Analysis of Semi-Rigid Steel Framed Structure

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Abstract- *This paper presents analysis & design of 3 storey steel framed structure with rigid, pinned & semi-rigid connections, under the effect of dead load, live load & seismic load (EQ). As suggested by IS 800:2007 (Annexure-F) secant stiffness (rotational stiffness) based on Frye-Morris polynomial model is used for analysis of semi-rigid structure. Values of secant stiffness are incorporated in analysis for all alternatives using STAAD Pro in place of assumption of ideal rigid and pinned end conditions. Analysis results in terms of parameter like shear force, bending moments, axial force in the member, top storey displacement, weight of frame for rigid & pinned connection have been compared with corresponding results for various semi-rigid connections.*

Keywords- Steel frames, Semi-rigid connections, Frye and Morris polynomial Equation, Secant stiffness

I. INTRODUCTION

1. General

In traditional analysis of steel frame structures, beam-to-column connection is idealized as either rigid or pinned. The degree of rigidity depends on so many parameters like connecting material, extent, length and type of moment resisting connection etc. Beam-to-column connections are an integral element of a steel frame, and their behavior affects the overall performance of the structure under different loadings. Connections provide flexibility for ideal rigid connections and provide rigidity in case of ideal pinned end conditions. The behaviour of connections which falls between ideal pinned and rigid conditions has been classified as semi rigid steel connections. Connections that connect beam to column using angles, plates, welds, and bolts are deformable and exhibit a nonlinear behavior. It is more reliable to consider all connections as semi rigid.

Connection flexibility affects both force distribution and deformation in beams and columns of the frame, and is to be accounted for in the structural analysis. It is important to know when the connections are to be assumed as rigid, semi rigid or flexible. For practical purposes, connections can be regarded as the rigid and the frame can be designed as a rigid frame if the limit EIg / (RkL) < 0.05 is satisfied, where, EIg is the flexural rigidity of the beam, L is the length of the beam, and Rk is the connection stiffness (Subramanian 2008). Extended end plate connections possessing initial stiffness more than 105.05 kNm/rad behave as rigid connections. All welded connections and extended end plate connections are considered as rigid for design purposes. Joint stiffness less than 0.001 kNm/rad may be assumed as hinged and if it is more than 1000 kNm it may be assumed as fixed. It is necessary to know the moment-rotation behavior of actual beam to column connections and to formulate appropriate m-θr model for use in analysis and design of semi rigid frames. More popular approach to describe M-θr curve is to curve-fit experimental data with simple expressions. A connection rotates through angle θr caused by applied moment M. Several moment-rotation relationships have been derived from experimental studies for modeling semi-rigid connections of steel frames. These relationships vary from linear model to exponential models and are non-linear in nature. Relative moment-rotation curves of extensively used semi-rigid connections are shown in Figure 1 (Subramanian 2008).

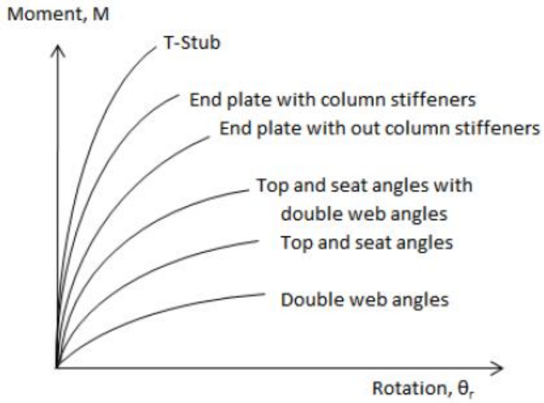

Figure 1. Moment-rotation curves for semi-rigid connections

Extensive investigation over the past thirty years has been performed to estimate the actual behaviour of such joints. Various investigations have been made on semi-rigid connections including: review reports, numerical studies and experiments performed. M. Hairil Mohd1[1] et. al presents the behaviour of semi-rigid connections in steel frame analysis by utilizing the total potential energy principal. K. N. Kadam[2] presents analysis of a pinned, rigid, semi rigid jointed portal frame using a versatile program developed in FORTRAN language using stiffness matrix formulation. Kartal et al.[3] perfomed analytical model for pinned, semi-rigid and rigid connection using “SEMIFEM” and Ansys and verified the results using FORTRAN language using moment curvation relation and justified that semi rigid connection shall be used in the design of beam-column joint. Pirmoz et al [4] had done experimental and FEM models for combined moment and axial tension force. Conclude that when the axial tension loading develops in the connection of the semi-rigid frame during seismic excitation or at the construction process then it will affect the moment-rotation response.

