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EFFECT OF COMPOSITE BEAM COLUMN EMBEDDED CONNECTION UNDER STATIC AND CYCLIC LOADING

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ABSTRACT

Investigation on the effect of Concrete Filled Steel Tubular (CFST) column to Girder beam embedded connection under static and cyclic loading conditions. Analytical non-linear 3D element model for exterior and interior connection were modelled and investigated. Connections consisted of rectangular concrete filled tube, girder steel beam and high yield strength deformed bars. Beam is connected to the tube wall of CFST Column by means of weld along with four deformed bars connected to the flanges of girder section acting as a stiffener. Under loading conditions, the forces acting on the flange are effectively transferred to the CFST by means of deformed bars which is welded on both side of flanges of girder beam. Parameters that aids in effective force transfer mechanism are strength ratio of beam and column, CFSTs thickness, diameter and bar embedded length into the column. Rebar stiffener is found to be effective in transferring forces into the concrete core thereby exhibits inelastic characteristic strength properties. The plastic hinge formation is to be restricted to beam rather in connection or all the bars thereby avoiding distortion of tube wall. Three dimensional modelling and analysis is done using finite element software considering non linearity for material and geometry of elements used. Detailed results on hysteresis behaviour, load deformation, energy dissipating capacity, stiffness degradation and are discussed. It was found that embedded connections system were easy to fabricate and effective in terms of seismic performance of the structural system and better stiffness characteristics rather than any other simple connection.

Keywords: concrete filled steel tube, I section steel beam, HYSD bars, embedded connections.

INTRODUCTION

Steel-concrete composite structures are generally preferred in high rise buildings for their load carrying capacity and possess better seismic resistance when compare to structures made of pure steel and reinforced concrete.(Mou, Li, Bai, He, & Patel, 2018) Composite structural systems utilises the ductility property of the steel and stiffness property of concrete thereby creating better moment resisting frames (Alostaz & Schneider, 1996) CFST columns are preferred due to their structural rigidity and energy absorption capacity and further eliminates formwork during construction (Yang, Sheehan, Dai, & Lam, 2017) (Ding, Yin, Jiang, & Bai, 2018) spalling of concrete is prevented and tube wall distortion is prolonged due to concrete (Alostaz & Schneider, 1996). Girder Steel beam is used for its superior inelastic behavioural characteristics under seismic conditions. (Alostaz & Schneider, 1996) have investigated connections with external diaphragm stiffening plates connected on to the tube wall, which is on loading creates an excessive tube wall tearing thereby reducing the strength and stiffness characteristics hence this complications led to development of internal connections which are effective in terms of transferring loads across the column. Analytical research on CFST connections which attempts for an better force transferring mechanism through embedment of any structural components into the column which would reduce the stress concentration on the tube wall (Internal connections) (Beutel, Thambiratnam, & Perera, 2001). (Azizinamini, Asce, Schneider, & Asce, 2004) investigated an internal connection system of extending the girder beam through the CFST and core of the concrete extending both sides as an interior joint connection. Anti-symmetrical loading is given at both ends with the ends of the column pinned. Under monotonic static loading, the corresponding connection performed well with superior load transfer onto the concrete core and with tube wall distortion. Internal connection system were found to be effective under various loading by extending structural component like rebar into the column thereby creating a medium for force transfer. These connections are found to be effective and efficient in transfer of stress from the flanges to the core of the concrete through rebar stiffener (Beutel *et al.*, 2001) Therefore embedded deformed bar stiffener connection were found behave well under monotonic and cyclic loading cases. The study of embedded systems involves two connections, one is interior beam column joint connection and the other is exterior beam column joint connection. In this connection systems, rebar stiffeners is adopted which is attached to the top and bottom flange by means of weld connecting beam to column. The Analysis is done using finite element software (ABAQUS) indicates that considerable percentage of flange forces is distributed to the column thereby improving the strength and stiffness characteristics of the connection system by enhancing its load carrying capacity (Sheet, Gunasekaran, & MacRae, 2013). Non-linear analysis of the various structural components helps in identifying the importance of each component in building up the strength of the connection system. This Study involves analytical investigation on the effect of embedded connection under static and cyclic loading conditions and their corresponding load deformation, hysteresis behaviour, stiffness degradation, energy dissipation of structural components are determined. Monotonic and seismic behaviour of the embedded systems is studied for effective energy dissipating mechanisms.

