“Effect of floating columns on buildings subjected to seismic forces”

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Abstract: In Recent Trends, buildings are planned to fulfill their architectural and functional requirements but sometimes this creates complexity in its structural strength. One such element is the floating column. It is used to boost Floor Space Index. The Earthquake forces developed at different storey need to be carried down by the shortest path. Discontinuity in the load transfer path leads to poor seismic performance of the structure. Hence as per IS: CODE-1893:2016 clause no-7.1, the Construction of Floating Column is restricted. But there is no limit to research work. The purpose of this research is to analyze the structural irregularity occurring due to floating columns and also to find out the optimized solution to decrease the risk due to earthquake excitation. For Simplicity, the focus of this study is limited to symmetrical G+8 Structure. Finite element Based ETabs software has been used for the analysis. Response spectrum analysis was done in the software. Total ten models are considered with different conditions and their results were compared in terms of Storey displacement, Storey drifts, Base Shear and Overturning moments. All results are compared with the conventional building.

Keywords: Floating Column, seismic Analysis, displacement, Base shear, ETabs

Abbreviations- ESA: Equivalent Static Analysis, IS: Indian Standard, FC: Floating Column, RCC: Reinforced cement concrete, RSA: Response spectrum Analysis, SI: Stiffness Irregularity

1. Introduction

Now a days, the population is increasing at fast rate. Due to shortage of spaces, it is very difficult to design the buildings in horizontal systems. As a result, Vertical systems comes into demand specially in High rise buildings, shopping malls, plaza building etc. Many Multi storeyed buildings are constructed for the purpose of Residential and commercial both. Some floors of commercial place contain banquet halls, conference rooms, parking areas, lobbies etc. These spaces require an uninterrupted movement of people and vehicles. Closely spaced columns act as barrier. Hence to avoid this condition; Floating Column comes into existence. Floating column is mainly used to fulfill architectural and functional requirement of the space.

Floating Column: Column is a vertical member which starts from the ground and is continued up to the height of the structure. This column transfers the load of the structure to the foundation. To fulfill the functional requirements, some columns does not go directly to the foundation. They rest on the Transfer beams and transfers the load of structure to the adjacent columns as shown in Fig 1. Such vertical structural member is called Floating Column. The Distribution of Seismic force depends on stiffness and the mass of structure. The presence of FC directly affects the stiffness of building. Hence due to stiffness irregularity the building is subjected to non-uniform earthquake forces.
The behavior of a structure during earthquake depends on its geometry, shape and size. It also depends on how the load is transmitted to the ground. The earthquake forces developing at different floor level need to be carried down to the ground by the shortest path. Any Discontinuity in the path leads to poor seismic performance of the building. Structure with vertical setbacks cause a sudden failure at the level of discontinuity. Hence these kinds of structure should be designed by certain seismic strengthening techniques.

The Present study Highlights the behavior of a building with Floating columns which is subjected to seismic forces. Response spectrum Analysis method was used in Etabs software. The main objective of this study is to compare the behavior of the different models having stiffness irregularities with FC. **Response Spectrum Analysis:**

For designing a structure in seismic zones, it is important to study the actual time history. During the Earthquake, response of the building depends not only on its frequency content of ground motion but also on its dynamic properties. Hence Seismic Analysis of such buildings cannot be done depending on its peak value of ground acceleration. To overcome these complexity, Response spectrum Analysis (RSA) is used. It is a linear-dynamic method of statistical analysis which evaluates the participation of each natural mode of vibration for indicating the maximum seismic response of an elastic structure. In this method maximum values of member forces and displacement are calculated as the average of different earthquake motions

**Stiffness Irregularity:**

Stiffness irregularity is the vertical irregularity in the structures. Here if the lateral stiffness is less than 70% as compared to above storey or if it is less than 80% of average stiffness up to 3 storey the structure is said to be soft storey. Floating columns are one of the such element which causes stiffness irregularity in the structure. Hence in the present study, Comparison of various cases of stiffness irregularities are studied and their results are compared.

