3 D Finite Element Analysis of Partially Restrained Beam to Column Connections in Steel Frames

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Abstract - The connection between beam and column is repeatedly used in steel structures. The response of steel frames is influenced by the mechanical properties of the joints such as strength, stiffness and rotation capacity etc. In practice the joints are usually consider as either rigid or pinned but partially restrained connections should be considered to obtain more realistic reliable and economical results. Partially restrained connection can resist some of internal bending moment in steel beam according to connection stiffness and then beam can be redesigned with saving in its weight. The stiffness of partially restrained connection is affected by many parameters as; type of connection end plate (flushed or extended), plate thickness, bolt diameter and stiffening of column panel zone. The analytical investigation utilizes finite element modeling techniques using ANSYS program. The functions of ANSYS are used to simulate the interface between each of end plate, column and bolts accurately. The results of the finite element models were verified. The main purpose of this study is to find the effect of all predominant parameters on the stiffness of partially restrained connections according to the basis of the moment-rotation curves.

Keywords: *Analysis 14, Catia, Meshing, PR Connections, Validation*

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I. INTRODUCTION

Connections form an important part of any structure and are designed more conservatively than members. This is because, connections are more complex than members to analyze, and the discrepancy between analysis and actual behaviour is large. Further, in case of overloading, we prefer the failure confined to an individual member rather than in connections, which could affect many members. Connections account for more than half the cost of structural steelwork and so their design and detailing are of primary importance for the economy of the structure[8]. Connections can be classified by their strength as well as their ductility, where ductility is a description of the rotation capacity. The strength classification of connection is based on the relative moment resistance of the connection compared to the moment resistance of the beam. Both strength and ductility are essential for the connection. As the structural connection transmit forces which results in linear and rotational movement. The linear movements at the joints are generally small but the rotational movement depends on the stiffness of the connection.

In most steel frame designs the beam to column connections are assumed to be Fully restrained(FR) or pinned. Fully restrained(FR) joints, where no relative rotation occurs between the connected members, transfer not only substantial bending moments, but also shear and axial forces. On the other extreme, pinned joints are characterized by almost free rotation movement between the connected elements that prevent the transmission of bending moments. Despite these facts, the great majority of joints doesn't exhibit such idealized behaviour. However, the connection behaviour significantly affects the displacements and internal force distribution of framed structures. A substantial effort has been made in recent years to characterize the behaviour of partially restrained(PR) connections. Most design codes included methods and formulas to determine both their resistance and stiffness. The codal specifications provide three basic types of framings related to the end connections of beams to columns. These types includes :

1)Fully Restrained Connections(Rigid Connections)
2) Simple connections or pinned connections
3) Partially restrained connections (Semi Rigid Connections)

II. MOMENT ROTATION CURVES

2.1 Moment-Rotation Behaviour

The conventional definition of joint rotation(Φ_j) is done by the change of the included angle between the axes of the beam and column that joint connects under load. So, the joint rotation Φ_j of the beam column end plate connection is defined as the relative rotation of the centre lines of the beam top and the lower flange at the beam end, and it usually includes two parts : Φ_{ep}, rotation caused by the relative deformation between end plate and column flange and Φ_S rotation caused by shearing deformation of the panel zone of the column.

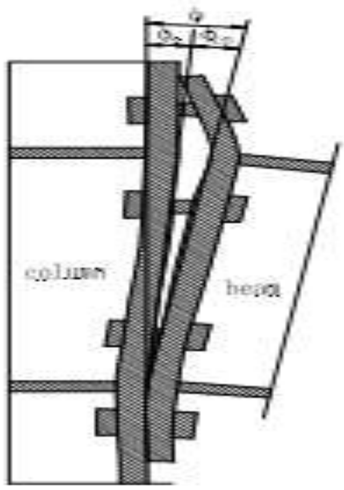

Fig.1 Rotational Deformation of Connection

2.2 M- Φ Curve

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Beam to column joint behaviour may be represented by the moment-rotation curve. This curves describe the relationship between the bending moment M_j applied to a joint and corresponding rotation Φ_j between the connected members. The bending moment acting on the connection corresponding to the applied load P multiplied by the distance (L)between point of application of load and the face of end plate is given by $M_j = P \times L$

