# Numerical Analysis of Strength Behaviour of Bolted Steel Beam Column Connection Based on Type and Position of Stiffeners

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**Abstract -** *Stiffeners are secondary plates or sections which are attached to the beam webs or flanges to stiffen them against out of plane deformations. A stiffness requirement increases the use of rigid connections in steel high rise and slender structures. Stiffeners should also be capable of transmitting the internal forces, without developing any significant moments which might adversely affect the members or the structure as a whole and be capable of accepting the resulting rotations under the design loads, providing the directional restraint to members which has been assumed in the member design and it should also have sufficient robustness to satisfy the structural integrity requirements. Rigid connections should therefore undergo negligible deformations at the joint and transfer significant moments to the columns. In sway frames these are necessary in resisting lateral loads. In this paper, Numerical analysis of bolted steel beam-column connections based on type and position of stiffener plates were done by means of a finite element model using the ANSYS 16.1 Workbench software was done and the specimen's load carrying capacity , moment carrying capacity and deformation was studied. Four specimens were analyzed and it was found that the specimen having side stiffener plate at the top bolt layer connecting the column flanges and also connecting the end plate welded with beam carrie more load and had the highest moment carrying capacity compared to the other models.*

***Key Words*: Beam-column joint, Bolted Connections, ANSYS 16.1 Workbench, Sway Frames, Finite Element Model**

## 1. INTRODUCTION

It is necessary to understand the strength and rigidity of the connection regions for efficient design of steel building systems [5].The structural response of the steel moment resisting frames (MRFs) is greatly dependent on the behaviour of beam-column joints [3]. Structural engineering design tasks are based on theoretical models and empirical evidence. These theories are developed into a design procedure, and the procedures are carried out and tested. These results are then used to formulate new and more accurate analysis procedures thereby making it an complex process. New developments in the analytical procedures have led to a greater understanding of how structures work. In the area of connections in structures, a fairly high degree of uncertainty in the behavior of connections exists, which makes their analysis and design difficult and makes experimental verification so important [8]. Connections can be classified by their strength as well as their ductility, where ductility is the description of rotation capacity. The strength classification of connections is mostly based on the relative moment resistance of the connection compared to the moment resistance of the beam. Both strength and rotation capacity are essential for the connections, and deformation too governs the failure of a connection. Structural connections can be typically categorized into one of two idealized types: pin connections and fixed connections. A pin connection fully transmits forces but not moments between the connected elements whereas a moment or rigid connection is one which fully transmits both moments and forces between the connected elements [4, 5].This paper is concerned with the numerical study of strength behaviour of bolted steel beam-column endplate connection arrangements. Stiffener plates were provided on endplate welded to the beam and column members for additional stiffness to the connection arrangement and the analysis of these models were carried out.

## 2. MODELLING OF SPECIMENS

In the construction field in India, the connections provided in steel structures plays an important role in its strength. So the analysis and design of the steel member connection arrangement is very important. In this project work, the Finite element modeling of the steel beam - column connection arrangement is carried out using AutoCAD and ANSYS Workbench 16.1 software. The numerical study of strength behaviour of bolted beam-column connections was carried out. ANSYS Workbench 16.1 software was used to perform the analysis of connections. The beam and column members are chosen as ISMB 250 having width 200mm and thickness of 10 mm. The beam member has a length of 1 m and column member is of 2 m length. The connection arrangement consisted of an end plate and eight numbers of bolts as shown in Fig -1.

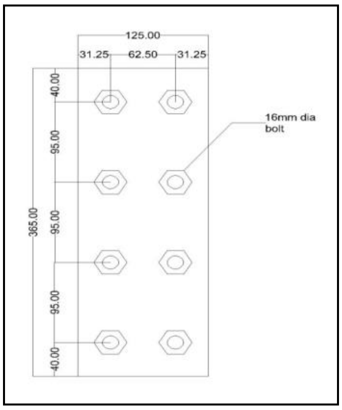


**Fig -1**: 8mm thick plate connection arrangement with equal bolt distance

8mm end plate and 16mm diameter bolts were used for the connection arrangement. In this connection arrangement the distance between the bolts were kept as constant of 95mm in vertical direction and 62.5mm in horizontal direction. Four different models were analyzed in this connection arrangement using ANSYS Workbench 16.1 software. 8mm thick plates were used as stiffeners in these models. The four different models analyzed based on this connection arrangement were explained below with detailed figures.

