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Experimental Study on Modified Blind Bolts Anchored in Concrete-filled Steel Tubular Columns

Huang Yao[1], Helen Goldsworthy[2], Emad Gad[3], Saman Fernando[4]

1. Research Fellow, Department of Infrastructure Engineering, The University of Melbourne, Vic 3010, Australia. Email: jacyao@unimelb.edu.au

2. Senior Lecturer, Department of Infrastructure Engineering, The University of Melbourne, Vic 3010, Australia. Email: helenmg@unimelb.edu.au

3. Professor, Faculty of Engineering & Industrial Sciences, Swinburne University of Technology, Hawthorn, Vic 3122, Australia. Email: EGad@swin.edu.au

4. Engineering R&D Manager, Ajax Engineered Fasteners, Braeside, Vic 3195. Email: Saman.Fernando@ajaxfast.com.au

Abstract

Although concrete-filled tubular columns are becoming popular in multi-storey building frames, connections between the columns and beams using normal blind bolts are limited in the level of moment-carrying capacity and stiffness they can achieve. This is because of the extensive localised yielding of the thin tube wall caused by the blind bolts bearing on the inside of the tube wall. This paper reports the results of an innovative modified version of blind bolt that aims to develop economical semi-rigid to rigid connections that are simple to construct. It uses a high tensile threaded rod cut to the required length with two special nuts, one acting as a bearing head on the inner tube wall in association with ONESIDE split washer and the other as an anchoring device in the concrete core. The results from full-scale pullout tests on bolts connected to concrete-filled circular and square hollow sections are presented. The objective of this work was to investigate the anchorage performance of the special blind bolts, including failure modes, strength and stiffness. The parameters selected were tube wall thickness, blind bolt diameter, and concrete strength. The results show that the full tensile capacity of the threaded rod can be achieved in the circular columns with higher strength concrete, whereas the performance is compromised in the square column with lower strength of concrete. These test results provide valuable information for developing a novel concept of blind-bolted moment connections to ensure sufficient strength and stiffness when they are used in moment-resisting frames in low seismic regions such as Australia.

Keywords: blind bolt, strength, stiffness, structural hollow section, anchorage

1. Introduction

Concrete-filled steel tubular columns are becoming popular in multi-storey building frames due to their excellent structural capacity, good fire resistance and speed construction (Han and Li 2010). The type of connections used between members of the frames has a large influence on the overall behaviour. The welded connections with interior, exterior or through diaphragms are quite complex and not suitable for Australian practice. It is difficult to achieve a substantial level of moment-carrying capacity and stiffness by using conventional blind bolts in the connections between the beams and columns. Studies conducted by Ghobarah et al. (1996), France et al. (1999), Loh et al. (2006), Wang et al. (2009) on connections to tubular columns using the Huck® blind bolt, Hollobolt® and flowdrill® indicated that the strength and stiffness of the connection were limited by the flexibility of the column face and pull out of those blind bolts.

This paper presents a research program on an innovative modified version of ONESIDE blind bolt concept that aims to develop economical semi-rigid to rigid connections that are simple to construct on site. Figure 1 shows the modified blind bolts with extensions. It uses a high tensile threaded rod (with the same yield and tensile strengths (660 MPa and 830 MPa respectively) as a typical structural bolt) cut to the required length and with two special nuts designed to suit ONESIDE concept, one acting as a bearing head on the inner tube wall and the other as an anchoring device in the concrete core. The original Ajax ONESIDE blind bolt is provided in Figure 2 for comparison (Fernando 2005). The modified bolt relies on the original ONESIDE concept developed by Ajax and the same installation tool.

Figure 1 Modified blind bolts with extensions

Figure 2 Original Ajax blind bolts and tool

2. Experimental program

The experimental program is composed of two series of anchorage tests. In the first series the blind bolts were tested in concrete-filled circular hollow sections (CHS); they were then tested in concrete-filled square hollow sections (SHS) in the second series of tests. The size of the structural hollow section is representative of a typical composite column in medium rise moment-resisting frames (Yao et al. 2010, Mirza and Uy 2011). The experiments form an essential part of the study on novel joint systems which can be used in composite frames to withstand earthquake loading.

