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A Review on Blind Bolt Connection to Concrete Filled Hollow Section Under Cyclic Load

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Abstract: Research on the blind bolt is currently being extended to the use of concrete filled hollow section to increase the overall strength of steel structures. However, information into blind bolted connection of concrete-filled hollow sections (CFHS) under cyclic loading remains ongoing. The objectives of this study is to review on different type of bolt connection and analyze the behaviour of the different type of blind bolt to CHFS under cyclic load. Three type of blind bolt is reviewed, Hollobolt, Extended Hollobolt, Slip Critical Blind Bolt and Double Headed Anchored Blind Bolt. From the review it is show that blind bolted connection is acceptable to be use as solution to connect steel hollow section under cyclic load.

Keywords: Blind Bolt Connection, Concrete Filled Hollow Section, Cyclic Load

1. Introduction

Structural Hollow Section (SHS) is widely used for architectural purposed. Hence, high strength-to-weight ratio. Their use, however, is presently restrained due to the problems associated with connections. Early attempts to clear up the connection issue, along with completely welding the connection, are now not an appealing solution [1].

Welded connection is widely use to connect the hollow section meanwhile bolted is not recommended to use due to the fact that the interior of the tube is crucial to allow tightening [2]. Therefore the use of blind bolted is one of the solution. The use of blind bolt had been widely use in connecting the SHS component. However blind bolt connection to SHS will increase buckling to the SHS, Therefore the use of concrete as a filledto hollow section section is one of the solution. Therefore this paper is aim to review the use of blind bolted as a connection to concrete filled hollow section (CFHS).

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2. Blind bolt

Blind bolt was developed to overcomed the lack of access for SHS. The blind bolt composed of a central standard bolt shank, bolt head, collar, rubber washer, sleeve and threaded cone as shown in Figure 1 [3]. There are several types of blind bolt available such as, Anchored blind bolt, Ajax Bolt, river, Hollobolt an others. Figure 2 show the typical form of Hollobolt. The Hollobolt system utilizes grade 8.8 bolts placed inside a special sleeve that spreads during tightening, hence clamping the connected plates together [1]. In this review three type of bolt is discussed i.e. Hollobolt (HB), Extended Hollobolt (EHB), Slip Critical blind bolt (SCBB) and Double Headede Anchored Blind Bolt (DHABB) as shown in Table 1.

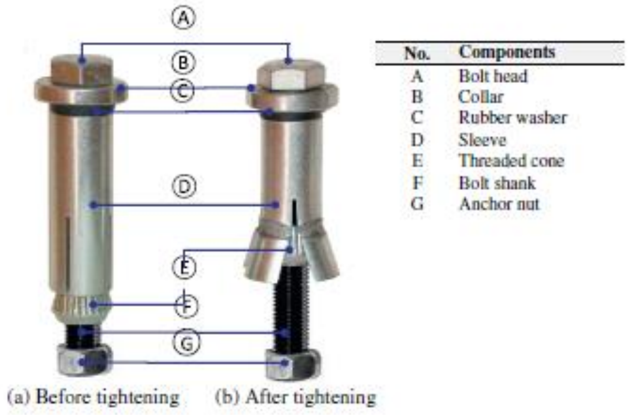

Figure 1 : General view of a blind bolt [4]

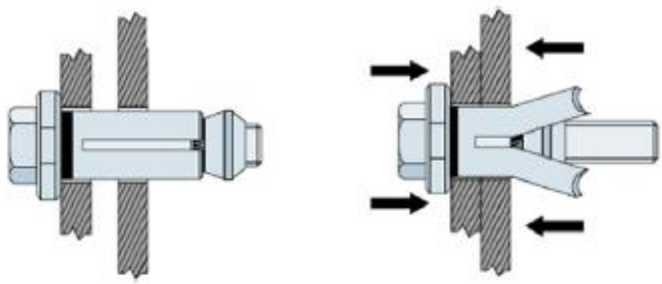

Figure 2 : A typical Hollobolt befire (left) and after (right) installation [5]

