Seismic Analysis and Design of Vertically Irregular RC Building Frames

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***Abstract*- This paper is concerned with the effects of various vertical irregularities on the seismic response of a structure. The objective of the project is to carry out Response spectrum analysis (RSA) and Time history Analysis (THA) of vertically irregular RC building frames and to carry out the ductility based design using IS 13920 corresponding to Equivalent static analysis and Time history analysis. Comparison of the results of analysis and design of irregular structures with regular structure was done. The scope of the project also includes the evaluation of response of structures subjected to high, low and intermediate frequency content earthquakes using Time history analysis. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. According to our observation, the storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The mass irregular structures were observed to experience larger base shear than similar regular structures. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts. The absolute displacements obtained from time history analysis of geometry irregular structure at respective nodes were found to be greater than that in case of regular structure for upper stories but gradually as we moved to lower stories displacements in both structures tended to converge. Lower stiffness results in higher displacements of upper stories. In case of a mass irregular structure, time history analysis gives slightly higher displacement for upper stories than that in regular structures whereas as we move down lower stories show higher displacements as compared to that in regular structures. When time history analysis was done for regular as well as stiffness irregular structure, it was found that displacements of upper stories did not vary much from each other but as we moved down to lower stories the absolute displacement in case of soft storey were higher compared to respective stories in regular structure. Tall structures were found to have low natural frequency hence their response was found to be maximum in a low frequency earthquake. It is because low natural frequency of tall structures subjected to low frequency earthquake leads to resonance resulting in larger displacements. If a high rise structure (low natural frequency) is subjected. to high frequency ground motion then it results in small displacements. Similarly, if a low rise structure (high natural frequency) is subjected to high frequency ground motion it results in larger displacements whereas small displacements occur when the high rise structure is subjected to low frequency ground motion.**

I. INTRODUCTION

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular' building.

IS 1893 definition of Vertically Irregular structures:

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated. There are two types of irregularities-

1. Plan Irregularities
2. Vertical Irregularities.

Vertical Irregularities are mainly of five types-

i a) Stiffness Irregularity — Soft Storey-A soft storey is one in which the lateral stiffness is less than 70

percent of the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.
b) Stiffness Irregularity — Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storeys above.
ii) Mass Irregularity-Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. In case of roofs irregularity need not be considered.
iii) Vertical Geometric Irregularity- A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.
iv)In-Plane Discontinuity in Vertical Elements Resisting Lateral Force-An in-plane offset of the lateral force resisting elements greater than the length of those elements.
v)Discontinuity in Capacity — Weak Storey-A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.

II.OBJECTIVES

- To calculate the design lateral forces on regular and irregular buildings using response spectrum analysis and to compare the results of different structures.
- To study three irregularities in structures namely mass, stiffness and vertical geometry irregularities.
- To calculate the response of buildings subjected to various types of ground motions namely low, intermediate and high frequency ground motion using Time history analysis and to compare the results.
- To carry out ductility-based earthquake-resistant design as per IS 13920 corresponding to equivalent static analysis and time history analysis and to compare the difference in design.

III. SCOPE OF THE STUDY

- Only RC buildings are considered.
- Only vertical irregularity was studied.
- Linear elastic analysis was done on the structures.
- Column was modeled as fixed to the base.
- The contribution of infill wall to the stiffness was not considered. Loading due to infill wall was taken into account.
- The effect of soil structure interaction is ignored.

IV.METHODOLOGY

- Review of existing literatures by different researchers.
- Selection of types of structures.
- Modelling of the selected structures.
- Performing dynamic analysis on selected building models and comparison of the analysis results.
- Ductility based design of the buildings as per the analysis results

V. ANALYSIS METHODS

SEISMIC ANALYSIS

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. In the past the buildings were designed just for gravity loads and seismic analysis is a recent development. It is a part of structural analysis and a part of structural design where earthquake is prevalent.
There are different types of earthquake analysis methods. Some of them used in the project are-
I. Equivalent Static Analysis
II. Response Spectrum Analysis
III. Time History Analysis

EQUIVALENT STATIC ANALYSIS:

The equivalent static analysis procedure is essentially an elastic design technique. It is, however, simple to apply than the multi-model response method, with the absolute simplifying assumptions being arguably more consistent with other assumptions absolute elsewhere in the design procedure.
The equivalent static analysis procedure consists of the following steps:

1. Estimate the first mode response period of the building from the design response spectra.
2. Use the specific design response spectra to determine that the lateral base shear of the complete building is consistent with the level of post-elastic (ductility) response assumed.
3. Distribute the base shear between the various lumped mass levels usually based on an inverted triangular shear distribution of 90% of the base shear commonly, with 10% of the base shear being imposed at the top level to allow for higher mode effects.

RESPONSE SPECTRUM ANALYSIS:

This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except for very simple or very complex structures. The structural response can be defined as a combination of many modes. Computer analysis can be used to determine these modes for a structure. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and the modal mass, and then they are combined to estimate the total response of the structure. In this the magnitude of forces in all directions is calculated and then effects on the building is observed. Following are the types of combination methods:

- absolute - peak values are added together
- square root of the sum of the squares (SRSS)
- complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes

The result of a RSM analysis from the response spectrum of a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, because information of the phase is lost in the process of generating the response spectrum.In cases of structures with large irregularity, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static or dynamic analysis.

TIME HISTORY ANALYSIS:

Time history analysis techniques involve the stepwise solution in the time domain of the multidegree-of-freedom equations of motion which represent the actual response of a building. It is the most sophisticated analysis method available to a structural engineer. Its solution is a direct function of the earthquake ground motion selected as an input parameter for a specific building. This analysis technique is usually limited to checking the suitability of assumptions made during the design of important structures rather than a method of assigning lateral forces themselves.

The steps involved in time history analysis are as follows:

1. Calculation of Modal matrix
2. Calculation of effective force vector
3. Obtaining of Displacement response in normal coordinate
4. Obtaining of Displacement response in physical coordinate
5. Calculation of effective earthquake response forces at each storey.
6. Calculation of maximum response

RESPONSE SPECTRUM ANALYSIS:

Response Structure analysis was performed on regular and various irregular buildings using Staad-Pro. The storey shear forces were calculated for each floor and graph was plotted for each structure.

STRUCTURAL MODELLING:

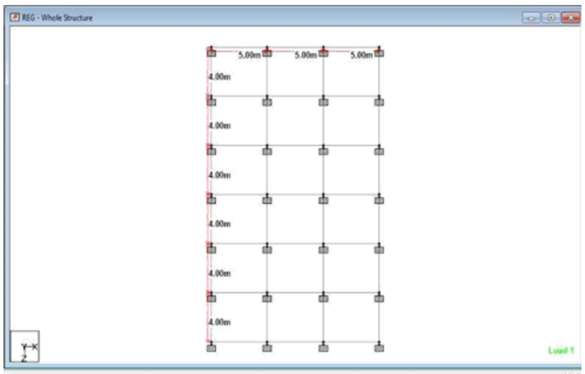
SPECIFICATIONS:

Live Load	3kN/m^2
Density of RCC considered:	25kN/m^3
Thickness of slab	150mm
Depth of beam	400mm
Width of beam	350mm
Dimension of column	400x400mm
Density of infill	20kN/m^3
Thickness of outside wall	20mm
Thickness of inner partition wall	15mm
Height of each floor	3.5m
Earthquake Zone	IV
Damping Ratio	5%
Importance factor	1

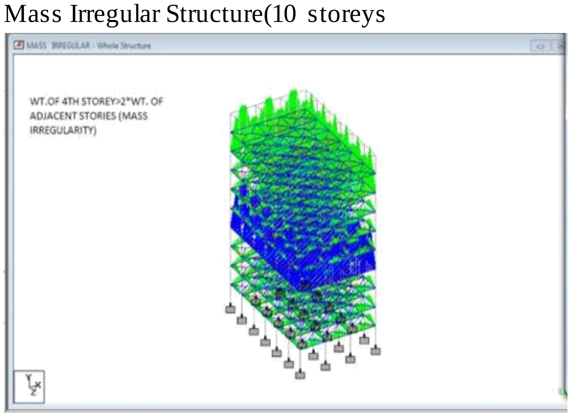
Type of Soil	Rocky
Type of structure	Special Moment Resisting Frame
Response reduction Factor	5

Four types of Irregular buildings were considered, Regular structure, Mass irregular structure, structure with ground storey as the soft storey and vertically geometric irregular building. The first three structures were 10 storeyed.

