Parametric studies on the behaviour of beam-column flush end plate connections using blind bolts

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ABSTRACT

This paper presents the results of parametric studies on the performance of semi rigid and composite beam-to-column flush end plate connections using the innovative blind bolts. The connection model is subjected to static loading conditions. The behaviour of this connection is very complicated and therefore requires special attention in order to monitor its behaviour precisely. The geometrical dimensions of the model are exactly of the same size as taken from the experimental model. The finite element model is verified with the experimental data and results obtained from finite element analysis are then exploited to conduct parametric studies in order to examine the important perimeters like thickness of the hollow steel column, thickness of the end plate, grade of blind bolts, grade of steel and compressive strength of concrete.

1. INTRODUCTION

The usage of concrete filled steel tubular columns is growing rapidly due to the variety of structural benefits associated with them such as, high strength, high ductility and high energy absorption capacity. Composite connections are the methods of joints in which the concrete filled steel tubular column is connected to the steel beams with the help of the end plates of beam bolted to the steel column. According to Wang et al. (2009), the steel tube provides support to the concrete whereas concrete helps to avoid the local buckling of the steel tube. Therefore, Loh et al. (2006) stated that the combine use of CFST columns and steel beams has developed as a widespread choice in composite construction due to being economical and its ease of construction. However, the connections between CFST columns and steel beams are very complex due to the interaction between non homogenous materials such as steel and concrete. These types of connections can be designed in three different ways which are rigid, semi rigid or pinned. The steel beam is connected to the thin walled steel tube through welding technique in order to obtain a rigid connection. In case of pinned connection normally fin plates and steel tube are welded together and bolted to the web of the beam to

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obtain a pinned connection. In case of semi rigid connections, the end plates are connected to the steel beams by welding process and then bolted to the concrete filled steel tubular columns. These connections are gaining a lot of attractiveness due to the ease of installation. The blind bolted system has also replaced the traditional welding system and it provides solution to the problem of not being able to reach inside of the steel tube of CFST columns during tightening of the bolts.

Many experimental studies on blind bolted connections have been conducted previously to examine their performance but they are tedious, laborious as well as expensive. Therefore, in order to overcome the experimental limitations, finite element models after validation against the experimental data can be used. Finite element analysis is a reliable method that can be applied to determine the result of various pertinent factors on the behaviour of these joints.
The modelling techniques to connect a steel beam to CFST column using blind bolted CFST column using normal bolted end plate. The main difference between them lies in the geometry of the bolt, contact between inner surface of the steel column and outer surface of the concrete core and the contact of the part of the bolt with concrete.

In this paper, a finite element model is developed to simulate the behaviour of a simple composite beam-to-column, blind bolted flush end plate connection designed by Mirza and Uy (2010). Modelling details of the connection are illustrated in this paper. The connection is modelled using the exact geometrical dimensions and material properties of the experimental model used in the reference paper. The finite element model developed study is authenticated with the experimental records. A parametric study is also performed to investigate the effect of using dissimilar thicknesses of end plates, altered thicknesses of columns, compressive strength of concrete, grade of steel and different grade of bolts.

2. DESCRIPTION OF SPECIMEN

The experimental model chosen for study in this paper is developed by Mirza and Uy (2010) as shown in Fig. 1. It is a simple composite beam-column joint system developed using flush end plates and innovative blind bolts which is exposed to static loading. The dimensional details of the steel beams, hollow steel column, concrete slab and other components of the specimen are illustrated as shown in Table. 1

Table 1**:** Dimensional details of the specimen

Member	Description	Quantity
Shear connectors	19 x 100 mm	28
Structural steel beam	610UB101x1770 mm	4
Steel beam	610UB101x850 mm	4
Steel column	300x300x12x1500 mm	2
Endplate	227x610x12 mm	16
Blind bolts	20mm diameter	48
Concrete slab	2000x3540 mm	1

Fig. 1 presents the details of the specimen for illustration. It consists of four steel beams connected to a CFST column with the help of four blind bolted flush end plates. The innovative one side blind bolt developed by Ajax Engineering Fasteners (1999) is used for the connection.
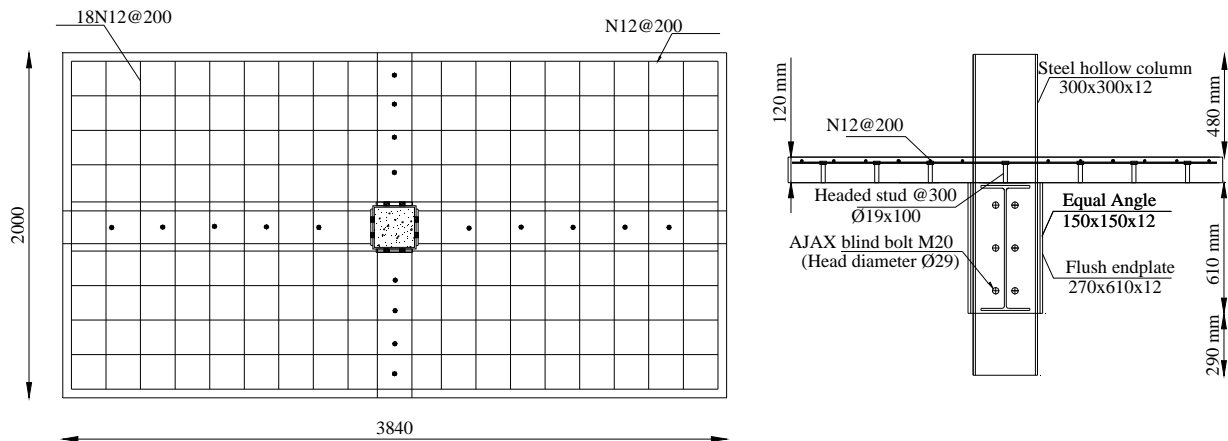

