Proceedings of 8th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2020 Month: June Volume: 8

Effects of Semi Rigid Connections in Response of the Steel Frame Structure

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Abstract

In steel structures,the connections in the joints are idealized as either rigid or pinned. However in reality the connections display characteristics over a wide range of spectrum between these two idealisations. Rigid connections have some degree of flexibility, whereas pinned connections have some stiffness. Connection stiffness has a considerable effect on forces developed in the frame members as well as the lateral displacements of joints. This paper aims in determining the effects of the semi-rigid behaviour of the beam-column connection in the response of the frames. The semi-rigid connections are specified by their moment-rotation relationship. Linear moment-rotation relationship based on secant stiffness corresponding to 0.01 rad rotation has been considered in this paper. Based on this moment rotation relationship,the moment resisting frame is modelled considering rigid connections as well as semi-rigid connections. Response parameters like lateral dislacement and frame bending moments are compared for both the rigid as well as different types of semi-rigid connections. The semi-rigidty of the connection was found to increase lateral displacements as well as mid-span moment and decreases the end moment as compared to rigid connections.

Keywords

Semi-rigid, Connections, Effective stiffness, Moment-rotation, SAP2000

1. Introduction

Steel frames usually consists of beams and columns assembled together by means of connections. In conventional analysis and design of steel and composite frames, beam-column connections are assumed to be either as “pinned” or as fully “rigid”. The behavior of connections which falls between ideal pinned and rigid conditions has been classified as semi rigid steel connections. Although the pinned or fixed assumption simplifies the analysis and design, real joint behavior exhibits characteristics lying between these two extremes. The degree of rigidity depends on so many factors like connection material, connection parameters and type of moment resisting connection etc. Connections provide flexibility for rigid connections and provide rigidity in case of ideal pinned end conditions. The accurate estimation of connection restraint is necessary as overestimation results in higher lateral dispalcements and underestimation results in undermining the forces developed in the structure. Thus, it is more realistic to consider all connections as semi rigid [1].

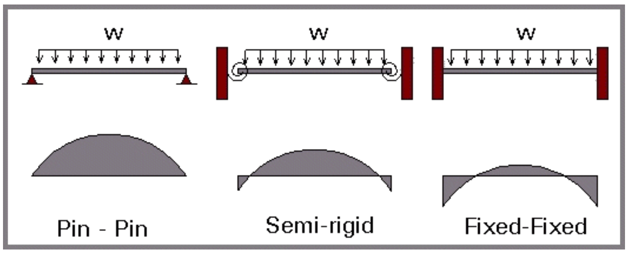

Figure 1: Effects of connection restraint on frame moments [2].

The type of connections used in the structure depends on the type of frame used. Moment frames refer to frames which have rigid or moment connections between structural elements. These types of frames are used when lateral bracing is unfeasible or undesirable. Moment frames are generally more flexible under lateral loads. In contrast to moment frames, braced frames have some type of bracing between structural elements. These types of frames only require pinned connections as the bracing elements provide the necessary lateral stability. In the design process, braced frames, which usually have pinned connections, are designed with regard to strength requirements, and unbraced frames, which rely on moment connections, are designed with regard to stability and deformation limits. Eight types of connections with different moment-rotation are considered in this study[3].

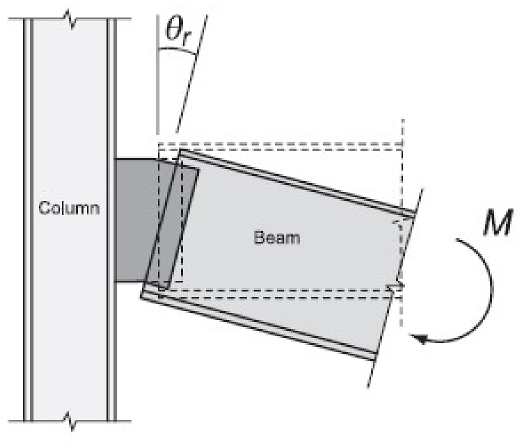

Figure 2: Rotational deformation of a connection [3].

