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EFFECT OF BRACINGS IN CONTROLLING THE STRUCTURAL RESPONSE UNDER SEISMIC FORCE

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ABSTRACT

The Buildings, which appeared to be strong enough, may crumble like houses of cards during earthquake and deficiencies may be exposed. Experience gain from the recent earthquake of Bhuj, 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of the present-day codes. In last decade, four devastating earthquakes of world have been occurred in India, and low to mild intensities earthquakes are shaking our land frequently. It has raised the questions about the adequacy of framed structures to resist strong motions, since many buildings suffered great damage or collapsed. To evaluate the performance of framed buildings under future expected earthquakes, a non-linear static pushover analysis has been done. To achieve this objective, G+10 structure with and without bracings of 4 models have been analyzed using the SAP2000 v16 software. The results in terms of Base Shear, displacements, Time Period, Location of Hinges and Pushover curve were compared.

The results obtained from the study shown that structure with bracings placed in the center has improved performance than other bracing arrangements.

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1. INTRODUCTION

A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to take in to account the seismic load for the design of structures. In buildings, the lateral loads due to earthquake are a matter of concern. These lateral forces may produce critical stresses in the structure, induce undesirable stresses in the structure, induce undesirable vibrations or cause excessive lateral sway of the structure.

Sway or drift is the magnitude of the lateral displacement at the top of the building relative to its base. Traditionally, seismic design approaches are stated, as the structure should be able to ensure the minor and frequent shaking intensity without sustaining any damage, thus leaving the structure serviceable after the event.

The structure should withstand moderate level of earthquake ground motion without structural damage, but possibly with some structural as well as non-structural damage. This limit state may correspond to earthquake intensity equal to the strongest either experienced or forecast at the site. In present study, the results were obtained for pushover analysis. The main parameters considered in this study to compare the seismic performance of a structure with and without steel braces.

2. OBJECTIVES OF THE STUDY

In the present study, following objectives were set:

- In this work, the study on seismic behavior of G+10 RC structure with and without Bracings for Gravity loads using Pushover analysis has been done using sap2000.
- To study the response in terms of displacements and base shear for buildings.
- Default hinge properties as in sap2000 were used for assigning hinges to beams and columns. The response of Multi storied building (G+10) in terms of displacements and base shear were determined.
- Push over curve and Hinge locations were determined by using Push over analysis.

3. METHODOLOGY

3.1. GENERAL

There are different methods available for the analysis of framed structures subjected to earthquake loads. The methods of analysis can be broadly classified into the following types.

- Linear Static Method (Equivalent Static Method)
- Linear Dynamic method (Response Spectrum and Linear Time History Method)
- Non-Linear Static Method (Pushover Analysis)
- Non-Linear Dynamic Method (Non-linear Time History Analysis)

Out of these four methods, in Linear static method, Equivalent Static & Time History and in Non-linear Static method, Pushover method is considered for studying the seismic performance of Structure with and without Bracings.

3.2. PUSH OVER ANALYSIS

Pushover analysis is defined as an analysis wherein a mathematical model directly incorporating the nonlinear load-deformation characteristics of individual components and elements of the building shall be subjected to monotonically increasing lateral loads representing inertia forces in an earthquake until a ‘target displacement’ is exceeded. Target displacement is the maximum displacement (elastic plus inelastic) of the building at roof expected under selected earthquake ground motion. Pushover analysis assesses the structural performance by estimating the force and deformation capacity and seismic demand using a nonlinear static analysis algorithm. The seismic demand parameters are global displacements (at roof or any other reference point), storey drifts, storey forces, and component deformation and component forces. The analysis accounts for geometrical nonlinearity, material inelasticity and the redistribution of internal forces. Response characteristics that can be obtained from the pushover analysis are summarized as follows:

- Estimates of force and displacement capacities of the structure. Sequence of the member yielding and the progress of the overall capacity curve.
- Estimates of force (axial, shear and moment) demands on potentially brittle elements and deformation demands on ductile elements.
- Estimates of global displacement demand, corresponding inter-storey drifts and damages on structural and non-structural elements expected under the earthquake ground motion considered.
- Sequences of the failure of elements and the consequent effect on the overall structural stability.
- Identification of the critical regions, where the inelastic deformations are expected to be high and identification of strength irregularities (in plan or in elevation) of the building.