2.1 Blind bolts anchored in CHS column

The blind bolts were arranged on a segment of circular hollow section in a spiral way as shown in Figure 3 to minimise the interference from the adjacent bolts. The dimension of the circular hollow section was 324 mm in diameter with thicknesses of 6, 8, and 10 mm. The grade of the steel tube was C350L0. The compressive strength of the concrete infill was designated to be 45 MPa. The actual measured compressive strength of the concrete was 47.8 MPa at the day of test (average of results from three cylinders). The threaded bars used for modified blind bolts were grade 8.8 as noted previously. The nuts at the end of the extensions were limited by the size of the hole on the tube wall. For bolt diameters of 20 mm and 16 mm, the diameter of the circular nuts were 29 mm and 23 mm respectively. The detailed features of the test specimens are listed in Table 1 indicating the tube size, bolt diameter, concrete strength, and embedment length. The embedment length chosen for the blind bolts is the longest practicable for the dimension of the tube used in these tests in the case of the connections are installed on two opposite faces of the tube. A minimum cavity space is required behind the hole to facilitate the blind bolt installation in the tube (Yao 2009). In the specimen notation, T refers to thickness of tube wall, D refers to bolt diameter, and N refers to nut. N1 and N2 refer to the number of nuts in the tube: N1 has just one at the inside of the tube wall and N2 has one in that same position as well as one at the end of the embedded extension in order to provide anchorage. Hence N1 represents the conventional ONESIDE blind bolt concept and N2 represents the modified one. In addition, supplementary pullout tests were also performed on two straight thread bars (diameter of 16 mm and 20 mm) to evaluate the bond between the concrete and threads.

Table 1 Test specimens of blind bolts anchored in CHS column

Specimen	Tube size	Concrete (MPa)	Bolt dia. (mm)	Embedment (mm)	Nut dia. (mm)
T6_D16_N1	CHS324 x 6	47.8	16	0	23
T6_D16_N2	CHS324 x 6	47.8	16	100	23
T6_D20_N1	CHS324 x 6	47.8	20	0	29
T6_D20_N2	CHS324 x 6	47.8	20	100	29
T8_D16_N1	CHS324 x 8	47.8	16	0	23
T8_D16_N2	CHS324 x 8	47.8	16	100	23
T8_D20_N1	CHS324 x 8	47.8	20	0	29
T8_D20_N2	CHS324 x 8	47.8	20	100	29
T10_D20_N1	CHS324 x 10	47.8	20	0	29
T10_D20_N2	CHS324 x 10	47.8	20	100	29

The test setup is shown in Figure 4. The concrete-filled circular tube was laid against two reaction blocks which were bolted to a strong structural slab. The loading bar passed through the U shape reaction frame and was fixed into a gripping mechanism. The tests were run under a displacement-controlled force arrangement using a hydraulic jack. The blind bolts were loaded in tension until the connection failed.

The outward displacement of the blind bolts was measured by four transducers mounted on the threaded bar at a predefined distance from the surface of the tube. The needles of the exterior two transducers were set on the tube wall, whereas those of interior two transducers were set on a reference bracket which was fixed on the bar right in front of the tube face. Therefore, the outward displacement of the blind bolt was obtained by subtracting the bar stretch measured by interior transducers from the average measurements from the exterior transducers. To monitor the strain generated around the hole, two strain gauges were mounted at 50 mm away from the edge of the hole in the longitudinal and transverse directions.

Figure 3 Blind bolts in the CHS

Figure 4 Setup of pullout test on CHS column

2.2 Blind bolts anchored in SHS column

For the blind bolts anchored in the 300x300x8 mm square hollow sections, there were two groups of the test specimens. The first group tested anchorage performance in a grade 450 tube filled with a concrete with a compressive strength of 33 MPa. The second group tested blind bolts anchored in a grade 350 tube with infilled concrete of 50 MPa compressive strength. The blind bolts were made of high tensile threaded bars and were of grade 8.8. The details of the specimens within the concrete-filled square column are listed in Table 2. For notation of specimens: A refer to the tube filled with 33 MPa concrete, B refers to the tube filled with 50 MPa concrete, M refers to bolt installed at the middle of the tube, S refers to bolt installed adjacent to the tube corner, and 16 and 20 refer to the bolt diameter. N1 and N2 have the same meanings as outlined previously.

