A Comparative Analysis on the Seismic Response of an Irregular Building with Floating Column and an Irregular Building without Floating Column

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Abstract— The study is done to check the earthquake resistance of an irregular building with floating in comparison to an irregular building without floating and also the behavior of the two buildings during earthquake excitations and how safe they are in earthquake-prone areas. Analysis on these building models where carried out using the non-linear push over method of analysis to study the story responses of the building under earthquake excitations. A modal analysis was also carried out to check the period of vibrations for each building type. The analysis was carried with the extended three-dimensional analysis of building systems (ETABs) software. The results plotted are the story responses obtained after analysis, that is, the story drift, story displacement, story shears, overturning moments and story stiffness. The story drift and story displacements obtained show a higher drift and displacement in the building with floating column than the building without floating column. The periods of vibration for the two building models remained the same indicating that the presence or absence of a floating column does not affect the period of vibrations.

Keywords: Irregular RC framed building, ETABs, Floating column, Seismic Analysis, Earthquake Resistance.

I. INTRODUCTION

Seismicity have been recorded in many books including the bible, “there will be great earthquakes, and in various places famines and pestilences. And there will be terrors and great signs from heaven”, (luke21:11). which is evident that earthquake occurrences have been in existence since the existence of humanity. It was only until recent that through the studies of earthquakes by engineers they began to understand the phenomenon of seismicity which are most likely to affect the fast-growing population demand and need for the construction of Multi-story buildings During an earthquake, waves from the ground are picked by buildings causing them to oscillate (vibrate) to and FRO, the intensity of the vibration is due to the building mass and its stiffness (Vijayanarayanan et al., 2017) . The intensity or magnitude of earthquake depends on the focal depth, epicentral distance, characteristics of the path through which seismic waves travel, shape of structure and soil strata. (Yong et al., 2016) assumed that the difference in time of arrival by Primary waves (P-waves), secondary waves (S-waves), Rayleigh and love waves propagating at different velocities is an attribute of time-varying frequency. Earthquakes are caused by a sequence of vibrations on the surface of the earth caused by seismic waves due to sudden movement within the earth’s crust during the release of accumulated strain energy” (Shah, 2012,). Many buildings within earthquake prone areas will undergo seismic excitations weather low or high-rise, Seismic design for most structures will be better considered starting from low to high rise building either using static or dynamic analysis. (F. S. Merritt et al., 2000).

The primary objective in designing an earthquake resistant structure is to ensure that the building has enough ductility to withstand the earthquake load. Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. Earthquake resistance can be analyzed using several methods and several software’s.
Mohit Sharma et al (2014) studied a G+30 storied regular building. The static and dynamic analysis was done using computer-aided software that is; STAAD-Pro software using the parameters for the design as per the IS-1893: 2002(Part-1) for the zones 2 and 3.

Y. Abhinay et al. 2017 made a “Comparison of Seismic Analysis of a Floating Column Building and a Normal Building”. In the analysis, residential buildings with 6 Stories and 12 Stories are analyzed with column, Beams & Slabs. The buildings are analyzed & designed with and without edge columns at the base story. The Buildings are analyzed in two earthquake zones III and V according to IS 1893-2002 with soil type I and III. Static Load combinations and Response Spectrum Analysis is done to compare the results. Results are compared in the form of Story displacements, Story Shear, Story Over turning Moments with & without columns at the base story in both Static and Dynamic Analysis. ETABS 2013 was used for analyzing the Building Structure. It was found that the displacement, shear and moment is more when the floating column is provided to reduce the displacement the section properties of the building are changed for better performance. Floating column building will suffer the extreme soft-story effect. So, the Floating column building is unsafe. After the analysis of buildings, comparison of the quantity of steel and concrete are calculated from which it is to be identified that floating column building with a change in dimensions has 40 % more quantity of rebar steel and 42 % more concrete quantity than Normal building. So, the Floating column building is uneconomical to that of a Normal building.

Sukumar Bahera (2012) found that irregularities occur due to the presence of floating column. He studied the response of structures under different earthquake excitation having different frequency content keeping the peak ground acceleration (PGA) and time duration factor constant they developed finite element method (FEM) codes for 2D frames with and without floating columns. The behavior of the building frame with and without floating column is studied under static load, free vibration and forced vibration condition. The finite element code was developed using MATLAB platform. The time history of the floor displacement, inter-story drift, base shear, overturning moment is computed for both the frames with and without floating column. The dynamic analysis of frame is studied by varying the column dimension. It is concluded that with increase in ground floor column the maximum displacement, inter-story drift values are reducing. The base shear and overturning moment vary with the change in the column dimension.

