Engineering Structures 148 (2017) 949–962

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Cyclic behavior of endplate connections to tubular columns with novel slip-critical blind bolts

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ARTICLE INFO

Article history:
Received 9 March 2017
Revised 6 June 2017
Accepted 6 July 2017

Keywords:
Blind bolt
Tubular column
Endplate connections
Cyclic behavior

ABSTRACT

This paper presents an experimental investigation on beam-to-column blind bolted endplate connections using innovative Slip-Critical Blind Bolts (SCBB). Common bolts cannot be adopted in hollow section columns due to the impossibility of reaching the inner side of the columns and the blind bolt is a good solution. A split-type spacer was introduced into the blind bolt, enabling almost the same pre-tightening mechanism as traditional high strength bolt. This special detailing provides possibility of sufficient pre-tightening force required by major codes and makes the blind bolt slip-critical. A specially-made instrument is developed to install the blind bolt expediently. A series of experiments was conducted to investigate the pre-tightening force and mechanical behavior of the individual blind bolts under tension, shear and combined tension and shear, and the SCBB demonstrated desirable fastening performance. Eight full-scale beam-to-column cruciform extended endplate connections using the SCBB were subsequently tested under cyclic loading. Three types of stiffening strategies were adopted for the SHS columns, i.e. inner diaphragms, thickened column wall, and filled concrete. For all the cases, the SCBB performed very well and exhibited almost identical behavior to the traditional high strength slip-critical bolts. Two failure modes of the connections, namely, beam bucking (mode 1) and column damage (mode 2), were generally observed and were found to be influenced by the column stiffening strategies. The stiffening measures were also found to greatly influence the stiffness, strength, ductility, and energy dissipation of the connections. The test result generally showed that a properly designed SCBB connection could exhibit very satisfactory cyclic performance, demonstrating a great potential of such connection for seismic resistance applications.

1. Introduction

The hollow section column has become an attractive choice for steel and composite building construction, owing to its several advantages over open sections. A square or rectangular hollow section (SHS or RHS) column is a typical kind of tubular column which presents the advantage of good bending and torsional resistance, due to its much larger flexural and torsional modulus than open sections. Besides, the column wall can provide constraints for filled concrete (if any), a case which increases the compressive capacity of the concrete. Moreover, the surface painting becomes much easier for tubular structures and the appearance is more elegant from an architectural point of view. Meanwhile, RHS/SHS columns can be connected with H-beam more easily than circular hollow section (CHS) columns.

Despite the advantages described above, traditional bolting is not readily applicable to the connections between H-beams and RHS/SHS columns due to the inaccessibility of the internal space of the tube. It is easy to connect H-columns and H-beams with bolts and good seismic performance can be obtained [1]. But when it comes to hollow section columns, nowadays welding, including cast modular panel zone joint [2], are still the main method employed for such connections, where using interior diaphragms, through diaphragms, and external diaphragms are typical solutions. These kinds of connections usually have large initial stiffness, and thus they can be considered as rigid connections according to Eurocode 3 [3]. However, compared with the bolting solution, welding is more demanding in terms of construction effort and may cause quality issues, recalling that a large number of welded connections were severely damaged in the 1994 Northridge and 1995 Hyogoken-Nanbu earthquake [4]. Alternatively, blind bolts,

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http://dx.doi.org/10.1016/j.engstruct.2017.07.015
0141-0296/

which can be installed and fastened from the outer side of the column, offer a convenient way for connecting H-beams to tubular columns. Several types of blind bolts have been developed over the past several decades, including BOM, HSBB and Ultra-Twist from the US, Flowdrill technology from Netherland, Hollo-bolt, RMH and EHB from the UK and Ajax-Oneside from Australia. However, it is found that almost none of them can achieve slip-critical bolted connections except Ajax-Oneside from Australia.

Mourad et al. [5] conducted experiments on connections using HSBB (High Strength Blind Bolt) under cyclic loading, but the sleeves were peeled off, leading to decreased preloading levels of the bolts. Mourad et al. [6] proposed a design method for extended endplate connections using Ultra-Twist (a new blind bolt in the USA), and some constructional requirements were also given. Harada et al. [7] found that TCBB (Torque-control high-strength Blind Bolt, the same as Ultra-Twist) experienced unexpected pulling out failure of the blind bolt. Yeomans et al. [8] tested several endplate connections with hollo-bolts (published by the British Steel Tubes & Pipes [9]) and also found that the bolts were pulled out, which indicated low pre-tightening forces of the blind bolts. Elghazouli et al. [10] studied the monotonic and cyclic behavior of hollo-bolt connections, and good ductility was exhibited. A theoretical model for the initial stiffness and bearing capacity of the hollo-bolt connections was proposed by Málaga-Chuquitaype [11]. Tizani et al. [12,13] reported an investigation on the cyclic behavior of endplate connections to concrete filled tubular columns using the EHB. The results showed that the performance of the blind bolted connections was mainly influenced by the failure modes, and connections with relatively weak columns could exhibit higher energy dissipation and ductility. Nethercot [14] conducted two types of T-stub connections using RMH and hollo-bolt. It was found that the RMH could provide much larger stiffness for the connections. Silva [15] studied the monotonic and cyclic performances of concrete filled steel tubular columns and different levels of axial loading were applied. Lee et al. [16,17] reported an experimental program investigation on blind bolted connections to unfilled hollow section columns using Ajax-Oneside [18] from Australia.