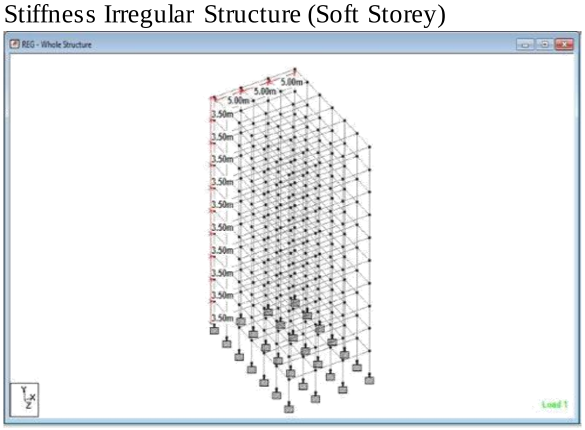
Regular structure (10 storeys)



Mass Irregular Structure(10 storeys



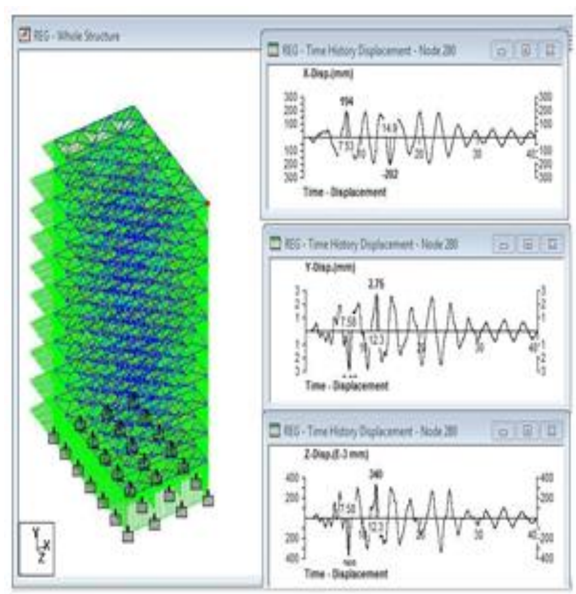
Stiffness Irregular Structure (Soft Storey)



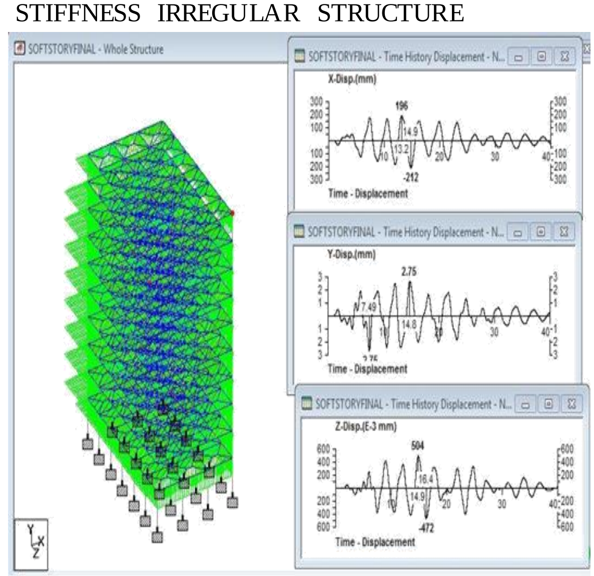
STRUCTURALMODELSAND THEIR FLOOR TIME HISTORY DISPLACEMENT SPECIFICATION

Live Load	$3kN/m^2$
Density of RCC considered:	$25kN/m^3$
Thickness of slab	150mm
Depth of beam	400mm
Width of beam	350mm
Dimension of column	400x400mm
Density of infill	$20kN/m^3$
Thickness of outside wall	20mm
Thickness of inner partition wall	15mm
Height of each floor	3.5m
Force Amplitude factor	9.81