Fig. 1 (a) Plan view of the specimen, (b) Transverse view of the specimen

3. FINITE ELEMENT MODEL

The method of analysis adopted by this study is the dynamic explicit analysis. This is a time dependent analysis which models the dynamic response of the structures to the imposed loading over time. This method can also be used to depict the nonlinear behaviour of structures and materials. In order to get smooth and continuous resulting values, sufficient analysis step time must be assigned. This method is suggested by ABAQUS for large models. The finite element model involves numerous stages which are very essential in order to precisely capture the response of these connections. These include appropriate consideration of element type, material properties, interactions, constraints, loadings and boundary conditions. For the existing model all these steps are briefly discussed below. Different views of the specimen displaying the components of the joint system are as shown in Fig. 2.

3.1 Selection of Elements

The most familiar elements types present in ABAQUS library comprise three dimensional solid elements (C3D8, C3D8H, C3D8I, C3D8R, C3D20, C3D20H, and C3D20R), trusss elements (T3D2), and shell elements (S4R). Each element type has some benefits and short comings therefore, care should be taken in choosing the most suitable elements. In this paper C3D8R is used to model concrete slab, Ajax bolt, concrete columns and end plate. To achieve more accuracy, they were meshed to be at least two elements thicker. Shell elements (S4R) has been used to model the thin

condek sheet whereas truss element (T3D2) has been used to model the reinforcement. A compact rectangular meshing was used for the structural members containing bolts in the models to represent the structural members evenly and to perfectly forecast the behaviour of the structure.

3.2 Steel

For the monolithic behaviour of steel a bilinear model which shows the elastic and plastic strain hardening behaviour is adopted for all steel components. According to this model, the stress increases linearly with respect to strain until the yield point. Afterwards, the stress rises linearly to its ultimate strength with reference to strain. The mechanical properties of the joint component are mentioned in Table. 2The modulus of steel is taken as 2x 10^5 MPa and Poisson ratio is taken as 0.3. For bolts the values of material strength calculated by Loh et al. (2006) were input.

Table. 2 Mechanical properties of joint components

Members	Yield strength (MPa)	Ultimate strength (MPa)
Beams, columns, endplates	300	380
Ajax bolt	750	940
Headed studs	447	532

3.3 Material Modelling

The two basic materials used were concrete and steel. The details of the materials are as follows.

a) Concrete

The stress strain relationship of concrete under monolithic loading was used according to Carreira and Chu (1985) as shown in Fig. 3. This is the same model that is used in Mirza and Uy (2010). According to this model stress in compression is linear with respect to strain up to 0.4fc'. Tensile stress in concrete increases linearly with respect to strain until the cracking of concrete occurs. After cracking occurs, the concrete stress decreases linearly to zero at a rate of 10 times the strain. The ratio of uniaxial tensile stress to the uniaxial compressive stress at failure was evaluated as 0.1

3.4 Interactions and Constraint Conditions

General contact which is the surface to surface contact was used in order to model the contact between the steel column and end plate, steel column and blind bolt, concrete column and steel column, shear studs and slab etc. Reinforcement was
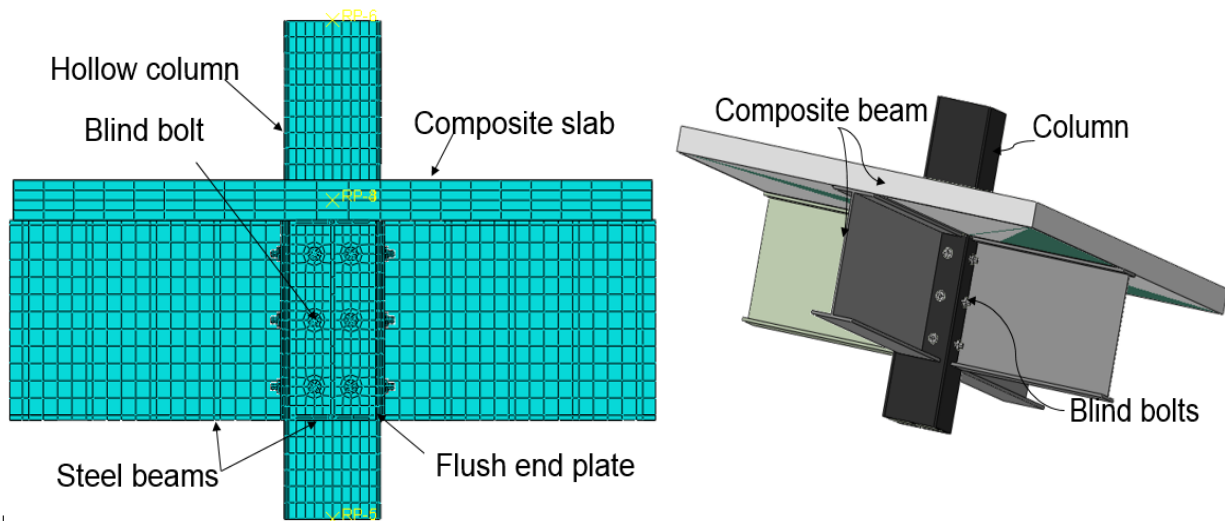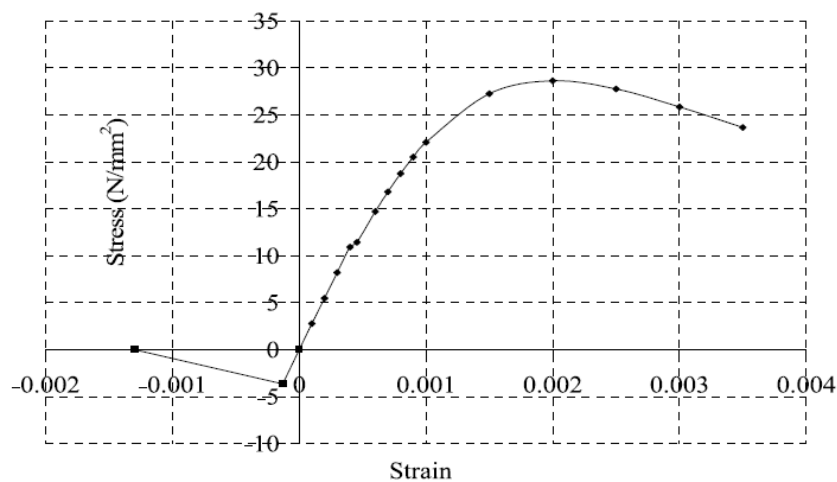
Fig. 2 Basic components of the finite element model

