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BOLTED RIGID CONNECTIONS OF STEEL I-BEAM TO SQUARE TUBE COLUMNS

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Abstract: In recent years, further studies have resulted in improvements in the design standard and the concrete quality has been greatly improved. For all of concrete-filled steel tubes are being employed in more constructions especially bridges, multi-story, and high-rise buildings. Hollow steel sections also can provide reduced weight and surface area when compared to equivalent open sections. Concrete filled steel tube (CFST) is a composite section integrated from a steel tube or a steel hollow section (SHS) with concrete filling inside the hollow part of the steel section. The steel section could be hot-rolled section or cold-formed section. However, the steel section type, grade, manufacturing, and concrete characteristic cylinder strength together control the overall section capacity. Concrete filled steel tubes combine the advantages of ductility associated with Steel structures, with the stiffness of a concrete structural system. After several pieces of research, it has been known that load transferred from the steel tube to the concrete by bond and shear connectors if the bond between the steel column and concrete inside is not made full use of, the flexural bearing capacity of concrete-filled steel tube column may not be fully acted. In this paper, an extensive parametric study is introduced to show the effect of concrete in the hollow steel section among different parameters. Moment rotation curves are plotted for various studied parameters as bolt grade, bolt diameter, pre-tension force, and endplate thickness. The main object of this research is to highlight the concrete filling effect on the connection between steel I-beam to steel hollow section column and studying the connection behavior in each parameter with and without concrete.

***Index Terms* - Concrete-filled steel tube (CFST), End-plate connections, Blind bolts, Finite element analysis (FEA).**

I. INTRODUCTION

Hollow steel sections have always had a very good reputation in the construction field. they are always recommended by the architects due to their excellent and attractive appearance. Moreover, the closed shape without sharp corners reduces the area to be protected and extends the corrosion protection life. The internal void can be used in various ways as increasing the bearing resistance by filling with concrete or to provide fire protection. Also, the heating or ventilation system sometimes makes use of the hollow section columns. Another aspect that is especially favorable for circular hollow sections is the lower drag coefficients if exposed to wind or water forces. Some of the strongest and most impressive structures today would not have been possible without hollow sections.

Due to the benefit of composite action of the two materials, the CFST columns provide excellent seismic event resistant structural properties such as high strength, high ductility, and large energy absorption capacity. They are erected without the need for the temporary shuttering or formwork associated with composite columns made from open sections. While many advantages exist, the use of Concrete filled Tubes in building construction has been limited, in part, to a lack of construction experience, a lack of understanding of the design provisions, and the complexity of connection details. Research work in this area is still underway and no definitive CIDECT design guidance is available. Consequently, a joint is needed that could utilize the favorable strength and stiffness characteristics of the concrete-filled tube column yet be constructible.

In the late 1960's most steel moment connections were designed following the AISC Manual of Steel Construction. The beam flanges were welded to the column face using full penetration weld and the beam web was connected to the column using shear tabs to transmit shear forces.

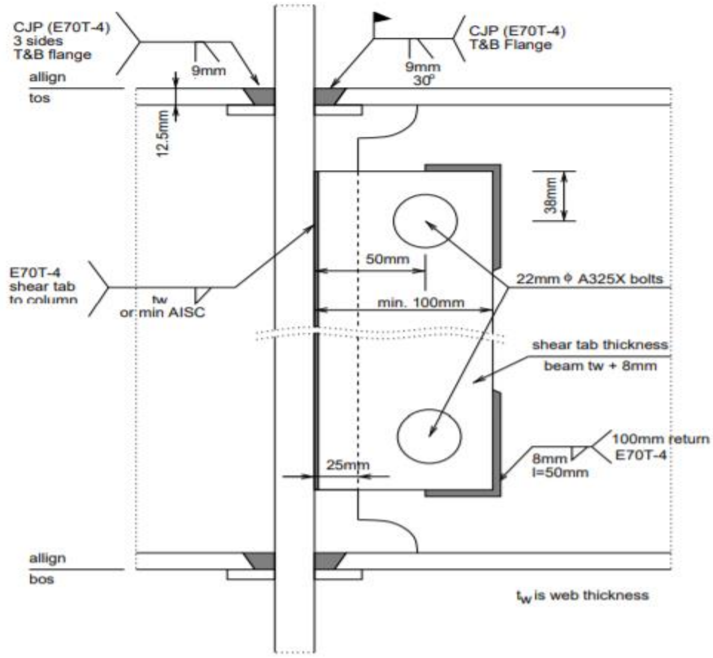


Figure 1 Pre-Northridge Connection Detail – (STOJADINOVIC, 2000)

After the Northridge earthquake that happened in 1994 in the USA, most engineers and scientific researchers were biased toward the bolted connection over the welded connection due to the big number of failures in the connection. The failure was initiated by cracks in the weld, it was realized then that this connection had a small plastic rotation capacity which didn't exceed 0.009 radians (Fry 1998). The welded connection by that time had many restrictions. New innovations and approaches are being researched today for hollow section bolted connections, one of the latest approaches is the blind bolting system. It is a system that doesn't need any weld, furthermore no need to get access from both sides as it is all about an idea of a bolt that is installed and tightened from one side.

The objective of this research is to study and develop the moment bolted connection between I-beam and the hollow steel section using the hollo-blind bolt. This study will discuss the connection behavior, strength, and stiffness. The initial stiffness and the plastic rotation capacity will be compared to the Eurocode 3 regulations. Also, the connection performance shall be investigated through many variables.

