Stiffener Configurations in Moment Connections Between Steel I-Beams and Composite Columns

Devu Richin Thomas
M.Tech student,
Department of Civil Engineering
Amal Jyothi College of Engineering
Kerala, India

George Mohan
Assistant Professor,
Department of Civil Engineering
Amal Jyothi College of Engineering
Kerala, India

Abstract: **The steel moment-resisting frame, in general, is considered to be a structure of excellent ductility and is widely used in high-rise buildings. Recently, composite column has drawn a widespread interest as column members of steel structures. The forces resulting from the transfer of moment from the beam to the column are relatively large concentrated forces. The strength of the column will therefore be impaired. The connection can be improved by providing additional strength to the column connection where the load is being transferred, in the form of stiffeners. Stiffeners reduce the stress concentration at the beam-column connection. The objective of this research is to study the ultimate moment capacity of the connections between steel I-beams and composite columns using different stiffener configurations. The main parameters considered here are stiffener configurations, stiffener dimensions and the cross section of the composite column. The composite column used here is Concrete Filled Steel Tube (CFST) column. This analytical study includes finite element models using ANSYS 14.5 program, taking geometric and material nonlinearities into consideration. The results show that the use of proper stiffener configuration affects the stress distribution through the connection and increases the ultimate moment capacity of the connections.**

Keywords— Concrete-filled steel tube column; Stiffener Configurations; Moment Connections

I. INTRODUCTION

In a rigid steel moment connection, most of the moment is transferred through the beam flanges to the column in the form of a couple. The couple is formed from this moment and acts at a moment arm equal to the depth of the beam ie, center-to-center of the flanges if directly welded. The beam is therefore exerting a tensile force through one flange and a compressive force through the other as shown in Fig.1. The forces resulting from the transfer of moment from the beam to the column are relatively large concentrated forces. At the beam tension flange of the connection, the pull created on the column flange may be great enough to cause slight deformation of the flange. The strength of the column will therefore be impaired. Similarly, the compressive force entering through the other flange may be large enough to cause instability in the column web. The connection can be improved by providing additional strength to the column connection where the load is being transferred in the form of stiffeners. Stiffeners are placed on the column at the locations of the beam flange forces to prevent distortion of the column flange where the beam exerts the tensile loading and web yielding and crippling at the compression loading. Stiffeners are therefore designed to prevent local column failure created by large beam forces at the moment connection. Recently, concrete-filled steel tube (CFST) has drawn a widespread interest as column members of steel structures. Compared to conventional steel, these columns possess many advantages such as confinement and convenient formwork for concrete core provided by the steel tube.

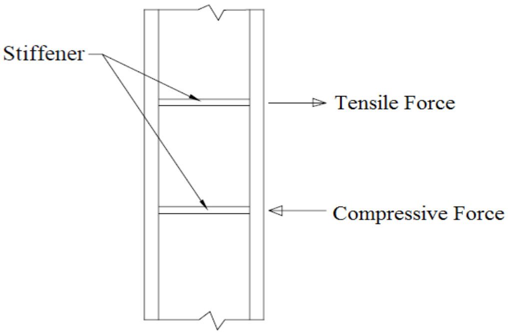


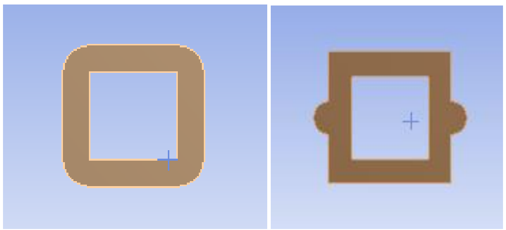
Fig.1. Moment Transfer Couple

The objectives of present study:

i. To understand the concept of Moment Connections between Steel I-beams and Composite columns
ii. To study the ultimate moment capacity of beam-column connections for different stiffener configurations
iii. To evaluate the stress developed on the model during loading.