Pushover analysis delivers all these benefits for an additional computational effort (modelling nonlinearity and change in analysis algorithm) over the linear static analysis. A typical pushover curve is shown in Fig 3.1.

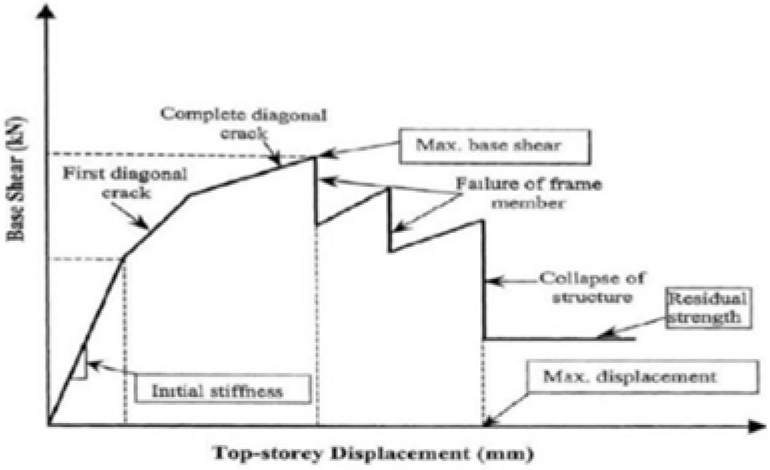
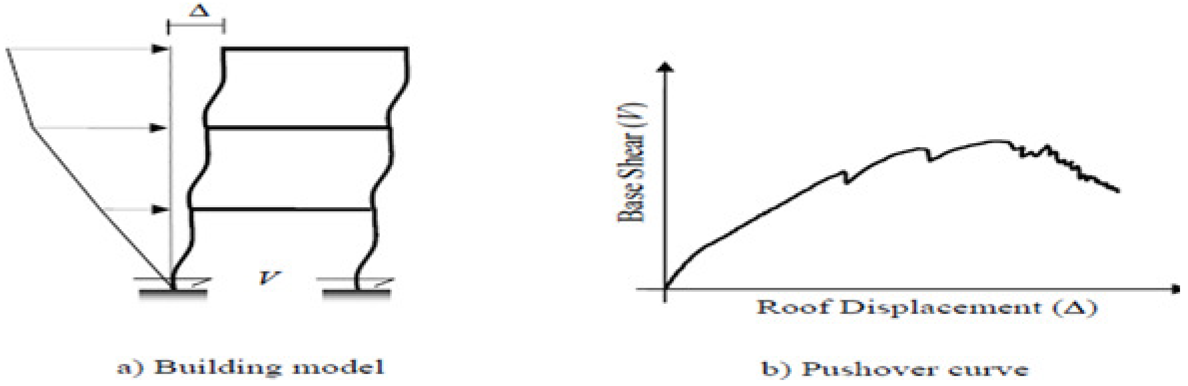


Figure 1 Idealized pushover Curve with salient features

3.2.1. Push Over Analysis Procedure

Pushover analysis is a static nonlinear procedure in which the magnitude of the lateral load is increased monotonically maintaining a predefined distribution pattern along the height of the building (Fig. 3.2 (a)). Building is displaced till the ‘control node’ reaches ‘target displacement’ or building collapses. The sequence of cracking, plastic hinging and failure of the structural components throughout the procedure is observed. The relation between base shear and control node displacement is plotted for all the pushover analysis (Fig. 3.2 (b)). Generation of base shear – control node displacement curve is single most important part of pushover analysis. This curve is conventionally called as pushover curve or capacity curve. The capacity curve is the basis of ‘target displacement’ estimation as explained in Section 3.4.4. So the pushover analysis may be carried out twice: (a) first time till the collapse of the building to estimate target displacement and (b) next time till the target displacement to estimate the seismic demand. The seismic demands for the selected earthquake (storey drifts, storey forces, and component deformation and forces) are calculated at the target displacement level. The seismic demand is then compared with the corresponding structural capacity or predefined performance limit state to know what performance the structure will exhibit. Independent analysis along each of the two orthogonal principal axes of the building is permitted unless concurrent evaluation of bidirectional effects is required.