Table 2 Test specimens of blind bolts anchored in SHS column

Specimen	Tube size	Tube grade	Concrete (MPa)	Bolt dia. (mm)	Embedment (mm)	Location
A_M16_N1	SHS300 x 8	450	33	16	0	middle
A_M16_N2	SHS300 x 8	450	33	16	100	middle
A_S16_N1	SHS300 x 8	450	33	16	0	side
A_S16_N2	SHS300 x 8	450	33	16	100	side
A_M20_N1	SHS300 x 8	450	33	16	0	middle
A_M20_N2	SHS300 x 8	450	33	16	50	middle
A_S20_N1	SHS300 x 8	450	33	20	0	side
A_S20_N2	SHS300 x 8	450	33	20	100	side
B_M16_N2	SHS300 x 8	350	50	16	100	middle
B_S16_N2	SHS300 x 8	350	50	16	100	side
B_M20_N2	SHS300 x 8	350	50	20	100	middle
B_S20_N2	SHS300 x 8	350	50	20	100	side

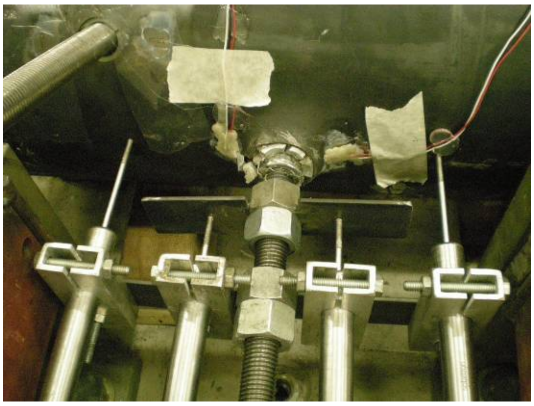
The location of the blind bolt connected to the square column can be crucial, i.e. whether it is at the middle of the face or the side (close to the corner). Two typical locations were selected for investigation, i) bolt installed at the middle of the tube (150 mm from the edge of the tube wall); ii) bolt installed close to the corner of the tube (75 mm away from the edge of the tube wall). The blind bolts were installed on the three sides of the square hollow section as shown in Figure 5. The test and the instrumentation for the square column were set up in a similar way to that for the circular column, as illustrated in Figure 6.

Figure 5 Blind bolts in the square hollow section **Figure 6 Test setup on SHS column**

3. Experimental results and discussion

3.1 Failure modes and strength

In the first series of experiments, specimens T6_D16_N1, T6_D20_N1, T8_D16_N1, T8_D20_N1, and T10_D20_N1 tested blind bolts directly bearing on the tube wall (standard ONESIDE blind bolts). All these specimens failed by extensive yielding of the tube wall and the blind bolts being pulled out as shown in Figure 7. The diameter of the yielding mechanism was approximately 3 times the bolt hole diameter. The yield capacity of the tube wall for the bolt size of 20 mm increased from 119 KN to 240 KN when the thickness of the tube changed from 6 mm to 10 mm. Specimens T6_D16_N2, T6_D20_N2, T8_D16_N2, T8_D20_N2, and T10_D20_N2 tested modified blind bolts with 100 mm extensions anchored in the concrete core (with a nut at the end). The failure was caused by breaking of the bar in all of these specimens as depicted in Figure 8. The potential cone failure of the concrete was restrained by the presence of the tube wall. Table 3 lists the failure mode and the ultimate strength for each specimen for the concrete-filled CHS columns.