II. STIFFENERS

Stiffeners are secondary plates or sections which are attached to beam webs or flanges to stiffen them against out of plane deformations. Almost all bridge beams will have stiffeners. They are designed to prevent local column failure created by large beam forces at the moment connection. Stiffeners have one or both of the following functions. One is to control local buckling and the other is to connect bracing or transverse beams. It is a common practice to provide stiffeners to achieve the necessary moment of resistance in the connection. Here, stiffeners are welded to both the column, and flanges of beam. The stiffener reduces the stress concentration at the column steel wall preventing it from failure. Stiffeners also ensure good seismic capacity of the beam-column joints. Therefore, recent investigations have focused on the development of various shapes of stiffeners. The stiffener attempts to transfer the forces through the connection, but stress concentrations are formed at corners, which become possible locations of failure by local buckling. Gradual transition of geometry is important in ensuring smooth flow of forces, which necessitates the development of various stiffener configurations. The use of proper stiffener configuration affects the stress distribution through the connection and increases the ultimate moment capacity of the connections. The stiffener configurations used in this paper are given below.



Stiffener 1 Stiffener 2

Fig.2. Stiffener Configurations

III. MOMENT CONNECTIONS

A Moment Connection in structural design is a connection joint between a beam and a column where the end of the beam is restrained from rotating, thus creating a rigid frame without the use of conventional cross-bracing. Standard or pinned connections are usually bolted and/or welded through the beam web and allow the beam to rotate in the Y direction when the beam is loaded. A moment connection freezes, or locks up the top and bottom flanges of the beam, thus making it rigid. In a rigid steel moment connection, most of the moment is transferred through the beam flanges to the column in the form of a couple. Moment connections are designed to transfer bending moments, shear forces and sometimes normal forces. The design strength and stiffness of a moment connection are defined in relation to the strength and stiffness of the connected members. The stiffness of the connection depends on the deformations of the components in the path that the forces follow. The deformation of each component gives the stiffness of the connection. A shear connection resists only shear forces, whereas moment connection resists both forces and rotation. In design of moment connection, the moment is transformed into a couple and the connection is designed for this forces. Moment resisting connections are used in multi-storey un-braced buildings and in single-storey portal frame buildings.

IV. CONCRETE FILLED STEEL TUBE COLUMN (CFST)

Concrete Filled Steel Tube (CFST) column utilize the advantages of both steel and concrete. They comprise of a steel hollow section of circular or rectangular shape filled with plain or reinforced concrete. They are widely used in high rise and multi-storey buildings as columns and beam-columns, and as beams in low rise buildings. There are a number of distinct advantages related to such structural systems in both terms of structural performance and construction sequence. The inherent buckling problem related to thin walled steel tubes is prevented here due to the presence of concrete core. The distribution of materials in the cross section makes the system efficient in structural performance. It provides great stiffness as the material lies furthest from the centroid. This combined with steel’s much greater modulus of elasticity provides the greatest contribution to moment of inertia. The concrete core gives greater contribution to resisting axial compression. CFST also has the advantage of ductility of steel.In this paper, two column cross sections are studied. The first is a square column of 500 × 15 mm and the second is a circular column of 500 × 15 mm. Length of the column is 3000 mm. The beam is a steel cross section of IPE 400.

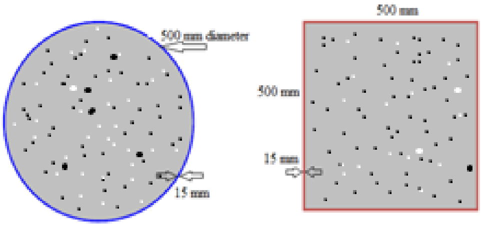


Fig.3. Cross section of CFST columns

V. FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) is the most efficient tool to perform the comprehensive parametric study provided its accuracy is verified. The finite element method is used to study the structural behavior of moment connections of steel I-beams and CFT columns incorporating all material properties and dimensions. The structural elements are divided into a number of finite elements. Here, the finite element models are created using ANSYS Workbench 14.5. The finite element model details are described in the following subsections.

A. Element types:

TABLE 1. ELEMENT TYPES

MATERIAL TYPE	ANSYS ELEMENT
Concrete model	SOLID 186
Steel model	SOLID 186
Contact between steel tube and concrete	CONTA174 & TARGE170

B. Material Properties:

The material properties given for the ANSYS models are as follows.

