Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 2 (2023) 057-063
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RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Review on Pull-out Test of Bolted Connection to Concrete Filled Hollow Section

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DOI: https://doi.org/10.30880/rtcebe.2023.04.02.007
Received 06 January 2022; Accepted 15 January 2023; Available online 20 July 2023

Abstract: Bolted connection is one of the steel connection that been used widely during construction due to its flexibility and cost beneficial. The bolted connection to the hollow section itself will have the difficulties of stiffness due to inherent flexibility. Therefore, bolted connection to concrete filled hollow section (CFHS) was introduced. CFHS has proven in enhancing the stiffness and the strength compared to unfilled hollow section. However, the bolted connection behaviour could be varying due to types of concrete, grade of concrete and the bolt size. The aim of this study is to review the behaviour of bolted connection to CFHS and compare its stiffness in term of concrete type, concrete grade and specimen size. Difference type of bolted connection under monotonic pull-out test is reviewed. The type of bolt that being discussed are AJAX Modified blind bolt, hollo bolt, extended hollo bolt, anchorage bolt, double headed anchorage bolt and M16 standard bolt. From the review analysis, the concrete types and grade play a major role in determining the behaviour of bolted connection to CFHS.

Keywords: Bolt Connection, Pull-out Test, Concrete Filled Hollow Section

1. Introduction

Bolts is one of the connections that very famous to be used in steel structure as its flexibility of assembling parts as well as dissembling it. The situation of assembling and dissembling is required during the inspection, replacement and routine maintenance. Bolted connection is not only used to connect a steel component to another steel component, but it is widely being used to connect a steel component to concrete component such as steel column to stump. At the same time, the concrete filled hollow section (CFHS) has been attraction in construction field due to its excellent strength capacity [1][2], higher fire resistance [3] and enhance the construction efficiency [4]. However, this element is presently restricted by the problems associated with making connections to other members. Early attempts of fully welding as the connection is not an attractive solution as it is restricted to highly skilled labors, required high cost and subjected to weather constraints. Certain countries found that there are brittle fractures on the welded connection of beam to column connection of CFHS during post-earthquake [5]. Meanwhile, the bolted connection is being famous and more economic to apply. Recent

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studies have developed more bolts types in order to achieve greater stiffness and strength when being connected to the CFHS such as blind bolt [6], anchorage bolt [6][7], double anchorage bolt [8] , hollo bolt, extended hollo bolt [9], and AJAX modified blind bolt [10]. Previous researchers have invented or modifying the origin bolt by adding the anchorage member or headed on the bolt body aimed to enhance the stiffness of the bolted connection to the CFHS Those bolt types is make from one side only since the concrete infilled restricted the access to the inside of the tube to facilitate tightening. Based on the literature review, several factors have influenced the grip or the stiffness of the bolted connection to CFHS. The factors are the anchorage member [7], bolt diameter [10][11] and concrete grade [12]. Thus, this review study aimed to review the behavior of the bolted connection to concrete filled hollow section and compare its stiffness. Pull-out tests have been used by most of the researchers to defined the behavior of the bolted connection by analysis the load-displacement curve. The graph results to ultimate tensile loading, the maximum displacement and the ductility of a bolted connection.

2. Literature Review

2.1 Comparison of bolted connection to CFHS and unfilled hollow section.

The concrete infilled the hollow section had a major influenced toward the stiffness of the bolted connection [13]. The additional stiffness from the concrete filled was sufficient to grip the bolt connection and enhance the friction between threaded shank and the concrete hole. From Figure 1, test no. 4 and test no. 15 is the blind bolt connection to CFHS with different specimen size while test no. 7 and no 16 are the bolted connection to unfilled hollow section. The portion of the moment-rotation characteristic for bolted connection on CFHS at high rotation which tends to be linear and not as smooth as the unfilled. However, higher moment is required for bolted connection filled with concrete to fail compared to unfilled. The apparent of the loss moment on Test no 4 is due to concrete cracking at the location of the bolted connection [13].