## 2.1 Beam Column Joint without Stiffeners (BM)

This is a simple model consisting of only an endplate and bolts in the connection arrangement. The end plate was welded to the cross section of the beam .Eight numbers of 16mm diameter bolts with length of 44mm were provided. In this arrangement no stiffener plates were added. The ANSYS model is as shown in Fig -2. 20 nodded SOLID 186 elements were used for the modelling of the elements in ANSYS 16.1 Workbench. The connections between the elements were provided by using the contact option in the ANSYS 16.1 Workbench. Bonded contacts were provided for welded connections and frictionless contact was provided between the column flange and the endplate. Friction contact was provided between the bolt hole and the bolts.

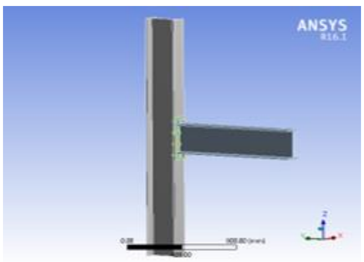


**Fig -2**: ANSYS model of Beam column joint without stiffeners

## 2.2 Beam Column Joint with Wing Plate Stiffeners at Bottom (BCJWB)

This model consists of endplate, wing plate stiffeners and bolts in the connection arrangement. The end plate was connected to the cross section of the beam as welded connection. Wing stiffener plates were provided at column member at two sides in between the flanges at the bottom flange level of the beam member at the centre of the second and third bolt. Rectangular shaped stiffener plates were provided having 225mm length and 59.05mm width and thickness of 8mm. Eight numbers of 16mm diameter bolts having a length of 44mm are provided. The ANSYS model is as shown in Fig -3. 20 nodded SOLID 186 elements were used for the modelling of the elements in ANSYS Workbench. The connections between the elements were provided by using the contact option in the ANSYS Workbench. Bonded contacts are provided for welded connections and frictionless contact was provided between the column flange and the endplate. Friction contact, with friction coefficient of 0.2 was provided between the bolt hole and the bolts. The contact between the wing stiffener plates and beam element was provided as bonded contact since it was welded connection. The contact between the stiffener plate and column element was provided bonded contact since it was welded connection.

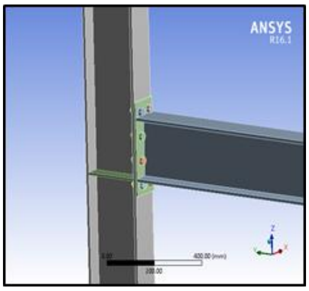


**Fig -3**: ANSYS model of beam column joint with wing plate stiffeners at bottom

## 2.3 Beam Column Joint with Side Stiffeners at First Bolts Layer (BCJS1BL)

This model consists of endplate, side plate stiffeners and bolts in the connection arrangement. The end plate was connected to the cross section of the beam as welded connection. Side stiffener plates was provided at column member with one side in contact with the leeward side of column flange and the other side bolted with the end plate attached with the other side of the column flange at the first bolt layer. Rectangular shaped side stiffener plates were provided having 274mm length and 58.4mm width and thickness of 8mm. Eight numbers of 16mm diameter bolts having a length of 44mm are provided. The ANSYS model is as shown in Fig -4. 20 nodded SOLID 186 elements were used for the modelling of the elements in ANSYS 16.1Workbench. The connections between the elements were provided by using the contact option in the ANSYS 16.1

Workbench. Bonded contacts are provided for welded connections and also for bolt to nut connections and frictionless contact were provided between the column flange and the endplate. Friction contact, with friction coefficient of 0.2 was provided between the bolt hole and the bolts. The contact between the end plate of the beam element to the column was provided as frictional contact, with friction coefficient of 0.2