The rotation deformation of joint Φ_j is the sum of connection rotation deformation (Φ_{ep}) and the shear deformation of the column web panel zone Φ_s.

$$\mathbf{\Phi_j = \Phi_{ep} + \Phi_s}$$

III. BOLTED END PLATE CONNECTIONS

End plate connections have become more popular in steel frames due to their economy, simplicity of fabrication and good structural performance. End plate connections can be classified into three types – 1) header connection 2) flush end plate connection 3) extended end plate connection.

If the length of the end plate is less than the depth of the beam, it is called header end plate. If it is approximately the same height as the beam depth, it is called flush end plate. And if its height is significantly larger than the beam height using space above and below the beam for additional rows of bolts, it is called extended end plate connection. The header and flush end plate are less used than the extended end plate connection as their strength and stiffness are lower. In this connectiov set up, a plate of defined size is fillet welded to the end of the beam in shop and then bolted to column flange in field. The behaviour of end plate connections significantly influence the internal forces and overall deformations of the structures. These connections are used to transfer moment, axial force and shear force from one member to another. Use of extended end plate connections can achieve to transfer about 80 % of the yield moment capacity of the beam. In these connections the bending moment, axial force and shear are transferred by tension and compression or shear through the flange welds and by shear through the web welds to the end plate. Then they are transfer from end plates to the bolts by bending and shear. Finally they are transferred to the supporting member by bolt shear and tension.

IV. METHODOLOGY

Due to complexity in behaviour and large number of variable associated with connection, experimental evidence is not be able to thoroughly examine aspects of the problem. Beside this cost involved in such experiments is high. An alternative numerical approach is a finite element method. So,

- Numerical approach i.e. finite element method will be used.
- Selected connections will be modeled as 3 D solid finite element.
- Catia software will be used for modeling.
- Ansys software will be used for analysis of FE models.
- Modeling and Validation of end plate connection will be carried out.
- Effect of no. of bolts and thickness of end plate on PR connection will be analyzed.
- Single wed and double web connections will be analyzed.
- Top and seat angle connections with or without DWA will be analyzed.

V. SYSTEM DEVELOPMENT

Geometry of a bolted flush end plate steel beam to column connection is very complex compared to geometry of individual members. These connections are consist of number of components such as horizontal beam, vertical column, thin end plate, welds, nut and bolts oriented in 3 dimensions in space. Hence, modeling of connections is difficult so, Catia software is used for modeling. Individual components of connections are modelled separately and then assembled. Thus, A bolted flush end plate, steel beam to column connection a 3 D model is created using modeling software Catia. Then to analyze the 3-D FE Model Ansys 14 Workbench environment is used.

VI. MODELLING OF FLUSH END PLATECONNECTION

Part Design of horizontal Beam Tools Required: CATIA Package Commands used in CATIA

- Profile (Lines, Rectangle, Circle, Point, Dotted Line)
- Operation (Quick Trim, Corner, Mirror)
- Constrain (Constrain, Constrain Define)
- View (Pan, Rotate, Zoom In-Out, Fit all in, Shading with edges, Normal view)
- Measure (Measure, Measure between)
- Tools (Sketch analysis, Sketch solving status)
- Sketcher based feature (Pad, Pocket, Hole, Shaft, Stiffener, Groove)
- Sketcher
- Sketch tool
- Exit Workbench

VII. PROCEDURE

Step1. : - Open the CATIA package.
Step2. : - Create the new part file and save it in the directory.
Step3. : - Set the dimensional units and limits for the display screen using View, Measure &Dimension command.
Step4. : - Select plane according to convince. Select ZY plane.
Step5. : - Draw the I section of required dimension in the selected plane by using the profile tool with help of line command.
Step6. : - Constrained the I section by using constrained
Step7. : - Exit workbench by using exit workbench command.

