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Fatigue behaviour of blind bolts under tensile cyclic loads

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ABSTRACT

This study presents an experimental investigation on the fatigue performance of a blind bolt under axial-tension cyclic loads. Static, constant-amplitude, and variable-amplitude fatigue tests on standard bolts and blind bolts are carried out. The bolt failure modes, static tensile force–displacement relationships, and fatigue life are presented. Based on the experimental results, S–N curves of the bolts under constant-amplitude fatigue tests are obtained by means of regression analysis, and the influence of the load amplitude as well as the load ratio on the fatigue performance of blind bolts are examined. It is found that S–N curves follow a power function with negative exponent, and exhibit similar S–N curves to standard bolts under higher load ratio. Meanwhile, the fatigue life of blind bolts under variable-amplitude loadings is estimated by using Miner's linear cumulative-damage theory. The fatigue strength of blind bolts under variable-amplitude fatigue loading is lower than the corresponding value for constant-amplitude fatigue tests. Finally, the fatigue strength of blind bolts is assessed by comparing the test results with existing specifications. It is concluded that the fatigue performance of blind bolts can be conservatively estimated by the corresponding specification of design codes.

1. Introduction

The use of fully welded connections has not always been an attractive option, owing to the costs and time involved in their fabrication and maintenance. This has motivated the development of bolted details for steel structures. However, traditional bolts cannot be utilized to connect hollow structural sections (HSS) because of the lack of access for installation. To overcome this difficulty, blind bolt systems have been developed and introduced for HSS connections, such as Hollo-bolt (HB) [1], Flowdrill bolts [2], Ajax Fasteners [3] and so on. These three types of blind bolts have been widely used due to their simple design and convenient application. However, the avoidance of close tolerance holes and specialized installation equipment renders the use of Hollo-bolts attractive. Therefore, this paper focuses on studying the fatigue performance of this type of blind bolt under axial-tension cyclic loads.

A general view of this blind bolt is depicted in Fig. 1(b). This bolt is based on the standard bolt (as shown in Fig. 1(a)) and composed of a central standard bolt shank, bolt head, collar, rubber washer, sleeve, and threaded cone. The standard bolt consists of bolt head, steel washer, shank, and nut. Moreover, the size and grade of this blind bolt depend on its central bolt shank. Thus, the main grades include G8.8 and G10.9, while M12, M16, and M20 are generally used in practical engineering [1].

A number of experimental and analytical studies have been carried out on the static performance of this type of blind bolt and the corresponding bolted connections [4–12]. Shear and tension tests were conducted by Yeomans [4]. Barnett et al. [5] performed a static tension test on a Reverse Mechanism Hollo-bolted (RMH) T-stub, and the results showed that it exhibited satisfactory strength and stiffness. Wang et al. [6] proposed a theoretical model for determining the initial stiffness of this type of blind bolt based on the T-stub connections, and the comparisons between the performances of the blind bolt and standard bolt were investigated. Liu et al. [7,8] conducted experimental and analytical investigations on blind bolts and bolted beam-to-tubular-column connections under shear and axial loads. More recently, the static performance of a blind-bolted connection in a concrete-filled hollow section was investigated by Tizani et al. [9,10]. The tensile behaviour of the Extended Hollo-bolt (EHB) for connecting concrete-filled hollow configurations was investigated by Pitrakkos and Tizani [11,12]. Most steel structures are potentially subjected to dynamic loads during their service life. Therefore, the dynamic response of blind bolts and their connection details need to be investigated.

Recently, many researchers have focused on the cyclic behaviour of blind-bolted connections to evaluate the performance of steel structures under dynamic loading. Elghazouli et al. [13] carried out an experimental study on the cyclic behaviour of blind-bolted angle connections between open beams and tubular columns. Wang [14] investigated the hysteretic behaviour of end-plate connections to concrete-filled tubular columns using the EHBs. Oktavianus et al. [15,16] investigated the cyclic behaviour of individual double headed anchored blind bolts (DHABBs) and group bolts within concrete-filled circular hollow section by

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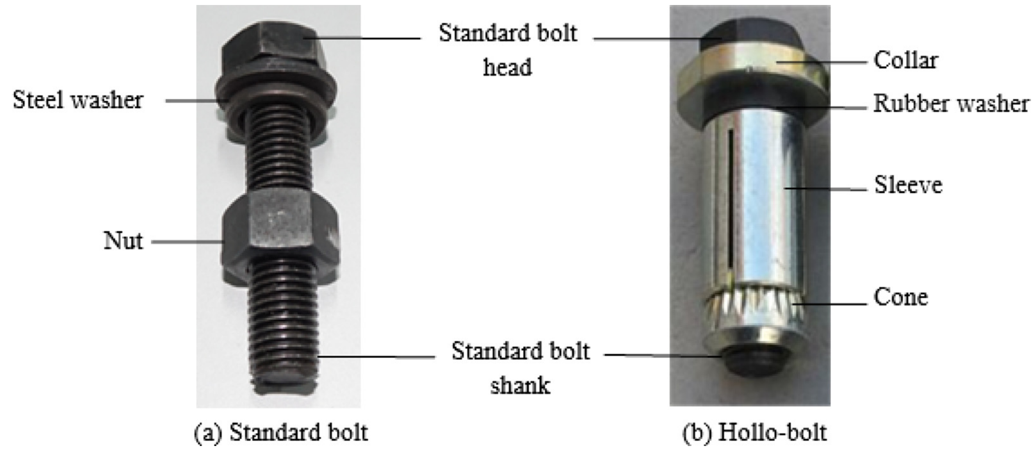

