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# Response of RCC Asymmetric Building Subjected to Earthquake Ground Motions

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*Abstract*: **The post-earthquake analysis of a structure has always revealed that most of the time the structure was unable to perform well due to the structure irregularities present in it either plan or elevation or in both. Nowadays because of the architectural constraints, or due to urbanization, there is less space available for construction due to which symmetric structure is nearly impossible. A regular structure is one which has a continuous load path and irregular structure is one which has a discontinuity in geometry (setback), mass or load resisting element. Though many researchers were conducted till date but the structural irregularity study as per latest revision IS 1893:2016 was limited and hence it was taken. In the present study, a G+12 existing RCC building asymmetric in the plan is taken to assess the effect irregularities present in it as defined by seismic code IS 1893:2002 and IS 1893:2016 with the help of ETABS (2017) software. Assessment is carried out using Time history method (El-CENTRO & BHUJ). Several models are prepared in ETABS includes a soft story, str. with basement, etc. The measured response includes story displacement, base shear, etc. The aim of this study is to make a designer aware of the effects of irregularities mainly soft story and also a structure with torsion irregularity and to make the structure good enough to withstand the possible lateral load.**

***Keywords—Structural irregularity; soft story; torsion irregularity; time-history;***

## I. INTRODUCTION

Field investigations of a post-earthquake disaster have always found that asymmetric structure or irregular structures suffer more damage than the regular one. Nowadays due to the increase in urbanization there is less space available for parking or for the usage of the space the ground floors are generally kept open due to which their arises discontinuity in the load path and thus structure becomes asymmetric and vulnerable to more damage during earthquake, thus a detailed study regarding behavior of structure during earthquake is always required.

An irregular structure is one in which the load path is not continuous due to improper mass or stiffness distribution. Structural irregularities are of two types:

1) Plan irregularity- re-entrant corners, diaphragm discontinuity, and non-uniform distribution of the lateral force resisting system.

2) Vertical irregularity- stiffness irregularity in elevation, very long projection and mass irregularity.

Previously many researchers have studied the structural irregularities. B.K. Raghu Prasad and Jagadish K S (1989)[1] have found out the effect of eccentricity in plan and the increase in the torsion response on a single story building when it is subjected to strong earthquake motion (EL-Centro). They observed that eccentricity up to 0.05b ('b' is the plan dimension) can significantly increase the ductility demand on the columns.

B.K. Raghu Prasad et al. (2007)[2] have presented an analytical method of quantification and location of seismic damage, through system identification methods. A G+3 structure was taken and the response of weak or soft first story was compared with the normal structure using a non-linear dynamic analysis program (IDARC). Multi-resolution analysis using wavelets was also done for damage identification of soft-story columns.

S. Vardharajan et al. (2013)[3] have studied different criteria of irregularities defined by different codes (IS 1893:2002, EC8:2004, etc.) and found the limitation of types of irregularities prescribed by the standard codes. Regarding the vertical irregularity, they have found that strength irregularity had more impact than mass irregularity on seismic response and during analysis, a dynamic analysis method was found to be more accurate than modal pushover analysis even after the improvement.

B.K. Raghu Prasad et al. (2016)[4] have studied the response of buildings symmetric and asymmetric in the plan. In the study, a single story structure was taken in which columns were modeled as fixed as well as with spring supports. A G+11 structure was taken to study the response of the structure. In both cases, it was found that the asymmetric structure was subjected to more lateral force and was subjected to torsion because of the eccentricity between the center of mass and center of rigidity.

Hemanth Kumar et al. (2018)[5] have studied the response of G+14 RCC asymmetric building using time history method and modal pushover method by considering three models of the structure i.e. bare frame, with infill and soft story and concluded that soft-story buildings are more vulnerable to damage.

## II. OBJECTIVES

The objective of this work is to analyze a G+12 RCC existing building asymmetric in plan and to know its responses for EL-CENTRO (MAY, 1940) time history and BHUJ (JAN, 2001) time history. Though many researchers were conducted till date but the structural irregularity study as per latest revision IS 1893:2016 was limited, hence it was taken and will help make the designer aware about the effects of irregularity in structures.

