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Fatigue Performance of Blind Bolt in Concrete-Filled Hollow Section

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Abstract. The strength performance of a blind bolt connection has been investigated under monotonic and cyclic loadings. However, the performance of these connections under fatigue loading remains unknown and is currently being studied. This paper examines and provides a better understanding of the fatigue performance of a blind bolt in a concrete-filled hollow section. A number of tests are conducted to determine the fatigue life of the blind connection in the concrete-filled tube. Comparison is made with the fatigue performance of a standard bolt. Analysis of the result indicates that the extended hollobolt has longer life than the hollobolt and lower fatigue life than those of the standard bolt.

Introduction

The use of the structural hollow section (SHS) as columns in a multi-story construction has attracted attention because of its aesthetic quality and high strength to weight ratio. However, the application of SHS at this capacity is limited by problems related to establishing connections to other sections. Early efforts in overcoming the connection problem included fully welding the connection, which in some countries is not a preferable option. The use of standard dowel, a principal alternative to welding an open section, is often impossible in the case of SHS because the procedure requires access to the inside of the tube to facilitate tightening [1]. The use of additional components, such as gusset plates and brackets, overcomes this problem, but these components are not generally considered an acceptable solution for aesthetic reasons. The need for one-sided mechanical connection emerged in a number of engineering fields and resulted in the development of several so-called blind fasteners. In the context of structural engineering, commercially available blind bolts include flowdrill, huck high strength blind bolt, and Lindapter hollobolt.

Recent studies had described the behavior of the blind bolt when subjected to monotonic load increase or cyclic loading. Generally, this situation is contributed by the reliance of engineers on strength (tensile, yield, proof, or threaded stripping strength) in specifying fastener requirements, without considering fatigue and stress concentration [2]. Non-consideration of fatigue and stress concentration may cause an unfortunate event as blind bolt connections are usually employed with service loading that varies with time. According to Barsom [3], many structural components are subjected to repeated fluctuating loads whose magnitude is well below the fracture load under monotonic loading.

For years, fatigue has been a significant and difficult problem for engineers, particularly for those who design structures such as aircraft, bridges, pressure vessel, and cranes [4]. Thus, a series of experiments is carried out to investigate the fatigue performance of blind bolts in a concrete-filled hollow section.

Materials

Blind Bolt. In this study, two types of blind bolt are used, namely, extended hollobolt (EHB) and standard hollobolt (HB). These types can only be tightened from one side. EHB is a variation of the Lindapter hollobolt that was developed at the University of Nottingham [1,5,6]. HB is one of the hollobolt types produced by Lindapter. Table I shows the properties of the 8.8 bolts used in the test.

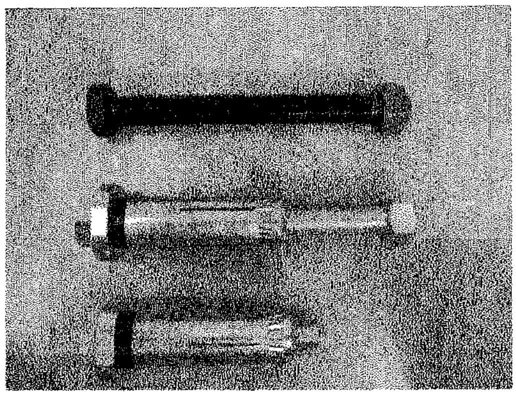

Fig. 1 From top: Standard bolt (M16), Extended Hollobolt (EHB), and Standard Hollobolt (HB)

Table 1 Mechanical properties of the blind bolt types

Type	Ultimate load (kN)	Yield stress (N/mm^2)	Ultimate tensile stress (N/mm^2)	Young's modulus (N/mm^2)
Extended Hollobolt (EHB)	131.082	813.197	852.39	204.701
Standard Hollobolt (HB)	135.894	816.025	967.132	208.115
Standard Bolt (M16)	128.461	851.353	925.923	209.444

Square hollow section. The square hollow section with dimensions of 200 x 200 x 12.5 mm was divided to several sections with a length of 500 mm. A hole with a diameter of 28 mm was drilled at the center of the tube face of the square hollow section. Table 2 lists the properties of the square hollow section.

