

# Review on Effect of Vertical Irregularity in Multistoried Building under Seismic Loading

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**ABSTRACT:** Major structural collapses occur when a building is under the action of Dynamic Loads which includes both Earthquake and Wind loads. 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. Hence, extensive research is required for achieving ultimate performance even with a poor configuration. In the present work, "Effect Of Vertical Irregularity In Multi-Storied Buildings Under Dynamic Loads Using Linear Static Analysis", considering 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.

**KEYWORDS:** Vertical Irregularity, Multistoried Building, Seismic Loading

## I. INTRODUCTION

### 1.1 General

At the time of earthquake, failure of structure starts at points of weakness. This shortcoming emerges arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are named as Irregular structures. Irregular structures contribute a big portion of urban infrastructure. At the time of earthquake, Vertical irregularities are one of the major reasons of failures of structures. For example structures with soft storey were the most notable structures which collapsed. Thus, the impact 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 dissimilar from the regular building. (Thowdoju et al. 2016)

The irregularity in the building structures might be because of irregular distributions in their mass, strength and stiffness along the height of building. At the point when such structures are built in high seismic zones, the investigation and configuration turns out to be increasingly confounded. There are two types of irregularities- (Thowdoju et al. 2016)

A structure 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, mass or load resisting rudiments. Asymmetrical arrangements cause a large torsion force. IS 1893: 2002 (part) has clarified building configuration system for better performance of RC buildings during earthquakes. The building configuration has been depicted as regular or irregular in terms of the size and shape of the building, arrangement of structural the elements and mass. There are two different types of irregularities 1) Horizontal irregularities refers to asymmetrical plan shapes (L, T, U and F) or discontinuities in horizontal resisting elements such as re-entrant corners, large openings, cut outs and other changes like torsion, deformations and other stress concentrations, 2) Vertical irregularities referring to sudden change of strength, stiffness, geometry and mass of a structure in vertical direction. The main objective of the present work is to learn the response of the irregular structures under dynamic loads. In this project it is proposed to consider the building frames that are irregular in elevation and analyze the response and behavior of the structures under earthquake and wind loads. For this purpose, four RC building frames are selected and it is proposed to analyze all the frames that are considered and are modeled. STAAD analysis package is proposed for the analysis of all structures, to get the all nodal displacements. Frames considered in this study are 15,20,25 Storied 3-D frames with symmetrical elevation configuration throughout its height and three other frames with unsymmetrical vertical configuration starting from tenth

floor, placed at corner, center and edge of the plan respectively as shown in Figure 1. It is proposed that the behavior of all the above frames are to be determined for all the load combinations. Lateral loads and Storey shears of all the three frames due to earthquake loads is proposed to determine using ESA (linear static analysis) method, even though the IS 1893(Part 1) : 2002 has suggested dynamic analysis (linear dynamic analysis)..

**1.2 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 storey’s above. (Thowdoju et al. 2016)

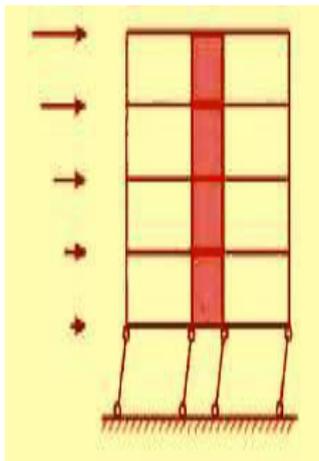


Figure 1.1 Stiffness Irregularities

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 storey’s above. (Thowdoju et al. 2016)

ii) **Mass Irregularity**-Mass irregularity shall be painstaking to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storey’s. In case of roofs irregularity need not be considered. (Thowdoju et al. 2016)

iii) **Vertical Geometric Irregularity**- A structure is painstaking 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. (Thowdoju et al. 2016)

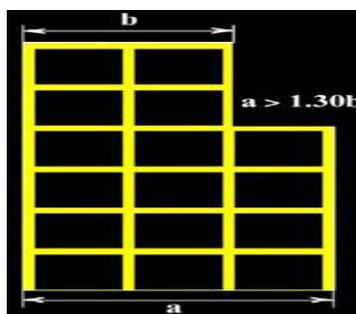


Figure 1.2 Vertical Geometric Irregularities in Building

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. (Thowdoju et al. 2016)

