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

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Abstract: The use of hollow section columns in steel construction is presently hindered by the lack of adequate connection technologies. Research on the blind bolt is currently being extended to the use of CFHS to increase the overall strength of steel structures. However, information into blind bolted connection of concrete-filled hollow sections (CFHS) under static loading remains ongoing. The objectives of this study is to review on different type of bolt connection and to analyze the strength of the different type of blind bolt to CHFS under static load. The information is obtained from literature review through reading of journals, books, and other sources. The stiffness and ductility of the component is measured under static load test, and the main parameters that have been selected for investigation involve the diamater and grade of the fastener's shank, and the strength of the concrete infill. Based on previous research the influence of important parameter in determine the strength of blind bolts, the bolt grade and diameter also had a significant influence on the stiffness and strength of the blind bolts.

Keywords: Blind bolt connection, Concrete filled hollow section, Static load

1. 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 use of SHS at this limit is restricted by issues identified with building up associations with different segments. Early endeavors in conquering the association issue included completely welding the association, which in certain nations is certifiably not an ideal alternative. The utilization of standard dowel, a chief option in contrast to welding an open area, is regularly outlandish on account of SHS in light of the fact that the technique expects admittance to within the cylinder to encourage fixing [1].

The need to make mechanical connections from one side only has arisen in a number of engineering fields and has resulted in the development of several types of so-called blind-bolts [3]. In the context of structural engineering, the commercially available blind-bolts include Flowdrill, the Huck High Strength Blind Bolt, the Ajax Blind Bolt and the Lindapter Hollobolt.

Tests performed elsewhere1[2] have already proved that it is possible to design nominally pinned connections (intended primarily to transfer vertical shear) to SHS columns using the Hollobolt and

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Flowdrill fasteners.The capacities of the bolts and the SHS face have been shown to be sufficient to withstand the shear load as well as the limited tensile loads arising from structural integrity requirements. Indeed, a guide for the design of connections of this sort has been available for a number of years2. However, the tests have also shown that such fasteners do not have sufficient stiffness to classify the connection as moment-resisting [4].

From previous research, tests have been conducted using different types of blind-bolts to CFHS under static load. One of these is the Lindapter Hollobolt and the other two are modifications to the Hollobolt made by the researchers at Nottingham.

2. Methodology

This section outlines the procedures used for obtaining and analysing data to achieve the objectives of the study. This research is to investigate the blind bolt connection to CFHS under static load. The information is obtained from literature review through reading of journals, books, and other sources. Figure 1 illustrate the flowchart of this study.