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METHODOLOGY

Analytical research involves finite element modelling and analysis software (ABAQUS 6.14.1). The connection details involving CFST column to girder beam connected by means rebar stiffener forming rigid connection. Static and cyclic loading is given to the beam keeping the ends of column fixed. Monotonic displacement is given in an Incremental manner at the ends of the girder beam. Cyclic loading is given using specified amplitude parameters. The Concrete filled steel tube is given pinned condition (U_x=U_y=U_z=0) at both the ends and the beam tip is MPC constraint for loading purposes (Alostaz & Schneider, 1996) (Beutel *et al.,* 2001). Equal and opposite displacement controlled loading is given at each end of the interior beam column joint. Both Monotonic and cyclic displacements is given to the adopted connections (Interior and Exterior joint connection) and corresponding stress strain behaviour is determined.

MATERIAL PROPERTIES

Composite elements possess both concrete and steel properties. These elements utilises unique properties of concrete as it is good in compression and steel behaves well under tension, thereby both act together in providing sufficient structural rigidity

Standard size cubic specimen is tested for its compression strength under compression testing machine. The nominal strength for the concrete was measured to be 40 MPa. Average compressive strength for 28 days was found to be 41.24MPa and its young modulus as 31.623GPa. Hot rolled ribbed bars of diameter 8mm were used as rebar stiffener welded onto the tube and beam with the characteristics strength of 415MPa. Steel with the yield strength of 250MPa were adopted for the girder beam and the Steel tube. Tests were done to determine characteristics of the steel used in the connection. Various material characteristics used in the connection were discussed in the following tables

Table-1. Concrete Properties.

Description	values
Density	2400 kg/m^3
Young's modulus	31622.77MPa
Poisson's ratio	0.3

Table-2. Material Properties.

Element	Yield Stress (σ_y) (Mpa)	Ultimate stress (σ_{ult}) (Mpa)	Young's modulus (E) (Mpa)	Poisson ratio (μ)
CFST Column	250	442	200000	0.3
Girder Beam	250	434	200000	0.3
HYSD bars	415	550	200000	0.3

FINITE ELEMENT ANALYSIS

The 3-Dimensional non-linear finite element modelling is done using ABAQUS (6.14.1). The Embedded connection systems involve various structural components like CFST column, girder steel beam and HYSD bars to be modelled and assembled. For this connection, a tube dimensions of 135*120mm with wall thickness of 5mm of length 1000 mm and girder beam of ISMB150 of 500mm in length. HYSD bars of 8mm is used for the length of 500mm.In case exterior joint specimen, the bars extents into the CFST throughout, while in case of interior joint the goes passes through the CFST and extends to 1/3rd of the length of the beam. Part instance are created using the dimensions given using modelling tool and after creating the model, structural components are assembled using the translate tools available as in the fig. The interaction between the tube and core is created by creating gap element available in ABAQUS to transfer the forces by creating frictional grip between the structural components. Different mesh sizes were used to identify the sizes which would give accurate results and lesser running time. Surface meshing is done with creating seed part instance for the corresponding components and extend of meshing depending upon the accuracy of results(Park, Choi, Kim, Park, & Kim, 2010). The steel tube wall was created using an 8-noded element with 5 dofs at each node. The concrete core was modelled using a 20-noded brick element with 3 dofs at each node(Alostaz & Schneider, 1996).

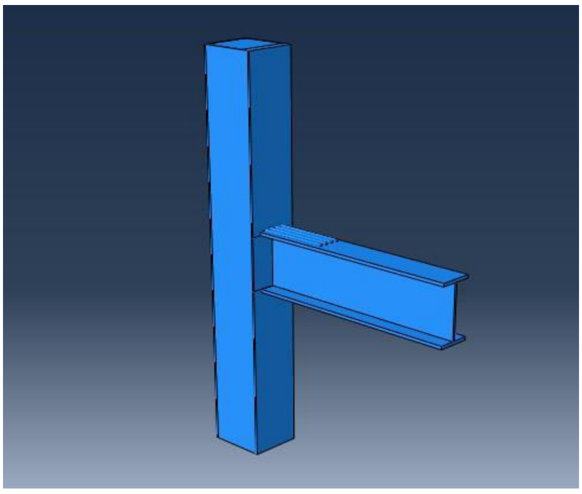

Figure-1. Exterior joint specimen.

