Seismic Behaviour of Buildings Having Vertical Irregularities

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I. INTRODUCTION

1.1 GENERAL

Major structural collapses occur when a building is under the action of Dynamic Loads which includes both Earthquake and Wind loads. So, very widespread research is required for achieving the ultimate performance even in a condition of poor configuration.

1.2 IRREGULARITIES

A building is said to be a regular when the building configurations are almost symmetrical about the axis and it is said to be the irregular when it lacks symmetry and discontinuity in geometry.

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.

1.3 TYPES OF IRREGULARITIES

There are two types of irregularities-

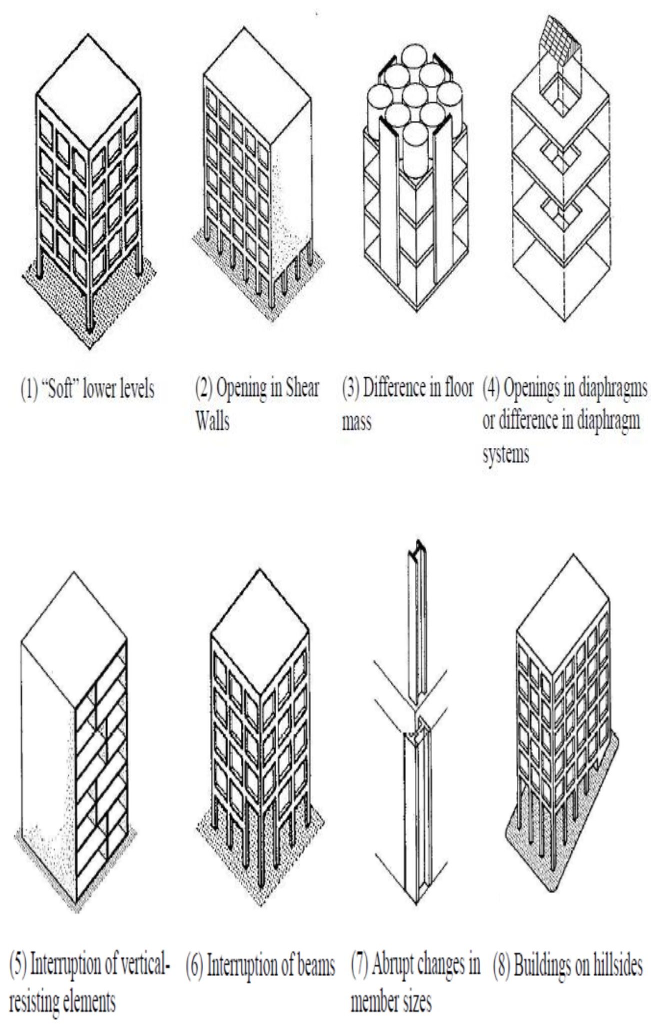
1. Plan Irregularities
2. Vertical Irregularities.

i) Stiffness Irregularity:

a) 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) 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) 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.



