# Non-Linear Static Analysis of G+6 Storey Buildings With and Without Floating Columns by Provision of Infill Walls Using User-Defined Hinges

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**Abstract** – The floating columns are given the priority in the multi-storey structures, as to cope up with the problems with continuing the columns from a lower storey, due to the disturbance caused by them to usable area and aesthetics. In the present study, performance based seismic evaluation of 3D G+6 storeys RC building with and without floating columns is carried out. The building models located on medium soil in seismic zone III, are considered. Brick masonry and solid concrete block infill walls are modelled as equivalent diagonal strut. Two distinct analyses are carried out namely, equivalent static and response spectrum as per the load combinations given in IS 1893 (Part I) 2002 using ETABS 2013 V13.2. All the building models are designed as per IS: 456-2000 and their performance based seismic investigation is assessed by pushover analysis considering FEMA 440 parameters. The pushover results like hinge status, ductility ratio, safety ratio and global stiffness are compared for different models.

***Key Words***: *Floating column, Infill, Pushover Analysis, User defined hinges, Ductility ratio, Hinge status, Global stiffness, Safety ratio*

## 1. INTRODUCTION

The floating columns or hanging columns are also vertical members similar to normal RC columns. The hanging columns are normally constructed above the ground storey, so that the ground storey can be utilized for the parking, play ground, and function halls. These floating columns disturb the uniformity of distribution of loads in the buildings, thus leading to more flexibility and there by weakening the seismic resistance of building shown in figure1.

Building with floating columns is constructed to take advantage of urban bylaws. As per urban bylaws, a pre-specified space should be left open between all sides of the building and the plot boundary.

The building with floating columns have both in-plane and out-of-plane irregularities in strength and stiffness and hence are seismically vulnerable. This type of construction does not lead to any problem under the conditions of vertical loading. But during earthquake a clear load path is not available for transferring the lateral forces to the foundation. Lateral forces accumulated in the upper floors during the earthquake have to be transmitted by the projected cantilever beams. Overturning forces thus developed overwhelm the columns of ground floor. Under this situation the columns tend to deform and buckle, resulting in total collapse. Therefore there is a need to understand the seismic behaviour of such building and to retrofit the existing buildings with floating columns so that they can withstand further probable earthquake generated forces.

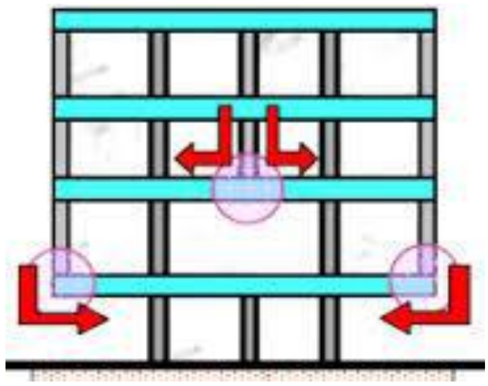


**Fig-1:** Building with floating column [23]

### 1.1 Objective of Study

The objective of this work is to evaluate through an analytical study, the seismic performance of three dimensional seven storey symmetric multistory RC buildings with and without floating columns. Following are the main objectives of the study:

- To study nonlinear static behaviour of multistorey building with and without floating columns.
- To study the seismic behaviour of floating column with the provision of infill
- To study the performance parameters like hinge status, ductility ratio, safety ratio and global stiffness.

## 2. METHODOLOGY

To carry out performance based evaluation of seven storey special moment resisting RC frame structure with and without floating columns located in seismic zone III on medium soil condition, pushover analysis is carried out to compare the basic parameters like hinge status, ductility ratio, safety ratio and global stiffness by using user defined hinges considering FEMA 440 parameters. Brick masonry and solid concrete block infill walls are modelled as equivalent diagonal strut. The buildings are modelled as 3D building using ETABS 2013 V13.2. For linear static analysis equivalent static method and response spectrum method as per IS: 1893 (Part 1)-2002 [10] are adopted and for non-linear static analysis pushover method is adopted.