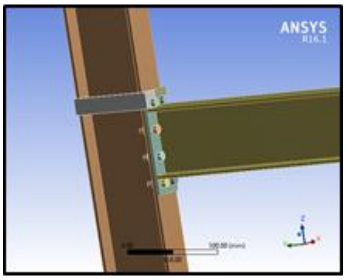


**Fig -4**: ANSYS beam column joint with side stiffeners at first bolts layer

### 2.4 Beam Column Joint with Internal Triangular Rib Stiffener at Middle of the Top Side of the Beam (BCJIMT)

This model consists of endplate, triangular rib stiffeners and bolts in the connection arrangement. The end plate was connected to the cross section of the beam as welded connection. Triangular shaped stiffener plates were provided having 59.05mm length for the perpendicular sides and 8mm width in the internal middle sides at the top of the internal sides of the beam. Rib stiffener plates were added at the two sides of the beam flange element on the two faces. Eight numbers of 16mm diameter bolts having a length of 44mm are provided. The ANSYS model is as shown in Fig -5.

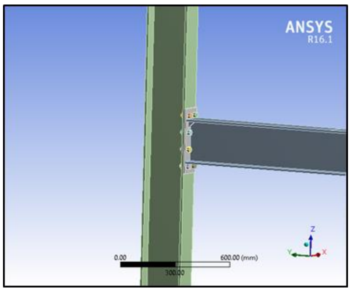


**Fig -5**: ANSYS model of beam column joint with internal triangular rib stiffener at middle of the top side of the beam

20 nodded SOLID 186 elements were used for the modelling of the elements in ANSYS 16.1 Workbench. The connections between the elements were provided by using the contact option in the ANSYS 16.1 Workbench. Bonded contacts are provided for welded connections and frictionless contact was provided between the column flange and the endplate. Frictional contact, with friction coefficient of 0.2 was provided between the bolt hole and the bolts. The contact between the stiffener plates and beam element was provided bonded contact since it was welded connection. The contact between the stiffeners plates were also provided as bonded contact since they were welded connection.

## 3. FINITE ELEMENT ANALYSIS USING ANSYS 16.1 WORKBENCH

The specimens were modelled in AutoCAD and then imported to ANSYS 16.1 Workbench. The meshing, boundary conditions and displacement were provided in the ANSYS 16.1 Workbench. The elements were meshed using the tetrahedral element. To ensure that the model acts in the same way as the experimental beam boundary conditions need to be applied at the points of symmetry, and at the existence of the supports and displacements as shown in Fig -6.The two ends of columns were provided with fixed support conditions and the free end of the beam was provided with no supports. A displacement of 50mm acting at the free end faces of the beam element was provided and corresponding load carrying capacity of the beam and moment carrying capacity of the joint was obtained.

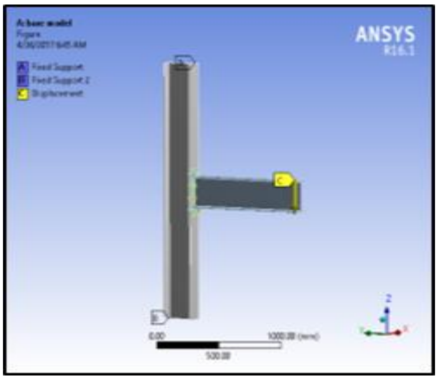


**Fig -6**: ANSYS model showing support and displacement of specimen without stiffener

The ANSYS meshed model of each specimen is as follows. The meshing was carried out using 4-nodded tetrahedral elements. The meshed model of the beam column joint without stiffener was shown in Fig -7.

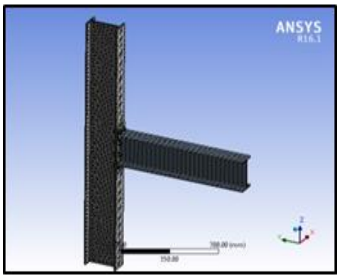


**Fig -7**: ANSYS mesh model of beam column joint without stiffeners

ANSYS mesh model of beam column joint with wing plate stiffeners at bottom and with side stiffeners at first bolts layer were shown in Fig -8 and Fig -9 respectively.

