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Hysteretic performance of a new blind bolted connection to concrete filled columns under cyclic loading: An experimental investigation

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ABSTRACT

The structural performance and reliability of a new blind-bolting technique is investigated in this study. The new blind-bolt is termed Extended Hollobolt (EHB) and is a modification of the standard Hollobolt. The EHB enhances the tensile resistance and stiffness of the fastener by anchoring it in the concrete infill of a tubular column. This paper reports on an investigation into the cyclic behaviour of end-plate connections to concrete filled tubular (CFT) columns using the EHB. A series of six full-scale connections were tested under quasi-static cyclic loading. The key parameters investigated were amplitude of cyclic loading procedure, bolt grade, tube wall thickness, and concrete grade. The strength, stiffness, rotation capacity and energy dissipation capacity of the connections were evaluated at different load cycles. The EHB provided stable hysteretic behaviour with appropriate level of strength and stiffness, where strength is comparable to that of standard bolt-and-nut fasteners and where rigid behaviour can be achieved. The influence of tube wall thickness and concrete grade on the performance of the connection in terms of strength, stiffness, ductility and failure mode is investigated. It is shown that the required performance can be achieved by controlling the tube wall thickness and concrete strength. The results indicate that the connection can offer energy dissipation capacity and ductility appropriate for its potential use in seismic design.

1. Introduction

The advantages obtained by using concrete-filled tubes (CFTs) in multi-storey construction have been recognised for a number of years [1]. Tubular sections are more efficient than open sections when dealing with compression, and their load carrying capacity can be significantly increased when filled with concrete. Moreover, the ductility and rotation capacity of the CFT columns is much enhanced when compared with other types of composite columns, as the infill concrete is confined and cannot split away even if its ultimate strength is reached [2]. As a result, CFT columns are very attractive for seismic design of moment resisting frames in seismic zones. The connection to CFT columns, however, tends to be complicated and would normally involve welding [3] or the use of embedded steel bars [4] to develop sufficient moment capacity. The post-earthquake survey conducted following the Northridge earthquake 1994 indicated poor performance of welded beam to column connections, as they led to brittle fractures and catastrophic failures in steel structures [5]. Although most of these failures were not associated with tubular columns, in general, they highlighted the existing problems with welded connections in seismic regions. As an alternative solution, some improved connection configurations have been suggested by contemporary researchers, such as bolted endplate connections, which are popular in Europe. This type of connection is also favoured since it involves shop welding and on-site bolting, thus avoids issues related to site welding. Endplate connections are also available for tubular sections through the use of blind bolts (such as Hollbolt and Flowdrill), but only as simple pin connections resisting shear loads and some tension mainly to satisfy the integrity criterion [2]. Blind bolts are bolts that are only tightened from one side (more details are available from [6]).

Moment-resisting blind-bolted connections to hollow columns are not currently available in practice. However, a number of research studies have been conducted to determine the resistance of such systems mainly for typical connections (such as those using Hollbolt, Flowdrill Ajax One-side). Examples of these studies include work done to evaluate the tensile strength and stiffness of blind-bolt fasteners using T-stub models [1–9] and full scale endplate connections to CFT columns [10] and other experimental connections types [11,12]. France et al. [13] conducted monotonic loading tests on Flowdrill connections to CFT columns, and showed that the strength and stiffness of such connections are dramatically higher than those without concrete infill. Loh et al. [14] tested cruciform composite blind bolted endplate connections to CFT column under bending. They reported that using CFT prevents local tube failures. In contrast, hollow steel would typically fail by excessive

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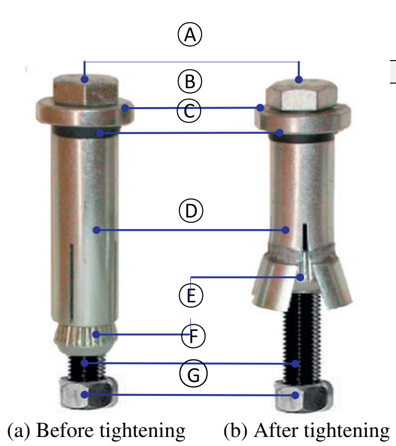
deformation of tube face and pull out of the Hollobolts. Goldsworthy and Gardner [15] conducted tests on blind bolted T-stub connections. They used a modified Ajax one-side blind bolt. The modification involved welding a piece of steel reinforcing bar to the end of the bolt shank that was anchored in the concrete infill. Good results regarding failure modes and capacities were reported except for unexpected fractures in welds which occurred at the extension bars in some tests. In another study, Wang et al. [16] performed monotonic and cyclic loading tests on eight cruciform bolted endplate connections with Hollobolts. They used cold-formed tubes, which have affected the failure mode of the tubes from face bending to splitting at the corners (a typical failure mode for cold-formed tubes).

