sleeve of the RMH

The tests, which were conducted in displacement control, exerted predominately pure tension forces in the bolts. This is because plate bending has been virtually eliminated due to the plate thickness employed. The bolts used in all the tests were grade 8.8 (with minimum ultimate tensile strength of 800 N/mm^2 providing design tensile strength of 450 N/mm^2) and of 16 mm shank diameter. These were used in conjunction with grade S355 square section SHS of external width 200 mm and thicknesses of 8, 10 and 12 mm. The size and grade parameters were selected to correspond with the common situation for construction in the United Kingdom.

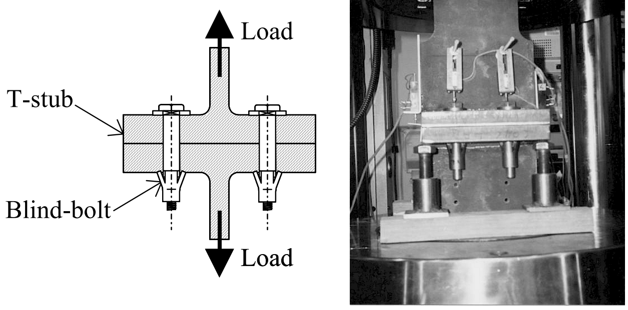

Figure 3. T-stub to t-stub testing arrangement.

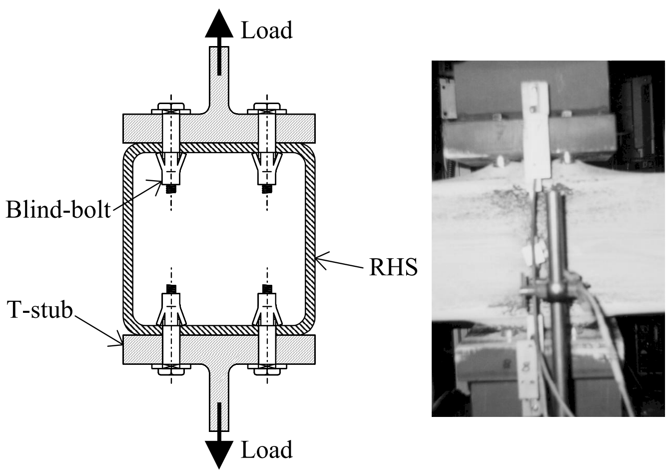

Figure 4. T-stub to SHS testing arrangement.

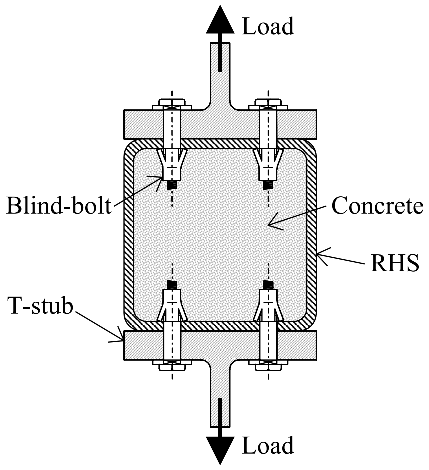

Figure 5. T-stub to concrete filled SHS testing arrangement.

The results of the tests have shown (Barnett et al. 2000) that connections made to unfilled Rectangular Hollow Sections (RHS) with the RMH are stiffer than corresponding connections made with the Hollobolt and have greater tensile strength and ductility (e.g. Fig. 6). The Hollobolt was seen to fail by being pulled through the hole in the tube due to the widening action of the conical expanded sleeve and shearing off of the sleeve's legs (Fig. 7). In contrast, the behaviour of the connections made with the RMH was governed by the behaviour of the tube wall, because the inverted expanding sleeve of the RMH was not susceptible to being pulled through the hole. Despite the difference in the failure mode, the tension-separation curves for the RMH connections were similar in shape to the equivalent Hollobolt connections and showed similar stiffness as the ultimate tensile capacity was approached.