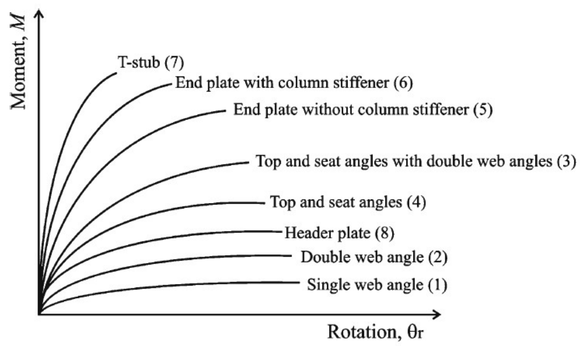

Figure 3: Moment-Rotation behaviour of different types of connections [3].

The concept of semi-rigid connections has been around for several years. Design codes like IS 800:2007, AISC 360-10, Eurocode 3 etc all have incorporated the introduction to semi-rigid connections in steel structures. Annexure-F of IS 800:2007 has been especially constructed for introduction to the concepts of semi-rigid connections. A lot of researches has been conducted in the concept of semi-rigid connections. Frye M.J and Morris.G.A (1975) outlined an method for expressing the moment rotation characteristics of all connections in non-dimensional form [4, 5, 6, 7].

Leigh Manson(2005) in his thesis provided basic insights to moment distribution method for analysis of frames with semi rigid connections and SAP2000 modelling of semi-rigid connections considering partial fixity assignments. Kishi and Chen(1990) studied the moment-rotation relationships of steel beam-column connections with angles. M.A Bhatti and J.D Hingtgen(1995) studied the effects of connection parameters on the serviceability limit state of unbraced steel frames [8].

Sanjay Kumar Mull (1999) developed a computer programme in FORTRAN for 2-D frame analysis in which a special consideration of joint or connection behavior [9].

2. Research objectives

The research objectives are:
1. To investigate the effects of semi-rigid connections on overall frame response.
2. To conduct a comparative study on behaviour of different types of semi-rigid connections.

3. Modelling of semi-rigid connections

Several mathematical models have been proposed so as to predict the moment rotation relationship of the connections ranging from simpler linear models to complex exponential models. In this study, a linear connection model considering effective stiffness of the connections is adopted for the study.

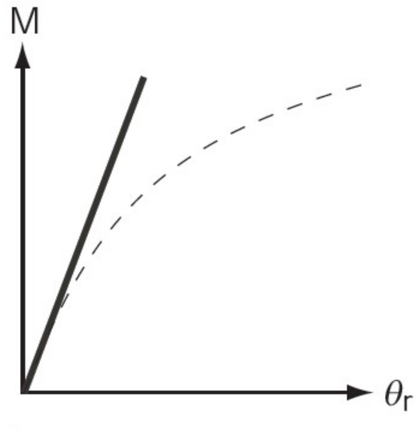

Figure 4: Linear moment-rotation model [3].

The moment-rotation parameters are generated using Frye-Morris polynomial equations. In Frye-morris model, for different connection size parameters, the

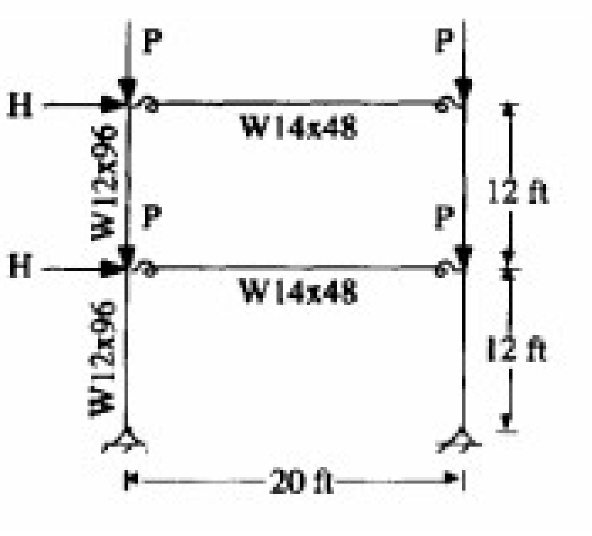

Figure 5: Flexframe model [8].