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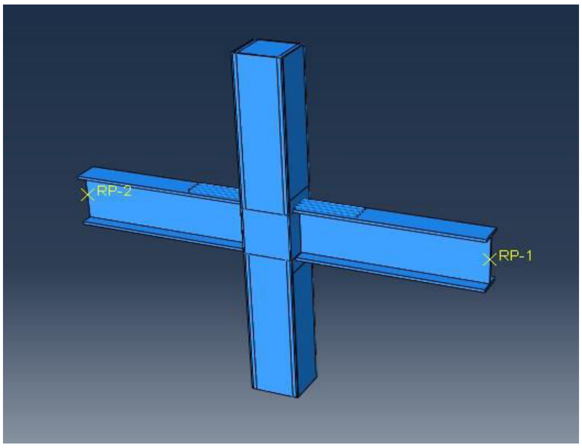


Figure-2. Interior joint specimen.

The column ends were pinned and behaves as a rigid body, where the beam tip is given displacement upto 30mm with incremental loading.Interaction between the instances aids in load transfer mechanisms. Interaction properties are defined based on the contact (hard contact) and friction coefficients (0.23).Creation of constraints represents connection between the instances where the structural instances are given tie constraint to enhance the connection property where the connection acts rigid. Embedded constraints are given to reinforcing bars which is embedded into the column and a tie constraint onto the flanges of the beam section. The end specimen is analysed under static and cyclic loading and their behaviour is compared with the simple rigid connection.

RESULTS AND DISCUSSIONS

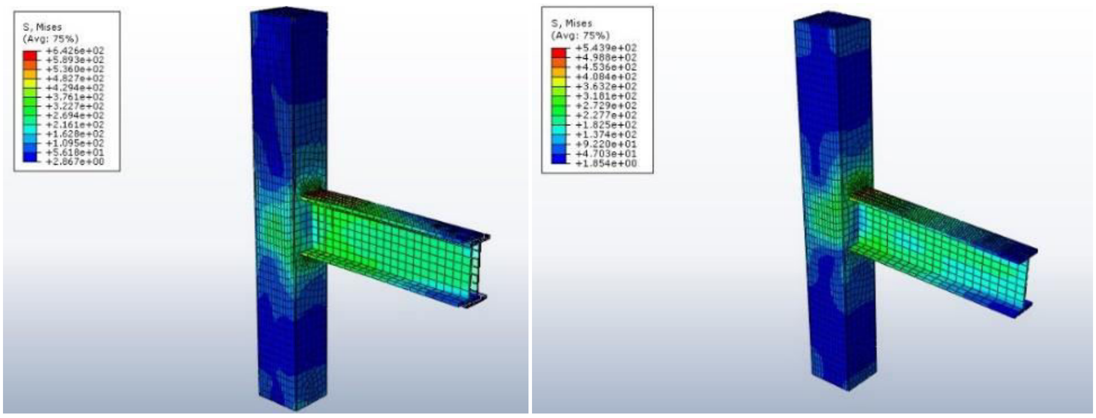
A Nonlinear analysis of the corresponding connection system is conducted in order to incorporate the effects of geometrical nonlinearity's (large deformations), material non linearity (elastic-plasto material) and contact and its corresponding behaviour characteristics are presented in the following sections.

A. Analysis of exterior beam column joint

Exterior beam column joint or T joint made of CFST and girder beam along with rebar stiffener. Where concrete and steel tube were given interaction so that it behaves as a single unit. Interaction between the rebar and the flanges is given selecting rebar as the surface master and the flange as the surface slave. Meshing of the structural components is important in maintaining the interaction property. Proper interaction between the components leads to effective load transfer. Tie constraint used between the girder section and the CFST is maintained by proper meshing. MPC constraint is adopted to connect the edges points of the girder section to the control point which is the centre of gravity of the section.

The loading condition is displacement controlled, where the girder beam is subjected to the displacement factor of 20mm as in case of monotonic loading. Using the yield displacement (d_y) results obtained, displacement factor of d_y, $2d_y$, $3d_{y,}$ $4d_{y,}$ $5d_y$ were given in form of cyclic displacements and corresponding force acting onto the beam is determined. Step is created and corresponding time period is adopted with ngleom on for non-linear character of the components. Behaviour of the corresponding connection system is compared to the normal joint system.

Von-mises stress criterion is used to predict the yield and ultimate stress capacity of the steel components, based on which the yield displacement is determined is shown in the Figures



(a) (b)

Figure-3. Von Mises Stress patterns under a) Static monotonic loading b) Cyclic loading.

Reduction in stress concentration at the junction, where the flange forces are transferred to the concrete core by means of friction. There is considerably decrease in strain inside and outside the CFST which is presented in the figures.

