

# Comparative Analysis of Steel Structure with Rigid and Semi Rigid Joints Using Analysis Tool ETABS

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# ABSTRACT

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## Article History

Accepted : 01 June 2022 Published : 10 June 2022 Generally, in steel structure the connection between beam and column are designed as moment connection and pinned connection, but in actual condition the structure behaves between these two conditions, resulted into semi-rigid condition which is intermediate stage between rigid and pinned joints. Effect of semi-rigid connection on multi-story multi-bay frame is accomplished in this paper. The present study introduces the effect of static and dynamic loading on high rise steel structure of G+12 story with 4m, 6m and 8m three bay span length. Structure is analyzed under two different condition of partial release of semi-rigid connections which is derived by fixity factor of values 0.5 and 0.75 in this study. The analysis is done commercially available software ETABS. From the non-linear analysis, the story displacement and story drift are obtained. The overall performance of the structure from the analysis, semi-rigid joints display more story displacement and story drift compared to rigid joints. To overcome the results, bracing system is introduced at different location of periphery of structure. These brace frame structure consist of X- bracing and diagonal bracing. Again, comparative analysis is to be performed in ETABS on these three-bay span lengths. It is found that braced semi-rigid frame structure perform quite well as compared to unbraced frame structure.

Keywords: Multi-story Multi-bay frame, Semi-rigid connections, Fixity factor, Brace frame, Rigid Connections.

# I. INTRODUCTION

The 2001 Bhuj earthquake of India was an eye opener. It made thousands of people lose their lives and rendered millions to lose their houses. The effect was so wide spread that it not only affected the people in the vicinity of the epicenter but also those living in a metro city Ahemdabad, about 250 km away from the epicenter were badly affected. A major damage was observed in RC framed structures which were in the range of G+3 to G+ 7 storeys. Further, most of the buildings were having a normal grid of 3m x 3m column spacing with a standard storey height of 3m. One important parameter concerned with the seismic behavior is the storey drift which should not exceed a

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permissible value. This fact is evident from the inclusion of a clause related to specifying a permissible value of storey drift in all country codes related to earthquake engineering including the Indian code IS 1893, 2002.

Types of Steel Beam Connections

Steel beam connections can likewise be required for slanted joints, pillars unusual to sections and association with segment networks. These are classed as extraordinary connections and are treated separately. Steel beam connections come up with various sorts. Presently steeloncall have given the explanation of the considerable number of sorts of steel beam connections in the below section.

# Bolted framed connections

Regularly, the connection is planned dependent on the heaps toward the end of the beam. It is required to take quality, type and size of latches and quality of base materials into thought while the connection is designed. The minimum length of connection angle ought to be at any rate half of the bar clear web profundity. This measure is indicated to guarantee adequate firmness and soundness. There are different standard sizes of bolted framed connections along with their ability given by codes. The reason for such institutionalized associations is to speed up the plan.



Fig 1 Bolted Framed Connections

## II. Objectives of the research

It is proposed to carryout analysis of multistory 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.

- To determine the stability of structure with rigid and semi rigid joints
- To determine the utilization of analysis tool etabs in analysis of a high rise steel structure under seismic loading.
- To determine the variations in forces and stresses in both the cases in comparison.
- To determine the stability of structure with x type bracing at the corner.

## **III. LITERATURE REVIEW**

Alfredo Reyes-Salazar et al (2014) research paper investigated nonlinear seismic responses of 3D steel buildings with perimeter moment resisting frames (PMRF) and interior gravity frames (IGF), explicitly considering the contribution of the IGF. The effect on the structural response of the stiffness of the beam-tocolumn connections of the IGF, which is usually neglected, was further studied. It is commonly believed that the flexibility of shear connections is negligible and that 2D models can be used to properly represent 3D real structures.