a) Building model

b) Pushover curve

Figure 2 Schematic representation of pushover analysis procedure

The analysis results were sensitive to the selection of the control node and selection of lateral load pattern. In general, the center of mass location at the roof of the building is considered as control node. For selecting lateral load pattern in pushover analysis, a set of guidelines as per FEMA 356 is explained in Section 3.4.3. The lateral load generally applied in both positive and negative directions in combination with gravity load (dead load and a portion of live load) to study the actual behavior.

4. MODELLING OF G+10 STRUCTURE

4.1. DESIGN CONSIDERATIONS

In order to understand the behavior of reinforced concrete frame with and without bracings, a 11-storey frame with typical bay width of 4 m is considered for the present study. Plan and Elevation view of the frame model considered for the study are shown in Fig.4.1.

The present study deals with 4-different kinds of G+10 Building models:

- RC Frame without Bracings model
- Model-1: RC Frame with Bracings placed in the centre
- Model-2: RC Frame with Bracings placed at the ends
- Model-3: RC Frame with Bracings of global arrangement

Preliminary data

Structure Details		
No.ofStoreys	11	
Dimension in X Direction	22	m
Dimension in Y Direction	22	m
Storey Height	3.3	m
Live Load (Typical)	3	kN/sq.m
Live Load (Terrace)	1.5	kN/sq.m
Floor Finish	1.5	kN/sq.m
I: Importance Factor	1.5	
Slab Thickness	125	mm
Wall Thickness external	230	mm
Wall Thickness internal	150	mm
Concrete Grade	M 25	
Steel Grade	Fe 415	
Wall Load External (2.7 m Height)	12.42	kN/m
Wall Load internal(2.7 m Height)	8.1	kN/m
Parapet Wall (1 m Height)	3	kN/m

Table 1: Structural Data

COMPARISION

Table 2 Beam and Column Details

Model	Gravity Load Building	
	Beam	Column
G+10 without Bracings	230x300m	400x400m
G+10 with Bracings	230x300m	400x400m