TABLE 2. MATERIAL PROPERTIES

PROPERTIES	CONCRETE	STEEL
1. Grade	M35	52 grade steel
2. Density	2400 kg/m^3	7850 kg/m^3
3.Yield Strength	35 MPa	360MPa
4.Young’s Modulus	29580 MPa	2 x 10^5 MPa
5. Poisson’s Ratio	0.15	0.3

C. Loads, Boundary conditions and Non-Linear analysis:

A load of 1000 kN is applied at the surface of the column upper end plate. The end surfaces of the CFT column are free while ends of steel I-beams are restrained in which vertical stiffener plates are used. One end of the steel beam is modelled with all three translation degrees of freedom restrained U_x , U_y , U_z as well as the rotational degree of freedom about the beam longitudinal axis, Rz. The other end is modelled with two translation degrees of freedom restrained Uy and Uz except for the longitudinal direction of steel beam Ux and also restraining the rotational degree of freedom, Rz. Fig.4 shows schematic drawing of steel I-beam to CFT column connection with loading and support conditions. The "Newton-Raphson" approach is employed to solve geometric nonlinearity.

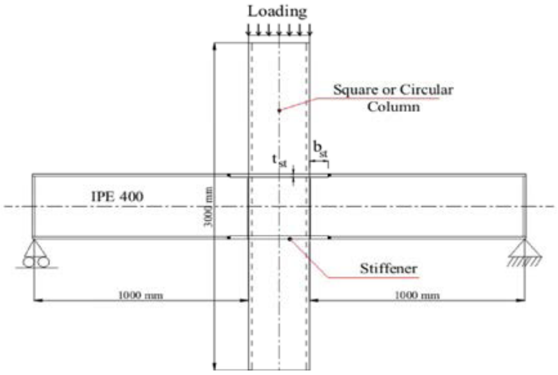
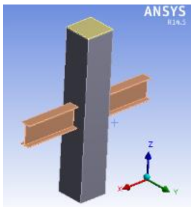
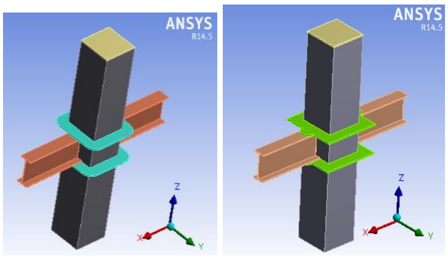


Fig.4.Schematic drawing showing steel I-beam to CFT column connection with loading and support conditions

VI. FINITE ELEMENT MODELS

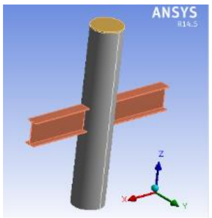


Without Stiffener

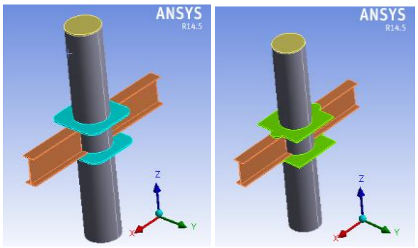


Stiffener 1 Stiffener 2

Fig 5: Beam – Rectangular column connections with different Stiffener Configurations



Without stiffener



Stiffener 1 Stiffener 2

Fig .6. Beam – Circular column connections with different Stiffener Configurations

VII. FINITE ELEMENT MESH OF MODEL

It is important to correctly select the mesh size and layout in finite element analysis. A good mesh means accurate results with better convergence but also has time consideration. A very fine mesh model will always provide accurate results but will require excessive computer time. In this analysis, suitable numbers of elements were carefully chosen for the the models based on convergence studies in order to obtain accurate results without excessive use of computer time.

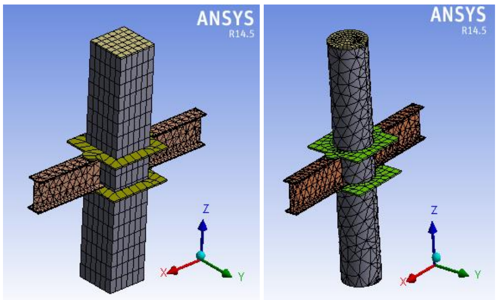


Fig .7. Meshing of the models

VIII. RESULTS AND DISCUSSION

Table 3 and 4 shows the effect of stiffener configurations and dimensions on the ultimate moment of the connection between beam IPE 400 and square (500×15) and circular (500×15) columns respectively.