Results stated that the moments developed on columns of IGF can be considerable and that modelling buildings as plane frames may result in very conservative designs. The contribution of IGF to the lateral structural resistance may be significant. The contribution increases when their connections are assumed to be partially restrained (PR). The



incremented participation of IGF when the stiffness of their connections is considered helps to counteract the no conservative effect that results in practice when lateral seismic loads are not considered in IGF while designing steel buildings with PMRF. Thus, if the structural system under consideration is used, the three-dimensional model should be used in seismic analysis and the IGF and the stiffness of their connections should be considered as part of the lateral resistance system.

Harsh Rana et al (2020) research paper introduced the effect of static and dynamic loading on high rise steel structure of G+15 story with 4m, 6m and 8m three bay span length. Structure is analyzed under two different condition of partial release of semi-rigid connections which is derived by fixity factor of values 0.5 and 0.75 (as per AISC) in this study. The analysis commercially available was done software-STAAD.Pro. From the non-linear analysis, the story displacement and story drift was obtained. The overall performance of the structure from the analysis, semi-rigid joints display more story displacement and story drift compared to rigid joints. To overcome the results, bracing system was introduced at different location of periphery of structure. These brace frame structure consist of X- bracing and diagonal bracing. Comparative analysis was performed in STAAD.Pro on these three-bay span lengths. It is found that

braced semi-rigid frame structure perform quite well as compared to unbraced frame structure.

Results stated that lateral displacement in semi-rigid connection is more than rigid connections as well as increasing in bay length. Reduction in results with increasing the flexibility of connection about fixity factor '0.75' as compare to fixity factor '0.5'. As span increase the more lateral displacement observed. To overcome this effect the bracing system is used to improve the lateral stability of structure. The analysis results of X-braced frame have indicated more lateral stability than diagonal braced frame. In the overall seismic analysis of high-rise structure, corner and full perimeter braced frame enhance to give least lateral displacement and drift comparing with middle braced frame.

#### IV. METHODOLOGY

Step 1- The first step in general is to review research papers from different authors or to identify the problem statement and the remedies adopted from different researchers. The review of the papers were summarized in section two.

Step 2- The grid system are defined from the predefined template or even provides the option to customize it as per the stature of the desired structure. The model is designed as per model initialization to define the unit and IS codes.

Model Initialization		;	×
Initialization Options			
O Use Saved User Default Settings		0	
O Use Settings from a Model File		0	
Use Built-in Settings With:			
Display Units	Metric SI	~ 🚺	
Steel Section Database	Indian	$\sim$	
Steel Design Code	IS 800:2007	~ <b>()</b>	
Concrete Design Code	IS 456:2000	~ ()	
ОК	Cancel		

Fig 2 Model Initialization

Step 3- the grip matrix for the structure is designed as per the quick template available in analytical application ETABS. The grid is defined in X and Y direction whereas the storey height is defined in Z direction.

ETABS 2016 Ultimate 16.1.0 - (Untitled)					- 0	×
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2	Mew Model Quick Templates			×		
	Grid Dimensions (Plan)		Story Dimensions			
	O Uniform Grid Spacing		Simple Story Data			
X	Number of Grid Lines in X Direction		Number of Stories	12		
1	Number of Grid Lines in Y Direction		Typical Story Height	3 m		
	Spacing of Grids in X Direction		Bottom Story Height	3 m		
	Spacing of Grids in Y Direction					
Γ.	Specify Grid Labeling Options	Grid Labels				
	Custom Grid Spacing		O Custom Story Data			
	Specify Data for Grid Lines	Edit Grid Data	Specify Custom Story Data	Edit Story Data		
14	Add Structural Objects					
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		81				
a1 <sup>R</sup>		ОК	Cancel			
PS <sup>®</sup>	1. 					
clr <sup>R</sup>						
12						
10						
8						

