International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 07 | July 2019 www.irjet.net p-ISSN: 2395-0072

# Comparative Study of Vertically Irregular Buildings Subjected to Seismic Load

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**Abstract** - *Multi-storied structures subjected to seismic forces must be properly analyzed and designed so as to absorb the energy from an earthquake and stand still without suffering any major damages. The buildings that are vertically irregular, have a tendency to attract more earthquake forces as compared to the regular buildings. Also, vertically irregular buildings have certain weaknesses in the lateral load resisting system and usually tend to fail at that points. These weaknesses may occur due to change in stiffness of buildings, change in the vertical geometry of buildings, floating columns, etc. In order to maintain the stability in such cases, the structures must be carefully analyzed for their complex behavior and must be designed accordingly.*

*The present work shows the performance & behavior of regular and vertically irregular RCC buildings subjected to seismic forces. Two types of vertical irregularities in buildings i.e. vertical geometric irregularity and floating column as mentioned in IS 1893 (Part I): 2016 are studied using non-linear static pushover analysis and response spectrum analysis. All the models are analyzed using Etabs 2016 software. Different parameter's like performance point, base shear, roof displacement etc. have been compared to study the behavior of vertically irregular buildings.*

***Key Words*: Vertically irregular buildings, Floating column, Response spectrum analysis, Pushover analysis, Etabs 2016, etc.**

## 1. INTRODUCTION

Nature forces have always influenced the existence of human life since time immemorial. Even in such worst cases, human beings have tried to control the nature and co-exist with it. In consideration to the natural disasters such as floods, tornadoes, hurricane, etc. earthquake is the most destructive and least understood of all the disasters. The destruction due to earthquake goes on increasing as the elevation of structures goes on increasing above the ground. Though the natural disasters excluding earthquake contribute a major part of the average annual loss. Earthquakes are instantaneous disasters that cannot be predicted with natural observation like all other disasters, creating a psychological impact on the society.

Multi storied Structures subjected to earthquake must be properly designed and constructed to absorb the seismic energy in order to protect it from collapsing. Post-earthquake review of structures has led to the conclusion that buildings with irregularities face major damages as compared to regular structures. A structure with regular configuration in plan and elevation along with adequate amount of ductility, stiffness and strength performs well during an earthquake. However, all the buildings constructed cannot be regular in configuration and are irregular in some sense. Irregular configurations are incorporated in a building to improve the functional planning of building, to gain major advantage of space, to improve the aesthetic view of the structure, etc. and hence play a major role in the seismic design of a building. Several vertical irregularities have been listed in IS 1893: 2016 (Part I) code such as stiffness irregularity, mass irregularity, vertical geometric irregularity, floating column, etc. However, geometric irregularities are a common term to observe in any building and are hence considered in this study. Also, floating column buildings are studied for their response to seismic forces.

## 2. OBJECTIVES

The comparison between various seismic parameters would allow us to propose the best suitable building configuration on the existing condition. More specifically, the salient objectives of this research are as under.

1) To perform a comparative study of the various seismic parameters of different types of reinforced concrete moment resisting frames (MRF) with varying elevational configurations and the effect of stiffness of masonry walls in structures.

2) Comparison between regular and vertical irregular frame on the basis of base shear, story displacement, torsion, hinge formation pattern in buildings, performance point, etc.

3) To study the change in different seismic response parameters of a building with the change in the location of floating column.

4) To propose the best suitable building configuration on the existing condition.

## 3.Methodology

The methodology adopted for achieving the above-mentioned objectives is as follows.

A) Vertical Geometric Irregularity:

1. Five building models are considered in vertical geometric irregularity in which one is a regular model and the remaining have irregularity in elevation.
2. The buildings are analysed with bare frames without any infill load, frames with infill load and frames with infill load and stiffness of masonry walls. The structures are analysed using static analysis and response spectrum analysis.
3. The vertically geometric irregular structures with infill load are also analysed using non-linear static pushover analysis. The performance point and hinge formation in the structure is studied.