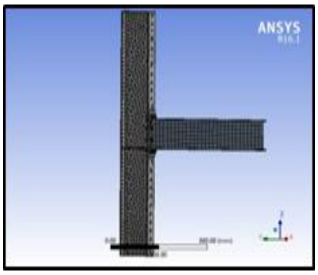


**Fig -8**: ANSYS mesh model of beam column joint with wing plate stiffeners at bottom

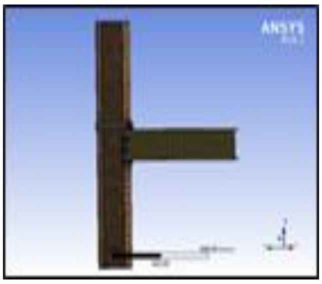

**Fig -9**: ANSYS mesh model of beam column joint with side stiffeners at first bolts layer

The beam column joint with internal triangular rib stiffener at middle of the top side of the beam was shown in Fig -10.

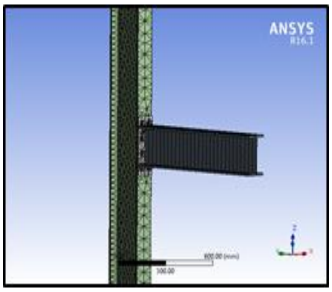


**Fig -10**: ANSYS model of beam column joint with internal triangular rib stiffener at middle of the top side of the beam

## 4. RESULTS AND DISCUSSIONS

After analysing the specimens for a displacement of 50mm acting at the free end of the beam the deformations occurred to the connection arrangement were observed. The deformations at each and every load were obtained from ANSYS 16.1 Workbench. Non-linear analysis was carried out for all specimens.

### 4.1 Beam Column Joint without Stiffeners (BM)

This specimen was analysed using ANSYS 16.1 Workbench. The connection arrangement on this specimen contained an endplate and eight numbers of bolts. A displacement of 50mm was applied at the free end of the beam element. The specimen took the maximum load of 74.07kN and the moment carrying capacity was obtained as 57.14kNm. The deformation values after the analysis is shown in Chart -1. The deformed shape of the specimen is shown in Fig -11.

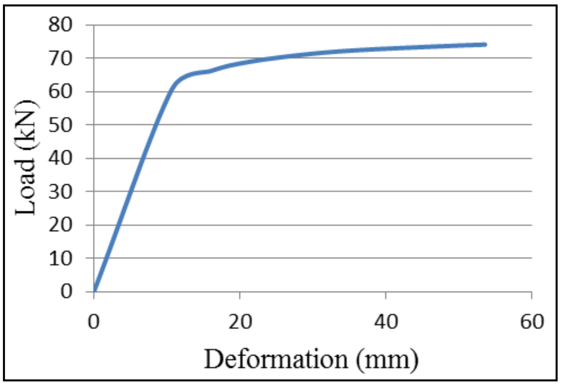


**Chart -1**: Load–deformation curve for beam column joint without stiffeners

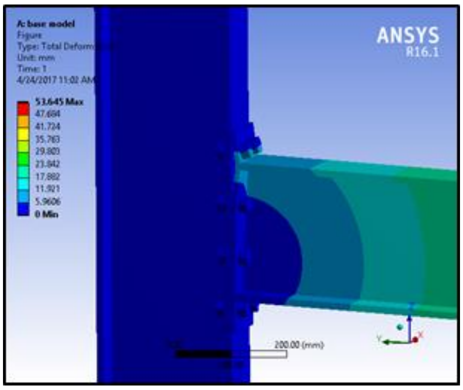


**Fig -11**: Deformation in connection arrangement of beam column joint without stiffeners

### 4.2 Beam Column Joint with Wing Plate Stiffeners at Bottom (BCJWB)

This specimen with wing stiffener plate was welded to the flanges of column members. The stiffener plate was been placed at the column web in between the flanges at bottom level of the beam member and was analysed using ANSYS 16.1Workbench. The connection arrangement of the specimen had endplate, eight numbers of bolts and two numbers of 8mm thick stiffener plates as same as in the previous model but is placed in column member. The specimen was subjected with a displacement of 50 mm acting at the free end face of the beam. The specimen had the load carrying capacity of 76.90kN and moment carrying capacity of the beam column joint as 62.93kNm. The deformation values after the analysis is shown in Chart -2. The deformed shape of the specimen is shown in Fig -12.