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Step8. : - In part designed select the I section and use the command pad for giving the thickness and length to the I section.

Step9. : - save the I section as Horizontal Beam and exit from the Part Design.

In this way horizontal beam is created as shown in fig.2.

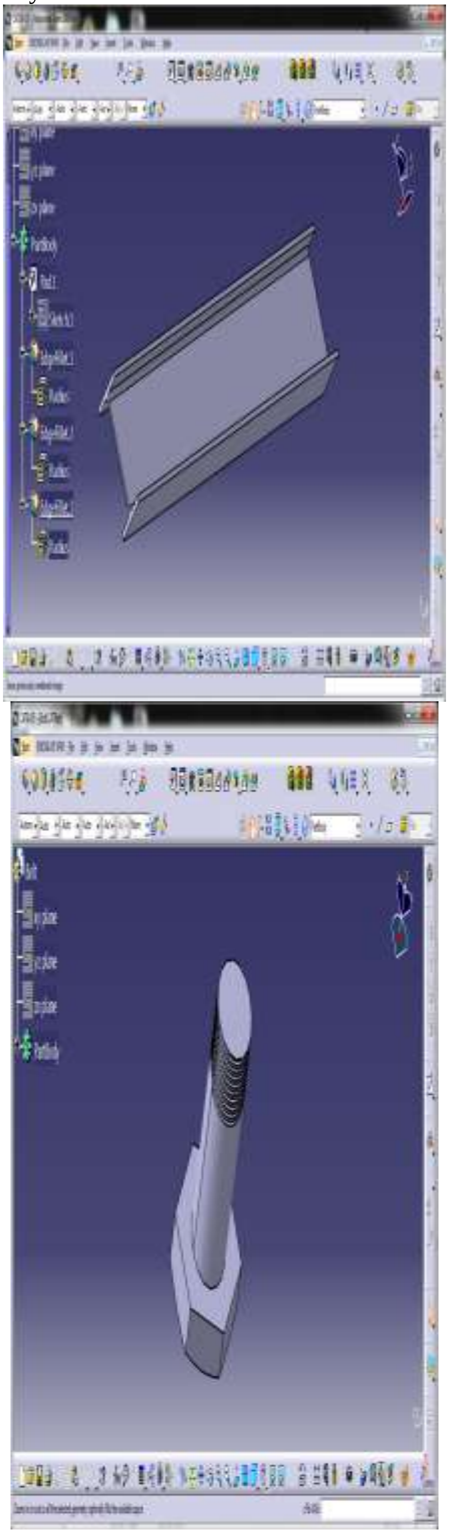


Fig 2 Modelling of Beam and Bolt

Similaraly, others Parts developed in Catia.