4.2. PLAN

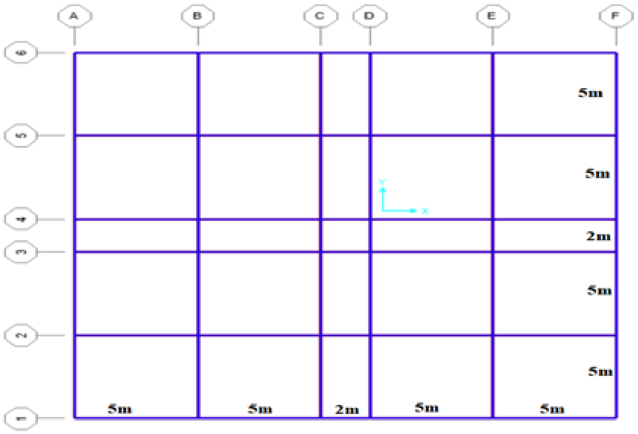


Figure 3 Plan of study area

4.3. ELEVATION

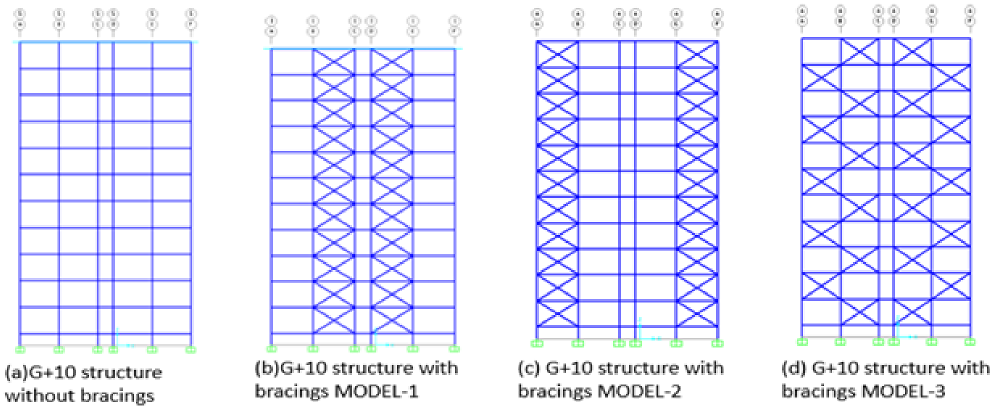


Figure 4 Elevation

Table 3 Beam and Column Details

Model	Gravity Load Building	
	Beam	Column
G+10 without Bracings	230x300m	400x400m
G+10 with Bracings	230x300m	400x400m

Material properties of the building are like M25 grade of concrete, Fe415 steel and 13800 N/mm2 of modulus of elasticity of brick masonry in the buildings.

5. RESULTS AND DISCUSSIONS

5.1. GENERAL

This chapter discussed the results obtained in the present work. To understand the static non-linear behavior of G+10 structure, the building models have been subjected to dead load, live load and load combinations and their responses are studied. The parameters studied are – Time period, drifts and displacements for static loads. Similarly, Non-Linear static analysis has been carried out to the above models. The parameters observed in this case are –Base Shear, Push over curve and Hinge locations.

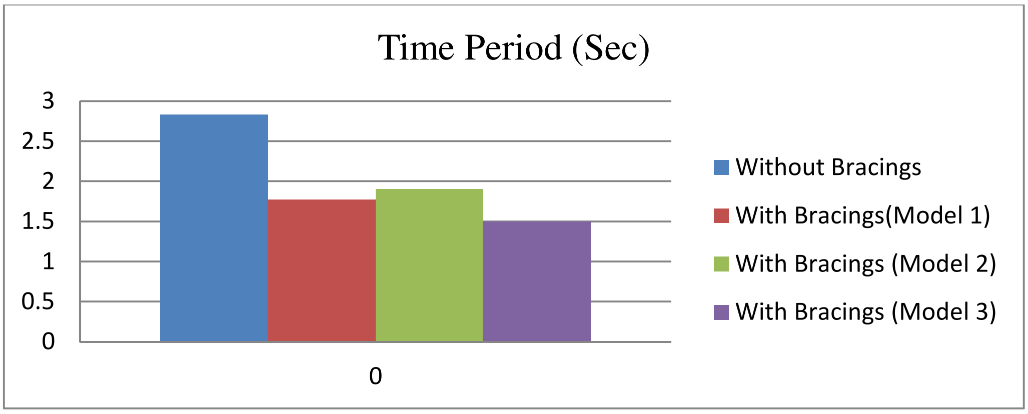
5.2 NON-LINEAR STATIC ANALYSIS OF REINFORCED CONCRETE FRAME WITH AND WITHOUT BRACINGS

5.2.1 Comparison of Time Period

The table 5.1 & 5.2 shows variations in the Time period for the two models

Table 4 Time period of structure with and without bracings

Model	Gravity Analysis
Without Bracings	2.83
With Bracings (Model 1)	1.77
With Bracings (Model 2)	1.9
With Bracings (Model 3)	1.5



Graph 1 Comparison of Time Period

From the observation of the results it states that the time period is less in steel brace model as compared to RC-frame model (without bracings). As we know time period is inversely proportional to stiffness, from which we can say that steel brace model is stiffer than the RC-frame model.

