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STUDY ON SEISMIC BEHAVIOR OF SOFT-STOREY BUILDINGS WITH STIFFNESS VARIATION AND BASEMENT INTEGRATION

Prasad Sudhakar Jamdhade[1]*, Aarti Santosh Jadhav[2], Prasad Gajnan Sonar[3]

[1,2]*UG Student, Department of Civil Engineering, CSMSS Chh. Shahu college of Engineering, Chh. Sambhajinagar, MH, India.*

[3]*Assistant Professor, Department of Civil Engineering, CSMSS Chh. Shahu college of Engineering, Chh. Sambhajinagar, MH, India.*

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***Corresponding Author: Prasad Sudhakar Jamdhade**

UG Student, Department of Civil Engineering, CSMSS Chh. Shahu college of Engineering, Chh. Sambhajinagar, MH, India.

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ABSTRACT

Due to rapid urbanization, the population increase in the center of big cities is rising steadily. This rise in urban migration, mainly caused by the search for improved job prospects, is contributing to the burden on the land with the subsequent rise in high-rise buildings being erected. Elaborating on this is vital in catering to the needs of the growing population. Such high-rise buildings are to be developed in accordance with earthquake-resistant designs and patterns due to the vast damage caused by earthquakes to life and property. In India, about 60% of the country has seismic regions, and this is depicted in the Indian Standard IS codes, which are prepared by experts in the profession after conducting detailed research and analyzing the regions. Simple structures with plan irregularity and non-uniform loads are more reliable during an earthquake since they have equal distribution of mass and stiffness, sufficient strength, and overall integrity. But complications set in when there is irregularity in the plan or non-uniform loads. Irregular structures pose risks when there are irregular patterns in the building or non-uniform loads since the structures will behave erratically during an earthquake. Some of the irregularities include irregular distribution of mass, irregular distribution of torsional, irregular distribution of diaphragm, and weak storeys and roofs. It will be imperative for the engineer to take into consideration and amend these irregularities, and this will be critical with the growing emphasis on performance-based designs.

The present research work covers mass irregularity in buildings and is one of the primary reasons for structural failure in seismic events. It was previously mentioned in IS code that mass irregularity is present in situations where "the seismic weight of a storey is in excess of 200% of the adjoining storey's seismic weight and has been reduced to 150% after several modifications."

In our research work, we consider a G+30 building situated in seismic zone V and include mass irregularity on every tenth storey to determine its behavior in structural analysis.

KEYWORDS: *Seismic analysis, Mass irregularity, Etabs 17, Story and base shear plots.*

INTRODUCTION

Earthquake: An earthquake can be defined as a natural phenomenon that can be detected either by human observation or by the use of scientific instruments. Earthquakes result from the sudden release of energy accumulated in the Earth's crust, which creates seismic waves that have strength measured by magnitude and intensity. depends primarily on its size, frequency, and type. The magnitude of an earthquake can be determined using an instrument known as a seismometer. For earthquakes with a magnitude less than 5, the local magnitude is typically measured using the Richter scale. However, when the magnitude exceeds 5, the moment magnitude scale is generally used for more accurate assessment. The intensity of ground shaking during an earthquake is measured using the Mercalli scale. Earthquakes often cause ground displacement and vibrations, which, if severe, can lead to devastating natural disasters such as landslides, tsunamis, or even volcanic eruptions.

Seismic waves generally fall into two main categories: one is body waves and the other is surface waves. Body waves are seismic waves that move along the internal layers of the Earth, while primary or P-waves and secondary or S-waves are their subcategories, basically named according to the mode of motion. P-waves are much faster than any other seismic waves, while they propagate by compressing and expanding the materials in the direction of propagation. S- waves have a slower speed than P-waves, while these waves cause oscillations perpendicular to the direction of wave propagation. Surface waves are another category of seismic waves that travel along the Earth's outer layers. As these waves travel through different Earth regions, such as crust, mantle, and core, their speeds and natures vary because of the variation in material density and elastic properties. Scientists and seismologists assess such differences using data collected from seismic waves. There are instruments called seismographs that detect other types of waves, such as P-waves, S-waves, and L- waves. Apart from these normally discussed types of seismic waves, there are other types of such waves, known as Rayleigh waves. Rayleigh waves propagate along the surface of the earth in the same direction that the wave travels. Additionally, Rayleigh waves cause elliptical movement of the earth.