2. Objectives

It is proposed to carryout analysis of multi-storey multi bay steel structure considering ideally rigid, ideally pinned & semi-rigid beam end conditions in STAAD Pro using IS 800:2007. The following are the objectives of the proposed work.

1) To Study the parameters like shear force, bending moments for beam with rigid, pinned & semi-rigid connections.
2) To Study the parameters like shear force, axial force for column with rigid, pinned & semi-rigid connections.
3) To study top storey displacement, weight of structure, base shear with rigid, pinned & semi-rigid connections.

3. Scope

1) The analysis and design of steel structure with ideally rigid & ideally pinned beam end condition under seismic loading.
2) The analysis and design of steel structure with semi-rigid beam end condition under seismic loading.
3) To compare response of rigid, pinned & semi-rigid frame structure subjected to seismic loads.
4) To study the parameters such as base shear, lateral displacement are compared along with the parameter obtained from seismic analysis.
5) Comparing the analysis results for rigid, pinned & semi-rigid end conditions in terms of parameters like shear force, bending moments, axial force in the member, top storey displacement, weight of frame, base shear etc.

II. METHODOLOGY

An analysis and design method has been employed for steel frames with semi-rigid connections using limit state design provisions. Analysis takes into account the nonlinear behaviour of beam-to-column connections. The analysis and design of members has been done considering ideally rigid and ideally pinned end conditions using STAAD Pro. for three storey framed structure. As suggestd by IS 800:2007 (Annexure-F) secant stiffness (rotational stiffness) based on Frye-Morris polynomial model is used for analysis of semi-rigid structure. The values of secant stiffness are incorporated in analysis for all alternatives using STAAD Pro in place of assumption of ideal rigid and pinned end conditions. Analysis results in terms of parameter like shear force, bending moments, axial force in the member, top storey displacement, weight of frame for rigid & pinned connection have been compared with corresponding results for various semi-rigid connections.

Design of members has been conducted using the codal provisions. The design process has been repeated for selecting member cross-sections and connection parameters.

The methodology includes:

1) The selection of framed structure for study.
2) Working out loading details as per IS 875:1987 (Part I & II) & seismic parameters in accordance with Code IS1893:2002 (Part-I).
3) Analysis & design of considered framed structure for ideally rigid and ideally pinned end conditions using STAAD Pro. software.
4) Analysis & design of considered framed structure for semi-rigid end conditions by using the values of secant stiffness incorporated at end conditions for all alternatives using STAAD Pro software.
5) Comparing the analysis results for rigid, pinned & semi-rigid end conditions in terms of parameter like shear force, bending moments, axial force in the member, top storey displacement, weight of frame.

III. PROBLEM STATEMENT

A four bay three storey steel structure building is selected for analysis. The structure is analyzed for various load combinations.

1. Geometrical Details of Structure:
    - X direction bay spacing = 5.0 m c/c
    - Z direction bay spacing = 4.0 m c/c
    - Floor height = 3.0 m c/c

2. SBC for Soil at 3 m = 300 kN/m2
3. Wind Speed in the Area = 39 m/s
4. Seismic Zone = III
5. Material Properties for Structural Steel :
    - Unit mass of steel = 7850 kg/Cu.m

Modulus of Elasticity (E) = 2.10x105 MPa
Poissons ratio = 0.3
Yield Stress (fy) = 250Mpa
Tensile or Ultimate Stress (fu) = 410 Mpa

