COMPARATIVE STUDY OF BEHAVIOUR OF STEEL BEAM-COLUMN JOINT WITH DIFFERENT MODES OF CONNECTIONS

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ABSTRACT: *Beam-column joint plays an important role in the response of a steel moment resisting framed structure. Generally, beam-column joint is the portion of the column that is common at the intersection to both the column and beam. Because of the poor performance of pre-Northridge moment connections, the researchers investigated the causes of failure and developed alternative connections for repair, rehabilitation and new construction. In this study, the behaviour of beam-column joint with different modes of connections studied analytically using finite element analysis and experimentally using loading frame with respect to ductility and plastic hinge formation. Four types of connections i.e. connection using weld, using stiffeners like cleat angle and plate, using haunches and by using combination of both stiffeners and haunches were used with standard ISMB steel section, plate forming I section and moreover with tube section. Modelling of the beam-column joint with different connections were done in finite element software named ANSYS – WORKBENCH 2019. The aim of this study is to work out the best behaviour of connections. Experimentally total six specimens with and without stiffening are prepared for testing. Quasi static test performed on the beam column joint using loading frame. Experimental work is validated with analytical results obtained by FE analysis.*

KEYWORDS: Beam-Column Joints, Quasi static test, Finite Element Analysis, Von Mises stress, ANSYS – WORKBENCH software.

1. INTRODUCTION

In 1995, after the Northridge and Kobe earthquakes, brittle fracture occurred in large numbers to the connections which was commonly used connection for steel moment resisting frames before the earthquake. It caused many high-rise steel structures to break and collapse. Research has shown that the cracking of weld under static and cyclic loading has damaged the connections and reduction in stiffness and brittle failure of the connection occurred.

In response to this, many solutions to the moment resisting connections have proposed. Either strengthening beam-column connection by the addition of stiffeners like cleat angle, cover plates, ribs or haunches or reducing the beam cross-section away from the column face. Reduced beam section (RBS) is one of the connection types, which is economical and popular for use in new steel moment frame structures. To form RBS connection, some portion of the beam flanges reduced from column face so that the yielding and plastic hinge occurs within this area of flanges. Use of RBS connection found advantageous. Strong-column weak-beam requirement is also satisfied.

In the Quasi-static test, the rate of application of load is very low so that the material strain-rate effects do not influence the structural behaviour of beam column joint and there is no formation of inertia forces. The loading pattern should be chosen to provide the full range of deformations that the structures would experience under the static loading. This method adequately captures the hysteresis behaviour, energy dissipation, stiffness degradation, ductility, hysteretic damping, the most distressed zone, lateral strength and deformation capacity.

Most of the Semi-rigid joints are given with high-strength bolts. Recently, extensive and increasing studies has carried out on the high strength bolted joints in steel structures. The issues in high strength bolted joint as compared with welded joint are the stiffness, complex behaviour, ductility and mainly the construction cost. It is therefore of practical importance to investigate the real behaviour of joints with respect to some rational test.

ANSYS simulation software gives designers the ability to access the influence of the range of variable in virtual environment. We can advance through the design and materials selection process quickly and efficiently. ANSYS still gives the user through coupled Rock and soil mechanics analysis; material specific maximum load assumptions; linear, nonlinear, static and dynamic analysis; sensitivity and parametric studies; and other related work, which together provide significant insight into design behaviour that would be difficult with single analysis runs.

2. LITERATURE REVIEW

In this research review various journal papers are being referred that are studied carefully before carrying out further work. The concept of stiffening depends upon parameters of column beam connection of special moment frame using stiffened and stiffened connection.

Guofeng Xue, Wei Bao, Jin Jiang and Yongsong Shao [1], in this study, a beam-to-column joint is connected with a new type of cast steel connector. The cast steel connector installed with bolted connections, keeping it a replaceable energy dissipation component and the rapid repair of the joint after an earthquake. In this test, 3 specimens were fabricated and tested to investigate the hysteretic behaviour of the joints under cyclic loadings. The results showed that the cast steel connector showed reliable ductility and energy dissipation capacity. The beam-to-column joints with cast steel connectors can reduce the deformation and protect the other joint components from plastic deformation. FE analysis was performed to investigate the hysteretic behaviour of the joint. The FEM results showed that the thickness of the vertical leg of the cast steel connector can influence the stiffness and bearing capacity of the joint. Also improve the hysteretic behaviour effectively. The proposed beam-to-column joints with cast steel connectors can achieve the requirement of stiffness and load-bearing capacity.

Abishek P, Karthikeyan G [2], in this study, theoretical and experimental study was made on different types of beam-to-column connections which is made using Reduced Beam Section (RBS) concept. The beam is reduced on the flange with specified radii on both sides of the section. Totally 6 different models have been analysed using ANSYS model. Additionally, Single and Double stiffeners are provided in order to increase the deformation time and also avoiding sudden collapse in the structure. Comparing the analytical results from the ANSYS software and thereby choosing the critical section. Then the critical section is developed into a 3 storey frame for which push over analysis is performed using E-TABS. Performance of the building is observed at different stages of hinge formation and also plotted the push over curve.

Abishek P, Mohan Kumar N S, Karthikeyan G [3], Northridge and Kobe earthquake in the year 1915 created the need to investigate the local brittle damage of beam-column connection of SMRF. The research after the earthquake revealed two critical factors causing failure. The factors like large ductility demand at the connection and High Stress concentration in the welded web and flanges are observed. To solve this problem, there is need to reduce the ductility demand on the welded areas and reduce the stress concentration level. Different types of connections in beam-column joint are Welded moment connection on the flanges, Bolted, endplate moment connection on the flanges, Simple shear connection on the flanges or on the web, Gusset plate connection with double plate flange splice of I sections or plate splice of hollow sections on the flanges or on the web. In this paper, the review of the different papers on the study of beam column joint using different connections has been made and given.