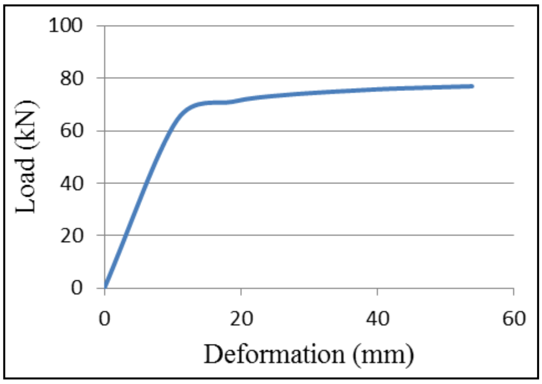


**Chart -2**: Load–deformation curve for beam column joint with wing plate stiffeners at bottom

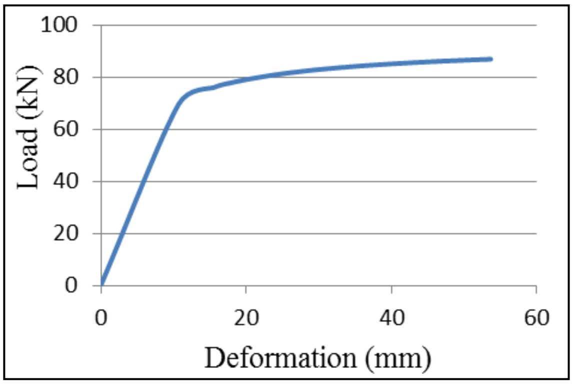


**Chart -3**: Load–deformation curve for beam column joint with side stiffeners at first bolts layer

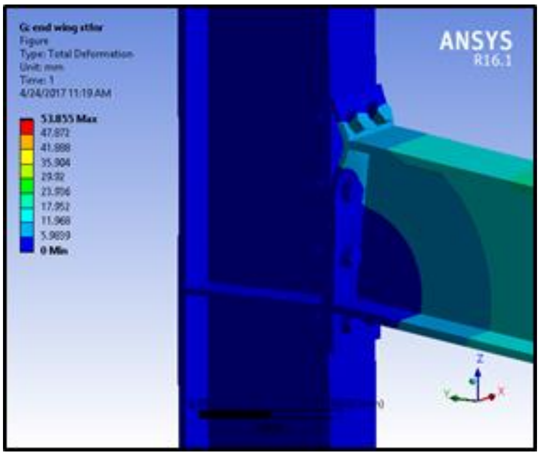


**Fig -12**: Deformation in connection arrangement for beam column joint with wing plate stiffeners at bottom

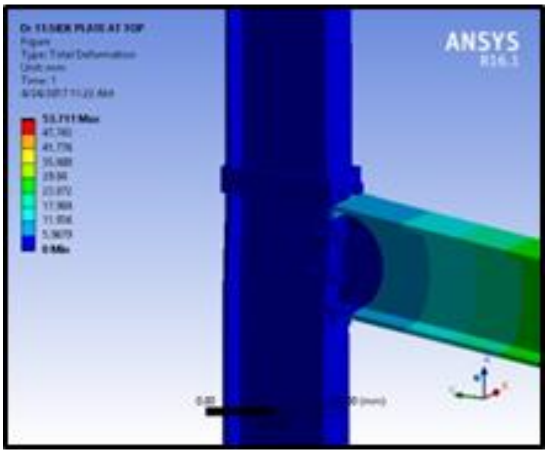


**Fig -13**: Deformation in connection arrangement for beam column joint with side stiffeners at first bolt layer

### 4.3 Beam Column Joint with Side Stiffeners at First Bolts Layer (BCJS1BL)

This model consists of endplate, side plate stiffeners and bolts in the connection arrangement. The end plate was connected to the cross section of the beam as welded connection. Side stiffener plates was provided at column member with one side in contact with the leeward side of column flange and the other side bolted with the end plate attached with the other side of the column flange at the first bolt layer. The model was analysed using ANSYS 16.1 Workbench. The connection arrangement of the specimen contains endplate, eight numbers of bolts and two numbers of 8mm thick stiffener plates as same as in the previous model but is placed in column member. The specimen was subjected with a displacement of 50mm acting at the free end face of the beam. The specimen had the load carrying capacity of 86.88kN and moment carrying capacity of the beam column joint as 70.46kNm. The deformation values after the analysis are as shown in Chart -3. The deformed shape of the specimen is as shown in Fig -13.

