# EFFECT OF CONNECTION RIGIDITY ON SEISMIC PERFORMANCE OF MULTISTOREYED STEEL FRAMES

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**ABSTRACT :** This paper presents the effect of connection rigidity on seismic performance of G+9 storeyed steel frame using ETABS software (Version 2016). Fixity factors are varied from 0 to 1 at an interval of 0.1. Fixity factor is taken as '1' and '0' respectively for rigid and flexible connections. Whereas for semi-rigid connections, fixity factor is varied from 0.1 to 0.9. The developed models are subjected to Response Spectrum Analysis as per IS 1893 (Part 1, 2002) codal guidelines. Similar variation of storey displacement and storey drift ratio are observed in both X and Y directions for all the fixity factors. Maximum storey shear is observed at the base of the developed steel frame. In both X and Y directions, maximum storey displacement (i.e. at top storey) increases with decrease in the values of fixity factors i.e. shifting from rigid to semi-rigid to flexible condition. From fixity factor 0.3 in X-direction and fixity factor 0.2 in Y-direction to zero fixity factor in both the directions, maximum storey drift ratio exceeds the allowable limit as specified by Cl. 7.11.1 of IS 1893 (Part 1, 2002). As the developed steel frame model shows variation in seismic parameters due to variation in fixity factors, connection rigidity should be considered in seismic analysis of steel structures.

**Keywords : Fixity factor, Rigid, semi-rigid and flexible connections, Response spectrum analysis, Storey displacement, Storey drift ratio and Storey shear.**

## 1. INTRODUCTION

Steel building is a metal structure and is fabricated with steel for the internal support and for exterior cladding as opposed to RCC buildings. Structural steel is fabricated with specific shape, size, gauge and chemical composition to suit for the project's applicable specifications. The steel sections are manufactured by hot or cold rolling and are connected by either welding or bolting. Shapes such as I-beam, Hollow structural sections, Channels, Angles and Plate are commonly used in steel structures. Steel structures are super-quick to build at site, easily expanded, easily repaired and retrofitted, and can be easily recycled. Steel structural components are flexible and are thus very good at resisting dynamic forces such as wind and earthquake forces. High rise buildings and industrial ware houses are constructed with steel structures due to high strength and low weight. Cold formed steel which is light in weight is widely used in residential buildings. However, fabrication and erection of steel structures requires time, skilled labours and also consistent maintenance as they are prone to corrosion in humid and marine environments. Further, steel structures analysis approach and assumptions should be quite clear and definitive prior to structural system formation.

## 2. TYPES OF BEAM-TO-COLUMN CONNECTIONS

AISC (American Institute of Steel Construction) classifies the beam-to-column connections under the following three types as

a) "Rigid Frames" or "Continuous Frames". The connection is assumed to have sufficient rigidity to prevent any rotation between the intersecting members.
b) "Simple Framing" or "Unrestrained Free-Ended". The ends of the members are assumed to be connected for shear only, thus allowing free rotation.
c) "Semi-Rigid Framing" or "Partially Restrained". The connections possess a dependable, and a known moment capacity intermediate between the rigid frames and simple frames. Figure 1 shows the types of beam-to-column connections.

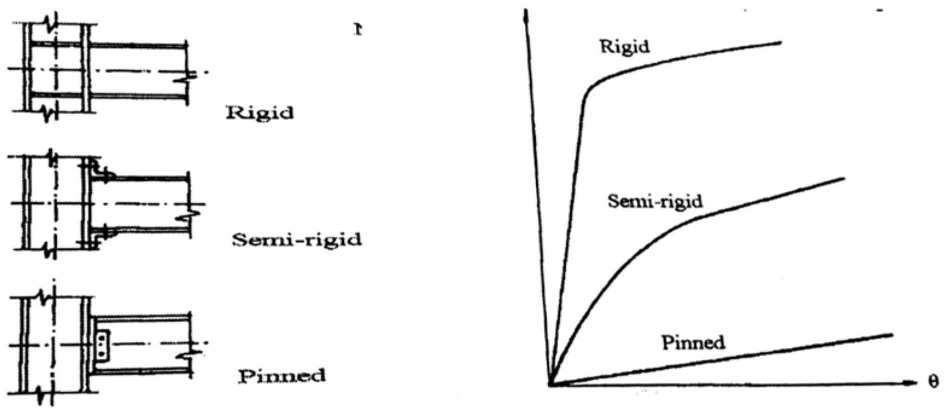


**Fig. 1 : Types of beam-to-column connections**

## 3. ASSUMPTIONS CONSIDERED IN THE DESIGN OF STEEL FRAMES

1. In beam designs, the beam-to-column connections are assumed to be rigid (i.e. fixed) or flexible (i.e. hinged or pinned) connected.