Hong Chao Guo, YanLong Lia, Gang Lianga, Yun He Liu [4], in this study, complicated interaction is found between the infill steel plate and frame edges in the Steel Plate Shear Wall (SPSW) structure. The bearing capacity and stiffness of SPSW structure is relies upon the section sizes of frame, wall and on pertains to the stiffness of joint connection. The beam-column connection enhances the deformation and power dissipation capacities of SPSW structure and avoids the brittle failure of welded joint. SPSW structure with cross stiffened not only has great deformation and rotation capacity, but also easy to install.

Kulkarni Swati Ajay, Vesmawala Gaurang [5], in this study, RBS is studied analytically as it is cost effective and new steel moment frame structures in seismic region. To form RBS connection, a few portion of the beam flanges s purposefully trimmed from the column face in which yielding and plastic hinge takes place inside the area of flanges. Non-linear FE Analysis of the connection models performed using ANSYS Multiphysics and the behavior of different cut profile modelled and compared using Von-Mises Stress diagram. Maximum Von Mises stress was found in between 65x103 psi to 75 x103 psi for 0.05 radians. Stress intensity is in between 35x103 psi to 55x103 psi for all connections. Lateral torsional buckling of beam and column flange of column at 0.05 radians was found same in every cases.

S. Loganathan, C.G. Sivakumar [6], in this study, the overall behaviour of the Steel Beam-Column joint is studied under Quasi-Static load Experimentally and the Ductility Characteristics of Beam-Column joint. Beam Column Joint is the portion of the column within the depth of the beam that frames into the column. The portion of the column that is common to both beam and column at the intersection is the beam-column joint. These are classified with respect to geometrical configuration and identified as interior, exterior and corner joints. The Quasi-static test, in which the rate of application of load is very low so that the material strain-rate effects do not influence the structural behaviour and inertia forces are not developed. This data is also utilized to make the hysteretic model of component for the dynamic analysis of the structure.

3. AIM AND OBJECTIVES

- To find out maximum load carrying capacities of steel sections with different modes of connection such as ISMB125, Plate forming I section and Tube section.
- To study the behaviour of shear and moment connections.
- Identification of plastic hinge formation in beam or column.
- To investigate the stresses and deflections at connection to prevent local buckling of column flanges.
- To compare analytical and experimental results and give conclusion.

4. PROBLEM STATEMENT AND METHODOLOGY

4.1 Significance of choosing the problem

Beam column connection plays very important role in behaviour of steel structure. Generally, in India mostly study carried out with the help of software analysis and experimentally with the help of UTM loading frame. However, the study carried preferably for I sections only. Now a days tube sections and plate forming I sections are also widely used in steel structures as they have better sectional properties with reduced weight. To utilise their properties more efficiently we need to verify it experimentally its load carrying capacity and need to study the behaviour of connections. Experimental investigation is not carried out that much to evaluate the strength but to evaluate the actual load carrying capacity of members, study of location plastic hinge formation and most distressed zone.

4.2 Problem statement

To study the behaviour of beam column connection with standard ISMB125 with four types of connections for plastic hinge formation, load carrying capacity, most distressed zone and failure mechanism.

To study the behaviour of beam column connection with plate forming I sections with four types of connections for plastic hinge formation, load carrying capacity, most distressed zone and failure mechanism.

To study the behaviour of beam column connection with standard tube sections with four types of connections with steel grade YST 310 MPa plastic hinge formation, load carrying capacity, most distressed and failure mechanism.

We finalized to do the analysis work with the help of ANSYS WORKBENCH 2019 software and experimental investigation carried out with the help of UTM loading frame.

5. FINITE ELEMENT MODEL

ANSYS software is capable of handling dedicated models for the non-linear response of beam column connection under static and dynamic loading. In this study, 12 models of steel beam-column joint in which four types of connection were used with ISMB 125, four with plate forming I sections and four with hollow tube sections has been modelled using ANSYS- WORKBENCH 2019. Different modes of connection i.e. using weld, using stiffeners like cleat angle or plate, using haunches and by using combination of both stiffeners and haunches with specific dimensions are used in the models.

5.1 Modelling Using ANSYS WORKBENCH 2019

The following steps are involved in analysing the models using the finite element software

- Defining material properties
- Model creation
- Meshing generation
- Applying boundary conditions and loading conditions
- Analysis
- Viewing results

5.2 Input Data

Following is the input data required to create a model for steel beam-column connection

- Modulus of Elasticity (Ec) = 200000 MPa
- Poisson's ratio (v) = 0.30
- Density = 7850 kg/cu.m
- ISMB125 = (F= 75x7.6 mm, W= 109.8x4.4 mm)
- Plate I section = (F=100x7 mm, W= 111x4 mm)
- Tube section = (120x60x3.25 mm)

5.3 Modelling

In this study analytical work is done totally in ANSYS WORKBENCH 2019. In which, steel beam-column joint using four modes of connections was modelled and then parameters were defined accordingly. After the modelling, the next important step is applying loading conditions. In this case, initially the top and the bottom plate of the column was fully restrained. This will restrict the movement when the loading is applied and help in resisting the load it can yield. Then the loading was applied on the face of the beam flanges for respective loads i.e. 5KN, 10KN and 15KN and accordingly the results were observed. Total deformation, Von-mises stresses at each section are calculated and accordingly the tables and graphs are plotted.