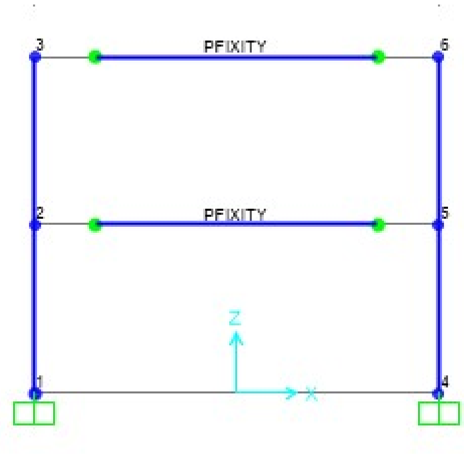

Figure 6: SAP2000 partial fixity assignment model.

appropriate non-dimensional functions are used to generate the force-deformation characteristics for the various connections. Frye-Morris have derived the following polynomial model for the moment curvature relationship of semi-rigid connections:

$$M = C1(K1) + C2(K2)^3 + C3(K3)^5$$

where M = moment at the joint, in kN m
K = standardization parameter which depend on the connection type and geometry.
Cl, C2, C3 = curve fitting constants.

4. Methodology

A Finite element based software SAP2000 has been used for the analysis of semi rigid connections in steel structure. Parial fixity equivalent to effective connection stiffness was assigned to the beam-column joints so as to incorporate the effects of semi-rigid connections. A validation study was conducted between SAP2000 partial fixity model and Flexframe software model which was especially written for study of behavior semi-rigid connections in steel structure. The connection stiffness of 786,732 k-in was considered in this study.

Table 1: Absolute maximum bending moments (kip-in) [8].

	Rigid		Semi-Rigid	
	FlexFrame	SAP2000	Flex Frame	SAP200
1	1450	1456	1634	1657
2	711	737	902	933
3	1443	1437	1739	1753
4	1437	1443	1731	1754
5	711	705	902	903
6	711	737	902	933

Table 1 shows the comparison of frame bending moments considering semi rigid connections from the Bhatti and Hingtgen study with that of SAP2000 model considered in this study. Table 2 shows comparison between the lateral displacement values.The results obtained are in close proximity and illustrates the significance of partial fixity assignment in SAP2000 to model linear moment-rotation characteristics of semi-rigid beam column connections. Moreover, L.Manson has also backed the use of partial fixity assignments in SAP2000 to represent semi-rigid connection in his study.

Table 2: Joints lateral displacements(mm)[8].

	Rigid		Semi-Rigid	
Jt	FlexFrame	SAP2000	Flex Frame	SAP200
3	1.011	1.06	1.477	1.55
5	1.509	1.59	2.292	2.41

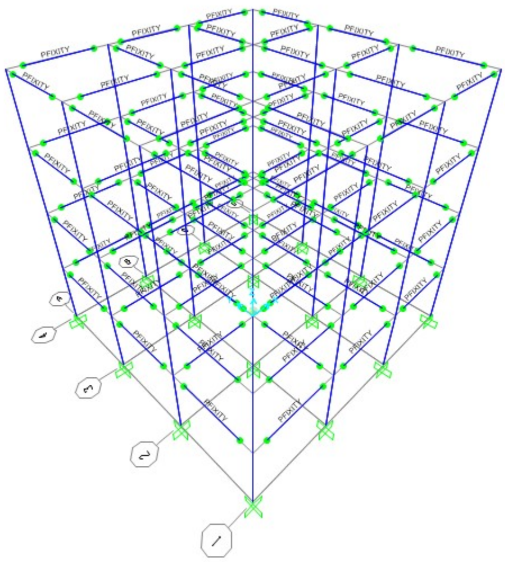

Figure 7: 3d model of the structure in SAP2000.

Table 3: Structural model parameters

Building Description	
No of Storey	4
No of grids in both direction	4
Storey Height	3m
Beam Span in both direction	4m
General Loading	
Wall Load	6 kN/m
Live Load	3 kN/m2
Self Wt of Slab	3 kN/m2
Floor Finish	1.5 kN/m2
Section Properties	
Beam	ISMB 250
Columns	H200 (Built up)
Material Properties	
Type	Steel
Poissons Ratio	0.3
Modulus of Elasticity of steel	2x105 kN/m2
Unit Wt of Steel	7850 kg/m3
Unit wt of Brick	19.2kN/m3
Grade of Steel	Fe250
Earthquake Loading	
Zone Factor	0.36
Soil Type	II
Importance Factor	1
Response Reduction Factor	5

5. Results and discussions

Linear Static Analysis was performed for a 4 story model. All together nine SAP2000 models were created, out of which 8 models were for different types of semi rigid connections whereas one model was created for rigid connection.

