RESPONSE OF STRUCTURAL STEEL FRAME BY USING SEMI-RIGID CONNECTIONS

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ABSTRACT

It is obvious that real beam-to-column connections have some stiffness, in between the extreme cases of fully rigid and ideally pinned. Generally it is assumed that the joints and supports in the structure are pinned or rigid while performing analysis. Several papers prove that in actual framed structures, rigid connections have some degree of flexibility, while pinned connections have some stiffness. But assuming joints to be rigid or pinned may not give effective results. So semi rigid connection should be considered to obtain more accurate, reliable and also cost-effective results.

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.

Keyword - *Steel frames, Semi-rigid connections, Frye and Morris polynomial Equation, Secant stiffness etc….*

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1. INTRODUCTION

Structural steel frames usually consist of universal beams and columns assembled together by means of connections. In conventional analysis and design of steel and composite frames, beam-to-column joints are assumed to behave either as “pinned” or as fully “rigid”. Although the pinned or fixed assumption significantly simplifies analysis and design procedures for the engineer, real joint behaviour exhibits characteristics over a wide spectrum between these two extremes. 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 behavior 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.

2. SCOPE & OBJECTIVES OF STUDY

2.1 Objectives of Study

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.

2.2 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.

3. LITRATURE SURVEY

V. D. Kapgate, Dr. K. N. Kadam (2015) [1] This paper presents analysis of a pinned, rigid, semi rigid jointed portal frame using a versatile program developed in FORTRAN language using stiffness matrix formulation, where analysis has been done without changing source program and only with a minimal change in data file. This paper describe in detail computer implementation of formulation of the program organization in the form of a flow chart. Numerical is presented to show the effect of joint flexibility on overall response of structures. Single story portal frame with semi rigid beam to column is analyzed by changing rotational spring stiffness. Results are presented to show variation of bending moment, shear force and axial force.

M.E. Kartal et. al. (2010) [2] In this study, rotational spring stiffness-connection ratio relation is clearly explained and revealed. A finite element program SEMIFEM is developed in FORTRAN language for the numerical analysis. This program provides to define semi-rigid connections in terms of rotational spring stiffness or connection ratio simultaneously. In the numerical applications, rotational spring stiffness-connection percentage relation of the semi-rigid connected structural members is submitted. Semi-rigid connections are considered in column-to-foundation connection of a portal frame, beam-to-column connection of a prefabricated structure, steel brace connection to reinforced concrete (RC) frame of a steel X-braced RC frame and truss member connection to joint of a steel truss system. The variation of moment, shear force, axial force, displacement and stress is investigated in a selected axis of the structures. Consequently, semi-rigid connections should be considered in structural analyses to obtain the most optimum results.

T. Otsuka1 et. al. (2008) [3] In this study, in order to obtain a rational design parameter involving the connection factor that can be used in Japan, a fundamental study about the characteristic of multi-storied steel frames with changes in the strength of the beam-to-column connections was performed via a static analysis. In order to formulate a design condition involving the connections, four parameters were defined. The main parameter is the connection factor, adopted when the small one changed to a large one, and a push-over static analysis with an earthquake load was conducted. From the analysis results, information about the availability of the use of semi-rigid frames in Japan was obtained.

A Csébfalvi, G. Csébfalvi (2005) [4] In this study, a simplified beam-to-column connection is presented which was specified in EC3 Annex J. The main aim of this paper was to investigate the effects of the rotational stiffness of beam-to-column connections in the optimal design problem while the structural response is changing. In order to capture the changes in the nodal force and moment distribution in terms of joint flexibility, the ANSYS finite element analysis is applied. The structural model is formulated as a combination of 3D quadratic beam elements and linear torsional springs. Present work deals with the effects of joint flexibility to the optimal design problem. The design variables - including joint properties - are discrete. Results are presented for sway frames under different load conditions. Also the relationship in between the end-fixity factor and the resulted optimal design is presented.