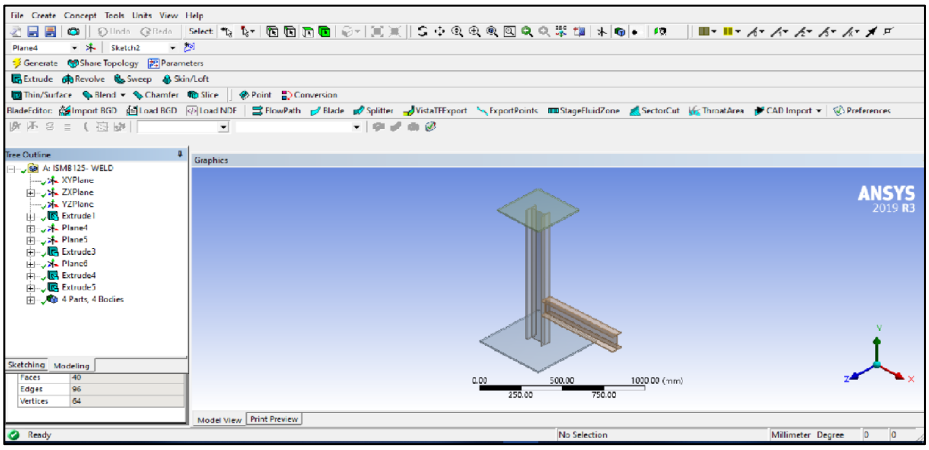


Figure 1: Modelling of beam column assembly

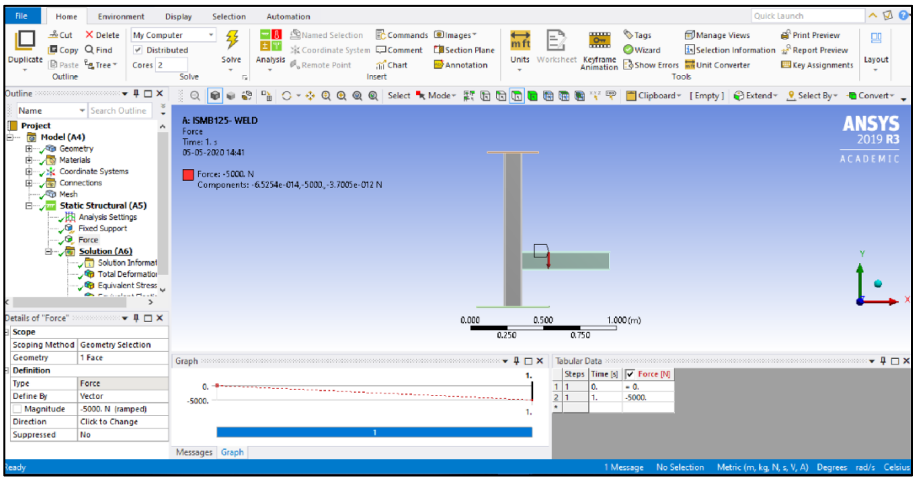


Figure 2: Meshing and applying loading conditions

6.0 EXPERIMENTAL INVESTIGATION

6.1 Loading Frame and its Details

RCC loading frame used for testing of beam column connection with following specification.

- Maximum load carrying capacity of frame with available arrangement: 50KN
- Maximum Hydraulic Jack available with Institute: 1000KN
- Proving ring capacity: 1000KN
- Dial gauge for deflection measurement: 25mm

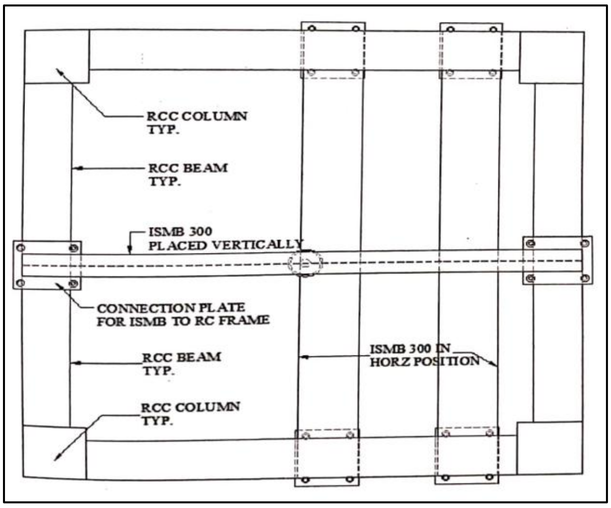


Figure 3: Loading frame (Plan)

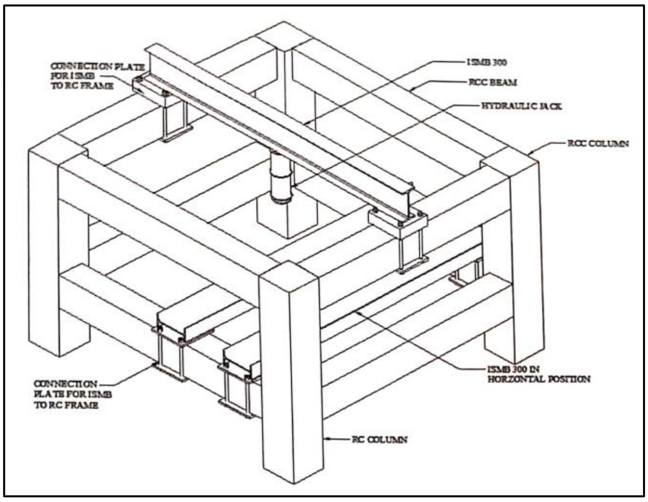


Figure 4: Loading frame (Isometric view)

Figure 5: Experimental arrangement of specimens

In this study, overall behaviour of the beam column joint will be studied experimentally with respect to ductility and plastic hinge formation. Quasi static test is performed using loading frame for different beam column joint. Total six specimens are prepared for testing. Two types of connection with and without stiffeners were used in standard ISMB125, plate forming I section and in tube section. Then it is tested with loading arrangement as shown in the respective figures. The top and the bottom plates of column are bolted in such a way that end fixity will be achieved. The load is gradually and measured with the help of proving ring. The load verses deflection data and load verses Von mises stress data are recorded. The bending phenomenon of each specimens observed along with failure mode. The material stressing and working mechanism in each specimen is closely observed. Same types of specimen are analysed using software ANSYS WORKBENCH 2019 by FE model for static loading. Stresses, deflections and loading values are compared with actual testing results. Accordingly, tables and graphs are plotted.