Prerna Nautiyal (2014) investigated the effect of a floating column under earthquake excitation for various soil conditions and as there is no provision or magnification factor specified in I.S. Code, hence the determination of such factors for safe and economical design of a building having floating column. Linear Dynamic Analysis is done for 2D Multi-story frame with and without floating column. For that purpose, two models were created that is; model G+4 and G+6 building having changing positions of floating column. A response spectrum analysis is carried out for both buildings. Dynamic response parameters such as base shear and moment for hard and medium soil condition are obtained for both building models.

Shrinkanth M.K. et al (2014) carried out a comparative study on RC frame having only floating columns and having and floating columns with irregularities or complexities. High rise RC frames were analyzed for seismic forces. Medium soil conditions, lower and higher seismic zones were considered. ETABS software was used for the analyses of the RC frames and it was concluded that frames having floating column with irregularities showed larger deflections than that on frames with only floating columns on both lower and higher seismic zones.

Mundada et al (2014) studied an existing G+7 RC frame using STADD Pro software. The author carried out equivalent static method) has been carried out three models, RC frame with floating column, RC frame without column, and RC frame with floating column with struts. It was confirmed that the failure in RC frame with floating is more than RC column with struts, and deflection with only floating column is larger than deflection of floating column with struts.

II. Objectives

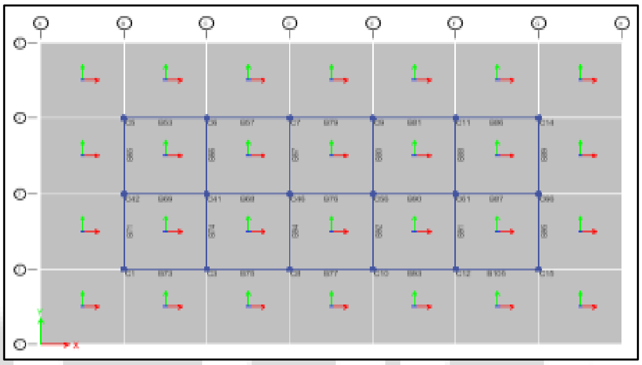
A 23 story building frame is considered for this study since most of the previous work reviewed Shaikh and Deshmukh (2013), Mahesh and Rao (2014), Isha Rohilla et al.,(2015) and Oman Sayyed et al.,(2017) considered a story height of less than 20 stories, higher buildings above 20 stories buildings are now adopted to meet the population demand and rule out the floor space index regularity(Keerthi Gowda B. S. 2014). This study seeks to identify the performance of a 23-story building frame under seismic excitation since and it is set out to achieve the following objectives:

1) Perform seismic Analyses of twenty-Three (23) story RC irregular framed building with floating column and without floating column in extended three-dimensional analysis of building systems (ETABS)
2) Compare the Story response results obtained after seismic analysis
3) To identify which is safer and more economical.

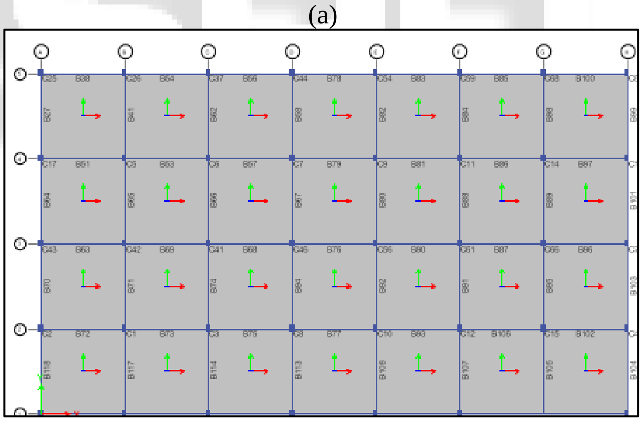
III. Methods and Analysis

A. *Structural Modelling*

The size, shape, depth and geometry of a building is critical in the response of earthquake excitation. The irregularity of the building and the ground motion also affects the response of a building to earthquake excitation. The model used in this paper (see figure 1a,1b, 2a,2b,3a,3b) is a multipurpose building for commercial purposes and for residential purpose. The building is a twenty-three (23) story building having floating column from the first floor with the basement as a parking lot. The building is irregular in shape and mass, it has three (4) different plans from base to top floor where the base is a parking lot, first fifteen (15) floors are for commercial use and the last eight (8) floors are for residential use.