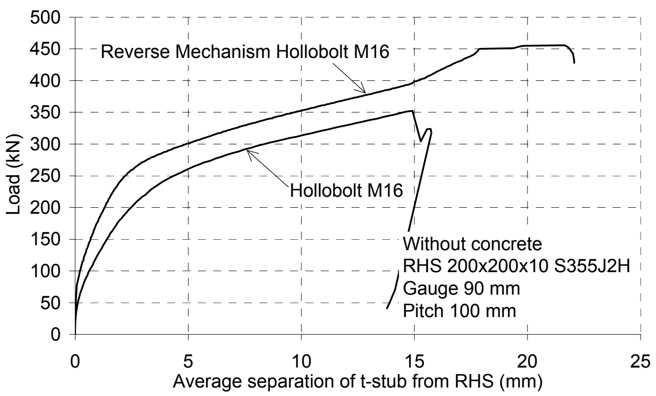

Figure 6. RMH and Hollobolt without concrete infill.

Figure 7. Hollobolt after being pulled through the hole in SHS.

Indeed, connections made with the RMH were seen to be almost as stiff as those made with standard bolts (e.g. Fig. 8), and the behaviour was seen to be comparable at the lower loads. Standard bolts were seen to be slightly stiffer following the onset of non-linearity, but the RMH connections were able to sustain greater deformation and a slightly higher tensile capacity. The behaviour of connections made with standard bolts and the RMH was seen to be heavily influenced by the flexibility of the tube wall (Fig. 9) and consequently the performance of connections to thinner tubes was not limited by the performance of the bolts themselves.

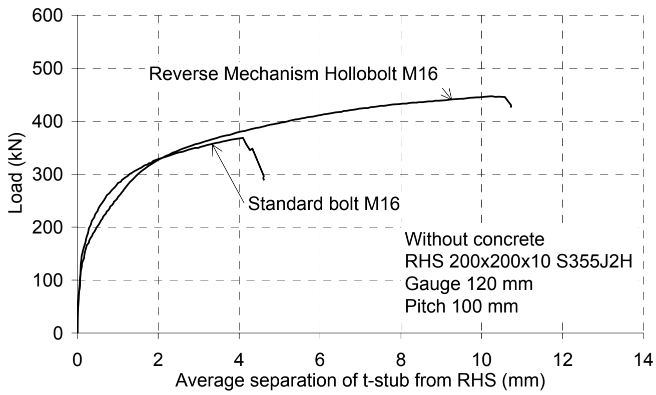

Figure 8. RMH and standard bolt without concrete infill.

A concrete infill (after bolting) to the tube improves the performance of a connection made with standard bolts (e.g. Fig. 10) by resisting the deformation of the tube wall. A concrete infill was seen to result in significant increases in ductility and strength as it allowed the full tensile capacity of the bolts to be developed. Ultimately, the failure of the filled connections made with standard bolts was seen to be due to tensile fracture of the bolts (Fig. 11).

Similarly, a concrete infill was seen to result in an improvement in the performance of connections made using the RMH (e.g. Fig. 12). As for standard bolts, this improvement stems from the concrete's resistance to deformation of the tube walls. It is also possible that the concrete encases the expanding mechanism of the bolt and resists further spreading under load. For the RMH, the concrete infill results in an increase in tensile capacity, but the ductility remains similar to that of the unfilled situation. The stiffness of the connection close to the development of the tensile capacity was also seen to be unaffected by the presence of the concrete.

The performance of the connection made with concrete infill was seen not to be influenced by the strength of the concrete. Indeed, the results of the tests (Fig. 13) showed the connection made with the weaker concrete performing slightly better at high deformation. It is thought that this is due to the effect of confinement of the concrete within the tube regardless of strength. Note that, in the case of the concrete filled connections, the tensile load resisted drops to the capacity of the unfilled connection once the capacity of the filled connection is surpassed. Ultimately, the failure of the filled connection made with RMH was seen to be due to the collapse (Fig. 13a) and subsequent shearing of the legs (Fig. 13b) of the expanding sleeve resulting in the bolts being pulled out of the RHS (Fig. 14).