2. In column designs, the moments introduced due to frame action are often neglected.

3. For calculating lateral loads due to earthquake and wind forces, the beam-to-column connections are treated as rigid.

Although the above assumptions, save calculation time and result in safe structures, but they overlook the economy aspect. The structures should be designed in accordance to the way they actually behave i.e. support conditions usually lie in between flexible and rigid support. Thus the connection should be a semi-rigid connection. In the past, many investigations have been carried out on semi-rigid connections to determine the savings in steel quantity. It has been found that about 20% saving in weight can be achieved if the semi-rigid approach is adopted.

## 4. STEEL FRAME MODELS FOR ANALYSIS

Table 1 shows the parameters considered in the development and analyses of bare steel frame models.

**Table 1 : Parameters of developed steel frame models**

| Sl. No. | Description | Remarks |
|---|---|---|
| 1 | Structural type | Commercial |
| 2 | Total stories | 10 (G+9) |
| 3 | Total height of building | 35 m |
| 4 | Size of column | ISWB 600 @ 145.1 kg/m |
| 5 | Size of beam | ISWB 300 @ 48.1kg/m, ISMB 400 @ 61.6 kg/m and ISMB 600 @ 122.6 kg/m |
| 6 | Thickness of slab | 150 mm |
| 7 | Floor height | 3.5 m |

| | | |
|---|---|---|
| 8 | Grade of slab concrete | M25 |
| 9 | Live load | 4 kN/m$^2$ |
| 10 | Dead load | 1.5 kN/m$^2$ |
| 11 | Seismic zone | II |
| 12 | Soil type | Medium |
| 13 | Importance factor | 1.0 |
| 14 | Response reduction factor | 5 |
| 15 | Damping ratio | 5% |

Table 2 shows the details of steel frame models with various fixity factors.

**Table 2 : Details of steel frame models**

| Models | Fixity factors | Remarks |
|---|---|---|
| M1 | 1 | Rigid connection |
| M2 | 0.9 | Semi-rigid connection |
| M3 | 0.8 | |
| M4 | 0.7 | |
| M5 | 0.6 | |
| M6 | 0.5 | |
| M7 | 0.4 | |
| M8 | 0.3 | |
| M9 | 0.2 | |
| M10 | 0.1 | |
| M11 | 0 | flexible connection |

Figures 2 to 4 show the plan and 3D view of the developed steel frame models.

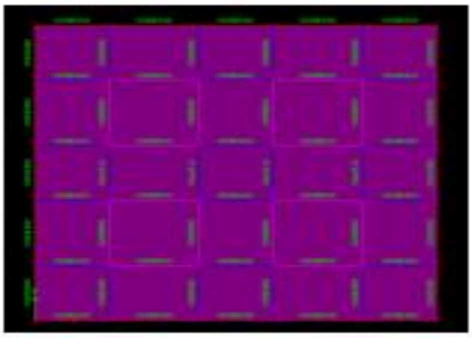
Fig. 2 (a) : Plan of rigid steel frame

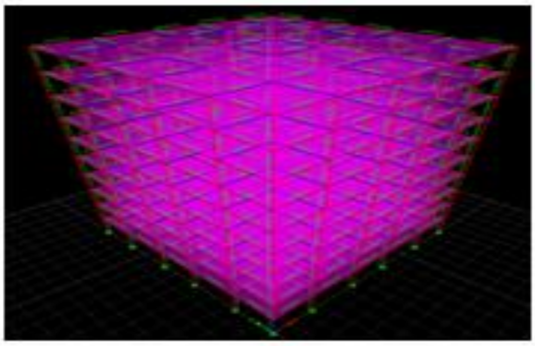
Fig. 2 (b) : 3D view of rigid steel frame