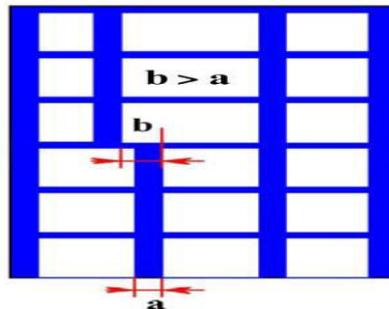


Figure 1.3 In-plane discontinuities in vertical lateral force-resisting element

v) **Discontinuity in Capacity** — Weak Storey-A weak storey is one in which the storey lateral strength is below than 80 percent of that in the storey above. (Thowdoju et al. 2016)

As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of restricted 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 impact of the higher modes of vibration and the actual distribution of forces in the elastic range in a improved way. (Ramayakrishna et al. 2017)

Buildings are designed mostly as per Design based earthquake, but the actual forces acting on the structure is far more than that of DBE. Thus, in higher seismic zones Ductility based design approach is preferred as ductility of the structure narrows the gap. The primary purpose in designing earthquake resistant structures is to assure that the building has enough ductility to withstand the earthquake forces, which it will be subjected to during an earthquake. (Ramayakrishna et al. 2017)

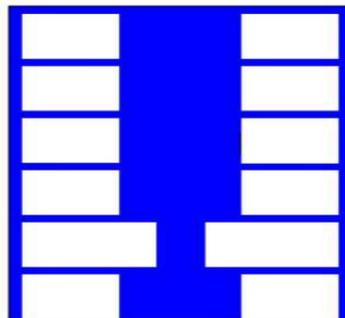


Figure 1.4 Discontinuity in capacity

### 1.3 Criteria for vertical irregularities in building codes

In the earlier versions of IS 1893 (BIS, 1962, 1966, 1970, 1975, 1984), vertical irregularity in building frames were not mentioned. However, in the recent version of IS 1893 (Part 1)-2016 (BIS, 2002), irregular configuration of buildings has been defined explicitly. Five types of vertical irregularity had been listed as shown in Figure 1. They are: stiffness irregularity (soft story), mass irregularity, vertical geometric irregularity (set-back), in-plane discontinuity in lateral-force-resisting vertical elements, and discontinuity in capacity (weak story). NEHRP code (BSSC, 2003) has classifications of vertical irregularities similar to those described in IS 1893 (Part 1)-2016 (BIS, 2002). As per this code, a structure is defined to be irregular if the ratio of one of the quantities (such as mass, stiffness or strength) between adjacent stories exceeds a minimum prescribed value. These values (such as 70-80% for soft story, 80% for weak story, and 150% for set-back structures) and the criteria that define the irregularities have been assigned by judgment. Further, various building codes suggested dynamic analysis (which can be elastic time history analysis or elastic response spectrum analysis) to come up with design lateral force distribution for irregular buildings rather than using equivalent lateral force (ELF) procedures.

### 1.4 PROBLEM STATEMENT

Present research involves the study of effect of vertical irregularity in multistoried building under seismic loading. For this study, a G+15, G+20, G+25 story building with 3.1 meters height for each story, regular in plan is considered. This building is considered to be situated in seismic zone III and designed in compliance to the Indian Code of Practice for Earthquake Resistant Design of Structures IS 1893(part-I):2016. The base of building is considered to



be fixed.. The building is modeled using relevant software. Model is studied for comparing base shear, Storey drift. We also study effect of mass irregularity and stiffness irregularity in various height structures.

**Table1.1: Problem Data**

Type of structure	Special Moment Resisting frame (SMRF)
Number of stories	G+15, G+20, G+25
Seismic zone	III
Floor height	3.1m
Type of soil	Medium
Size of Column	300*600, 300*450
Size of Beam	300*600
Depth of Slab	150mm
Live Load	3.5 KN/m <sup>2</sup>
Material	M30 & Fe 500 reinforcement,
Unit weight	Concrete -25 KN/m <sup>3</sup>
Damping in structure	5%
Importance factor	1.5

**1.5 OBJECTIVES OF THE STUDY**

The main objectives of the present work is to study the effect of vertical irregularity in Multi-Storied building

- 1) To calculate the design lateral forces on regular buildings using Equivalent static method.
- 2) To study two irregularities in structures namely mass and stiffness irregularities.
- 3) To study the structural response of the building models with respect to following aspects Base shear, Storey drift.
- 4) To determine the percentage variation of quantity of steel of various heights of Building.

**1.6 NEED FOR RESEARCH**

Irregular buildings constitute a big portion of the modern urban infrastructure. Structures are never perfectly regular and hence the designers routinely need to determine the likely degree of irregularity and the effect of this irregularity on a structure during an earthquake. Need for research is required to get economical & efficient lateral stiffness system for high seismic prone areas for optimization & design of high rise building with different structural. Framing systems subjected to seismic loads to improve the understanding of the seismic behavior of building structures with vertical irregularities.