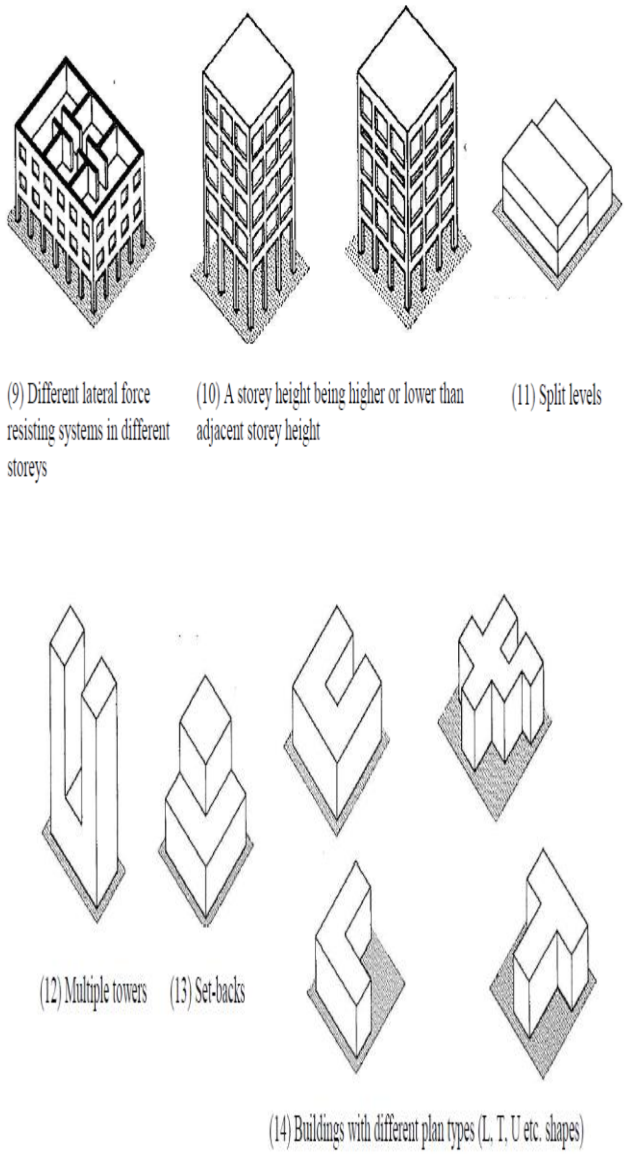


Figure 1.1 Types of Irregularities

As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of limited height as in this process lateral forces are calculated as per code based fundamental time period of the structure. Linear dynamic analysis are an improvement over linear static analysis, as this analysis produces the effect of the higher modes of vibration and the actual distribution of forces in the elastic range in a better way.

1.4 <u>Seismic behaviour of vertically irregular buildings:</u>

Several studies have been conducted in the past explaining the behavior of irregular structures. However, such studies have not been conducted particularly to quantify the variation in response associated with a particular degree of irregularity so the validity of the irregularity limits, or the variation in response due to structures meeting these limits, is not known.

1.5 <u>Software used:</u>

Analysis of all the cases is done with the help of software STAAD.Pro-2005 for windows XP. This is comprehensive structural engineering software that addresses all aspects of structural engineering-model development, analysis, design, verification and visualization. This is based on the principles of "concurrent engineering".

1. STAAD-Pro Analysis and Design
2. STAAD-Pre Graphics Input Generation
3. STAAD-Post Graphical Post-Processing

Utilities of software:

Apart from various windows facility like temporary exit to other programs running concurrently with STAAD.Pro-2005 for Windows XP. This software also offers the following utilities within its Graphical User Interface Environment.

1. **Text Editor**
2. **View Facility**
3. **Plot/ Print Facility**
4. **Data Exchange with CAD Programme**
5. **On Screen Calculator**
6. **On Line Manual**

1.6 <u>Objectives:</u>

1. To study three irregularities in structures namely mass, stiffness and vertical geometry irregularities.
2. To study the seismic behavior of buildings having vertical irregularities.
3. To analyse regular and vertically irregular buildings and to compare its parameters with vertical irregularity at different positions for zone II, zone III, zone IV and zone V.

II. LITERATURE REVIEW

2.1 <u>General:</u>

In these modern days, most of the structures are involved with architectural importance and it is highly impossible to plan with regular shapes. These irregularities are responsible for structural collapse of buildings under the action of dynamic loads. Research on the seismic behavior of irregular buildings is described below:

2.2 Reviews:

2014, Neha P. Modakwar, Sangita S. Meshram, Dinesh W. Gawatre, "Seismic Analysis of Structures with Irregularities" said that irregularities are not avoidable in construction of buildings; however the behaviour of structures with these irregularities during earthquake needs to be studied. Adequate precautions can be taken. A detailed study of structural behaviour of the buildings with irregularities is essential for design and behaviour in earthquake. The main objective of this study is to understand different irregularity and torsional response due to plan and vertical irregularity and to analyze cross shape and L shape building while earthquake forces acts and to calculate additional shear due to torsion in the columns. This study was initiated to quantify the effect of different degrees of irregularity on Structures designed for earthquake using simplified analysis.

