Impact of Structural Abnormalities on Seismic Performance of Buildings as per IS 1893:2016 Guidelines

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ABSTRACT

Structural abnormalities in buildings, particularly in the seismic force-resisting (SFR) components or lateral force-resisting systems (LFRS), can significantly compromise structural integrity. These systems, such as shear walls, moment-resisting frames, and dual systems, are crucial in transferring seismic forces. However, inconsistencies in mass, stiffness, and strength distribution—especially due to functional variations across floors (e.g., parking, storage, or observatory towers)—introduce vulnerabilities. These abnormalities are broadly classified as vertical and horizontal. Vertical irregularities result from discontinuities in stiffness, mass, and strength distribution along the building height, affecting the load transfer path during earthquakes and increasing collapse risk. Horizontal abnormalities include sudden plan shape changes, re-entrant corners, and wide openings, which lead to torsional effects and stress concentrations. As per IS 1893:2016 (Part 1), stiffness and mass abnormalities, such as soft and extreme soft stories, and excessive mass on certain floors, are key indicators of structural weakness. Understanding and addressing these abnormalities through design and codal compliance is essential for improving seismic performance and preventing catastrophic structural failures.

Key Words: *Structural Abnormality, Seismic Irregularities, Soft Story.*

1. INTRODUCTION

STRUCTURAL ABNORMALITY IN STR. BUILDINGS

The SFR elements component of the Str. building, is known as LFRS (L.F.R.S), it could be of several types. Shear walls, special moment resisting frames and frame-shear wall dual components are typical types of these systems in the structure. Building systems comprises of structural weak planes are more susceptible to damage. These flaws leads to structural degeneration, and also leading to structural collapse. The occurrence of abnormalities in stiffness, strength, and mass in a structure system causes these vulnerabilities.

Due to Different utilities of floors of Str. buildings in recent times, such as cars parking's, storing's large mechanical appliance's, and constructing observatory towers at the top. This leads to mass, strength, and stiffness to vary at different story's.

The abnormalities in the Str. buildings mainly divided into two groups.

Vertical Abnormalities: Along the vertical height of Str. building contingent change of strength's, stiffness's, geometry's and mass's will results in abnormal distribution of force's and deformation's.

Horizontal Abnormalities: sudden change & uneven plan shapes or discontinuities in hori-zontal resisting components like wide-openings, re-entrant's corner's, etc. leads to torsional effect, diaphragm-deformation's, and concentration-of-uneven-stress's. As per IS-1893: 2016(Part-1), abnormality in structure can be broadly classified in to two types.

VERTICAL ABNORMALITIES

Due to major earthquake structural damages cause is mainly by the Abscission /Abnormalities in path or transfer the load in the structure building which develop due to summation of acceleration of individual each elements w.r.t. the ground. Failing in providing of continuous path for safely transferring load of earthquake force proportionate strength and toughness of all individual each element in the building system or failing to hold-up individual each-elements unitedly could be result in distress or complete-collapse of the building-system. Seismic forces originate in all elements of the Str. building and are delivered to horizontal diaphragms through structural connections therefore to cater his all-structural elements must be properly connected to the structural system, and the load route must be comprehensive and strong enough.

Vertical abnormalities are characterized as geometric, mass distribution, stiffness, and strength discontinuities that run vertically. Structures setback are a sort of vertically unequal construction with geometric breaks. On the other side, geometric abnormality causes a Abscission in the vertical distribution of mass, stiffness, and strength. Real Str. buildings are frequently uneven and uneven structural designs in plan and elevation are major cause of collapse in prior earthquakes therefore for practical purposes, major earthquake codal provisions across the world distinguish between abnormality in plan and abnormality in elevation, but it's important to remember that abnormality in the structure will be result of a_mix_of_both.

Stiffness abnormality**:**

As per (IS-1893-Part-1-2016)

Stiffness Abnormality (Soft-Story):

Soft-story supposed to be one shall be that have the lateral stiffness is not more than 70% limit of that in the story just above or not more than 80% limit of the avrg. lateral stiffness of_the_consecutive_three_stories_just_above.

Extreme Soft Story:

Extreme-soft-story supposed to be one shall have the lateral stiffness is not more than 60% limit of that in the story just above or not more than 70% limit of the avrg. stiffness of the consecutive three stories just above. For eg., Str. buildings on stilts shall be come under this category.