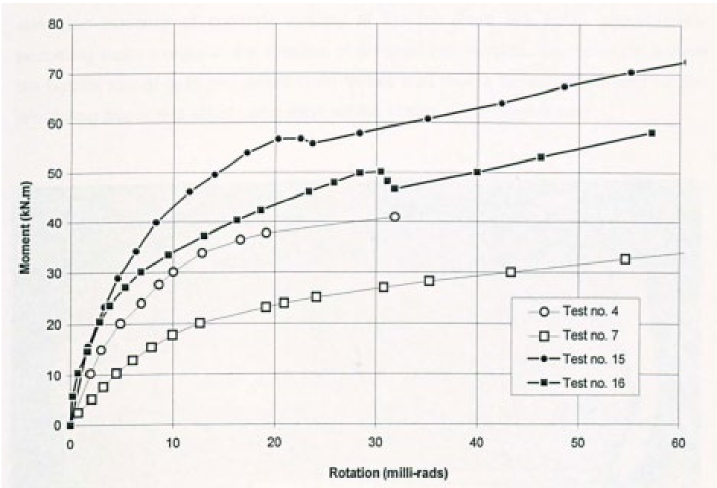


Figure 1: Moment-rotation curve for bolted connection on CFHS and unfilled hollow section [13]

2.2 Monotonic Pull-out test

Pull out test is one of the testing that used to investigate the behavior of bolted connection. Pull out test also used to measure the strength of a particular material by injecting specialised tension jacks into the specimen being test. Moreover, this test is also being used to determine the tensile or the fatigue behaviour under cyclic loading [7][8][14]. According to those previous study, pull out test that been carried out was by using the Universal Testing Machine (UTM) to pull out the bolted connection from the CFHS. As the specimen finish prepared, the bolt being mounted into CFHS. Then, the tension jack of UTM machine linked on the bolted head and load being applied gradually until the connection achieve it failures. As a result, the UTM produced the reading of loading applied and displacement. Figure 2 shows the example of the pull-out test set up by previous research.

The pull-out test that been carried by the research resulted to load-displacement curve. The behavior of a bolted connection defined by referring to the graph. All the specimen's results being compared towards its behavior and its stiffness at ultimate loading. Since each specimen has different properties such as concrete types and grade and specimen size used. These three elements also considered to compare the reviewed. The pull-out test that being considered in this review is the pull-out test by using the monotonic loading only.

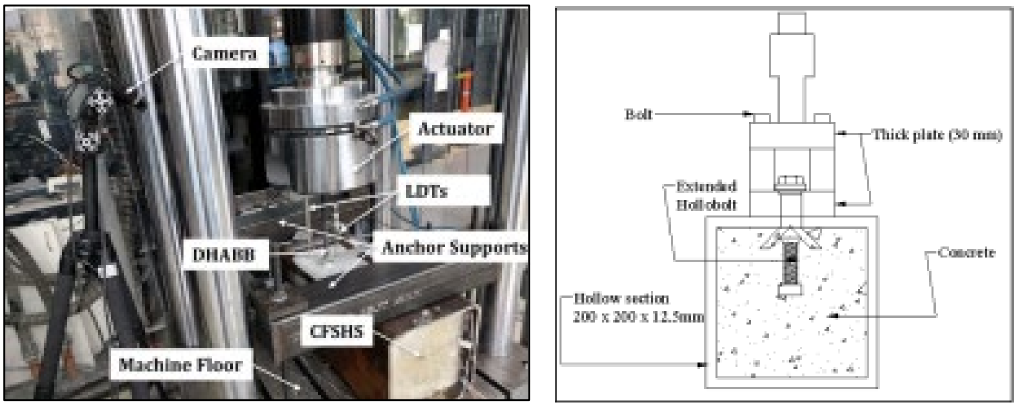


Figure 2: Example of the setup of pull-out test [10][15]

3. Materials and Methods

In order to review the behaviour of bolted connection to CFHS from previous study. Five type of bolted connection had been chosen for further investigation. All the bolted connection was tested under pull out test to determine the behaviour of bolted connection Material for CFHS also is discussed to review the effect of concrete grade. Hence the bolt grade is discussed.

For this review study, the materials preparation factors that were considered are the types of concrete used to fill the hollow section, the sample sizes and the types of bolts used on the specimen. Table 1 summarize the information regarding materials used.

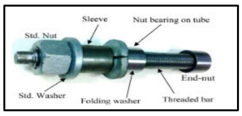
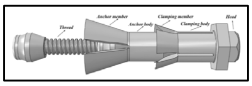
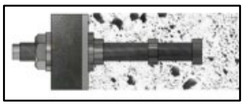
4. Results and Discussion

The pull-out test that been carried by the research resulted to load-displacement curve. The behaviour of a bolted connection defined by referring to the graph. All the specimen's results being compared towards its behaviour and its stiffness at ultimate loading. Since each specimen has different properties such as concrete types and grade and specimen size used. These three elements also considered for the reviewed. The pull-out test that being considered in this review is the pull-out test by using the monotonic loading only.