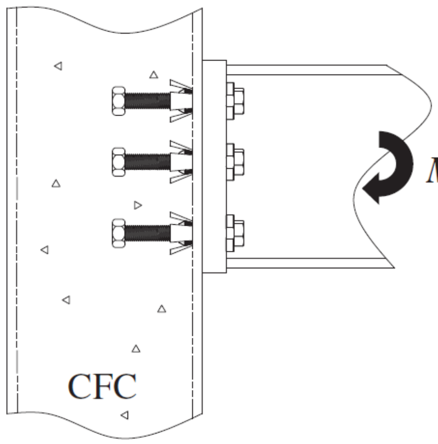


Figure 2 Hollo-Bolt Moment Connection Between I-Beam to Concrete Filled Column – (Tizani-2013)

II. LITERATURE REVIEW

Blind bolting systems make use of either special types of bolts or special drilling systems. As the name implies, these can be used when only one side of the connection is accessible, and, therefore, access to both sides is not necessary. This allows, for example, bolted beam to structural hollow section column connection details to be designed in a similar way to a beam to open section column connection. Various types of blind bolting systems are discussed in this part of the paper, with a special focus on the hollo-bolt.

2.1 Flow drill system

The Flow drill system is done through two processes; First thermal drilling of the parent material extrusion of holes using a four-lobed tungsten-carbide friction drill. The second process subsequent thread forming where tungsten-carbide drill bit a truncated cone on the inaccessible side of the workpiece, which gets an effective thread length about twice the material thickness.

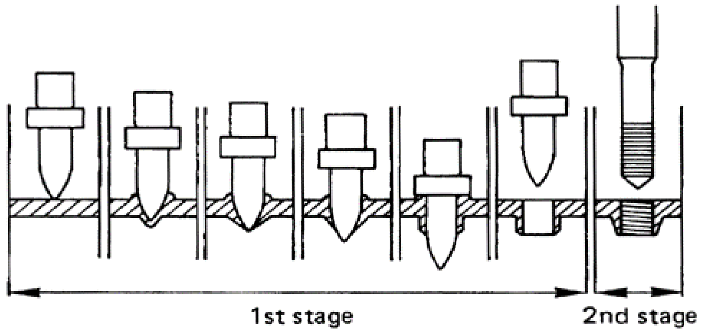


Figure 3 Flow drill process (Yeomans, 1996a)

2.2 Ultra-Twist bolt

The Ultra-Twist bolt is a pre-assembled unit manufactured by Huck International Incorporated. There are two types of structural blind fasteners produced by HUCK, the high strength blind bolt (HSBB) and Ultra-Twist. This type of blind bolt is installed using an electric bolting wrench in holes 2 mm larger than the bolt diameter so that providing conventional clearances for fit-up. These bolts have installed tensions, shear capacities, and tensile strengths meeting the requirements of ASTM A325 bolts.

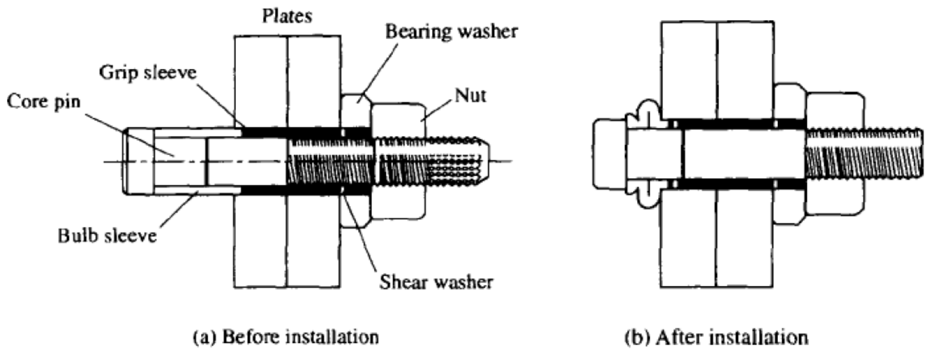


Figure 4 Huck Ultra-Twist bolt before and after installation (Tabsh & Mourad, 1997)

2.3 Ajax one side blind bolt

The Ajax one side blind bolt is a relatively new product made in Australia and can achieve the full pretension load (Fernando 2005). According to Fernando's suggestion, the Ajax one side can be designed according to the Australian Steel Standard AS4100 if the appropriate bolt properties are assumed.

Figure 5 AJAX Bolt Components & The Installation Tool – Ajaxfasteners.com

2.4 Hollo-Blind Bolt

The Hollo-Bolt was first launched in 1995, They are like standard high strength bolts but are designed but with a quite different geometry, it has sleeves around the shank. Previous researches mentioned that the ultimate load capacity of the Hollo-bolted endplate connection is higher than that of the Ajax one side bolted endplate connection. Also, Barnett et al. stated that the Hollo-Bolt blind bolts have favorable strength and stiffness to be used in this type of connection, and the flexibility of HSS face often limits the moment capacity of such a connection. The geometries of the Hollo bolt before and after tightening are completely different this difference can provide more tensile resistances in the Hollo-bolted joints compared to other blind bolted joints if the tubular column was filled with concrete. The Hollo-Bolt provides a ductile connection and the chord face of the hollow section can deflect.