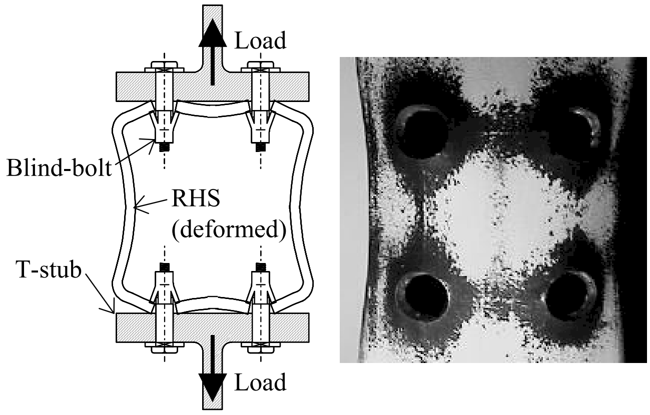

Figure 9. Deformation of the walls of unfilled SHS.

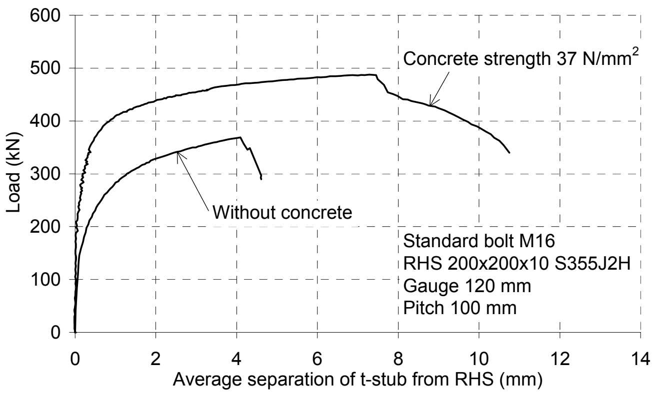

Figure 10. Standard bolt with and without concrete infill.

Figure 11. Tensile failure of standard bolt with concrete infill.

Connections made with the RMH to concrete filled tubes were seen to perform as well as, if not better than, equivalent connections made with standard bolts to concrete filled tubes (e.g. Fig. 15). The connections made with the RMH were slightly less stiff than those made with standard bolts, but were seen to be slightly stronger and more ductile. It is thought that the improvement in tensile capacity may be due to the load being more evenly distributed between the RMH bolts than the standard bolts.

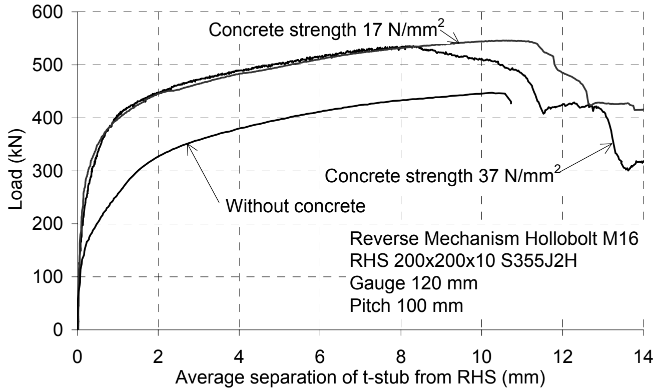

Figure 12. RMH with and without concrete infill.

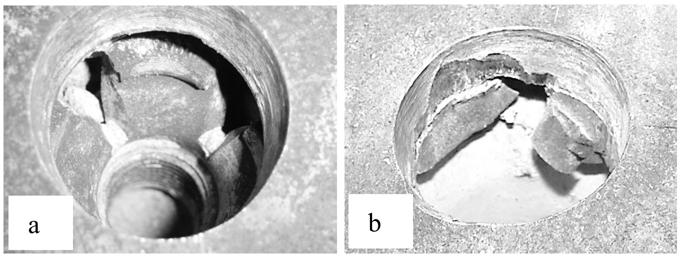

Figure 13. Failure of RMH connection to concrete filled tube.