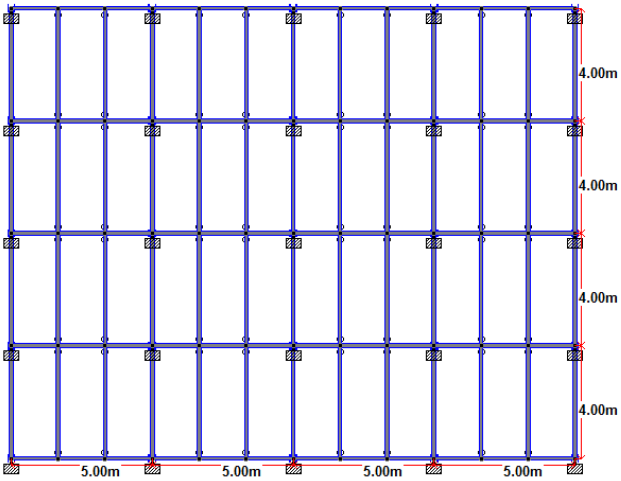

Figure 2. Plan for Floor & Roof Beam Arrangement

IV. MODELING OF STRUCTURE

For this study G+2 model is prepared as shown in the plan & 3D frame structure below. Analysis is done by using STAAD Pro software, is followed by designing these members in STAAD Pro by using IS 800:2007. Bolted connections are considered for the frame. Support conditions for column considered as fixed.

Initially two models were done for analysis and design:

1) With rigid end condition
2) With pinned end condition (i.e. moment release at beam ends)

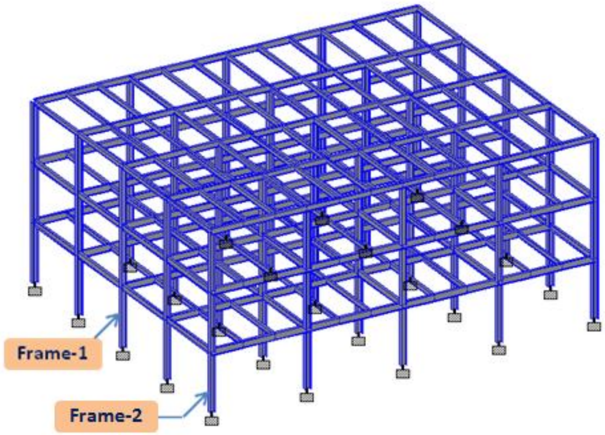

Figure 3. 3-D Structural View of Building

Followed by two different models for semi-rigid framed structure have been done. To study the behavior of semi rigid connections the values of secant stiffness used for beam end conditions as per suggested in IS 800:2007 (Annexure-F) depending upon the connection type.

3) Single web angle connections (SWCA)
4) Double web angle connections (DWCA)

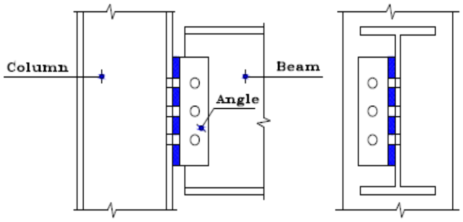

Figure 4. Single web angle connection.

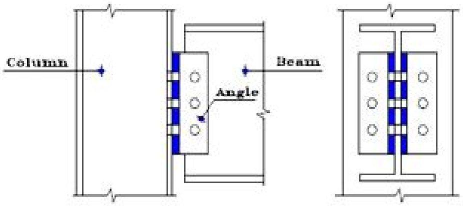

Figure 5. Double Web Angle Connection

Aanlyses is done for all the four models mentioned above to evaluated its structural performance with respect to member strength, ductility and storey displacement.

Also to get stability against the earthquake loads, the bracings at end frames is provided. Otherwise for pinned connection, all columns will behave as cantilever and the frame is unstable.

V. DETAILS OF LOADING FOR ANALYSIS

1. Dead Load (DL):

The dead loads are calculated on basis of unit weights of materials given in IS 875(Part I):1987. It includes the self-weight of beams, columns. The floor slab loads & wall loads have been calculated and assigned as uniformly distributed loads on the beams. Assuming 125 mm thick RCC metal deck slab & 200 mm thick brick wall.

