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Fatigue life of an anchored blind-bolt loaded in tension

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ABSTRACT

This paper investigates and reports on the fatigue behaviour of a novel blind-bolt system termed the Extended Hollo-bolt (EHB). The new blind-bolt is a modified version of the standard Lindapter Hollo-bolt, and its application relates to the construction of bolted, moment-resisting connections between open profile beams and concrete-filled tubular columns. The fatigue behaviour of the system is studied on the basis of constant amplitude loading tests, with a total of 56 experiments being reported. The specimens were subjected to tensile loading for various stress ranges, with the repeated load being selected relative to the design yield stress of the blind-bolt's internal shank. The influence of testing frequency and strength of concrete infill is also examined. An analysis of the results indicates that an increase in the concrete strength can increase the fatigue life of the EHB system. Within the tested range, the failure mode of the EHB under repeated loading was found to be due to internal bolt shank fracture, a mode which is consistent with its monotonic behaviour and also comparable with standard bolt–nut–washer system behaviour. The experimental results (S–N data) were further compared with the Eurocode 3 Part 1-9 guidelines. The fatigue design strength of the anchored EHB blind-bolt is found to be adequately represented by the current specification detail Category 50 that is provided for standard bolting systems.

1. Introduction

The use of structural hollow members as columns in steel construction is very attractive to architects and structural engineers. This is mainly due to the aesthetically pleasing appearance that the profiles have to offer. From a structural point of view, it is also generally accepted that the combination of hollow section columns and open profile beams can offer many advantages [1]. Their use, however, is inhibited by problems in establishing structural connections with other members. The application of traditional bolts – that are typically used to form bolted connections between open profile sections – cannot be utilised in the case of hollow columns. This is because the technique requires access to the inside of the section to facilitate tightening. To overcome this complexity, early development included the provision of intense welding among members, as well as the use of additional components, such as gusset plates and brackets in order to construct such joints. But, arguably, these methods are not efficient solutions; for practical and aesthetic reasons.

More recent development in connection technology has introduced a fastening system that does not require access to both sides of the connection being formed; blind fasteners. Several types of blind-bolts have been developed over the years for use in a number of engineering fields. Commercially available examples include the Flowdrill, the Huck, the AJAX Oneside, and the Lindapter Hollo-bolt (Fig. 1). This study relates to the so-called Extended Hollo-bolt (EHB) blind-bolt (Fig. 2), which was developed as an experimental modification of the standard Hollo-bolt (HB) [2] at The University of Nottingham, UK [3].

The EHB fastener was developed specifically for use with concrete-filled hollow columns, where the infill is applied to the column in view of increasing the connection stiffness and strength by: 1) limiting the bending of the connected tube face, and 2) preventing bolt pull-out from the development of mechanical anchorage on the column side [3,4]. The performance of this innovative blind-bolting system has been studied under both monotonic [5] and quasi-static cyclic [6] loading in previous studies. The monotonic moment-rotation characteristics of the proposed technology have been assessed in accordance with the current connection classification system that is outlined in Eurocode 3 Part 1-8 [7]. In terms of stiffness, the tested connections were found to mostly exhibit semi-rigid behaviour for the relatively stiff connecting beam used; noting that none performed as a nominal pin. And analysis of normalised moment-rotation data with varying beam section sizes illustrated that in the case of using an extended endplate configuration, the connection can achieve rigid behaviour in braced frames [5]. When subjected to cyclic loading in accordance with the ECCS procedures [8], the proposed technology has demonstrated a high energy dissipation and ductility ratio, allowing for its use in moment-resisting frames that are designed for high ductility class in high seismic zones [6].

Structural joints, however, are not only subjected to a monotonic and/or cyclic increasing load. Commonly, steel structures are also subject to variable service loading, with most of the structural components being subjected to repeated fluctuating loads whose magnitude is well below the fracture load under monotonic loading [9]. When fluctuating loads

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Nomenclature

d_b	nominal bolt diameter size
E_b	bolt Young's modulus of elasticity
$f_{cu,a}$	actual compressive cube strength of concrete (on the day of testing)
$f_{cu,n}$	nominal compressive cube strength of concrete
f_{yb}	bolt nominal design stress
$f_{yb,a}$	bolt actual yield strength
$f_{ub,a}$	bolt actual ultimate strength
N_f	number of cycles to failure
$\Delta\sigma$	stress range
$\Delta\sigma_a$	actual stress range
$\Delta\sigma_n$	nominal stress range
$\Delta\sigma_C$	detail category
$\Delta\sigma_D$	constant amplitude fatigue limit
$\Delta\sigma_L$	cut off limit

are applied to a material, they may induce local stresses and strains which are sufficient to induce localised micro structural changes resulting in the development of cracks. This process is known as fatigue. The cracks, fatigue cracks, can grow to a size sufficient to cause failure [10]. And therefore, additionally, bolted connections require attention in terms of fatigue loading to prevent fatigue damage. Although not reported as frequently, one of the most common bolt failure mechanisms is fatigue [11]. Existing codes and standards that are typically applied in fatigue design, namely Eurocode 3 Part 1-9 [12] and ECCS [13], are based on nominal stress ranges and detail classification tables. These standards are applicable to conventional bolted connections, but their applicability has not been extended for the various blind-bolted connections. And due to the originality of the EHB fastening system, a fatigue design assessment for the EHB anchor blind-bolt has not yet been established.

