RESEARCH REVIEW JOURNALS
Volume-03
Issue-11
November -2018

ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com [UGC Listed Journal]

Analysis and Design of Semi Rigid Steel Frame and Joints

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ARTICLE DETAILS

Article History
Published Online: 10 November 2018

Keywords
Steel Frames, Joints, Rigid, Semi-rigid. .

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ABSTRACT

Presently the joints in the steel frames are designed as fixed or pinned joint. Generally the welded joints are designed as fixed joints and bolted joints are considered as or designed as pinned joints. While designing the joints it is assumed that the fixed joint is not having any kind of flexibility and pinned joint are not having any kind of stiffness. i.e. while designing it is considered as fixed joints are totally stiff and pinned joints are totally flexible. It is assumed that the pinned joint allows the rotation and translation and fixed joint allow only translation .In present study the five bays five storey steel structures of commercial cum residential building will be analyzed with semi rigid connections. In the analysis the rigidity of the connections will be varied from 0% to 100% with interval of 10. Design of members (beams and column) will be done and quantities of material will be calculated for each case. Comparison of quantity of material required will be carried out to decide the most economic but safe rigidity case. Design of connections between beam and column will be done for selected rigidity case.

1. Introduction

Every joint is not perfectly fixed or pinned. Fixed joint has some amount of flexibility and pinned joint has some amount of rigidity. Analysis and design of the structure by considering fully fixed or fully pinned joints i.e. having only rigidity or flexibility leads to incorrect results and higher side of material and costing. Some examples of semi rigid connections are

a. Racks used for storing material in industries and malls.
b. Ankle of foot.
c. Helicopter rotors
d. Two spring one inside the other

1.1 Significance of Topic

Cost saving and safety are necessary for any structure. Even a 5 % to 6 % savings in steel is much helpful to reduce total cost of structure. Comparative study of regular and semi rigid structure will help to find out alternative yet economic solution for analysis and design of structures.

1.2 Scope of Work

A commercial cum residential structure is situated in Pune MIDC area. It was constructed five years back. The design was done manually by considering joints fixed. The material required was 75 tones. Scope of present work is to analyze and design the same structure with semi rigid connections and comparing the results. Comparison will be done on the basis of cost and stability. Also design of semi rigid connections will be done.

2. Aim and Objectives

The aim and objective of the present study is to analyze and design a five bay five storey building frame for various rigidities varying from 0 to 100% at an interval of 10 % are as follows:

a. Preparing 3D model of structure.
b. Analysis of frame for all rigidities.
c. Analysis for sway.
d. Design of the members.
e. Comparison of results for quantity, horizontal displacement and costs for various rigidities.
f. Selection of optimum rigidity for minimum quantity and horizontal displacement.
g. Designing beam column connection.
h. Finding out actual cost savings.

3. Problem Statement

Analysis and design of a five bay five storey steel frame of a commercial cum residential building for the rigidities varying from 0 % to 100 % at an interval of 10.Determine the total quantity of material required and maximum horizontal displacement of the frame for all rigidity. Compare the results for all rigidities. Choose rigidity case with minimum material quantity and satisfying horizontal displacement criteria. Design the individual connections between beams and columns for selected rigidity.

3.1 Dimension of Building

The plan and elevation of residential cum commercial building with dimension along x and z direction are shown in Fig-1. Horizontal dimensions of the frame are 3.2 m, 4.0 m, 6.0 m, 5.0 m and 4.0 m from left to right along x-direction. Horizontal dimensions of the frame are 3 m, 3.2 m, 3.8 m, 3.8 m and 3 m from left to right along z-direction. Frames in x-direction are named as A, B, C, D, E, F and frames in z-direction are known as 1, 2, 3, 4, 5, and 6. The ground floor height is 3.0 m, first floor height is 3.6 m, second, third and fourth floor height is 3.0 m. Height of parapet is 1.2 m.