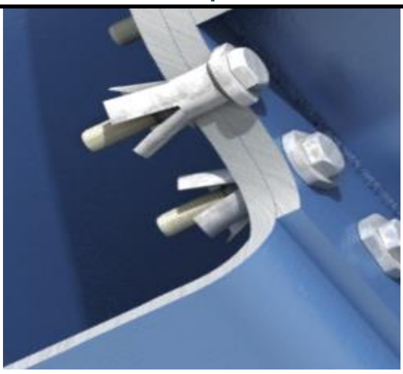


Figure 6 Hollo-Bolt Assembly - lindapterinternational.com

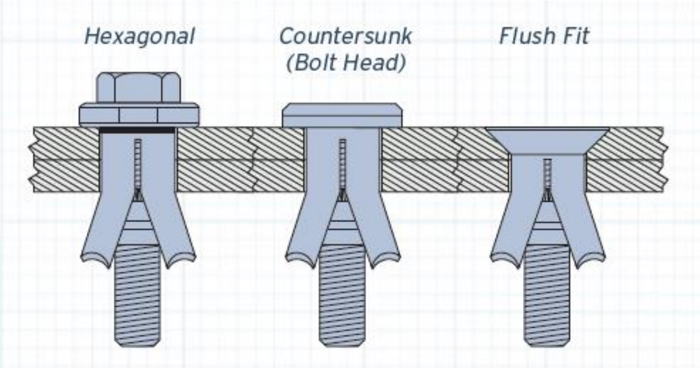


Figure 7 Hollo-Bolt Head Types - lindapterinternational.com

2.5 Extended Hollo-bolt EHB

The principal purpose of using the Extended Hollo-bolt EHB is to increase the tensile strength and stiffness of the blind-bolt. The research work illustrates the primary difference between the standard Hollo-bolt and the Extended Hollo-bolt EHB is the maximization of the use of the concrete infill to enhance its strength and stiffness. The strength is enhanced by moving the failure mode from bolt pull-out to bolt shank tensile fracture. The stiffness is enhanced by the added bolt anchorage and end-nut embedment. The concrete infill will also provide additional stiffness to the face of the hollow section against bending.

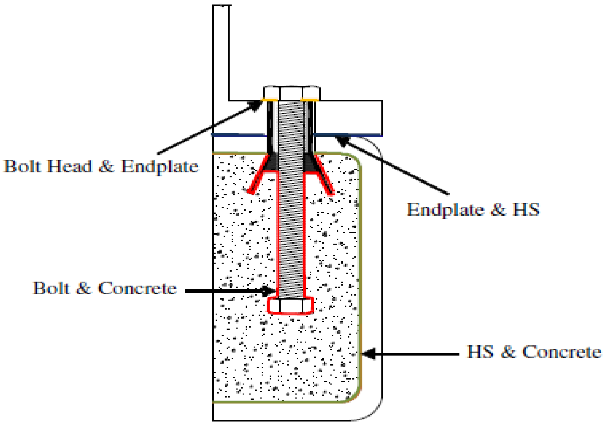


Figure 8 Extended Hollo-Bolt in Concrete Filled Steel Tube - (Tizani)

2.6 Related Work

France et al. (1999) were among the first researchers in this field, he studied the effect of hollow tube section slenderness, bolt spacing, endplate type, and thickness and concrete filling on the moment capacity and rotational stiffness of the endplate connections for square SHS or CFST columns using flow drill connectors by making a series of joint tests under monotonic loading. He concluded that the difference between filled and un-filled is a shift in the axis of rotation position which makes the concrete-filled joint has higher moment capacity and rational stiffness but less ductile than the un-filled joint. H.Y. Loh et al. (2006) studied the shear degree of several flushed hollo-bolted connections through varying shear connectors spacing and the number of shear connectors. He studied the moment rotation response and the ductility of the joint. He concluded that the partial shear connection system is very effective that it shall be considered in the existing design standards. JingFeng Wang et al. (2009) focused his studies on the endplate thickness and the steel tube type. He showed that the endplate thickness can evidently affect the stiffness and moment rotation capacity of such connections. Tizani et al. (2013) investigated the feasibility of achieving blind-bolted rigid connections using extended Hollo-bolt (EHB). The extended Hollo-bolt is mainly used to increase its tensile stiffness by increasing the embedding length in the concrete fill, as it is a modified configuration of the standard Hollo-bolt with an attached anchor head to it. He made eight samples testing program to study the effect of varying the steel tube thickness, beam section, and bolt pitch. The experimental results were verified and similar to his numerical model using ANSYS software. Thai et al. (2015) also studied the degree of shear connection based on H.Y. Loh et al. approach, he took the same connection configuration. He studied the effect of shear studs and the reinforcement ratio of concrete slab on the connection behavior. He made a numerical 3D model through ABAQUS software, also he made an analytical model based on the component method to predict the initial stiffness, moment resistance, and rotation capacity of the connection. The width-to-thickness ratio and column sections and the difference between hollo-bolt and ajax one-side were two important parameters in his study. He concluded that the composite joint under the effect of static loading isn't sensitive to the blind bolt type or the bolt diameter as well as the column slenderness ratio, the factor that has great dominance is the concrete slab and the reinforcement ratio. Thai et al. (2017) focused on his numerical model through ABAQUS software, he mentioned his mesh sizing trails as a parameter, he studied the effect of different loading rates, mass scaling, smooth step, and linear step amplitudes. He stated that the hollo-bolt geometry should be modeled with special attention, so that accurate results and predictions are obtained. He also stated that the hollo-bolt mesh only affects the bolt stress and the area around the bolt.

III. FINITE ELEMENT MODELING

The finite element model was conducted with ANSYS structural analysis software version (18.2) program. Various Finite Element models were conducted to investigate the effect of different parameters on the studied connection. The modeled connection is a flushed end plate moment connection between the square hollow section (SHS) steel column connected to the steel I-beam by a rectangular endplate. The steel I-beam is connected to the endplate by fillet weld and the end-plate with the welded I-beam are connected to the square hollow section (SHS) steel column by blind Hollo-bolts (M16).

3.1 Finite element model description

SOLID186 is used which is a higher-order 3-D 20-node structural solid element that exhibits quadratic displacement behavior. SOLID186 is defined by 20 nodes having three degrees of freedom in each node: translations in the nodal x, y, and z directions as shown in Figure 9. The element supports plasticity, hyper-elasticity, stress stiffening, creep, large strain capabilities, and large deflection. It also has mixed formulation capability to simulate deformations of near incompressible elastoplastic materials and full incompressible hyper-elastic materials.