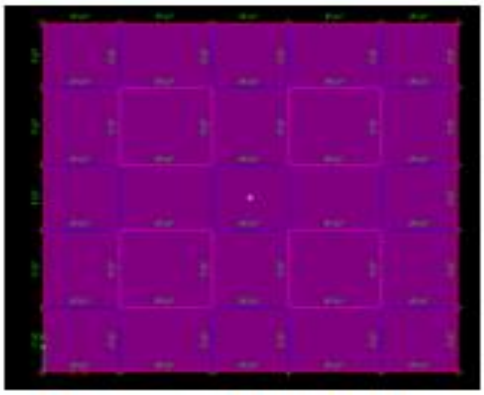
Fig. 3 (a) : Plan for semi-rigid steel frames

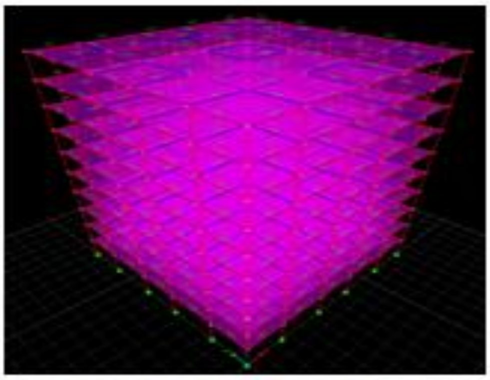
Fig. 3 (b) : 3D view for semi-rigid frames

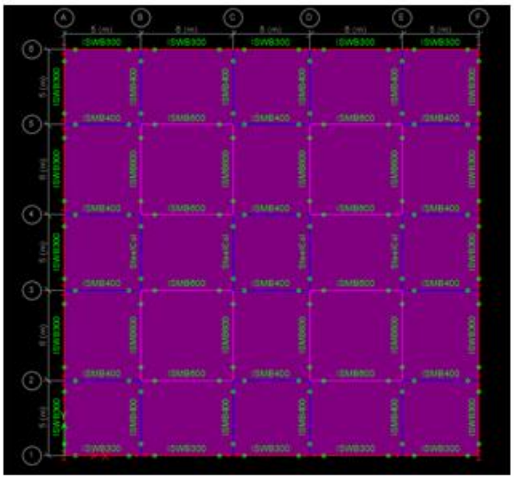
Fig. 4 (a) : Plan of flexible steel frame

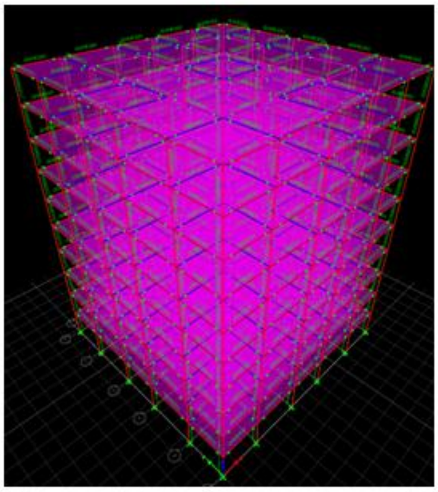
Fig. 4 (b) : 3D view of flexible steel frame

## 5. ASSIGNING FIXITY FACTORS IN ETABS SOFTWARE

One of the conventional methods of analysing a steel beam whose end restraints fall in between the idealized pinned and idealized fixed end is the concept of "End fixity factor". The fixity factor defines the rotational stiffness of the attached member. The end fixity factor '$r_i$' is given by

$$r_i = \frac{1}{1 + \frac{3EI}{R_i L}}$$

Where,

EI/L is the flexural stiffness of the attached member

Ri is the connection spring stiffness and is given by

$$R_i = \frac{3EI}{L}\left(\frac{r_i}{1 - r_i}\right)$$

Table 4 shows the values of rotational spring stiffness ($R_i$) obtained for various steel sections considered in present study.