Table 1 : Different type of blind bolt

Author	Abd Rahman and Tizani [6]	Wang *et al.* [7]	Pokharel *et al.* [8]
Type of bolt used	EHB	SCBB	DHABB
Blind bolt grade	8.8	8.8	8.8

The use of an Extended Hollobolt was choosed due the most research conducted on blind bolt connection and it is also show a good performation under cyclic loading [6]. Meanwhile a review on Slip Critical Blind Bolt (SCBB) was choosed because it have a different configuration with the hollobolt where it has a split-type spacer and made up of four separate parts, with a rubber ring around its outer profile, quadrant for each part. These bolts were used to investigate whether the connecting performance of the blind bolt can make it slip critical under cyclic load [9]. Lastly, a Double Headed Anchored Blind Bolt (DHABB) is a bolt that was a modified version of the normal Headed Anchored Blind Bolt (HABB) with one additional head called the middle head which is between the existing heads in the embedded region[8].

The discussion that for this review involve fatigue behavior, ultimate tensile strength, yield moment, and effect of concrete strength. These parameters were important to analyze the strength and behavior of the blind bolt connections to the hollow section.

3. Blind Bolt connection to concrete filled hollow section

The performance of blind bolt connection to concrete filled hollow section under cyclic load are depend on the their behaviour such as fatigue behaviour, yield moment

3.1 Fatigue behavior

Fatigue sample is cycled at various degrees of stress as in the standard observed at until there is a fracture at consistent stress or strain amplitude. Stress levels typically range from a high value at which failure instantly occurs to a lower value at which failure occurs only after a surprisingly high number of cycles [10]. Moreover, the constants-amplitude fatigue loading was terminated when the blind bolts fractured it the cycled number reached 2000000 cycles [3]. On the other hand, the fatigue life of the blind bolt had a consistent increasing pattern in the applied stress range and showed a more stable fatigue life at the highest applied stress range. Furthermore, the number of cycles showed a decreased pattern as the applied stress range was increased [1]. The findings of previous studies indicate that with a slight decrease in stress, high cycle fatigue causes a greater number of cycles, while with low cycle fatigue, a larger stress range provides fewer cycles. Therefore, the low-cycle fatigue test can be graded as high-cycle fatigue in the same way [6].

It can be observed based on Table 2, when the stress range reach about 585 N/mm^2, the number of cycle to failure reach up to 12000 cycles and the bolt experienced a shank failure[6]. The next result was similar to before which the stress range reach 584 N/mm^2 and the number of cycle to failure were in the 10000 [1]. However, the study by Liu *et al.* [4] reached a higher number of cycle to failure with nearly 21000 cycles while the stress range was only 415 N/mm^2. The similarity of these researches had been that the entire blind bolt had the same type of fracture failure which is shank failure.

It can be concluded that all of the blind bolt has reach failure before the number of cycle reach the maximum cycle which is 2000000 cycles. These proves that a large number of stress range can result in a low cycle fatigue and large cycle fatigue result in low stress range.

Table 2 : Comparison on the stress range, number of cycle to failure, and type of fracture of the blind bolt

Reference	Bolt Type	Stress range (N/mm^2)	Number of cycle to failure	Fracture failure
Abd Rahman and Tizani [11]	EHB	585.24	12063	(Bolt fracture) Shank
Liu *et. al.* [3]	SCBB	415	20973	(Bolt fracture) Shank
Tizani *et. al.[*1]	EHB	584	10489	(Bolt fracture) Shank

3.2 Yield moment

The moment of yield is defined as when the entire cross-section has reached its yield stress. Theoretically, when a plastic hinge is formed at this point, this is the highest bending moment that the segment will resist and any load above this point would theoretically result in infinite plastic deformation. Many components are hardened to operate in operation, leading to improved rigidity and time resistance until the material fails. This is of little interest in structural mechanics, since the deflection previous to this event is known to be an earlier failure point in the member [12]. An experimental on cyclic behaviour of blind bold connection was conducted and it was found out that plastic hinges started to form until yielding bolt was reached. The significant deformations actually prevented the blind bolt of additional strains in the angle near the bolt zone [5].