Table 3: Ultimate moment of the connection (kNm) between IPE 400 and square column 500×15 mm

Unstiffened Column	Stiffener 1		Stiffener 2	
284.77	b_{st}=100	b_{st}=150	b_{st}=100	b_{st}= 150
	417.19	439.89	419.65	450

Table 4: Ultimate moment of the connection (kNm) between IPE 400 and circular column 500×15 mm

Unstiffened Column	Stiffener 1		Stiffener 2	
279.19	b_{st}= 100	b_{st}= 150	b_{st}=100	b_{st}= 150
	299.86	305.92	312	314.2

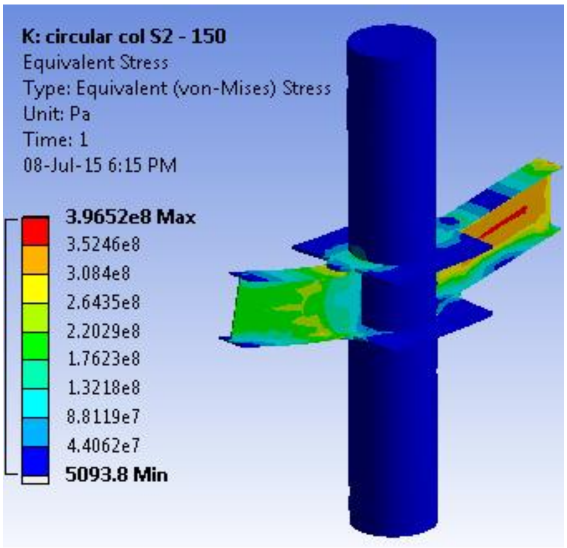


Fig. 8. Stress distribution of Beam-Circular column connection with stiffener 2

A. Effect of stiffener configuration:

From Table 3 and 4, it is evident that stiffener shape 2 gives the highest ultimate moment of the connections followed by stiffener shape 1. In case of rectangular column, the increase in ultimate moment of connection between unstiffened case and stiffener 1 case is 10% whereas the increase is 13% between unstiffened case and stiffener 2 case. Hence, it is seen that stiffener 2 shows marked difference in ultimate moment capacity when compared to stiffener 1 by 3%.

B. Effect of stiffener dimension:

The increase in the ultimate moment of the connections is directly proportional to the stiffener dimensions, as shown in Tables 3 and 4. In case of circular column with stiffener 2 configuration, the larger stiffener provides 7% increased ultimate moment at the connection than the smaller stiffener.

C. Effect of column cross section shape:

By comparing results between circular and square columns, circular column is more efficient than the square column as it provides confinement that decreases local buckling of the column wall.

D. Deformed Shape:

When the columns are unstiffened, high distortion occurs in the steel column wall in which the failure occurs. When the column is stiffened, two different failure modes occur either at stiffener or at compression beam flange regardless of the column cross section shape because the maximum stresses are shifted away from the column. Generally, failure of the connection at steel column wall and stiffeners shall be avoided and move towards beam flanges to obtain ductile connections.

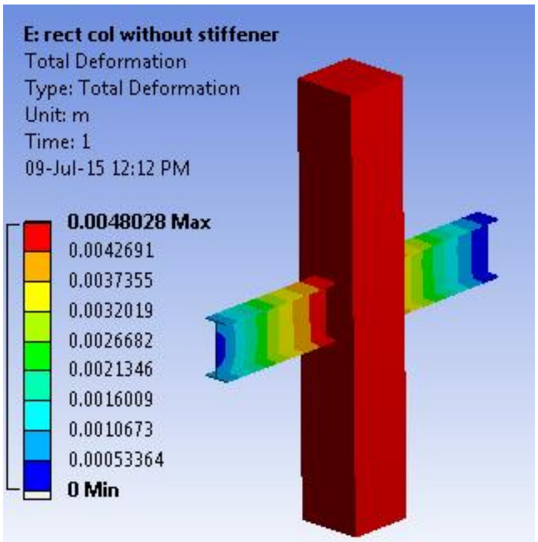
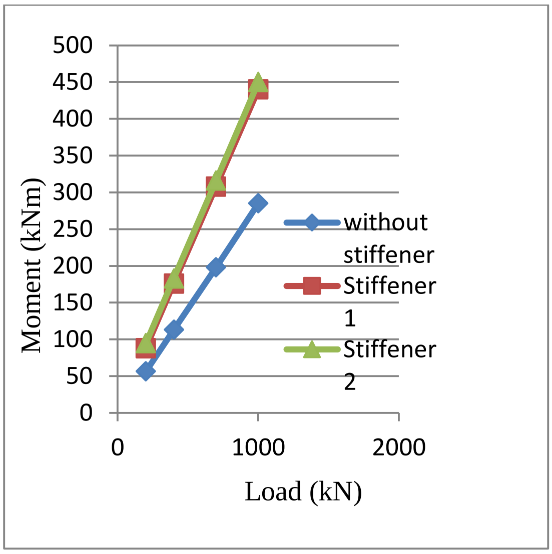
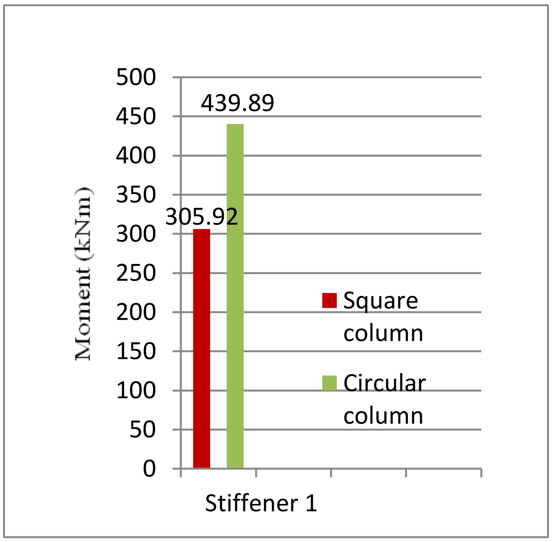