J.M.Cabrero, E.Bayo (2005) [5] The proposed method allows to optimize not only the size of the structural profiles, but also the joint design to make it fit to the optimal theoretical values. Pre-design methods for semi-rigid extended end-plate joints were also provided to easily check the feasibility and suitability of a connection design. Two design examples were proposed to demonstrate the application of the proposed semi-rigid design methods, and their results compared to pinned and rigid alternatives. The semi-rigid approach results in more economical solutions. It must be pointed out that, in spite of optimizing the structural profiles, if the joints were not optimized, the resulting structure cannot be considered optimal and even adequate, as its main differential characteristic, the semi-rigid joint, has not been yet fully exploited. A design method suitable for semi-rigid joints was proposed. Apart from minimizing the need for iteration, the main advantage is its similarity to the design method used at present for the traditional types of joints (pinned and rigid).

4. 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 behavior 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 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. 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.

5. 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/m^2
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) = 2.10x10^5 MPa
   - Poissons ratio = 0.3
   - Yield Stress (fy) = 250 Mpa
   - Tensile or Ultimate Stress (fu) = 410 MPa

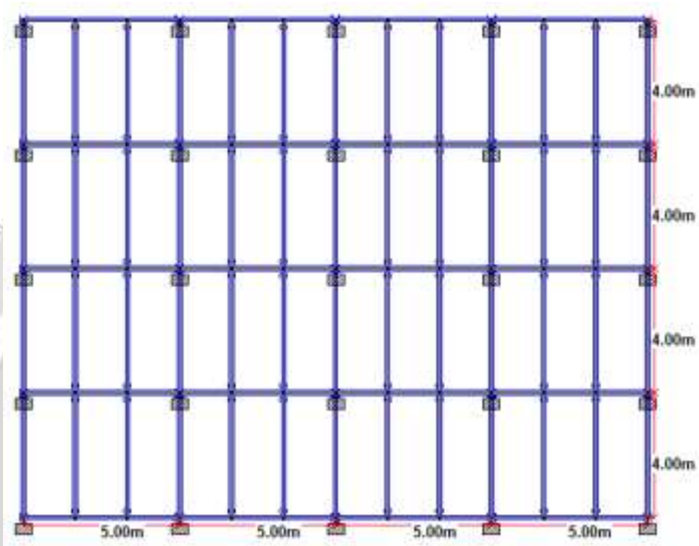

Fig-1: Plan for Floor & Roof Beam Arrangement

6. 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.

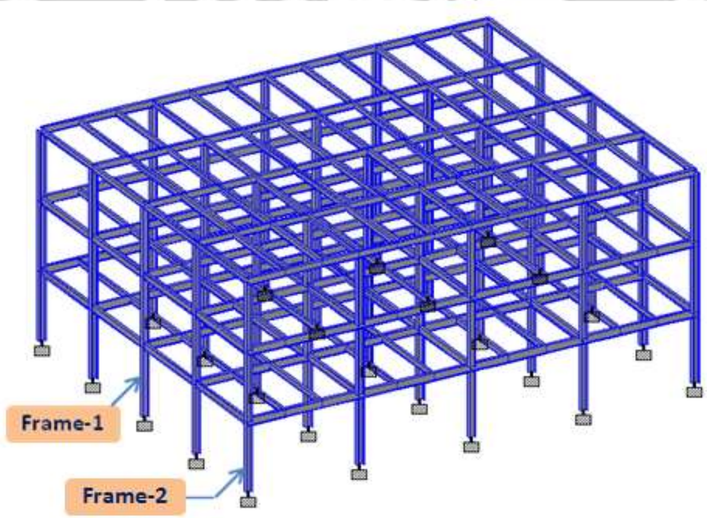

Fig-2: 3-D Structural View of Building

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)

Followed by four 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)
5) Top and Seat without Web Angel Connections (TSWA)
6) Header Plate Connections (HPC)

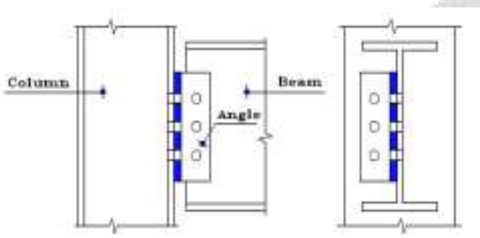

Fig-3: Single web angle connection.