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## III. METHOD OF ANALYSIS

### *A) Equivalent Static Method*

For a symmetric building up to a certain height defined by IS codes and a structure situated in the less seismic prone region this method can be adopted and this method requires less computational efforts. By this method, design base shear is computed for the whole building and it is then distributed along with the height of the building. The lateral forces obtained are distributed to the individual lateral resisting element. This method is less accurate because it does not consider the dynamic effect.

### *B) Response Spectrum Method*

It is linear dynamic analysis; Response spectrum is a set of ordinates that describes max response (acceleration, velocity, displacement) of a set of SDOF systems subjected to ground motion. These max values are plotted against the undamped natural periods for various damping values.

### *C) Time History Analysis*

Time History Method is the most accurate method among all and is also used for both elastic and inelastic analysis. This method requires the ground acceleration data of the previous earthquakes. It is a step by step analysis of the dynamic response of the structure to a specified loading which varies with time

## IV. MODELING AND ANALYSIS

A G+12 RCC existing structure asymmetric in plan situated in seismic zone III having soil condition medium. The building consists of two groups of a column of 200mm x 700mm, 200mm x 600mm and beams of different size 200mm x 450mm, 200mm x 800mm and slab thickness of 125mm. The building is analyzed for its irregularities defined as per IS 1893 (Part 1): 2002 & 2016 in a structure modeling software ETABS 2017 with response reduction factor-3 and for 5% damping. The plan and elevation are described in fig.1 and fig.2 respectively. The base dimension in X-direction is 36.5m and in Y-direction is 17.34m. The structure has two parts which can be seen in plan and among which the second part is at 13° to X-axis because of the site configuration.

The analysis was carried out on a four structure models described as follows:

Model 1: A model of the building with a floor height of 3m was used as a reference model to compare the results for the irregularities.

Model 2: The building is divided into two parts by providing a separation joint between two wings. In software a gap element is provided between the two wings thus the software understands the structure as a single structure.

Model 3: A ground soft story model was created to know the behavior of the building for the stiffness irregularity, in which ground story height was kept as 4m and was kept open as such buildings are nowadays created and used for the parking place due to lack of space available for it.

Model 4: A fourth model was created by adding a basement to the building which is the next common thing to open story used for the parking, storage, etc.

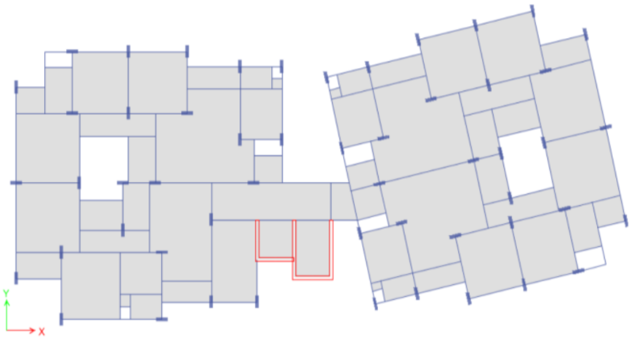

Figure 1: Plan

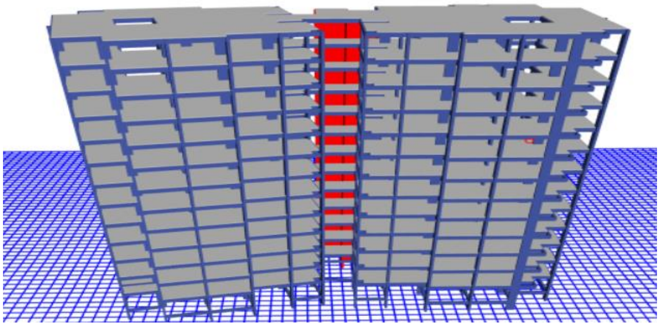

Figure 2: Elevation

The analysis of the building is carried out using time history method. The accelerogram of previous earthquakes i.e. El-Centro (1940), USA and Bhuj (2001), India were applied to the building.