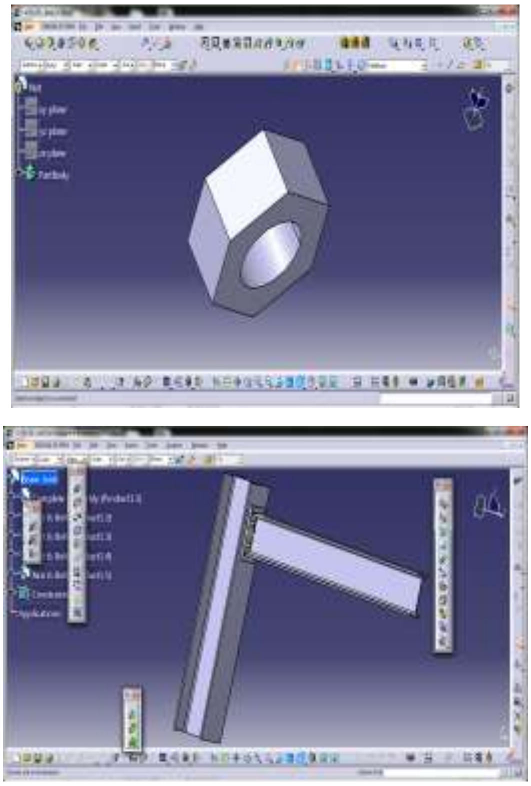


Fig 3 Modelling of Nut and Assembly

FEA of Flush End Plate Connection

Numerical models based on the finite element method, can be used to determine the ,mechanical behaviour of joints. The steel end plate connections can be studied using FEM for the following reasons:

1) such models are in expensive and robust;
2) they allow the understanding of local effects which are difficult to measure accurately physically; and
3) they can be used to generate extensive parametric studies

A full 3 Dimensional finite element model of steel beam to column, bolted flush end plate connections created in Catia is imported into Ansys Workbench environment in iges format to determine behaviour of the connection.

Material Properties:

Density- 7.85 e -06 kg/m^3

Yield Strength- 250 MPa(Compressive), 250 MPa(Tensile)

Young's Modulus – 2 e 05

Shear Modulus- 7692 MPa

Poisson's Ratio-0.3

Ultimate Stregth-0 (Compressive),460 MPa (Tensile)

Bulk Modulus- 1.67 e 05

Boundary Conditions

The applied boundary conditions are

1) The web of both column and beam and also the upper and bottom face of the column are prevented with any

movement along x - axis i.e. it has the value of degree of freedom along the x-axis or the horizontal plane is zero.

2) The elastic support with the stiffness force of 250 N/mm^3 is also provided on the upper and bottom face of the column which restricts the movement of the column along the y axis as well as along the z-axis.

3) The bottom face of end plate is provided with zero degree of freedom along the y axis.

VIII. FEA OF BOLTED FLUSH END CONNECTION
IX.

All the dimensions shown below are referred from reference no. 11 The other additional sectional dimensions are referred from steels tables

Column- ISMB 250 - (250 * 250 * 1500)

Beam-ISMB 250 - (250 * 125 * 1500)

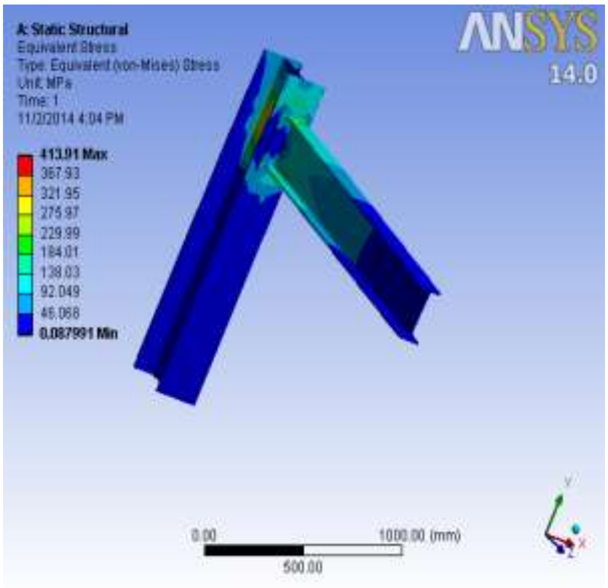
End Plate-(W * Th * L)-(160 * 20 * 320)

Sr. No.	Test Load(KN)	Von Mises Stresses (Reference No. 11)* MPa	Von Mises Stresses (Reference No. 11)**MPa	Von Misses Stresses In Present Model (MPa)	% Difference between Reference and Validation Model
1	10	312.68	350	388.38	10.97
2	12	–	–	413.91	–
3	21.5	552.56	598	640.41	7.09
4	29	759.45	799.98	889.91	11.37

Joint configuration is consist of rectangular end plate welded by 3 mm fillet weld to beam cross section, further fixed to the column flange by the two rows of bolts of diameter 16 mm(Hexagonal bolts and Nuts).