7.0 OBSERVATIONS & RESULTS

7.1 Finite Element Analysis Results

Analysis results of standard ISMB125, plate forming I section and tube section using four modes of connection using ANSYS WORKBENCH 2019 software are presented in below tables. The static load is applied on each beam for load variations such as 5KN, 10KN and 15KN and the stresses and the corresponding deflections were also noted below. The values obtained from FE analysis were then plotted in the graphical format to give us better understanding of the stress and total deformation with respect to applied load.

Table 7.1.1: FEM results of ISMB125 using four modes of connection for Von mises stress and Total deformation

Sr. No.	Specimen Designation	Von Mises stress (MPa)	Member Deflection (mm)	Applied Loading (KN)
1.	Weld	83.11 166.2 249.3	0.564 1.129 1.694	5.00 10.00 15.00
2.	Stiffeners	63.31 126.6 189.9	0.490 0.981 1.478	5.00 10.00 15.00
3.	Haunches	92.42 184.8 277.2	0.557 1.123 1.675	5.00 10.00 15.00
4.	Stiffeners + haunches	93.92 187.8 281.7	0.546 1.097 1.646	5.00 10.00 15.00

Graph 1

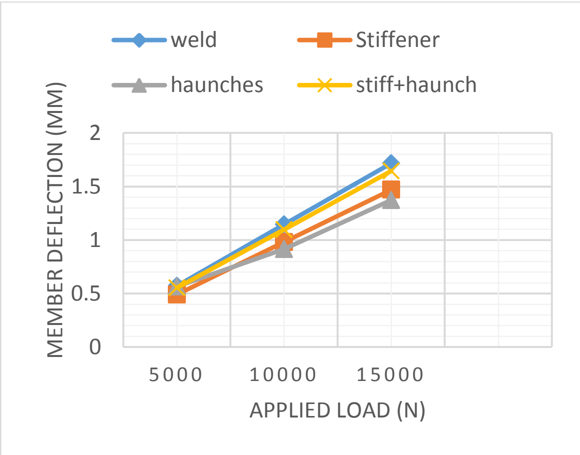
Graph 2

Graph 1: Member deflection vs loading applied for ISMB125

Graph 2: Von mises stress vs Loading applied for ISMB125

Table 7.1.2 FEM results of Plate forming I section using four modes of connection for Von mises stress and Total deformation

Sr. No.	Specimen Designation	Von mises stress(MPa)	Member Deflection(mm)	Applied Loading(KN)
1.	Weld	85.88 171.73 257.6	0.572 1.146 1.716	5.00 10.00 15.00
2.	Stiffeners	60.88 121.7 182.6	0.491 0.982 1.470	5.00 10.00 15.00
3.	Haunches	68.42 136.66 205.23	0.565 0.915 1.372	5.00 10.00 15.00
4.	Stiffeners + haunches	105.11 210.23 315.34	0.553 1.097 1.645	5.00 10.00 15.00



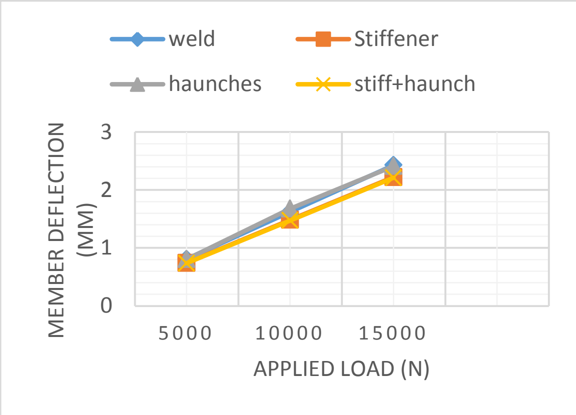
Graph 3

Graph 4

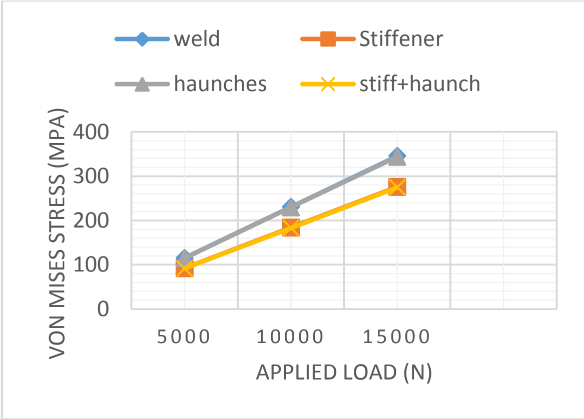
Graph 3: Member deflection vs Loading applied for Plate I section
Graph 4: Von mises stress vs Loading applied for Plate I section

Table 7.1.3 FEM results of Tubular section using four modes of connection for Von mises stress and Total deformation