According to study by Tizani *et. al.* [4], a total of 4 tests had been made to obtain the yield moment of blind bolt with an average of 159.13 N/mm^2. Meanwhile, researches from Elghazouli [9] and Wang *et. al.* [13] did not reach high yield moment as Tizani *et. al.* [4] with both have an average of 10 N/mm^2 and 47.06 N/mm^2, respectively. Table 3 shows a comparison of Yield moment in three different research papers. Yield moment is one of the parameter that is needed to determine the strength of the blind bolt. The moment of yield is defined as when the entire cross-section has reached its yield stress.

It can be concluded that the result obtained in Table 3 was possibly due to the degradation of both loss of blind bolt pretension force with loading cycles and the permanent deformation of steel hollow section. Although the slippage and the deformation were small at small load, as the number of cycles increase, the deformation increase quickly and were not recovered. Moreover, the ultimate capacities of all tested joints clearly reduced under cyclic loading.

Table 3 : Comparison on yield point of the blind bolt

Test No.	**Tizani *et.al.* [1]**	**Elghazouli *et.al.* [5]**	**Wang *et. al.* [13]**
	Yield point		
	Yield Moment (kNm)	**Yield Moment (kNm)**	**Yield Moment (kNm)**
1	154.0	6.4	22.42
2	173.0	10.2	43.36
3	177.0	13.5	51.62
4	132.5	9.9	70.85
Avg	159.13	10.0	47.06

3.3 Ultimate tensile strength

Ultimate tensile strength is the highest stress that a material can endure before cracking when being stretched or pulled. In contrast to compressive strength, tensile strength is the opposite and the values can be quite different. In what is called a brittle failure, some materials will break sharply, without deforming. Others, including most metals, which are more ductile, will stretch some and shrink or neck at the point of maximum stress for rods or bars as that area is stretched out [14].

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Based on Abd Rahman and Tizani [6], four different tensile load ranges were used which is 90kN, 70kN, 60kN, and 50kN. While in a study by Tizani *et.al.* [4], a horizontal cyclic loading were applied to the steel section by using an actuator. On the other hand, the study conducted by Pokharel *et. al.* [8] stated that the tensile load of the blind bolt will not be allowed to exceed 60% of their nominal tensile capacity to avoid damage in the anchorage [8]. Hence the result showed in Table 4 was observed.

Table 4 : Comparison on ultimate tensile strength

Reference	**Abd Rahman and Tizani [11]**	**Tizani *et. al.* [4]**	**Pokharel *et. al.* [8]**
Ultimate tensile strength (Mpa)	852.39	918.18	929.00

According to Table 4, the ultimate tensile strength that obtained from all three researches were similar to each other. Abd Rahman and Tizani [6] obtained 852.39 Mpa of tensile strength for the EHB while Tizani *et. al.* [4] obtained 918.18 MPa on the ultimate tensile strength of blind bolt. Out of all the three research, Pokharel *et. al.* [8] obtained the highest tensile strength of blind bolt which is 925 MPa. It can be concluded that under cyclic load, blind bolt connection could withstand high tensile strength thus proving the strength of the connection to concrete filled hollow section.

3.4 Effect of concrete strength

Concrete is one of the main materials in a concrete filled hollow section. Table 5 show a comparison of the different concrete strength used to investigate the performance of blind bolt connection to CFHS. The effect of concrete grade on the connection of blind bolt has a significant impact on the behaviour and the failure mode of the connection to the concrete filled hollow section [4]. Pokharel *et. al.* [8] uses a normal concrete grade of N50 and S50 fibre reinforced concrete to observe the effect of different type of concrete can make to the blind bolt behaviour. While Abd Rahman and Tizani [6] uses concrete grade of C40 and C60 to determine the difference of concrete strength has to the blind bolt behaviour.