Fig. 3 Stress strain relationship of concrete

considered embedded in concrete. Shear studs were considered embedded in the slab whereas beam was considered tied with the end plate and studs were also considered to be tied with the beams

3.5 Modelling of Blind Bolts

The innovative blind bolts of size M20 developed by Ajax Engineering Fasteners (1999) are used in this research. The geometry of the bolt is simplified to exactly model its behaviour. Predefined temperature is also applied to the body of the bolt to cater for the shrinkage and temperature stresses. This predefined force tends to produce the effect of clamping between the bolt and the nut. Geometrical details of this bolt are shown in Fig. 4
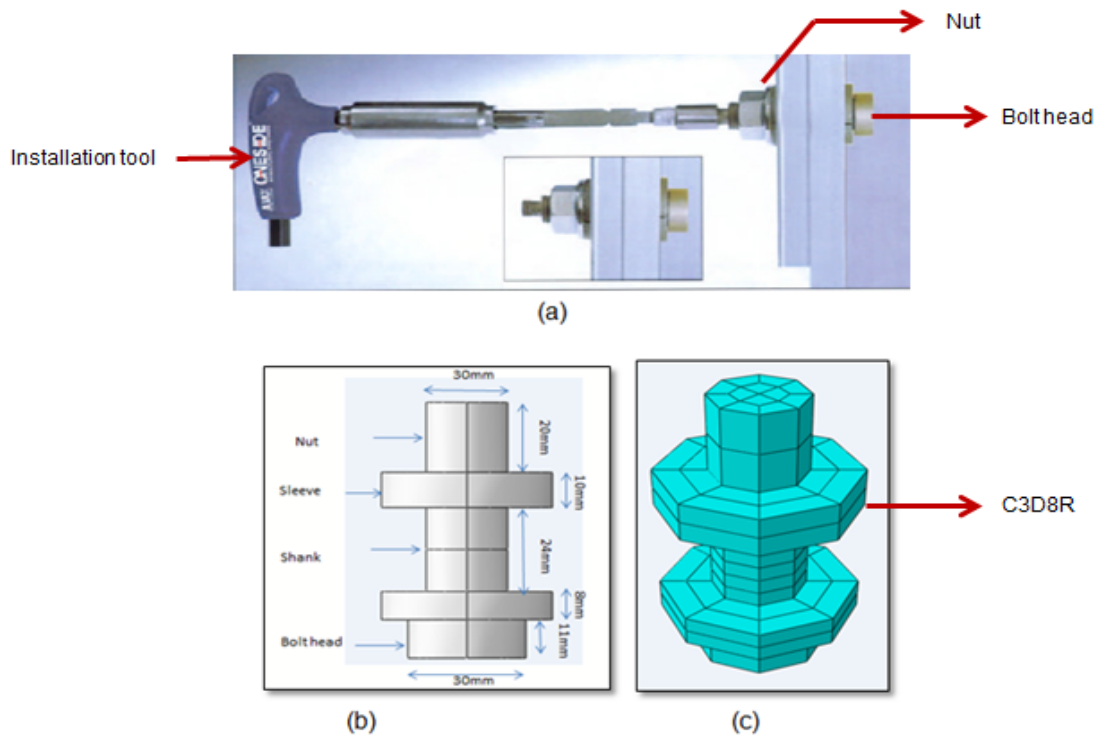
Fig. 4 (a) AJAX one side blind bolt (Ajax Engineering Fasteners 1999)
(b) Dimensional details of Ajax blind bolt
(c) Meshing in FE modelling of Ajax blind bolt

These blind bolts have a very sophisticated engineering design and require installation from one side only. They are economical, quick, provide a replacement to the traditional welding process and comprise several benefits. They are available in sizes M16 and up and in class 4.6, 8.8, 10.9 and 12.9. In this study blind bolt of M20 size and grade 8.8 is used. These bolts do not require any sophisticated installation system and are very easy to install. They not only double the job efficiency but also reduce the requirements of labour. Another major advantage of using these bolts is that they are suitable for dynamic and earthquake applications. The design parameters of this type of bolt as specified by AJAX fasteners are presented in Table 3.