Self-weight of Structure = From Model
Dead Load of Floor Slab = 3.125 kN/sq.m
Dead Load of Floor finishes = 1.0 kN/sq.m
Dead Load of Brick wall = 10.0 kN/m

2. Live Load/Imposed Load (LL):

Live load are assumed in accordence with IS 875(Part-II): 1987, as follows

For floor live load consider as = 5.0 kN/sq.m
For roof live load consider as = 1.5 kN/sq.m

3. Seismic Load (EL):

The following values are used for seismic response in accordence with IS 1893:2002 (Part I), as

Seismic Zone = III
Seismic Zone factor (Z) = 0.16
Importance factor of structure (I) = 1
Response reduction factor (R) = 3
Type of Soil Site = II

4. Load Combinations:

Table -1: Primary Load Case

DL	Dead Load
LL	Live Load
ELX	Earthquake in X direction
ELZ	Earthquake in Z direction

Table -2: Load Combination for Strength

Sr.No.	For Strength Criteria
1	1.5DL + 1.5LL
2	1.2DL + 1.2LL + 1.2ELX
3	1.2DL + 1.2LL - 1.2ELX
4	1.2DL + 1.2LL + 1.2ELZ
5	1.2DL + 1.2LL - 1.2ELZ
6	1.5DL + 1.5ELX
7	1.5DL - 1.5ELX
8	1.5DL + 1.5ELZ
9	1.5DL - 1.5ELZ
10	0.9DL + 1.5ELX
11	0.9DL - 1.5ELX
12	0.9DL + 1.5ELZ
13	0.9DL - 1.5ELZ

Table -3: Load Combination for Serviciabilty

Sr.No.	For Serviciabilty Criteria
1	1.0DL + 1.0LL
2	1.0DL + 1.0LL + 1.0EL(+)X
3	1.0DL + 1.0LL + 1.0EL(-)X
4	1.0DL + 1.0LL + 1.0EL(+)Z
5	1.0DL + 1.0LL + 1.0EL(-)Z
6	1.0DL + 1.0EL(+)X
7	1.0DL + 1.0EL(-)X
8	1.0DL + 1.0EL(+)Z
9	1.0DL + 1.0EL(-)Z
10	1.0DL

V. COMPARISION OF RIGID, PINNED & SEMI-RIGID ANALYSIS RESULTS

The comparison has been made between ideal pinned and rigid end conditions for steel frame with different semi rigid steel connections for assessment of different parameters like end span bending moment, mid span bending moment, shear force, axial forces in member, weight of columns, weight of beams, total weight of frame, top storey displacements. Variation of above parameters has been availed from analysis results using STAAD Pro.2006. For presentation of results, middle bay Frame-1 have been considered as shown in figure-8.

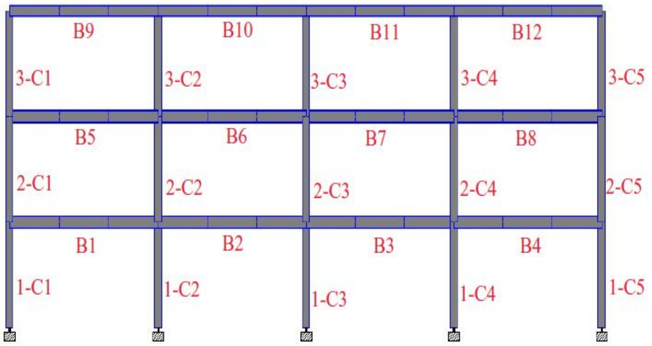

Figure 6. Elevation for Frame-1

Table -4: Beam End Span Bending Moment (1.5DL+1.5EL)

Member	Beam End Span Bending Moment (KNm)			
	Pinned	SWCA	DWCA	Rigid
B1, B4	0	10.5	32.7	137.0
B2, B3	0	10.5	32.8	131.0
B5, B8	0	10.5	32.4	133.0
B6, B7	0	10.5	32.6	128.0
B9, B12	0	9.5	26.6	80.7
B10, B11	0	9.5	26.6	76.3

Table -5: Beam Span Bending Moment (1.5DL+1.5LL)

Member	Beam Span Bending Moment (KNm)			
	Pinned	SWCA	DWCA	Rigid
B1, B4	167.5	157.2	136.3	60.2
B2, B3	167.5	157.0	135.7	55.2
B5, B8	167.5	157.2	136.2	59.2
B6, B7	167.5	157.0	135.7	55.7
B9, B12	109.0	99.0	82.5	39.9
B10, B11	109.0	98.9	81.4	36.2

Table -6: Beam Shear Force (1.5DL+1.5EL)