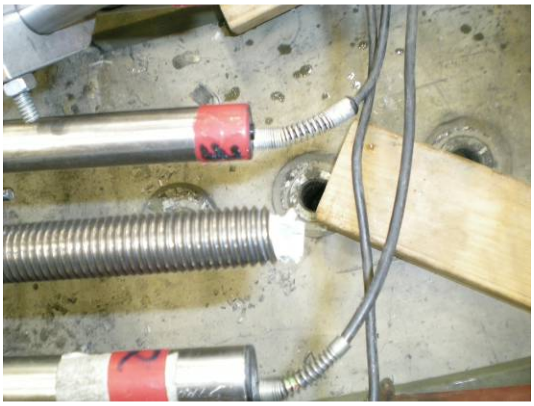


Figure 7 Tube wall yield & bar pullout **Figure 8 Bar fracture**

In the second series of experiments, specimens A_M16_N1 and A_M20_N1 tested two different sizes of blind bolts acting at the middle of the tube wall, whereas A_S16_N1 and A_S20_N1 tested blind bolts acting adjacent to the tube corner. Without extensions into concrete, all of these specimens exhibited extensive yielding around the hole. Specimens A_M16_N1 and A_S16_N1 reached the ultimate tensile capacity of the size 16mm bolt and failed by fracture at 130 kN, whereas the size 20 mm bolts were pulled out at 193 kN in specimens A_M20_N1 and A_S20_N1 due to plastic deformation around the hole. This is 10kN less than the specified ultimate tensile strength of the bolt (203kN). By providing extensions into the lower grade of concrete (33MPa in first group), tube wall yielding was not observed in specimen A_M16_N2 & A_S16_N2 and bolt capacity was achieved. However, the weaker concrete in specimens A_M20_N2 & A_S20_N2 was not able to provide sufficient anchorage to resist the pullout of the blind bolts at a load of 200 kN, and so it was not possible to fracture those bars. In second group of tests, the concrete strength was increased to 50 MPa; the three specimens of B_M16_N2, B_S16_N2 and B_S20_N2 reached the bolt tensile capacity and failed by facture. Specimen of B_M20_N2 still failed by tube wall yield at the middle of the tube face and bolt pull-out. Due to the grade 350 tube was used in specimen B-M20_N2, the ultimate load was reduced to 165 kN. The failure mode and ultimate strength of each specimen on SHS column are listed in Table 4.

Table 3 Failure mode and strength of specimens on CHS column

Specimen	Failure mode	Ultimate strength (kN)
T6_D16_N1	tube wall yield & pullout	100
T6_D16_N2	bar fracture	150
T6_D20_N1	tube wall yield & pullout	119
T6_D20_N2	bar fracture	257
T8_D16_N1	tube wall yield & bar fracture	140
T8_D16_N2	bar fracture	131
T8_D20_N1	tube wall yield & pullout	168
T8_D20_N2	bar fracture	240
T10_D20_N1	tube wall yield & pullout	215
T10_D20_N2	bar fracture	258

Table 4 Failure mode and strength of specimens on SHS column

Specimen	Failure mode	Ultimate strength (kN)
A_M16_N1	tube wall yield & bar fracture	130
A_M16_N2	bar fracture	129
A_S16_N1	tube wall yield & bar fracture	128
A_S16_N2	bar fracture	130
A_M20_N1	tube wall yield & pullout	193
A_M20_N2	tube wall yield & pullout	201
A_S20_N1	tube wall yield & pullout	197
A_S20_N2	tube wall yield & pullout	200
B_M16_N2	bar fracture	155
B_S16_N2	bar fracture	150
B_M20_N2	tube wall yield & pullout	165
B_S20_N2	bar fracture	246

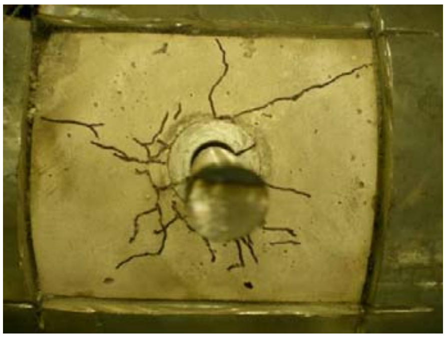


Figure 9 Concrete in specimen T6_D20_N2

Figure 10 Concrete in specimen A_M20_N2

To examine the concrete at the anchorage zone, the blind bolts and tube wall were cut away after the test. Several small hairline cracks can be seen in Figures 9 for specimen T6_D20_N2. As shown in Figure 10, concrete in the square hollow section cracked more severely than that in circular hollow section.

