Response spectrum analysis of a G+4 building with mass irregularity on a sloped surface

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Abstract: The behaviour and stability of a multi-storey building in a sloped region depends on structural configuration. Irregularities in the structure are recognized as one of the chief sources of its failure. Structures commonly have a grouping of irregularities such as vertical irregularity, mass regularity, stiffness irregularity etc. Also, for the analysis of such a structure, it is necessary to carry out dynamic analysis to determine the maximum peak response of the building with respect to the natural time period. Since it would be difficult to get the time history record for all the places, it is feasible to go with Response Spectrum Analysis. In this paper, a G+4 RCC building having each storey of height 3.5m placed in the sloping ground with horizontal angle of inclination 20° for the purpose of dwelling of people during disaster with one of the storey to be used for storage of food and water which induces Mass irregularity. The structure is modelled in ETABS software. Here the mass irregularity is induced at every storey by inducing on one storey at a time for 3 different zones (III, IV, V) and the same has been analysed by inducing gravity loads and seismic load cases using Response Spectrum Analysis. The response of the structure with respect to variation in the Storey Drift and Storey displacement has been recorded and will be discussed elaborately.

Keywords: Seismic Analysis, mass irregularity, Response Spectrum Analysis, Storey Drift, Storey displacement.

1. Introduction
Rapid urbanization in hilly areas has led to the modification and redefining the building style, optimal usage of construction materials and different types of construction methods. Owing to the lack of the flat surfaced land on slopes, houses constructed on slopes, would need a unique structural design and would encounter certain construction inconveniences. Reinforced concrete framed structures built on hill slopes illustrate dissimilar structural performance compared to the one on flat surface. Buildings are generally constructed in step-back configuration at the steep sided slopes. Different configurations of the centre of mass and stiffness at all storeys causes eccentricity. The position of the setbacks has led to the concentration of stress; once the structure is supported by seismic activity has also been reported from the study. Earthquakes in the recent years have proved that buildings at the sloping ground have varying mass and stiffness along the vertical and horizontal planes, ensuing in the centre of mass and centre of rigidity does not overlap on all storey levels. A noteworthy quantum of investigation was carried out relating structures constructed in hilly region. Preceding researches have illustrated a variety of inconveniences and recommended diverse methods about mathematical modelling formulation and the analysis of step-back and setback buildings under lateral loads.
Mindala Rohini and Venkat Das [1] studied that the value of story displacement in Zone-V is greater than Zone-III at the topmost story and the storey shear in both response spectrum method and time history technique at the ground is maximum. Shaik Akhil Ahumad and Pratap [2] studies that the structure with shear walls provided at all edges gave enhanced outcome by means of maximum displacement, storey drift and base shear and concluded that building with uniform stiffness gives more suitable results. Nagargoje and K.S.Sable [3] suggested that Step-back-Setback building may be more favourable on sloping. Birajdar and Nalawade [4] investigated diverse arrangements of step-back and setback structures, and examined that in step-back structures a shorter frame on the uphill side draws added base shear force compared to the other frames of the structure. Anvesh et al. [5] examined that drifts in buildings exclusive of mass irregularity are more compared to the structures inclusive of mass irregularity. Satish Kumar and Paul [6] have carried out the seismic analysis of structures on varying slope angles and the results were evaluated with the structures on the flat surface. It is observed from the study that the footing column of shorter height attracts more forces and this increases the horizontal force and the bending moment significantly. Himanshu Bansal [7] the storey shear force was inversely proportional to the storey taken into account (i.e) the storey shear force was found to be minimum for the top storey and it was the maximum for the first storey in all the cases. Valmundsson and Nau [8] show that the building and structure rested on sloped ground have higher degree of displacement and base shear compared to the other buildings constructed in flat surfaces and showed that the earth quake actuated load on the building(or structure) can be narrowed down to notable amount by use of isolated system. Also, the response of low to medium rise buildings is affected by the method of analysis. Vinod Sadashiva [9] concluded that there is a maximum displacement response at the combination of vertical and stiffness irregularities when compared to vertical irregularities.

Research involved in the past has afford a enhanced examination on structural behaviour of building constructed in hilly area but the performance in diverse arrangements has not been investigated comprehensively. Also, IS 1893 [10] recommends that the structures with geometric irregularity and or comprising unbalanced sharing of mass and stiffness can be analysed by modal analysis. Therefore, a 3D modelling of structure is essential, taking into consideration of genuine structural behaviour of beams/columns, rigid slabs, infill masonry walls and RC shear walls, etc, to get the realistic behaviour of building in slope, subjected to seismic load. In the present study, mass irregularity has been induced for a G+4 building using ETABS software, as per the building codes – IS 875 for dead load [11] and live load [12] and lateral stability checks depending on story drifts and displacements are discussed.