Sr. No.	Specimen Designation	Von mises stress(MPa)	Member Deflection (mm)	Applied Loading (KN)
1.	Weld	115.2 230.4 345.6	0.809 1.619 2.429	5.00 10.00 15.00
2.	Stiffeners	91.90 183.8 275.7	0.741 1.485 2.223	5.00 10.00 15.00
3.	Haunches	114.6 229.3 343.8	0.805 1.678 2.412	5.00 10.00 15.00
4.	Stiffeners + haunches	91.36 182.7 274.8	0.737 1.474 2.211	5.00 10.00 15.00



Graph 5



Graph 6

Graph 5: Member deflection vs Loading applied for Tubular section

Graph 6: Von mises stress vs Loading applied for Tubular section

7.2 Experimental Results

In this dissertation six types of connections are analysed experimentally using loading frame and analytically with the help of ANSYS WORKBENCH 2019 software in which stresses and member deflection are observed. The Modelling and fabrication of samples are completed properly as per codal provisions. Results of all specimens are given in the form of stresses and deflection. Equivalent stress is called as Von mises stresses were observed in all specimen and the respective values of the stresses and deflection were noted in tabular form to compare the connections. Experimental investigation carried out to study behaviour of beam column connection with respect to ductility and plastic hinge formation. For the validation of experimental work, same types of specimen modelled and analysed in ANSYS WORKBENCH 2019 software and the results compared and presented in tables and graphs.

CBCJ0- Conventional beam column assembly without angle stiffeners

CBCJS- Conventional beam column assembly with angle stiffeners

PBCJ- Plate formed I section without stiffeners

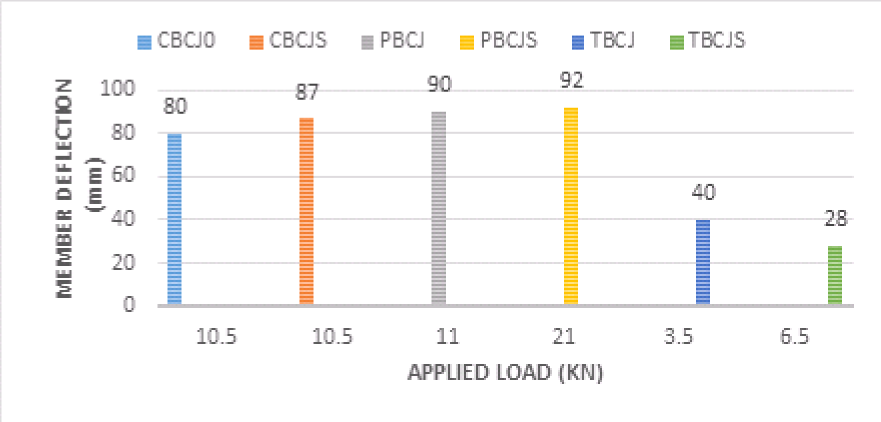
PBCJS- Plate formed I section with stiffeners

TBCJ- Tubular beam column assembly without stiffeners

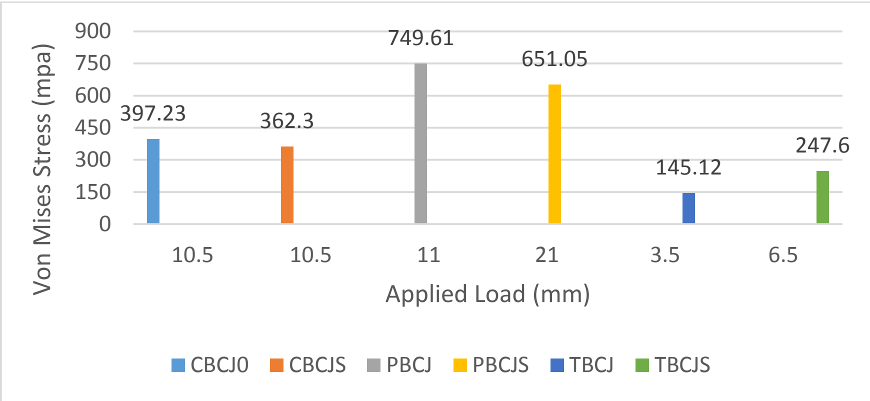
TBCJS-Tubular beam column assembly with stiffeners

Table 7.2.1: Experimental results of beam column connection with and without stiffening for Von mises stress and total deformation

Sr. No.	Specimen designation	Von Mises Stress (MPa)	Maximum Deflection(mm)	Maximum Loading(KN)
1	CBCJ0	397.23	80.00	10.50
2	CBCJS	362.30	87.00	10.50
3	PBCJ	749.61	90.00	11.00
4	PBCJS	651.05	92.00	21.00
5	TBCJ	145.12	40.00	3.50
6	TBCJS	247.60	28.00	6.50



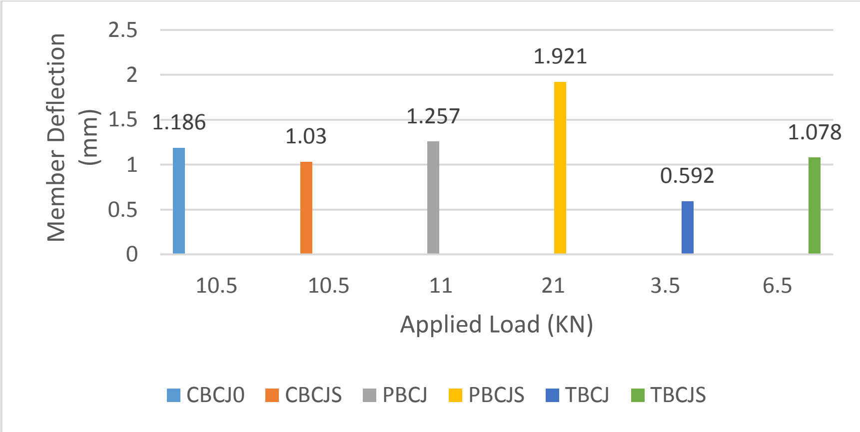
Graph 7: Member deflection vs Loading applied for experimental results



