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Progressive collapse behaviour of endplate connections to cold-formed tubular column with novel Slip-Critical Blind Bolts

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ABSTRACT

A novel blind bolt, named Slip-Critical Blind Bolt (SCBB), was recently invented at Tongji University to be used as slip-critical high strength bolt for moment connections with handy installation from outside of tubular column. This paper applied SCBBs in extended endplate connections to cold-formed Square Hollow Section (SHS) columns, and investigated this application in the beam-to-column assembly against progressive collapse. The performance of SCBBs at connection regions was evaluated in four full-scale specimens with different configurations. Four distinct failure modes were identified, including fracture at beam section, pull-out of bolts from column wall, plastic deformation of endplates and welded bottom flange fracture forcing the reinforcing component to work. Throughout the damage evolution, the SCBBs performed satisfactorily by clamping the connected plates firmly without slip occurring at the plate interface, showing a good mechanical property as being slip-critical high strength bolts. Under the progressive collapse scenario, SCBBs maintained the integrity of the blind bolted connection, thus facilitated the assembly to effectively develop the catenary mechanism which provided significant vertical resistance under large deflection. The considerable potential of SCBB to be applied into the blind bolted moment connections against progressive collapse and its effectiveness were further verified by comparison between the test specimens and other published moment-resisting beam-to-column assemblies.

1. Introduction

Hollow section has become a popular alternative to open sections for columns owing to its good mechanical behaviour of flexural and torsional capacities as well as the favourable composite effect when filled with concrete. At present, the connections between hollow section columns and adjacent structural components are mainly made by welding with outer-diaphragm, inner-diaphragm or through-diaphragms [1]. The traditional bolting, which requires operations on both ends to install the bolts, has limited use in building structures with hollow sections due to the inaccessibility into the internal space of the normal-sized tubes. Therefore, a number of blind bolts (or one-side bolt), as listed in Table 1, have been developed in order for the convenient installation and fastening of bolts from only one side (outside the hollow section column). The products of blind bolts are featured by a number of factors, such as applicable clamping thickness of the connected plates, specified pre-tightening force, tensile and shear capacities, diameter of bolt shank, gap between the shank and the bolt hole, and the installation tools. In order to obtain large stiffness and capacity, a moment connection in high seismic zones normally requires slip-critical high strength bolts with sufficient pre-tightening force. However, relevant experimental researches on the application of various products of blind bolts to structural connections [2–12] have revealed that most blind bolts cannot act as slip-critical high strength bolts. It is only stated in the specification of Ajax-Oneside [13] that the product exhibits the similar pre-tightening force and ultimate capacity as common high strength bolts.

In order to explore the blind bolted connections which meet the slip-critical requirement for seismic purpose as per the Chinese standard [22], a novel Slip-Critical Blind Bolt (SCBB) was recently developed by Tongji University in China, and a series of experiments have been conducted to obtain the fundamental performance of SCBB [23]. The SCBBs were then adopted in extended endplate connections whose cyclic behaviour was experimentally investigated [24]. However, a further investigation under the extreme loading condition of progressive collapse scenario is essential to evaluate the effectiveness of SCBBs and extend its application into the beam-to-column connections.

Under a progressive collapse scenario, such as following the column

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Table 1
Commercially developed blind bolts.

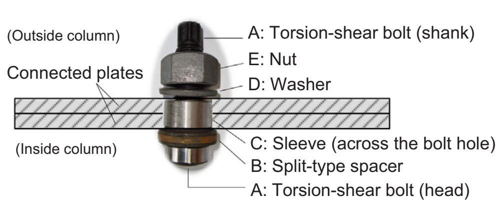
Region	Producer	Name of blind bolt	Locking mechanism
USA	Huck International Inc.	Blind Oversized Mechanically Locked Bolt (BOM)	Buckling of sleeve
		High Strength Blind Bolt (HSBB) [14]	Expanded sleeve
		Ultra-Twist (named Torque-Control Blind Bolt (TCBB) in Japan [15])	Buckling of sleeve
Netherland	Flowdrill B.V.	Flowdrill [16]	Drilling through plate
UK	Lindapter International	Hollo-Bolt (HB) [17,18]	Expanded sleeve
		Reverse Mechanism HB (RMH) [9]	Reversely expanded sleeve
		Extended HB (EHB) [19]	Expanded sleeve, anchor nut
	Advanced bolting solutions	Molabolt [20]	Expanded sleeve
	Blind bolt	Blind bolt [21]	Locking anchor
Australia	Ajax Engineered Fasteners	Ajax-Oneside [13]	Foldable split washer

loss in a frame, a favourable moment connection would enable the beam-to-column assembly to utilize its flexural mechanism at the early stage and develop the catenary mechanism with the deflected beam at the later stage. Such responses were observed in various connections through welding or bolting [25–32]. In order to achieve the above-described performance, bolted connections need to adopt bolts which are able to maintain sufficient tightening force for sake of integrity of the bolted connections.