Member	Beam Shear Force (KN)			
	Pinned	SWCA	DWCA	Rigid
B1, B4	80.8	81.7	83.9	102.0
B2, B3	80.8	81.7	83.8	97.5
B5, B8	80.8	81.7	83.7	99.8
B6, B7	80.8	81.7	83.7	96.5
B9, B12	52.8	53.2	54.7	63.1
B10, B11	52.8	53.2	54.5	59.4

Table -7: Column Axial Force (1.5DL+1.5EL)

Member	Column Axial Force (KN)			
	Pinned	SWCA	DWCA	Rigid
1C1,1C5	456.0	459.0	464.0	491.0
1C2,1C4	654.0	654.0	654.0	665.0
1C3	653.0	653.0	653.0	653.0
2C1,2C5	282.0	284.0	287.0	301.0
2C2,2C4	408.0	408.0	408.0	414.0
2C3	407.0	407.0	407.0	407.0
3C1,3C5	108.0	108.0	109.0	112.0
3C2,3C4	162.0	162.0	162.0	164.0
3C3	161.0	161.0	161.0	161.0

Table -8: Column Shear Force (1.5DL+1.5EL)

Member	Column Shear Force (KN)			
	Pinned	SWCA	DWCA	Rigid
1C1,1C5	13.1	15.8	20.8	44.4
1C2,1C4	13.1	15.3	19.3	44.0
1C3	13.1	15.4	19.3	43.1
2C1,2C5	9.1	13.0	18.3	42.6
2C2,2C4	9.5	11.9	16.3	43.0
2C3	9.3	11.6	15.9	41.8
3C1,3C5	5.6	7.2	11.4	37.2
3C2,3C4	5.2	7.0	10.5	29.5
3C3	5.1	6.8	10.3	26.2

Table -9: Top Storey Displacement for Structure

Direction	Top Storey Displacement for Structure (mm)			
	Pinned	SWCA	DWCA	Rigid
Z-Dir	35.55	34.20	30.31	17.44
X-Dir	20.50	17.50	12.36	11.72

Table -10: Total Weight of Structure

Total Weight of Structure (KN)			
Pinned	SWCA	DWCA	Rigid
725	710	705.3	670.6

Above results can be graphically represented as below:

SWCA - Single Web Connection Angle
DWCA - Double Web Connection Angle

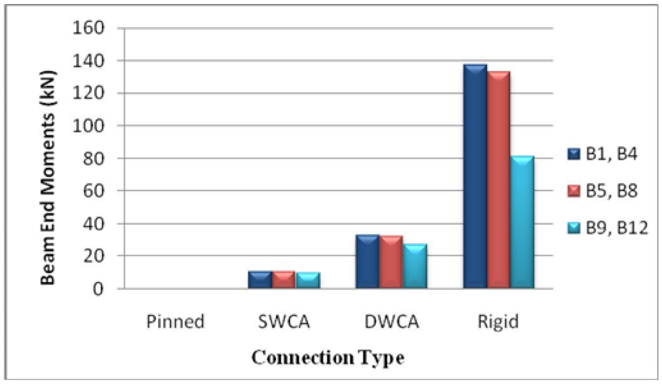

Figure 7. End Span Bending Moment for 1.5DL+1.5EL

It has been observed that increase in end span moments in the beam enhances with increase in rigidity of end conditions for the beam as presented in Figure 7.

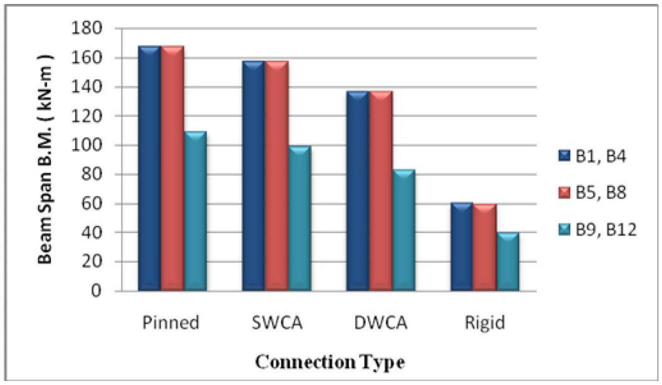

Figure 8. Beam Span Bending Moment for 1.5DL+1.5LL

Mid span moments in beam reduce with increase in rigidity of end conditions of the beam for vertical load cases as shown in Figure 8.