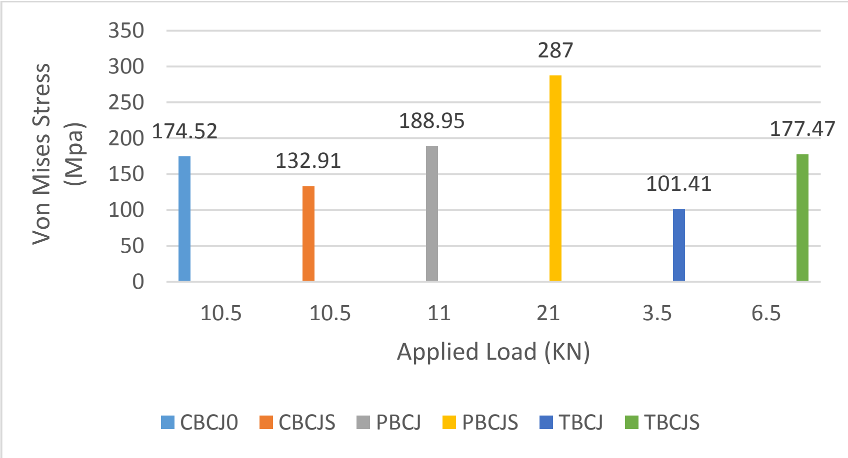
Graph 8: Von mises stress vs Loading applied for experimental results

Table 7.2.2: Analytical results of beam column connection with and without stiffening for Von mises stress and total deformation

Sr. No.	Specimen Designation	Von Mises Stress (MPa)	Maximum Deflection (mm)	Maximum Loading (KN)
1	CBCJ0	174.52	1.186	10.50
2	CBCJS	132.91	1.030	10.50
5	PBCJ	188.95	1.257	11.00
6	PBCJS	287.00	1.921	21.00
9	TBCJ	101.41	0.592	3.50
12	TBCJS	177.47	1.078	6.50



Graph 9: Member deflection vs Loading applied for analytical results



Graph 10: Von mises stress vs Loading applied for analytical results

8.0 ANALYTICAL FINITE ELEMENT RESULTS

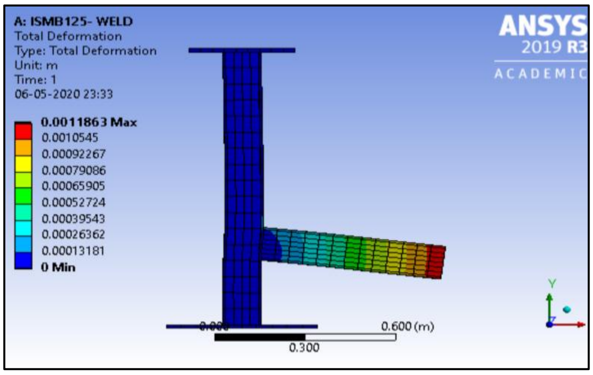


Figure (8.1)

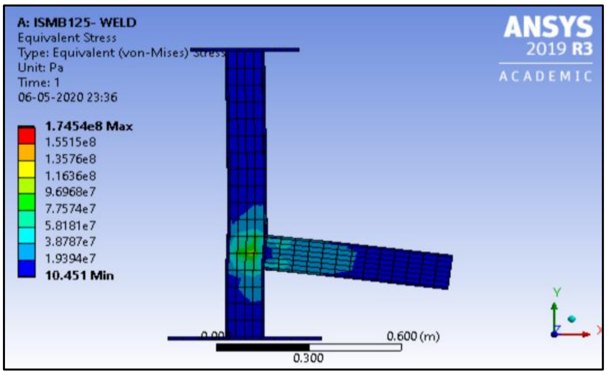
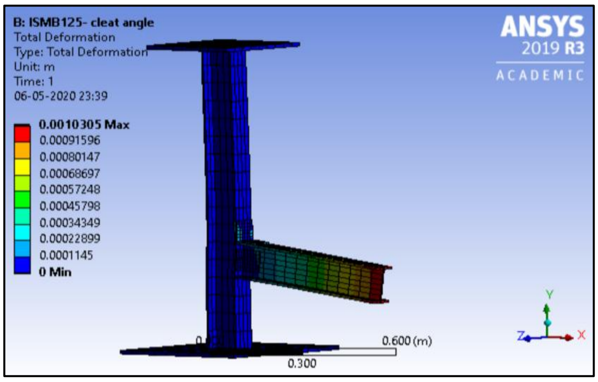


Figure (8.2)

Figure (8.1): Total deformation of ISMB125 without angle stiffener (CBCJ0)

Figure (8.2): Von mises stress of ISMB125 without angle stiffener (CBCJ0)