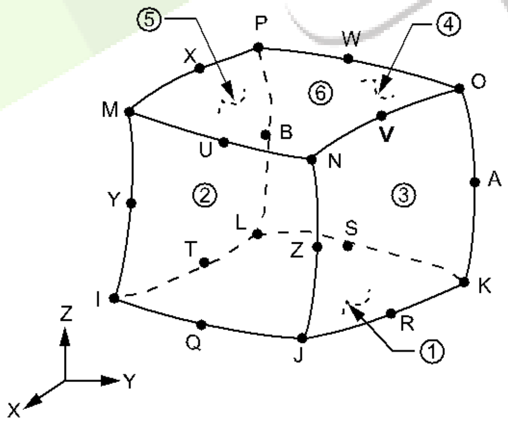


Figure 9 SOLID186 Element Configuration

In studying the contact between two bodies, the surface of one body is conventionally taken as a contact surface and the surface of the other body as a target surface. For the rigid-flexible contact, the contact surface is associated with the deformable-body; and the target surface must be the rigid surface. For flexible-flexible contact, both contact and target surfaces are associated with deformable bodies. The contact and target surfaces constitute a "Contact Pair". CONTA 174 is an 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis. In a general contact analysis, the area of contact between two or more bodies is generally not known in advance. It is applied for the contact between solid bodies or shells. The contact forces vary smoothly during large sliding, and the forces do not jump when contact nodes slide off edges of target surfaces. The surface projection method also satisfies the moment equilibrium for frictional or bonded contact. The CONTA 174 contact element is associated with the 3-D target segment elements (TARGET170) using a shared real constant set number. TARGE170 is used to represent various 3-D "target" surfaces for the associated contact elements, this element is located on the surface of the 3-D solid, shell elements.

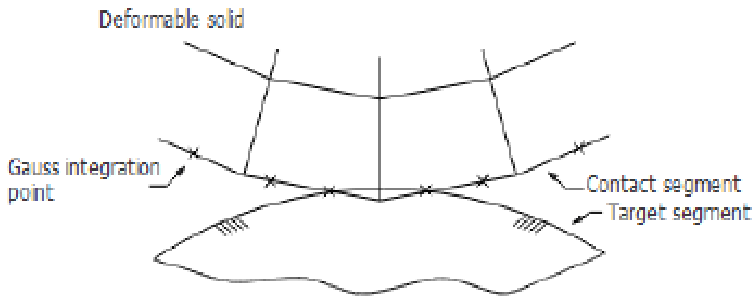


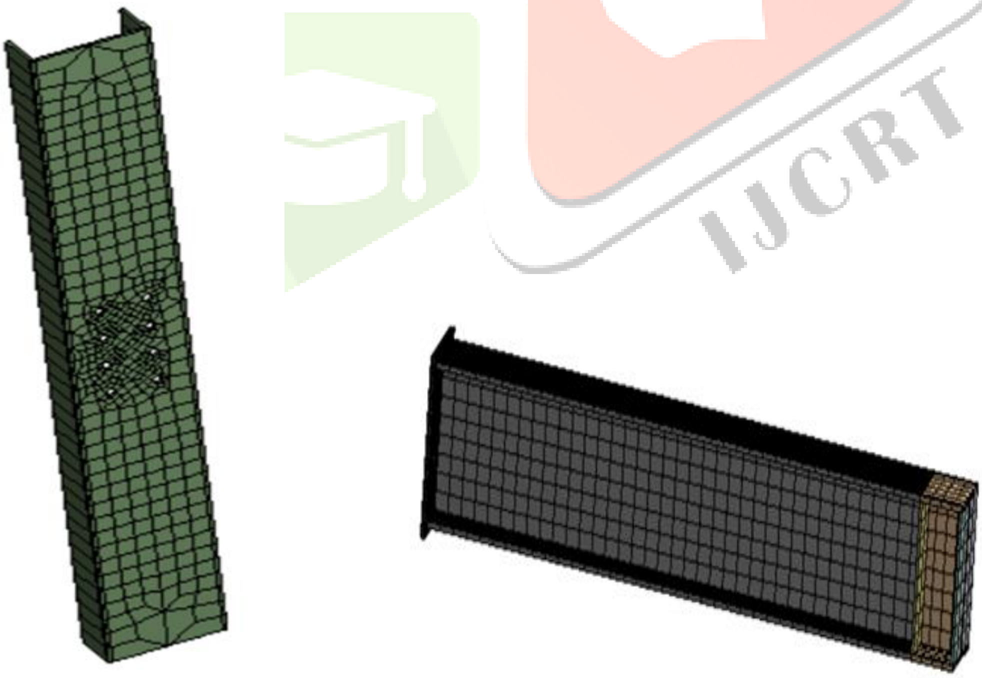
Figure 10 Geometry, nodes locations of contact

3.2 Material properties

The elastic-plastic model was used to describe the constitutive behavior of steel. The determination of the stress-strain relationship for steel material is concerned with the types of steel material. For high strength steel as in bolts, a simplified elastic-plastic stress-strain relationship with bi-linear stages is used, while in carbon steel used in all steel members and concrete a simplified elastic-plastic stress-strain relationship with multi-linear stages is used. The tangent modulus (Et) for all materials was taken 0.01 the young’s modulus, (Et = 0.01Es). Table 1 and Table 2 summarize all details of used materials.

3.3 Meshing

There are two meshing techniques free meshing and mapped meshing. Free meshing is preferred when having irregular element shapes, while mapped meshing is characterized by restrictions of the element shape and the pattern, i.e (tetrahedron and hexahedron elements). In the current study, hexahedron elements (quadratic 20 nodes) are used. The ideal meshing process is to use adaptive meshing to achieve accurate stress distribution with the optimum analysis time. Poor meshing shall give inaccurate results or sometimes it can make the finite element analysis to stop solution in a very early stage due to very high deformations and stresses that can’t be solved using that poor meshing.