## 3. BUILDING DESCRIPTION

The plan layouts of the 3D reinforced concrete special moment resisting frame of seven storey buildings with and without floating columns are shown in Fig-2 and Fig-3. The base storey height is 4.8 m and upper storey height is 3.6m for all the buildings [25]. The bay dimensions in both directions are kept as 6m. The building is thought to be situated in the seismic zone III with medium soil. The elevations of the different building models considered are shown in Fig-4 and Fig-5, with open ground storey and unreinforced brick masonry and concrete infill walls in the upper. The floor finishes of 1kN/m$^2$ and Live loads of 3kN/m$^2$ are considered. The earthquake live loads are considered as per IS 1893 (Part-1): 2002. Concrete grade of M25 and M30 (for cantilever beams) with Poisson's ratio 0.2 and the steel grade of Fe-415 are assumed for the study. The brick infill of elastic modulus 1067MPa and density of 20kN/m$^3$ [20] are assumed for the purpose of present study. The size of all the beam sections is 300 mm by 500mm and size of all cantilever beams is 300 mm by 900 mm. All interior columns of size 500 mm by 500 mm and periphery columns of size 600mm by 600 mm are provided. The size of floating column is 300 mm by 300 mm. The thickness of slab is 125 mm. There are six distinct building models namely,

**Model 1:** Bare frame building without floating columns.

**Model 2:** Bare frame building with floating columns of cantilever length 1.5 m at the periphery of the building starting from first floor level up to roof level.

**Model 3:** Building without floating columns with the open ground storey and one full brick masonry infill walls in the upper storeys.

**Model 4:** Building with floating columns of cantilever length 1.5 m at the periphery of the building, with the open ground storey and one full brick masonry infill walls in the upper storeys.

**Model 5:** Building without floating columns with the open ground storey and solid concrete block infill walls in the upper storeys.

**Model 6:** Building with floating columns of cantilever length 1.5 m at the periphery of the building, with the open ground storey and solid concrete block infill walls in the upper storeys.

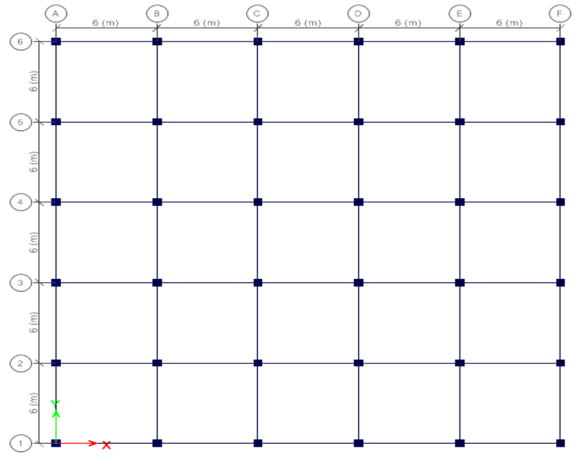


**Fig-2:** Plan of the building model without floating columns

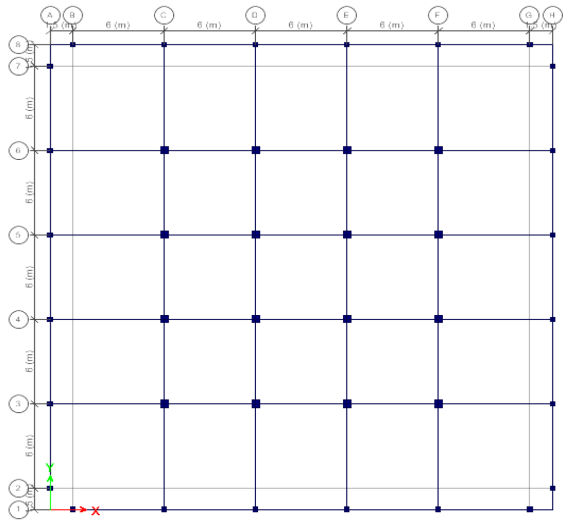
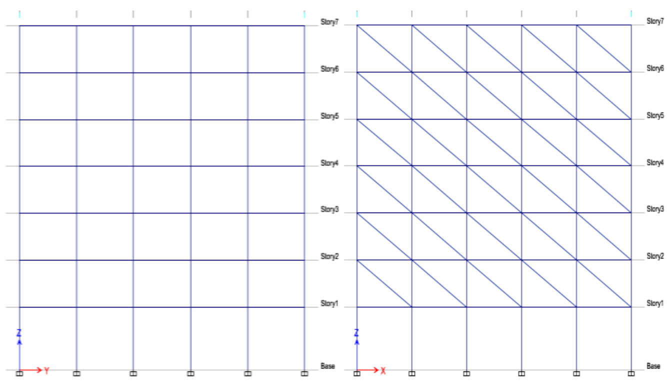
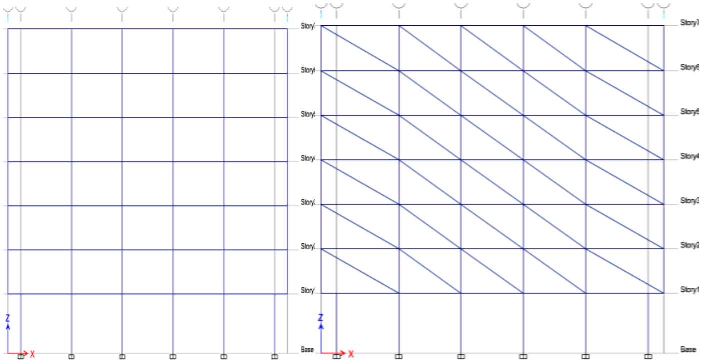