3.2 Load-displacement response

Tension load versus outward displacement is a key aspect in evaluating the performance of the blind bolts anchored in the concrete-filled circular and square tubular columns. Figures 11 and 12 show the response of load versus outward displacement of the 16 and 20 mm diameter blind bolts anchored in the CHS324 column with tube wall thicknesses of 6 mm and 8 mm. Figure 13 presents the blind bolts (size 20 mm) in the CHS324 with a thicker tube wall of 10 mm. It is apparent that both the strength and stiffness of the connected bolts (specimens T6_D16_N2, T6_D20_N2, T8_D16_N2, T8_D20_N2, T10_D20_N2) are significantly increased by providing the 100 mm extensions into the concrete core compared with those in specimens T6_D16_N1, T6_D20_N1, T8_D16_N1, T8_D20_N1, T10_D20_N1.

The thickness of the tube wall has a pronounced effect on the specimens with the conventional blind bolts.. The strength of the connected bolt in a 10 mm thick tube reached 215 kN in specimen T10_D20_N1, whereas only 119 KN was achieved for specimen T6_D20_N1 with a 6 mm thick tube. The tube wall thickness had only a marginal effect on the specimens with modified blind bolts. All of the specimens T6_D20_N2, T8_D20_N2, T10_D20_N2 reached the ultimate strength of the bolts.