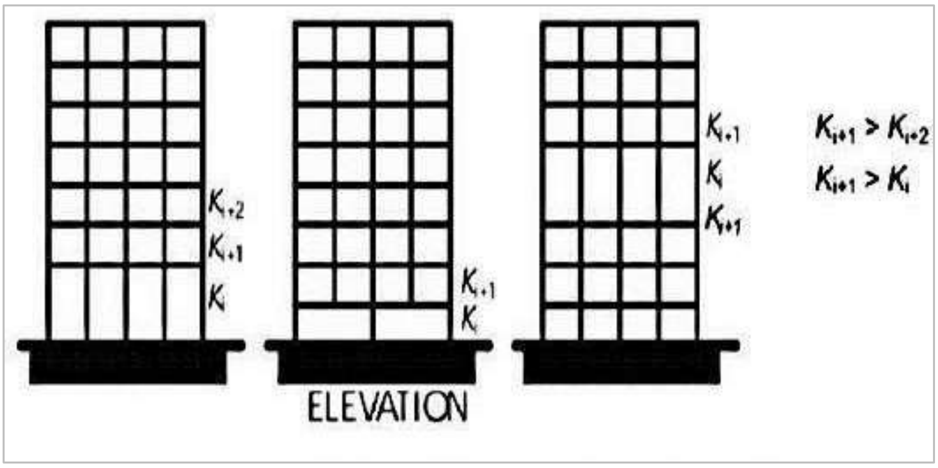

Fig 1: Stiffness Abnormality (Soft-Story)

Mass Abnormality:

Mass abnormalities are supposed to be there where the effective-mass's of any story is higher than 150% limit of effective mass of an immediate adjacent consecutives story. Dead wt. of the story including actual wt. of Partition and other equipment constitute the effective-mass's of the story. Lateral inertial forces may increase inline with increase in mass and lead to reduction in vertical loads causing ductility resisting elements and increased capacity towards-collapse pertaining to P-Δ effect.

Unpredictable responses and complicated dynamics are the results of abnormal mass-distribution in the vertical as well as horizontal-planes. Masses positioned in the higher floors produce significantly more adverse impacts than masses placed lower down Because of the swaying motion of a Str. building during an earthquake (Lateral forces Centre of gravity may shift above the base if there heavy loads in upper levels is placed, causing in bending moments increase).

Generally, large plant rooms and massive roofs at high levels should be avoided. When mass abnormalities exist then always check the LFR elements by using a dynamics-analysis for a more real base-shear distribution due to lateral loads.

A non-uniform distribution of mass along its height lead to "mass abnormal structure Str. building". Many factors can cause mass abnormality for example, Fulfilment of different functions, utility at various levels over their height and the use of a Particular floor differs from that of surrounding floors, may resulting in mass abnormality.

Some examples are:

1. When a Str. building is used for a different purpose other than that for which it was created, it attracts a huge number of people/loads.
2. When a section of the floor is set for the machine tools or a swimming pool etc.
3. When a floor is used for a certain purpose, such as a library or offices area.

As per (IS-1893-Part-1-2016), definition of Mass abnormality:

If seismic-wt. of any-story is more above than 150% limit of adjacent consecutive story then Mass abnormalities exist to that floor.

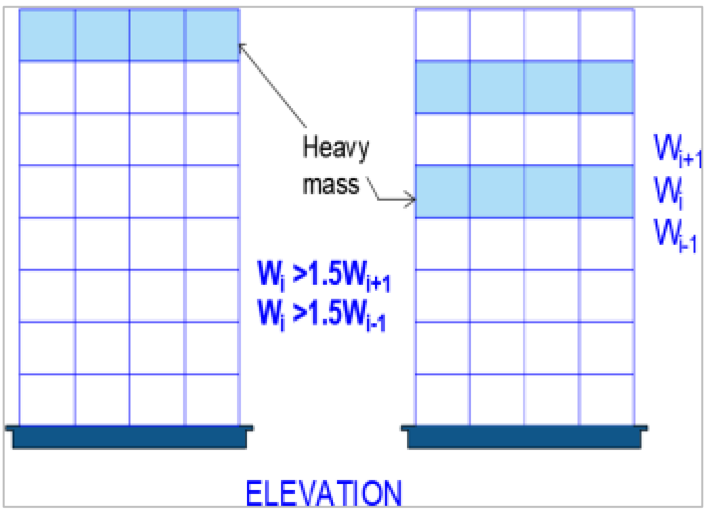

Fig 2: Mass Abnormality

Vertical- Geometric Abnormality:

Vertical set back in a vertical plane, is vertical geometric abnormality. It can also be pointed out as vertical re-entrant-edge. Always check the LFR element using by dynamic-analysis.