Table 4: Bending Moments for different types of connections(kN-m).

Connection Type	k(kNm/rad	(+) M	(-) M
Rigid		17.63	-31.47
SWAC	700	45.48	-4.24
DWAC	2500	39.15	-9.95
TSAC	1800	41.23	-8.23
TSAC+DWAC	2900	36.22	-12.88
EPC	5200	34.82	-14.28
EP+stiffners	7200	31.16	-17.94
T-Stub	9100	35.81	-13.29
HPC	2250	29.40	-19.70

Results for secant stiffness corresponding to the rotation of 0.01 rad is presented in the table. The positive and negative moment for a beam resulting in the extreme values in the 3D model has been presented. From the table above, it is clearly evident that semi-rigidity in frame connections redistribute the positive and negative moments depending upon the connection stiffness. As the connection stiffness increases, the value of positive moment decreases whereas the value of negative moment increases.

Table 5: Joint lateral displacements for different types of connections(mm).

Connection	k(kNm/rad)	Ux (mm)	Uy (mm)
Rigid		2.24	4.40
SWAC	700	15.01	17.52
DWAC	2500	7.84	11.17
TSAC	1800	9.63	12.50
TSAC+DWAC	2900	6.16	9.04
EPC	5200	5.57	8.30
EP + Stiffners	7200	4.40	6.89
T-Stub	9100	8.36	11.63
HPC	2250	3.97	6.39

6. Conclusion

Linear static analysis of a framed steel structure was performed considering linear model of moment-rotation relationship to account for the

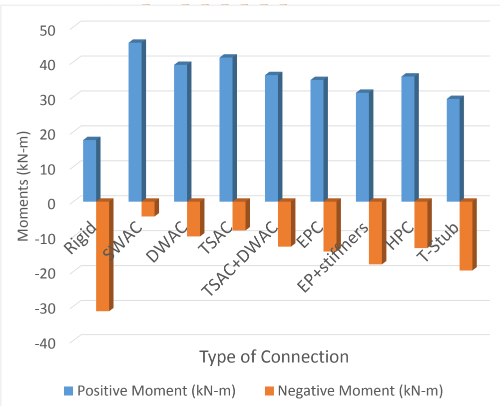

Figure 8: Moments(kN-m) for different types of connections.

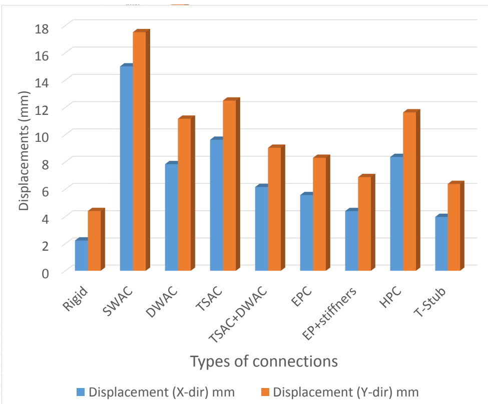

Figure 9: Joint Displacements (mm) for different types of connections.

semi-rigidity of the connections. The connection moment-rotation characteristics influence the response of the structures in terms of drifts, displacement and member forces. The semi-rigidity of the connections increases the mid-span moment and decreases the end moment as compared to rigid connections. It is also found that the use of semi-rigid connections with low moment rotation values like single web angle connection, double web angle connection, header plate connection, top and seat angle connection, top and seat angle connection with double web angle connection , the value of lateral joint displacements due to lateral forces increases with decrease in connection stiffness. Thus, a proper bracing system or other lateral load resisting systems may be incorporated in the structure so as to limit the drift and lateral displacements within permissible limits. The moment-rotation relationship of the connection is highly sensitive to its connection parameters.So, a detailed parametric study for connections can be quite handy in accurate modelling of moment-rotation relationship of the connections.

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