Table 2 Square hollow section properties

Section (mm)	Steel grade	Yield strength (N/mm^2)	Young's modulus (kN/mm^2)	Ultimate load (kN)
200 x 200 x 12.5	355	393.404	205.174	125.28

Concrete. The design compressive cube strength was 40 N/mm^2. This compressive strength of the 100 mm concrete cubes was determined after seven days from the day of testing.

Test setup

To evaluate the performance of the blind bolt under fatigue loading, tensile tests were carried out. The tensile test utilized a 30 mm thick plate, bolt (EHB, HB, and standard bolt grades of 8.8), and a hollow section measuring 200 x 200 x 12.5 filled with concrete. Example of the connection is shown in Fig. 3. The thicker hollow section eliminated the effect of the tube face bending. The test was conducted using a 100 kN capacity servo-control hydraulic system.

Under the load control, a constant tensile force was applied. A constant applied load has simpler loading history than that of the variable applied load that is more complex and with fluctuating histories. Different load/stress ranges were applied. These ranges were based on the design yield stress of the bolt according to the Eurocode 3 [7], which is 640 N/mm^2. Four different load ranges were used, namely, 90, 70, 60, and 50 kN, which correspond to the nominal stress ranges of 584, 455, 390, and 325 N/mm^2, respectively.

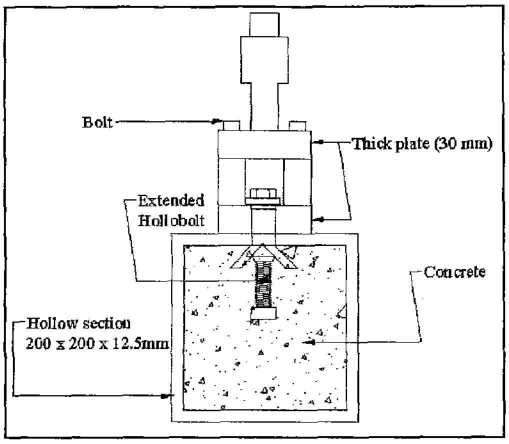

Fig. 3 Extended hollobolt in the concrete-filled hollow section

Result

Fatigue performance. To discuss the performance of the blind bolt under fatigue load, data are presented as the S-N curve shown in Fig. 4. EHB indicated a longer fatigue life than that of standard HB. Statistical analysis [8] showed that EHB had higher fatigue strength than that of a standard HB. Analysis results are summarized in Table 3. However, in terms of fatigue life, a standard HB exhibits a behavior opposite to that of EHB. Standard HB has less scatter life at different stress ranges. Furthermore, the additional mechanical anchorage and the nut exerted an influence on the fatigue characteristic of EHB. The bond between the nut and the shank in relation to concrete also prevented EHB from pulling out and provided EHB with additional fatigue strength. Meanwhile, the sleeve of HB functioning as the nut of the standard bolt did not totally contribute to a longer fatigue life. Instead, the sleeve provided EHB with better fatigue strength and fatigue life than those of standard HB. For standard HB, the fatigue life at a higher stress range can achieve a higher degree of plasticity.

Unlike the standard bolt, EHB exhibited lower fatigue strength and fatigue life. As expected, the M16 bolt showed higher fatigue strength than that of EHB. Although M16 exhibited a longer fatigue life than EHB, both intercepted results at a higher stress range ($\Delta\sigma_n$= 584 N/mm^2). Thus, the fatigue life of the bolts is nearly the same when a higher stress is applied.