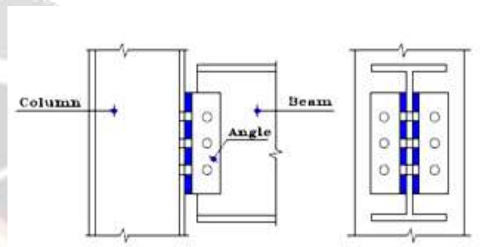

Fig-4: Double Web Angle Connection.

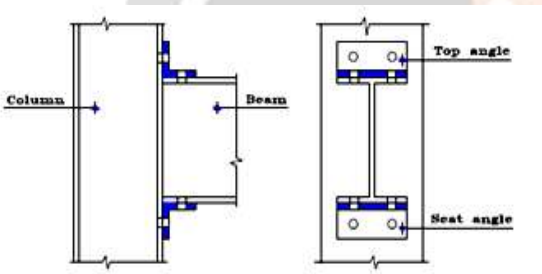

Fig-5: Top and Seat Angle Connection.

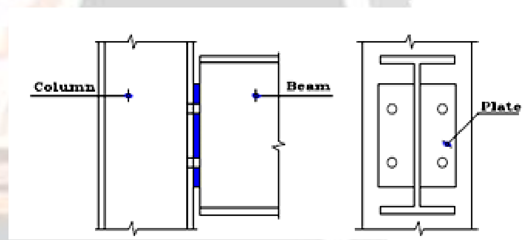

Fig-6: Header Plate Connection

Analysis is done for all the six 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.

7. DETAILS OF LOADING

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 STAAD 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 accordance 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 accordance 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 Serviceability

Sr.No.	For Serviceability Criteria
1	1.0DL + 1.0LL
2	1.0DL + 1.0LL + 1.0ELX
3	1.0DL + 1.0LL - 1.0ELX
4	1.0DL + 1.0LL + 1.0ELZ
5	1.0DL + 1.0LL - 1.0ELZ
6	1.0DL + 1.0ELX
7	1.0DL - 1.0ELX
8	1.0DL + 1.0ELZ
9	1.0DL - 1.0ELZ
10	1.0DL

8. COMPARISION OF ANALYSIS RESULTS FOR RIGID, PINNED & SEMI-RIGID CONNECTIONS

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.

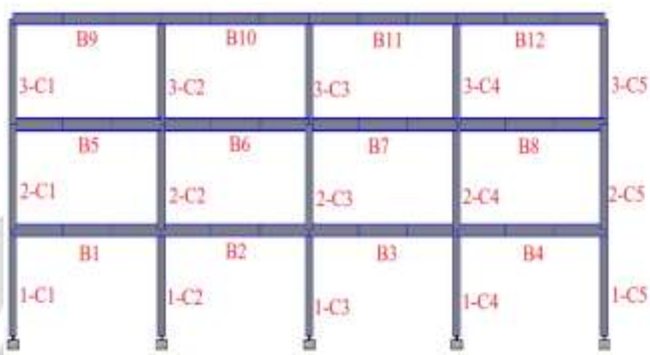

Fig-7: Elevation for Frame-1

Table -4: Types of Semi-rigid Connections

SWCA	Single Web Angle Connections
HPC	Header Plate Connections
TSWA	Top and Seat without Web Angel Connections
DWCA	Double Web Angle Connections

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

Member	End Span Bending Moment (KNm)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
B1, B4	0	10.5	20.1	22.4	32.7	137.0
B2, B3	0	10.5	20.2	22.5	32.8	131.0
B5, B8	0	10.5	20.5	22.5	32.4	133.0
B6, B7	0	10.5	20.5	22.5	32.6	128.0
B9, B12	0	9.5	17.8	19.2	26.6	80.7
B10, B11	0	9.5	17.9	19.3	26.6	76.3