Table: 3 Dimensional details of Ajax one side blind bolts

ONESIDE JOINT DESIGN PARAMETRS						
Bolt	PC8.8		PC10.9		Joint	Minimum
Size M	Proof Load (kN)	Breaking Load(kN)	Proof Load (kN)	Breaking Load(kN)	Nominal Hole Dia.	Bolt length	Cavity space + grip length
20	147	203	203	255	30	38	89

3.6 Loading and Boundary Conditions

This model consists of the application of three types of loadings. These are pretension in the bolt, axial load on the column and load on the beam which are applied in three steps. Fig 5 provides a basic idea of the loading and boundary conditions for this model.
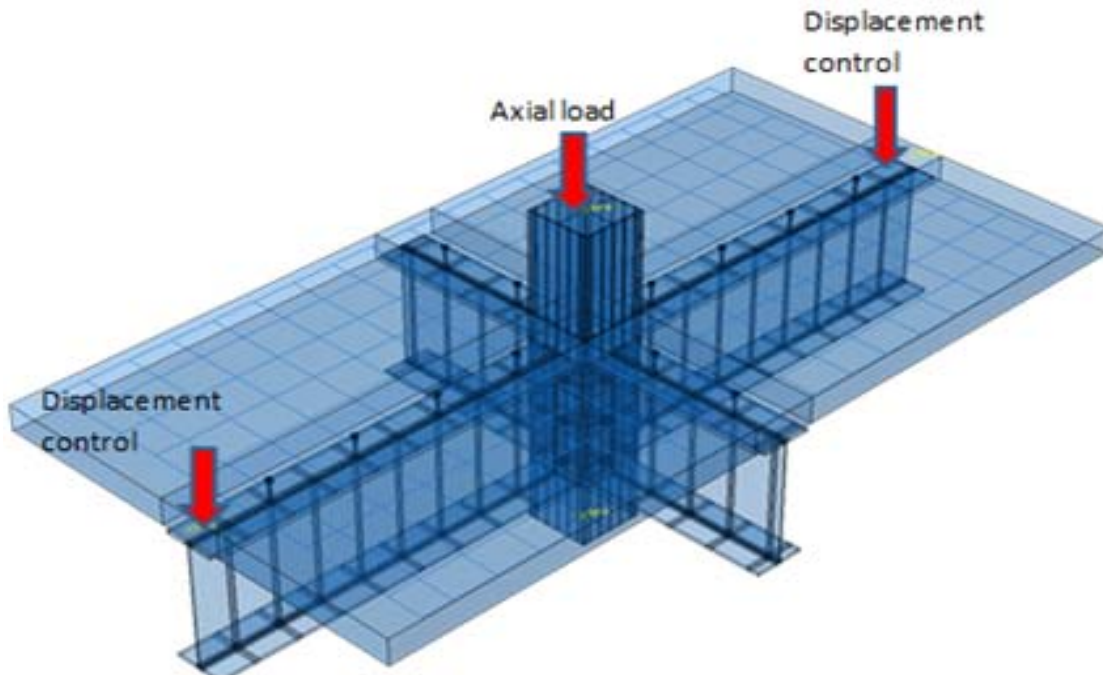

Fig. 5 Details of loading and boundary conditions

Pretension force is applied in the first step. Axial load is applied in the second step, whereas displacement control is applied in the last step. Unlike the static RIKS analysis by Mirza and Uy (2010), the method of analysis used in this paper is dynamic explicit as recommended for large models by Abacus. The dynamic explicit is a time dependent method of analysis which models the dynamic response of the structures to the imposed loading over time. Explicit solver is used in this study to avoid the difficulties associated with the numerical convergence caused by large deformations and complex contact problems. Amplitude in smooth step has also been provided to reduce the computational time. Sufficient analysis time step must be assigned to ensure that the resulting values are continuous as dynamic explicit does not require iteration or convergence checking.

4. VALIDATION OF FINITE ELEMENT MODEL

A noticeably good agreement is obtained between the experimental results from this model as compared to Mirza and Uy (2010) experimental model as shown in Fig. 6.
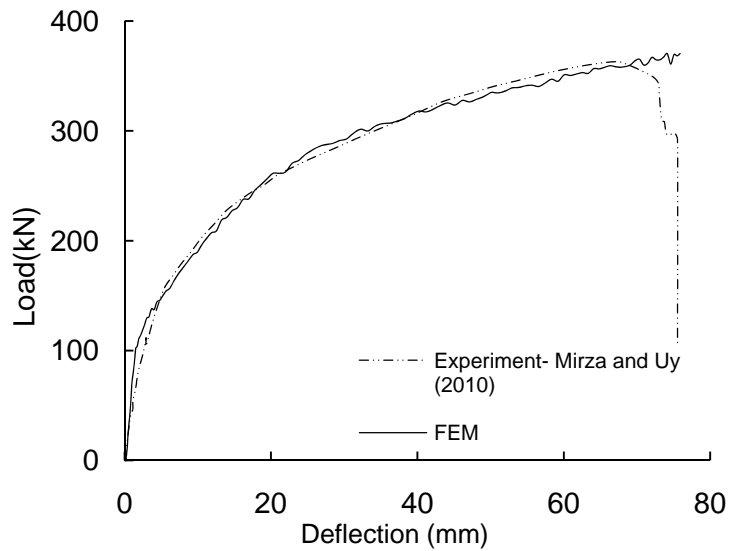
Fig. 6 Comparison of the finite element model and experimental data from Mirza and Uy (2010)
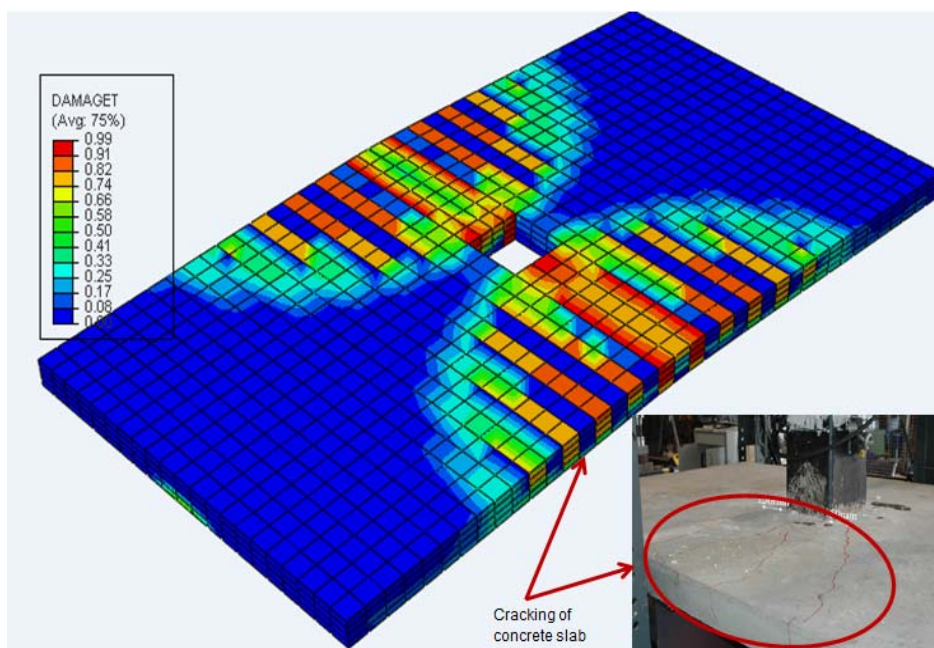