**Fig-3:** Plan of the building model with floating columns



a) Without infill wall b) With infill wall

**Fig-4:** Elevation of G+6 storey models without floating columns



a) Without infill wall b) With infill wall

**Fig-5:** Elevation of G+6 storey models with floating columns

## 4. NON-LINEAR ANALYSIS

Pushover analysis is a nonlinear static procedure wherein monotonically increasing lateral loads are applied to the structure till a target displacement is achieved or the structure is unable to resist further loads. With the increase in the magnitude of the loading, weak links and failure modes of the structure can be identified.

The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. Static pushover analysis is an attempt by the structural engineering profession to evaluate the actual strength of the structure and it promises to be a useful and effective tool for performance based design.

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design of earthquakes by means of static inelastic analysis and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter-storey drift, inelastic element deformations (either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations), The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behavior. The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis.

The Pushover curve is split into various performance levels, namely, immediate occupancy level, Life safety level, Collapse prevention level, Collapse and structural stability. The performance of the building is measured at a performance point, obtained by intersection of demand spectra and capacity curve. The present study considers FEMA 440 [5] parameters for the pushover analysis of the building models.

### 4.1 User Defined Hinge Properties

The user defined hinge properties are defined based on moment-curvature analysis of each element. For the present study, the assumption is made such that building deformation occurs due to bending moments, when subjected to lateral seismic loads only. Thus, only M3 hinges were assigned at the two ends of each member. The P-M3 hinges are assigned to columns. The moment-curvature relation for beams and columns is defined manually for a certain group of similar elements. The stress-strain relationship for strut elements is also defined manually.

**Table-1:** Calculation sheet for Moment-Curvature relation for a concrete beam section [17]

| Points | Moment/ SF | Curvature/ SF |
|---|---|---|
| A (Origin) | 0.0000 | 0.0000 |
| B (Yielding) | 1.0000 | 0.0114 |
| C (Ultimate) | 1.7169 | 0.0157 |
| D (strain hardening) | 0.2000 | 0.0157 |
| E (strain hardening) | 0.2000 | 0.1704 |

**Table-2:** P-M interaction and Moment Curvature data for Column section [17]

| Points | Moment/SF | Curvature/SF |
|---|---|---|
| A (Origin) | 0 | 0 |
| B (Yielding) | 1 | 0.00518 |
| C (Ultimate) | 1.006912 | 0.011667 |
| D (strain hardening) | 0.2 | 0.011667 |
| E (strain hardening) | 0.2 | 0.07775 |

### 4.2 Modelling of wall hinges

#### 4.2.1 Brick as infill wall

In order to define the user defined axial hinge to input in ETABS 2013 as per FEMA 356 masonry prism to be constructed and tested under uniaxial compression in order to get the load-deformation curve, in present study masonry prism is constructed and test were carried out in order to evaluate performance limit states of the masonry material.

**Table-3:** Stress Strain points for yield, ultimate, strain hardening and residual strain [17]

| Points | Load /SF | Deformation/SF |
|---|---|---|
| A | 0 | 0 |
| B | 1 | 0.0055 |
| C | 1.76 | 0.009 |
| D | 0.78 | 0.012 |
| E | 0.6 | 0.0125 |

### 4.2.2 Solid concrete block as infill wall

The following points were adopted for the infill as solid concrete block, stress strain relation is developed from the numerical equation provide by Hemant, B.K. *et al* (2007) [8].