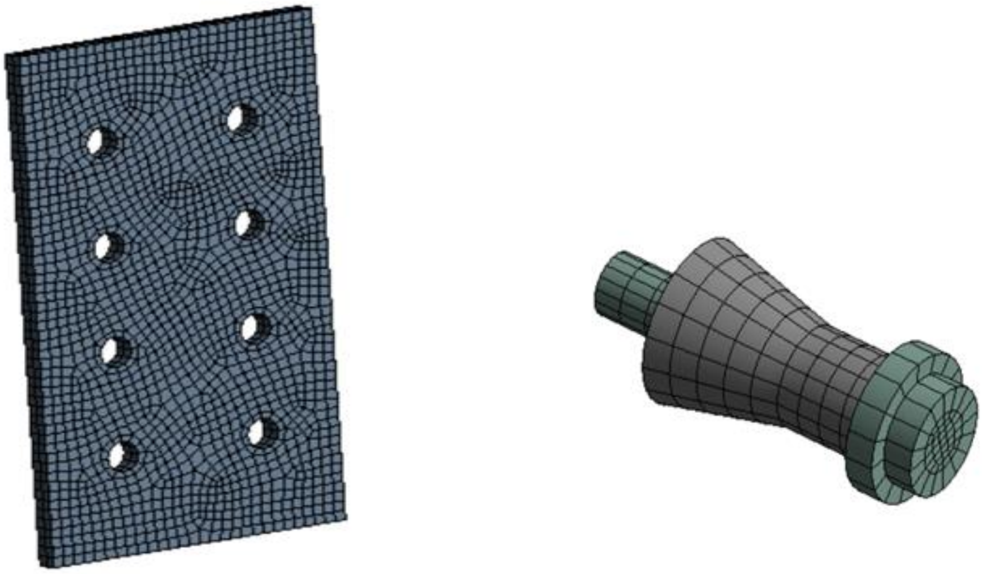


Figure 11 (3-D) idealization of the connection components

3.4 Bolt pretension force

The pretension force was assigned to the hollo-blind bolt by bolt pretension tool in Ansys workbench, each bolt was tightened to 190 N.M which corresponds to a pre-load force equals to 59,375 N. The pre-load force is calculated by substituting in the equation, $\tau = \mu \times$ Bolt diameter $\times$ pre-load force. where τ = tightening torque and μ = coefficient of friction = 0.2

3.5 Boundary conditions

All the parametric models were representing interior joints, so the advantage of symmetry was taken into consideration. The axis of symmetry is in the YZ plan.

IV. PARAMETRIC STUDY

This section discusses the results of parametric study analyses on the behavior of hollo-blind bolt end plate connections. Using the proposed model, a parametric study of the main variables in a composite joint design was conducted against non- composite joint to determine the increase in the moment capacity and rotational stiffness of a composite joint. Parameters studied for both joints are:

1. SHS thickness
2. Endplate thickness
3. Bolt diameter
4. Bolt grade
5. Pre-tension force
6. Slenderness ratio of column

The first type of connection in this study which has a steel tube filled with concrete. The steel column is a square hollow section (SHS), the steel I-beam is a built-up section and the hollo-bolt is (HB16-2-Gr8.8). The slenderness ratio which is equal to twice the column length divided by the column width. The vertical load on the beam end is equal to 100 kN, while the pre-loading force on each bolt is equal to 59,375 N. The geometric details of the joint components' areas are mentioned in table 3.

This type has an axial load level on the steel column and concrete core equal to 0.6 Nu where Nu is the maximum axial load for this column. The maximum axial load is calculated according to the Eurocode 4, equation 6.30

$N_{pl,RD}$=Aa×Fyd+0.85×Ac×Fcd+As×Fsd.

Where:

$N_{pl,RD}$ is the plastic resistance to compression.

Aa, Ac, and As are the cross-sectional area of the steel section, concrete core, and reinforcement respectively.

Fyd, Fcd, and Fsd are the yield strength of steel, cylinder compressive strength of concrete, and yield strength of reinforcing steel.

The second type of connection in this study which has an empty steel tube. This type has the same geometric and loading features as the first type exactly, except for the axial load level is taken equal to 0.5 Nu where Nu is the maximum axial load for this column and the vertical load on the beam end is equal to 25 kN. Table 4 summarizes the Parametric study with all specimens. The specimens are divided into two groups, the first one the square hollow section is filled with concrete (CFST) and its name is (X-F). In the second group, the square hollow section is empty with no filling and its name is (X-U). X refers to the specimen number or arrangement, F refers to filled with concrete and U refers to un-filled with concrete.

4.1 Parametric results for the I-beam to CFST joint:

4.1.1 SHS thickness

Three models are conducted with different SHS thicknesses 6mm, 10mm, and 16mm. The obtained moment rotation curves are shown in figure 12. Curves show that the thickness range of SHS from 6mm to 10mm is the same. The thickness of 16mm gives different curve tends to be more rigid with less rotation. This leads us to the fact that concrete filling is not effective on the connection behavior after SHS thickness of 10mm.

4.1.2 Endplate thickness

Five parametric models are conducted with different endplate thickness 15mm, 18mm, 20mm, 22mm, and 25mm. It is very clear from the curves shown in figure 13, that bigger endplate thickness gives a more rigid connection. The connection with 15mm endplate thickness has the maximum rotation unlike the connection of 25mm endplate thickness which has the least rotation.

4.1.3 Bolt diameter

The following graph shows the connection becomes more rigid when using M20 instead of M16. Increasing the bolt diameter leads to an increase in the moment capacity and the connection stiffness. At rotation of 9.5 milli-rad which is the maximum rotation in the M20 moment rotation curve, the moment capacity for the M20 case is equal to 1.4 times the moment capacity for M16. The bolt diameter is a very sensitive parameter in the blind bolted connection.

4.1.4 Bolt Grade

The bolt Grade just made a little difference in the connection. Bolt grade 10.9 gives better numbers than bolt grade 8.8. The connection moment capacity increased by 4% in case of bolt grade 10.9, also the rotation increased about 10 milli-rad for bolt grade 10.9. The bolt grade is not a very effective parameter to the moment capacity in this study.