Displacement controlled loading is adopted and corresponding reaction force and displacement is plotted and presented in the Fig.

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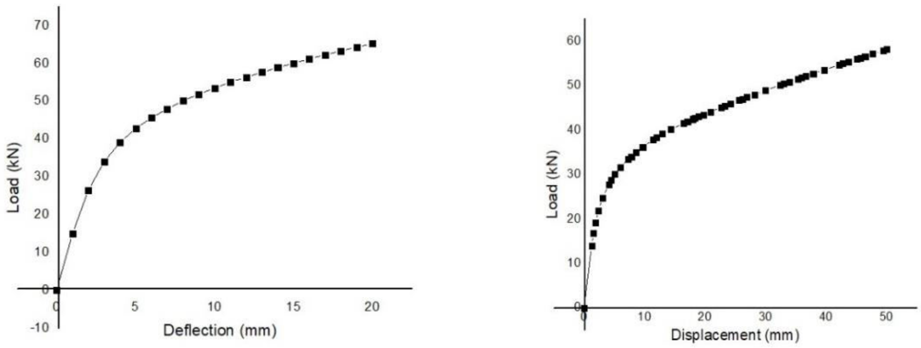
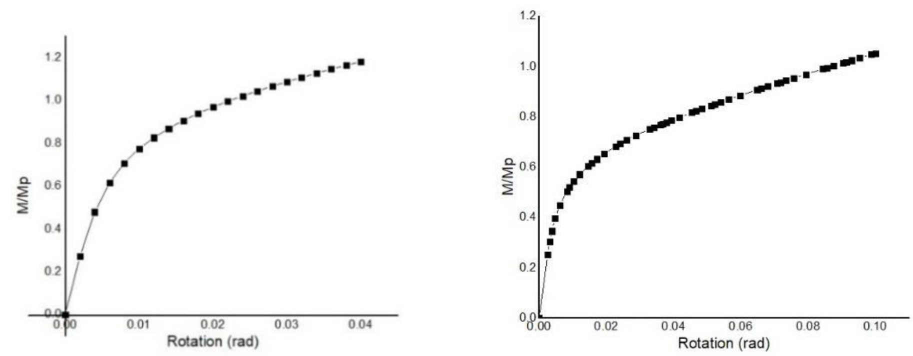


(a) (b)

Figure-4. Load deflection curve for a) Embedded connection b) Normal connection.

Moment of the connection is calculated by load applied at the beam tip multiplied to the distance till the face of the column and the rotation is obtained by dividing the displacement to the distance till the connection. Moment is normalised with the beam's plastic moment (M/M_p) to the rotation at the connection is plotted in a graph as shown, where M is the connection's moment and M_p is the beam's plastic moment which accounts to 27.619GPa.

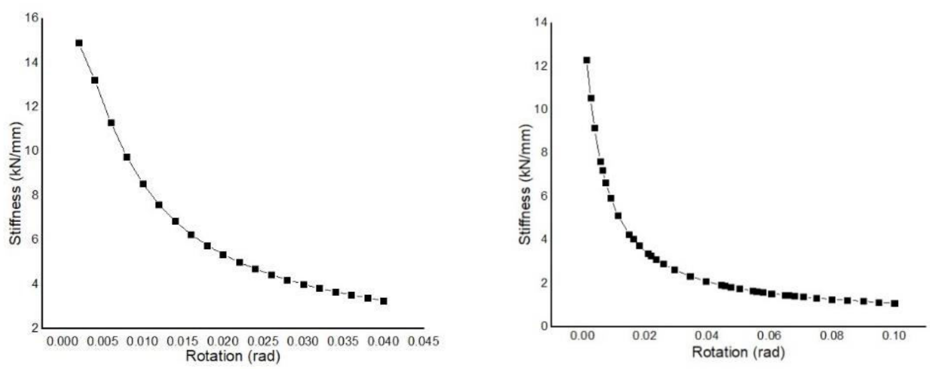


(a) (b)

Figure-5. Moment rotation curve for a) Embedded connection b) Normal connection.

The yield moment (M) of the connection is about $0.85M_p$ at the rotation of 0.015rad. The ultimate moment (M_u) reaching up to $1.15M_p$ at the rotation of 0.035rad.For normal connection, the yield moment (M) is about $0.65M_p$ at the rotation of 0.02rad. The ultimate moment (M_u) reaching up to $1.05M_p$ at the rotation of 0.1rad

The stiffness of the joint section gradually decreases after the yield of the connection along the increment of displacement controlled loading conditions.