4.1 Bolt Behaviour

The behavior is the pattern of each specimen throughout the pull-out test until it achieves its maximum resistance and the failures or cracking occurred. Based on the graph, most of the specimens follow the initial behaviour, where the displacement is directly proportional to the monotonic load applied. The changes of the displacement is low when the specimen near the breaking point. The highest load is called as ultimate tensile load. After the breaking point or failure point, the graph become decreasing which means there is still displacement even though lower load being applied. The lifetime of the specimen A-1M20-Mid take longer time compared to the other. This is because the failures mode for this specimen is concrete cone where it is failed due to rupture of the concrete infilled the hollow section. However at the first peak or point of 150 kN, the hollow section start yielding and it is fail when the concrete splitting at load 165 kN with displacement of 25mm. This related to the stiffness of the connection with the concrete infill. Specimen A-1M20-Mid being hold by the concrete infill. The concrete used is compatible to tensile strength of bolt made it difficult to be removed and took longer time to fail [9]. The stiffness of the specimens could be referred to Table 2.

Table 1: Summary of the material used for sample preparation

Ref.	Authors	Specimen Name	Type of bolt	Bolt	Bolt Size	Specimen Size	Concrete Type and Grade
[11]	(Yao et al., 2011)	A_M16_N1	Modified ONESIDE Ajax blind bolt		16	300 x 300 x 8	Normal Concrete (M30)
		A_M20_N1	Modified ONESIDE Ajax blind bolt		20	300 x 300 x 8	Normal Concrete (M30)
[15]	(Abd Rahman & Tizani, 2013)	T2	Extended Hollo bolt		16	200 x 200 x 12.5	Normal Concrete (M40)
		T3	Standard Bolt M16		16	200 x 200 x 12.5	Normal Concrete (M40)
[9]	(Aghesh lui et al., 2016)	A-1M16-Mid	Anchored Blind Bolt		16	300 x 300 x 8	Normal Concrete (M50)
		A-1M20-Mid	Anchored Blind Bolt		20	300 x 300 x 8	Normal Concrete (M50)
[7]	(Jeddi & Sulong, 2018)	POT 3	Extended Hollo Bolt		16	200 x 200 x 8	Normal Concrete (M40)
		POT 4	Hollo Bolt	-	16	200 x 200 x 8	Normal Concrete (M40)
[10]	(Pokharel et al., 2019)	F-M-24-10	Double headed anchored blind bolts		24	400 x 400 x 10	Fibre Reinforced Concrete (M50)