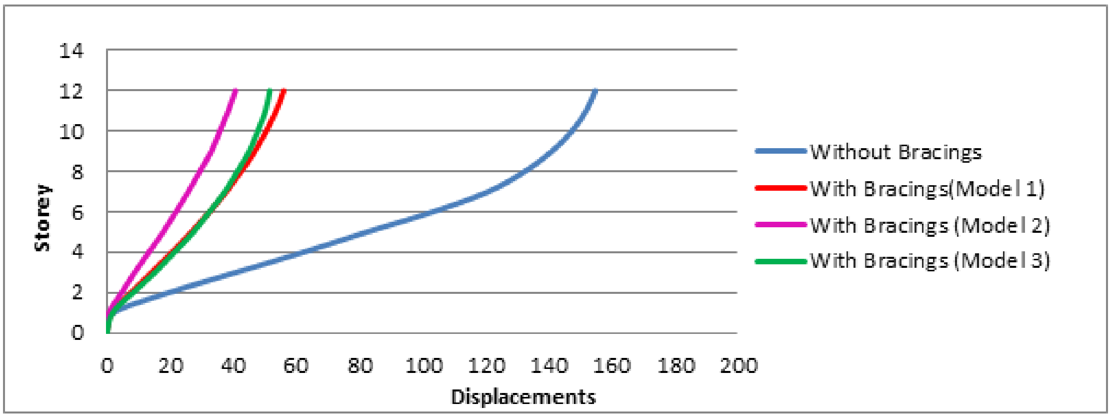
5.2.2 Comparison of Displacements for RC Frame and Steel Brace Concrete Frame (Table and Line chart)

From the analysis, maximum displacement values are evaluated for the two models.

Below table and graph shows the displacement of the structure.

Table 5 Maximum Displacements of structure with and without bracings

Storey	Without Bracings	With Bracings (Model 1)	With Bracings (Model 2)	With Bracings (Model 3)
10	154.80	56.1	40.76	51.6
9	151.94	53.67	38.5	50.3
8	147.45	50.55	35.8	47.8
7	141.09	46.9	33.09	45.1
6	132.56	42.6	29.5	41.4
5	120.93	37.9	25.8	37.4
4	103.45	32.61	21.9	32.5
3	82.58	26.84	17.9	27.5
2	62.35	20.66	13.3	21.4
1	41.12	14.21	8.8	15.3
Ground	19.69	7.64	4.7	8.3
Plinth	2.13	1.48	0.67	1.79
Base	0	0	0	0



Graph 2 Displacement comparison

From the following graphs, it was observed that, the displacement is drastically reduced in bracings model when compared to RC Frame (without Bracing). Also Model 2 has lesser displacements than other bracing models.

Hence significant effect of steel bracings was observed.

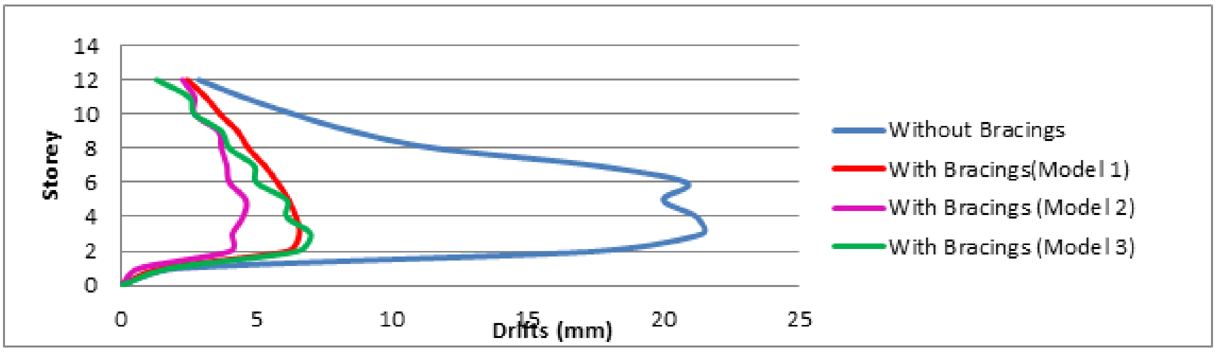
5.2.3 Comparison of Storey Drift for RC Frame and Steel Brace Concrete Frame (Table and Line chart)

From the analysis, maximum drift values are evaluated for the two models.