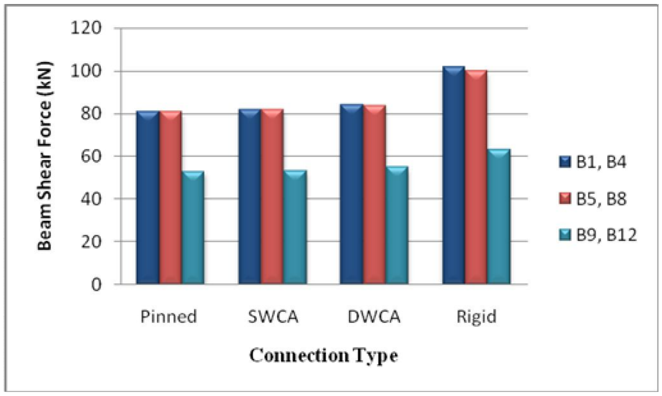

Figure 9. Beam Shear Force for 1.5DL+1.5EL

Enhancement has been observed in shear force with increase in rigidity for beams horizontal load cases as shown in Figure 9.

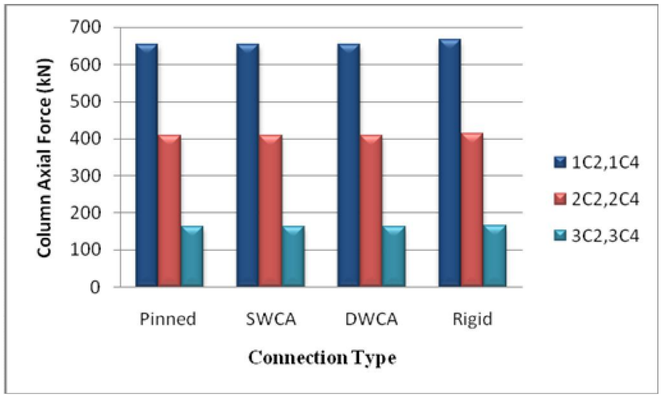

Figure 10. Column Axial Force for 1.5DL+1.5EL

It has been observed from comparison of axial force in column that it slightly increases with increase in rigidity of end conditions for horizontal load cases as given in Figure 10.

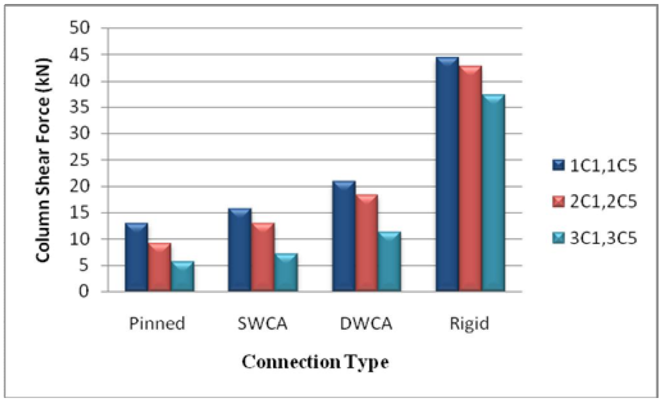

Figure 11. Column Shear Force for 1.5DL+1.5EL

Shear force in columns increase with increase in rigidity of end conditions for horizontal load cases as narrated in Figure 11.

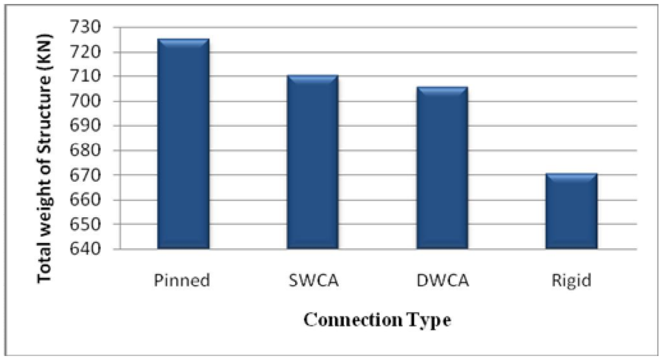

Figure 12. Total Weight of Structure

Weight of structure decreases with increase in rigidity of the frame as presented in Figure 12.