**Table-4:** Stress Strain points for the yielding, ultimate, strain hardening and residual strain [8]

| Points | Stress in terms of $f_m$ | Strain in prism for 1:3 mortar mix |
|---|---|---|
| A | 0 | 0 |
| B | 0.75 $f_m$ | 0.0014 |
| C | $f_m$ | 0.0025 |
| D | 0.5 $f_m$ | 0.0045 |
| E | 0.2 $f_m$ | 0.0053 |

## 5. RESULTS AND DISCUSSION

The results obtained for different models considered for different types of analysis carried out namely equivalent static analysis, response spectrum analysis and nonlinear static analysis by ETABS 2013. An effort is made to study the effect of structure with floating columns in comparison with the structure without floating columns.

### 5.1 Hinge locations and performance levels of building models

The pushover analysis is performed by incorporating user defined hinge properties, for both equivalent static and response spectrum load cases. The target displacement is set to 4 % of the building height. The results of hinge location at various performance levels are presented in the Table-5 and Table-6.

**Table-5:** Location of hinges for seven storey building models by equivalent static analysis

| Model No. | Displacement (mm) | | Base Force (kN) | Hinge Locations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | Total |
| 1 | IY | 78.65 | 7194.11 | 846 | 238 | 260 | 0 | 0 | 0 | 1344 |
| | CY | 369.2 | 7585.39 | 850 | 192 | 230 | 16 | 0 | 56 | 1344 |
| 2 | IY | 108.3 | 3077.66 | 1456 | 328 | 0 | 0 | 0 | 0 | 1784 |
| | CY | 435.54 | 5608.1 | 887 | 546 | 253 | 25 | 2 | 71 | 1784 |
| 3 | IY | 96.7 | 15522.05 | 1306 | 398 | 0 | 0 | 0 | 0 | 1704 |
| | CY | 176.6 | 21435.09 | 1314 | 320 | 68 | 0 | 0 | 2 | 1704 |
| 4 | IY | 126.5 | 6335.04 | 1844 | 188 | 54 | 18 | 0 | 0 | 2144 |
| | CY | 187.6 | 6801.68 | 1868 | 192 | 22 | 6 | 0 | 56 | 2144 |
| 5 | IY | 67 | 16689.7 | 1370 | 334 | 0 | 0 | 0 | 0 | 1704 |
| | CY | 150.2 | 24316.06 | 1344 | 229 | 81 | 43 | 0 | 7 | 1704 |
| 6 | IY | 94.97 | 6409.17 | 1961 | 126 | 57 | 0 | 0 | 0 | 2144 |
| | CY | 169.36 | 6827.24 | 1954 | 112 | 8 | 11 | 0 | 59 | 2144 |

**Table-6:** Location of hinges for seven storey building models by response spectrum analysis

| Model No. | Displacement (mm) | | Base Force (kN) | Hinge Locations | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | Total |
| I | IY | 60.79 | 8911.95 | 856 | 332 | 156 | 0 | 0 | 0 | 1344 |
| | CY | 250.64 | 9948 | 848 | 304 | 120 | 18 | 0 | 54 | 1344 |
| II | IY | 90 | 3535.93 | 1538 | 246 | 0 | 0 | 0 | 0 | 1784 |
| | CY | 360.86 | 6645.9 | 1109 | 434 | 129 | 40 | 0 | 72 | 1784 |
| IV | IY | 67.1 | 17025.84 | 1380 | 324 | 0 | 0 | 0 | 0 | 1704 |
| | CY | 347.5 | 31596.46 | 1197 | 368 | 25 | 22 | 0 | 92 | 1704 |
| V | IY | 87.1 | 4041.76 | 2057 | 87 | 0 | 0 | 0 | 0 | 2144 |
| | CY | 289.33 | 6944.4 | 1925 | 141 | 14 | 8 | 2 | 54 | 2144 |
| VII | IY | 63.35 | 18232.33 | 1496 | 208 | 0 | 0 | 0 | 0 | 1704 |
| | CY | 216.8 | 32288.92 | 1290 | 288 | 6 | 26 | 2 | 92 | 1704 |
| VIII | IY | 74.1 | 6357.53 | 1986 | 110 | 48 | 0 | 0 | 0 | 2144 |
| | CY | 236.98 | 6956.91 | 1982 | 88 | 4 | 13 | 0 | 57 | 2144 |