Table -6: Beam Span Bending Moment (1.5DL+1.5LL)

Member	Beam Span Bending Moment (KNm)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
B1, B4	167.5	157.2	148.6	145.8	136.3	60.2
B2, B3	167.5	157.0	148.5	145.6	135.7	55.2
B5, B8	167.5	157.2	148.6	145.8	136.2	59.2
B6, B7	167.5	157.0	148.5	145.6	135.7	55.7
B9, B12	109.0	99.0	91.9	89.7	82.5	39.9
B10, B11	109.0	98.9	91.5	89.1	81.4	36.2

Table -7: Beam Shear Force (1.5DL+1.5EL)

Member	Beam Shear Force (KN)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
B1, B4	80.8	81.7	82.8	82.9	83.9	102.0
B2, B3	80.8	81.7	82.8	82.8	83.8	97.5
B5, B8	80.8	81.7	82.9	82.8	83.7	99.8
B6, B7	80.8	81.7	82.9	82.8	83.7	96.5
B9, B12	52.8	53.2	54.3	54.1	54.7	63.1
B10, B11	52.8	53.2	54.2	54.0	54.5	59.4

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

Member	Column Axial Force (KN)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
1C1,1C5	456	459	462	462	464	491
1C2,1C4	654	654	654	654	654	665
1C3	653	653	653	653	653	653
2C1,2C5	282	284	286	286	287	301
2C2,2C4	408	408	408	408	408	414
2C3	407	407	407	407	407	407
3C1,3C5	108	108	109	109	109	112
3C2,3C4	162	162	162	162	162	164
3C3	161	161	161	161	161	161

Table -9: Column Shear Force (1.5DL+1.5EL)

Member	Column Shear Force (KN)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
1C1,1C5	13.1	15.8	18.8	19.4	20.8	44.4
1C2,1C4	13.1	15.3	17.7	18.7	19.3	44.0
1C3	13.1	15.4	17.8	18.7	19.3	43.1
2C1,2C5	9.1	13.0	16.1	16.5	18.3	42.6
2C2,2C4	9.5	11.9	14.6	15.5	16.3	43.0
2C3	9.3	11.6	15.2	15.5	15.9	41.8
3C1,3C5	5.6	7.2	7.9	9.5	11.4	37.2
3C2,3C4	5.2	7.0	8.2	9.0	10.5	29.5
3C3	5.1	6.8	8.1	9.2	10.3	26.2

Table -10: Top Storey Displacement for Structure

Direction	Top Storey Displacement for Structure (mm)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
Z-Dir	35.55	34.20	33.81	31.06	30.31	17.44
X-Dir	20.50	17.50	15.65	13.03	12.36	11.72

Table -11: Total Weight of Structure

Total weight of Structure (KN)					
Pinned	SWCA	HPC	TSWA	DWCA	Rigid
725	710	710	705	705	671

Table -12: Base Shear

Direction	Base Shear (KN)					
	Pinned	SWCA	HPC	TSWA	DWCA	Rigid
X & Z Dir	598.43	598.24	598.07	597.87	597.87	595.44

Above analysis results can be graphically represented as below:

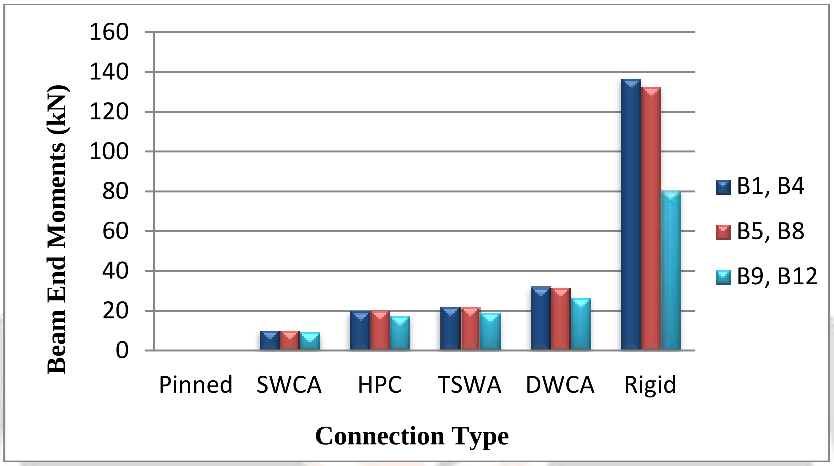

Fig-8: End Span Bending Moment for 1.5DL+1.5LL

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 8**.