Fig 3 New Model Quick Template

id System Name			ange Option		Click to Modify				
G1			)efault		F	Reference Points		(A)	BCDE
stem Origin		_ οι	Jser Specified		F	Reference Planes		5	HH
Global X	0 m		Top Story		Options			4	
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ectangular Grids	d Data as Ordinates		)isplay Grid Data as S	òpacing	Grid Color		Quick Sta	nt New Rectangular	Grids
Display Grid			) isplay Grid Data as S Bubble Loc	òpacing		Y Ordinate (m)	Quick Sta	nt New Rectangular	Grids
<ul> <li>Display Grid</li> <li>X Grid Data</li> </ul>	d Data as Ordinates	0 0		Spacing	Y Grid Data	Y Ordinate (m) 0			Grids
<ul> <li>Display Grid</li> <li>X Grid Data</li> <li>Grid ID</li> </ul>	d Data as Ordinates X Ordinate (m)	) [ Visible	Bubble Loc	Add	Y Grid Data Grid ID		Visible	Bubble Loc	Add
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Display Grid     X Grid Data     Grid ID     A     B	d Data as Ordinates X Ordinate (m) 0 4	Visible Yes Yes	Bubble Loc End End	Add	Y Grid Data Grid ID 1 2	0	Visible Yes Yes	Bubble Loc Start Start	Add

Fig 4 Grid System Data.

Step 4- this step involves the properties of material as here in this case, a steel structure is considered and the properties of steel is defined.

General Data				
Material Name	Fe345			
Material Type	Steel		$\sim$	
Directional Symmetry Type	Isotropic		$\sim$	
Material Display Color		Change		
Material Notes	Modi	fy/Show Notes		
Material Weight and Mass				
Specify Weight Density	O Spe	ecify Mass Density		
Weight per Unit Volume		76.9729	kN/m³	
Mass per Unit Volume		7849.047	kg/m³	
Mechanical Property Data				
Modulus of Elasticity, E		210000	MPa	
Poisson's Ratio, U		0.3		
Coefficient of Thermal Expansion,	Α	0.0000117	1/C	
Shear Modulus, G		80769.23	MPa	
Design Property Data				
Modify/Show	Material Property	y Design Data		
Advanced Material Property Data				
Nonlinear Material Data		Material Damping Pr	operties	
Time		perties		

Fig 5 Properties of Steel



Step 5- Defining section properties for the steel frame and steel slab where the sections are defined for steel beams and columns.

General Data				
Property Name	ISMB150			
Material	Fe345		~	2
Display Color		Change		3
Notes	Modify/Show Notes			ě –
Shape				
Section Shape	Steel I/Wide F	lange	$\sim$	
Section Property Source				
Source: Indian	Conver	t To User Defined		
Section Dimensions				Property Modifiers
Total Depth		150	mm	Modify/Show Modifiers
		80		Currently Default
Top Flange Width			mm	
Top Flange Thickness		7.6	mm	
Web Thickness		4.8	mm	
Bottom Flange Width		80	mm	
Bottom Flange Thickness		7.6	mm	
Fillet Radius		0	mm	ОК
	ow Section Properties			Cancel

Fig 6: Frame Section Property Data for Wide Flange

General Data			
Property Name	ISNB50M		
Material	Fe345	~	2
Display Color	Change		3
Notes	Modify/Show Notes		
Shape			
Section Shape	Steel Pipe	$\sim$	
Section Property Source			
Source: Indian	Convert To User Defined		
Section Dimensions			Property Modifiers
Outside Diameter	60.3	mm	Modify/Show Modifiers
Wall Thickness	3.6		Currently Default
			ОК
	Show Section Properties		Cancel

Fig 7: Bracing Frame Section



eneral Data				
Property Name	ISMB200			
Material	Fe345		~	2
Display Color		Change		3
Notes	Modify	/Show Notes		<
hape				
Section Shape	Steel I/Wide FI	ange	$\sim$	
ection Property Source				
Source: Indian	Convert	To User Defined		
ection Dimensions				Property Modifiers
Total Depth		200	mm	Modify/Show Modifiers
Top Flange Width		100	mm	Currently Default
		10.8		
Top Flange Thickness			mm	
Web Thickness		5.7	mm	
Bottom Flange Width		100	mm	
Bottom Flange Thickness		10.8	mm	
Fillet Radius		0	mm	ОК
	w Section Properties			Cancel

