Analytical Design of Irregular Buildings founded on soft soil

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Abstract. In modern day, due to the need of unique architectural appearance or aesthetics of building, irregularities in mass, stiffness and symmetry may get disturbed, making the whole structure vulnerable to certain damages either minor or major. Some of the functional considerations of these structures are use of ground floor as car parking in residential buildings, use of basement as car parking in malls, etc. Seismic range is one the most important factors to be considered to analyze any irregular structure. In this study, the design of different G+6 structures having vertical regularity was done. These irregular structures models were compared with a regular G+6 structure having similar properties as other structures. For the designing and analysis of these structures, use of StaadPro software was done. It is one of the most used software, whenever it comes to the digital analysis of any structure. Different types of Vertical irregularities like mass irregularity, Vertical Setback Irregularity, Stiffness Irregularity (Discontinuous Column, Middle weak storey and Bottom Weak Storey) were considered for the analysis. The Seismic Zone for the structure is considered to be Delhi (Seismic Zone IV) with a Seismic Factor of 0.24. All the model structures were compared for the parameters of their Storey Drift and Storey Displacement. For irregular buildings though, certain damages/fatigue may be observed in some structures but the structures will not fail and will be serviceable for a long time with proper care. It was observed that the structures with stiffness irregularity showed the most increase in storey displacement and storey drift values.

Keywords: Seismic, Irregularity, storey drift, StaadPro

1. Introduction

Any building is considered irregular not only if its shape is visible to be irregular, but also due to different/irregular distribution of mass, stiffness, load and strength. Most of our urban infrastructure now a day is covered by irregular buildings. Soft soil is considered to be not good for construction due to its low stabilizing property as it is clayey in nature and due to the presence of loose space between its constituent particles that hold it together. When buildings are located in a high seismic zone and founded on soft soil, the structure becomes more challenging to withstand. In reality, many existing buildings or buildings in construction contain irregularity due to aesthetic and functional requirements. These types of Irregularities can be classified due to the presence of vertical discontinuities, caused by the distribution of mass, stiffness and strength in any structure. Also due to the distorted vertical symmetry these types of irregularities can be caused in any structure. These Irregularities are one of the major causes of failures of structures during seismic activities.

Vertical Irregularities are classified into following types:

i. Stiffness Irregularity
This is considered to exist when the lateral stiffness of a storey is less than 70% of any adjacent storey, or less than 80% of the corresponding average stiffness of the three storeys above or below.

i. Mass Irregularity
Weight irregularity shall be considered to exist where the weight, „Wi”, of any storey is more than 150 percent of the weight of an adjacent storey.

ii. Geometry or Vertical-Setback Irregularity
Vertical geometric irregularity/ Vertical-Setback Irregularity shall be considered to exist where the horizontal dimension of the LFRS (Lateral Force Resisting System) in any storey is more than 150 percent of that in an adjacent storey.

Figure 1. (a) Stiffness Irregularity, (b) Mass Irregularity, (c) Vertical-Setback Irregularity

Discussion on the Literature Review: Omkar and J. Salunke [1], Authors, in their paper presented in 2019, examined the behavior of the buildings and structures having stiffness irregularity and undergone through seismic excitations. The authors observed the comparison between different building models having stiffness and without stiffness. Later they found the stability of the both structures and compared the analysis result of the same to find out which type of structure is the most stable under seismic forces.

Shaikh and Ansari [2], Authors, in their paper presented in 2018, determined that the building with different mass irregularity will not be safe when subjected to lateral forces. The Authors found that buildings having more than 200 % more mass in any of their story, as compared to their adjacent story are not safe under seismic forces. He analyzed how a normal regular structure when undergone through lateral forces shows more and such great stability as compared to structures having different mass irregularities.

Chiniwalar [3], Author, in their paper presented in 2015, conducted an analytical study on the behavior of the model structure with vertical irregularity including the soil structure interaction. Parameters like displacement and base shear were also used for the analysis project using StaadPro software and irregular structures were designed with lateral/ seismic forces acting on them. Soil Interaction/ type of soil were also used for the analysis and result outcome of this project.

Sehgal [4], Author, in their paper presented in 2012, Explained and studied the earthquake response of the structures subjected to combination of irregularities including mass, stiffness and strength by conducting time history analysis. It was found by the author how presence of structural irregularities effects the seismic behavior of structure and the main aim of the research paper was to evaluate the effect of these irregularities by analyzing the same through time history analysis.

2. Methodology
   I. Selection of Model Structures to be prepared.
   II. Preparing Different Irregular Models for Analysis in Staad pro, G+6 Structures.
   III. Analyzing the different irregular models and comparing them.
Firstly, the various models which we have to be prepared are selected. Both regular and irregular models are to be prepared. The regular model will be a G+6 structure without any irregularities on it. It will be the base model, wherein the other prepared irregular models will be compared. Doing so will help us determine which irregular structure will be the most stable when founded on soft soils. The irregular models are ones having irregularities such as mass, stiffness and vertical setback irregularities. The various models are to be designed and prepared separately in Stadd Pro. After which the graphs and various data of the irregular models will be compared with the regular G+6 structure and the most stable irregular model which can be founded on soft soil will be found out.