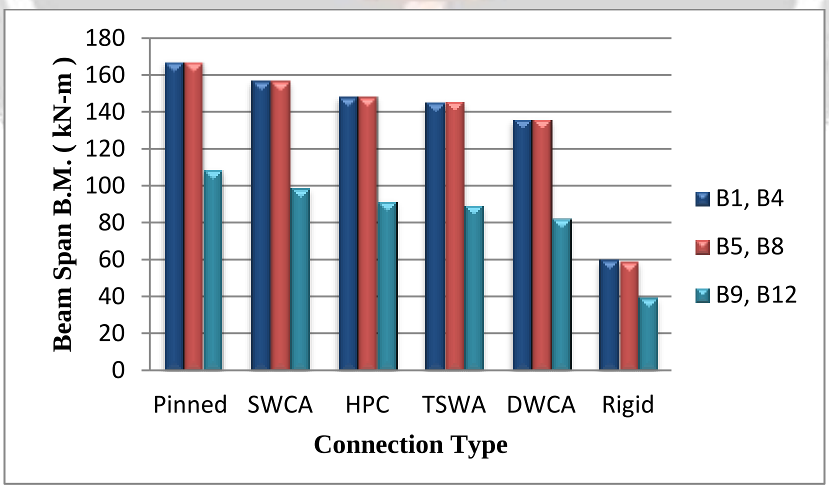

Fig-9: Beam Span Bending Moment for 1.5DL+1.5LL

Mid span moments in beam reduce with increase in rigidity of end conditions of the beam for vertical load cases as shown in **Figure 9**.

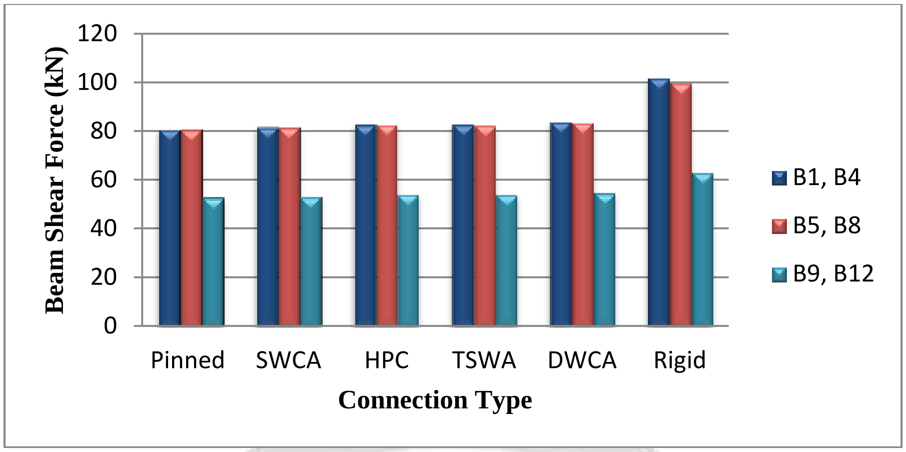

Fig-10: Beam Shear Force for 1.5DL+1.5EL

Enhancement has been observed in shear force with increase in rigidity for beams horizontal load cases as shown in **Figure 10.**