**Table-1: Problem statement for vertical geometric irregularity.**

| Details of building: | |
|---|---|
| Type of structure | Fixed base moment resisting frame |
| Type of building use | Hotel |
| Foundation type | Isolated |
| Depth of foundation | 2 m |
| No. of stories | G+8 |
| Typical storey height | 3m |
| Grid size | 5m x 5m |
| **Material properties:** | |
| Grade of concrete | M20 |
| Grade of steel | Fe 415 |
| Density of concrete | 25 kN/m³ |
| Density of masonry | 20 kN/m³ |
| **Member properties (mm):** | |
| Beam | 300 X 500 |
| Column | 600 X 600 |
| Slab | 120 |
| External wall | 230 |
| Internal wall | 115 |
| Parapet wall height | 1m |

**MODELS:**

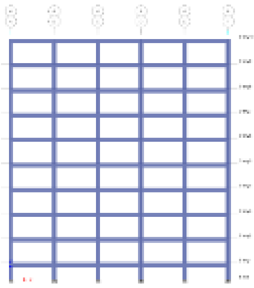


**Fig-1: Regular**

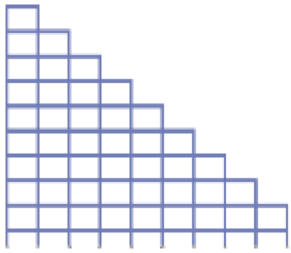


**Fig-2: GMI 1**

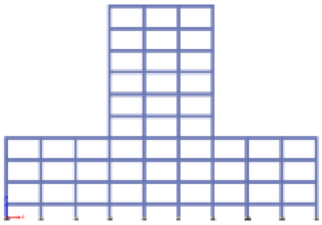


**Fig-3: GMI 2**

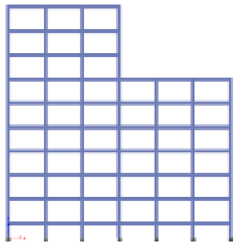


**Fig-4: GMI 3**

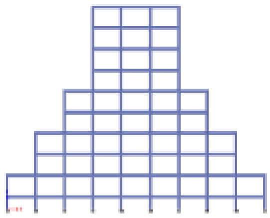


**Fig-5: GMI 4**

B) Floating Column:

1. Twelve models are analysed for floating column analysis. One is a regular model and in the remaining models, column are removed at each storey from bottom to top storey.
2. The structures are analysed using linear static analysis and non-linear static pushover analysis.
3. Parameters like base shear, roof displacement, hinge formation pattern and performance point are studied.

**Table-2: Problem statement for floating column.**

| **Details of building:** | |
|---|---|
| Type of structure | FIXED BASE MOMENT RESISTING FRAME |
| Foundation type | ISOLATED |
| Depth of foundation | 2 m |
| No. of stories | G+10 |
| Typical storey height | 3.3m |
| Storey height at | 4.3m |

| | |
|---|---|
| discontinuity | |
| Grid size | 25m X 25m |
| **Material properties:** | |
| Grade of concrete | M25 |
| Grade of steel | Fe 415 |
| Density of concrete | 25 kN/m³ |
| Density of masonry | 20 kN/m³ |
| **Member properties (mm):** | |
| Beam | 300 X 500 |
| Beam under floating col. | 400 X 1000 |
| Column | 600 X 600 |
| Slab | 120 |

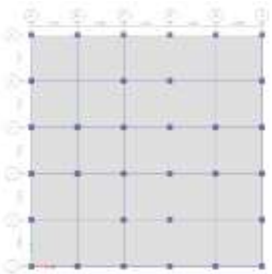


**Fig-6: Plan**

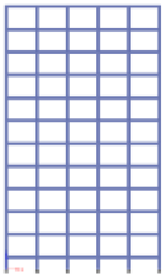


**Fig-7: Elevation of building with no discontinuity**

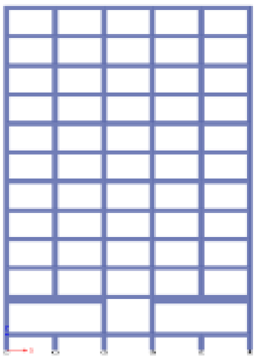


**Fig-8: Column discont-inuity at 1st floor**

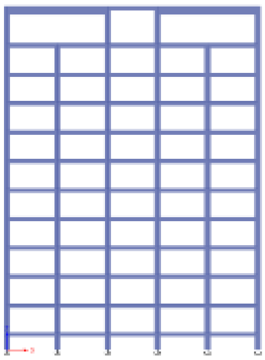


**Fig-9: Column discontinuity at 10th floor**

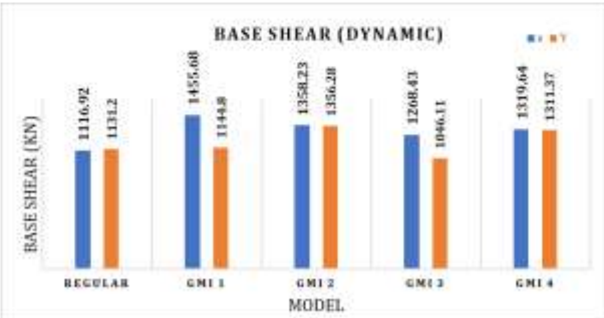
**Table-3: Details of loading and seismic data for vertical geometric irregularity & floating column**

| | |
|---|---|
| **Dead load intensity:** | |
| Self-weight | 3 kN/m² |
| Floor finish | 1 kN/m² |
| Roof finish | 2 kN/m² |
| **Live load intensity:** | |
| Floor | 3 kN/m² |
| Roof | 1.5 kN/m² |
| **Seismic data:** | |
| Zone | IV (Z=0.24) |
| Importance factor | 1.5 |
| Response reduction factor | 5 (SMRF) |
| Type of soil | II |
| Damping ratio | 5% |