For seven storey building models, the base force is found more in building models without floating columns compared to building models with floating columns by 35.25% at the ultimate state for bare frame buildings. And for brick masonry infill models, the building without floating columns shows higher base force compared to buildings with floating columns by 215.14%. For solid concrete block infill models, the building without floating columns shows higher base force compared to buildings with floating columns by 256.16%. In seven storey bare frame building models, hinges formed within the life safety range at the ultimate state are 94.64% and 94.50% for models without floating columns and with floating columns, respectively. The hinges formed for brick infill models within life safety range at ultimate state are 99.88% and 97.10% for models without floating columns and with floating columns, respectively. Similarly for concrete block infill, 97.06% and 96.73% for models without floating columns and with floating columns, respectively. It is also observed that, the hinges are formed beyond the CP range at the ultimate state is 5.35% and 5.49% for bare frame models without floating columns and with floating columns, respectively. The hinges formed beyond the CP range at ultimate state is 0.12% and 2.89% and 2.98% for brick infill models without floating columns and with floating columns, respectively. Similarly, 2.93% and 3.26% for concrete block infill models without floating columns and with floating columns respectively.

## 5.2 Ductility ratio

Ductility ratio is defined as the ratio of collapsed yield to the initial yield [17]. The lateral stiffness of the building increases the lateral strength, but reduces the energy absorption capacity of the building, hence ductility ratio decreases. The ductility of a structure is in fact one of the most important factors affecting its earthquake performance. In present study the ductility parameter is studied in order to know the behaviour of the building under seismic loading The Fig-6 and Fig-7 presents the ductility ratios of all the models.

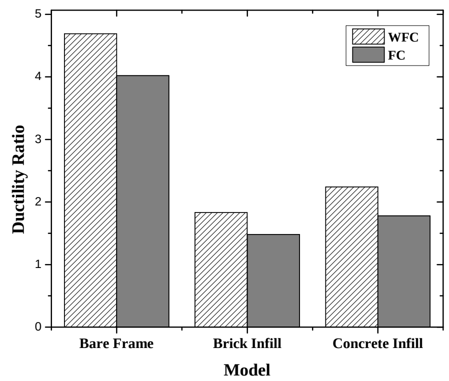



**Fig-6:** Ductility ratio of seven storey building models by equivalent static pushover analysis

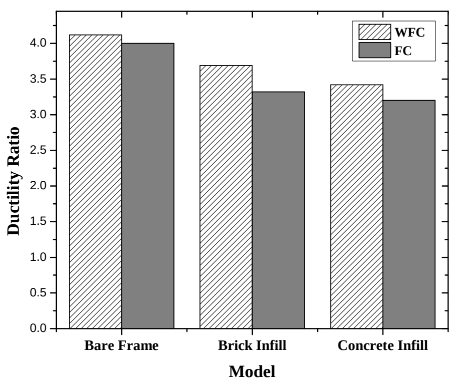



**Fig-7:** Ductility ratio of seven storey building models by response spectrum pushover analysis

From above results, it is clear that the ductility ratio of the bare frame is larger than that of the soft storey models, hence ductility ratio increases in the column stiffness and decreases with increase in the wall stiffness. For seven storey building models, the ductility of bare frame building models 1 and 2 are in the range of 4 to 6. For infill building models 3, 4, 5 and 6, the ductility ratio is less than the reduction factor equal to 4 by both equivalent static and response spectrum pushover analysis.

## 5.3 Safety Ratio

Safety ratio is defined as the ratio of base force obtained at performance point to the base shear obtained by equivalent static method. If the safety ratio is equal to one then the structure is called safe, if it is less than one than the structure is unsafe and if ratio is more than one then the structure is over safe [17]. Safety is one of the prime importance criteria in the seismic design in order to understand the concept of safe structure the safety ratio is studied in the present study Fig-8 and Fig-9 shows the safety ratio.