Figure 14. Failure of RMH bolt with concrete infill.

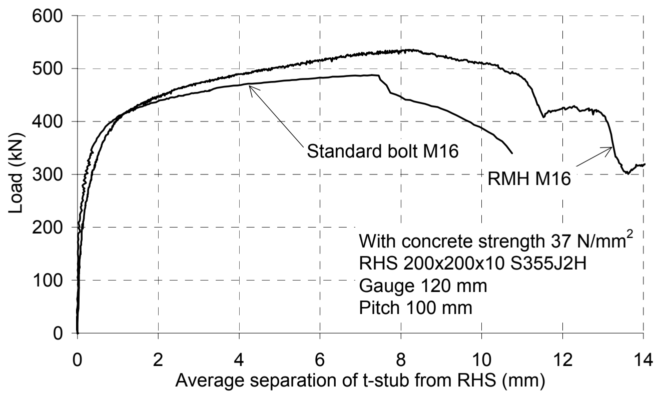

Figure 15. RMH and standard bolt with concrete infill.

The performance of connections made with the Lindapter Hollobolt were also seen to be improved by the addition of a concrete infill (e.g. Fig. 16). The strength and ductility of the Hollobolt connections were equivalent to the RMH connections. However, the stiffness of connections made with the Hollobolt were lower than those of the RMH. This is because the Hollobolt remained susceptible to being pulled partially through the hole prior to the development of the tensile capacity. However, failure of the filled connections made with Hollobolts was seen to be due to tensile fracture of the bolts (Fig. 17).

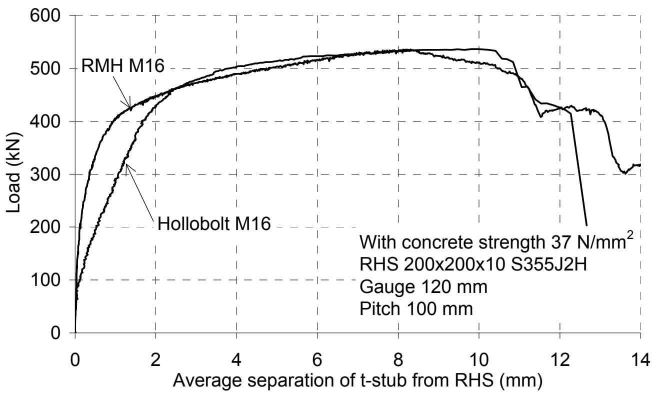

Figure 16. RMH and Hollobolt with concrete infill.

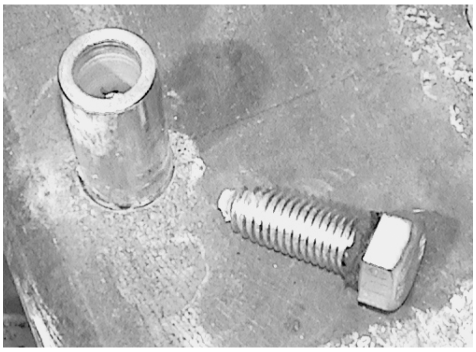
Figure 17. Tensile failure of Hollobolt (end-plate removed).

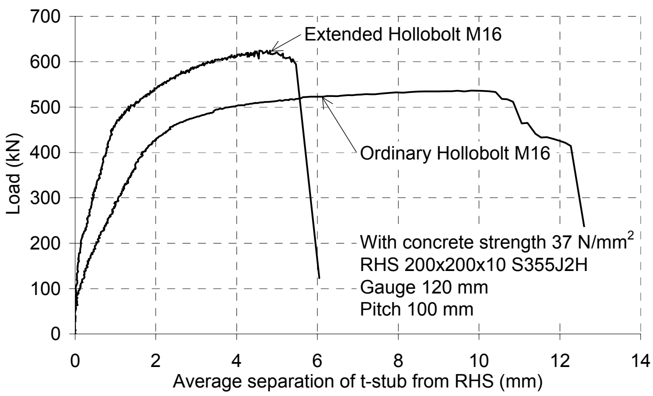

Figure 18. Extended Hollobolt with concrete infill.