As per (IS-1893-Part-1-2016) Vertical geometric abnormality:

When planer dimension of the LFR-elements in any immediate story is more above 125 % of adjacent consecutive story then vertical-geometric abnormality will be supposed to exist there.

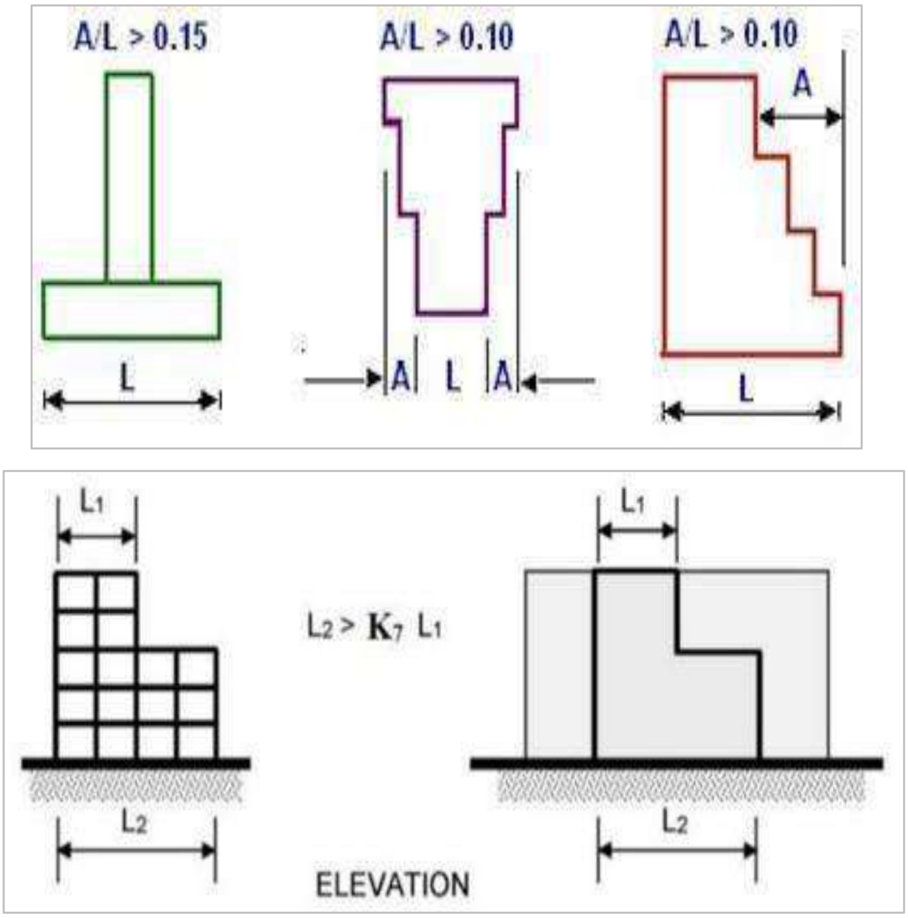

Fig 3: Vertical Geometric Abnormality

Strength Abnormality (Weak-Story):

If story-lateral-strength of not more than 80% limit of the story just above then it supposed to be weak-story, summation of strength of all SFRM (seismic-force-resisting materials) that sharing the story-shear in that supposed Axis is called story-lateral-strength. Story-shear is the story-lateral-strength. That cover overall all strength sharing SFR elements in the supposed Axis.

As per (IS-1893-Part-1-2016) Strength Abnormality:

If story-lateral-strength is not more than 80% limit of consecutive story above is called weak-story. Total summation of all strength SFR elements share's the story-shear in the Supposed Axis is called story lateral strength.