2.1 Standard Parameters
The standard parameters considered while designing of models for our analysis project are written.

Table 1. Standard parameters considered for designing of Models

| Parameter                          | Value                        |
|------------------------------------|------------------------------|
| Horizontal dimensions of structure:| 15 X 15 m                    |
| Height of each floor:              | 3 m                          |
| Density of RCC considered:         | 25 kN/m³                     |
| Thickness of slab:                 | 150 mm                       |
| Supports:                          | Fixed                        |
| Dimension of beam:                | 230X400 mm                   |
| Dimension of column:              | 400x400 mm                   |
| Loading due to Parapet wall:       | 5.4 kN/m²                    |
| Loading due to main wall:          | 13.8 kN/m²                   |
| Loading due to partition wall:     | 6.9 kN/m²                    |
| Live Load:                         | 3 kN/m²                      |
| Earthquake Zone:                  | IV (DELHI)                   |
| Damping Ratio:                    | 5%                           |
| Importance factor:                | 1                            |
| Type of Soil:                     | Soft Soil                    |
| Type of structure:                | Special Moment Resisting Frame|
| Response reduction Factor:         | 5                            |
3. Results and Discussion
The results obtained by us during the analysis of the G+6 Regular and Irregular structure and these were plotted on a graph and compared to each other.

**Figure 2.** Comparison Graph between Storey No. with respect to Storey Drift

Figure 2 represents the storey drift response with respect to increase in the height of the storey. It can be defined as the displacement of any two floors with respect to the height of that floor, under seismic responses. As per IS Code, the storey drift should not exceed the “0.004 h” value, where ‘h’ is the storey height. We have considered the story drift in X-direction for analyzing which structure is most stable when undergone through seismic activities and to understand the responses with compared to a regular structure. In the above Graph, No. of storey (G+6, X-Axis) with respect to the Storey Drift (Y-Axis) is plotted for the responses of the storey drift comparison of Irregular structures to a G+6 regular structure. As per IS: 1893[5], it is specified storey drift for any storey should not exceed the 0.004 times the storey height. If the Value exceeds this permissible amount, then the structure leads to collapse under the given seismic conditions. If Storey height = 300 cm, storey drift should not exceed 1.2 cm. Above Figure, depicts the storey drift for each structure is Less than 1.2 cm, that depicts that in the given seismic and soil conditions in Delhi Zone, these structures will withstand with full serviceability.

**Figure 3.** Comparison Graph between Storey No. with respect to Storey Displacement
Figure 3 represents the storey displacement response as the height of the storey increases. It is defined as sum of Total lateral displacement of any storey as respect to ground and as per the IS Code, it should not exceed “H/500”, Where H is the Total height of the building. We have considered the storey displacement in X-direction for analyzing which structure comes out to be the most stable among all the others, under seismic excitation/ activity and to understand the responses with compared to a regular structure. In the above figure, No. of storey (G+6, X-Axis) with respect to the Storey Displacement (Y-Axis) is plotted for comparison of storey displacement response of Irregular structure to a G+6 regular structure. As per IS: 1893(3), it is specified that the storey displacement for any storey should not exceed H/500, where H = The Total height of the model structure. If the Value exceeds this permissible amount, then the structure fails and collapses under the given seismic conditions. If total height of the building is 2100 cm, permissible Storey Displacement = H/500 = 2100 / 500 = 4.2 cm. In Figure depicts clearly, the Value of Storey displacement with respect to the No. of Storey (G+6) does not exceed the allowed storey displacement value of 4.2 cm or 4.6 (For storey height = 2300 cm) and therefore the Irregular Structures are proved to be stable in the mentioned Circumstances of Seismic and Soil Conditions.

4. Conclusion
The structural behavior of multi-storey bay frame structures with the different types of irregularities is studied and the results lead towards the considerable structural response to different irregularities. Stiffness irregularity also has a critical effect on the structure during the seismic lateral forces, such types of irregularity become more prone to damage when it is located at the ground floor which is the floor that is weak, although as per our findings these types of structure do not fail but according to the graphs, considerable damage/ fatigue may be experienced by these structures when undergo through seismic responses.

We have considered 3 types of stiffness irregular structures, i.e. Ground Storey, height is more than that of height of each floor of the structure, making it a weak storey with stiffness irregularity at the bottom (Ground), then we have Stiffness irregularity in the middle of the model structure, by providing height of the middle floor greater than the other floor heights and the last stiffness irregular structure considered is the structure with discontinuous columns at the bottom (Ground) Floor, that makes the structure a weak storey structure (Stiffness Irregularity).

After the analysis it was concluded that the Stiffness irregular models showed the most increase in the Storey displacement and Storey drift values. The location of irregularity also affected the stability in cases of 3 different stiffness irregular structures. Comparatively, the regular structure showed no drastic change in parameter values. It has been observed that the parameters like structural irregularities have a significant impact on the response of seismic. In the modern world, the incorporation of irregularities in structures due to its aesthetic and functional purposes has become inevitable. Regular structures were found to be more stable compared to Vertical Irregular structures. Although, certain damages/ fatigue may be observed in some structures but the structures will not fail and will be serviceable for a long time with proper care.

References
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