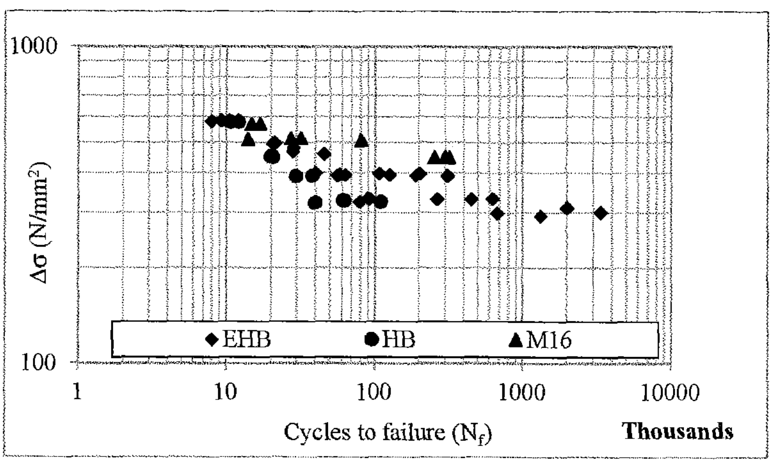

Fig. 4 Fatigue life of the blind bolt

Table 3 Fatigue strength at 2 million cycles

Type of bolt	Fatigue strength at 2 million cycles (N/mm^2)
Extended Hollobolt (EHB)	253
Hollobolt (HB)	103
Standard Bolt (M16)	377

Eurocode 3 S-N curve classification. The proposed fatigue assessment based on the Eurocode 3 [9] belonged to the category of 50. Category 50 consisted of bolts and a rod with roller or cut thread in tension. Figure 5 shows both types of blind bolts above the detail category of 50, as proposed by Eurocode 3. Therefore, a blind bolt in a concrete-filled hollow section is acceptable for fatigue resistance.

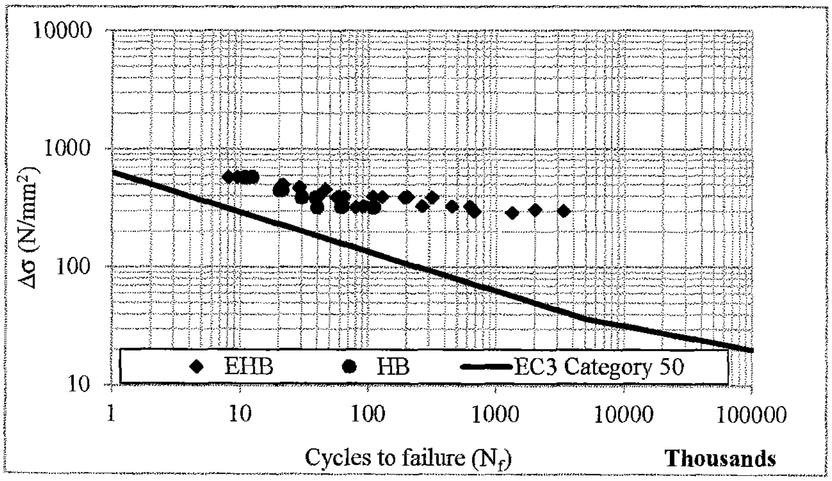

Fig. 5 Blind bolt comparison with classification of Eurocode 3

Conclusion

The fatigue life and strength of an EHB were lower than those of a standard bolt, but higher than those of a HB. This finding was proven by the S-N curve, which shows that the fatigue strength at two million cycles of EHB was 253 N/mm^2, while those of standard bolt and HB were 377 and 103 N/mm^2, respectively. The blind bolts show an acceptable fatigue assessment compared with that of category 50 in Eurocode 3.

For further investigation on the fatigue performance of the blind bolt, further tests for grade 10.9 bolt connections should be conducted to determine the differences in values and the effects of fatigue when different bolt grades are used. The effects of axial loading resulting from torque on the fatigue life of bolts should be tested to assess the fatigue life of actual bolts.

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