## 4. Analysis and Results:

A] Vertical geometric irregularity:

1) <u>Without infill load:</u>
   Time period (x/y direction) = 0.937 sec
   Base shear (Static) = 1832.94 kN




**Graph-1: Base shear of buildings without infill load.**

**Table-4: Roof displacement of buildings without infill load.**

| ROOF DISPLACEMENT (mm) | | | | |
|---|---|---|---|---|
| MODEL | EQ X | | EQ Y | |
| | X | Y | X | Y |
| REGULAR | 27.51 | - | - | 26.77 |
| GMI 1 | 20.48 | - | 8.34 | 29.09 |
| GMI 2 | 28.03 | - | - | 26.09 |
| GMI 3 | 23.86 | - | 5.62 | 28.93 |
| GMI 4 | 26.22 | - | - | 26.03 |

2) <u>With infill load:</u>
   Time period (x/y direction) = 0.937 sec
   Base shear (Static) = 2884.66 kN

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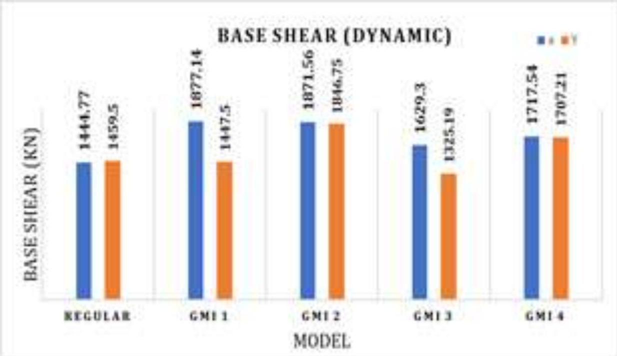
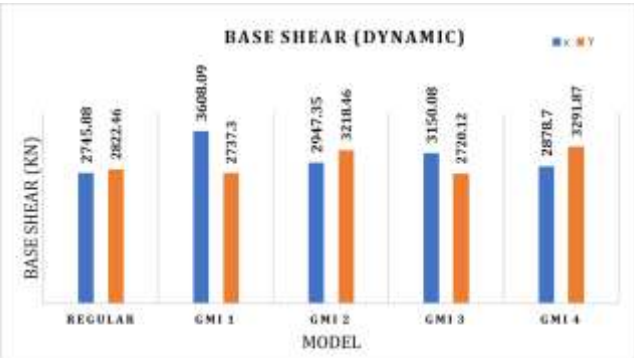



**Graph-2: Base shear of buildings without infill load.**

**Table-5: Roof displacement of buildings with infill load.**

| ROOF DISPLACEMENT (mm) | | | | |
|---|---|---|---|---|
| MODEL | EQ X | | EQ Y | |
| | X | Y | X | Y |
| REGULAR | 41.96 | - | - | 40.83 |
| GMI 1 | 30.96 | - | 13.91 | 45.45 |
| GMI 2 | 42.67 | - | - | 39.79 |
| GMI 3 | 36.16 | - | 9.244 | 44.64 |
| GMI 4 | 36.80 | - | - | 36.76 |

3) <u>With infill load and stiffness of wall:</u>
Time period (x/y direction) = 0.937 sec
Base shear (Static) = 4969.96 kN



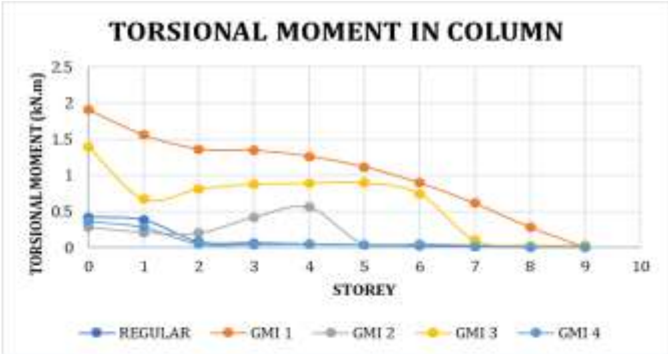

**Graph-3: Base shear of buildings with infill load and stiffness of wall.**

**Table-6: Roof displacement of buildings without infill load.**

| ROOF DISPLACEMENT (mm) | | | | |
|---|---|---|---|---|
| MODEL | EQ X | | EQ Y | |
| | X | Y | X | Y |
| REGULAR | 19.72 | - | - | 18.45 |
| GMI 1 | 10.26 | - | 3.18 | 12.53 |
| GMI 2 | 21.37 | - | 0.234 | 17.56 |
| GMI 3 | 17.44 | - | 3.34 | 19.65 |
| GMI 4 | 21.62 | - | - | 16.35 |