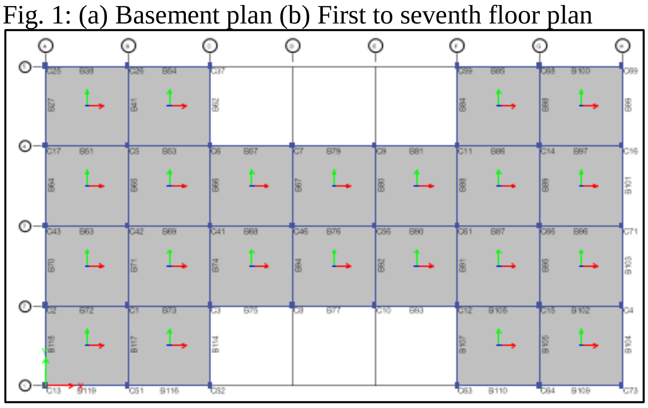


(a)

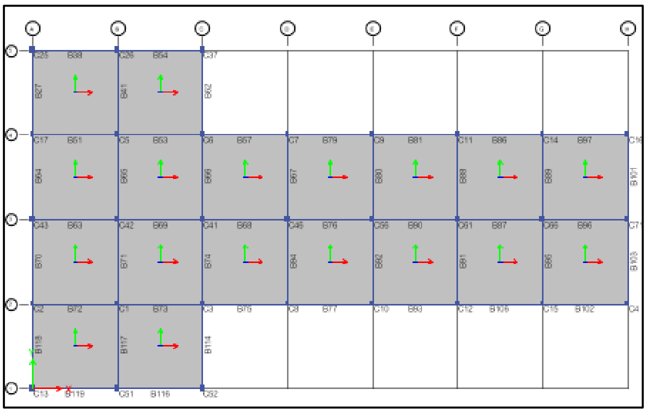


(b)

Fig. 1: (a) Basement plan (b) First to seventh floor plan

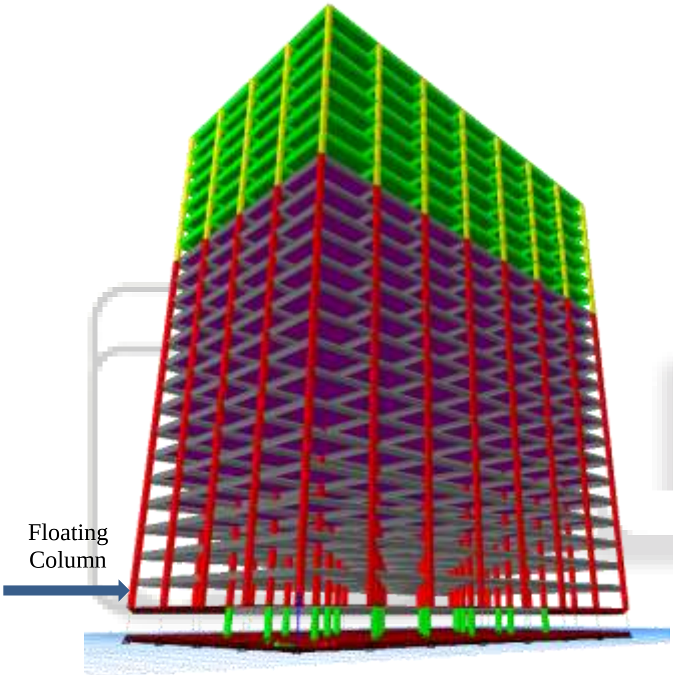


(a)

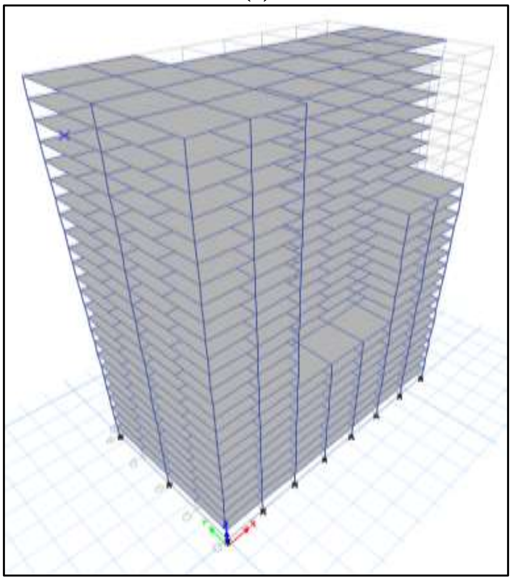


(b)