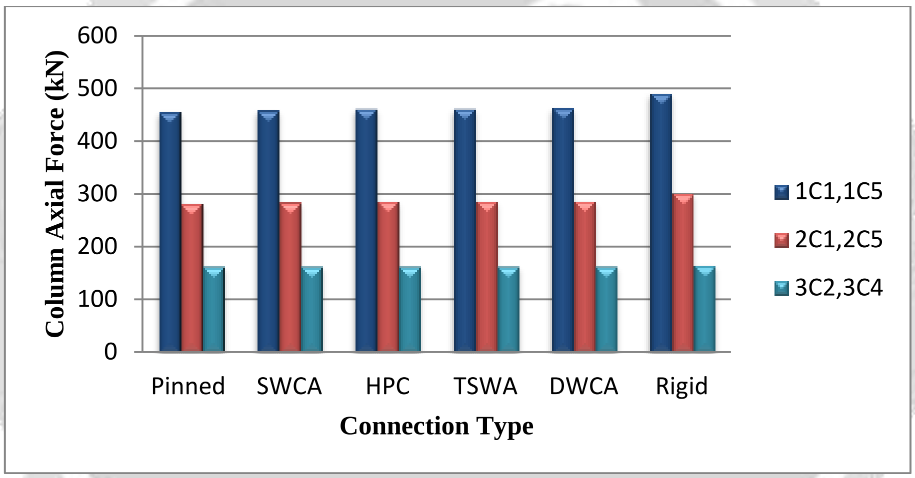

Fig-11: Column Axial Force for 1.5DL+1.5EL

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 11.**

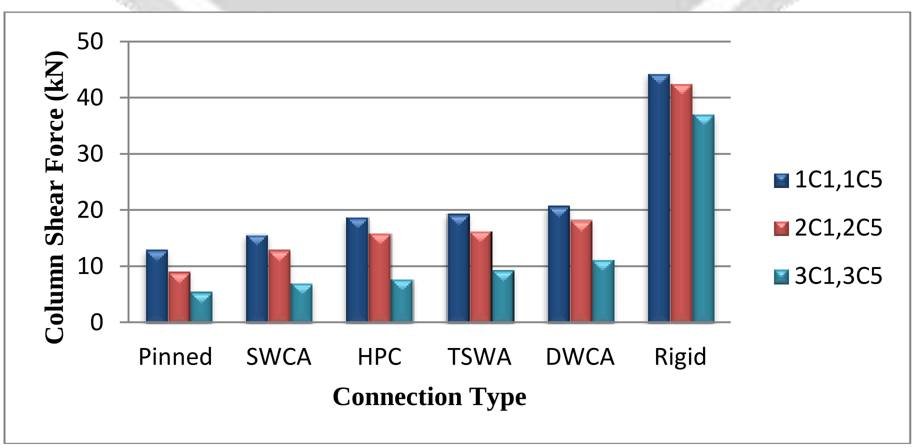

Fig-12: Column Shear Force for 1.5DL+1.5EL

Shear force in columns increase with increase in rigidity of end conditions for horizontal load cases as narrated in **Figure 12.**

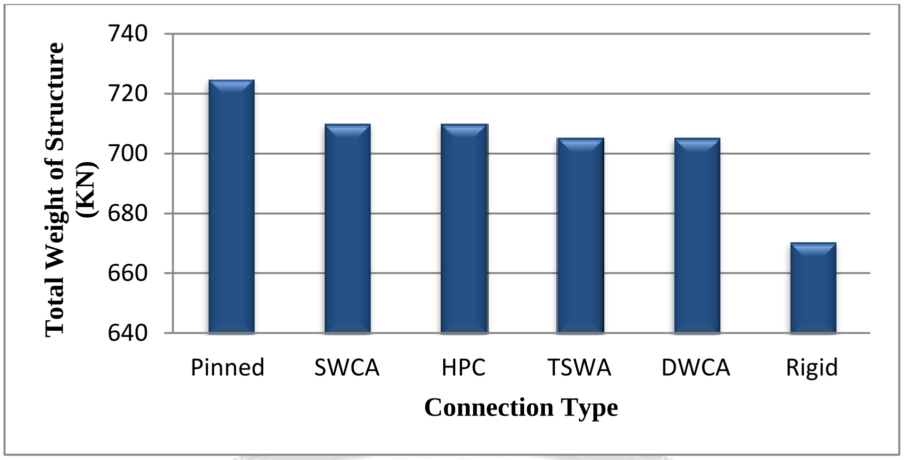

Fig-13: Total Weight of Structure

Weight of structure decreases with increase in rigidity of the frame as presented in **Figure 13.**