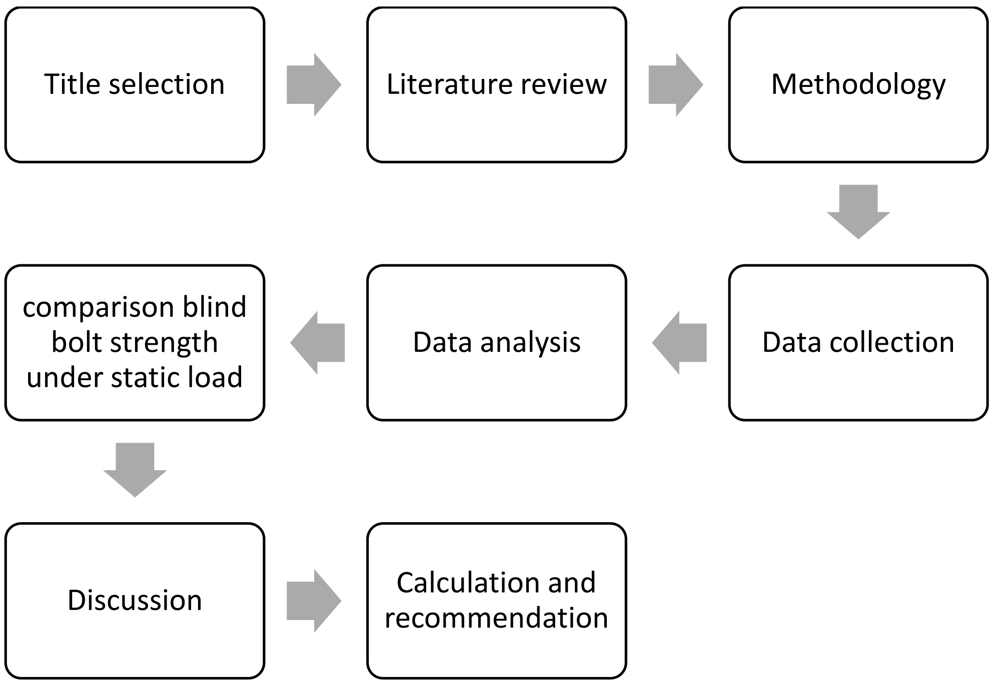

Figure 1 : Flowchart diagram

2.1 Blind bolt

Three types of blind bolts from previous study were used in this review, a standard bolt, Sean Ellison and Walid Tizani [16], a hollobolt, Elghazouli [15], and an extended hollobolt, Pitrakkos [14]. In this review, comparison of blind bolt based on different type of bolt, bolt grade and concrete grade as shown in Table 1.

Table 1 : Different type of blind bolt

Author	Sean Ellison & Walid Tizani, (2003)	Elghazouli et al., (2009)	Pitrakkos et al., (2013)
Type of bolt used	Standard Bolt	Hollobolt	Extended Hollobolt
Blind bolt grade	8.8mm and 10.9mm	8.8mm and 10.9mm	8.8mm and 10.9mm
Concrete grade	C40 and C60	C40 and C60	C40 and C60

3. Results and Discussion

This section discussed about the data and result collected from different published paper that being review, Based on the effect of concrete strength, the effect of bolt grade and the effect of bolt diameter in term of stiffness and ductility.

3.1 Comparison on different type of blind bolt

Table 3 shown the result of different blind bolt connection to CFHS under static load. Sean Ellison and Walid Tizani [16], Standard bolt, Elghazouli [15], Hollobolt and Pitrakkos [14], Extended Hollobolt used in this research. The strength of different types of bolts, specifically the standard bolt, Hollobolt and the Extended hollobolt is the characteristic used as the basic for comparison and discussion.

Table 2: Properties of bolt

Author	Type of bolt	Diameter (mm)	Shank length (mm)	Bolt grade	Concrete grade
Sean Ellison & Walid Tizani, (2003)	Standard bolt	16	150	10.9	C60
Sean Ellison & Walid Tizani, (2003)	Standard bolt	20	150	8.8	C40
Elghazouli et al., (2009)	Hollobolt	16	100	10.9	C60
Elghazouli et al., (2009)	Hollobolt	20	120	8.8	C40
Pitrakkos et al., (2013)	EHB	16	150	10.9	C60
Pitrakkos et al., (2013)	EHB	20	150	8.8	C40

Two concrete mixes, grade C60 and C40 were used in pull-out specimen casting. A nominal maximum aggregate size of 10mm was specified. The age and strength of the specimens on the day of testing as well as the 28-day strength of the concrete mixes are summarised in Table 3. Mechanical properties of the hardened concrete were determined using standard 100 mm cubes. Unless otherwise stated, all cubes were air cured in order to equate with the curing conditions of the actual pull-out specimens. Pull-out specimens were allowed a minimum of seven days for curing under room temperature conditions. Compression strength was measured just prior to testing, usually for a group of specimens with the same concrete. The concrete infill of all specimens had gained a compressive strength of 75% of the 28-day strength, on the day of testing.

Table 3: Summary of test results

Author	Type of bolt	Bolt grade	Concrete grade	Age (days)	*f*cu (MPa)	*f*cu, 28 days (MPa)	*f*cu / *f*cu, 28 days
Sean Ellison & Walid Tizani, (2003)	Standard bolt	10.9	C60	7	36.5	47.1	0.78
Sean Ellison & Walid Tizani, (2003)	Standard bolt	8.8	C40	7	38.0	43.6	0.87
Elghazouli et al., (2009)	Hollobolt	10.9	C60	7	57.1	61.7	0.93
Elghazouli et al., (2009)	Hollobolt	8.8	C40	7	39.6	45.1	0.88
Pitrakkos et al., (2013)	EHB	10.9	C60	7	60.0	61.7	0.97
Pitrakkos et al., (2013)	EHB	8.8	C40	7	39.0	47.1	0.83