**II. LITERATURE REVIEW**

Arelekar et al. (1997) had discussed importance of explicitly recognizing the presence of the open first storey in the analysis of the building. The open first storey is an important functional requirement of almost all the urban multi-storey buildings, and hence, cannot be eliminated. Alternative measures need to be adopted for this specific situation. The under-lying principle of any solution to this problem is in (a) increasing the stiffness’s of the first storey such that the first storey is at least 50% as stiff as the second storey, that is., soft first storey’s are to be avoided, and (b) providing adequate lateral strength in first storey. The possible schemes to achieve the above are (i) provision of stiffer columns in the first storey, and (ii) provision of a concrete service core in the structure.

Sadjadi et al. (2007) presented an analytical approach for seismic assessment of RC frames using nonlinear time history analysis and push-over analysis. The analytical models were validated against available experimental results and used in a study to evaluate the seismic behavior of these 5-story frames. It was concluded that both the ductile and the less ductile frames behaved very well under the earthquake considered, while the seismic performance of the GLD structure was not satisfactory. The retrofitted GLD frame had improved seismic performance.

Stefano and Barbara (2007) carried out review on the seismic behavior of irregular structure. The paper presents an overview of the progress in research regarding seismic response of plan and vertically irregular building structures. Three areas of research are surveyed. The first is the study of the effects of plan-irregularity by means of single-storey and multi-storey building models. The second area encompasses passive control as a strategy to mitigate torsional effects, by means of base isolation and other types of devices. Lastly, the third area concerns vertically irregular structures and setback buildings. They discuss the review on the paper which includes effects of torsional coupling in one story, Multi-storey and vertically irregular structures setback multi-storey buildings asymmetric building structures.

Athanassiadou (2008) concluded that the effect of the ductility class on the cost of buildings is negligible, while performance of all irregular frames subjected to earthquake appears to be equally satisfactory, not inferior to that of the regular ones, even for twice the design earthquake forces. DCM frames were found to be stronger and less ductile than the corresponding DCH ones. The over strength of the irregular frames was found to be similar to that of the regular ones, while DCH frames were found to dispose higher over strength than DCM ones. Pushover analysis seemed to underestimate the response quantities in the upper floors of the irregular frames.

Karavasilis et al. (2008) had discussed the inelastic seismic response of plane steel moment-resisting frames with vertical mass irregularity. The analysis of the created response databank showed that the number of storeys, ratio of strength of beam and column and the location of the heavier mass influence the height-wise distribution and amplitude of inelastic deformation demands, while the response does not seem to be affected by the mass ratio.

Sarkar et al. (2010) discussed on 'Stepped building' frames, with vertical geometric irregularity, are now increasingly encountered in modern urban construction. This paper proposes a new method of quantifying irregularity in such building frames, accounting for dynamic characteristics (mass and stiffness). The proposed 'regularity index' provides a basis for assessing the degree of irregularities in a stepped building frame. This paper also proposes a modification of the code specified empirical formula for estimating fundamental period for regular frames, to estimate the fundamental time period of the stepped building frame. The proposed equation for fundamental time periods is expressed as a function of the regularity index. It has been validated for various types of stepped irregular frames.

Duana and Mary (2012) According to the numerical results, the structures designed by GB50011-2010 provides the inelastic behavior and response intended by the code and satisfies the inter-storey drift and maximum plastic rotation limits recommended by ASCE/SEI 41-06. The push-over analysis indicated the potential for a soft first story mechanism under significant lateral demands.

Kumar and Gupta (2012) Studied the results of the numerical analysis showed that any storey, especially the first storey, must not be softer/weaker than the storeys above or below. Irregularity in mass distribution also contributes to the increased response of the buildings. Their regularities, if required to be provided, need to be provided by appropriate and extensive analysis and design processes.

Ravikumar et al. (2012) Studied fragility based seismic vulnerability of structures with consideration of soft -storey (SS) and quality of construction (CQ) was demonstrated on three, five, and nine storey RC building frames designed prior to 1970s. Probabilistic seismic demand model (PSDM) for those gravity load designed structures was developed, using non-linear finite element analysis, considering the interactions between SS and CQ. The reaction surface strategy is utilized to build up a prescient condition for PSDM parameters as an element of SS and CQ. Result of the analysis shows the sensitivity of the model parameter to the interaction of SS and CQ.