**Table 4 : Rotational spring stiffness of beam sections for different fixity factors**

| Fixity factor | Rotational spring stiffness ( $R_i$ ) kN-m / rad | | | |
|---|---|---|---|---|
| | ISWB 300 | ISWB 300 | ISMB 400 | ISMB 600 |
| | Clear span of beam | | | |
| | 5m | 6m | 5m | 6m |
| 0.1 | 1374.80 | 1145.67 | 2864.18 | 10711.52 |
| 0.2 | 3093.30 | 2577.75 | 6444.40 | 24100.91 |
| 0.3 | 5302.80 | 4419.00 | 11047.54 | 41315.85 |
| 0.4 | 8248.80 | 6874.00 | 17185.06 | 64269.10 |
| 0.5 | 12373.20 | 10311.00 | 25777.58 | 96403.65 |
| 0.6 | 18559.80 | 15466.50 | 38666.38 | 144605.48 |
| 0.7 | 28870.80 | 24059.00 | 60147.70 | 224941.85 |
| 0.8 | 49492.80 | 41244.00 | 103110.34 | 385614.60 |
| 0.9 | 111358.80 | 92799.00 | 231998.26 | 867632.85 |

The semi-rigid connections of steel frame are incorporated in ETABS software (Version 2016) by using partial fixity factor or equivalent rotational spring stiffness. The structure with semi-rigid connections are modelled using the joint releases. The user can either choose to completely release the moment transfer between connected elements or to specify a partial fixity factor. Figure 5 shows the typical view of assigning fixity factors in ETABS software to simulate semi-rigid beam-to-column connections.

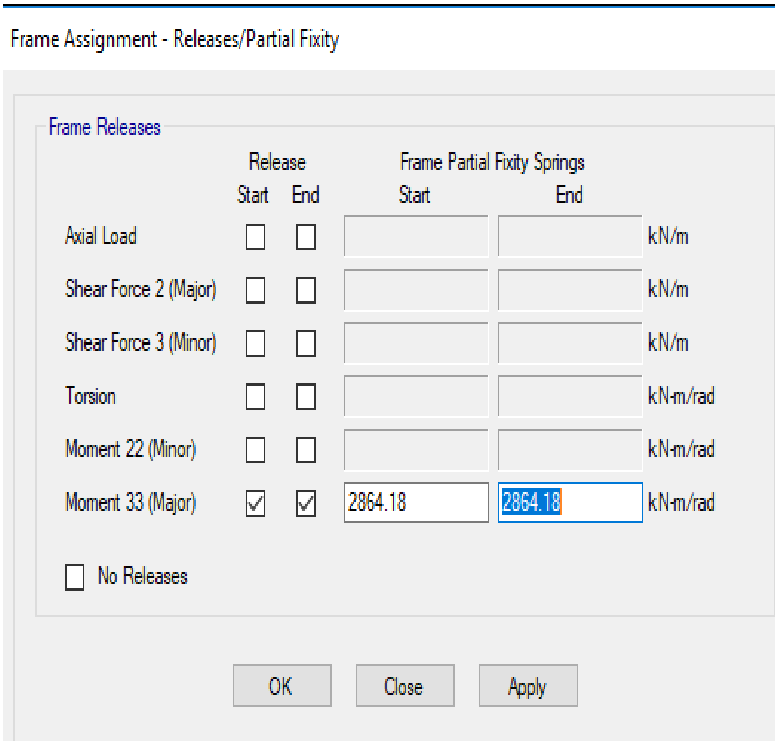


**Fig. 5 : Assigning fixity factors in ETABS software**

## 6. SEISMIC ANALYSIS OF DEVELOPED STEEL FRAME MODELS

Using ETABS software (Version 2016), the developed steel frame models are subjected to Response Spectrum Analysis (RSA) as per IS 1893 (Part 1, 2002) codal guidelines. Seismic parameters viz. storey displacement, storey drift ratio and storey shear values are obtained for all the developed steel frame models.

## 7. RESULTS AND DISCUSSION

Figures 6 and 7 show respectively the variation of storey displacement for all the fixity factors predicted by RSA in X and Y directions.