Fig. 7 Comparison of the failure mode of the concrete slab

From the results obtained using finite element modelling of this connection it is proved that finite element analysis is a reliable method of analysis which effectively replicates the actual behaviour of the components of the structure. The decrease in stiffness of this joint according to FEM took place due to the destruction of concrete in the occurrence of higher loads. It was noticed from the results that the end plate had

deformed outwards and bending in the column face occurred. The results from finite element model exhibit a very similar variation of stresses in the slab as the experimental model. During the loading procedure, when loads reached a value of 170mm, cracks in concrete slab started appearing as illustrated in Fig. 7.

It was observed that at the beginning, the concrete surrounding the column reached its cracking stress. It verified that the concrete close to the column face started to crack. As the load progressed the cracks begin to expand towards the edges and increase in load finally led to cracks at the end of the slab and encouraged deformation to take place in the endplates as shown in Fig. 8. Higher values of stresses were observed in the top of the end plates connected to the primary beams which became the reason for deformation in the end plates. No deformation occurred in the endplates attached to the secondary beams. The finite element model results when compared to the experimental data demonstrate an exactly similar behaviour as presented in Fig. 8.

As the load continued to increase, the end plates started to deform as shown in Fig. 9. The deformation in the end plates was a consequence of the total stiffness depleting and due to the large deflection of the steel beam. It was seen that when the downward load was applied, the thin wall of the column face and end plate started to bend. As the load proceeded, the bending of column wall and end plate kept on becoming severe which eventually led to the failure of the connection. As soon as the beam and end plate began to deflect, the headed shear studs began to experience loads greater than their ultimate capacity eventually ending up in deformation of the shear connectors and being pull out from the structural beam as presented in the Fig. 10 below.
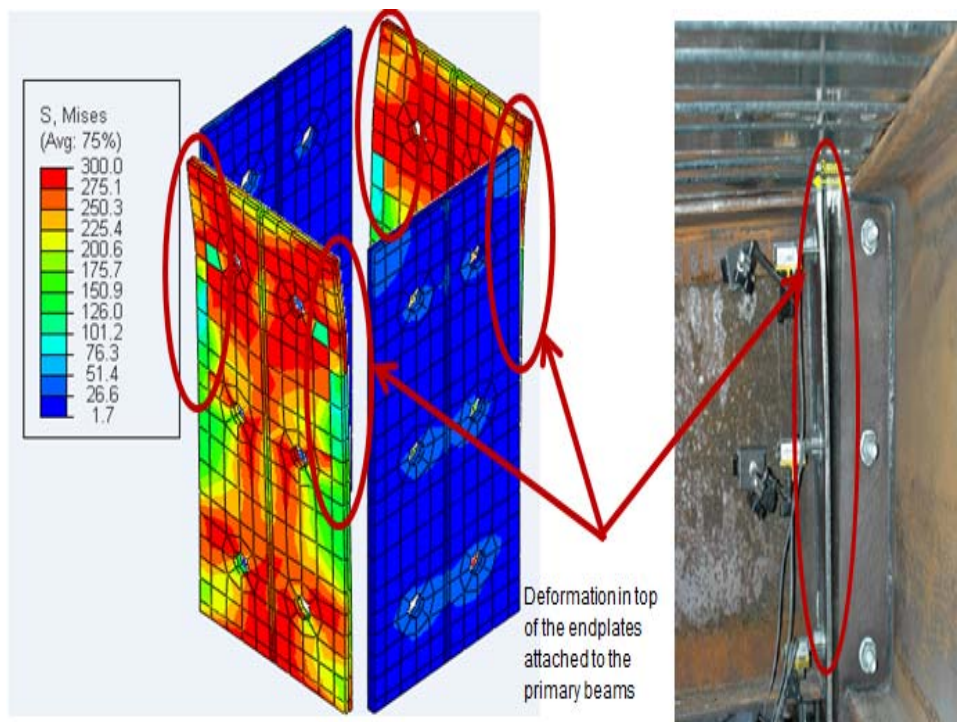