Below table and graph shows the displacement of the structure.

Table 6 Storey drifts of structure with and without bracings

Storey	With out Bracings	With Bracings (Model 1)	With Bracings (Model 2)	With Bracings (Model 3)
10	2.86	2.43	2.26	1.3
9	4.49	3.12	2.7	2.5
8	6.36	3.65	2.71	2.7
7	8.53	4.3	3.59	3.7
6	11.63	4.7	3.7	4
5	17.48	5.29	3.9	4.9
4	20.87	5.77	4	5
3	20	6.18	4.6	6.1
2	21.23	6.45	4.5	6.1
1	21.43	6.57	4.1	7
Ground	17.56	6.14	4.03	6.51
Plinth	2.13	1.48	0.67	1.79
Base	0	0	0	0



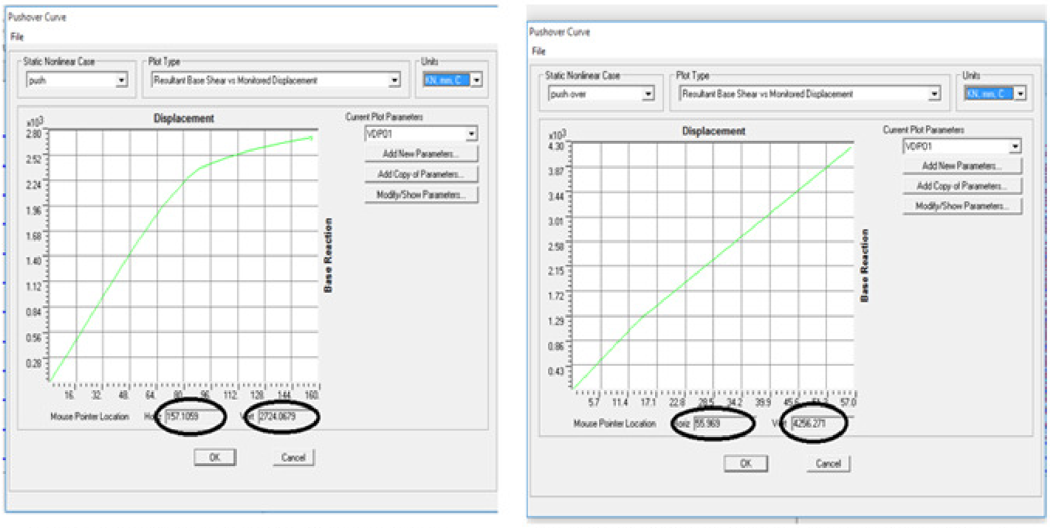
Graph 3 Comparison of Storey Drift

5.3. PERFORMANCE EVALUATION OF REINFORCED CONCRETE FRAME WITH AND WITHOUT BRACINGS

Performance based seismic evaluation of all the models is carried out by nonlinear static pushover analysis. Default hinges are assigned for the Gravity designed building model.

5.3.1. Push over Curve

At each step, the base shear and the roof displacement can be plotted to generate the pushover curve. It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake. For regular buildings, it can also give a rough idea about the global stiffness of the building.