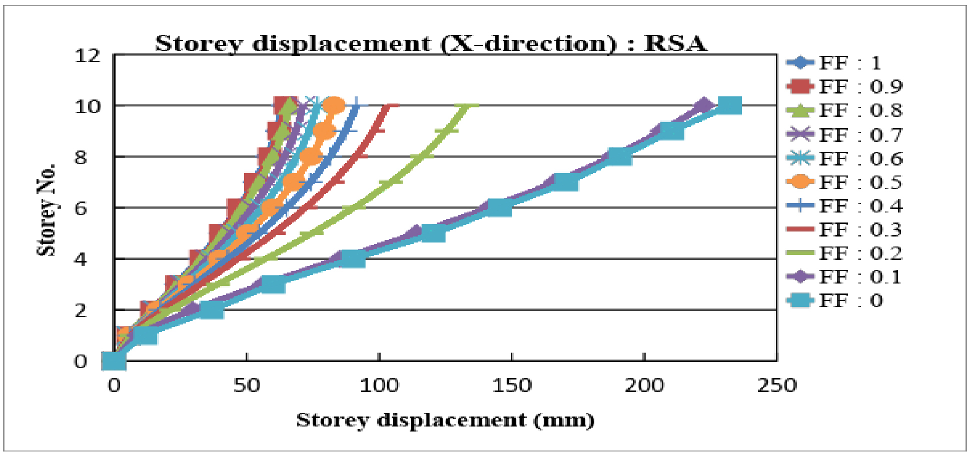


**Fig. 6 : Variation of storey displacement for all the fixity factors predicted by RSA in X-direction**

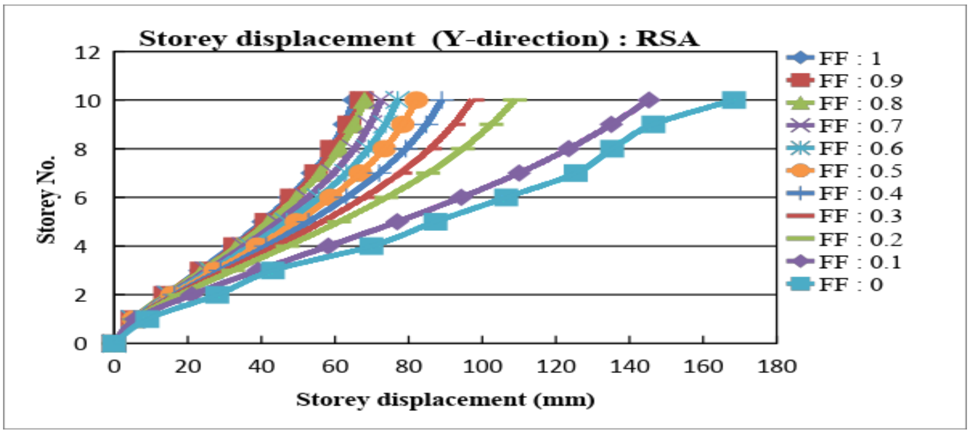


**Fig. 7 : Variation of storey displacement for all the fixity factors predicted by RSA in Y-direction**

From Figs. 6 and 7, it can be observed that all the steel frame models show similar variation of storey displacement in both X and Y directions.

Figures 8 and 9 show respectively the variation of storey drift ratio for all the fixity factors predicted by RSA in X and Y directions.