2. Methodology
The assumed plan of a G+4 RCC building (for purpose of dwellings of people during disaster with one of the 5 storeys to be used as a store room for food and water, is placed in the sloped surface with an inclination of 20° with the horizontal. Due to this inclination, the height of columns at the bottom storey varies as follows. 0.7 m, 2.43 m, 4.4 m, 6.6 m and 8 m from left to right. The height of the columns in the rest of the storeys is given as 3.5m. The 2D plan and elevation was drafted using Autodesk CAD as shown in figure1 and the 3D, as shown in figure2 has been modelled using ETABS software for 3 different zones i.e, Zone III, IV and V. The concrete with grade M30 and reinforcements of grade HYS500 and Mild steel 250 were defined. The sizes of both beams and columns were defined using the auto select option in ETABS, so that the software would start to design members with a dimension having least area in the defined properties and if the member happens to fail, the software would automatically assign the next dimension for the member with respect to area and the process repeats until the all members are designed with suitable dimension to sustain the load. The beam sizes were taken as 230mm X 300mm, 300mm X 300mm and 450mm X 350mm and for columns, the sizes were taken as 300 mm x 300 mm, 300 mm x 450 mm, 450 mm x 450 mm, 600 mm x 600 mm and 700 mm x 700 mm by the software. The inner walls and outer walls with respective thickness of 230mm and 115mm are assumed to be built with Common burnt clay
bricks and so the respective wall loads calculated by considering the unit weight of brick as 15.7 kN/m$^3$ as per IS : 875 as shown in Table 1.

The calculated load has been applied as a UDL to the respective beams. As one of the storeys is to be used for storage, the mass irregularity would be induced in that particular storey of the building. So the building model is applied with extra mass in each storey, one at a time to find the suitable storey to be used for storage. For this purpose, the mass irregularity in the structure i.e., the change of mass due to storage of food and water were applied at one storey, whereas the other storeys are induced with normal loadings. The storey with mass irregularity is denoted as MR along with the storey number, i.e if the first storey is induced with mass irregularity then it is indicated as MR1. The dead load for food & floor finish is taken as 7.35 kN/m$^2$ and 1.47 kN/m$^2$ (extra dead load of 2 kN/m$^2$ is taken as building is to be used for dwellings) respectively as per IS 875 Part 1 and The live load for storage area and living area is taken as 5 kN/m$^2$ and 2 kN/m$^2$ respectively as per IS 875 Part 2. Likewise the mass irregularity has been applied as mentioned above for all the three zones.

Table1: load calculations

| Purpose               | Height (m) | Thickness (m) | Unit Weight of Brick (kN/m$^3$) | Dead Load | Live Load |
|-----------------------|------------|---------------|---------------------------------|-----------|-----------|
| Outer Wall Load       | 3.5        | 0.23          | 15.7                            | 12.64 kN/m| -         |
| Inner Wall Load       | 3.5        | 0.115         | 15.7                            | 6.32 kN/m | -         |
| Parapet Wall Load     | 1          | 0.23          | 15.7                            | 3.61 kN/m | -         |
| Slab Load (Normal Case)| -         | -             | -                               | 3.47 kN/m$^2$ | 2 kN/m$^2$ |
| Slab Load (For Mass Irregularity)| - | - | - | 8.82 kN/m$^2$ | 5 kN/m$^2$ |

Then the seismic loads are assigned to the model with considering the Zone as III having the Zone factor of 0.16 assuming Type II soil. Also, the importance factor of 1.2 is taken as the building to be designed is a dwelling place assumed to have more than 200 people and the Reduction factor of 5 is assigned considering the Building possesses a Special Moment Resisting Frame (SMRF). Then the Response Spectrum function is assigned to the building model with predefined period and values in ETABS software. Then, building is analysed and the Storey Displacement and Storey Drift values both along and across the surface of the slope.

The above step for Seismic analysis and Response Spectrum analysis are carried out for Zone IV and Zone V having Zone factor of 0.24 and 0.36 respectively, with all other details remaining the same.
Figure 1: 2D draft and mass irregularities induced in the building.
3. Results and discussions
The mass irregularity was induced as mentioned and the corresponding storey drift and storey displacement for each storey, for both along and across the slope was obtained from ETABS. The values were noted for drift and displacement for each storey. Thus five sets of values were noted for each zone, that is fifteen sets in total. Graphs were drawn with storey in x-direction and storey displacement in y direction, for all the five cases. Separate graphs were drawn for across and along the slope. The same was followed for storey drift. Thus each zone has four graphs, which sums up to a total of twelve graphs for all the three zones together.
From figures 3 and 4, for zone III, it is observed that the displacements in one direction, say along the slope, for all the five cases (i.e. MR1 MR2 MR3 MR4 MR5) shows only a minimal variation and when plotted, with a similar path for all the five cases. For storey displacement across the slope, the values for all the five cases were more or less the same when plotted as that of along the slope. The displacement in both the directions were minimum at the bottom storey and maximum at the top storey. Also the values of storey displacements increased as the zones increased.