The S-waves become invisible at the outer core of the Earth at a depth of approximately 2900 kilometers. This happens because the outer core of the Earth is liquid. Smaller earthquakes produce tiny faults. The faults produced by these earthquakes can be for smaller portions of major faults. The motion of the faults occurs rapidly and for a short time. Large earthquakes produce large faults that can extend to thousands of kilometers. The motion of the faults, along with the vibration, can last for several minutes.

- **Irregularity**

In every structure, there are some weak zones that prove extremely crucial and vulnerable during earthquakes. These irregularities occur due to some discontinuity in geometry, mass properties, or stiffness. Such buildings that have these discontinuities come under the category of irregular buildings. A major portion of present-day constructions consists of buildings that have these irregularities. Irregular buildings that have vertical irregularities can easily be devastated and get destroyed due to the forces of earthquakes. For example, buildings with soft storeys have consistently been found more vulnerable to collapse during seismic events. Therefore, it is essential to examine the effects and impact of earthquakes on vertically irregular structures. When stiffness varies with height, the dynamic behavior of the building changes, and mass distribution is also affected.

According to IS 1893:2016, a vertically irregular building is defined as:
Irregularity in structure is caused when mass, stiffness, and strength are not distributed evenly up to a particular height in a building with varying levels of complexity in its structural system, and in particular in seismically active areas. Currently, it is prevalent in modern constructions for buildings to have some irregular characteristics in their structural system. The impact of an irregular system on seismic behavior is largely dependent on the model used in analysis. There are two basic kinds of irregularities in structural systems, namely plan irregularity and vertical irregularity.

- **Stiffness Irregularity:**

1. Soft Storey- A soft storey is defined as a storey whose lateral stiffness is less than 70 percent of the stiffness of the storey immediately above it. A storey is also considered to be soft if its lateral stiffness is reduced by more than 80 percent in comparison with the average lateral stiffness of the three storeys above.

2. **Extreme Soft Storey:-** A storey is considered to be an extreme soft storey if lateral stiffness of that particular storey is less than 60% of the storey above it. It is further classified as extreme when the stiffness reduction is more than 70% compared to the average stiffness of the three storeys above the concerned storey.

3. Mass Anomaly:- Mass irregularity is considered to occur when the seismic mass of a storey is more than twice that 200% of the seismic mass of adjacent storeys. The transfers of weight across roofs are not excluded. According to the IS code modified criteria, even if the seismic weight difference between the adjacent stories falls between 150% and 200%, it will also be classified as mass irregularity.

4. Vertical Geometric Irregular: - In the case of vertical geometric irregularity, if the horizontal dimension of the lateral force resisting system of any storey is greater than 1.5 times that of the adjacent storey, this condition is considered unsatisfactory. Such an abrupt change in the storey dimension can have a profound effect on the structure's seismic response.

5. In-Plane Discontinuity in Vertical Lateral Load-Res:- This is a form of irregularity that occurs if there is a large in- plane displacement in a vertical element resisting.

6. Discontinuity in Capacity: A storey is said to be a weak storey if its lateral load-carrying capacity is less than 80% of that of the storey directly above it. For low-height regular buildings, seismic analysis is normally carried out using the linear static method according to IS 1893 (Part 1): 2016, based on the codal estimation of the fundamental natural time period. For taller buildings or for cases where the higher-mode effect cannot be neglected, the preferred method is LDA, as it gives a fairly realistic representation of the structural behaviour.

LITERATURE REVIEW

Seismic Response of Mass Irregular Structure:

Darshan D and Shruthi H K (2016) A study was conducted to examine the effects of mass irregularity on high-rise buildings. With the increasing need to accommodate growing populations, constructing high-rise structures has become essential. These buildings need to be designed in such a way that they resist seismic forces effectively. Regular buildings are easy to design as they have equal form and strength characteristics. But irregular buildings that have offsets, setbacks, torsional irregularity, mass irregularity, weak planes, and discontinuity of diaphragms have complex behavior when exposed to seismic forces. In regular buildings, seismic forces act in increments of 30° due to the symmetry of buildings. But for other buildings, these forces act at all points in time due to a lack of symmetry.