Fig. 2: (a) Eight to fifteen floor plan (b) sixteenth floor plan



(a)



(b)

Fig. 3: (a) Irregular building with floating column (b) irregular building without floating column

The structure is prepared on ETABS 17.0.1 as shown in the model above, gridlines of horizontal sides are spaced at a distance 8m center to center from (grid A to grid H) and the vertical sides are spaced 8m center to center from (grid 1 to grid 5), the basement plan is found in the center of the entire plan from (grid B to grid G) and (grid 2 to grid 4), the first(1st) floor plan to seventh(7th) floor plan is a rectangular shaped building designed that way to be able to spread the load coming from the top to the base, the eight to seventh floor is an "H" shaped building designed by taking out the beam and columns on grid line "D" and "E" beneath and above and the sixteenth(16th) to twenty third(23th) floor plan is a "T" shaped building designed by taking off beams and columns on gridlines "D","E","F","G" "and H". ETABS is structural analysis software developed for the analysis of structures as manual analysis may be very tedious and time consuming. ETABS makes it very easy to analyze a building according to the standards and method of analysis in the various codes of analysis. IS code is used for this study. The structure is a 23-story building on floating column (raised 2m above ground level), each floor is 3m high. The 3-dimensional model is generated and loads are assigned as per IS 875 already included in the software. Material properties as well as Section properties are defined and structure is checked for warnings by ETABS.

B. Design Data

The following data was used for the design of the RC frame building:

Structural Element/Material	**Section/Material Property**
Beams (Basement)	500mmx450mm
Columns (Basement)	500mm diameter
Beams (1st to 15th floor)	450mmx300mm
Beams (16th to 23rd floor)	400mmx300mm
Columns 1st to 15th floor	450x300
Columns 16th to 23rd	400x300
The total height of the building	69m
Type of Structure	Irregular RC framed building
Seismic zone	IV (Table 3, IS 1893 (part1):2016
M30 grade of Concrete	Characteristic Compressive strength ($f_{ck} = 30N/mm^2$)
Imposed loads on floors	3.5KN/m^2 IS 875 (part2):1987
Floor finish	1.0KN/m^2 IS 875(part 2):1987
Slab thickness (first to 15th floor)	200mm
Slab thickness (16th to 23th floor)	150mm
Self-weight of reinforced concrete	25KN/m^3 (part 1):1987
Response spectrum	As per IS 1893 (part 1) :2016
Earthquake load	As per IS 1893 (part 1) :2016
Total area of building	96m^2

Table. 1: Design Data

C. Load Combination

As per IS 1893 (part 1):2016 clause 6.3.2.2, the following load cases were considered for the analysis.

(a) 1.5 [DL +IL±(ELx±0.3ELy)
1.5 [DL +IL±(ELy±0.3ELx)

(b) 1.2 [DL+IL±(ELx±0.3ELy)
1.2 [DL+IL±(ELy±0.3ELx)

(c) 0.9 DL±1.5(ELx±0.3ELy)
0.9 DL±1.5(ELy±0.3ELx)

Load combination (a) is considered for basement and first floor plan, combination (b) considered for 2nd to 15th floor plan and load combination (c) for 16th to 23rd floor

1) Load Cases

The following load cases where considered for the analysis

Sr. No	Load cases	Load
1	Dead load (DL)	Gravity
2	Live load (L.L)	Gravity
3	Super imposed DL	Gravity
4	Wind Load	IS 1893:2016
5	Earthquake load (EQX)	IS 875:1987
6	Earthquake load (EQY)	IS 1875:1987

Table. 2: Load Cases

2) Load Considerations

Load case	Load consideration
Imposed/Live load on 1st floor to 15th Floor	5KN/m^2 (IS 875:1987 Part 2)
imposed/Live load on 16th floor to 23rd floor	3KN/m^2 (IS 875:1987 Part 2)

Table. 3: Load Considerations

IV. Results and Discussions

The analysis of a structure in structural engineering design aims at achieving a workable level of probability that the designed structure will perform satisfactorily for the intended purpose for construction. The Structure in this study was analyzed by nonlinear push over analysis method as an irregular building frame in ETABS. From the analyses, modal analysis, story drift response, story displacement, overturning moments, story shear, etc. were obtained and presented below.