Static Nonlinear Case: push
Plot Type: Resultant Base Shear vs Monitored Displacement
Units: KN, mm, C
Current Plot Parameters: VDP01
Mouse Pointer Location Ho 157.1059 Ve 2724.0679

Static Nonlinear Case: push over
Plot Type: Resultant Base Shear vs Monitored Displacement
Units: KN, mm, C
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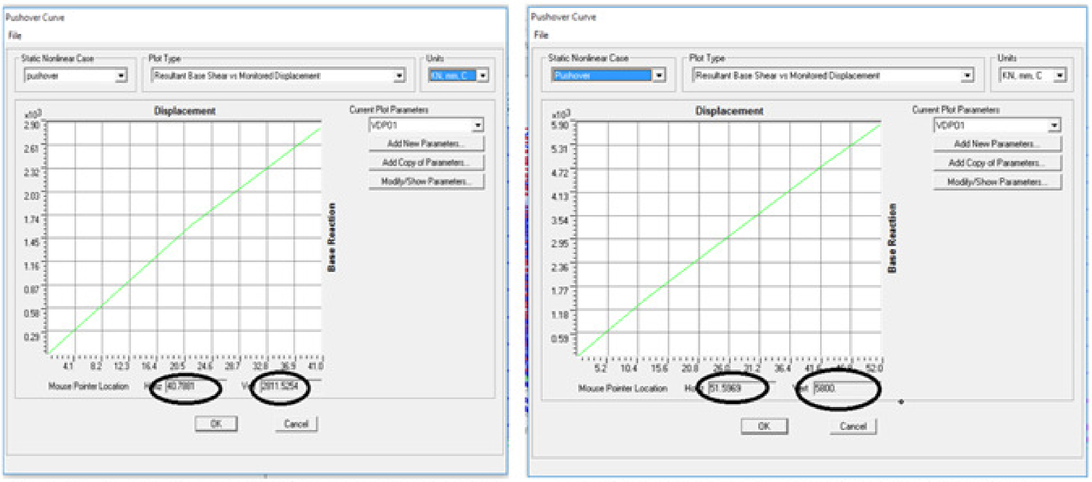
Base Shear vs Displacement Without Bracings

Base Shear vs Displacement With Bracings MODEL-1

Figure 5



Static Nonlinear Case: pushover
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Static Nonlinear Case: Pushover
Plot Type: Resultant Base Shear vs Monitored Displacement
Units: KN, mm, C
Current Plot Parameters: VDP01
Mouse Pointer Location Ho 51.5969 Vert 5800

Base Shear vs Displacement With Bracings MODEL-2

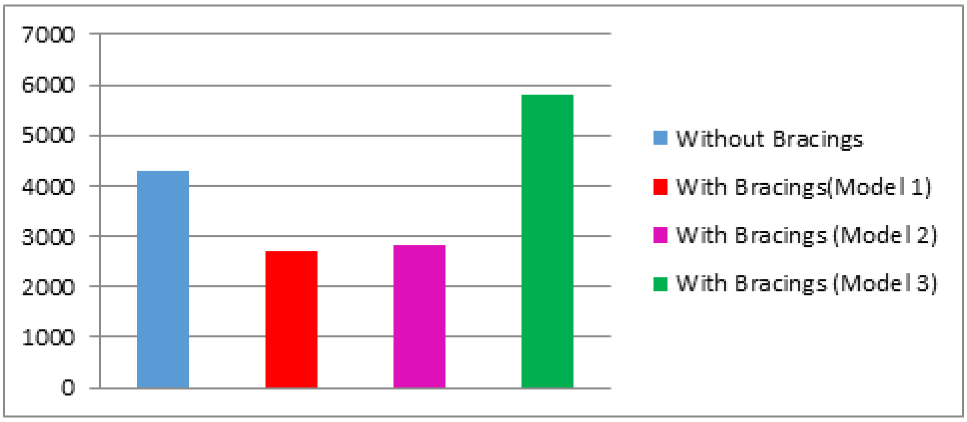
Base Shear vs Displacement With Bracings MODEL-3

Figure 6

5.3.2. Base Shear

Table 7 Storey drifts of structure with and without bracings

Model	**Base Shear (kN)**
Without Bracings	4295.59
With Bracings(Model 1)	2695.59
With Bracings (Model 2)	2811.52
With Bracings (Model 3)	5800