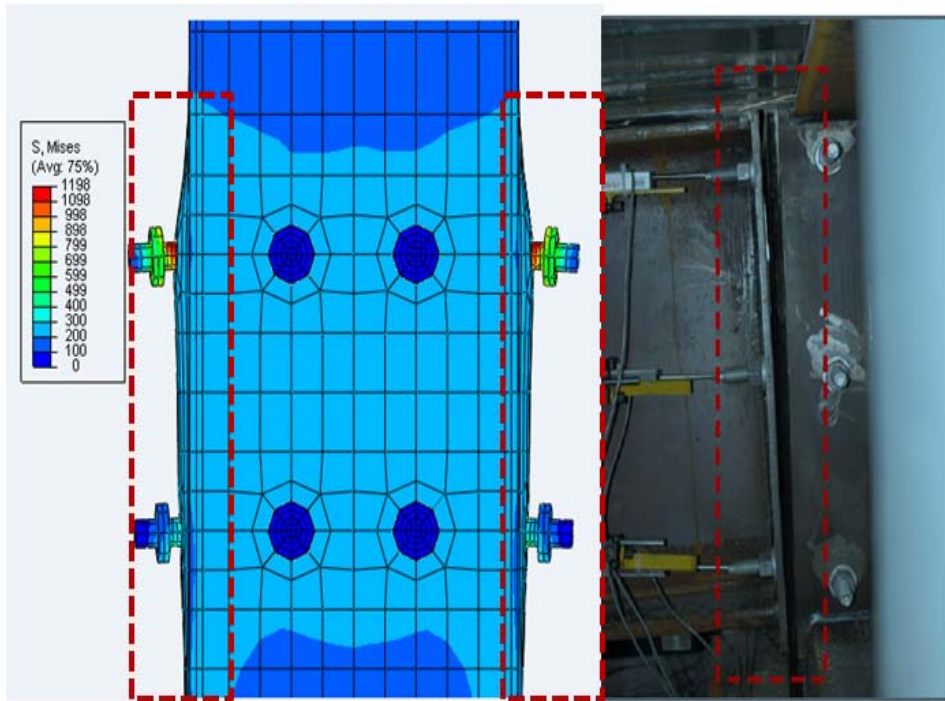Fig. 8 Comparison of the deformation of the end plate

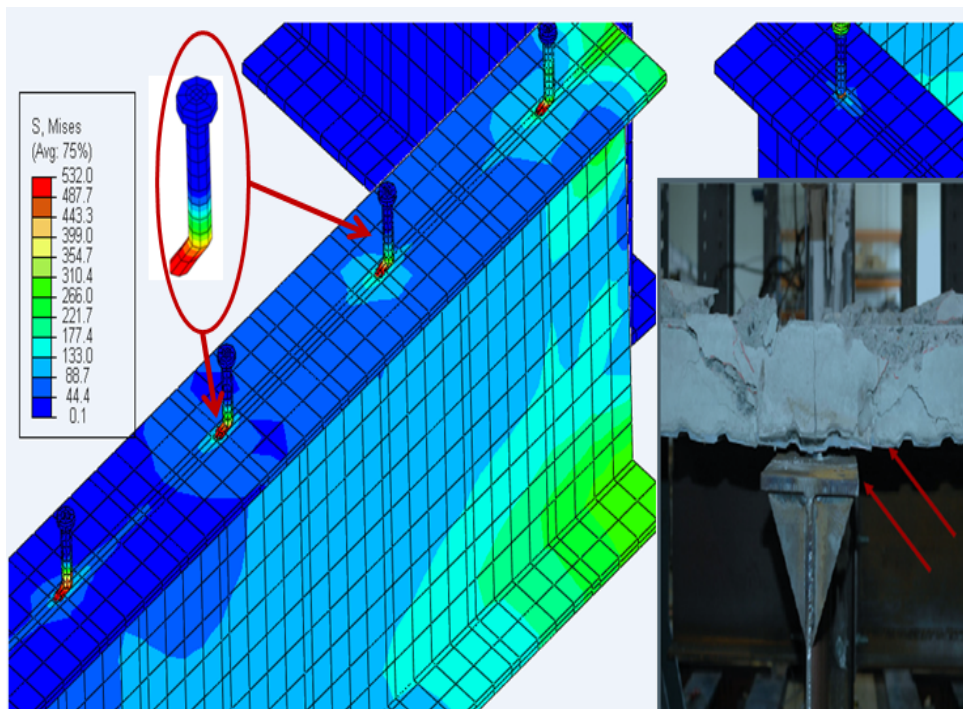Fig. 9 Bending at column faces and end plate
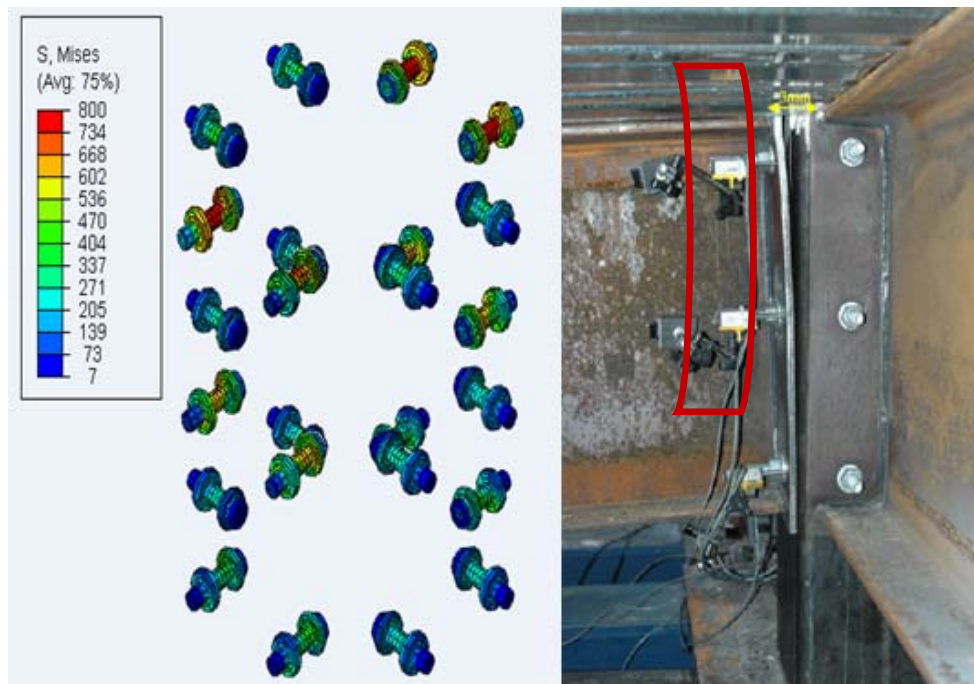