A. Modal Analysis

Modal analysis is carried out on irregular building model with floating column and irregular building model without floating column. Modal analysis is done using eigen values, modal analysis is determined using vibration modes to check the structural dynamic behavior of the building, it also checks the structural connectivity of all elements to ensure they are properly connected. This analysis was done using the ETABS. The building models underwent translation mode in the X-Direction, Translation mode in the Y-direction and Torsional mode. The first (1st) mode underwent translation in the X-direction with a period of 4.535 sec for the irregular building with floating column, 4.535 sec for the irregular building without floating column. The second (2nd) mode is also a translation mode but, in the Y-direction, which has periods of 4.187 sec for the irregular building with floating column, 4.187 sec for irregular building without floating column.

The third mode which is a torsional mode was having periods of 3.843sec for irregular building with floating column, 3.843 sec for irregular building without floating column. The period of vibrations remains unchanged for irregular building with floating column and irregular building without floating. This shows that the floating column may not affect the period of vibration but the irregular shape of the building will affect the period of vibration. Table 4 shows all the periods of all the 12 modes used. From the table, the periods of vibrations of the first 3 modes are very close and repeated more closely distributed among the other modes. Thus, the mode superposition used in performing the analysis was carried out using CQC method as defined in clause 7.7.5.3 of IS 1893(part 1):2016.

Mode	Period/sec	
	Irregular building with floating column (23-story)	Irregular building without floating column (23-story)
1	4.535	4.535
2	4.167	4.167
3	3.843	3.843
4	1.915	1.915
5	1.669	1.669
6	1.543	1.543
7	1.193	1.193
8	1.025	1.025
9	0.948	0.948
10	0.768	0.768
11	0.677	0.677
12	0.63	0.63

Table. 4: Modes and periods of Vibration

Mode	Frequency (cycle/sec)	
	Irregular building with floating column (23-story)	Irregular building without floating column (23-story)
1	0.22	0.22
2	0.24	0.24
3	0.26	0.26
4	0.522	0.522
5	0.599	0.599
6	0.648	0.648
7	0.838	0.838
8	0.976	0.976
9	1.054	1.054
10	1.302	1.302
11	1.477	1.477
12	1.588	1.588

Table. 5: Modes and frequency

Model	Building Height	Sum of frequency (cycle/sec)
Irregular building with floating column	69m	9.724
Irregular building without floating column	69m	9.724

Table. 6: Building height and sum of frequency

The height of both models are the same since the number of stories and height of stories remain the same, the total height of the building is 69m which has a total frequency of 9.724cycle/sec and 9.724cycle/sec respectively. Which indicates that ratio of height of the building to frequency is inversely related. This is an acceptable trend. According to IS 1893 (part 1) if the mode frequency exceeds 33Hz, missing mass correction procedures should be done. Since the frequencies of the models are below 33Hz, this step is ignored.

B. Nonlinear Static push over analysis

The pushover analysis in this study shows the story drift, story displacement, base shear and overturning moments behaviors of each model under nonlinear static push over analysis.

1) Story Displacement

The results below show the story response subjected to push over analysis for irregular building with floating column (Model 1) and irregular building without floating column (model 2). Below is the story displacement obtained after analysis.