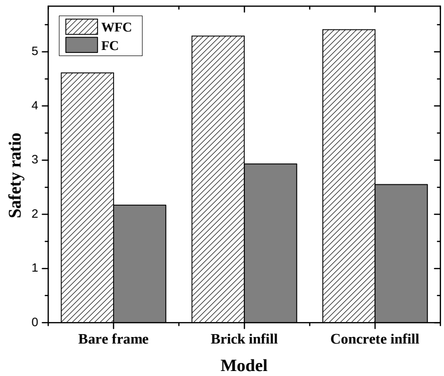



**Fig-8:** Safety ratio of seven storey building models by equivalent static pushover analysis

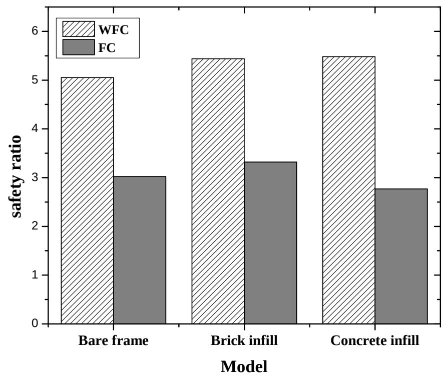



**Fig-9:** Safety ratio of seven storey building models by response spectrum pushover analysis

It is seen from the above figures that, the bare frame models without floating columns are found to be 2.12 times safer than the models with floating columns. For brick infill models without floating columns, it is found to be 1.80 times safer than the models with floating columns. Similarly for concrete infill models without floating columns is found to be 2.12 times safer than the models with floating columns and by equivalent static pushover analysis. The bare frame, brick infill and concrete block models without floating columns are1.67, 1.64 and 1.97 times safer than the models with floating columns by response spectrum pushover analysis. From the above results it can be concluded that, the safety ratio for all the models are more than one, hence building models are over safe. The concrete infill models are safer compared to brick masonry infill models and bare frame models.

### 5.4 Global Stiffness

Global stiffness is defined as the ratio of performance base shear to the performance displacement [25]. The global stiffness is shown in Fig-10 and Fi9-11 for seven storey models with and without floating columns by equivalent static and response spectrum pushover analysis.

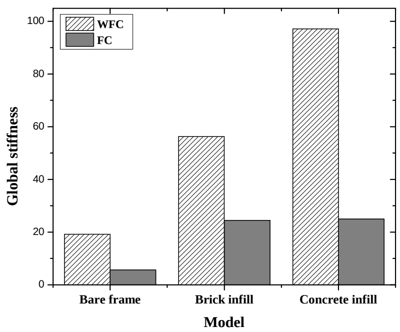



**Fig-10:** Global stiffness of seven storey building models by equivalent static pushover analysis

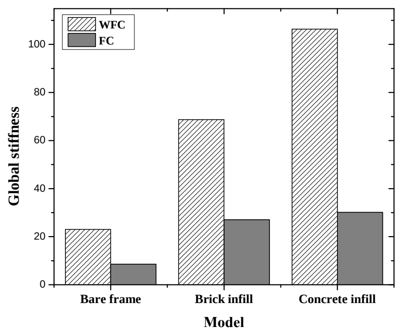



**Fig-11:** Global stiffness of seven storey building models by response spectrum pushover analysis

From the figures it is observed that, the stiffness of the building models without floating columns is higher than the building models with floating columns. In seven storey building models, there is an increment in the percentage of global stiffness of bare frame models without floating columns compared to models with floating columns by 236.90%. The increment in the percentage of global stiffness of brick infill building models without floating columns compared to with floating columns is by 130%. Similarly, the increment in the percentage of global stiffness of concrete block infill building models without floating columns compared to with floating columns is by 288.83% by equivalent static method. The global stiffness of bare frame, brick infill and concrete infill without floating columns is higher than the models with floating columns by 169.27%, 153.91% and 253.10%, respectively by response spectrum pushover analysis.

## 6. CONCLUSIONS

On the basis of present study following conclusions are drawn:

1. The critical hinges formed in buildings with floating columns are higher than those of conventional buildings.
2. The displacement at performance point of buildings with floating columns is more compared to building without floating columns. The base force at performance point of building without floating columns is more.
3. Ductility ratio for seven storey bare frame buildings is greater than the targeted value; whereas the infill framed building models resulted in ductility ratio within the target value.
4. Safety ratio of all the models are greater than one, hence all the models are over safe. Compared to the bare frame building models, the unreinforced masonry infill framed buildings are safer. And the regular buildings are safer compared to the buildings with floating columns.
5. Global stiffness is more in the soft storey building models compared to the bare frame building models. Global stiffness of the floating column building is found to be very less when compared to the regular building so it is better to avoid floating columns in the building.

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