The details of El-Centro (1940) earthquake are as follows:

1) Magnitude- 6.9
2) Duration- 54 s
3) Peak ground acceleration- 0.347g at 2.41 s.

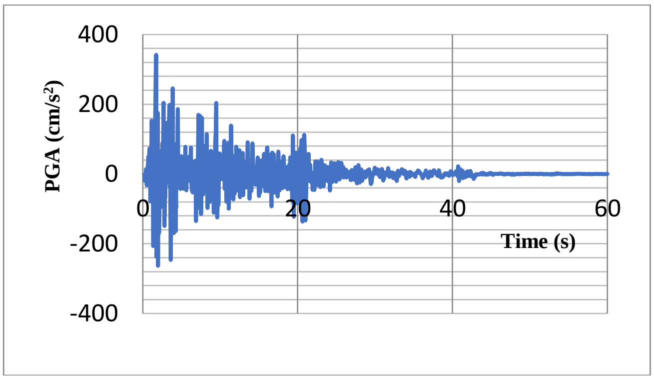


Figure 3: Time-History of El-Centro (May, 1940)

The details of Bhuj (2001) earthquake are as follows:

1) Magnitude- 7
2) Duration- 135 s but considered up-to 60 s as PGA was achieved
3) Peak ground acceleration- 0.105g at 46.94 s.

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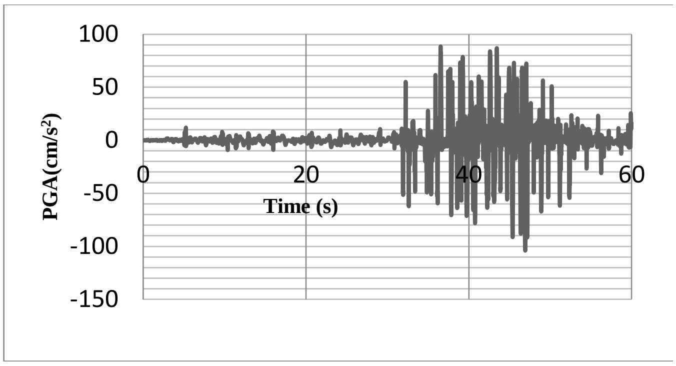


Figure 4: Time-History of Bhuj (Jan, 2001)

## V. RESULTS AND DISCUSSION

The above RCC building is analyzed using the static and dynamic method and results are as follows:

### A) Base Shear comparison

The Fig.5-Fig.8 shows the base shear in the principal X direction and Y direction for IS 1893:2002 and 2016 and it was seen that base shear in model 1 is high compared to all in each case. The base shear in response spectrum analysis obtained was less compared to base shear from the equivalent static method (EQ/RS).

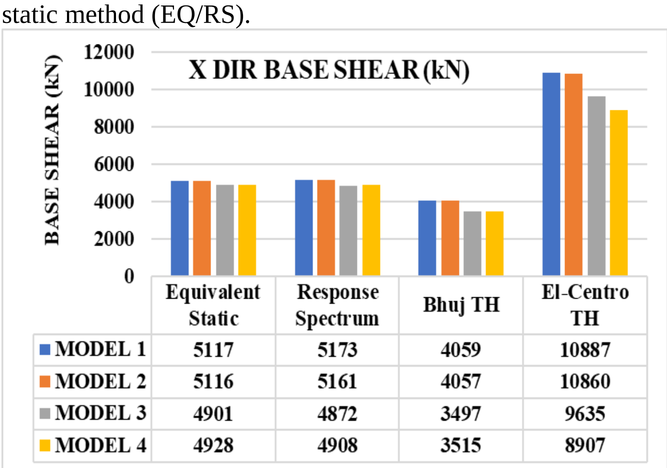


Figure 5: Base Shear (kN) in X-dir.(IS 1893:2002)