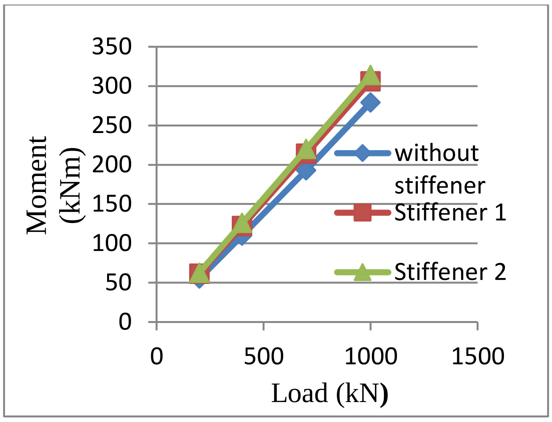
Fig 9: Total deformation values of unstiffened square column



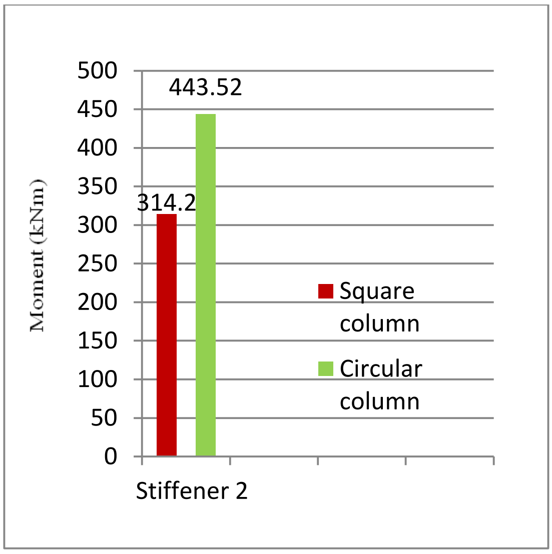
Graph 1. Moment at connection versus load applied (Circular column)



Graph 2.Moment at connection versus load applied (Square column)



Graph 3. Ultimate moment capacity of the connection in case of stiffener 1 for square and circular column



Graph 4. Ultimate moment capacity of the connection in case of stiffener 2 for square and circular column

IX. CONCLUSIONS

In this study, at attempt was made to compare the ultimate moment capacity of the moment connection between steel I-beam and composite columns using different stiffener configurations. The main parameters considered were stiffener configurations, stiffener dimensions and the cross section of the composite column. Following are the conclusions obtained from this work:

1. Presence of the stiffener at the outer column perimeter, reduces stress concentration; therefore the ultimate moment capacity of the connections of square and circular column cross sections is increased considerably.
2. Stiffener shape 2 is more efficient than stiffener shape 1 for both square and circular columns.
3. The increase in the ultimate moment of the connection is directly proportional to the stiffener dimensions.
4. Circular column is advantageous than the square column for all stiffener shapes and dimensions as

it provides confinement that decreases local buckling of the column wall.

5. For unstiffened tubular columns, high distortion occurs in the steel column wall in which the failure occurs.

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