Fig. 10 Deformation of shear connectors

Fig. 11 Yielding of blind bolts

The yielding of blind bolts in the top row which were located on the primary beams was also observed which is very similar to the model developed by Mirza and Uy (2010) as shown in Fig. 11.It proves that the blind bolts transmitted the tension force owing to the fact that the top two blind bolts of the end plate moved outwards by roughly 3mm-4mm.The above description shows that this finite element model is reliable and can be used to conduct parametric studies.

5. PARAMETRIC STUDIES

The authenticated finite element model is then employed to conduct parametric studies in order to study the effect of different parameters on the behaviour of these connections. The different parameters considered are shown in Table 4.

Table 4: Values of parameters considered for parametric studies

VARIABLE	RANGE
Column thickness	10mm, 12mm, 16mm
Endplate thickness	10mm, 12mm, 16mm
Grade of bolts	8.8, 9.9, 10.8
Grade of steel	250, 350, 450

4.1 Effect of Column Thickness

The finite element modelling results for variation in the thickness of column exhibit much variation as shown in Fig. 12.

The three thicknesses of the column chosen were 10mm, 12mm and 16mm. The results show that initial stiffness and ultimate load increases with the increase in thickness of the column.
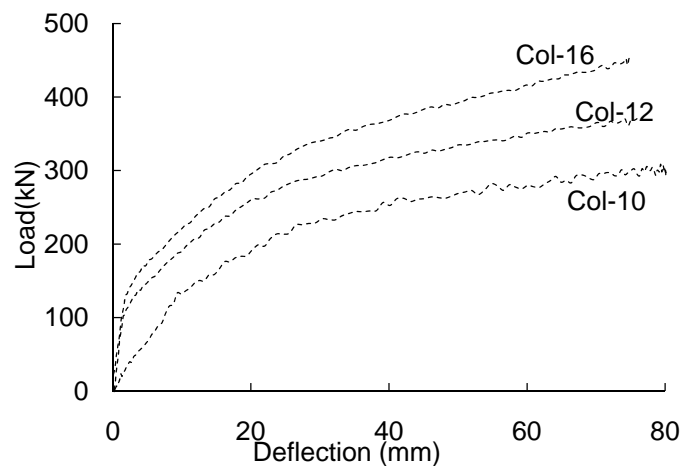

Fig. 12 Effect of different thicknesses of the steel tubular column
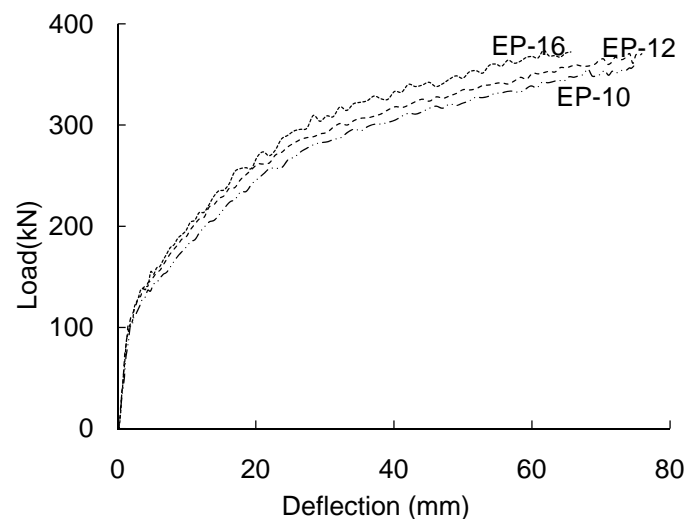

Fig.13 Effect of different thicknesses of the end plates

4.2 Effect of Thickness of the Endplate

The three thicknesses of end plates chosen for parametric studies were 10mm, 12mm and 16mm. If we look at the comparison graphs resulting from the variation in thickness of the end plate, it is seen that if the endplate thickness is decreased to 10mm, a decrease in value of the initial stiffness is observed as shown in Fig. 13. The overall trend is quite similar but with the increase in thickness of the end plates, the

initial stiffness seems to increase slightly whereas, the magnitude of ultimate load increases significantly. Therefore, an increase in the thickness of the end plate can considerably improve the strength of the connection. The results from parametric study reveal that the thickness of the endplate has a significant impact on the behaviour of the connection