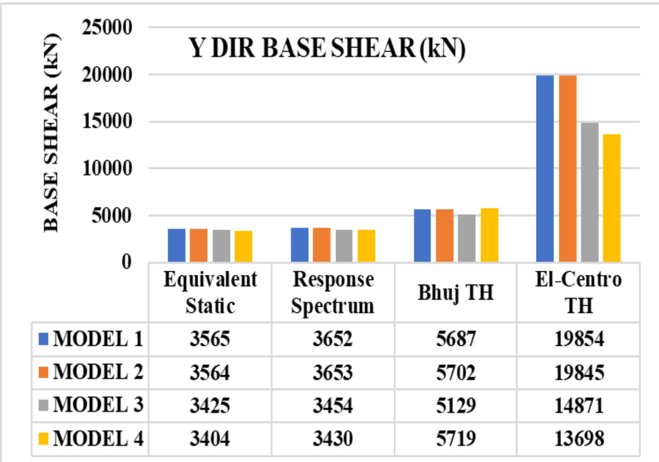


Figure 6: Base Shear (kN) in Y-dir.(IS 1893:2002)

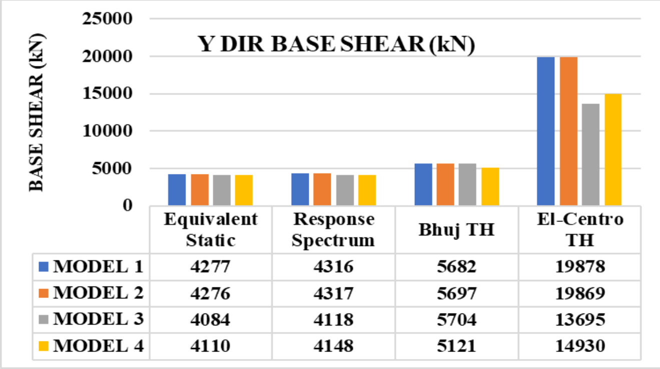


Figure 7: Base Shear (kN) in X-dir.(IS 1893:2016)

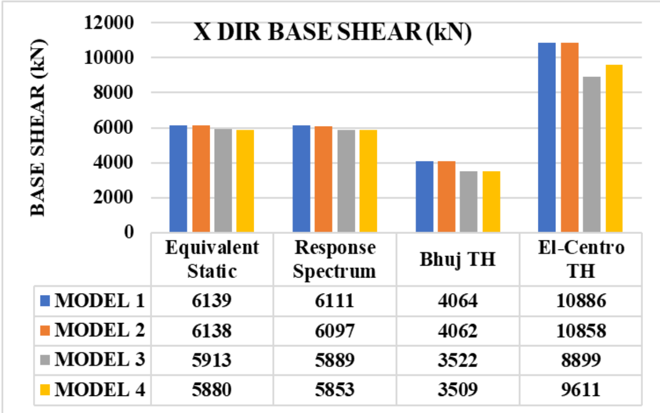


Figure 8 Base Shear (kN) in X-dir.(IS 1893:2016)

### *B) Maximum Top Story Displacement*

IS 456 and IS 1893 have specified limit for lateral sway of any structure which should not exceed (height/250).
Maximum Permissible Lateral Sway in different models as per IS 1893:2002 & 2016 shown in table 1

Table 1: Max. Allowable Sway

| Model | Lateral Sway (mm) |
|---|---|
| MODEL 1 | 163 |
| MODEL 2 | 163 |
| MODEL 3 | 168 |
| MODEL 4 | 179 |

The graphs (Fig.9 & Fig.12) showing the displacement values shows that model 1 has very less lateral sway and is also in the limiting range specified by the standards.