In a research by Pokharel *et. al.* [8], normal concrete N50 were used. On the test day, the average compressive strength of the concrete cylinders was 55.6 MPa. For the pull-out of M24 Double Headed Anchored Blind Bolt (DHABB) from the concrete filled square hollow section, monotonic and cyclic loading were both investigated separately.

It is noted in the study by Pokharel *et al.* [8] and Tizani *et al.[*4], the concrete was subjected to a normal cyclic loading while fatigue loading was subjected to the concrete in the experimental work as stated in Abd Rahman and Tizani [6].

Table 5 : Comparison on type of concrete grade used

Reference	**Pokharel *et. al* [8]**	**Tizani *et. al* [4]**	**Abd Rahman and Tizani [6]**
Type of concrete	N50	N50	C40
Compressive strength (Mpa)	55.60	53.20	40.00

According to the study by Tizani *et. al.* [4], the concrete infill can provide the tube with confinement and the blind-bolt with anchorage. It was originally thought that the concrete strength would not be a major factor because sufficient containment effects could still be provided by low strength concrete. The test results showed, however, that concrete strength can have a significant impact on the behaviour of CFT columns with a relatively high slenderness ratio of the tube wall.

According to a study by Abd Rahman and Tizani [6], As a packaged substance confined in the pipe section, concrete was used. The enclosed concrete acted as a rigid mass in each test. No apparent bending of the tube segment was found based on the EHB fatigue test. A concrete failure of 100 mm in diameter from the middle of the bolt was seen in the centre of the failure sample. The crack propagation at various stress ranges on the concrete is shown in Figure 3. Alongside the red line, the crack line is located. The crack pattern for each EHB fatigue test is almost similar. It can be concluded that the grade of concrete plays an important role to the overall strength of the blind bolt connection to a hollow section. Different type of concrete grade can greatly influence the strength of the blind bolt connection and its failure modes.

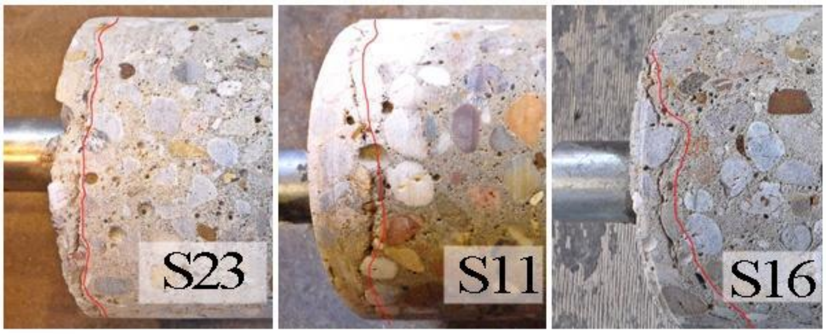

Figure 3 : Crack propagation on the concrete at stress ranges 584, 455, and 325 N/mm^2 [11]

4. Conclusion

Based on the comparison of previous study it is can be concluded that the strength of the blind bolt show an acceptable performance. In term of strength Extended Hollobolt obtaining 852.39 MPa, the Slip Critical Blind Bolt achieving 918.18 MPa and the Double Headed Anchored Blind bolt achieving 925 Mpa in show a higher strength value , 852.39 MPa, 918.18 MPa and 925MPa respectively. Moreover, most of the blind bolt has the same failure which is fracture failure at the shank location. Furthermore, the fatigue life of the blind bolt also shows a promising result as it reach a high cycle before the fracture happened where the SCBB shows the highest cycle to fracture which is 20973.

It can also be concluded that the strength of concrete greatly affect the strength of the blind bolt as the use of low strength concrete resulted in a 17 % decrease in rotation capacity, an 18 % decrease in initial stiffness, and a 260 % increase in rotation capacity. From the results, it is clear that the low strength concrete led to the failure of the anchorage of the bolt. Lastly, the yield moment of the blind bolt can be concluded as inconsistent as all three type blind bolt shows different result where one has a relatively higher yield moment as high as 139 kNm to as low as 10 kNm due to the difference of degradation throughout the experiment process.

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