### 4.4 Beam Column Joint with Internal Triangular Rib Stiffener at Middle of the Top Side of the Beam (BCJIMT)

This model consists of endplate, triangular rib stiffeners and bolts in the connection arrangement. The end plate was connected to the cross section of the beam as welded connection. Triangular shaped rib stiffener plates were provided in the internal middle sides at the top of the internal sides of the flanges of beam. They were added at the two either sides of the beam flange element on the two faces. The specimen was subjected with a displacement of 50mm acting at the free end face of the beam. The specimen had the load carrying capacity of 82.87kN and moment carrying capacity of the beam column joint as 62.82kNm. The deformation values after the analysis are as shown in Chart -4. The deformed shape of the specimen is as shown in Fig -14.

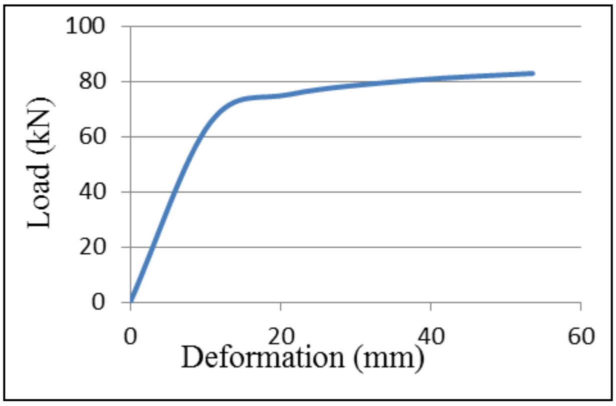


**Chart -4**: Load–deformation curve for beam column joint with internal triangular rib stiffener at middle of the top side of the beam

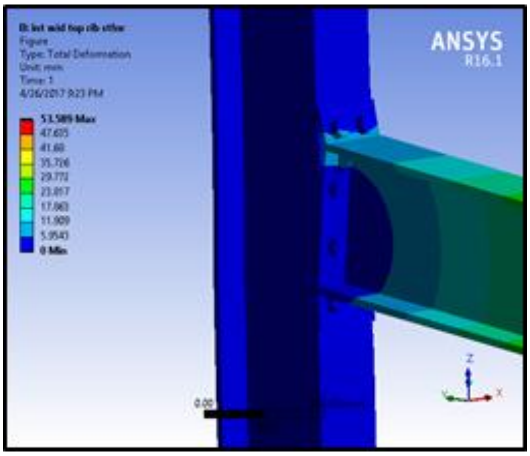


**Fig -14**: Deformation in connection arrangement for beam column joint with internal triangular rib stiffener at middle of the top side of the beam

Failures generally occur first on the connections rather than on the steel members in steel structures. And if it is not so, then it can be concluded that the structure was not designed properly. In this analysis, the expected result was also the failure of connections, thereby obtaining the load carrying capacity and moment carrying capacity of the connection arrangement. The load carrying capacity and moment carrying capacity of each specimen are shown in Table -1 and Chart -5.