Loading System-

Incremental point load on the edge of beam is applied and von misses stresses are calculated shown in fig.4.2 and 4.3.



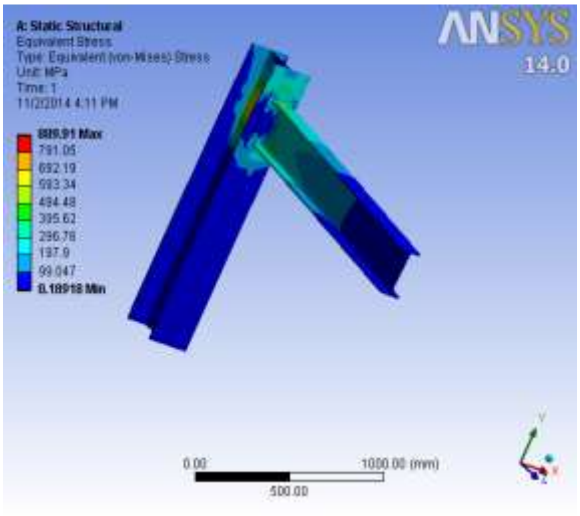


Fig. 4 Equivalent Stresses at 12000 N and 29000 N Loading

X. RESULTS

The Von-Mises stress developed in the flange of the beam is validated with the reference model available in the literature. It is observed that flange stresses developed in validation model is found to be little higher as compared to reference model.

The model of flush end plate connection of steel beam to column is analyzed by FEM in present work using Ansys. As the FEM is an approximate method results will not exactly matched with the reference. Since the difference is in the engineering accuracy the results of present model are validated.

* – Results for model by Kuldeep Kaushik

**– Model Referred by Kuldeep Kaushik

REFERENCES

[1] Martin Steenhuis , Nol Gresnigt, Klaus Weynand, ‘Pre Design of Partially restrained(PR) Joints In Steel Frames’,*Second State of the Art Workshop on Partially restrained(PR) Behaviour of Civil Engineering Structural Connections,ed by Word,* COST CI,Prague, Czech Republic , 1994, pp 131-140.

[2] Bahaari MR, Sherbourne AN, ‘ Behaviour of eight bolt large capacity end plate connections’ *Computers and Structures*,2000, pp 315-325

[3] A.M. Citipitioglu, R.M. Haj-Ali , D.W. White, ‘ Refined 3D finite element modeling of partially restrained connections including slip’ *Journal of Constructional Steel Research* 58 ,2002, pp 995–1002.

[4] Swanson J.A., Kokan G.S., Leon R.T. , ‘Advance finite element modeling of bolted T- stub connection components’, *Journal of constructional steel research*,2002,pp. 1015-101

[5] Pirmoz A., Danesh F., ‘The seat angle role on moment-rotation response of bolted angle connections’, *Electronic journal of structural engineering*,2009,pp.73-79

[6] L.R.O.de Lima , S.A.L. de ANDRADE, P.C.G.da S. Vellasco, L.S. da Silva,‘Experimental and Mechanical Model for Predicting the Behaviour of Minor Axis Beam to Column Partially restrained(PR) Joints’, *International Journal of Mechanical Sciences(44)*, pp.-1047-1065,2002.

[7] M.E.Kartal, H.B.Basaga , A.Bayraktar, M.Muvafik,‘Effects of Partially restrained(PR) Connection on Structural Responses’, *Electronic Journal of Structural Engineering*,(10),2010, pg. no.-22-35.

[8] Diaz C., Victoria M., Marti P., Querin O.M.,‘FE Model of beam to column extended end plate joints’, *Journal of constructional steel research*,2011, pp. 1578-1590

[9] Beatriz Gil , Rufino Goni and Eduarbo Bayo,‘*Proposal of a Three Dimensional Partially restrained(PR) Composite Joint:Test and Finite Models*’,SDSS’Rio 2010 Stability and Ductility of Steel Structures, Brazil, September 8-10,2010,pp 215-222.