3.2 Parameters of Building

Location of building: Pune MIDC

Seismic Zone: III
Foundation strata: Hard
150 mm thick brick walls with 50 mm plaster on both side
150 mm thick slab with 50 mm thick flooring
First floor (commercial) live load: 4 KN/m^2 as per IS: 875
Upper floors (residential) live load: 2 KN/m^2 as per IS: 875

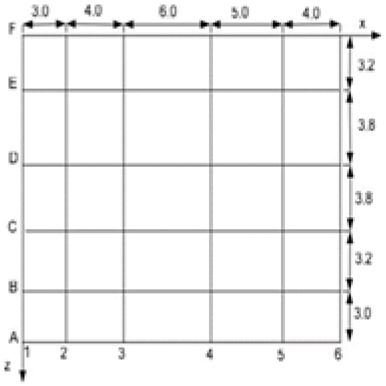

Fig- 1: Plan of building

4. Modeling and Analysis

A STAAD.Pro V8i is used for modelling and analysis of the selected structure. A model of five bay five storey frame is prepared. Analysis is done by adjusting the rigidities as required.

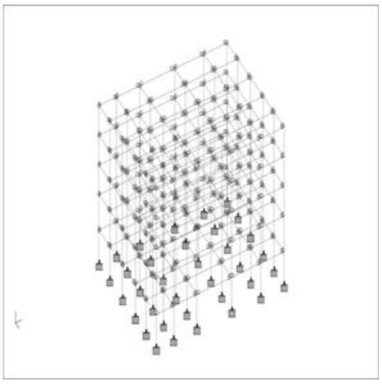

Fig- 2: STAAD.Pro 3D model

4.1 Analysis of the Frame

Analysis of steel frame is done by STAAD.Pro V8i software for the rigidities varying from 0 %, to 100% at interval of 10. Forces (moments, shear forces and axial loads) coming on all members of the frame, horizontal displacements and rotation of all nodes are calculated. Load combination for maximum forces is found out. Typical bending moment diagram and shear force diagram for member 226 for 40 % release is given in Fig. 3 and 4.

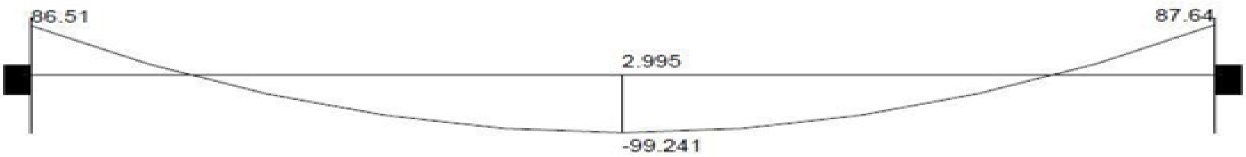

Fig- 3: BMD for beam 226 for 40 % release in STAAD.Pro V8i

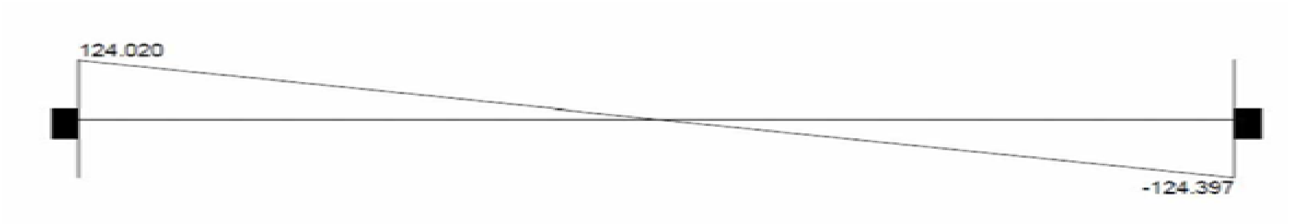

Fig- 4: SFD for beam 226 for 40 % release in STAAD.Pro V8i

5. Design of Members and Joints

For all rigidities the design of the frame is done by computer program written in GW Basic. The sections required for the beams and columns are found out for each rigidity case. A typical design for beam no. 226 and column no. 126 is given.

5.1 Typical Beam Design

The beams are designed and checked for bending stress, shear stress and deflection. Typical beam design for member no 226 for 40 % release is as below. Material used for design is rolled steel of Fe 250, Fu 410 and fy 250.

5.2 Typical Column Design

The columns are checked for compression stress, bending stress in both directions, and utilization ratio. Typical column design for member 126 for 40 % release is as below. Minimum section satisfying all these checks is selected for the member. Material used for design is rolled steel of Fe 250, Fu 410 and fy 250.

After designing all members, total weight of the frame for all rigidity is calculated. Weight of frame is tabulated in Table 1.Similarly maximum horizontal displacement of structure found out from analysis and tabulated in Table 1. The maximum horizontal displacement is coming for node 193 of fifth floor.