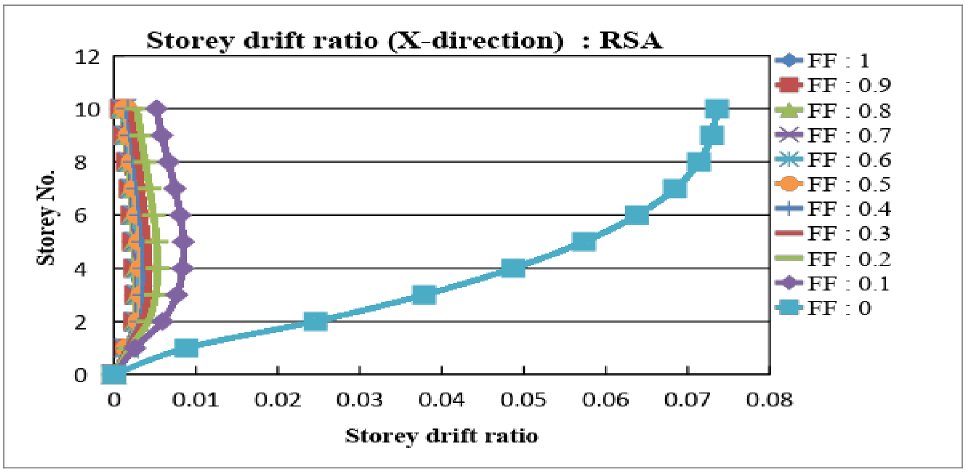


**Fig. 8 : Variation of storey drift ratio for all the fixity factors predicted by RSA in X-direction**

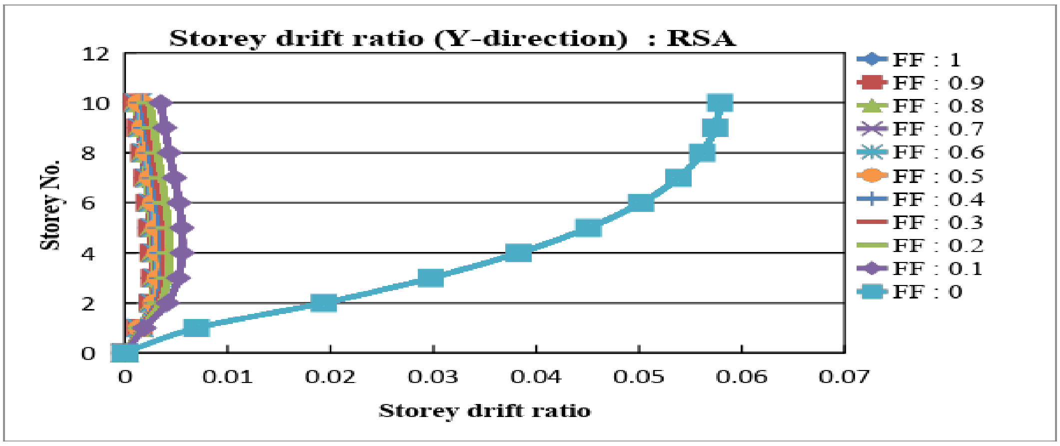


**Fig. 9 : Variation of storey drift ratio for all the fixity factors predicted by RSA in Y-direction**

From Figs. 8 and 9, it can be seen that all the steel frame models show similar variation of storey drift ratios in both X and Y directions.

Figure 10 shows the variation of storey shear over the number of storeys for the developed steel frame model. Maximum storey shear is observed at the base of the developed steel frame.

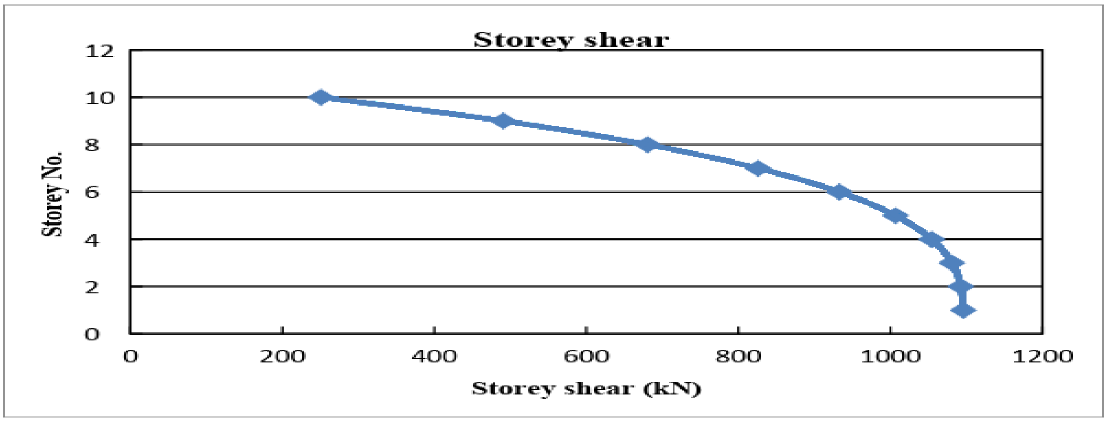


**Fig. 10 : Storey shear values**

Figures 11 and 12 show respectively the maximum storey displacements (i.e. at top storey) predicted by RSA for all the fixity factors in X and Y directions.