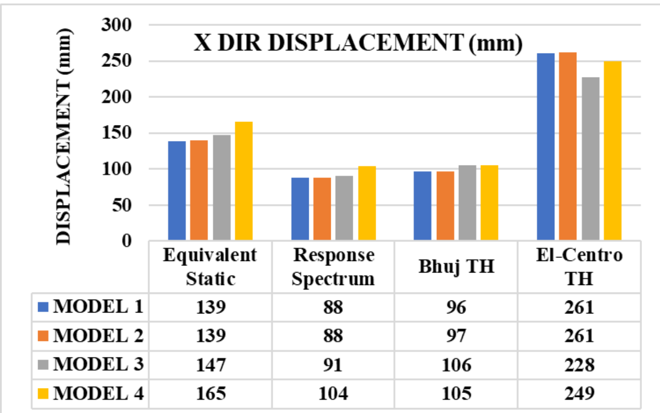


Figure 9: Max Story Displacement X-dir. (IS 1893:2002)

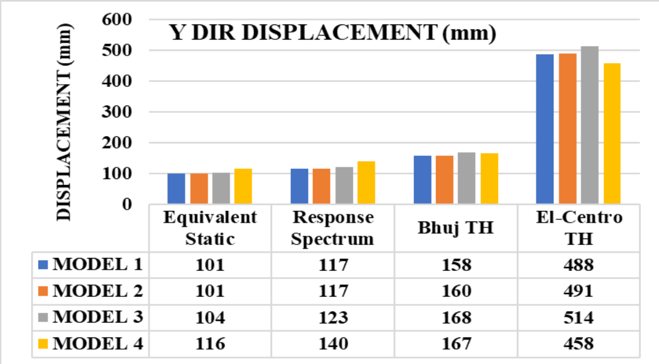


Figure 10: Max Story Displacement Y-dir. (IS 1893:2002)

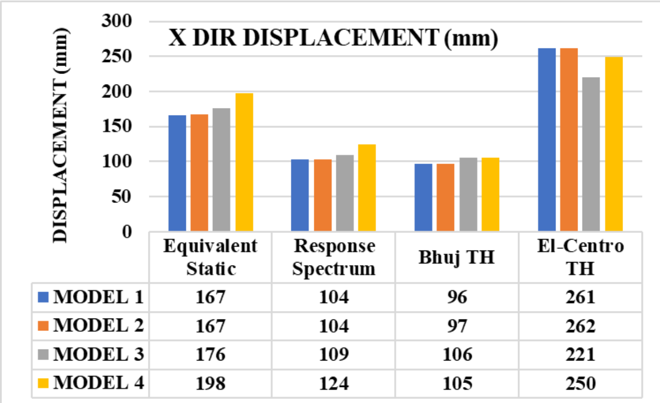


Figure 11: Max Story Displacement X-dir. (IS 1893:2016)

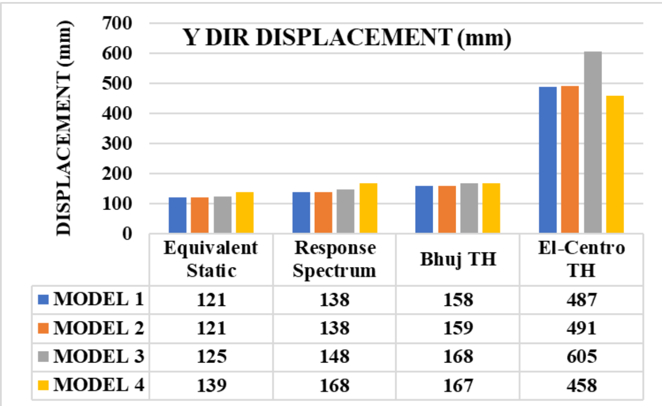


Figure 12: Max Story Displacement Y-dir. (IS 1893:2016)

*C) Torsional irregularity*

Torsion irregularity is one of the most important factors which can cause severe damage to the structure. The irregularity depends on a number of factors such as plan geometry, the arrangement of structural elements and their dimensions and also on the story numbers. This ratio governs the multi-directional response of the structure and also recognizes the ability of elements resisting lateral forces.