Fig 8: Frame Section Property Data for Wide Flange (ISMB 200)

General Data	
Property Name	Slab1
Slab Material	Fe345 🗸
Notional Size Data	Modify/Show Notional Size
Modeling Type	Shell-Thin 🗸
Modifiers (Currently Default)	Modify/Show
Display Color	Change
Property Notes	Modify/Show
Type Thickness	Slab ~ 100 mm

Fig 9: Slab Property Data

Step 6 Defining properties for Rigid Joints and Semi RIgid Joints for the steel structure

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Link/Support Pr	roperty Name	Stiffness	Values Used F	or All Load Cases				
RIGID JOINT		۲	Stiffness Is	Uncoupled		O Stiffness Is	Coupled	
		_	U1	U2	U3	R1	R2	R3
Directional Con	trol		Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Direction	Fixed							
✓ U1	Ves							
✓ U2	Ves							
<b>₩</b> U3	Ves							
✓ R1	Ves	Damaina \	/aluan Lland E	or All Load Cases				
✓ R2	Ves					O Damping Is	Coupled	
🖂 R3	Ves		U1	U2	U3	R1	R2	R3
			Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Shear Distance	•							
U2	m							
U3	m							
	ce is measured to J-End of the							

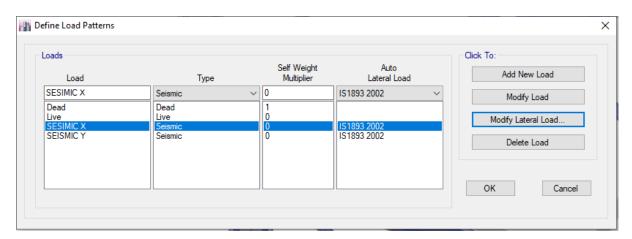
Fig 10: Rigid Joints

.ink/Support P	roperty Name	Stiffness Va	lues Used	For All Load Case	s			
SEMI-RIGID .	JOINT	۲	Stiffness	Is Uncoupled		O Stiffness	Is Coupled	0
			U1	U2	U3	R1	R2	R3
Directional Cor	itrol		Fixed	0	Fixed	Fixed	0	Fixed
Direction	Fixed							
V1	Ves							
✓ U2	Yes							
<b>₩</b> U3	Ves							
🗹 R1	Ves							
✓ R2	Yes			For All Load Cases s Uncoupled		O Damping	ls Coupled	0
🗹 R3	Ves		U1	U2	U3	R1	R2	R3
			Fixed	0	Fixed	Fixed	0	Fixed
Shear Distance	e							
U2 0	m							
U3	m							
Note: Distan	ce is measured							
	t to J-End of the							

# Fig 11: Semi Rigid Joints

Step 6 Defining loading conditions and load patterns assigned to the frame of the structure.





# Fig 12: Defining Load Pattern

Load Case Name		SESIMIC	×		Desire	
Load Case Name		SESIMIC	^		Design	
Load Case Type	Load Case Type		Linear Static 🗸 🗸			
Exclude Objects in this Grou	qu	Not Appli	cable			
Mass Source		MsSrc1				
-Delta/Nonlinear Stiffness	inge N. 1	- Karal -		Madifa /Cha		
Use Preset P-Delta Sett Note: Nonlinear ca	ase option for P-Delt	ative based on ta does not app		Modify/Show et P-Delta is		
Ose Preset P-Delta Sett	ase option for P-Delt					
Use Preset P-Delta Sett Note: Nonlinear ca	ase option for P-Delt					
Use Preset P-Delta Sett Note: Nonlinear ca noniterative based	ase option for P-Delt on mass.				0	
Use Preset P-Delta Sett Note: Nonlinear ca noniterative based bads Applied	ase option for P-Delt on mass.	ta does not app		et P-Delta is	<b>1</b> Add	
<ul> <li>Use Preset P-Delta Sett</li> <li>Note: Nonlinear canoniterative based</li> <li>Dads Applied</li> <li>Load Type</li> </ul>	ase option for P-Delt on mass. Loa	ta does not app	ly when Pres	et P-Delta is		
<ul> <li>Use Preset P-Delta Sett</li> <li>Note: Nonlinear canoniterative based</li> <li>Dads Applied</li> <li>Load Type</li> <li>Acceleration</li> </ul>	ase option for P-Delt on mass.	ta does not app d Name	ly when Pres	et P-Delta is	Add	