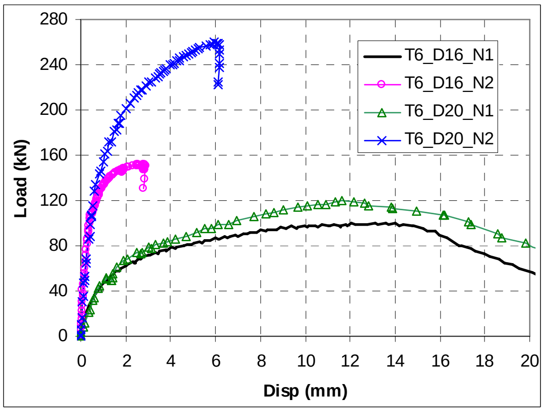


Figure 11 Blind bolts anchored in CHS324x6

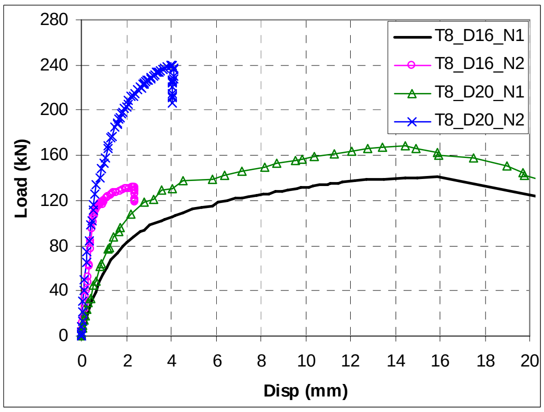


Figure 12 Blind bolts anchored in CHS324x8

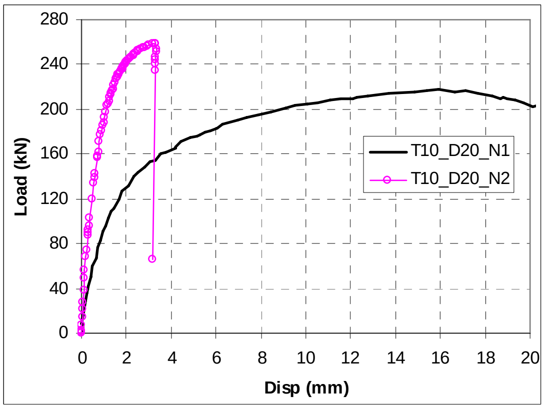


Figure 13 Blind bolts anchored in CHS324x10

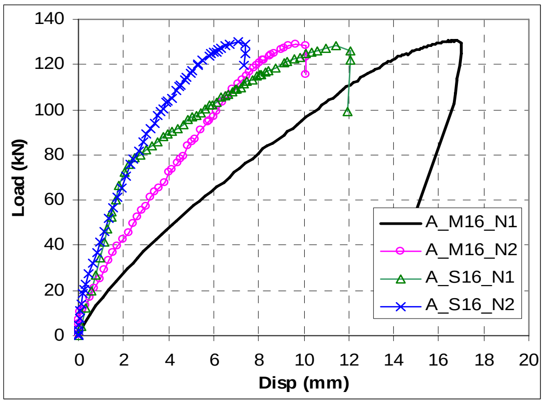


Figure 14 Size 16 bolts anchored in SHS_A

For the second series of tests on concrete-filled square columns, Figures 14 and 15 show load vs. outward displacement relationship for blind bolts anchored in the weaker concrete. The responses of blind bolts anchored in the higher strength concrete are provided in Figure 16. It can be seen that the specimen with 50 MPa concrete in the second group performed better than those with 33 MPa concrete in the first group, both in terms of stiffness and strength. Specimen B_S20_N2 failed by bar fracture at 246 KN whereas specimen A_S20_N2 failed by bolt pullout at 200 kN. It is also shown that the blind bolts installed adjacent to the tube corner are stiffer than those installed at the middle of the tube. For the cases without extensions, both the side bolt and middle bolt achieved similar ultimate strengths. When anchorage extensions were provided to the 20 mm diameter side bolts, however, the strength of the side bolt was much higher that that of the middle bolt.

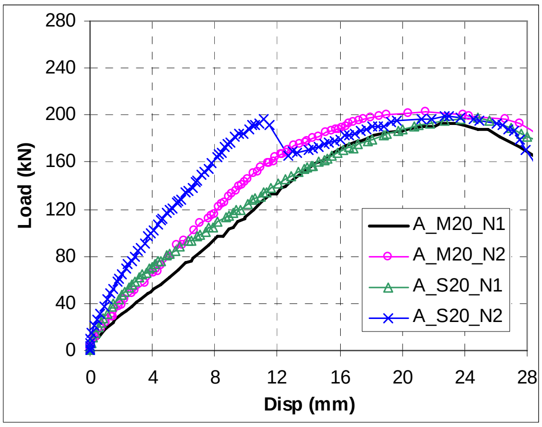


Figure 15 Size 20 bolts in SHS_A

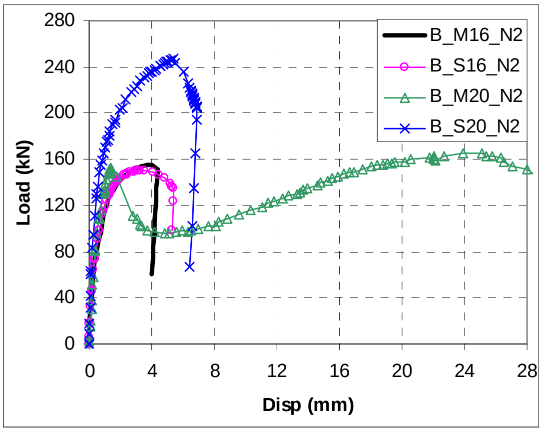


Figure 16 Blind bolts anchored in SHS_B

It is clearly shown that the stiffness of blind bolt bearing on the tube wall is relatively low and this produces a flexible connection. Conventional blind-bolted connection is very difficult to achieve a reasonable level of rigidity. With the modified blind bolts with headed extensions anchored in the concrete core, the stiffness of the connection is greatly improved. The semi-rigid and rigid moment connection can be feasible in the composite structural frames by using this new type of blind bolts.

4. Conclusions

This extensive testing program investigated the performance of conventional and modified blind bolts connected to concrete-filled circular and square columns. The test results show the effectiveness of providing headed extensions to the blind bolts to enhance the strength and rigidity of the connection. They indicate that it will be possible to develop moment-resisting connections with a higher degree of strength and stiffness when using the modified bolts rather than the conventional ones. The effects of the tube wall thickness, blind bolt diameter, and concrete strength were explored. The tube wall thickness had a pronounced influence on the specimen with the conventional blind bolt connection due to all the tension load being carried by the bolt bearing on the inside of the tube wall. It had a marginal effect on the modified bolt with headed extensions. In that case the full tensile capacity of the bolt could be achieved and extensive yielding of the tube wall was prohibited. In the square hollow section, the blind bolt installed adjacent to the tube corner exhibited stiffer behaviour compared to those located at the middle of the tube. The failure mode of the connected bolt depended on the diameter of the blind bolt, the presence or not of a headed extension, the wall thickness of the structural hollow section, the compressive strength of the concrete infill and the location of the bolt (whether at the side or middle of the face). The group effect induced by having two or more bolts on the same face has been explored and is presented in a separate paper.

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