(a) (b)

Figure-6. Stiffness degradation for a) Embedded connection b) Normal connection.

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In case of cyclic displacement loading, forces both in positive and negative direction are getting involved. Load versus displacement and curve representing moment rotation of the corresponding joint in given as:

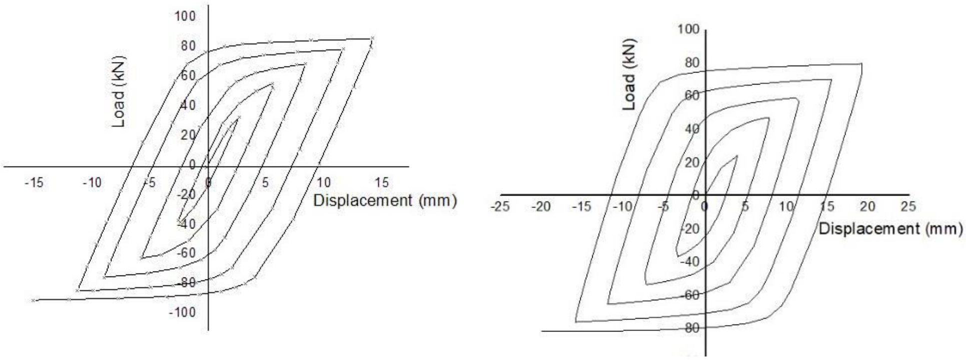

Figure-7. Load displacement curve for a) Embedded connection b) Normal connection.

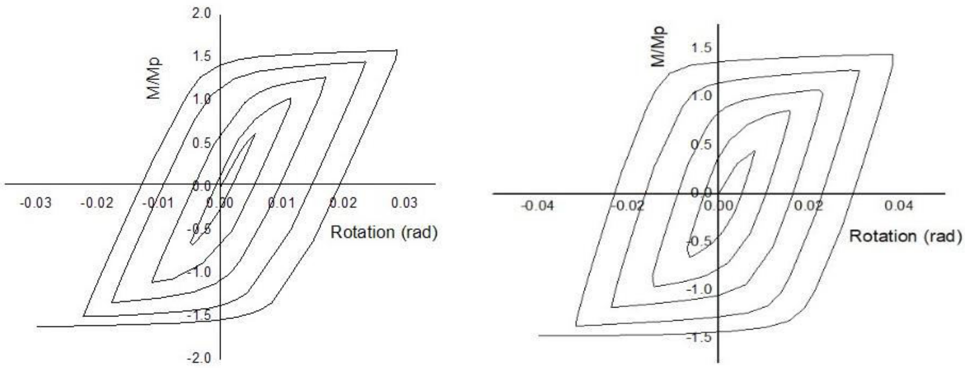

Figure-8. Moment rotation curve for a) Embedded connection b) Normal connection.

The yield moment (M) of the connection is about $0.95M_p$ at the rotation of 0.0095rad. The ultimate moment (M_u) reaching up to $1.5M_p$ of at the rotation of 0.03rad. For normal connection, the yield moment (M) is about $0.70M_p$ at the rotation of 0.01rad. The ultimate moment (M_u) reaching up to $1.25M_p$ at the rotation of 0.04rad

B) Analysis of interior joint connection

Interior joint specimen consists of two girder beam connected to the CFST by means of tie constraint, which gives the property of a weld thereby forming a rigid connection. Four deformed bars runs through CFST on both side of the flanges connected by means of an interaction property. The bars passing through the CFST is given an embedded constraint with the concrete as its host element. Anti-symmetrical displacement controlled loading on both the ends of the beam by means of MPC constraint. Loading condition is similar the exterior joint loading system but the load direction differs at each ends of the beam i.e. positive and negative loads. Behaviour of the interior joint specimen is analysis using stress patterns, deflection patterns, load deformation, hysteresis behaviour etc.

Von-mises stress of the specimen gives reliable behaviour for the steel specimens such yield stress and ultimate stress distributions. These patterns showcases the extent of each component contributing to the plastic bending strength of the beam.