It is the purpose of this paper to focus on the fatigue behaviour of this novel fastening system. The experimental programme is described in detail, and the experimental results are given in the form of stress range versus cycles to failure (S–N) plots. The results are discussed in terms of fatigue life, fatigue strength, and observed failure mode. The analysis concentrates on the influence of: 1) testing frequency, 2) level of loading (stress range), and 3) strength of concrete infill on the fatigue life of the blind-bolt system. A comparison of the fatigue behaviour among the EHB, HB and traditional bolts is examined. Lastly, the EHB experimental S–N data is compared with the Eurocode 3 characteristic S–N curve, and the paper concludes on the performance of the novel blind-bolt under fatigue loading conditions in comparison with the fatigue behaviour of standard bolt–nut–washer systems.

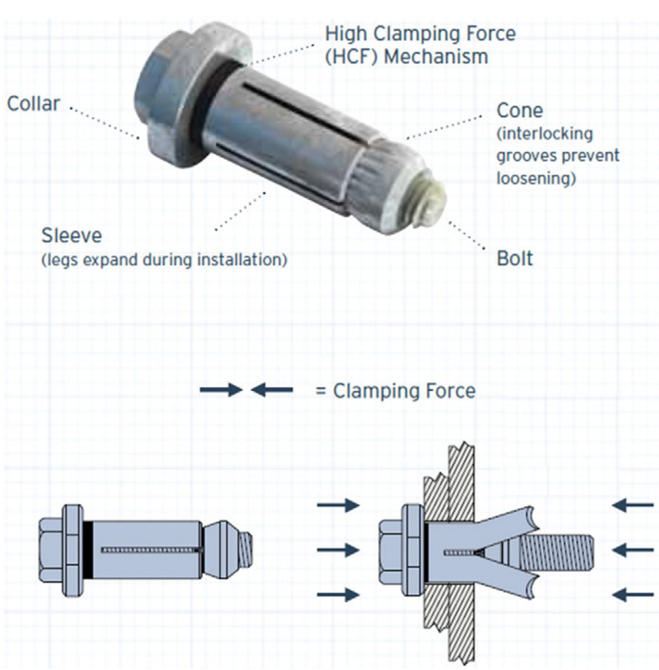

Fig. 1. The Lindapter Hollo-bolt blind-bolt [2].

Fig. 2. The Extended Hollo-bolt (EHB).

2. Experimental details

2.1. Test matrix

The test matrix for the fatigue test series is summarised in Table 1, with each type of test bolt schematically shown in Fig. 3. Type HB involves the standard Hollo-bolt, type EHB involves the novel Extended Hollo-bolt, and type M represents a standard bolt–nut–washer system. The variables include: the stress range, $\Delta\sigma$ (from 45 to 90% of the design bolt stress); the grade of the concrete infill (C40 and C60); and the testing frequency (from 0.25 to 5 Hz).

The aim of the tests was to establish the baseline for fatigue strength by evaluating the fatigue performance of the EHB blind-bolt. Further objectives were to determine a suitable testing frequency, and to investigate the influence of the infill strength on the fatigue life of the fastening system.

2.2. Test setup and loading

To determine the fatigue behaviour of the EHB, a tensile, single bolt pull-out setup was adopted (Fig. 4). The setup consisted of a 30 mm thick, circular loading frame (to eliminate prying effects), that was connected to a relatively thick square hollow section (SHS) using either of the above mentioned test bolts (i.e. type HB, EHB, M). Upon tightening of the test bolts, the hollow sections were filled with concrete, and further tested under fatigue load once the nominal concrete strength was achieved. The thickness of the SHS was selected as such to minimise the bending of the SHS face.

All tests were conducted under load control – using the hydraulic (100 kN) Servocon system – adopting the loading protocol shown in Fig. 5; where the stress range is defined as the algebraic difference between the maximum and minimum stresses in a stress cycle. The different stress ranges ($\Delta\sigma$) that were applied are outlined in Table 1 with respect to the nominal bolt design stress (f_{yb}). An actual specimen ready for testing is presented in Fig. 6.