4.1.5 Pre-tension force

Four analysis models are done by different pre-tension force values Po, 0.75Po, 0.5Po, and 0.25Po. The results obtained from analysis models showed that the initial stiffness and moment connection rarely increase by increasing the pre-tension force.

4.1.6 Slenderness ratio of column

In order to study the effect of slenderness ratio effect on the connection behavior, three finite element models are done. The values taken for the slenderness ratio are 13.56, 16.95, and 20.34. The effect seems to be negligible for both moment capacity and initial stiffens.

4.2 Parametric results for the I-beam to SHS joint:

4.2.1 SHS thickness

The conducted models represented three square hollow sections of different SHS thicknesses 8mm, 10mm, and 16mm. Curves from the finite element models show that the increase in the thickness of SHS reflects on the connection behavior by increasing the initial stiffness and moment capacity.

4.2.2 Endplate thickness

To study the effect of endplate thickness, five models are conducted with different endplate thickness 15mm, 18mm, 20mm, 22mm, and 25mm. The endplate thicknesses are the same values from a previous study of the CFST joint. The curves shown in figure 19 illustrate that increasing endplate thickness increases the moment capacity of the studied connection.

4.2.3 Bolt diameter

The following graph shows the effect of increasing the bolt diameter on the connection. The moment capacity increases by 15% when using M20. It is obvious now from curves that bolt diameter doesn't deal much with the joint rotation, as we see the difference in rotation between the two bolt diameters is not as big as the previous study.

4.2.4 Bolt Grade

The initial stiffness for both bolt grades is the same. Bolt Grade 10.9 has a greater rotation capacity and moment capacity than bolt grade 8.8. Both curves are identical until the connection reaches the inelastic deformation limit. The connection of bolt grade 8.8 deformed and failed earlier than the bolt grade 10.9 connection. The connection moment capacity increased about 10% in the case of bolt grade 10.9, also the rotation increased by 2 milli-rad for bolt grade 10.9. The bolt grade is an effective parameter to the moment capacity in this study.

4.2.5 Pre-tension force

To study the effect of the pre-tension force on the connection behavior, four analysis models are done by different pre-tension force values Po, 0.75Po, 0.5Po, and 0.25Po. The results obtained from analysis models showed that the initial stiffness and moment connection increase by increasing the pre-tension force with a higher rate than that of the previous pre-tension moment rotation curves.

4.2.6 Slenderness ratio of column

Three parametric finite element models are conducted to study the effect of slenderness ratio effect on the SHS connection behavior. Values taken for the slenderness ratio are 13.56, 20.34, 28.8. The effect this time is promising than before. The SHS in this study is facing the slenderness effect alone without the concrete confinement. Figure 23 shows the different behavior of the three curves. The moment capacity and initial stiffness increase dramatically as the slender ratio decreases.