Fig 13: Load Case Data



Direction and Eccentricity		Seismic Coefficients			
<ul> <li>✓ X Dir</li> <li>✓ X Dir + Eccentricity</li> <li>✓ X Dir - Eccentricity</li> <li>Ecc. Ratio (All Diaph.)</li> <li>Overwrite Eccentricities</li> </ul>	Y Dir Y Dir + Eccentricity Y Dir - Eccentricity 0.05 Overwrite	Seismic Zone Factor, Z <ul> <li>Per Code</li> <li>User Defined</li> </ul> Site Type Importance Factor, I		0.36 III 1.5	~
Story Range		Time Period			
Top Story	Story12 V	<ul> <li>Approximate</li> </ul>	Ct (m) =		
Bottom Story	Base 🗸	Program Calculated			
Factors		O User Defined	Τ=		sec
Response Reduction, R	5				

Fig 14: Seismic Load Patterns as per IS 1893:2002.

Step 8- Analyzing the model on parameters of displacement, shear force, bending moment and Joint Analysis.

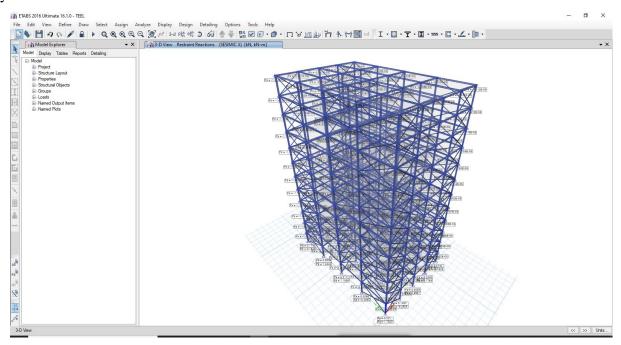


Fig 15: Joint Output



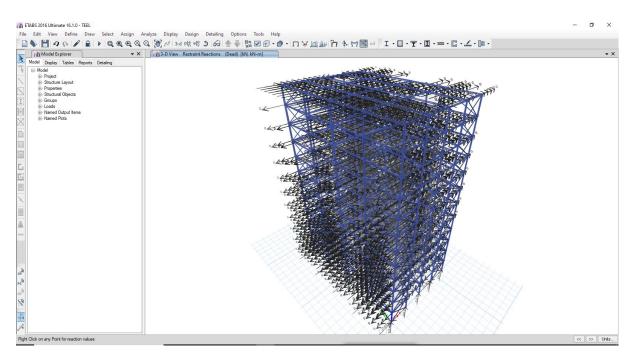


Fig 16: Joint Analysis

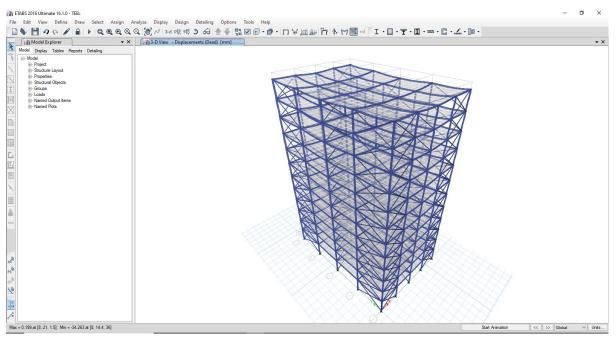


Fig 17: Displacement

Step 9- This last step is to present the comparative analysis of steel structure with two different joints namely rigid and semi rigid joints. The results will be tabulated and presented graphically in section 5.