**Table-7: Performance point for geometrically irregular building.**

| MODEL | BASE SHEAR (kN) | ROOF DISPLACEMENT (mm) | RESERVED STRENGTH RATIO |
|---|---|---|---|
| REGULAR | 8911.58 | 131.26 | 6.17 |
| GMI 1 | 8503.81 | 82.68 | 4.53 |
| GMI 2 | 11273.07 | 103.63 | 6.02 |
| GMI 3 | 9189.89 | 117.70 | 5.64 |
| GMI 4 | 10359.17 | 102.98 | 6.03 |




**Graph-4: Torsional moment in columns of building with infill load and stiffness in EQ-Y direction.**

B] Floating column:

As per IS code formula,

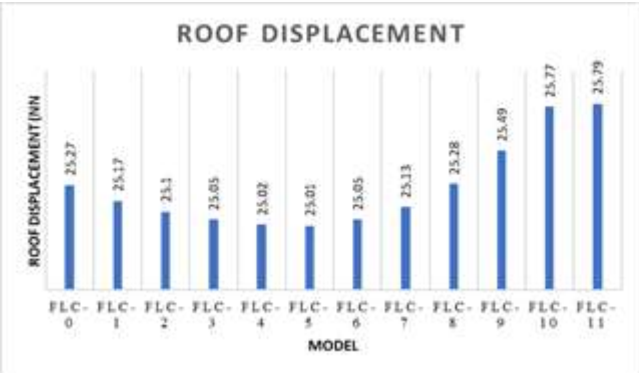
- <u>Building without discontinuity:</u>
  Time period= 1.155 sec
  Base shear = 310.35 kN
- <u>Building with discontinuity:</u>
  Time period= 1.177 sec
  Base shear = 307.98 kN

The time period, base shear and roof displacement values for change in discontinuity level as calculated by program are as follows.


**Graph-5: Variation of Base shear with respect to level of discontinuity.**

**Table-5: Results of linear static analysis of floating column building.**

| MODEL NO. | TIME PERIOD (T) (Sec) | BASE SHEAR (kN) | ROOF DISPLACEMENT (mm) |
|---|---|---|---|
| FLC-1 | 1.682 | 216.21 | 25.17 |
| FLC-2 | 1.689 | 215.58 | 25.10 |
| FLC-3 | 1.699 | 214.60 | 25.05 |
| FLC-4 | 1.708 | 213.45 | 25.02 |
| FLC-5 | 1.716 | 212.32 | 25.01 |
| FLC-6 | 1.723 | 211.29 | 25.05 |
| FLC-7 | 1.728 | 210.46 | 25.13 |
| FLC-8 | 1.730 | 209.86 | 25.28 |
| FLC-9 | 1.730 | 209.54 | 25.49 |
| FLC-10 | 1.728 | 209.54 | 25.77 |
| FLC-11 | 1.677 | 209.80 | 25.79 |




**Graph-6: Variation of roof displacement with respect to level of discontinuity**

## 5. CONCLUSIONS

### Vertical geometric irregularity

- Comparison of vertical geometric irregular buildings with regular buildings shows that, buildings with irregular configuration attract more base shear as compared to regular ones.
- It is encountered from non-linear analysis, that the reserve strength of vertical irregular buildings is less in comparison to regular buildings.
- The external beams present at the locations where the lateral dimension of the building changes abruptly, are subjected to considerable amount of torsional moment as compared to the internal beams.
- The columns of buildings with irregular configuration are also subjected to torsional moments. However, if the stiffness of infill wall is considered then the torsional moments in columns are reduced.

### Floating column irregularity

- Time period and base shear changes with the change in location of discontinuity. Base shear goes on decreasing as the column discontinuity moves from down to upper floors.
- Roof displacement changes with the change in location of column discontinuity. It initially decreases for discontinuity at lower floors and thereafter increases.
- Locating discontinuities at upper floors provides advantage for designing the structure with lower value of lateral forces and gaining sufficient amount of reserved strength.

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