Tizani and Ridley-Ellis [9] performed investigation using a modified Hollobolt, called the Extended Hollobolt (EHB). In the EHB, bolt and extension are made in one piece and an extended bolt shank is used with an additional nut (called the anchor nut) as shown in Fig. 1. The extended shank is immersed in the concrete infill and thus can provide an enhanced blind-bolt tensile strength and stiffness. This technique has proved to be very beneficial as the tensile failure mode of the EHB resembles that of the standard bolt-nut fastener (i.e. the ultimate tensile resistance of the bolt shank is achieved through bolt shank fracture). This is compared with the typical failure mode of the standard Hollobolt, which is the pulling out of the connected tube by either the shear failure of its sleeve or the punching shear of the tube. This latter failure mode tends to occur at a lower resistance level compared to the ultimate resistance of the bolt shank. Although no direct quantitative comparisons were made, the performance of the EHB is considered superior to alternatives, in term of strength and stiffness. Higher strength and stiffness are evident when compared with the connections that used the standard Hollobolt with CFT [e.g. 16]. The extension being part of the bolt also eliminates undesirable failures such as those experienced in welded extensions [e.g. 12].

Recent design guidelines, such as FEMA-350 [17] and Eurocode-8 [18], have incorporated the use of semi-rigid and/or partial strength connections. The performance of moment-resisting (semi-rigid to rigid) blind-bolted connections under cyclic loading has been investigated for top and bottom cleat connections made with Hollobolts [11] and for endplate connections to circular hollow sections using Ajax One-side blind bolts [15]. In these studies, the influences of relevant material and geometric parameters on the cyclic behaviour of the connections were examined.

Al-Mughairi et al. [10] reported significant improvement in the stiffness of endplate connections made with the EHB under monotonic loading where the connections exhibited rigid or semi-rigid behaviour. This outcome was encouraging for this type of connection. However, the performance of this type of blind-bolted connection under cyclic loading has not yet been examined.



No.	Components
A	Bolt head
B	Collar
C	Rubber washer
D	Sleeve
E	Threaded cone
F	Bolt shank
G	Anchor nut

Fig. 1. Components of the proposed Extended Hollobolt (EHB).

The work presented in this paper attempts to address this issue by investigating the inelastic hysteretic behaviour of the new proposed blind-bolted connection. The expected response of such connection is more complex than those not involving concrete infill. This is due to the unknown contribution of the EHB anchorage in the concrete under cyclic loading. The current study involves conducting representative experimental programme to examine the contribution of the EHB, the confined concrete and the column face. Based on the experimental results, the cyclic characteristics of the blind-bolted connection using the EHB are presented and discussed in terms of failure modes, strength, stiffness, and energy dissipation.

2. Experimental programme

2.1. Test specimens

To study the hysteretic behaviour of the blind-bolted connections to CFT using the EHB, six full-scale beam to column connections have been tested under quasi-static cyclic loading. The connection detailing and the test arrangements are shown in Figs. 2 and 3, respectively. The following parameters were varied in the test specimens: tube wall thickness (t_c), blind bolt grade (b_{gr}), concrete grade (c_{gr}), and loading procedure (l_p) (see Table 1). The specimens were designated as BBEC-t_c-b_{gr}-c_{gr}-l_p, where BBEC denotes blind-bolted-endplate-connection. For instance, the reference for Test 4 in Table 1, BBEC-5-8.8-50-LII, stands for a tested specimen using 5 mm thick tube, 8.8 blind bolt grade, and with nominal concrete strength of 50 N/mm^2, tested using cyclic loading procedure type II. The applied quasi-static cyclic loadings (types I and II) will be introduced in the next section. All test specimens were designed with similar configurations of steel beam (UB356 × 171 × 67 mm), endplate (404 × 220 × 25 mm) and three rows of bolts as shown in Fig. 2. This configuration was determined to provide sufficient capacity and stiffness of the beam and endplate, thereby eliminating their influence on the joint failure mechanism. The design of the test specimens is outlined as follows: tests T1 and T2 to study the influence of bolt grade; tests T2 and T3 to study the influence of cyclic loading procedure; tests T1, T4 and T5 to study the influence of tube wall thickness; and tests T5 and T6 to study the influence of concrete strength.

The blind bolts used in the tests were 16 mm diameter (M16) with extended shank length and an end anchor nut (Fig. 1). The blind bolts were initially tightened with a spanner and then with a torque wrench in accordance to the specified torque values listed in Table 1. Prior to concrete casting and vibration, the anchor nut was prevented from unexpected rotation and removal by securing it using special glue. Standard concrete cubes were cast at the same time as the test specimens and cured in water at room temperature of approximately 20 °C. The compressive strengths of the concrete cubes at the time of testing are summarised in Table 1. The material properties of the steel components are shown in Table 2. These values were obtained using tensile coupons designed and tested according to EN 10002-1: 2001 [19].

2.2. Experimental test set-up

Figs. 2 and 4 show the experimental test set-up used in this study. The specimens have been tested in the horizontal plan to lower the height of the actuator and reduce the loading demands on the reaction frames fixed on the strong floor (see Fig. 4). The CFT column (d) was securely fastened into the test rig by roller supports positioned at both column ends to prevent any sideway