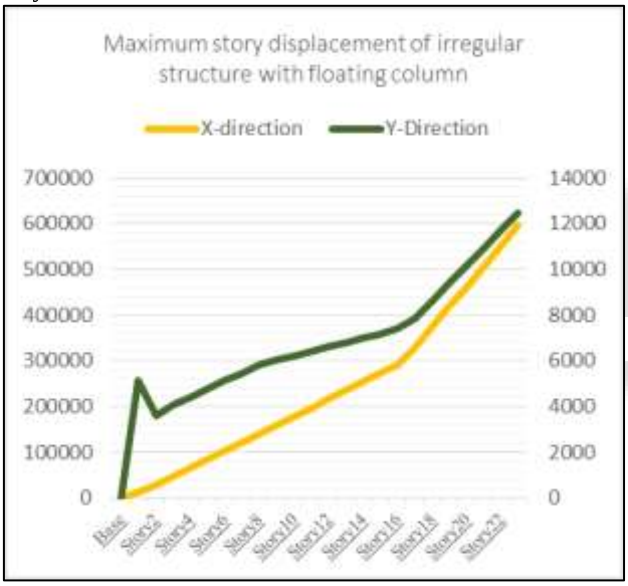


Fig. 4: Maximum story displacement of irregular structure with floating column

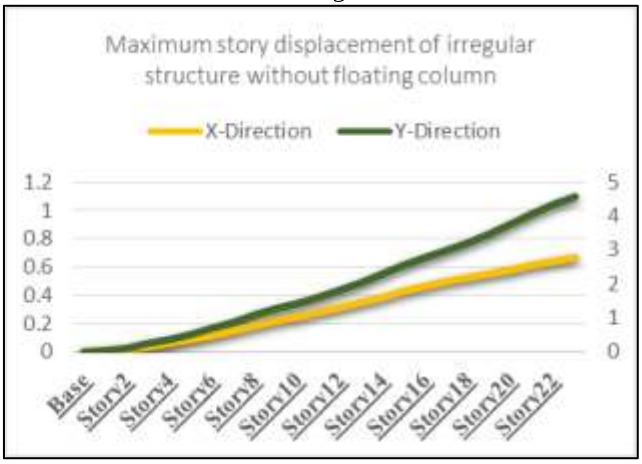


Fig. 5: Maximum story displacement of irregular structure without floating column

The maximum story displacement for model 1 shows a significant displacement from the base up to story 2 in the Y-direction, model 2 shows an evenly distributed displacement from base to the top floor in both X and Y directions. Model 1 has floating columns starting from story 1 and it shows some magnitude of displacement within the base to story 2 in the Y-Direction. This shows that floating columns do not pose any risk to displacement in the horizontal direction but may undergo an appreciable amount of displacement in the vertical direction. Also, from story 17 in model 1 a small amount of displacement is recorded. This signifies that the irregularity of the structure will also influence the story displacement, however, model 2 despite being an irregular structure did not show a displacement in story 17 which only means that the absence of a floating column will ultimately reduce the maximum story displacement.

2) Story Drift

The story drift results obtained under push over static analysis is given below for models 1 and 2.

Fig. 6: Maximum Story Drift for irregular building with floating Column

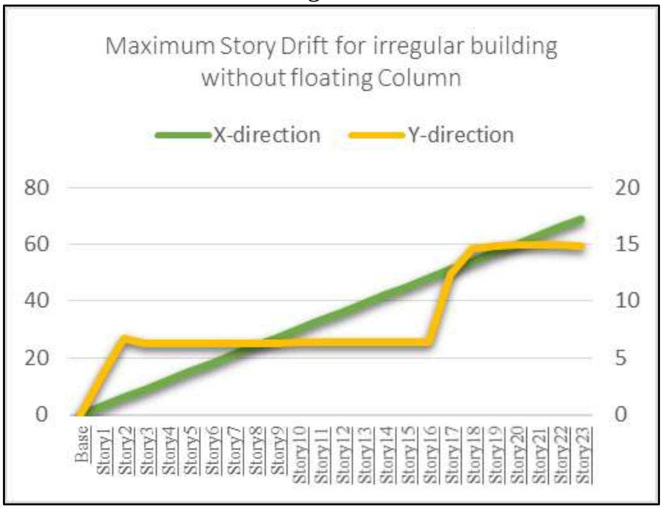


Fig. 7: Maximum Story Drift for irregular building without floating Column

Model 1 shows a lateral displacement of story 1 to the base below and story 2 above, a lateral displacement is also recorded from the moment there is a change in shape from the story below to the story above as seen in story 7 to story 8 and story 16 to story 18. In model 2 a lateral displacement is shown from the base to story 2, from story 16 to 17 and story 21 to 23. Story drift will always occur especially from the base and will continue to experience lateral displacements from story having irregular shapes.

3) Story Shears

The story shears obtained after push over non -linear analysis is explained below.