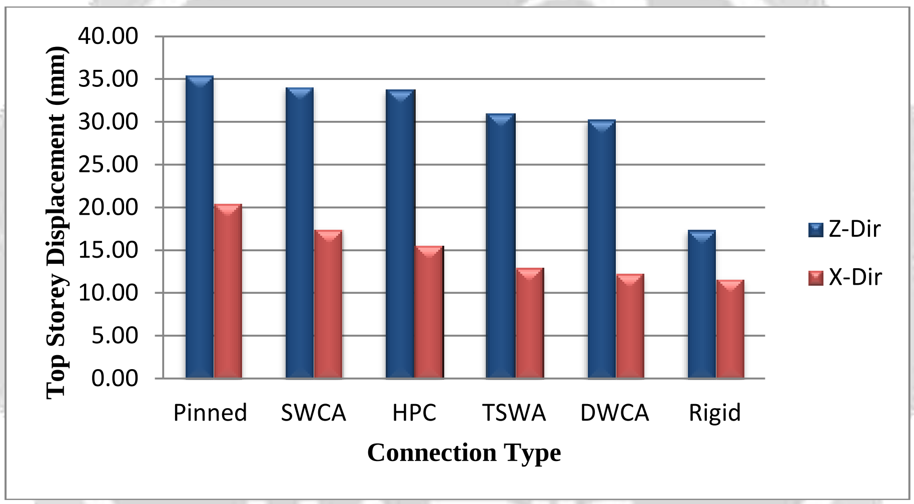

Fig-14: Top Storey Displacement of Structure

Increment in top storey displacements is observed with increase in flexibility of semi-rigid connections as presented in **Figures 14.**

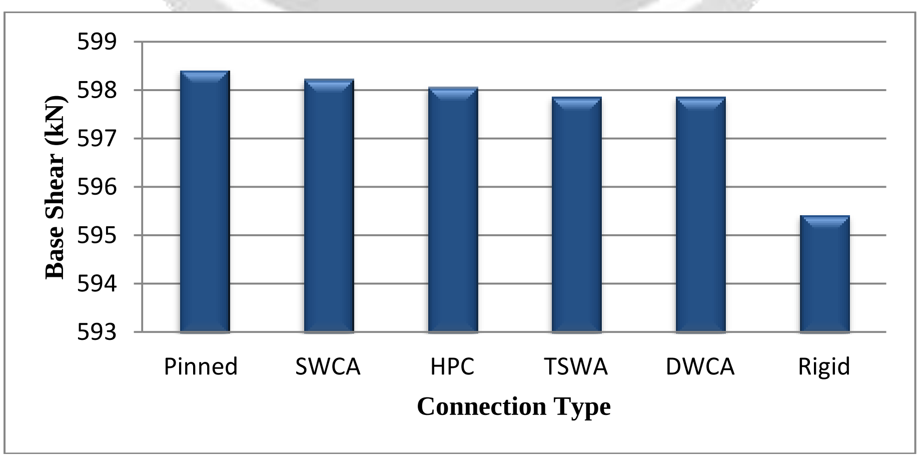

Figure 15. Base Shear for Structure

Increment is observed in base shear with increase in flexibility of semi-rigid connections as presented in **Figure 15.**

9. CONCLUSIONS

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 BM at ends reduced from fixed, Double Web Connection Angle (DWCA), Top and Seat without Web Angel Connections (TSWA), Header Plate Connections (HPC) to Single Web Connection Angle (SWCA) connection. Also increase in BM at mid span is observed from DWCA, TSWA, HPC, SWCA to pinned 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 Header Plate Connection, 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.

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