S. N.	% Release	Weight in M. T.	Maximum horizontal displacement in mm
1	0	72.97	32.11
2	10	71.71	34.84
3	20	70.07	38.35
4	30	68.82	42.88
5	40	67.38	48.84
6	50	65.23	56.9
7	60	62.88	68.23
8	70	61.33	85.28
9	80	62.76	114.27
10	90	66.19	178.75
11	100	75.32	476.89

Table-1: Weight and maximum horizontal displacement per release

The variation of weight and maximum horizontal displacement with respect to % release are shown in Fig. 5 and Fig. 6.

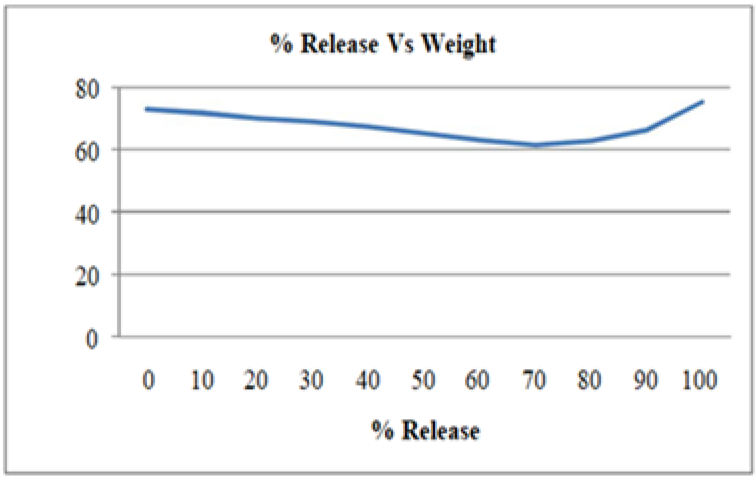

Fig- 5: Total weight VS % release

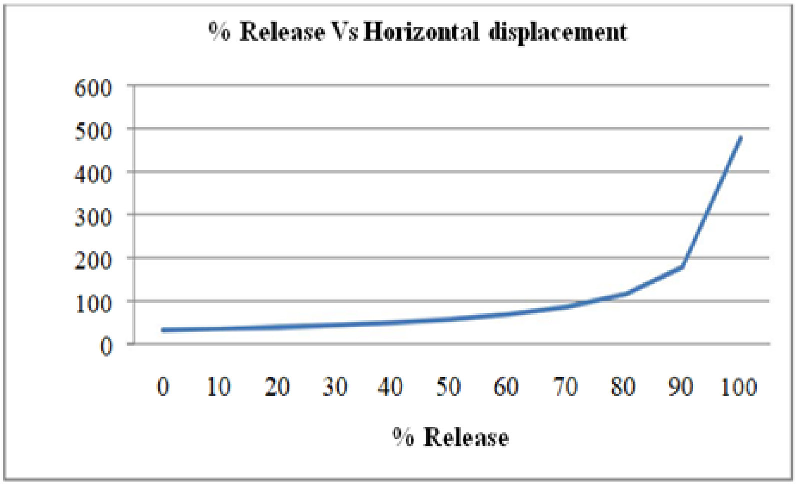

Fig- 6: Horizontal displacement VS % release

5.3 Finalize the rigidity case

Total weight of frame is calculated for all rigidities and tabulated in Table 6.1.Comparison is done between all cases, to decide the minimum weight criteria. It is observed that minimum weight of 61.33 tones is coming for 70 % release. The horizontal displacement for 70 % release case is 85.28 mm.

For 50 % release horizontal displacement is 56.9 mm which is less than 62.4 mm but storey drift of fourth floor is more than the limit as shown in Table 1.

Level	Node	Displacement in mm	Floor Drift in mm	Floor Ht. in m	Per. Drift in mm
L0	15	0			
L1	51	5.815	5.82	3.00	12.00
L2	87	21.525	15.71	3.60	14.40
L3	123	35.364	13.84	3.00	12.00
L4	159	47.564	12.20	3.00	12.00
L5	195	56.899	9.34	3.00	12.00

Table-2: Floor drift for 50 % release

For 40 % release horizontal displacement is 48.84 which is less than permissible limit also the storey drift is within limits as shown in Table 3.