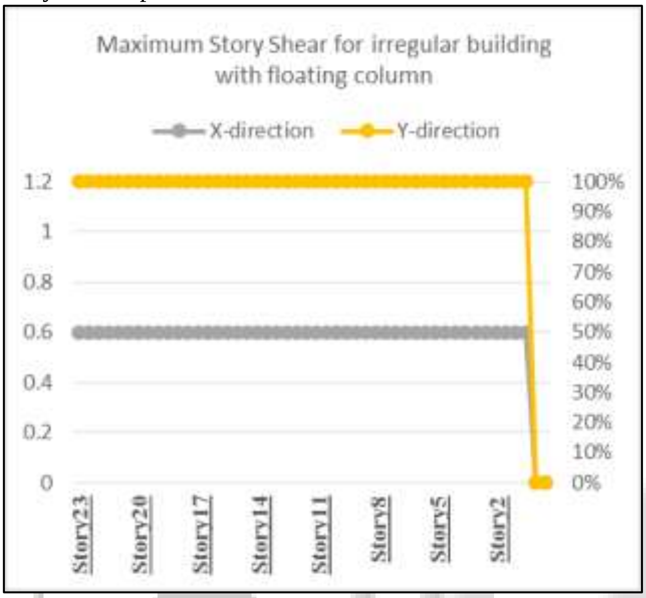


Fig. 8: Maximum Story Shear for irregular building with floating column

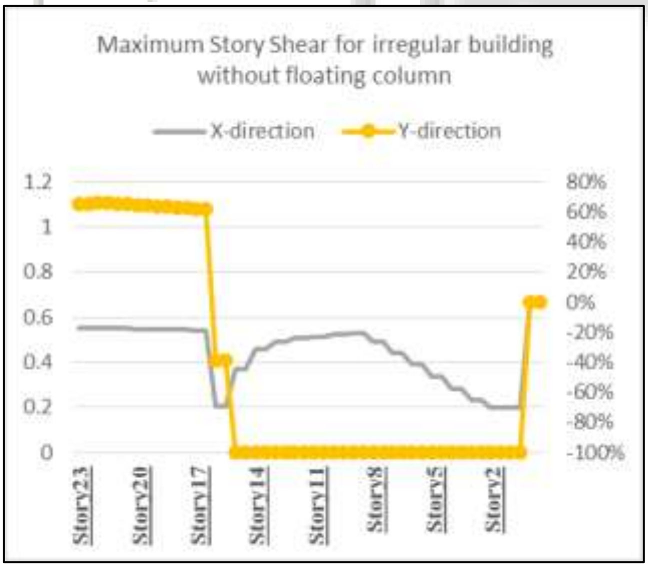


Fig. 9: Maximum Story Shear for irregular building without floating column

The story shears show the lateral load acting on each story. Both models show greater shear at the bottom stories that is from the base to story 2. Model 1 show an even distribution of shear on all other stories but model 2 showed an increase in shear from story 15 and story 16 in both X and Y-directions.

4) Overturning Moment

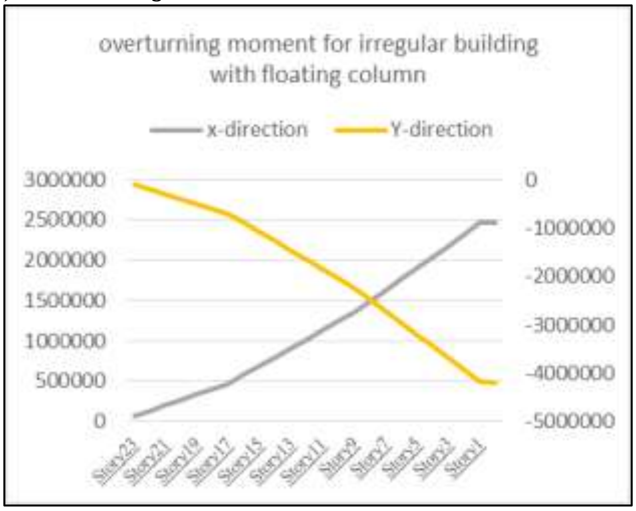


Fig 10: overturning moment for irregular building with floating column

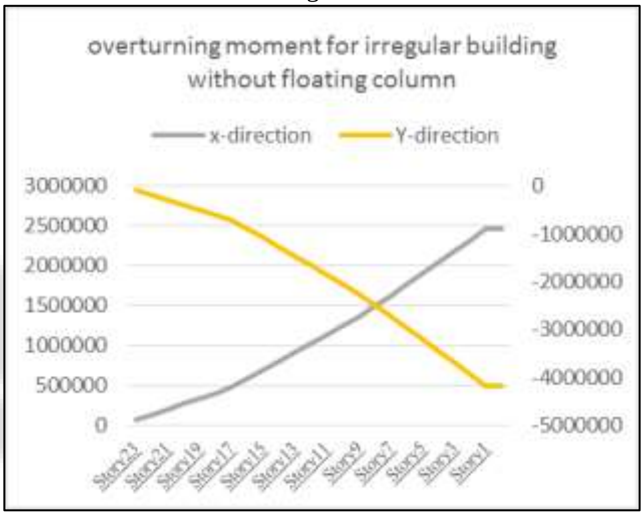


Fig. 11: overturning moment for irregular building without floating column

The torque applied due to the resulting forces about the points of contacts within the base and story 1 in both models shows that the torque is within the torque due to self-weight about the base line.