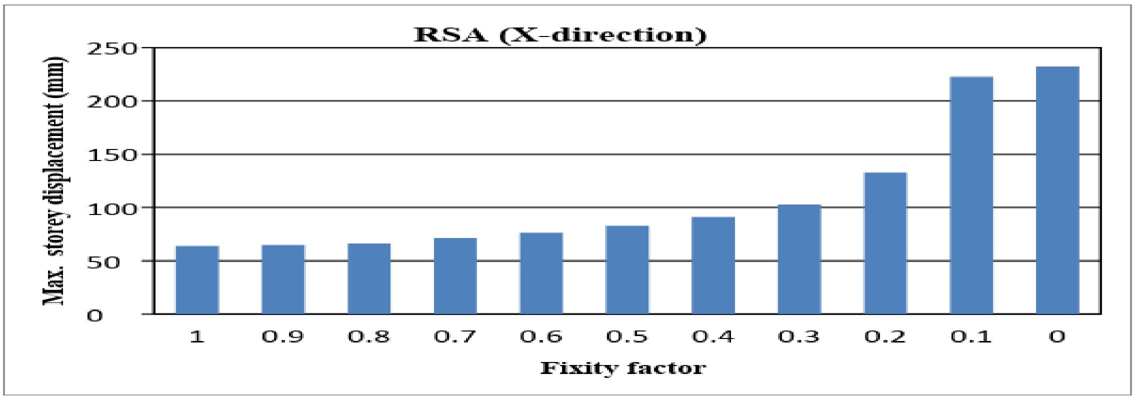


**Fig. 11 : Maximum storey displacement predicted by RSA in X-direction**

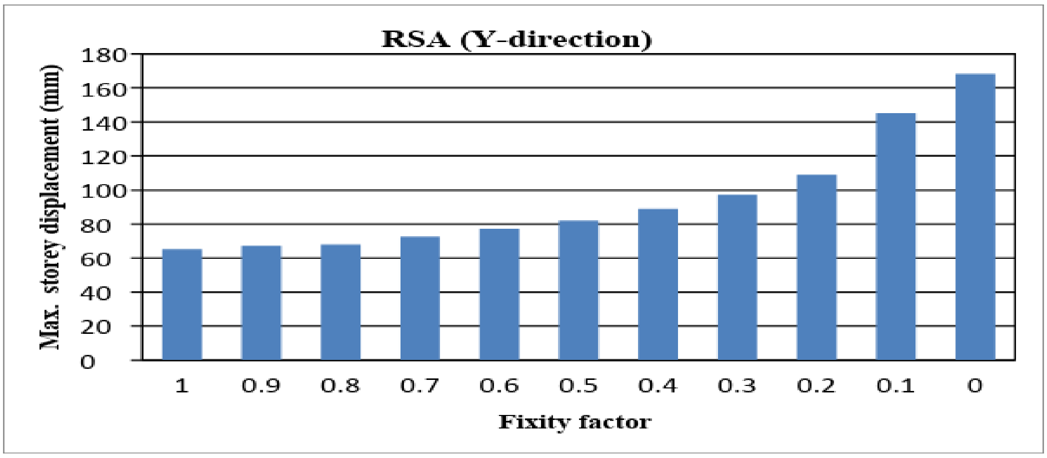

**Fig. 12 : Maximum storey displacement predicted by RSA in Y-direction**

From Figs. 11 and 12, it is inferred that in both X and Y directions, maximum storey displacement increases with decrease in the values of fixity factors i.e. shifting from rigid to semi-rigid to flexible condition.

Figures 13 and 14 show respectively the maximum storey drift ratios predicted by RSA for all the fixity factors in X and Y directions.