Graph 4 Base Shear comparison

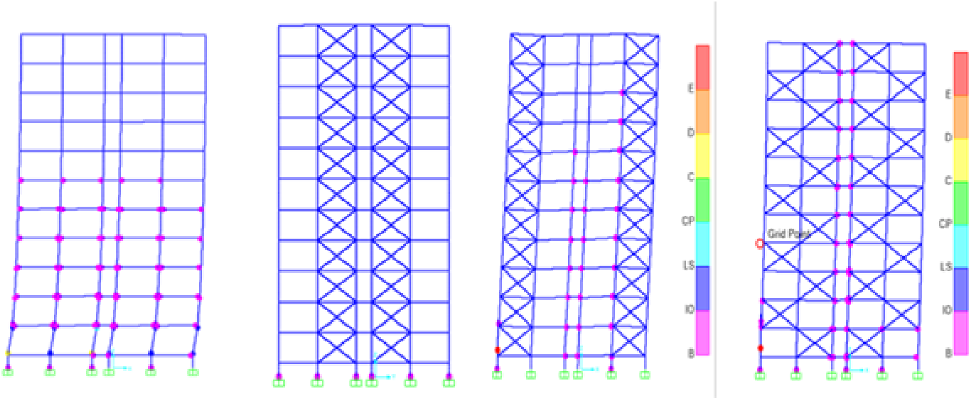
From the obtained graphs we can observe that base shear is maximum in bracings Model 3 when compared to other models and also displacement at roof is lesser in bracings model i.e., displacement decreases when stiffness increases. Therefore, presence of bracings concrete Frame has a positive effect on the buildings.

5.3.3. Location of Hinges (Tables)

The location of the hinges for user defined hinges and performance levels for all building models are presented in the below Table 5.4

Table 8 Hinge Results

	MODEL	**A to B**	**B to IO**	**IO to LS**	**LS to CP**	**CP to C**	**C to D**	**D to E**	**BEYOND E**	**TOTAL**
1	Structure without Bracings	1726	493	66	15	0	4	0	0	2304
2	Structure with Bracings (Model 1)	2104	198	0	0	0	0	0	0	2304
3	Structure with Bracings (Model 2)	2184	118	0	0	0	0	0	2	2304
4	Structure with Bracings (Model 3)	2060	242	0	0	0	0	0	2	2304



(a) Location of Hinges without bracings

(b) Location of Hinges with bracings MODEL-1

(c) Location of Hinges with bracings MODEL-2

(d) Location of Hinges with bracings MODEL-3

Figure 7

From the above results in RC Frame (without Bracings), maximum hinges are formed till collapse state, where as in RC Frame (with Hinges) Maximum hinges are formed till Immediate occupancy state and most of the hinges are formed in the columns of bottom storey.

Hence RC frame building (without Bracings) can reach collapse state and building with bracings can sustain with less damages because of the stiffness of bracings.

Model 2 has shown better performance; therefore, it is suggested to arrange the bracings as shown in model 2.

6. CONCLUSIONS

The present study was focused on the seismic performance of RC structure with and without Bracings. Nonlinear static (pushover analysis) analysis has been carried out to understand the behavior of two models.

6.1. Conclusions

Some of the important conclusions of the present study are:

It has been observed that bracings modelled buildings has less time period than RC Frame (without Bracings) buildings, from which we can say that bracings model building is stiffer.

From the displacement and Drift graphs, it was observed that displacement is drastically reduced in bracing models when compared to RC Frame (without Bracing) and model 2 has less displacements.

we observed that base shear was minimum in bracings Model when compared to RC Frame model (without Bracings) and also displacement at roof is lesser in bracings model i.e., displacement decreases when stiffness increases. Therefore, presence of bracings concrete Frame has a positive effect on the buildings.

Hence RC frame building (without Bracings) can reach collapse state and building with bracings can sustain with less damages because of the stiffness of bracings.

Therefore, we can conclude that model 2 improved the performance of the structure than the other bracing models.

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