**2. Literature Review:**

Patel T [1], Chand D [2] has done a comparative analysis of different cases of Floating column building using SAP2000. They concluded that corner position should be avoided for minimum displacement. Pundir A [3] used E-Tabs for analysis of steel Structure with FC. Here author introduced mass irregularity at different floors as per various cases. Further, it was observed that an increase in the total weight of the structure increases its stability. Vyas Y [4], Mandawle [5] has done a Review on various literature and found out that many researchers have adopted shear walls to compensate effects of FC. It was also observed that shear walls were effective below G+10 storey. Sasidhar T [6] analyzed the six cases of G+5 storey building using E-tabs and concluded that the second floor is the optimum location to provide FC. Sredha R [7] has analyzed the G+5 structure using ESA and RSA. This study highlighted that if FC is shifted to a higher level, then it will cause more damage to the structure. Sanas P [8] suggested that internal FC and external FC gives increased torsion values at all the floor. By provision of Alternate floor FC, the torsion values can be reduced. Bargir M N [9] analyzed the G+10 structure using E-tabs by placing a triangular plate at the junction of the beam-column in the building with FC.
It was observed that the story Drift and displacements have been reduced as compared to normal Floating Column Buildings. Singh J [10] concluded in their study that buildings can be safe if the size of Beams and columns are increased. Shashikumar N S [11] analyzed FC building by RSA using E-tabs. Here Author placed Bracings under FC. Kini V [12] has done RSA of normal FC building and FC building of Steel concrete Composite structure. The study showed that the Composite structure had more moment carrying capacity than 1st model. Mohammed U [13] analyzed the G+10 structure and found out that shear and displacement values depend on the Position and orientation of FC. Agrawal V [14] has performed RSA and ESA of FC building. Here the author has introduced chevron bracings under FC which reduced the shear force on the beam on which FC is rested. Siva Naveen [15] has conducted the study on various Irregularity and their combination and concluded that the displacement can be controlled by incorporating combination of irregularities in irregular structure.

3. Problem Identification
- Stiffness irregularity in open ground
- Discontinuity in load path due to FC
- More displacement occurs during earthquake
- Increment in Storey Drift
- Torsional Irregularity due to horizontal irregularity

4. Proposed Work
As per IS: CODE-1893:2016 clause no-7.1, the Construction of Floating Column is restricted. But the Research work has no limitation. Hence The main objectives of present study are as follows
- To compare Maximum Storey displacement, Storey drifts, Base Shear and Overturning moments of all the cases
- To study the structural behaviour of Floating Column Buildings with variation of irregularities.

5. Methodology:
In the present study, A G+8 high rise structure with special moment resisting frame is considered. Various configuration of building is analyzed using FEM based software ETabs. The inputs are Geometry of frames which includes dimensions of building, storey height, Beams and columns sizes, Thickness of slabs, Loading conditions, Modulus of elasticity, Response spectrum data, damping ratio and earthquake data. The structural response of all configurations is compared in the form of Maximum Storey displacement, Storey drifts, Base Shear and Overturning moments. In order to validate the results, the calculation of seismic weight and base shear of regular structure is done by manual calculation as per IS 1893:2016 part 1. The structural details of Regular Structure are as follows:

| Table 1. Details of Model |
|---------------------------|
| **Section Properties**    |                               |
| Plan Dimensions           | 25m X 25m                     |
| Total Height              | 25.6m                         |
| Column Size 1             | 0.50m x 0.50m                 |
| Beam Size                 | 0.40m x 0.40m                 |
| Live load on floors       | 4 Kn/m²                      |
| Live load on roofs        | -                             |

| **Material Properties**   |                               |
| Fck                       | 30 Mpa                        |
| Fy                        | 500Mpa                        |
| Es                        | 20,000 Mpa                    |

| **Seismic Properties**    |                               |
| Type of Analysis          | RSA                           |
| Structure Type            | RCC Frame Structure           |
| Zone                      | V                             |
| Type of Soil              | Medium                        |
| Damping                   | 5%                            |
| Importance factor         | 1                             |
5.1 Validation

Calculation of Total Seismic Weight and Base Shear of Regular Structure using ESA:

The floor area of the building is 20\(\times\)20=400 sq. m. Since the live load class is 4KN/m\(^2\), only 50% of the live load is lumped at the floors. There is no live load to be lumped at the roof. Hence, the calculation seismic weight on the roof and the floors are as follows:

- Weight of beams: \(l \times b \times h \times \text{density of concrete} \times \text{Number of beams} = 0.4 \times 0.4 \times 5 \times 25 \times 40 = 800\text{KN/m}\)
- Weight of Columns: \(l \times b \times h \times \text{density of concrete} \times \text{Number of columns} = 0.5 \times 0.5 \times 3.2 \times 25 \times 25 = 500\text{KN/m}\)
- Weight of Slabs: \(l \times b \times t \times \text{density of concrete} \times \text{Number of panels} = 5 \times 5 \times 0.15 \times 25 \times 16 = 1500\text{KN/m}\)
- Weight of floors due to live load: \(L \times B \times 50\% \times \text{Live load} = 20 \times 20 \times 0.5 \times 4 = 800\text{KN}\)