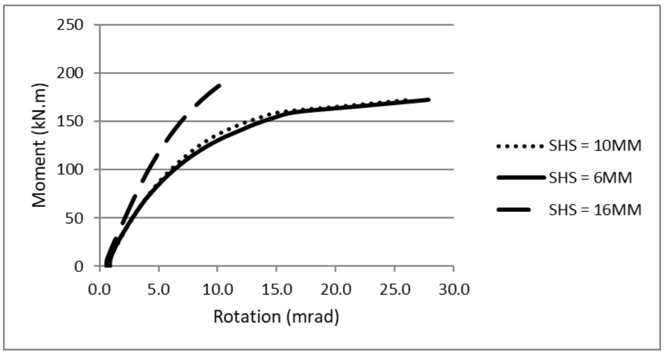


Figure 12 – SHS Thickness – CFST

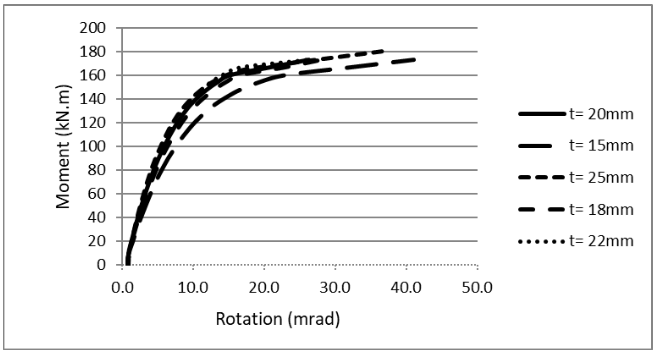


Figure 13 – Endplate Thickness – CFST

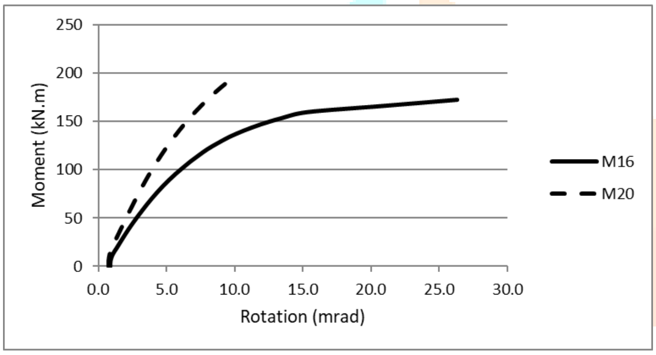


Figure 14 – Bolt Diameter – CFST

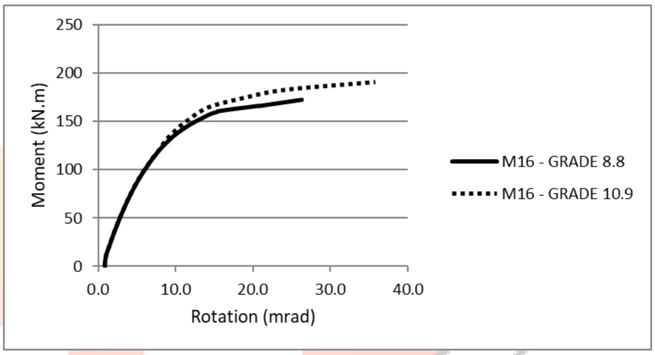


Figure 15 – Bolt Grade – CFST

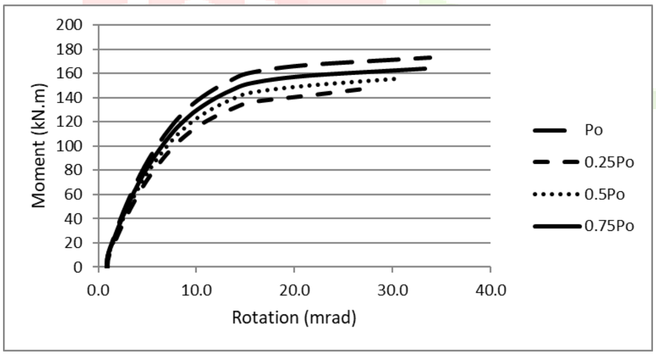


Figure 16 – Pre-tension Force – CFST

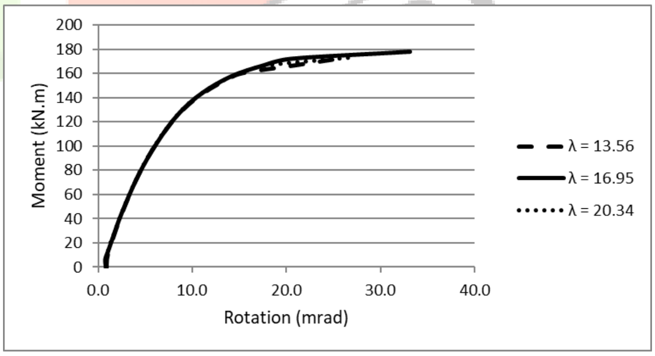


Figure 17 – Slenderness Ratio – CFST

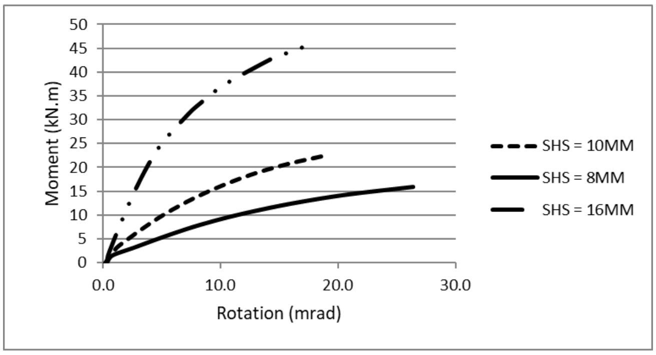


Figure 18 – SHS Thickness – SHS

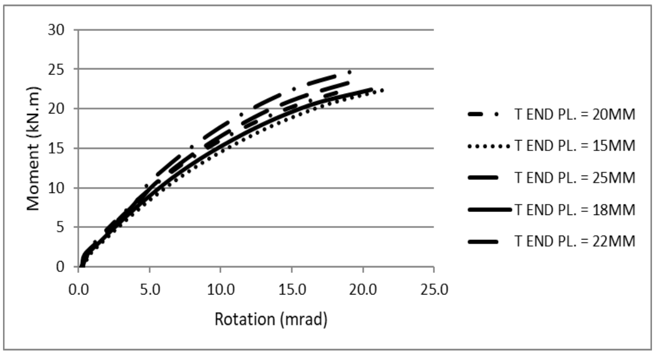


Figure 19 – Endplate Thickness – SHS

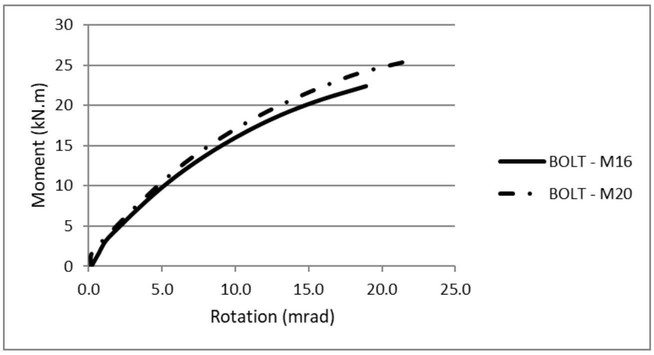


Figure 20 – Bolt Diameter – SHS

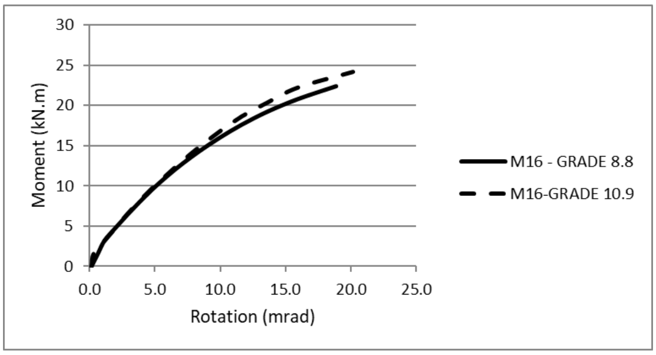


Figure 21– Bolt Grade – SHS

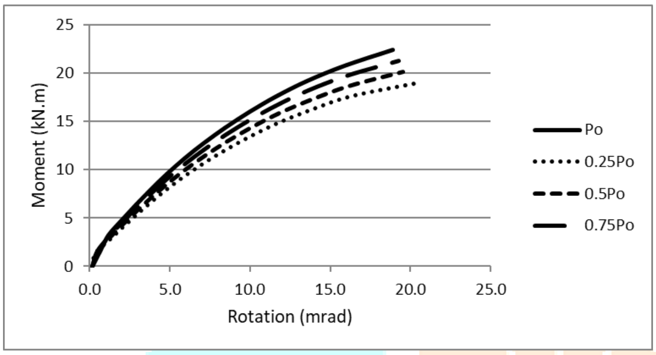


Figure 22 – Pre-tension Force – SHS

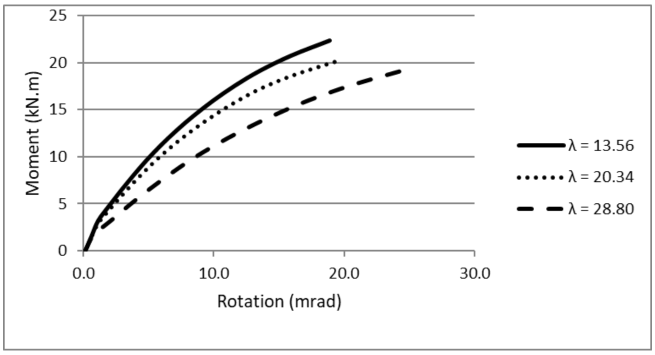


Figure 23– Slenderness Ratio – SHS

Table 1: Material Properties of Steel

Variable	Yield Strength (MPa)	Ultimate strength (MPa)	Young's Modulus (MPa)	Tangent Modulus (MPa)
Beam Flange	275	430	200000	2000
Beam Web	275	430	200000	2000
HSH	275	430	200000	2000
Endplate	275	430	200000	2000
Bolts 8.8	640	800	200000	2000
Bolts 10.9	900	1000	200000	2000

Table 2: Material Properties of Concrete

	Compressive strength (MPa) - Fcu	Compressive strength (MPa) – Fc'	Young's Modulus (MPa)
Concrete	60	48	37000

Table 3: Geometric Details of Joint Components

SHS (b×t)	SHS height (H)	I-beam (h×b×tw×tf)	I-beam Length (L)	Beam stiffeners (h×b×t)	Endplate (h×b×t)
300×10	2000	400×200×10×15	2000	370×95×10	440×250×20

*ALL DIMENSIONS ARE IN mm

Table 4: Specimens Details

SPECIMEN INDEX	SHS SIZE	Column Height (m)	Endplate thickness (mm)	Bolt-Diameter	Bolt-Grade	Pre-tension force	Slenderness ratio (λ)
C-F	300×10	2	15	HB - M16	8.8	Po	13.56
D-F	300×10	2	25	HB - M16	8.8	Po	13.56
E-F	300×6	2	20	HB - M16	8.8	Po	13.56
F-F	300×16	2	20	HB - M16	8.8	Po	13.56
G-F	300×10	2	20	HB - M20	8.8	Po	13.56
H-F	300×10	2	20	HB - M16	8.8	0.75Po	13.56
I-F	300×10	2	20	HB - M16	8.8	0.5Po	13.56
J-F	300×10	2	20	HB - M16	8.8	0.25Po	13.56
K-F	300×10	3	20	HB - M16	8.8	Po	20.34
L-F	300×10	2.5	20	HB - M16	8.8	Po	16.95
M-F	300×10	2	20	HB - M16	8.8	Po	13.56
R-F	300×10	2	20	HB - M16	10.9	Po	13.56
S-F	300×10	2	18	HB - M16	8.8	Po	13.56
T-F	300×10	2	22	HB - M16	8.8	Po	13.56