2014, Ramesh Konakalla, Ramesh Dutt Chilakapati, Dr. Harinadha Babu Raparla, "Effect of Vertical Irregularity in Multi-Storied Buildings Under Dynamic Loads Using Linear Static Analysis", considered four types of 20- Storied 3-D frames (i.e., a symmetrical elevation configuration throughout its height and three other frames with unsymmetrical vertical configuration starting from tenth floor, placed at corner, at the center and at edge of the plan respectively) it is focused to study their response using Linear Static Analysis. From the studied results of the analysis of four frames, it is observed that in the regular frame, there is no torsional effect in the frame because of symmetry. The response for vertically irregular buildings is different for the columns which are located in the plane perpendicular to the action of force. This is due to the torsional rotation in the structure.

It is observed that, there is no torsional effect in the frame because of symmetry that is the centre of mass coincides with the centre of rigidity and the lateral displacements of the four corners are same in the direction of earthquake force. The same is observed in the case of wind loads. The responses in the case of earth quake load is more than wind load, this is because the earthquake load is dominating than the wind load of given intensity and exposure for the regular building.

2013, Ankesh Sharma, Biswobhanu Bhadra, "Seismic Analysis and Design of Vertically Irregular RC Building Frames", focused on the effects of various vertical irregularities on the seismic response of a structure. The objective of the project was 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.. The stiffness irregular building experienced lesser base shear and has larger inter storey drifts. They summarized the results as:

1. 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.
2. According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.
3. According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.
4. 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.
5. 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.
6. 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.
7. Tall structures have low natural frequency hence their response was found to be maximum in a low frequency earthquake.

2013, Monalisa Priyadarshini, "Seismic Risk Assessment of RC Framed Vertically Irregular Buildings", focused on the performance of typical OGS buildings designed considering various magnification factors as well as the stepped type buildings with different geometry configurations using fragility analysis and reliability analysis. The critical inter-storey drift is considered as an intensity measure.

OGS Building frames designed with various MFs and stepped irregular frames with different infill configurations, and having heights (6, 8 &10 stories) are considered for the present study. Fragility curves are developed for each type of buildings as per the methodology introduced by Cornell (2002). PSDM models are developed for each frames and the corresponding fragility curves are generated. Conclusions on the relative performances of each frame are drawn from the PSDM models and fragility curves. It is observed that in terms of performance, a building with infill walls in all stories is equally comparable with an OGS framed building with MF of about 1.5. Performance of the OGS frame increases with the increase in MF, but it makes the adjacent storey vulnerable.

III. METHODOLOGY

ADOPTED

3.1 Analysis Methods:

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-

1. Equivalent Static Analysis
2. Response Spectrum Analysis
3. Time History Analysis

3.1.1 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.

3.1.2 Response Spectrum Analysis:

Response spectra method is an elastic dynamic analysis approach that relies on the assumption that the dynamic response of a structure may be found by considering the independent response of each natural mode of vibration and then combining response in the same way. For analysis, the mass of the structure is assumed to be lumped at the floor levels. Thus, for planer system, only one degree of freedom per floor results and for three-dimensional analysis three degrees of freedom per floor- two lateral translation and angle of twist around the vertical axis must be considered.