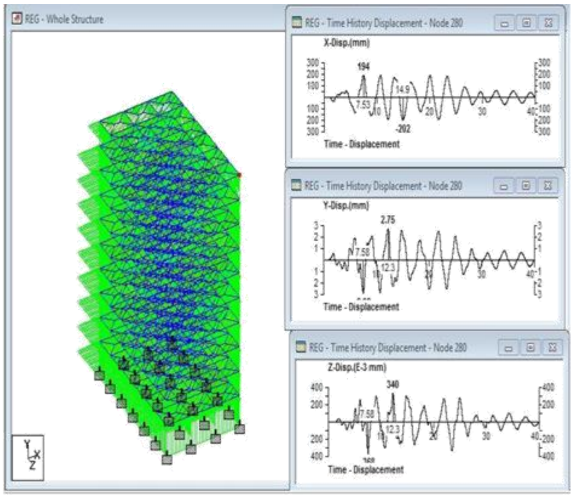
REGULAR STRUCTURE



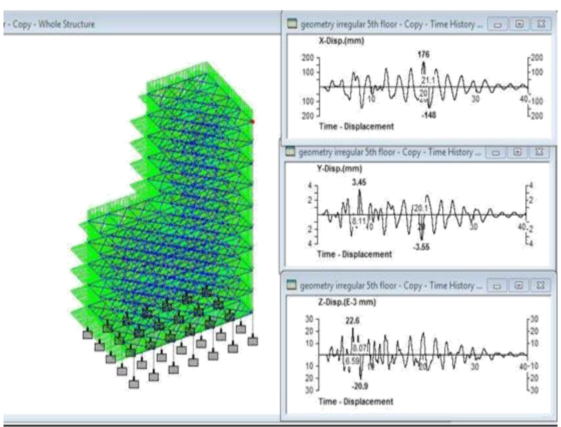
STIFFNESS IRREGULAR STRUCTURE



MASSIRREGULAR STRUCTURE



VERTICALL GEOMETRIC IRREGULAR STRUCTURE



The above figures show the Time history displacements of the topmost node of regular, stiffness irregular and geometry irregular structure respectively. Similarly time history displacements were obtained for other floors in the structure and the maximum displacement was plotted in the graph. The graphs of Irregular structure were compared with that of Regular structure.

V. CONCLUSIONS

Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered .All three kinds of irregular RC building frames had plan symmetry. Response spectrum analysis (RSA) was conducted for each type of irregularity and the storey shear forces obtained were compared with that of a regular structure. Three types of ground motion with varying frequency content, i.e., low (imperial), intermediate (IS code),high (San Francisco) frequency were considered. Time history analysis (THA) was conducted for each type of irregularity corresponding to the above mentioned ground motions and and nodal displacements were compared. Finally, design of above mentioned irregular building frames was carried out using IS 13920 corresponding to Equivalent static analysis (ESA) and Time history analysis(THA) and the results were compared. Our results can be summarized as follows-

- According to results of RSA, the storey shear force was found to be maximum for the first storey and it decreased to a minimum in the top storey in all cases.
- According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.
- According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.
- The absolute displacements obtained from time history analysis of geometry irregular building at respective nodes were found to be greater than that in case of regular building for upper stories but gradually as we move to lower stories displacements in both structures tended to converge. This is because in a geometry irregular structure upper stories have lower stiffness (due to L-shape) than the lower stories. Lower stiffness results in higher displacements of upper stories.
- In case of a mass irregular structure, Time history analysis yielded slightly higher displacement for upper stories than that in regular building, whereas as we move down, lower stories showed higher displacements as compared to that in regular structures.
- When time history analysis was done for regular as well as stiffness irregular building (soft storey), it was found that displacements of upper stories did not vary much from each other but as we moved down to lower stories the absolute displacement in case of soft storey were higher compared to respective stories in regular building.
- Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.

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