(a) Standard bolt (b) Blind bolt

Fig. 1. General view of a standard bolt and a blind bolt.

experimental and FE models, with emphasis on the influence of concrete and bolt parameters. Moreover, Tizani et al. [17] reported the fatigue behaviour of the EHB system, based on constant-amplitude tensile loading tests, and the effects of the loading frequency and the infill-concrete strength on its fatigue life were examined in detail. Rahman et al. [18] performed tensile fatigue tests to determine the influence of the frequency and stress range on the fatigue behaviour of EHBs in concrete-filled tubes. However, most studies mainly examined the cyclic behaviour of blind bolts and blind-bolted connections considering concrete filling. Further investigation on the fatigue response of standard blind bolt is lacking.

In addition, the fatigue strength of standard bolts has been specified in design codes for steel structures, e.g. Eurocode 3 [19], BS 7608 [20], and AISC-LRFD (American Institute of Steel Construction - Load and Resistance Factor Design) [21]. These codes, though different, have similar criteria for assessing the fatigue behaviour of a standard bolt. However, the resistance of blind bolts to fatigue failure is unknown, and the fatigue behaviour of a single blind bolt, based on the existing specifications, remains to be understood.

To this end, this study experimentally investigates the fatigue behaviour of a blind bolt under axial-tension cyclic loads (as shown in Fig. 1(b)). The experimental programme involves static, constant-amplitude, and variable-amplitude fatigue axial tension tests. The specimen details and test set-up are introduced first. The failure modes, static tensile force–displacement relationships, and fatigue life of the tested bolts are then presented. The experimental S–N curves for constant-amplitude fatigue are obtained by regression analysis, while the fatigue life of blind bolts under variable-amplitude fatigue loading is estimated by means of Miner's linear cumulative-damage theory. Finally, the fatigue strength of blind bolts is assessed by comparing the test results with existing specifications.

2. Experimental programme

2.1. Specimen details

Static axial-tension tests were initially performed on three standard bolts and three blind bolts to obtain benchmark data on the static capacity of the bolt specimens and to further design the fatigue tests. To investigate the fatigue behaviour of blind bolts under axial cyclic tension, constant-amplitude fatigue tests were carried out on five standard bolts and twenty-one blind bolts, while variable-amplitude fatigue tests were performed on nine blind bolts.

The specimen details are summarized in Tables 1, 2, and 3 for the static, constant-amplitude, and variable-amplitude fatigue tests, respectively, including the loading arrangement and testing results. In the specimen reference, the first letter, *S*, *C*, or *V*, stands for static, constant-amplitude, or variable-amplitude fatigue tests, respectively. The second letter, *S* or *B*, represents standard bolt (SB) or blind bolt (BB), respectively. The last Arabic number is a sequence number referring to the testing order. All the bolts are Grade 10.9 M16.

2.2. Test set-up

Fig. 2 shows the set-up of the static and fatigue tests on a single bolt. The clamping system was designed for repeated use during the tests. The clamps, including Clamps A and B, were made by cutting and drilling a Q345-B steel billet. In order to eliminate the influence of the clamping system, the thickness of the baseplates was set as 16 mm, while the vertical plates of the clamps were designed as 30 mm. The clamp for the blind-bolt tests has a bolt hole with a 28-mm diameter in the centre of the baseplates, while a bolt hole of 17.5-mm diameter was drilled in the same position of the clamp for the standard bolt tests. The bolt-hole diameter is denoted by d_0 in Fig. 2. The other parts of the clamps were the same for both bolts.

The bolts' static and fatigue tests were carried out using an SDS500 electro-hydraulic testing machine. Clamps A and B were connected and tightened by applying a preload to the bolts before the tests. The bolt preload was applied using a handheld torque wrench with tightening torques of 315 N·m and 244 N·m for the standard bolts and blind bolts, respectively [1,7,13]. Importantly, the test bolts could only be installed after the vertical axis positions of Clamps A and B were aligned.

2.3. Loading scheme

Mixed load–displacement control was employed for the static test to obtain the complete tension–displacement relationships of the bolts, where the tensile load was gradually increased up to a force of about 50 kN at a rate of 5 kN/min, afterwards the test was carried out in displacement control at a rate of 0.5 mm/min until failure of the specimen. The fatigue loading was applied by a 6.0-Hz sine-wave load for both the constant-amplitude and variable-amplitude fatigue tests.

The cyclic loading procedure of the constant-amplitude fatigue test is shown in Fig. 3, where *T* and *C* represent tension (+) and compression (−), respectively, and F_V and F_P refer to the valley load and peak load, respectively. The corresponding valley stress (σ_{min}) and peak stress (σ_{max}) can be obtained based on the simplified method proposed