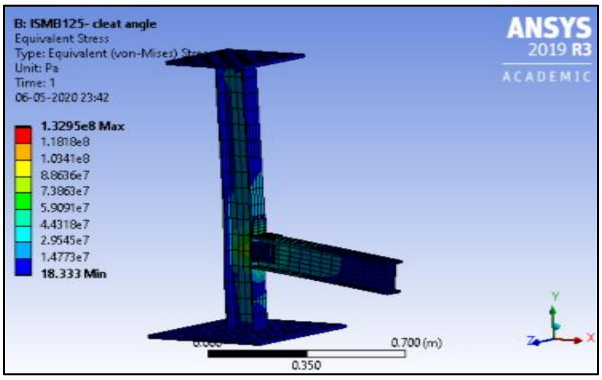
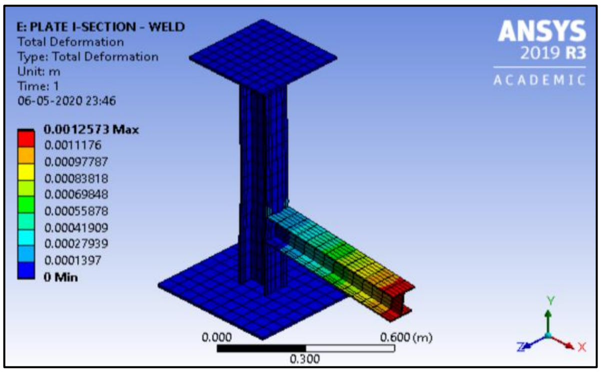


Figure (8.3) Figure (8.4)

Figure (8.3): Total deformation of ISMB125 with angle stiffener (CBCJS)

Figure (8.3): Von mises stress of ISMB125 with angle stiffener (CBCJS)



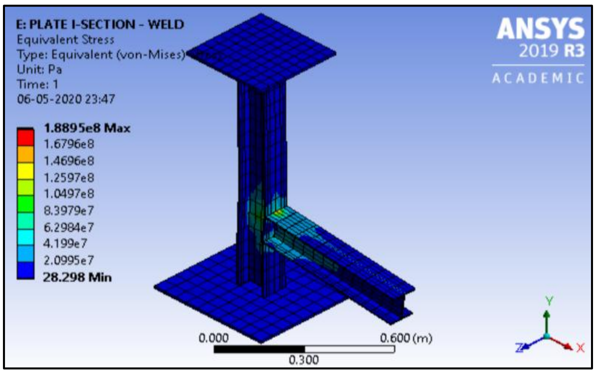
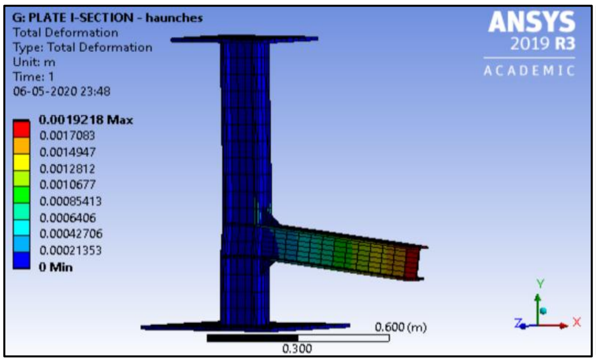


Figure (8.5) Figure (8.6)

Figure (8.5): Total deformation of Plate formed I section without stiffener (PBCJ)

Figure (8.6): Von mises stress of Plate formed I section without stiffener (PBCJ)



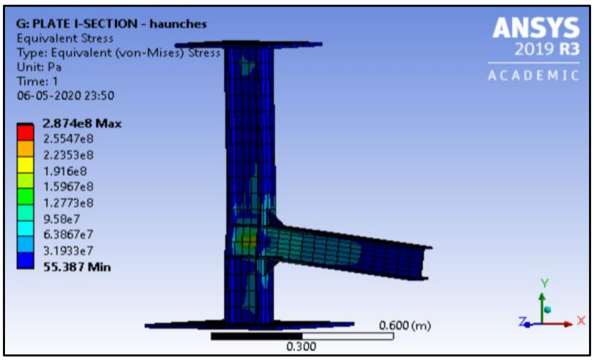
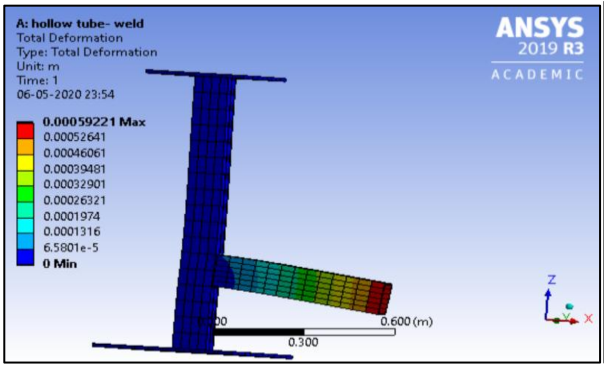


Figure (8.7) Figure (8.8)

Figure (8.7): Total deformation of Plate formed I section with stiffener (PBCJS)

Figure (8.8): Von mises stress of Plate formed I section with stiffener (PBCJS)



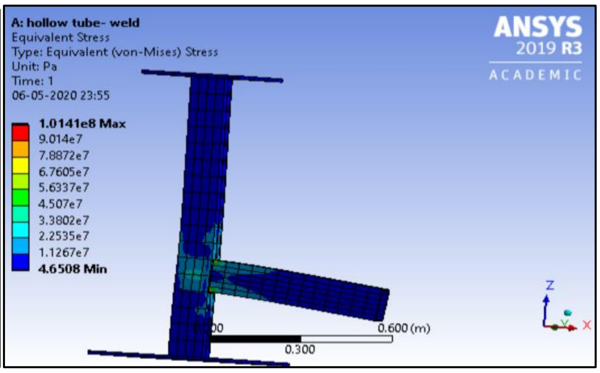
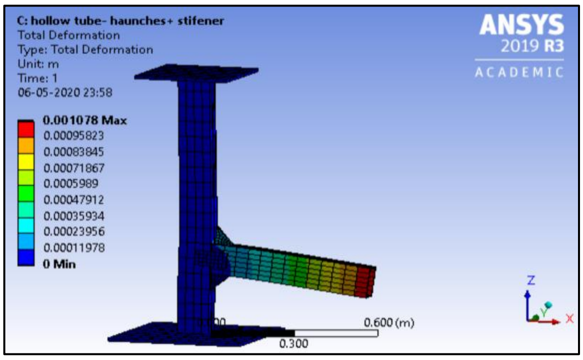