Ankesh Sharma and Biswobhanu Bhadra (2013) The various structural irregularities have been analyzed in detail to study their effect on seismic behavior and emphasis has been given mostly to vertical irregularity. The seismic response of the building has been studied by Response Spectrum Analysis and Time History Analysis. Equivalent Static, and Time History analyses have also been performed to check ductile design requirements as per IS 13920. A comparative study was also done between regular and irregular structures to determine the difference in seismic response. In addition, building responses for earthquake motions corresponding to low, medium, and high frequency characteristics were studied with Time History Analysis.

Anibal G. Coasta, Carlos S. Oliveira, Ricardo T. Duarte (1998) This study will attempt to lead to an analysis of the earthquake response of reinforced concrete buildings, in which vertical irregularities are present. The analysis will focus principally on a sixteenth- storey structure having a fixed plan shape, and five different vertical configurations. Furthermore, a simplified analysis will be carried out on a similar structure having 12 and 20 stories. These buildings will be modeled as a network of fixed plan moment-resisting frames, shear walls, which are connected via a rigid floor diaphragm. nonlinear behavior of frames, shear walls will be established through appropriate behavior parameters. The results will be obtained through a step-by-step solution of equations of motion, using a series of ground motion accelerations.

Eggert V. Valmundsson and James M. Nau (1997) The research highlighted that while there are certain codal provisions regarding evaluation methods for both regular and irregular buildings, it has only been relatively recently that criteria for identification of irregular buildings have become clear. In the research, the values for the mass, strength, and stiffness of the regular building are determined in accordance with the regulations of the Uniform Building Code (UBC) Standard. For the two-dimensional models with 5, 10, and 20 stories, six primary periods of vibration are explored. Irregular conditions were generated through certain parameters being changed for a single story or a tier. Ground mass ratios varying from 1 to 5 have also been considered. There have been variations for the stiffness and strength ratios for the first storey and mass ratios varying from 1.0 to 5. Design ductility levels have also been calculated for response calculations at 1 (elastic), 2, 6, and 10 for four different sets of earthquake motion inputs.

PROBLEM ANALYSIS

A seven-storey RCC building located in Seismic Zone V is selected for the case study to understand the effect of mass irregularity on seismic performance. Various models were created, including one in a mass-regular configuration, and others introducing mass irregularity at alternate floors, at the lower level, at mid-height level, and at the top floor. An LDA using a response spectrum approach is performed. Seismic performance was assessed by including some important response parameters: base shear, fundamental time period, storey drift, and lateral displacement.

- The structural analysis process uses the following parameters:
- **RC Frame Configuration:**

a) Structural Details:

1. The tower has thirty stories.
2. Every level has an equal floor to floor height of 4m
3. It is meant for residential living
4. Beams will be provided with a cross- sectional size of 230 mm×800 mm.
5. The columns have different dimensions from top to bottom:

600mm x 1200mm to the top of the 10th floor

600 mm × 900 mm on the 11th to 20th story sides

600 mm × 900 mm on the 11th to 20th story sides

The slab thickness of 150 mm is taken uniformly in the entire structure.

b) Parameters of seismic motion:

1. Importance factor taken for the structure: 1
2. The response reduction factor is 5.
3. The structural damping is assumed to be 5%.
4. The seismic analysis is performed based on the Response Spectrum approach, as per IS 1893 (Part 1): 2016

- **Material properties:**

a) Concrete:- The concrete is of grade M30 The unit weight of concrete is 25 kN/m³. The Poisson's ratio is taken as 0.20

Modulus of elasticity is cal. as 27,386.13 MPa.

b) Steel:- High-strength reinforced steel of Fe- 500 grade is used. The unit weight of steel is taken as 78.5 kN/m³.

c) Loadings for mass regular and irregular structure:

- **1.5DL**
- **1.5DL+1.5LL**
- **1.2DL+1.2LL+1.2EQX**
- **1.2DL+1.2LL-1.2EQX**
- **1.2DL+1.2LL+1.2EQY**
- **1.2DL+1.2LL-1.2EQY**
- **1.5DL+1.5EQX**
- **1.5DL-1.5EQX**
- **1.5DL+1.5EQY**
- **1.5DL-1.5EQY**
- **0.9DL+1.5EQX**
- **0.9DL-1.5EQX**
- **0.9DL+1.5EQY**
- **0.9DL-1.5EQY**

Modeling Details:

The plan details of the vertical mass regular building modeled in Etabs is shown in following figure:

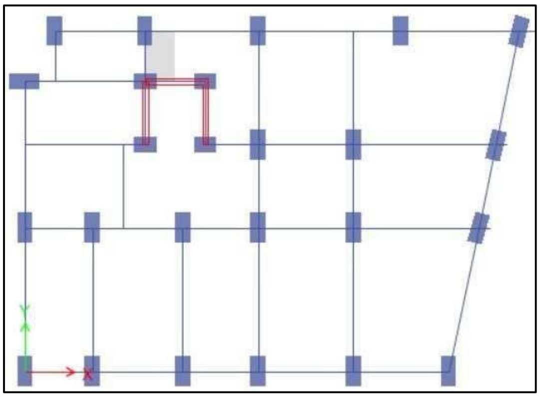


Figure 01: Thirty storied mass regular building.

The plan details of the vertical mass regular building modeled in Etabs is shown in following Figure:

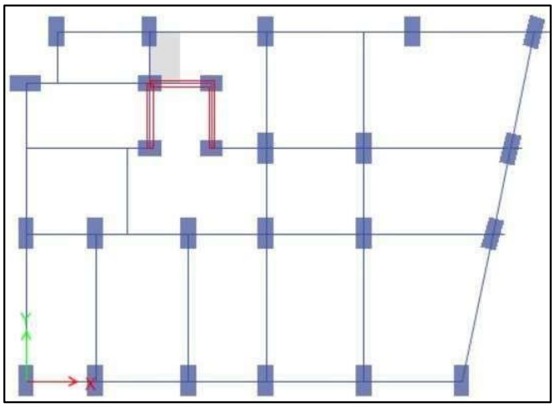


Figure 02: Typical floor plan from base to storey. 10

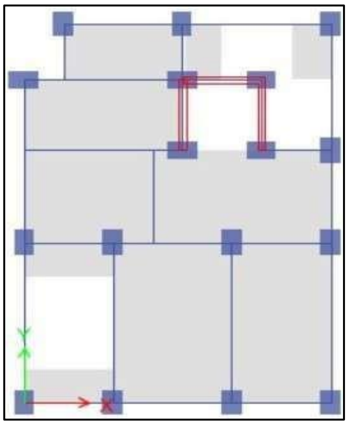


Figure 03: Typical floor plan from story 11 to story 20.

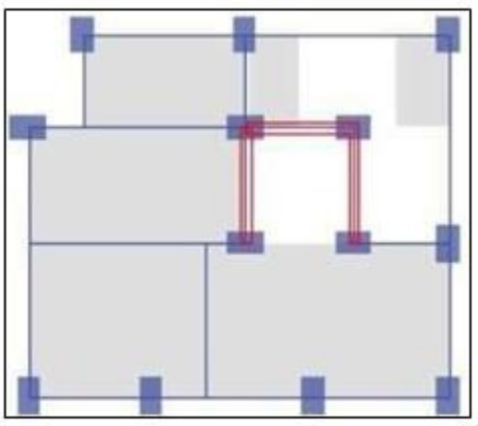


Figure 04: Typical floor plan from story 21 to story 30.

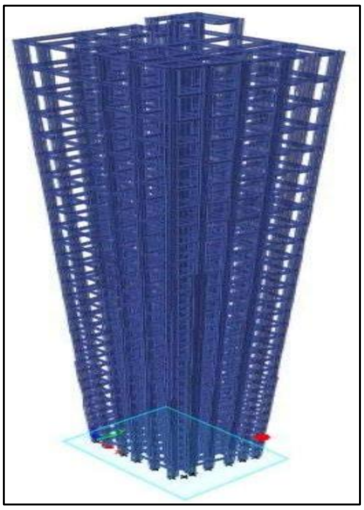


Figure 05: 3D rendered view of the mass regular building.