In -Planer Abscission in Vertical structural lateral Force Resisting Element:

As per (IS-1893-Part-1-2016), Planer Abscission in vertical-element's resting lateral forces:

If in-planer Abscission in vertical-LFR elements shall be supposed to exit. When the in-planer off set of the LFRE (lateral-force-resting-elements) is larger than 20% limit of plan-length of that particular elements.

Vertical-force-resisting components (seismic bracing, seismic walls, and columns) transmit their internal force downward through a horizontal transmission component (truss and beam).

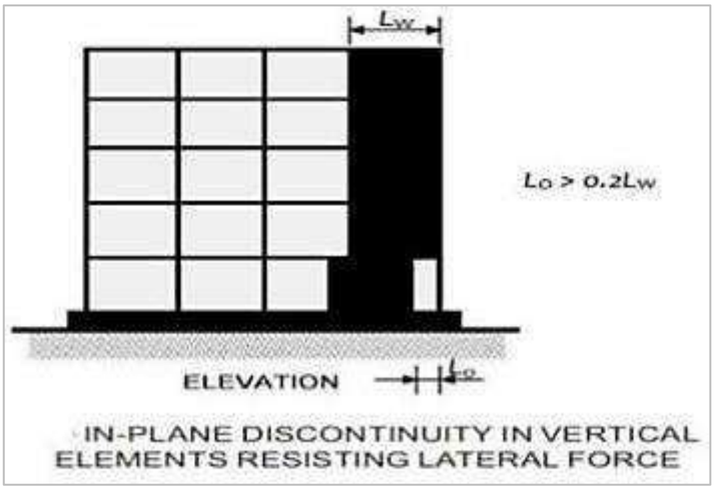

Fig 4: In-Planer Abscission in Vertical Lateral Force Resisting Elements

2. REVIEW

Remya, K. V., & Prasad, R. (2024, June). The majority of building structures in underdeveloped countries like India are low-rise buildings. However, the lack of available land and the quickening rate of population growth create a need for vertical growth. “Medium-high rise” structures have become a feasible solution in answer to this need. There are many factors to take into account while creating high-rise structures, and composite materials have benefits like increased strength, improved aesthetics, and environmental sustainability. In a seismic zone of 3 (comprising G+30 storeys), this thesis compares irregular constructions built of steel, composite materials, and reinforced cement concrete. The research employs response spectrum analysis, a dynamic analytical method, on three building categories with distinct irregularities. The Etabs software is utilized for this purpose, comparing results such as time period, storey displacement, storey drift, maximum storey stiffness, and maximum storey shear. The study also explores construction options for irregular high-rise buildings, specifically focusing on steel-concrete-composite and RCC (Reinforced Cement Concrete), evaluating their characteristics. The equivalent linear dynamic analysis method in E-tabs version 13 software is applied, comparing results for various parameters, including base shear, storey drifts, axial forces, and bending moments for columns and beams at different levels. The findings indicate that steel-concrete-composite buildings are deemed safer, more economical, and a preferable option. The research utilizes the commercial software package E-tabs 2013 to analyse G+30 high-rise buildings with different irregular structures one constructed with composite steel-concrete material and the other with RCC situated in earthquake zone III with medium soil conditions. The study also involves analysing an irregular RCC structure by replacing traditional concrete with high-performance concrete. The behaviour of these structures under dynamic loads is examined, aiming to optimize the design of structural members, specifically columns, and minimize the quantity of materials through the use composite members instead of RCC members. The conclusion is drawn based on the analysis and comparison tables, offering insights into the most effective structural solutions.

Intekhab, et.al. (2023). Seismic analysis of structures is required for the design of high-rise building as these are hazards that threat the built environment and human life. However, it was observed that most of the high-rise structures show irregularities in form of mass, stiffness, strength, plan, etc. The irregularities occur due to the architectural designs, non-orthogonal placement of columns, irregular placement of mass in structure, etc. The researchers observed that the irregular structures could not be analysed using the regular methods as given in the design codes as the codes consider the regular structures. Therefore, different methods were developed for analysis of seismic irregularities. The methods for analysing irregular structures under the seismic loads are static methods such as equivalent lateral force method and pushover analysis, and dynamic methods such as Response Spectrum Analysis and Time History Method. From the study, it was observed that the non-linear time history analysis, increment dynamic analysis, considers several intensity of ground vibrations to perform nonlinear analysis. Therefore, the method performs well against the other analytical techniques as all the scaled ground motions are recorded to predict the damage due to earthquake.