Level	Node	Displacement in mm	Floor Drift in mm	Floor Ht. in m	Per. Drift in mm
L0	15	0			
L1	51	5.207	5.21	3.00	3.00
L2	87	18.88	13.67	3.60	3.60
L3	123	30.56	11.68	3.00	3.00
L4	159	40.78	10.22	3.00	3.00
L5	195	48.85	8.07	3.00	3.00

Table-3: Floor drift for 40 % release

Therefore 40 % release case is finalized for individual joint designing.

6. Result and Discussion

Total weight of original structure designed with fixed joints was 75 tones. But for the structure designed with semi rigid connections for 40 % release weight coming is 67.38 tones. The actual saving is 7.62 tones i. e.10.16 %. The effectiveness of 40 % release is clearly seen in Table 4.

S. N.	% Release	Weight in M. T.	Maximum horizontal displacement in mm	Remark
1	0	72.97	32.11	High Weight
2	10	71.71	34.84	High Weight
3	20	70.07	38.35	High Weight
4	30	68.82	42.88	High Weight
5	40	67.38	48.84	Ok
6	50	65.23	56.9	Fail for Drift
7	60	62.88	68.23	Fail for Horizontal deflection
8	70	61.33	85.28	Fail for Horizontal deflection
9	80	62.76	114.27	Fail for Horizontal deflection
10	90	66.19	178.75	Fail for Horizontal deflection
11	100	75.32	476.89	Fail for Horizontal deflection

Table-4: Effectiveness of 40 % release

6.1 Validation

As per the study by K. Weynand, J. P. Jaspart, M. Steenhuison, Economy Studies of Steel Building Frames with Semi-Rigid Joints, it was observed that minimum cost of structure selected by them was coming for rigidity in between 40 % to 50 %. In present study the minimum cost is coming for 40 % release. In present study savings with respect to rigid joints is 7.66 %. Cost savings with respect to original building and with fixed joint design in present study is shown in Table 5. This validates our results.

S. N.	% Release	Weight in M. T.	Saving with Original Building Wt. (75 Tonnes)	Saving with Fully Fixed Joints (72.97 Tonnes)
1	0	72.97	2.71 %	0.00 %
2	10	71.71	4.39 %	1.73 %
3	20	70.07	6.57 %	3.97 %
4	30	68.82	8.24 %	5.69 %
5	40	67.38	10.16 %	7.66 %
6	50	65.23	13.03 %	10.61 %

7	60	62.88	16.16 %	13.83 %
8	70	61.33	18.23 %	15.95 %
9	80	62.76	16.32 %	13.99 %
10	90	66.19	11.75 %	9.29 %
11	100	75.32	-0.43 %	-3.22 %

Table-5: Cost comparison in present study

7. Conclusion

After analysis and design following conclusion is obtained;

1. As we change the rigidity weight of the structure decreases up to 70 % release and then again starts increasing up to 100 % release.
2. The sway of the building increases from 0 % release to 100 % release. But after 60 % to 70 % release the sway increases drastically as shown from the Fig. 6.
3. Minimum weight comes for 70 % release but sway is more than permissible limits for 70 % release.
4. The condition satisfying both permissible sway and minimum weight is for 50 % release case.
5. But for 50 % release case criteria for drift is not satisfied as shown in Table 2 and Table 3.
6. For 40 % release case both criteria i. e. for maximum horizontal displacement and for drift are satisfied as shown in Table 1 and 3.
7. Saving of steel is about 7.62 tones i.e. 10.16 % when compared to original building and 5.59 tones i. e. about 7.66 % when compared with building designed with fixed joints.
8. Thus frame structures designed as a semi-rigid is possible and optimistic results can be easily achieved.

7.1. Future Scope

A hybrid structure of fixed and semi rigid joints can be designed in which few joints will be fixed and few joints will be semi-rigid. For example beam in the range of 4.5 to 6.0 m may have semi rigid joint and 3.0 or 3.5 m beam in the range of 3.0 m to 4.5 m may have rigid connections. Similarly type of connection can be varied. The results can be compared. Also in designing of semi-rigid joints use of spring washers can be explored.

7.2. Limitations

In present study for analysis STAAD.Pro V8i software were is used, software like ETABS or STRUDS were explored.

In STAAD.Pro V8i software, while assigning the sections, only predetermined sections have to be chosen. To assign section defined by user gives error. Also to give release as 0 % or 100 % it was necessary to give factor as 0.0001 or 0.999 instead of 0 and 1. Also for assigning seismic loads calculated joint weights have to be copied and assigned separately in STAAD editor.

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