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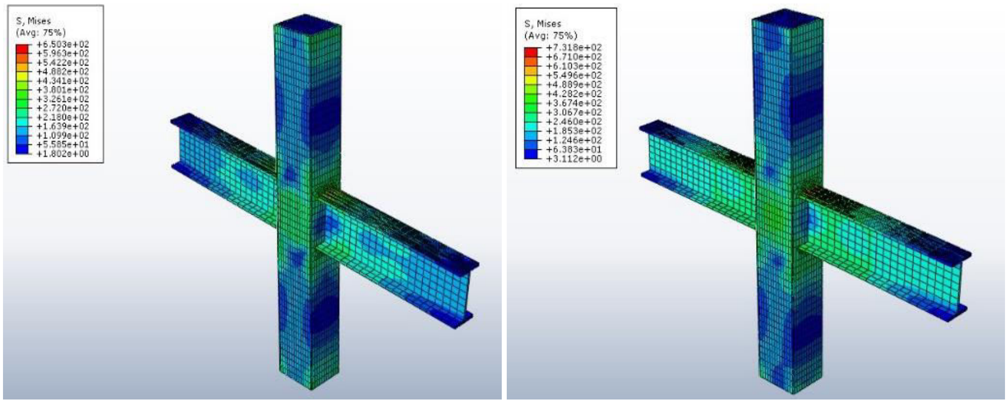
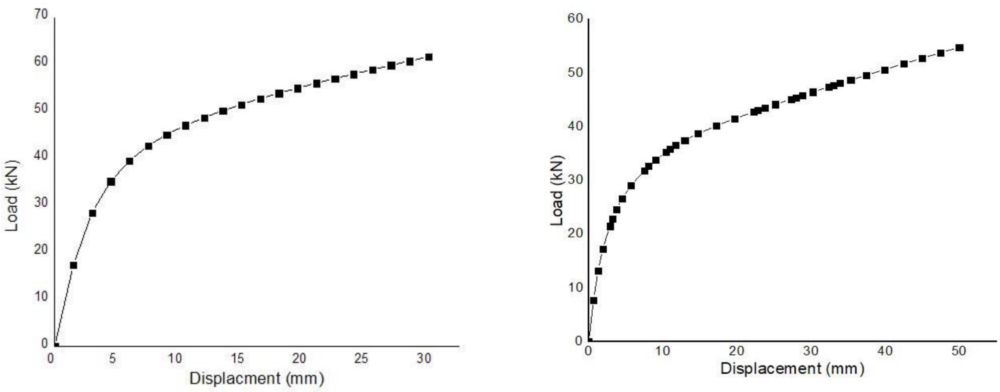


(a) (b)

Figure-9. Von Mises Stress patterns under a) Static monotonic loading b) Cyclic loading.

On loading conditions, there is considerable percentage reduction in stress and strain in and out the column specimen, which denotes transfer of forces among the structural components.

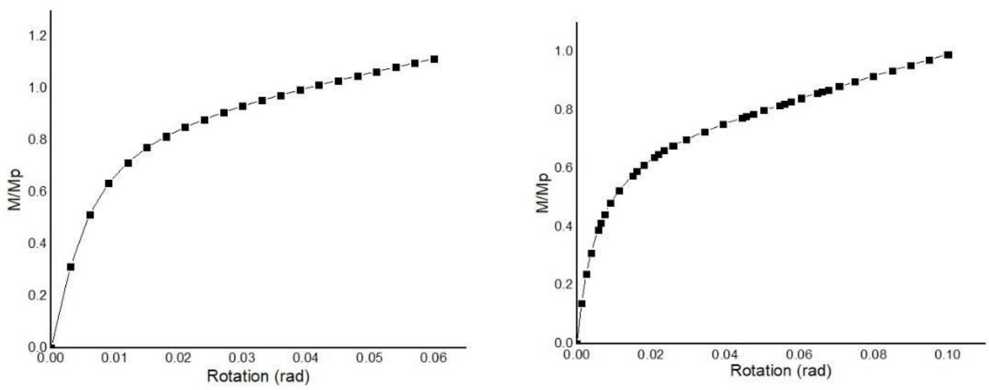
Behaviour of joint under loading conditions is represented in curve representing load displacement and moment rotation is given.



a) Embedded connection

b) Normal connection

Figure-10. Load displacement curve for 1) Embedded connection 2) Normal connection.



(a) (b)

Figure-11. Moment Rotation curve for a) Embedded connection b) Normal connection.