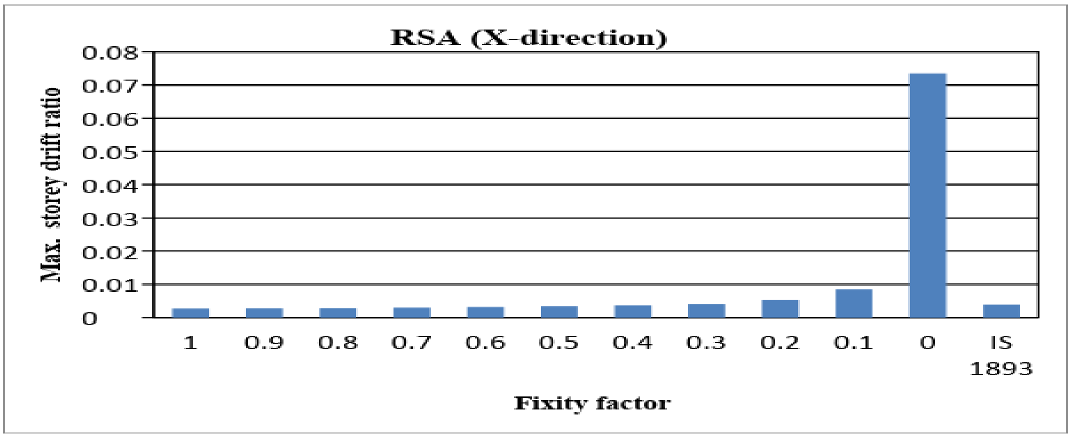


**Fig. 13 : Maximum storey drift ratio predicted by RSA in X-direction**

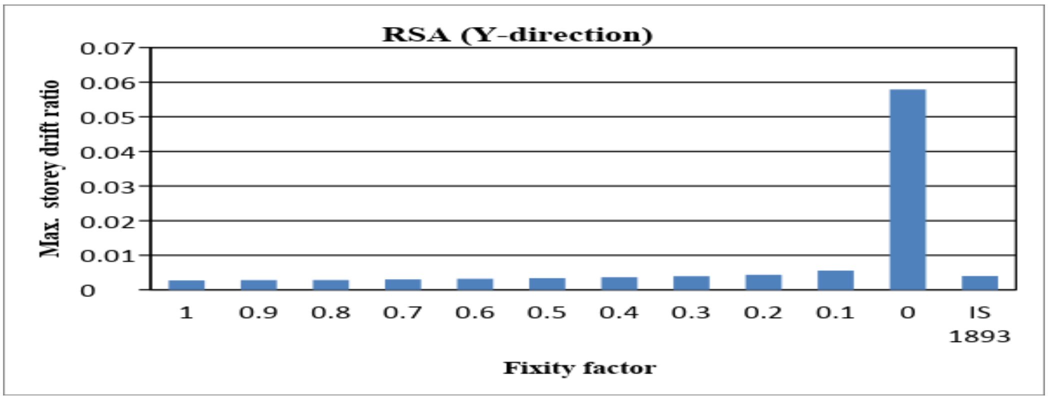


**Fig. 14 : Maximum storey drift ratio predicted by RSA in Y-direction**

From Figs. 13 and 14, it can be inferred that, from fixity factor 0.3 (semi-rigid connection) in X-direction and fixity factor 0.2 (semi-rigid connection) in Y-direction to zero fixity factor (flexible) in both the directions, maximum storey drift ratio exceeds the allowable limit (i.e. 0.004) as specified by Cl. 7.11.1 of IS 1893 (Part 1, 2002).

## CONCLUSIONS

In the present study, G+9 storeyed steel bare frame models with different fixity factors are developed using ETABS software (Version 2016). Fixity factors are varied from 0 to 1 at an interval of 0.1. Fixity factor is taken as '1' and '0' respectively for rigid and flexible connection. Whereas for semi-rigid connections, fixity factor is varied from 0.1 to 0.9. The developed models are subjected to Response Spectrum Analysis considering IS 1893 (Part 1, 2002) codal guidelines.

The important conclusions drawn from the present study are summarized below.

1. RSA predict similar variation of storey displacement and storey drift ratio in both X and Y directions for all the fixity factors.
2. Maximum storey shear is observed at the base of the developed steel frame.
3. In both X and Y directions, maximum storey displacement (i.e. at top storey) increases with decrease in the values of fixity

factors i.e. shifting from rigid to semi-rigid to flexible condition.

4. From fixity factor 0.3 (semi-rigid connection) in X-direction and fixity factor 0.2 (semi-rigid connection) in Y-direction to zero fixity factor (flexible) in both the directions, maximum storey drift ratio exceeds the allowable limit (i.e. 0.004) as specified by Cl. 7.11.1 of IS 1893 (Part 1, 2002).

**Concluding Remarks :** As the developed steel frame model shows variation in seismic parameters due to variation in fixity factors (which represent rigid, semi-rigid and flexible beam-to-column connections), connection rigidity should be considered in seismic analysis of steel structures.

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