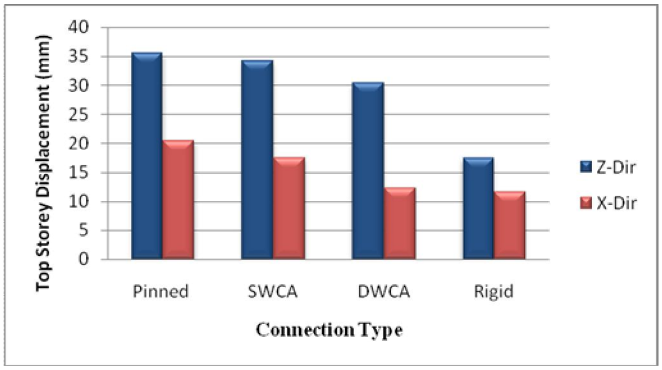

Figure 13. Top Storey Displacement of Structure

Increment in top storey displacements is observed with increase in flexibility of semi-rigid connections as presented in Figures 13.

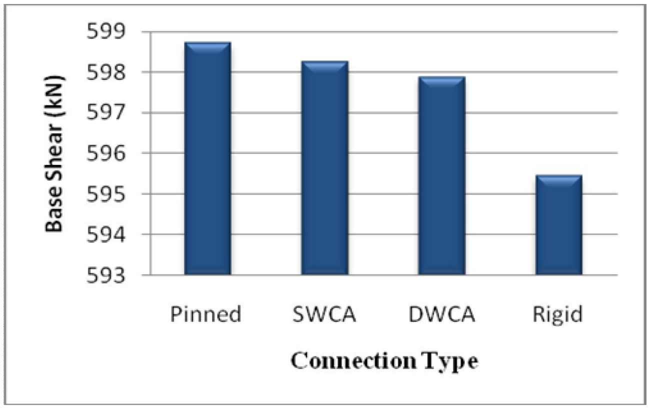

Figure 14. Base Shear for Structure

Increment is observed in base shear with increase in flexibility of semi-rigid connections as presented in Figure 14.

VI. CONCLUSION

Based on the Analysis results, the following conclusion can be made:

In general it is observed that bending moments in floor beams are reduced at the ends and increased at mid span due to change over from rigid to semi-rigid beam and column connection. The variation in BM depends on the semi rigidity of connection. It means that reduction in BM at ends is less in Double Web Connection Angle (DWCA) and still lesser for Single Web Connection Angle (SWCA) connection while increase in BM at mid span is more in DWCA and still more in SWCA connection. This observation is quite obvious structurally.

At fixed base Axial force is not appreciably affected due to type of connection but shear force in the column is reduced substantially. Therefore, in semi rigid steel frames, the columns do not derive any benefit of beam framing because of poor horizontal support. The column resists major horizontal action.

The storey displacement is increases in semi rigid connection and it is larger in case of Single Web Connection Angle & pinned connections. Need to provide suitable bracing system to control the deflection.

The analysis response of the frames has indicated that a reduction in the joint moment is accompanied by an increase in the span moments. Reducing joint moments is advantageous as detailing, modeling and design of joints is the most cumbersome part of steel frame design. In RCC -steel structural construction beams are usually laterally restrained and have sufficient strength to sustain design loads in their span than connection region. This will make semi rigid connections an economical design solution.

Also, it is observed that base shear reduces with increase in rigidity. Hence, it is recommended to use semi rigid connection for realistic behaviour check of Steel structural frames.

All these connections are idealized for analysis and presently many researcher are of the opinion that the actual stiffness shall be used for analysis instead of restricting to rigid or pinned depend upon the type of connection provided.

IV. ACKNOWLEDGMENT

I express my deepest gratitude to my project guide Prof. Dr. Nagesh Shelke & Co-guide Prof. Shoeb Kalyani, whose encouragement, guidance and support me to develop an understanding of the subject.

I would like to thank Principal, Dr. Ashok S. Kasnale and Dr. Sanjay K. Kulkarni H.O.D of Civil Department, Dr. D.Y.Patil School of Engineering & Technology for providing their invaluable advice. This would help me to work and completing this project.

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