Total weight of each storey \(W_1 = W_2 = W_3 = W_4 = W_5 = W_6 = W_7\) = Weight of beams + Weight of Columns + Weight of Slabs + Weight of floors due to live load = 800+500+1500+800 = 3600\text{KN}\)

Total weight at the top storey is taken at the middle height of the storey, hence weight of the columns should be considered at \(H/2 = 3.2/2 = 1.6\text{m}\)

\(W_8 = \text{Weight of beams} + \text{Weight of Columns} + \text{Weight of Slabs} = 800 + (0.5 \times 0.5 \times 1.6 \times 25 \times 25) + 1500 = 2550\text{KN}\)

Total Seismic weight of the structure \(W = (7 \times 3600) + 2550 = 27,750\text{KN}\)

Calculation for Fundamental Period: (Clause 7.6.2. of IS: 1893 Part 1) EL in X-Direction:

\(\text{Tax} = \frac{0.09h}{\sqrt{g}} = \frac{0.09 \times 25.6}{20} = 0.515\text{sec}\)

Therefore, \((Sa/g) = 2.5, Z=0.36, I=1, R=5\)

Horizontal acceleration coefficient: Therefore, \(A_h = \frac{Z_s q I}{2 g R}\)

Now Base shear \(V_b = A_h \times X \times W = 0.09 \times 27,750 = 2497\text{KN}\)

The Seismic weight of the Regular Structure in ETabs Software is obtained as 27650\text{KN} and storey shear as 2488\text{KN}. Hence, these values are approximately similar to the manual calculations.

5.2 Building Configurations

First model is the conventional building having no irregularities in it. In Model SI-1 and SI-3, 8 columns were reduced at exterior edge at Ground floor and First floor respectively as shown in Fig. 3a. In SI-2 and SI-4, 4 columns are removed at inner periphery Ground floor and First floor respectively as shown in Fig. 3b. In case SI-5 to SI-10, Floating column effects were as per model SI-1. In SI-5, SI-6 and SI-7 the storey height is increased to 4.2m at 2\(^{nd}\), 4\(^{th}\) and 6\(^{th}\) storey respectively. In case SI-8, the 1\(^{st}\) two storey’s rectangular columns were replaced with Circular column having same cross sectional area to satisfy this condition, diameter of column is taken as 565mm. In SI-9, the 1\(^{st}\) two storey’s rectangular columns were replaced with Circular column with increasing 1.5 times cross sectional area of column. Hence the diameter of the column is taken as 690mm. In case SI-10, the size of 1\(^{st}\) two storey’s rectangular columns were increased to 650mm x 650mm. The elevation of all the cases is shown in Fig. 2.
Figure 2. Elevations of all the Building Configurations

Figure 3 Plan of irregular buildings at Ground floor and First Floor

Table 2. Details of Building Configuration

| Model | Description |
|-------|-------------|
| Model 1 | Regular Structure |
| SI-1  | Removing Exterior Columns at Ground Floor |
| SI-2  | Removing Interior Columns at Ground Floor |
| SI-3  | Removing Exterior Columns at 1st Floor |
| SI-4  | Removing Interior Columns at 1st Floor |
| SI-5  | Increasing height of 2nd Floor of SI 1 Model |
| SI-6  | Increasing height of 4th Floor of SI 1 Model |
| SI-7  | Increasing height of 6th Floor of SI 1 Model |
| SI-8  | Replacing 1st two storey's column with circular c/s without changing its c/s area of SI 1 |
| SI-9  | Replacing 1st two storey's column with circular c/s with increased c/s area of SI 1 |
| SI-10 | Increasing 1st two rectangular storey's column size area of SI 1 |
6. Results and Discussions:
The Seismic response of G+8 vertically irregular structure with floating columns is examined in this study. The results of all the models are compared with the regular structure. The responses are explained in terms of Maximum Storey displacement, Storey drifts, maximum Base Shear and Overturning moments. These parameters are presented through Graphs and table as follows:

Figure 5 shows the maximum displacement of all cases. Here it is observed that among all the SI cases, the SI-8 in which the first two floors’ columns were replaced by circular column having the same cross-sectional area shows the maximum displacement at top as 67.33 mm. Here the increment in displacement is 44.9% as compared to regular structure. SI-9 and SI-10 also have greater displacement as compared to other models. This showed that by increasing the cross-sectional area of first two storey by 1.5 times, the storey displacement can be reduced as compared to case SI-8. On the other hand, even after keeping the cross-sectional area constant, SI-9 displaces more than SI-10. In SI-1 and SI-2, displacement in SI-2 is lesser than SI-1. Case SI-3 and SI-4 shows lesser displacement as compared to SI-1 and SI-2 respectively. This indicates that location of irregularity affects the displacement responses. The SI-4 shows the minimum displacement as 47.24mm which is nearly equal to the regular structure. There is only increment of 1.67% as compared to regular building.
Table 3. Displacement in X direction in all Cases (mm)

| Storey | RS | SI-1 | SI-2 | SI-3 | SI-4 | SI-5 | SI-6 | SI-7 | SI-8 | SI-9 | SI-10 |
|--------|----|------|------|------|------|------|------|------|------|------|-------|
| Story8 | 46.461 | 50.962 | 49.035 | 50.653 | 47.24 | 58.223 | 57.267 | 54.634 | 67.326 | 60.786 | 59.872 |
| Story7 | 44.489 | 48.57 | 47.118 | 48.264 | 45.285 | 55.808 | 54.766 | 51.964 | 65.148 | 58.553 | 57.624 |
| Story6 | 40.97 | 44.649 | 43.69 | 44.339 | 41.794 | 51.875 | 50.633 | 45.602 | 61.65 | 54.935 | 53.976 |
| Story5 | 35.823 | 39.12 | 38.662 | 38.796 | 36.682 | 46.308 | 44.554 | 39.663 | 56.701 | 49.81 | 48.809 |
| Story4 | 29.221 | 32.149 | 32.185 | 31.808 | 30.114 | 39.176 | 33.156 | 32.493 | 50.367 | 43.26 | 42.206 |
| Story3 | 21.453 | 24.007 | 24.509 | 23.651 | 22.373 | 30.414 | 24.401 | 24.22 | 42.74 | 35.368 | 34.245 |
| Story2 | 12.971 | 15.1 | 16.003 | 14.803 | 13.842 | 15.928 | 15.265 | 15.215 | 33.771 | 25.979 | 24.746 |
| Story1 | 4.767 | 6.306 | 7.336 | 4.698 | 4.783 | 6.462 | 6.356 | 6.346 | 22.577 | 15.722 | 14.613 |
| Base   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 6 shows the maximum storey Drift of all models. Here it is observed that SI-5, SI-6, and SI-7 shows the maximum storey drift as the height of 2nd, 4th and 6th storeys were increased to 4.2m. Maximum Storey drift is observed in SI-7 as 0.000861mm. There is % increase as compared to regular building. By observing the drifts of SI-1, SI-2, SI-3 and SI-4; it can be observed that Storey drifts depends upon location of floating column. Drifts in SI-8 is nearly similar to Regular structure.

![Figure 6. Maximum Storey Drift in RX Direction](image1)

Figure 7. Base Shear in RX Direction

![Figure 7. Base Shear in RX Direction](image2)
Here maximum Base Shear is found out in SI-10 as 2098.28 KN. The least Base shear is observed in SI-3 where the interior columns at ground storey were floated. In SI-5, SI-6 and SI-7, there was not any variation in base shear. Base shear is same in case of change in height.

![Figure 8](image_url)  
**Figure 8.** Maximum Overturning Moments at base in RX Direction

Here the SI-1 and SI-3 has more overturning moments than regular structure which shows that Floating columns placed at outer edges creates excessive moments at the base. Whereas I case of SI-2 and SI-4 results are exactly opposite

![Figure 9](image_url)  
**Figure 9.** Maximum Storey Stiffness in RX Direction

7. Conclusions:  
In this study, the structural behavior of Building with floating column is examined with the different conditions of stiffness irregularities. All the considered cases were compared with the regular structure and also with each other. The present analysis concluded that interior placement of floating columns reduces the seismic hazard of structure as compared to outer periphery floating columns. There was not any significant improvement in structural behavior of the structure SI-1 and SI-8. But after increasing the diameter of the column the displacement is reduced. It is also concluding that the displacement in FC building decreases as the upper story height increases but the overturning moments are increased abruptly. In modern trends, the architectural requirements are designed so as to provide more space with less obstruction. Hence Incorporating Floating columns with the combination of various irregularity can be adopted not only to fulfill Architectural requirements but also the Structural requirements

8. Future Scope:  
Buildings with Floating columns can be analyzed incorporating Torsional Irregularity, Mass Irregularity
ad their combination. Here one single irregularity is considered, hence for further study Combination of Stiffness Irregularity along with Mass Irregularity and Horizontal Irregularity can be considered.

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