3.2 Effect of concrete strength

3.2.1 Stiffness

According Pitrakkos [14], the effect of increasing the strength of the concrete infill from grade C40 to C60 is found that the initial stiffness of the Extended hollobolt component is markedly enhanced in the case of the higher concrete grade, with the effect evidently seen once the pre-load in the bolt is overcome. With regard to strength, the Extended hollobolt component is not seen to be affected by the parameter variation. For the investigated concrete grades, the yield and ultimate strength of the component both correspond with the yield and ultimate strength of the internal bolt shank, respectively. This indicates that the yield strength and ultimate capacity of the Extended hollobolt component are independent of the strength of the concrete infill when a variation in grade of C40 to C60 is considered.

In research Elghazouli [15], the effect of increasing the strength of the concrete infill from grade C40 to C60 is found that the initial stiffness of type Hollobolt is enhanced in the case of the higher concrete grade, with the effect evidently seen once the preload in the bolt is overcome. With regard to strength, the Hollobolt blind-bolt is not affected by the parameter variation the global yield and ultimate strength of Hollobolt both correspond with the yield and ultimate strength of the internal bolt shank, respectively. This indicates that the global yield strength and ultimate capacity of Hollobolt are independent of the strength of the concrete infill when a variation in grade of C40 to C60 is considered.

Research by Ellison and Tizani [16], the effect of increasing the strength of the concrete infill from grade C40 to C60 is found that the initial stiffness of the standard bolt element is markedly enhanced in the case of the higher concrete grade, reaching a pull-out strength that is equivalent with the yield strength of the bolt shank. On the other hand, the ultimate strength of the element is not seen to be affected by the parameter variation.

3.2.2. Ductility

In terms of ductility, the component is seen unaffected by the variation in concrete strength. Since the commencement of the softening branch of the component (upon ultimate strength) corresponds with the onset of internal bolt necking, it is thus concluded that the ductility of the Extended hollobolt component is also directly related to the mechanical properties of the internal bolt shank pitrakkos [14]. Moreover, the failure mode among the different concrete strength specimens was not altered; likewise with the grade C40 specimens, the high strength concrete pull-out specimens failed by bolt shank fracture upon ultimate capacity, and the loaded end surface did not exhibit any form of concrete breakout [14].

Research by Elghazouli [15], a visual inspection of the loaded end surface of the high concrete grade Hollobolt specimens indicated that the enhanced characteristics of Hollobolt are attributed to the ability of the high strength of the concrete infill in resisting the formation of a concrete breakout. In contrast with the grade C40 specimens, the C60 grade pullout specimens failed by bolt shank fracture upon ultimate capacity, but the loaded end surface did not exhibit any form of concrete breakout[15].

According Ellison and Tizani [16], with the grade C40 specimens, the C60 specimens failed by bolt shank fracture, with no involvement of a concrete breakout failure. It is thus indicated that the pull-out strength of standard bolt is directly related to the strength of the concrete infill when a variation in grade of C40 to C60 is considered an effect that is reflected in the force-global displacement relationship of the Extended hollobolt component. This observation also agrees with the literature which states that pullout strength of mechanical anchorage is dependent upon concrete strength.

Overall results from previous research shows that the standard bolt with the grade C40 and C60 failed by bolt shank fracture, with no involvement of a concrete breakout failure and the size effect with respect to the failure of Hollobolt shows that the extent of concrete breakout in comparison with that of the benchmark specimen when diameter is 16mm increases from 175mm to 215mm when an internal bolt of 20mm diameter is considered attributed to the larger size of the expanding sleeves element in Hollobolt 20. On the contrary, type Extended hollobolt 20 was able to develop the full tensile capacity of the 20mm internal bolt, exclusive of any formation of concrete breakout.

3.3 Effect of bolt grade

3.3.1. Stiffness

Pitrakkos [14], the effect of using an internal bolt of higher grade, under increased tightening torque conditions in the Extended hollobolt component is that when grade 10.9 bolts are employed in the Extended hollobolt, the initial stiffness of the component is marginally improved and maintained to a much higher force. On the other hand, the post-limit stiffness of the component (upon yielding) is notably reduced in the case of the higher bolt grade. Expectedly, the yield and ultimate strength of the component is increased in the case of the higher bolt grade. Such notable effects are attributed to the difference in mechanical properties between grade 8.8 and 10.9 bolts - which exhibit different force-deformability responses – in combination with the effects arising from the level of pre-load that is induced in the internal bolts of the assemblies.