[10] Mohamed Eldemerdash ‘Finite Element Analysis of Large Capacity Endplate Steel Connections’ Journal of Computer Science 8 (4): 482-493, 2012 ISSN 1549-3636 © 2012 Science Publications

[11] Kuldeep Kaushika, Avadesh Kumar Sharma and Rishi Kumar, **‘**Modeling and FE analysis of column to beam end-plate bolted connection’ Growing Science Ltd. All rights reserved,2013.11.001

[12] Syahril Taufik, ‘Numerical Modelling of Partially restrained(FR) Connection with High Strength Steel’, *Study of Civil Engineering and Architecture (SCEA)* Volume 2 Issue 2, June 2013

[13] S. Taufik and S. Baharom **‘**Finite Element Model for the Behaviour of Partially Restrained High StrengthWeb Angle Connections’, *Research Journal of Applied Sciences, Engineering and Technology* , 950-960, 2013,ISSN: 2040-7459, Maxwell Scientific Organization, 2013 ,June 30, 2013

[14] Kuldeep Kaushik, Avadesh K. Sharma, Rishi Kumar**, ‘** A Review on Finite Element Analysis of Beam to Column Endplate Bolted Connection’, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 8, Issue 1 (Jul. - Aug. 2013), PP 97-103

[15] Sebastian-Lucian Buzuleac, **‘**Finite Element Analysis Of Beam-Column Bolted End-Plate Connections In Steel Frames’, *Buletinul Institutului Politehnic Din Iaşi publications*, September 25, 2013

[16] Cinitha A. Umesha, P.K.Nagesh R. Iyer,‘Performance Levels and Acceptance Criteria for Joints with Rigid, semirigid and Flexible Connections’, *International Journal of Civil and Structural Engineering*, volume-3,No3,2013,ISSN 0976-4399, pp.-526-535

[17] S.Loganathan, C.G.Sivakumar**,** ‘Experimental Study on Steel Partially restrained(FR) Beam-Column Joints under Quasi Static Loading’ ,*International Journal of Engineering Science* Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726 ,Volume 2 Issue 10 ǁ October 2013 ǁ PP.39-49

[18] Prof.Bogatinoski Z., Arsova-Milosevska G.2, Trajanoska B, ‘Theoretical And Experimental Researches Of Rigid And Partially restrained(FR) Beam-Column Connections’,*Machines Technologies, MaterialS* ISSUE 12/2013, ISSN 1313-0226.

[19] Fattouh M.F. Shaker and Waseem M. Abd Elrahman, ‘ Analytical Behaviour of Steel Pre- Tensioned Bolted Connections with Flushed and Extended End Plates under Bending’ World applied Sciences Journal,2014, 6, Pg. no.-1818-4952

[20] Rafaat E.S. Ismail, A ShamelFahmy et. Al., ‘ Behaviour of end plate steel connections stiffened with stiffeners of different geometrical dimensions’ *Global advanced research journal of engineering, technology and innovation*, 2014, pp.55-69

[21] P.Prabha, V.Marimuthu, M.Saravanan, M.Surendran and G.S.Palani, ‘Effect of Air Gap on the Behaviour of Double Web Angle Connections’, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE*) e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 30-35

[22] Finite elements in Analysis using ANSYS 11 ,PHI, By Paleti Shrinivas, Krishna Chaitanya Sambana, Rajesh Kumar Datti

[23] Practical finite element analysis ,finite to infinite publications,pune,By Nitin Gokhale,Sanjay Deshpande

[24] Design of Steel Structures by N.Subramanian, Oxford Higher Education.

[25] Fundamental of Structural Steel Design, M L Gambhir, McGraw Hill International Edition.