Kabade and Shinde (2012) Studied a G+3 vertically irregular building was modeled as 3D space frame for the analysis with discontinuous column at top floor. To response parameters like base shear, storey displacement of the structure under seismic force under the linear dynamic & non linear static analysis is studied. The result remarks the conclusion that, a building structure with irregularity produced due to column discontinuity provides instability and increases storey displacement. They concluded that base shear of regular and irregular frame in both the orthogonal direction is more than the calculated base shear. It is very clear that the structural irregularity produced due to column discontinuity increases displacement but reduces the base shear under seismic loading for irregular buildings. The common observation is that the drift in both the orthogonal direction is suddenly increases at the discontinuous level. It is recommended that the irregularity in column is vulnerable condition for the building structure and it creates the soft storey effect. It also affects on overall performance of the building under the seismic loading.

Rajeev and Tesfamariam (2012) discussed on Poor seismic performance of non-code conforming RC buildings, mainly designed for gravity loads prior to 1970s highlights the need for reliable vulnerability assessment and retrofitting. The vulnerability is compounded since the RC buildings are subject to different irregularities such as weak storey, soft

storey, plan irregularities, and poor construction quality; and interaction of different irregularities. Fragility based seismic vulnerability of structures with consideration of soft storey (SS) and quality of construction (CQ) is demonstrated on three-, five-, and nine-storey RC frames designed prior to 1970s. Probabilistic seismic demand model (PSDM) for those gravity load designed structures is developed, using the nonlinear finite element analysis, considering the interactions between SS and CQ. The response surface method is used to develop a predictive equation for PSDM parameters as a function of SS and CQ. Result of the analysis shows the sensitivity of the model parameter to the interaction of SS and CQ. The accuracy of the predictive equations is checked for randomly selected SS values and three levels of CQ. Further, the fragility curves are developed for the three structures considering SS, CQ and of their interactions. Finally, confidence bounds on the fragilities are also presented as a measure of their accuracy for risk-informed decision-making.

Mahdia and Bahreinib (2013) discussed the nonlinear seismic behavior of intermediate moment-resisting reinforced concrete (RC) space frames with unsymmetrical plan in three, four and five stories are evaluated. The plan configurations of these space frames contain reentrant corners. Analyses of these buildings are made with and without considering the masonry infill (MI). For infills, three types of arrangements and two material types (strong and weak) have been considered. For lateral seismic loads, two types of lateral loads distributions have been assumed. The results revealed that the existence of infill increases the stiffness and decreases the drifts. However, by omitting infills from the ground floor (the soft story arrangement), the beams and the columns of the ground floor show inferior performance.

Marco (2013) discussed that the effectiveness of different strategies for the seismic retrofitting of a gravity-load-designed plan-wise irregular R/C building tested at the JRC Elsa Laboratory. An alternative retrofitting intervention based on both FRP wrapping and R/C jacketing applied to selected critical columns was proposed. The retrofitting strategy was focused on two main objectives: 1) relocating the centre of stiffness and strength in order to reduce the torsional component of the response of the structure; 2) increasing the local deformation capacity of columns and thus the global deformation capacity of the structure. Nonlinear dynamic time history analyses and simplified procedures based on nonlinear static pushover analyses were carried out and comparison with the retrofitting interventions carried out at the JRC ELSA Laboratory were performed. Bidirectional damage indexes were used to identify the most critical columns affecting the seismic performance of the structure. The simplified procedure provided results consistent with the experimental evidence and allowed to easily select a suitable retrofitting strategy. Numerical results showed the effectiveness of the strength-and stiffness relocation strategy based on R/C jacketing of selected columns, but the local ductility increase based on FRP wrapping of the other columns was necessary for significantly improving the global seismic performance of the structure in case of severe seismic excitation.

### III. CONCLUSION

1. The storey shear force is Minimum for the first storey and it increases to maximum in the top storey.
2. It is concluded that storey drift of G+25 is more than G+15, G+20 Storey frame.
3. It is concluded that base shear of G+25 is more than G+15, G+20 Storey frame.
4. The stiffness irregular structure experiences lesser base shear than similar regular structures.
5. It is concluded that stiffness irregular building frames experience larger base shear than similar regular building frames.
6. It is concluded that mass regular building frames experience larger base shear than similar irregular building frames.
7. Quantity of steel increases as storey height increases.
8. Vertical sporadic structures can be planned precisely and monetarily for seismic tremor obstruction building utilizing STAAD.pro v8i.

According to NTH results, the storey shear force was found to be maximum for the last storey and it increased to maximum in the bottom storey in all cases. It was discovered that mass sporadic structure casings experience bigger base shear than comparative customary structure outlines. The solidness sporadic structure experienced lesser base shear and has bigger bury story floats. If there should be an occurrence of mass sporadic structure, Time History Analysis yielded marginally higher relocations for upper stories than that in ordinary structure, though as we descend, lower stories appeared higher relocations when contrasted with that in normal structures.



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