**Table -1:** Load carrying capacity and moment carrying capacity of each specimen

| No. | Beam column joint specimen | Load carrying capacity(kN) | Moment carrying capacity(kNm) |
|---|---|---|---|
| 1. | Without stiffener plates | 74.07 | 57.14 |
| 2. | With wing stiffener at the bottom of column flange | 76.90 | 62.93 |
| 3. | With side stiffener at the top bolt layer | 86.88 | 70.46 |
| 4. | With internal triangular rib stiffeners at middle of the top side of the beam | 82.87 | 62.82 |

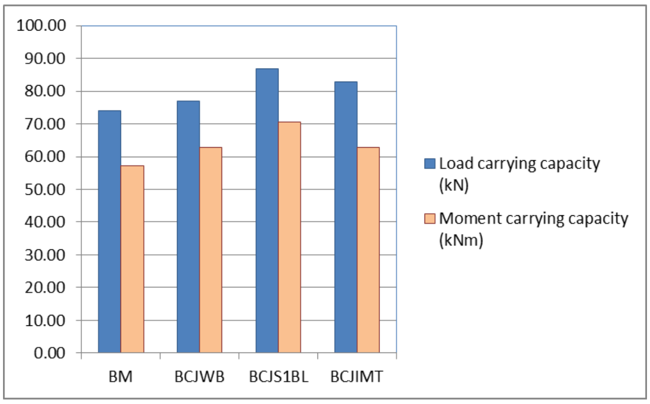


**Chart -5**: Comparison of load carrying capacity and moment carrying capacity for specimens

## 5. CONCLUSIONS

The finite element analysis of steel beam-column connection arrangement was carried out for studying the strength behaviour of steel beam column joint. Specimens were categorized to four different models with equal bolt distance. Beam column joint without stiffener plates, wing stiffener plate provided at the bottom level of the beam in the flange of column, side stiffener plate provided with side stiffeners at first bolts layer and beam column joint with internal triangular rib stiffener at middle of the top side of internal side of the beam. The effect of the type and position of the stiffener plate in the connection arrangement were analysed. The load carrying capacity of the specimen increases with the addition of stiffener plate. The specimen having side stiffener plate at the top bolt layer connecting the column flanges and also connecting the end plate welded with beam carried more load and had the highest moment carrying capacity compared to the other models. Thus column stiffened model carries highest load amongst the models with equal bolt distance. So it can be concluded that proper placing and effective shape of the stiffener plates along with proper bolt distance increases the strength of the connections in steel structures.

## REFERENCES

[1] David Hutton, Fundamentals of Finite Element Analysis, Vol.1 McGraw-Hill, NewYork, 2004.

[2] Evgeny Barkanov, Introduction to finite element method, Institute of materials and structures, Riga University, Riga, 2001.

[3] E. Brunesi, R . Nascimbene and G . A . Rassati, "Response of partially-restrained bolted beam-to-column connections under cyclic loads", Journal of Constructional Steel Research 97, June 2014, pp 24–38, doi:10.1016/j.jcsr.2014.01.014.

[4] Fattouh M.F. Shaker and Waseem M. Abd Elrahman, "Analytical Behavior of Steel Pre-tensioned Bolted Connections with Flushed and Extended End Plates under Bending", World Applied Sciences Journal 30 (6) 2014, pp 673-684, doi: 10.5829/idosi.wasj.2014.30.06.14091.

[5] Gary Prinz, Alain Nussbaumer, Luis Borges and Shyam Khadka , "Experimental testing and simulation of bolted beam-column connections having thick extended endplates and multiple bolts per row, Engineering Structures 59, 2014, pp 434–447.

[6] Hiroshi Tagawa and Yudu Liu ,"Analytical Stiffening of bolted end-plate connections with steel member assemblies", Journal of Constructional Steel Research ,103,2014 pp 190–199.

[7] IS : 800 - 2007, "Indian Standard Code of Practice for General Construction in Steel", Bureau of Indian Standards, New Delhi.

[8] Sanoop Poulose and Dr. Sabeena M , "Analytical Study of Strength and Behaviour of Bolted Steel-beam Column Endplate Connection Arrangements", International Conference On New Frontiers In Science Engineering & Technology(ICNFSET ) , 2015 Paper ID- CE09 ,pp 22-27.

[9] Yongjiu Shi , Gang Shi and Yuanqing Wang , "Experimental and theoretical analysis of the moment–rotation behaviour of stiffened extended end-plate connections", Journal of Constructional Steel Research 63, 2007, pp 1279–1293.

[10] Y.Q. Wang, L. Zong and Y. J. Shi. "Bending behavior and design model of bolted flange-plate connection", Journal of Constructional Steel Research 84, 2013, pp 1–16.