Elghazouli [15], the effect of using an internal bolt of higher grade, under increased tightening torque conditions in the concrete-filled Hollobolt is shown that when grade 10.9 bolts are employed in Hollobolt, the initial stiffness is not affected however it is maintained to a much higher force. Conversely, the post limit stiffness is significantly reduced, whereas the global yield and ultimate strength of Hollobolt increase in the case of the higher bolt grade attributed to the mechanical properties of grade 10.9 bolts.

Sean Ellison and Walid Tizani [16], the effect of using a bolt of higher grade is shown that when grade 10.9 bolts are employed in standard bolt, the initial stiffness of the element is not affected however it is maintained to a higher force. The pull-out strength of grade 10.9 bolts is larger however the post limit stiffness of the element is found to be comparable with that of grade 8.8 specimens; up to the yield strengths of the bolt shanks, an equivalent slope is seen. Likewise with the behaviour exhibited by the benchmark grade 8.8 specimens, the subsequent and final reduction in stiffness which is seen in the 160-180kN force range corresponds with the yield strength of the test bolts indicating the relation between the element and the mechanical properties of the bolt shank.

3.3.2. Ductility

Research by pitrakkos [14], the ductility capacity of the component is seen unaffected by the variation in bolt grade, however a sharp drop in resistance is observed upon ultimate capacity for grade 10.9 specimens. Generally, bolts of grade 10.9 are characterized as non-ductile in comparison with grade 8.8 bolts, and this general behaviour is observed in the test results herein the linear softening branch of the grade 10.9 pull-out specimens indicates the limited ductility of high grade bolts. Nevertheless, the failure mode among the different bolt grade specimens was not altered with the bolt grade 8.8 specimens, the grade 10.9 specimens failed by bolt shank fracture upon ultimate capacity and the loaded end surface did not exhibit any form of concrete breakout. Thus, the use of grade 10.9 bolts in comparison with 8.8 improves the stiffness and strength characteristics of the Extended hollobolt component at the expense of a reduction in post limit stiffness due to the mechanical properties involved in high grade bolts. The test results demonstrate the ability of Extended hollobolt in distributing the additional applied forces when internal bolts of grade 10.9 are employed allowing for their full tensile capacity to develop [14].

Elghazouli [15], the ductility capacity of Hollobolt is seen unaffected by the variation in bolt grade however resistance is seen to drop immediately upon ultimate capacity in the grade 10.9 specimens. Although the employment of grade 10.9 internal bolts seems to improve the tension characteristics of Hollobolt, the failure mode that the configuration exhibits hinders its application. The ultimate failure of grade 10.9 specimens was found to be due to a combination of the expanding sleeves failing in shear and a concrete breakout that formed at its loaded end surface. Such an alteration in failure mode demonstrates that the expanding sleeves element in Hollobolt is the limiting factor when grade 10.9 bolts are considered. The configuration of Hollobolt does not allow for forces higher than those anticipated in grade 8.8 to be reached without exhibiting the dominant shear failure of its expanding sleeves.

Sean Ellison and Walid Tizani [16], the ultimate strength of the component is increased in the case of the higher bolt grade attributed to the difference in mechanical properties between grade 8.8 and 10.9 bolts. Standard bolt is able to develop the full capacity of grade 10.9 bolts, with a failure mode that is exclusive of concrete breakout. With regard to ductility capacity, the element of grade 10.9 is also comparable to that of grade 8.8, reflecting the effect that was seen in the force-global displacement relationship of the Extended hollobolt component when grade 10.9 bolts are considered [16].

Overall conclusion shows that the use of grade 10.9 bolts in comparison with 8.8 improves the stiffness and strength characteristics of Hollobolt at the expense of a sudden ultimate failure. The failure mode involves a dominant shear failure of the expanding sleeves element which does not allow for the full tensile capacity of the internal bolt to develop. In contrast, when grade 10.9 internal bolts are employed in Extended hollobolt, the component allows for their full tensile capacity to develop.