Figure (8.9) Figure (8.10)

Figure (8.9): Total deformation of Tubular beam column assembly without stiffener (TBCJ)

Figure (8.10): Von mises stress of Tubular beam column assembly without stiffener (TBCJ)



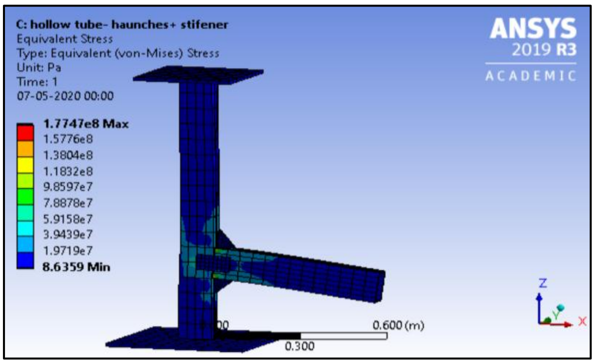


Figure (8.11) Figure (8.12)

Figure (8.11): Total deformation of Tubular beam column assembly with stiffeners (TBCJS)

Figure (8.12): Von mises stress of Tubular beam column assembly with stiffeners (TBCJS)

9.0 RESULTS & DISCUSSION

- As per analysis of specimen 1 CBCJ0, experimentally member showing stress value of 397.23 MPa at 10.5KN with maximum deflection of 80 mm and analytically 174.52 MPa at 10.5KN with deflection of 1.186mm. Seen some cracks on column web so web is stressed and flanges of columns are buckled. Therefore, plastic hinge formed in column.
- Specimen 2 CBCJS experimentally member showing stress value of 362.3 MPa at 10.5KN with maximum deflection of 87mm and analytically 132.91 MPa at 10.5KN with deflection of 1.03 mm. Top angle connected to top flange of beam is cracked. Load carrying capacity of member remained same but ductility is increased.
- After analysing specimen 3 PBCJ, experimentally member showing stress value of 749.61 MPa at 11 KN with maximum deflection of 90 mm and analytically 188.95 MPa at 11 KN with deflection of 1.257 mm.. Higher inertia and higher stress values are observed analytically. Load carrying capacity is same compared to specimen 1 and 2. No cracks are observed in connection only stresses are seen on column web and column flanges are buckled.
- In specimen 4 PBCJS, experimentally member showing stress value of 651.05 MPa at maximum loading of 21KN with maximum deflection of 92 mm and analytically 287 MPa at 21 KN with deflection of 1.921 mm. In this section will get more inertia and less stresses also load carrying capacity is almost double as compared to all above three specimens. Plastic hinge formed in column. No cracks observed until 91 mm deflection. Plastic hinge formed in column.
- In specimen 5 TBCJ with YS 310 MPa are analysed, analytically showing stress value of 101.41 MPa at 3.5KN load and experimentally 145.12 MPa at maximum loading of 3.5KN with maximum deflection of 40 mm. Analytically seen lesser stresses in this section with lesser weight as compared to standard MB sections and plate forming I

section. load carrying capacity is much less as compared to specimen 1 to 4. Not recommended to use tube sections without stiffeners for heavy structures as seen experimentally much less capacity carried with respect to analytical design.

- In specimen 6 TBCJS with YS 310 MPa are analysed, analytically showing stress value of 177.47 MPa at 6.5 KN load and experimentally 247.6 MPa at 6.5 KN with maximum deflection of 28 mm. Analytically seen lesser stresses in this section with lesser weight as compared to standard MB sections and plate forming I sections. More inertia and less stress value are observed analytically. Load carrying capacity is also less.

10.0 CONCLUSIONS

- From experimental investigation it is concluded that the PBCJS section i.e. plate formed I section using haunches on top and bottom will prove better in all respect as load carrying capacity is 21KN which is more as compared to all other sections. Shear and moment carrying capacity is also much more in this section as compared to all other sections. No cracks are observed on the member until 92 mm deflection.
- Tubular section using combination of both stiffener and haunches i.e. TBCJS analytically 5KN of load is carried safely and practically also 6.5KN of load carried so tube sections with correct stiffening can be used for most economical design as cost is the important parameter.
- For temporary structures, tubular sections using combination of both stiffener and haunches proved better than any other sections as weight is much lesser as compared to any other steel section. Not recommended to use tubular section with weld connection (without stiffeners) for heavy structures as seen experimentally much less capacity carried with respect to analytical design.
- As per the FE analysis of model ISMB125 and plate formed I section with four modes of connection, connection using stiffeners and in tubular section connection using combination of both stiffeners and haunches has proven better than the weld connection as it's taken higher load with less stress and less deflection.
- In terms of ductility and plastic hinge formation in our case, plastic hinge formed in column itself as columns are found weak than beams. Local flange buckling is also found in column itself as column sections are found weak. Therefore, concluded that we need to increase the column sections, so strong-column weak-beam methodology need to follow with stiffened connection. Accordingly using stiffeners at connection at most distressed zone will get behaviour that is more ductile.

11.0 FUTURE SCOPE

This work is done analytically and experimentally for only static loading, dynamic behaviour is not analysed or studied. Further study can be done for cyclic loading. Earthquake excitation can considered in future study. Cyclic loading can applied with same system also, only some extra instruments can be required for the same. Behaviour of beam column connections under seismic excitation and cyclic loading will be the future scope for this subject.

12.0 REFERENCES

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