4.3 Effect of Grade of Bolts

The grades of bolts chosen were 8.8, 9.8 and 10.9. Variation in the grade of bolts did not produce any variation in the overall behaviour of the connection as explained in Fig. 14. The results are very similar to the experimental model in terms of stiffness throughout loading, peak load capacity and ductility.
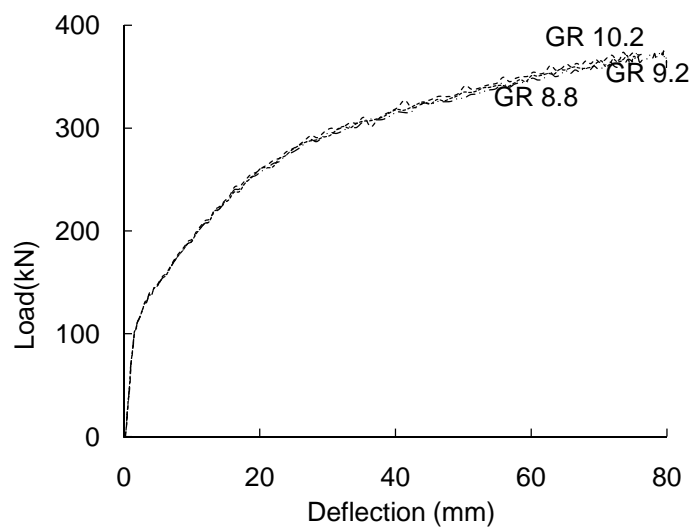

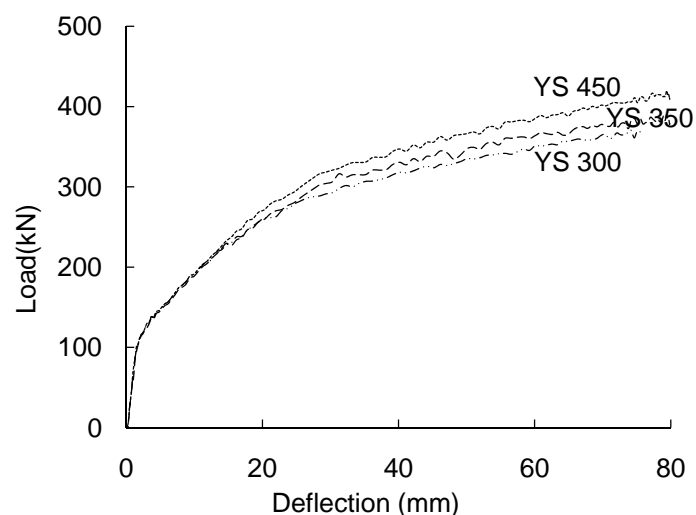Fig. 14 Effect of different grades of bolts

Fig. 15 Effect of different grades of steel

4.4 Effect of Grade of Steel (f_{sy})

The different grades of steel chosen for parametric study are: 250, 350 and 450 respectively as shown in Fig. 15. Increase in the grade of steel appears to affect the magnitude of ultimate load capacity of the connection. Bigger grade of steel tend to generate much higher values of ultimate load capacity. However, only a little increase in the initial stiffness occurs.

4.5 Effect of Compressive Strength of Concrete (f'_c)

Fig. 16 presents the effect of three different compressive strengths of concrete on the load versus deflection behaviour of these connections. The three different compressive strengths chosen are 20, 30 and 50. It can be observed from Fig. 16 that the initial stiffness and ultimate strength of the composite beam-column flush end plate connection slightly increases with the increase in the compressive strength of concrete.
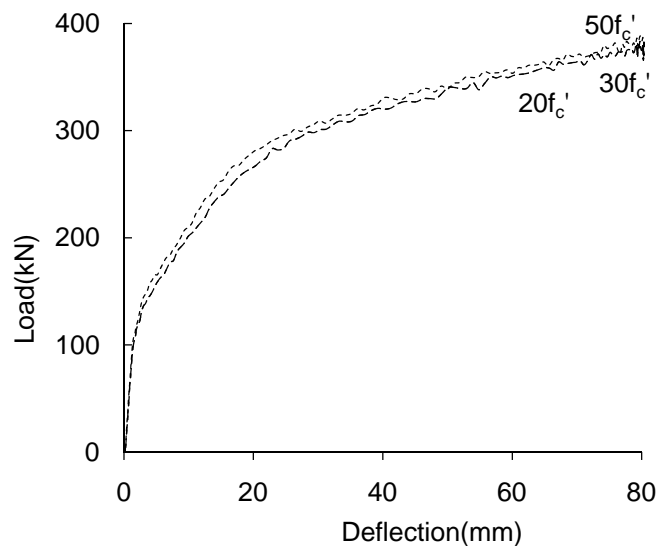
Fig. 16 Effect of different compressive strengths of concrete

5. CONCLUSION

According to the numerical research reported in the paper, the subsequent findings can be drawn inside the boundaries of the research:

(1) The stiffness and ultimate strength of the blind bolted connections can be influenced by the thickness of end plate and thickness of steel tube cross-section. An increase in the thickness of the endplate can obviously improve the stiffness and strength of supposedly comparable connections and decrease the rotation capacity of connections (2) It is observed that with the variation in the grade of steel, no difference in the initial stiffness appears. However, the ultimate load capacity seems to be increasing with the increase in grade of steel.

(3) No significant change appears with the change of grade of bolt. The overall behaviour of the connection regarding stiffness, yield point and ultimate load appears to follow very closely to the experimental model.

(4) Increase in the compressive strength of concrete slightly increases the stiffness and ultimate strength of the connection.

(5) A three dimensional finite element model incorporating contact and nonlinear material properties can be employed to numerically study the stiffness and deformation of composite beam-column flush end plate connections as in this study it was able to reasonably predict the load versus displacement behaviour of the composite beam-column flush end plate connection. It also provides a basis for further numerical study on the behaviour of flush end plate joints to concrete-filled steel tubular columns.

ACKNOWLEDGMENTS

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