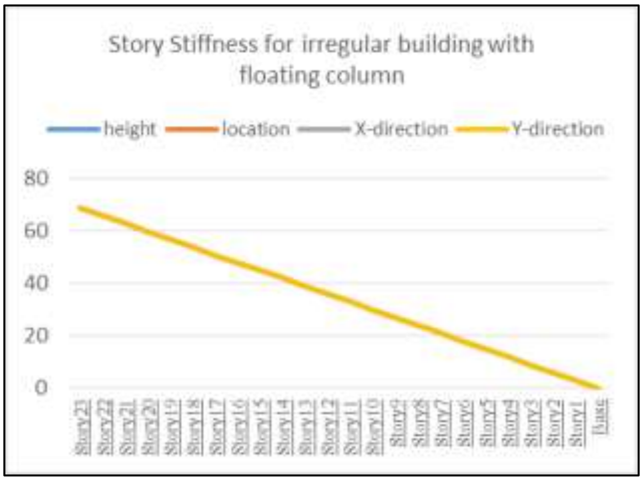


Fig. 12: Story Stiffness for irregular building with floating column

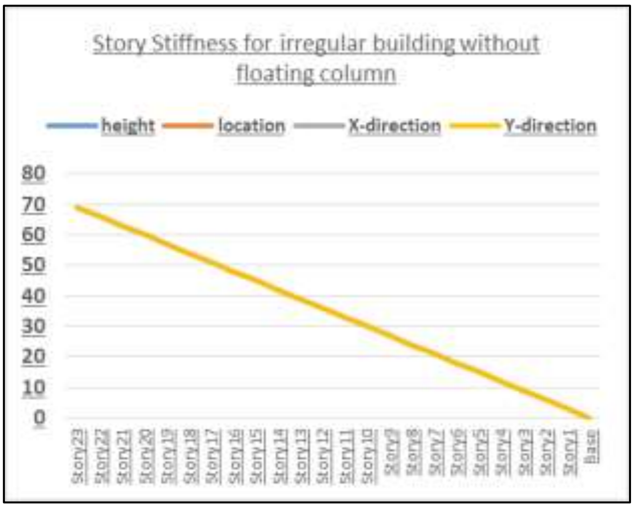


Fig. 13: Story Stiffness for irregular building without floating column

The story stiffness both models shows a good rigidity from one story to another. The story stiffness in both the X and Y directions do not show any deformation in any story. The irregular structure in this study is influenced by the varying shapes of stories and not the increase in height of the story. The irregular RC frames have heights of 3m from bottom floor to top floor respectively. Per IS 1893:2016 (part1) the stiffness of each column can be calculated as 12 EI/L^3. Therefore, stiffness of story= $(12^3/3^3)$=1.3>0.7. Hence, as per IS code 1893:2016 (part 1) the building has no stiffness irregularity.

V. Conclusion

After studying, analyzing and comparing the frequency, period and story response of the irregular frame with floating column and irregular frame without floating column, the following conclusions are drawn;

The period and frequency of vibration will remain the same with or without floating column as far as the story heights and shape remain the same. According IS code 1893:2016 (part 1) stiffness irregularity will occur if the floor stiffness is less than 0.7. the floor stiffness of the irregular building calculated is 1.5 which is greater than 0.7. therefore, the buildings analyzed in this study is safe against stiffness irregularity. Stiffness irregularity is also influenced by variation of story height from one floor to another. However, in this study, the building has equal height from bottom to top floor which eliminates the probability of stiffness irregularity.

Story drift recorded after analysis shows that both buildings will experience some amount of drift from the base to first two stories but the drift will be more intense and will affect the other stories differently if it has a floating column. The story shear in model 1 as compared to story shear in model 2 shows a relatively low shear action in model 1 than model 2. Irregular buildings having floating column will experience a lesser shear action or failure as compared to an irregular building without floating column.

In conclusion, comparatively both models have similar story responses and can both serve the purposes to which they will be constructed. Economically, buildings having floating column will require expertise and supervision to ensure that the building is constructed well. More materials like concrete and reinforcement will be needed to build thicker and stronger beams to withstand the load coming from the building. Economically, it is better to build without floating column.

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