From figures 5, 6, 7, 8, for zones IV and V, the similarity was observed. In general, the variation between two cases (say MR1 and MR2) at one particular direction and for one particular zone, was not less than 0.00573 mm and not more than 1.84234 mm. This was same for all the cases in both the directions for all the three zones.
Figure 9: drift along the slope (zone III)

Figure 10: drift across the slope (zone III)

Figure 11: drift along the slope (zone IV)

Figure 12: drift across the slope (zone IV)

Figure 13: drift along the slope (zone V)

Figure 14: drift across the slope (zone V)
Figure 9-14 shows the storey drift both across and along the slope, for all the three zones. Like Storey displacements in each zones, the storey drifts also increases with the increase of zones. From the figure 9 -14, though the zone varies, the maximum drift of particular case of mass irregularity occurs at the same storey for all the three zones. For example, the maximum drift due to mass irregularity at 5th storey is maximum at storey 3 for all three zones along the slope and is maximum at storey 4 across the slope. Also, it can be found that, though the mass irregularity was induced at different storeys in all three zones, the storey drift along the slope is maximum at either Storey 3 or Storey 5 and the storey drift across the slope is maximum at storey 4. So, the drift between the storeys doesn’t change irrespect of the mass irregularity induced at different levels.

From the graphs it can be found that the storey induced with mass irregularity is not experiencing the maximum storey drift. For example in Figure 10, the mass irregularity was induced in storey 4(MR4), but the maximum storey drift occurred at storey three, while the maximum drift due to mass irregularity at 4th storey occurred at Storey 5. In most case, the maximum drift for any particular storey, induced with mass irregularity occurred at its adjacent storey. For example, from figure 9 & 10, the maximum drift for MR3 occurred at storey 4 in both the direction. There has been a maximum change in the storey drifts between storey 1 and storey 2 all 5 cases in each zone as the relative displacement between the first and second storey is maximum.

Now, the percentage difference between values of storey displacement along the slope and across the slope was found out for all the five cases, MR1, MR2, MR3, MR4 and MR5. (formula for finding the percentage difference is higher value minus lower value divided by lower value and multiplied by hundred). Each case would contain 6 values, onc for each storey. The corresponding storey values from the five cases were added and the average for a particular storey was found. This was followed for all the three zones. A graph plotted with storey in x-axis and the percentage difference in y-axis as shown in figure15.

From figure15, it is observed that percentage change decreases as the zone increases. Also the change in percentage is maximum in storey one, about fifty percentge and the values decreases drastically.
from storey two to storey six for all the three zones (the values lies between 10%-25%). The percent change

4. Conclusions
A G+4 RCC building in a sloped region was modelled using ETABS and mass irregularity was induced in each storey to identify which storey is suitable for storage of food and water. The mass irregularities were induced in all the storeys and corresponding storey displacements and drifts were obtained, the conclusions were drawn.

- Though the mass irregularities were applied at different stories, the values of storey displacement was more or less the same in both across and along the slopes i.e., the application of the mass irregularities at different storeys as no significant effect on the displacement of the building.
- When mass irregularity is induced in a building on a sloped surface, storey one experiences a maximum percentage change in displacement between the slopes in both the directions.
- The storey induced with mass irregularity does not experience the maximum storey drift, whereas it occurs at its adjacent storey.
- Though the zone varies, the maximum drift of particular case of mass irregularity occurs at the same storey for all the three zones.
- The maximum storey drift experienced by MR5 in all the zones, in both the directions is less when compared to other cases (MR1 MR2 MR3 MR4). So it is safer to provide storage for food and water at fifth storey in all the three zones.

5. References

[1] Mindala Rohini, Venkat Das T (2019) Seismic Analysis of Residential Building for Different Zones using ETABS. International Journal of Recent Technology and Engineering (IJRTE) 7 293.
[2] Shaik Akhil Ahamad, Pratap K V (2020) Dynamic analysis of G + 20 multi storied building by using shear walls in various locations for different seismic zones by using Etabs Materials Today Proceedings In Press.
[3] Nagargoje S M, Sable K S (2012) Seismic performance of multi-storeyed building on sloping ground Elixir Elec. Engg. 53 11980.
[4] Birajdar B G, Nalawade S S (2004) seismic analysis of buildings resting on sloping ground 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, Paper No. 147.
[5] Anvesh N, Shaik Yajdani, Pavan Kumar K (2015) Effect of Mass Irregularity on Reinforced Concrete Structure Using Etabs Int. J. Innovative Res. Sci. Eng. Technol. 4 10091.
[6] Satish Kumar & Paul D K (1999) Hill buildings configurations from seismic considerations, J. Struct. Eng. 26 179.
[7] Himanshu Bansal (2014) Seismic analysis and design of vertically irregular RC building frames Int. J. Sci. Res. 3 207.
[8] Valmundsson E V, Nau J M (1997) Seismic response of building frames with vertical structural irregularities J. Struct. Eng. 123 30.
[9] Vinod Sadashiva K (2009) Determination of structural irregularity limits – Mass irregularity example Bulletin of the New Zealand society for earthquake engineering. 42.
[10] IS 1893- 1 (2016) Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings, Bureau of Indian Standards, India.
[11] IS 875-1 (1987) Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures, Part 1: Dead Loads - Unit Weights of Building Material and Stored Materials, Bureau of Indian Standards, India.

[12] IS 875-2 (1987) Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures, Part 2: Imposed Loads, Bureau of Indian Standards, India.