The yield moment (M) of the embedded connection is about $0.78M_p$ at the rotation of 0.015rad. The ultimate moment (M_u) reaching up to $1.1M_p$ at the rotation of 0.05rad. For normal connection, the yield moment (M) is about $0.6M_p$ at the rotation of 0.019rad. The ultimate moment (M_u) reaching up to $0.95M_p$ at the

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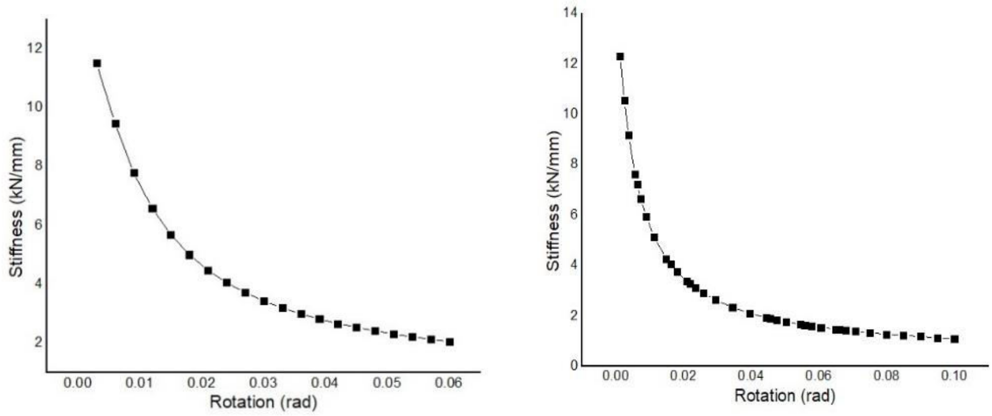
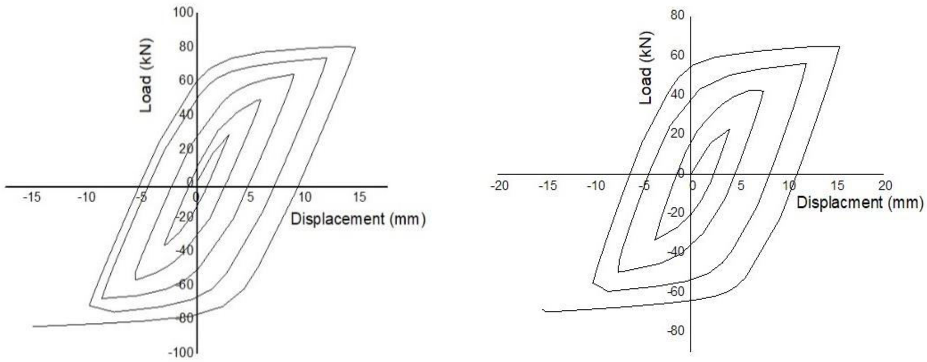
rotation of 0.1rad.Degradation of stiffness of the connection drops off linearly with the onset of fracture of the deformed bars. After yielding of structural component like girder beam the stiffness tends to degrade gradually which is represents in the form of graph



(a) (b)

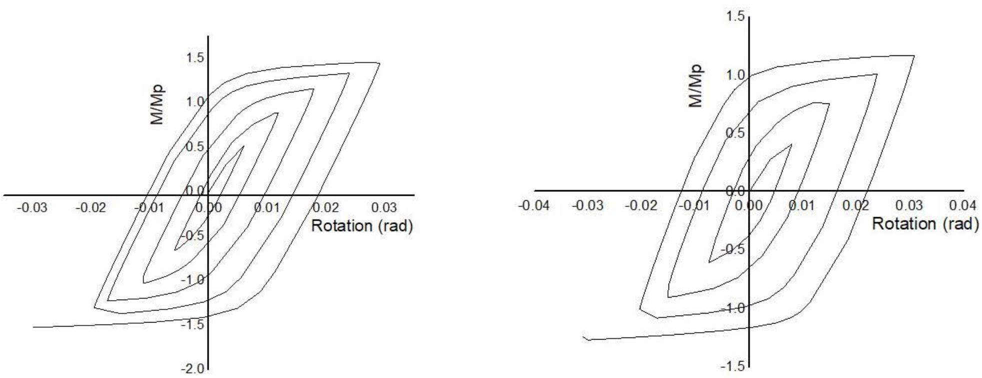
Figure-12. Stiffness degradation for a) Embedded connection b) Normal connection.

Hysteresis behaviour of the joint specimen under cyclic displacement controlled loading system is represented in terms of load versus displacement and moment rotation curve.



(a) (b)

Figure-13. Load displacement curve for a) Embedded connection b) Normal connection.



(a) (b)

Figure-14. Moment rotation curve for a) Embedded connection b) Normal connection.

The yield moment (M) of the connection is about $0.9M_p$ at the rotation of 0.01rad. The ultimate moment (M_u) reaching up to $1.25M_p$ at the rotation of 0.03rad. For normal connection, the yield moment (M) is about $0.7M_p$ at the rotation of 0.01rad. The ultimate moment (M_u) reaching up to $1.0M_p$ at the rotation of 0.03rad.