The first step in the analysis of response spectra method is determining the lumped masses at the floor level due to dead load and appropriate amount of live load. Then the free vibration analysis of entire building shall be performed as per established methods of mechanics using the appropriate masses and elastic stiffness of the structural system, to obtain natural periods (T) and mode shapes {¢}. The CL. 7.8.4.2 of IS 1893:2002 gives guideline for the number of modes to be considered. As per this clause the number of modes to be considered in the analysis should be such that the sum of modal masses of all modes considered is at least 90 percent of the total seismic mass. If modes with natural frequency beyond 33 Hz are to be considered, modal combinations shall be carried out only for modes upto 33 Hz. The effect of modes with natural frequency beyond 33 Hz shall be included by considering missing mass correction. As per Cl. 7.8.4.5 buildings with regular and nominal irregular plan configuration may be modeled as a system of masses lumped at the floor levels with each mass having one degree of freedom, that of lateral displacement in the direction under consideration. After satisfying the above condition the modal mass is calculated using the expression given in the code,

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \phi_{ik}\right]^2}{g \sum_{i=1}^{n} W_i (\phi_{ik})^2}$$

3.1.3 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

3.2 <u>Design Methods:</u>

3.2.1 <u>Ductility Based Design:</u>

Ductility in the structures results from inelastic material behavior and reinforcement detailing such that brittle fracture is prevented and ductility is introduced by allowing steel to yield in a controlled manner. Thus the chief task is to ensure that building has adequate ductility to withstand the effects of earth quakes, which is likely to be experienced by the structure during its lifetime. Ductility of the structure acts as a shock absorber and reduces the transmitted forces to the structure.
The ductility of a structure can assessed by-

1. Displacement ductility
2. Rotational and Curvature ductility
3. Structural ductility

Ductility is the capability of a material to undergo deformation after its initial yield without any significant reduction in yield strength.

The factors which affect the ductility of a structure are as follows-

1. Ductility increases with increase in shear strength of concrete for small axial compressive stress between 0-1MPa. The variation is linear in nature.
2. Ductility varies linearly up to the point when axial compressive stress becomes equal to the compressive stress at balanced failure.
3. The ductility factor increases with increase in ultimate strain of concrete. Thus confinement of concrete increases ductility.
4. The ductility increases with increase in concrete strength and decreases with the increase in yield strength of steel.
5. The effect of lateral reinforcement is to enhance the ductility by preventing the shear failure. It also restrains the compression reinforcement from buckling.

Requirements of ductility:

1. It allows the structure to develop its maximum potential strength through distribution of internal forces.
2. Structural ductility allows the structure as a mechanism under its maximum potential strength resulting in the dissipation of large amount of energy.

IV. RESULT AND DISCUSSION

4.1 <u>Result Parameters:</u>

The performance of multi-storey buildings is assessed for four frames in which one is regular and other three are irregular vertically at different conditions for zone II, zone III, zone IV and zone V. The results obtained from analysis are given in various tables and figures are as follows:

1. Storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone II are represented in table 5.1 to 5.4.
2. Storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone III are represented in table 5.5 to 5.8.
3. Storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone IV are represented in table 5.9 to 5.12.
4. Storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone V are represented in table 5.13 to 5.16.
5. Graphical representation showing variations of storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone II are presented in figure 5.1 to 5.4.
6. Graphical representation showing variations of storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone III are presented in figure 5.5 to 5.8.
7. Graphical representation showing variations of storey drift and lateral displacement in all the frames

without shear wall and with shear wall in zone IV are presented in figure 5.9 to 5.12.

8. Graphical representation showing variations of storey drift and lateral displacement in all the frames without shear wall and with shear wall in zone V are presented in figure 5.13 to 5.16.

V. CONCLUSION

Within the scope of present work following conclusions are drawn:

1. For all the frames considered, drift values follow a similar path along storey height with maximum value lying somewhere near the thirteenth to fifteenth storey.
2. From drift point of view, frame 1, 2 and 3 are within permissible limits in zone IV and zone V although at some storeys frame 2 and 3 exceeds marginally. But frame 4 in zone V exceeds permissible limits largely after tenth storey. In zone II and III all the frames are within permissible limit, hence there is no requirement of shear wall in these zones.
3. From displacement view point, only in zone II all the frames are within permissible limit. In zone III frame 1, 2 and 3 are in permissible limit but frame 4 requires shear wall to control the limit. In zone IV only frame 1 is within permissible limit, all other exceeds limits largely. And in zone V all the frames exceeds largely.

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