Torsion irregularity to be considered to exist when the maximum story drift, computed with design eccentricity, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. The limiting ratio ($\Delta_{max} / \Delta_{avg}$) ≤ 1.2 defined as per IS 1893:2002 is 1.2, and ($\Delta_{max} / \Delta_{min}$) as per IS 1893:2016 in the range of 1.5-2.0 and if the ratio exceeds 2.0, the building configuration to be revised. When the building is subjected to a torsion irregularity, it is affected by differential deformation in plan and will affect the seismic performance of the structure and thus the design of resisting elements should be formulated in such a way that it reduces the torsional effects.

Tables 2 and 3 show the torsion irregularity ratios ($\Delta_{max} / \Delta_{avg}$) and ($\Delta_{max} / \Delta_{min}$) as defined by IS 1893:2002 and 2016 respectively of different models for the response spectrum analysis of the building under lateral load and was seen that all models have torsion irregularity because of plan deformation in geometry.

Table 2: Torsion irregularity ratio (Δ max /Δ avg) of different models in X-dir. And Y-dir. as per IS (1893:2002)

| | MODEL 1 | | MODEL 2 | | MODEL 3 | | MODEL 4 | |
|---|---|---|---|---|---|---|---|---|
| DIR → / STORY | X | Y | X | Y | X | Y | X | Y |
| 12 | 1.12 | 1.26 | 1.12 | 1.26 | 1.12 | 1.27 | 1.12 | 1.27 |
| 11 | 1.12 | 1.27 | 1.12 | 1.27 | 1.12 | 1.28 | 1.12 | 1.28 |
| 10 | 1.12 | 1.28 | 1.11 | 1.28 | 1.11 | 1.29 | 1.11 | 1.29 |
| 9 | 1.11 | 1.29 | 1.11 | 1.29 | 1.11 | 1.30 | 1.11 | 1.30 |
| 8 | 1.11 | 1.30 | 1.11 | 1.30 | 1.10 | 1.31 | 1.10 | 1.30 |
| 7 | 1.10 | 1.31 | 1.10 | 1.31 | 1.10 | 1.31 | 1.10 | 1.31 |
| 6 | 1.10 | 1.32 | 1.10 | 1.32 | 1.10 | 1.33 | 1.10 | 1.32 |
| 5 | 1.09 | 1.33 | 1.09 | 1.33 | 1.11 | 1.34 | 1.11 | 1.33 |
| 4 | 1.10 | 1.34 | 1.10 | 1.35 | 1.12 | 1.35 | 1.12 | 1.35 |
| 3 | 1.10 | 1.36 | 1.10 | 1.36 | 1.13 | 1.38 | 1.13 | 1.37 |
| 2 | 1.10 | 1.39 | 1.10 | 1.39 | 1.13 | 1.40 | 1.14 | 1.39 |
| 1 | 1.10 | 1.42 | 1.10 | 1.42 | 1.13 | 1.44 | 1.14 | 1.42 |
| 0 | 1.09 | 1.46 | 1.09 | 1.46 | 1.12 | 1.49 | 1.15 | 1.46 |
| BASEMENT | | | | | | | 1.14 | 1.52 |

Table 3: Torsion irregularity ratio (Δ max /Δ min) of different models in X-dir. And Y-dir. (IS 1893:2016)