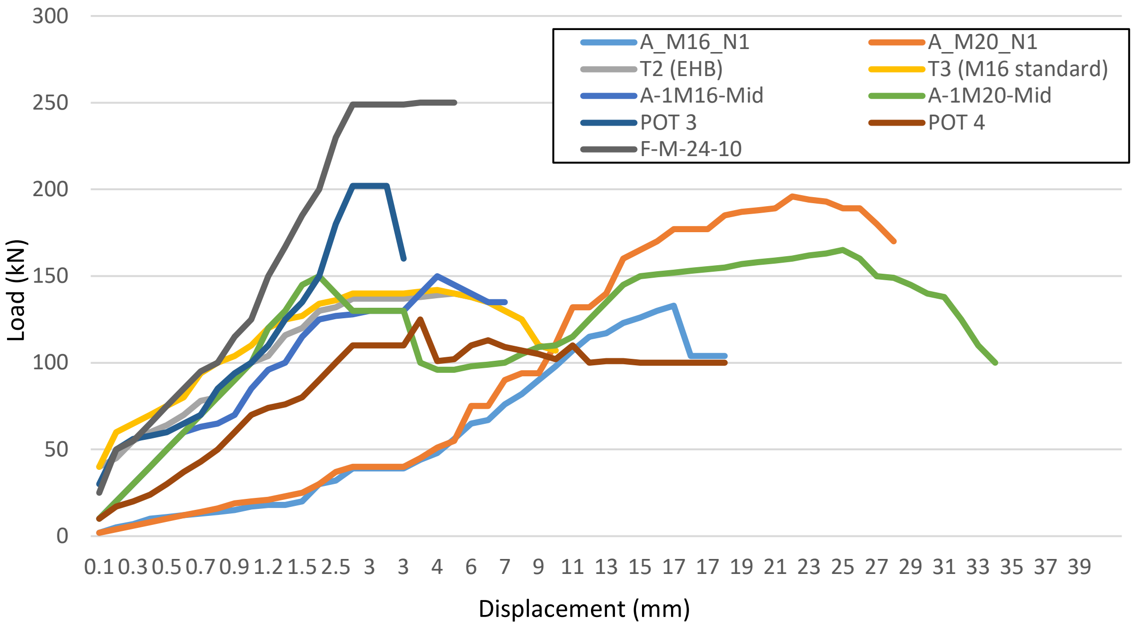


Figure 3: Load vs. displacement curve for those nine samples [7][9][10][11][15]

Table 2: The stiffness of each bolted connection

Specimen Name	Ultimate Load (kN)	Displacement (mm)	Stiffness (kN/mm)
A_M16_N1	133	17	7.82
A_M20_N1	196	22	8.91
T2	140	5	28
T3	142	4	35.5
A-1M16-Mid	150	4	37.5
A-1M20-Mid	165	25	10
POT 3	202	3	67.3
POT 4	125	3.5	35.71
F-M-24-10	250	3.5	71.42

4.1 Effect of Concrete Filled

4.2.1 Types of Concrete Filled Hollow Section

Types of concrete used filled the hollow section plays a significant role toward the stiffness of the bolted connection. According to Table 2, F-M-24-10 has the highest stiffness compared to others. This sample is used fibrous concrete where the steel fibre being added into the concrete. The steel fibre create a honeycombing around the double head anchored blind bolt thus increase the stiffness between the bolt and the concrete [10]. Other than that, additional of steel fibresinto the concrete also being proven having 52.38% greater tensile strength compared to plain concrete [16]. The steel fibre react as small reinforcing bars extending across the cracks of the cement matrix. Therefore, as long as the fibres and cement matrix remains intact, the steel fibres could carry the tensile load.

4.2.2 Grade of Concrete Filled Hollow Section

Higher grade of concrete resulted into the higher concrete strength towards compressive test. The effect of the concrete grade toward the bolted connection is variety. The highest strength of concrete (M50) however not result into the highest stiffness among those samples. A-1M16-Mid result into 37.5 kN/mm while A-1M20-Mid weaken the stiffness of the connection which give the value of 10 kN/mm. By looking into the M40 concrete, all the samples give results into high stiffness. This shown by the specimen T2, T3, POT3 and POT4. The stiffness value is within the range of 28 kN/mm - 67.3 kN/mm. M30 grade of concrete results are shown by specimen A_M16_N1 and A_M20_N1 are 7.82 kN/mm and 8.91 kN/mm. M40 grade of concrete seem to be more suitable to be used for the standard bolt and extended hollo bolt and hollo bolt connection. However, M50 grade of concrete with addition of fibre raise up the stiffness of blind bolt to the highest.

4.2 Effect of Bolt Size

According to literature review he stiffness of larger size of bolt is higher compared to the small one [10]. This is because the hole inside the tube is bigger allowing larger heads to pass through and hence a higher bearing area at each head. However, according to the stiffness of those samples in Table 2 the sample F-M-24-10 gain the highest stiffness by using 24mm diameter of bolt. This factor slightly contribute to the performance. However, the result need to be reviewed since the specimen is aided by the fibrous concrete. Comparing the stiffness of A_M16_N1 and A_M20_N1 and the results shows the 20mm diameter of bolt has higher stiffness than 16mm. The result however not being support by [9] since A-1M20-Mid stiffness is lower than A-1M16-Mid because the specimen of shows the ductile behaviour on graph in Figure 3.

5. Conclusion

In conclusion, the bolted behavior of normal concrete experienced the same behavior throughout the pull-out test while the fibrous concrete has the highest ultimate tensile loading and stiffness. Three factors that considered gave the effect towards the bolted connection. The fibrous concrete give extra stiffness compared to normal concrete. In term of concrete grade, M40 concrete that used by the standard bolt, hollo bolt and extended hollo bolt have been classified into the high range among the samples. M50 of concrete grade has a great performance if being added with the fiber. The bolt size has a slight effect on the connection.

Acknowledgement

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for providing the facilities and the sources throughout this study.

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