3.4 Effect of bolt diameter

3.4.1. Stiffness

Pitrakkos [14], Compares the force-global displacement relationship of the Extended hollobolt component in consideration of 16 and 20mm internal bolt diameters, with the latter involving an increased tightening torque. It is found that the initial stiffness of the component is enhanced to some extent in the case of the larger bolt diameter, and as anticipated, it is also maintained to a much higher force.

(Elghazouli [15], the effect on the tensile behaviour of the Hollobolt in consideration of 16 and 20mm internal bolt diameters, with the latter involving an increased tightening torque. It is found that the initial stiffness is enhanced to some extent in the case of the larger bolt diameter, and as anticipated, it is also maintained to a much higher force.

Sean Ellison & Walid Tizani [16], the force-slip relationship of standard bolt with varying diameter is shown in consideration of 16 and 20mm bolt diameters, with the latter involving an identical head bearing area. It is found that the initial stiffness of the element is not influenced by the parameter variation, but is maintained to a much higher force. The pull-out strength is higher in the case of the larger bolt diameter, and as anticipated, the ultimate strength as well as the ductility of the element both increase notably with the variation in bolt diameter. The higher pull-out strength is attributed to the larger head bearing area that is provided by the end anchor head of the 20mm bolt diameter specimens.

3.4.2. Ductility

According to pitrakkos [14], the yield and ultimate strength, as well as the ductility of the component increase notably with the variation in bolt diameter; nevertheless the failure mode of the specimens involved the yielding and eventual fracture of the internal bolt shank.

The global yield and ultimate strength, as well as the ductility increase notably with the variation in bolt diameter, Elghazouli [15], the failure of the specimens involved the yielding and eventual fracture of the internal bolt shank, in combination with a concrete breakout at the loaded surface. The size effect with respect to the failure of Hollobolt is shown that where the extent of concrete breakout is compared with that of the benchmark specimen when diameter is 16mm. It is found that the diameter of the concrete cone breakout increases from 175mm to 215mm when an internal bolt of 20mm diameter is considered; attributed to the larger size of the expanding sleeves element in Hollobolt 20. On the contrary, type Extended hollobolt 20 was able to develop the full tensile capacity of the 20mm internal bolt, exclusive of any formation of concrete breakout.

Sean Ellison & Walid Tizani [16], the failure mode of the specimens involved the yielding and eventual fracture of the bolt shank, exclusive of concrete breakout demonstrating that standard bolt is able to develop the full tensile capacity of 20mm diameter, grade 8.8 bolts.

For the overall conclusion shows the size effect with respect to the failure of standard bolt involved the yielding and eventual fracture of the bolt shank, exclusive of concrete breakout demonstrating that standard bolt is able to develop the full tensile capacity of 20mm diameter. For Hollobolt shows that the extent of concrete breakout in comparison with that of the benchmark specimen when diameter is 16mm increases from 175mm to 215mm when an internal bolt of 20mm diameter is considered; attributed to the larger size of the expanding sleeves element in Hollobolt 20. On the contrary, type Extended hollobolt 20 was able to develop the full tensile capacity of the 20mm internal bolt, exclusive of any formation of concrete breakout.

4. Conclusion

Based on the comparison of previous study, there are different kinds of blind bolt connection to CFHS under static load. The blind bolts that are reviewed in this study are Extended Hollobolt, Standard bolt and Hollobolt. The findings of previous study show that the initial stiffness of the Extended hollobolt component is affected by the variation in concrete strength, with high concrete grade specimens exhibiting higher stiffness. Meanwhile the yield and ultimate strength, and the ductility of the component are directly related to the material property of the internal bolt shank. The study also shows that the higher grade of bolt and larger bolt diameter improves the stiffness and strength characteristics of the component. Hence, Extended hollobolt allows for the development of the full tensile capacity of 20mm diameter internal bolts. Previous study also show that failure occurred by fracture in the bolt shank, exclusive of concrete breakout.

Based on the research, it there following suggestion are recommended for further research:

- Bolts with different diameters and connected with different concrete strengths should be tested to complete the assessment of Blind bolts connected under static load.
- Further investigations on reliability and probability using more experimental data to compare with other types of bolt should also be conducted.
- Finite element modeling should be used to investigate the behaviour of Blind bolts under static load for comparison with the experimental results and for parametric studies.

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