| | MODEL 1 | | MODEL 2 | | MODEL 3 | | MODEL 4 | |
|---|---|---|---|---|---|---|---|---|
| DIR → STORY | X | Y | X | Y | X | Y | X | Y |
| 12 | 1.27 | 1.71 | 1.27 | 1.71 | 1.27 | 1.73 | 1.27 | 1.73 |
| 11 | 1.27 | 1.74 | 1.27 | 1.75 | 1.26 | 1.77 | 1.27 | 1.77 |
| 10 | 1.26 | 1.78 | 1.26 | 1.79 | 1.25 | 1.80 | 1.26 | 1.80 |
| 9 | 1.25 | 1.82 | 1.25 | 1.82 | 1.24 | 1.84 | 1.24 | 1.84 |
| 8 | 1.24 | 1.85 | 1.23 | 1.85 | 1.23 | 1.88 | 1.23 | 1.87 |
| 7 | 1.22 | 1.89 | 1.22 | 1.89 | 1.22 | 1.92 | 1.22 | 1.90 |
| 6 | 1.21 | 1.93 | 1.21 | 1.93 | 1.22 | 1.96 | 1.22 | 1.95 |
| 5 | 1.21 | 1.98 | 1.21 | 1.99 | 1.25 | 2.02 | 1.25 | 2.00 |
| 4 | 1.22 | 2.05 | 1.22 | 2.05 | 1.27 | 2.09 | 1.27 | 2.06 |
| 3 | 1.22 | 2.14 | 1.23 | 2.14 | 1.28 | 2.20 | 1.30 | 2.15 |
| 2 | 1.22 | 2.27 | 1.23 | 2.27 | 1.30 | 2.35 | 1.32 | 2.27 |
| 1 | 1.21 | 2.45 | 1.21 | 2.45 | 1.29 | 2.59 | 1.34 | 2.45 |
| 0 | 1.19 | 2.67 | 1.19 | 2.67 | 1.27 | 2.92 | 1.34 | 2.73 |
| BASEMENT | | | | | | | 1.33 | 3.19 |

*D) Stiffness Irregularity (Soft Story)*

A soft story is one which has more openings such as in one or more floor there are more windows or large openings for doors, which may result in a decrease in stiffness of the floor. A typical soft story building is defined as a building with three or more stories in which ground level is kept open for parking or for the stores having large openings for doors or windows or the structure which is designed for less strength on the upper story also known as upper soft story, such structures performance is less during an earthquake and is seen in the past earthquakes that most of the building got damage at soft story termed as soft story failure.

A soft story is one whose stiffness is less than 70% of the story above or 80% of the average of above three stories defined as per code.

Tables 4 shows the value of stiffness of the different models. It was found that in soft story model 3, the stiffness of the ground floor is less than 70% of the first floor and model is irregular in stiffness.

| STORY | MODEL1 kN/m | MODEL 2 kN/m | MODEL 3 kN/m | MODEL 4 kN/m |
|---|---|---|---|---|
| 12 | 167130 | 166442 | 151719 | 143535 |
| 11 | 306186 | 304859 | 286778 | 272273 |
| 10 | 382326 | 380600 | 366030 | 349450 |
| 9 | 407757 | 405985 | 394484 | 379005 |
| 8 | 427820 | 425985 | 415674 | 399925 |
| 7 | 448249 | 446352 | 435340 | 417518 |
| 6 | 474653 | 472690 | 458822 | 436519 |
| 5 | 512410 | 510390 | 491891 | 461770 |
| 4 | 563914 | 561852 | 539512 | 498178 |
| 3 | 626907 | 624883 | 604567 | 550011 |
| 2 | 708355 | 705745 | 659653 | 615853 |
| 1 | 828136 | 825353 | 712676 | 653751 |
| 0 | 1065720 | 1062753 | 519295 | 562048 |
| Basement | | | | 658200 |

Table 4 Stiffness of the building (IS 1893:2016)

## VI. CONCLUSIONS

In this study, the existing structure of G+12 RCC was assessed for irregularities defined as per IS 1893:2002 and IS 1893:2016. The analysis for the lateral load is carried out using time history of past earthquake i.e. EL-CENTRO (May 1940) and BHUJ (Jan 2001) on four different models and the following conclusions are summarized:

- From the analysis, it was found that base shear in model 1 is the largest.
- The lateral sway was more than the allowable limit in all the models.
- All the models undergo torsion irregularity.
- The structure configuration for model 2, model 3 and model 4 need to be revised as torsion irregularity ratio exceeds 2.0 as per latest revision of the seismic code
- The soft story model 3 has stiffness irregularity which may result in soft story failure.
- To make the structure less un-symmetric a separation joint should be provided somewhere in between.
- Irregularity in the structure either in mass or stiffness will increase the forces to be resisted by the structural elements which will affect the overall cost of the structure.
- When the results were compared from both the codes it is seen that the latest edition of the code is stringent towards the structural irregularity.

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