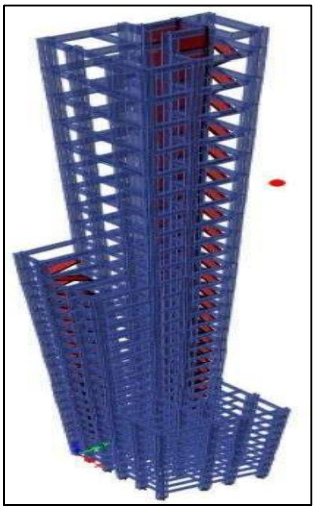


Figure 06: 3D rendered view of the mass regular building.

RESULTS ANALYSIS

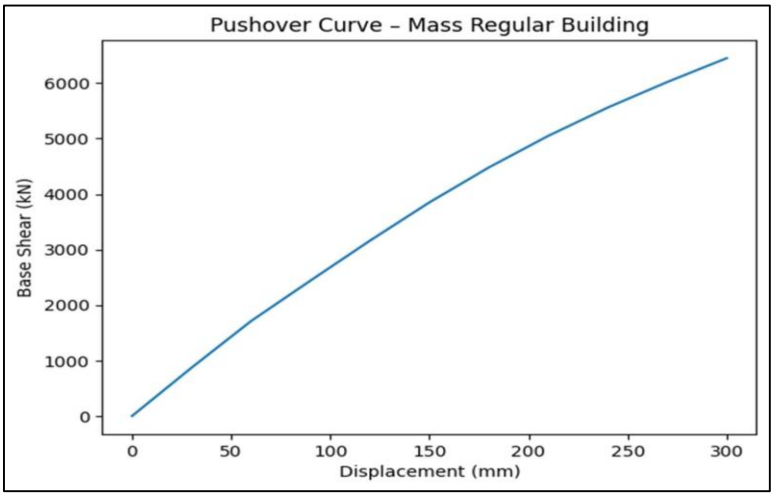
Pushover Analysis: The nonlinear static analysis is carried out to determine the behavior of the structure after the elastic region for various infill materials. The target displacement applied to the structure to show the maximum probable

Pushover curve for mass regular structure:

Force to be experienced during the earthquake. The graph that relates the base shear to the displacement is referred to as the capacity curve of the system obtained from the pushover analysis. The capacity curves for mass regular structure and irregular structure are shown below.

TABLE 01:- Capacity Curve Coordinates for Mass Regular building.

MONITORED DISPLACEMENT (mm)	BASE SHEAR (KN)
0	0
30	870
60	1710
90	2440
120	3160
150	3850
180	4480
210	5050
240	5560
270	6020
300	6450

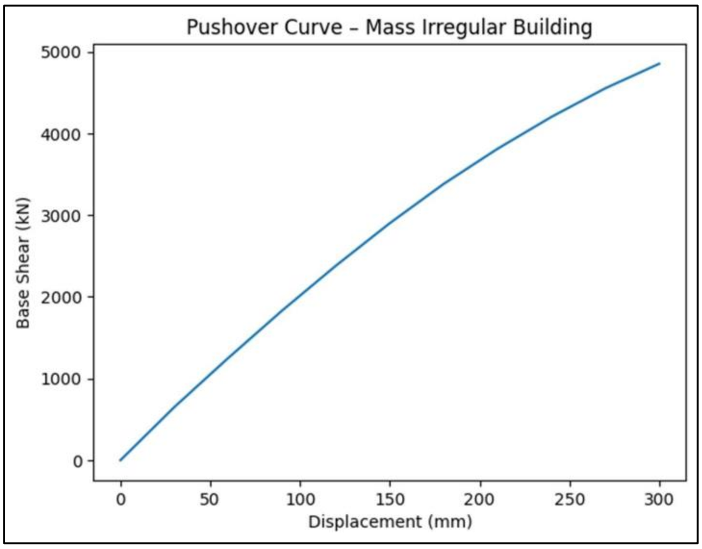


GRAPHS NO.01:- Static Pushover Curve for Mass Regular Building.