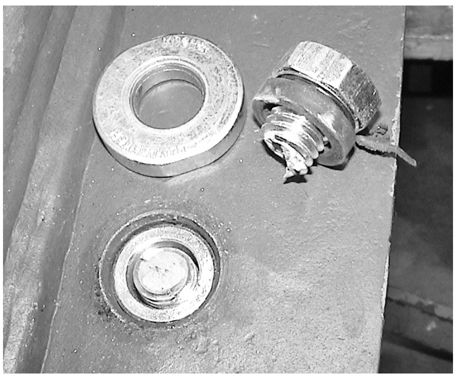
Figure 19. Tensile failure of extended Hollobolt.

The lower tensile stiffness of connections made using the Hollobolt, even to tubes subsequently filled with concrete, means that the Hollobolt remains unsuitable for use in moment resisting connections for the majority of configurations. However, a preliminary test has indicated that the use of a longer (by 30 mm, Fig. 1c) bolt and additional standard nut to anchor the Hollobolt in the concrete (Fig. 18) results in a stiffness improvement. Tensile capacity was also seen to be increased, although the ability of the connection to absorb deformation was reduced. Very little deformation of the tube wall was observed and, ultimately, the failure of the filled connection made with extended Hollobolts was seen to be due to tensile fracture of the bolts at the bolt head (Fig. 19).

4 ASSESSMENT OF POTENTIAL

The use of structural bolted connections of primary beams to hollow sections columns is not widespread in practice despite the advantages they provide in terms of construct-ability and cost. In the UK, design guidance is available for designers to provide such a connection but only for shear-resisting connections. Presently, there does not seem to be an alternative to welding (whether fully welded beams to column connection or stubs welded to columns) in the case of providing moment-resisting connections.

The provision of bolted moment-resisting connections to hollow sections would be beneficial in practice, especially where smaller column and beam cross-sectional areas are required. The achievement of such a connection has been hindered, so far, by two factors: namely the non-existence of an available blind-bolt offering performance equal to that of standard bolt and the fact that the flexibility of the tube wall means that even if such a bolt existed the connection is, at best, semi-rigid in behaviour, which in itself is problematic due to there being no guidance as to the moment-rotation stiffness for such a connection.

This paper has presented preliminary findings of tests carried out on a new blind bolt that posses relatively high axial stiffness that is comparable to standard bolts. The paper also showed that when such a bolt used in concrete filled hollow sections columns, high axial stiffness, adequate to classify such a connection as rigid, is achieved.

These results are promising, but further tests appraising the behaviour of these connections under tension and shear, will need to be carried out.

It is anticipated that such a bolted moment-resisting connection would be beneficial in practice by providing a bolted alternative to welded connections and is likely to further promote the use of hollow sections as columns.

From the construction viewpoint such a connection is feasible. The beams can be bolted to the columns in the first instance providing a working structure capable in most situations to withstand construction loads. The concrete infill can then be provided to the assembled structure.

5 CONCLUDING REMARKS

The paper introduced the principal findings of a testing programme carried out to assess the performance of a newly developed blind-bolt. The blind-bolt, an evolution of the Lindapter-Hollobolt, is intended for use when making moment-resisting connections to Rectangular Hollow Sections.

To date, the testing programme has concentrated on ascertaining the tensile strength and axial stiffness of the bolt, with tests subjecting the blind-bolt to a predominantly tensile load in a representation of the tensile region of such a connection.

The results of the initial tests have shown the new blind-bolt to possess sufficient stiffness to classify the connection as moment-resisting but a lower tensile strength than standard bolts. However, the addition of a concrete infill to the tube in later tests has resulted in a tensile strength equivalent to standard bolts together with axial stiffness sufficient to classify the connection as rigid.

Exploratory tests carried out on an extended Hollobolt have also shown promising results in that higher axial stiffness was achieved. However, lower deformation capacity was also recorded.

The results obtained so far are promising, but further tests appraising the behaviour of these connections under tension and shear, will need to be carried out.

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