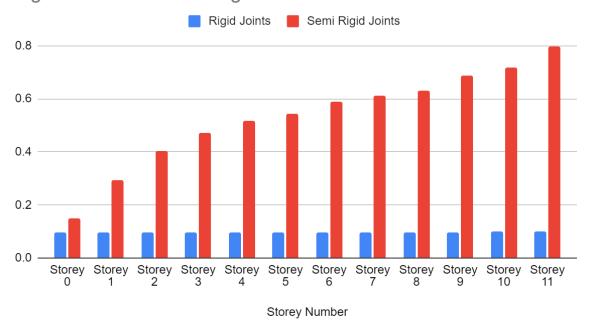
Structural type	Commercial	
Total stories	12 (G+11)	
Total height of building	42 m	

 Table 1: Parameters of developed steel frame models



Size of column	ISWB 600 @ 145.1 kg/m		
Size of beam	ISWB 300 @ 48.1kg/m, ISMB 400 @ 61.6 kg/m and ISMB 600 @ 122.6 kg/m		
Thickness of slab	150 mm		
Floor height	3.5 m		
Grade of slab concrete	M25		
Live load	4 kN/m2		
Dead load	1.5 kN/m2		
Seismic zone	V		
Soil Type	Medium		
Importance factor	1		
Response reduction factor	5		
Damping ratio	5%		

# **ANALYSIS RESULT**



Rigid Joints and Semi Rigid Joints

Shear Force in kN						
Storey Number	Rigid Joints	Semi Rigid Joints				
Storey 0	11.98	11.02				
Storey 1	12.34	11.41				
Storey 2	12.96	11.77				
Storey 3	13.55	12.31				
Storey 4	11.03	11.33				
Storey 5	10.13	10.24				
Storey 6	8.49	8.79				
Storey 7	7.99	8.05				
Storey 8	6.67	6.75				
Storey 9	5.98	6.02				
Storey 10	5.21	5.28				
Storey 11	4.76	4.81				

Table	2:	Shearforce

## Table 3: axial force

Shear Force in kN						
Storey Number	Rigid Joints	Semi Rigid Joints				
Storey 0	11.98	11.02				
Storey 1	12.34	11.41				
Storey 2	12.96	11.77				
Storey 3	13.55	12.31				
Storey 4	11.03	11.33				
Storey 5	10.13	10.24				
Storey 6	8.49	8.79				
Storey 7	7.99	8.05				
Storey 8	6.67	6.75				
Storey 9	5.98	6.02				
Storey 10	5.21	5.28				
Storey 11	4.76	4.81				



## V. CONCLUSION

An Effort was made to evaluate the behavior of rigid and semi rigid connection. The performance point, storey drift and time period of the G+11 storied structure was evaluated with respect to rigid and semi rigid connection. Based on Analytical results, following conclusion can be drawn.

- Semi rigid connections show enhanced performance to the number of steps, 16% higher displacement, at a considerably greater base shear which helps to prove analytically that semi rigid connections are better replacement for hinged and fixed connections which are down by 2% and 16% respectively.
- It also indicates the collapse point of the various models analytically and it is shown that the collapse point for semi rigid structures are 2% higher than the hinged structures and more than 20% higher than fixed structures.
- from the performance point for hinged connection is seen to be higher than the performance point for fixed and semi rigid connections, but as the loading proceeds towards the collapse point, the semi rigid connections show a greater yield for base shear than the hinged and fixed connections.
- It shows us significant readings in terms of base shear and displacement. The base shear in fixed frames are the highest followed by the semi rigid model frames and the hinged frames. The following observation thus implying that fixed frames collapse after reaching the particular saturation point.
- From the modal analysis the time period is increased for the semi rigid by 36% whereas it is decreased by 34% for hinged models and very less for fixed models by 17%
- Table 3 gives us the drift ratio for the various models and shows us that the drift ratio is 1.5% for the hinged models while it comes up to 3%

for semi rigid models and it take only 1% for rigid models.

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