Pushover curve for mass irregular structure:

TABLE 02:-Capacity Curve Coordinates for Mass Irregular building

MONITORED DISPLACEMENT (mm)	BASE SHEAR (KN)
0	0
30	650
60	1250
90	1830
120	2380
150	2900
180	3380
210	3810
240	4200
270	4550
300	4850



GRAPHS NO. 02:- Capacity Curve Coordinates for Mass Irregular building.

- **Discussion for Pushover Analysis:**

Elastic analysis allows identifying the first yielding and provides a quantification of the overall strength of the structure. However, elastic analysis alone cannot capture the post-yielding force redistribution and predict the actual modes of failure. In order to overcome these limitations, nonlinear static analysis techniques have been increasingly applied as an effective method to assess structural behavior beyond the elastic range. Push-over analysis is performed in this study for mass- regular and mass-irregular models. A nonlinear analysis provides the following key findings:

1) Where structural mass-regular models demonstrate a much higher ultimate load- carrying capacity than the mass-irregular ones.

2) The capacity curves show that the buildings that have mass irregularities have lower strengths compared to buildings that have equal masses.

➢ Performance Point: The performance point is where the structural capacity curve intersects with the seismic demand curve. This point represents the real behavior of a structure during an earthquake because it gives a more precise estimate of structural performance rather than a capacity calculation.

➢ For Mass Regular Structure: The Performance point for mass regular structure is found at a point of (**137, 3813.22**) where **137.44** is the displacement in (mm) and **3813.22** is the base shear in (KN).

- For the structure with mass irregularity: The performance point is determined when the displacement is 267.33mm with the associated base shear of 5519.64kN.

- **Discussion for Performance Point:**

Capacity curves obtained from the pushover analysis are used to assess the actual structural response incorporating nonlinear behaviour by plastic hinge formation. The seismic demand obtained from the response spectrum is based on site classification and regional seismicity, which is a probable earthquake corresponding to a specified return period. Displacement control pushover analysis has been performed for both mass regular and irregular structural models. The nonlinear static analysis reveals that a mass regular structural model is performing better compared to a mass irregular structural model.

- **Other Comparative Results:**

➢ Story Drift: Maximum story drift values for mass-regular and mass-irregular

➢ structures for various building floors, independent of the direction, are presented in tables.

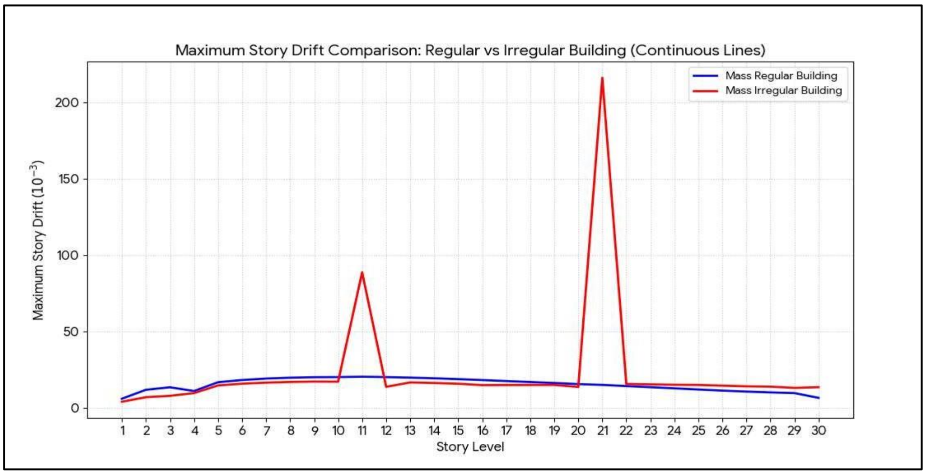
TABLE 03:- MAXIMUM STORY DRIFT OF MASS REGULAR BUILDING

STORY	MAX STORY DRIFT	STORY	MAX STORY DRIFT
1	6.21	16	18.40
2	12.05	17	17.75
3	13.68	18	17.12
4	11.22	19	16.49
5	16.98	20	15.76
6	18.44	21	15.24
7	19.38	22	14.48
8	19.95	23	13.73
9	20.27	24	12.99
10	20.35	25	12.23
11	20.59	26	11.50
12	20.35	27	10.87
13	20.00	28	10.34
14	19.56	29	9.89
15	19.02	30	6.77