To further explore the potential of blind bolts for H-beam to RHS/SHS columns, an innovative Slip-Critical Blind Bolt (SCBB) is presented in this paper. The component parts, pre-tightening mechanism, installing procedures and the performances of SCBB are discussed in detail. A novel split-type spacer, allowing almost the same pre-tightening mechanism as traditional high strength bolt, was introduced into the blind bolt. This special detailing provides a possibility for the SCBB to possess sufficient pre-tightening force recommended by major codes and makes the blind bolt slip-critical. Experiments were conducted to investigate the connecting performances of the bolts and the cyclic behavior of the connections using SCBB with various types of stiffening strategies, and the failure modes, strength capacity, ductility, initial stiffness, and energy dissipation are fully examined.

2. Experimental program

2.1. Blind bolts used in the experiments

2.1.1. Slip-critical blind bolt

A Slip-Critical Blind Bolt (SCBB) consists of five parts: tor-shear type high strength bolt, nut, washer, split-type spacer, and sleeve, as shown in Fig. 1. The bolt head is machined into a circular shape from its original hexagonal shape, in order to be put inside the column through the bolt hole. The nut and washer are exactly the same as those used in traditional high strength bolts. The split-type spacer is the key part of the blind bolt. It is made up of four separate parts, quadrant for each one, with a rubber ring around

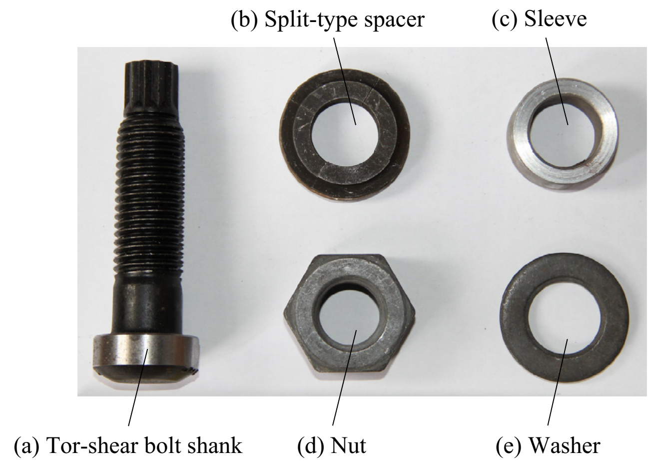

Fig. 1. Component parts of SCBB.

its outer profile. The circular dimension of the spacer can be compressed when encountering an external force, as shown in Fig. 2, and is then recovered to a complete circle immediately after the release of the force. This character makes it possible to get the spacer through the bolt hole, and then the spacer can be pressed by the bolt head. The sleeve is used to fill the gap between the bolt shank and the hole, since the diameter of the hole is larger than usual ones. The sleeve also helps improve its shear resistance and centre the shank during installation. The assembled SCBB is shown in Fig. 3. It can be seen that the pre-tightening mechanism of the SCBB is exactly the same as current high strength bolt. On the contrary, the blind bolts HSBB, Ultra-twist, Hollo-bolt and

Fig. 2. The split-type spacer.

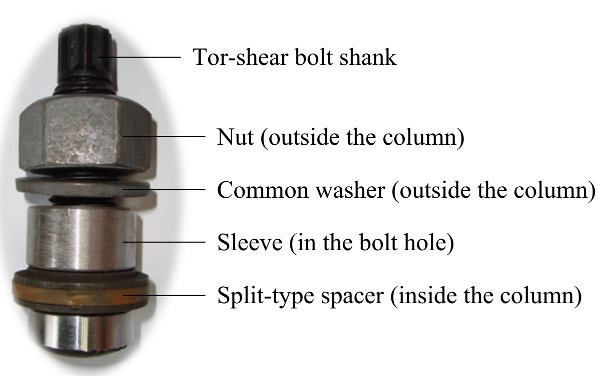

Fig. 3. Assembled SCBB.