C-U	300×10	2	15	HB - M16	8.8	Po	13.56
D-U	300×10	2	25	HB - M16	8.8	Po	13.56
E-U	300×8	2	20	HB - M16	8.8	Po	13.56
F-U	300×16	2	20	HB - M16	8.8	Po	13.56
G-U	300×10	2	20	HB - M20	8.8	Po	13.56
H-U	300×10	2	20	HB - M16	8.8	0.75Po	13.56

I-U	300×10	2	20	HB - M16	8.8	0.5Po	13.56
J-U	300×10	2	20	HB - M16	8.8	0.25Po	13.56
K-U	300×10	3	20	HB - M16	8.8	Po	20.34
L-U	300×10	2	20	HB - M16	8.8	Po	13.56
Q-U	350×10	5	20	HB - M16	8.8	Po	28.8
R-U	300×10	2	18	HB - M16	8.8	Po	13.56
S-U	300×10	2	22	HB - M16	8.8	Po	13.56
T-U	300×10	2	20	HB - M16	10.9	Po	13.56

V. CONCLUSION

By comparing the behavior of both studied connections to each parameter, the steel tube thickness and the endplate thickness have a great effect on connection to SHS, unlike connection to CFST the effect is remarkable within a certain range and beyond this range, there is no difference. For bolt diameter, the effect was much obvious in connection to CFST than SHS. Bolt grade and pre-tension force parameters have the same slight and uniform effect on both connections. The slenderness ratio of the steel column has a big influence on the behavior of SHS connection while there is no change in the CFST connection behavior.

1. Concrete filling plays a great role in the connection stiffness, rotational capacity, and moment capacity.
2. Some parameters have a significant and a big effect on the connection behavior for both studied connections such as; steel tube thickness and bolt diameter.
3. Endplate thickness and pre-tension force also have a remarkable effect for both connections, either endplate thickness or pre-tension force increases, the connection moment capacity and initial stiffness increase.
4. The bolt grade parameter just affects the moment capacity and rotation capacity for both connection, there is no change in the initial stiffness in any of the two connections between bolt grade 8.8 and bolt grade 10.9.
5. The slender ratio for the steel tube is a very important parameter for the second connection which has not concrete filling, as the slender ratio decreases the moment capacity and the initial stiffness increase, while in the first connection this factor represents no change in the moment rotation curve due to concrete filling which constrain the steel tube.

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