TABLE 04:- MAXIMUM STORY DRIFT OF MASS IRREGULAR BUILDING

STORY	MAX STORY DRIFT	STORY	MAX STORY DRIFT
1	4.23	16	15.09
2	7.20	17	15.17
3	8.09	18	15.21
4	9.88	19	15.23

5	14.88	20	13.90
6	16.02	21	216.25
7	16.73	22	15.85
8	17.18	23	15.58
9	17.42	24	15.33
10	17.33	25	15.21
11	88.90	26	14.75
12	13.98	27	14.31
13	16.87	28	14.10
14	16.48	29	13.28
15	16.00	30	13.73



GRAPHS NO. 03:- MAXIMUM STORY DRIFT.

- **Analysis and Interpretation of Results:**

From the analysis of the results, it has been observed that sudden changes in mass and geometry result in a considerable increase in maximum drift of each storey of the irregular building. This occurs at a maximum at levels 11 and 21. Whereas in the mass regular building it doesn't show such results.

Story Stiffness:

The story stiffness of the mass irregular and mass regular building on different floors is shown in the table below.

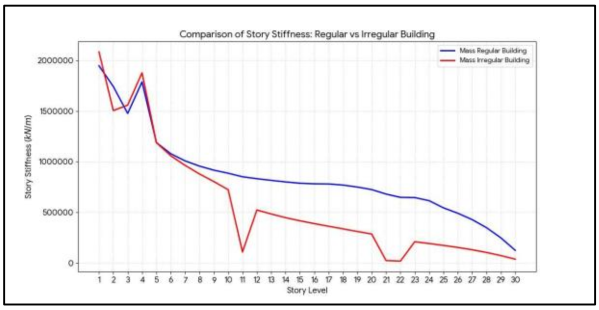
TABLE 05:- STORY STIFFNESS OF MASS REGULAR BUILDING.

STORY	STORY STIFFNESS	STORY	STORY STIFFNESS
1	1,944,950	16	783,045
2	1,740,390	17	781,467
3	1,474,916	18	770,722
4	1,786,166	19	750,991

5	1,188,550	20	726,207
6	1,079,145	21	681,816
7	1,008,837	22	649,484
8	956,955	23	647,370
9	917,248	24	616,991
10	887,206	25	546,361
11	852,167	26	493,157
12	833,266	27	430,607
13	816,560	28	351,010
14	801,430	29	250,839
15	788,465	30	128,110

TABLE 06:-STORY STIFFNESS OF MASS IRREGULAR BUILDING

STORY	STORY STIFFNESS	STORY	STORY STIFFNESS
1	2,081,072	16	391,115
2	1,503,873	17	365,028
3	1,557,032	18	339,468
4	1,875,466	19	313,456
5	1,187,962	20	288,402
6	1,059,186	21	27,520
7	964,387	22	21,879
8	879,898	23	212,737
9	805,176	24	195,038
10	724,823	25	176,568
11	111,559	26	156,547
12	525,400	27	134,134
13	485,677	28	107,162
14	449,755	29	76,209
15	418,886	30	41,129



GRAPHS NO. 04:- STORY STIFFNESS.

- **Analysis and Interpretation of Results**

From the above result it can be noticed that story stiffness in the irregular building drastically changes on the floor where mass and geometry of the building changes suddenly, i.e. on story 11 and story 21 story stiffness decreases by the large value. Whereas in the mass regular building it doesn't show such results.

CONCLUSION

From the above analysis it can be concluded that when we compare the mass regular and mass irregular G+30 buildings it is found that in mass irregular building there is a drastic change in the values of the story drift and story stiffness on the 11th and 21st floor. These are the floors where geometry and mass of the building changes suddenly.

Therefore for these floors a special attention must be given so that an additional safety for the building can be achieved.

Results yielded by the nonlinear static (pushover) analysis indicate that the structures with mass regularity possess considerably higher structural capacities as well as capacities compared to the structures with mass irregularity.

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