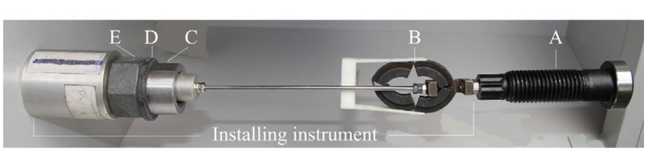
This paper experimentally investigates the performance of this novel SCBBs used in the extended endplate connection under an inner column removal scenario. Four full-scale specimens of planar beam-to-column assembly were vertically loaded on the unsupported central column to simulate the loss of column and study the consequent structural response. Various special configurations at the connection region were respectively designed to assess the behaviours of SCBBs under different failure modes. Damage evolution, load mechanism and strain evolution were specifically studied. The performance of the blind bolted connections was evaluated by comparison between the tested specimens with other traditional moment connections.

2. Slip-Critical Blind Bolt (SCBB)

The SCBB was developed and patented by Tongji University [23] in China. As shown in Fig. 1(a), a SCBB is composed of five parts: torsion-shear type high strength bolt (A), split-type spacers (B), sleeve (C), washer (D) and nut (E). The split-type spacer (B) is a key part for installation, which consists of four separate quadrant parts as illustrated in Fig. 1(b), with a rubber ring around the outer profile. The ring assists the split-type spacer to recover to a full circle after it passes through the bole hole under the compressing force exerted from the designed instrument. To facilitate the split-type spacer passing smoothly, the bolt hole was machined a bit greater in diameter than the adopted bolt shank, but the gap between the bolt hole and the bolt shank is then filled by the sleeve (C) which is essential for ensuring sufficient shear resistance of the bolt.



(a) An assembled SCBB.



(b) Installation by a purposely designed instrument.

Fig. 1. Slip-Critical Blind Bolt.

Before installation, the five components of the SCBB are placed into a purposely designed instrument in a sequence illustrated in Fig. 1(b). The split-type spacer (B) is firstly compressed by a clamp to a smaller size than the bolt hole and then inserted through the hole after the bolt (A). With the assistance of the rubber ring, the spacer (B) recovers to the full cycle after getting to the other side, and rotates to fit the room between the bolt head (A) and column wall. The sleeve (C) is then placed into the gap between the bolt shank and bolt hole. Lastly, the installation is completed by applying a pre-tightening force using an electrical torque-controlling wrench in a way same for the traditional high strength bolts.

A series of experimental studies [23] was carried out at Tongji University on grade 8.8 SCBBs of M12, M20 and M24 to investigate the failure mode, pre-tightening force, ultimate bearing capacity and load-displacement response. It was verified by the test results that all the pre-tightening forces reached the required value for high strength bolt in Chinese standard [22]. The measured ultimate anti-sliding capacities were greater than the theoretically designed values. Failure occurs at bolt shank for all the tested SCBBs, as demonstrated in Fig. 2, indicating that the other parts (split-type spacers, sleeve, washer and nut) have greater strengths than the bolt shank and the ultimate capacity of a SCBB is governed by the strength of the bolt shank. The split-type spacers, on the other hand, demonstrated favourable mechanical performance without any damage observed other than some minor surface abrasions due to pressure, and enabled SCBBs to behave as satisfactorily as the traditional slip-critical high strength bolts.

The SCBBs were introduced into seismically designed beam-to-column cruciform extended endplate connections [24]. Eight full-scale specimens were tested under cyclic loading where three types of stiffening methods were adopted for the SHS columns, which are inner diaphragms, thickened column wall, and filled concrete. It was exhibited by the test results that SCBBs again had a satisfactory behaviour equivalent to the traditional high strength slip-critical bolts when applied in seismic cases, in terms of stiffness, strength, ductility and energy dissipation of the connections. Two failure modes of connection were observed in the tests, which are beam buckling and column damage. The test result generally showed satisfactory hysteretic properties of properly designed SCBB connections and proved a great potential of such connection in high seismic zones.

Fig. 2. Shear failure of bolt shank of SCBB.