The strength of the interior joint connection is reduction due to high diagonal force acting onto the steel tube between the girder beams. Thereby reducing the capacity of the steel tube wall.

C. Energy dissipation capacity

Energy dissipation capacity is the capacity of the connection system to withstand seismic forces in characteristics of both strength and durability. Energy dissipated through yielding and buckling of beam until the strength of the connection is reduced. Greater capacity of connection system in terms of strength and stiffness, greater is its energy dissipation capacity. Energy dissipation is obtained by the area enclosed by the hysteresis load versus displacement.

Table-3. Energy dissipation for connections.

S. No	Specimen		Energy dissipation (kNmm)
1	Embedded connection	Exterior Joint	6037.89
		Interior Joint	5091.70
2	Normal connection	Exterior joint	4874.31
		Interior joint	4112.44

CONCLUSIONS

Analytical investigation of composite beam column embedded connection indicates that the rebar stiffener effectively transfers girder forces to the core of the concrete.

- In case of exterior joint, under loading conditions the yield moment of the connection is 0.85-0.95 times the plastic moment of the beam (M_p) where the simple weld connection under similar loading conditions the yield ranges 0.65-0.7 M_p, thereby acting as effective load transfer system.
- On cyclic loading, the rebar connected to the CFST yields when the yield displacement is reached yet forming stable hysteresis behaviour without any pinching effect both on positive and negative loading.
- In case of interior joint, similar response as that of the exterior joint but the yield moment of the connection is about 0.70-0.9 times the plastic moment of the beam when compare to simple weld connection, the yield ranges from 0.6-0.7 M_p. Where embedded system behaves well after yielding of the connection when compare to simple rigid connection.
- Under anti- symmetric cyclic loading the load deformation and moment rotation behaviour were stable beyond the plastic moment of beam until failure when compare to simple weld connection. Column to beam flexural strength ratio, thickness of the CFST, diameter of the rebar stiffener, type of weld used plays a vital role in force transfer mechanisms.
- Flexural strength of the column must be at least twice than that of the strength of the beam thereby following strong column weak beam concept. Diameter of the rebar used is the important parameters to be considered as it increase the strength and stiffness characteristics of the connection system. Hence increasing the diameter of the bars helps in forming the plastic hinge away from the connection region thereby creating effective connection system.

REFERENCES

Alostaz Y. M. & Schneider S. P. 1996. Analytical behavior of connections to concrete-filled steel tubes. Journal of Constructional Steel Research. 40(2): 95-127. https://doi.org/10.1016/S0143-974X(96)00047-8

Azizinamini A., Asce M., Schneider S. P. & Asce M. 2004. Moment Connections to Circular Concrete-Filled Steel Tube Columns, (February), 213-223.

Beutel J., Thambiratnam D. & Perera N. 2001. Monotonic behaviour of composite column to beam connections. Engineering Structures. 23(9): 1152-1161. https://doi.org/10.1016/S0141-0296(01)00002-5

Ding F. xing, Yin, G. an, Jiang, L. zhong & Bai Y. 2018. Composite frame of circular CFST column to steel-concrete composite beam under lateral cyclic loading. Thin-Walled Structures, 122(June 2017), 137-146. https://doi.org/10.1016/j.tws.2017.10.022

Mou B., Li X., Bai Y., He B. & Patel V. I. 2018. Numerical evaluation on shear behavior of irregular steel beam-to-CFST column connections. Journal of Constructional Steel Research, 148(April), 422-435. https://doi.org/10.1016/j.jcsr.2018.06.002

Park S. H., Choi S. M., Kim Y. S., Park Y. W. & Kim J. H. 2010. Hysteresis behavior of concrete filled square steel tube column-to-beam partially restrained composite connections. Journal of Constructional Steel Research, 66(7): 943-953. https://doi.org/10.1016/j.jcsr.2010.01.006

Sheet I. S., Gunasekaran U. & MacRae G. A. 2013. Experimental investigation of CFT column to steel beam connections under cyclic loading. Journal of Constructional Steel Research, 86, 167-182. https://doi.org/10.1016/j.jcsr.2013.03.021

Yang J., Sheehan T., Dai X. & Lam D. 2017. Structural Behaviour of Beam to Concrete-filled Elliptical Steel Tubular Column Connections. Structures. 9, 41-52. https://doi.org/10.1016/j.istruc.2016.09.005.