Kumar, et.al. (2022, December). The greatest challenge for any structural engineer in today's scenario is to design seismic-resistant structures. The presence of vertical geometrical irregularity in building is a matter of concern when it is subjected to devastating earthquakes. Irregular configuration either in plan or in elevation is recognize as one of major causes of failure during earthquakes. The performance of a high rise building during strong earthquake motions depends on the distribution of stiffness, strength and mass along both the vertical and horizontal directions. If there is discontinuity in stiffness, strength and mass between adjoining storeys of a building then such a building is known as irregular building which triggers structural collapse of building when subjected to seismic loading. In present study G+14 story building with mass and vertical geometrical irregularity is analysed using static method and dynamic method in ETABS v 18.0.2 as per IS-1893-2016 (part 1). Analysis is performed for zone III. Also, response spectra analysis is done for torsion check in building. For dynamic analysis linear time history data of Bhuj, Mexico, and Kobe (Medium, Low & High Intensity) is used. Comparison of behaviour of irregular building is done with G+14 regular building in form of max storey shear, story displacement, story drift. From the analysis results, it is found that the mass irregularity has maximum storey shear, story displacement, story drift compares to regular and vertical geometrical irregular building. Also, sudden change in story shear is observed at set back level.

Raagavi, M. T., & Sidhardhan, S. (2021). The buildings constructed in the present scenario are mostly irregular in geometry and elevation for aesthetic view. These irregularities may also be due to economical feasibility, land availability and other factors. From the past earthquake, researches says that regularly configured structures stay safe in Earthquakes, but irregularly configured structures could not able to withstand effectively during an earthquake. Structures experience lateral deflections under earthquake loads. This work focuses on studying the various sorts of building irregularities possible and their behaviour during seismic forces. This study focuses on learning the parameters to be analysed while analyzing a structure for seismic force. The various structural behaviour parameters such as displacement, base shear, storey drift, stiffness, strength etc., are needed to be studied. Also to know the model analysis methods those are available for seismic analysis of a structure. Some model analysis methods are Response Spectrum Analysis, Time History Analysis.

Allena, P., & Chowdary, T. B. (2020, December). This Paper describes about effect of mass irregularity in regular and irregular high rise structure under seismic loads. These Irregularities refer to abrupt change of geometry, mass, strength and stiffness as well. This leads to uneven distribution of forces and their corresponding deformation over the height of structure. Performing dynamic analysis and comparing the responses of Mass irregularity taken at various stories of regular and irregular buildings. Various aspects such as Modal periods, Modal frequencies, Story drifts, and Response of Time history graphs are drawn while these structures are subjected to Mass irregularity and seismic loads.

3. RESEARCH OBJECTIVES

As responsible Civil Engineering we to design structures that will severe, withstand earthquakes in designed earthquake zones and thus lowering the damages of destructiveness and economic-losses, to address these issues. The earthquake parameters of the structure change as a result of these modern provisions. This is referred to as a vertical abnormal structure. As conducted a literature review of vertical-mass abnormal structures by different engineers and reached to the majority of cases are coming from earthquake Zones-IV and-V. Thereby in this particular thesis, focusing to vertical abnormal structure design in earthquake Zone-IV with the using E-TABS for reliable and accurate results.

The objectives of this thesis are:

1. Modelling and analysis of regular and abnormal Str. building using E-TABS software.
2. To perform dynamic analysis by using RSM.
3. Analyze the Str. building as per IS-1893-2016-Part-I ("criteria-for-earthquake-resistant-structure)
4. To study the seismic performance of Str. buildings with & without mass abnormality.
5. To compare the behavior of structures without & with mass abnormality.
6. To perform a comparative study of various seismic parameters of story forces, story-stiffness, Time-period, story-shear, story-displacements, story-drift, and story-acceleration.

METHODOLOGY

A. **Modelling:** using **E-TABS -2018 v18**

B. **Mode of Data-Collection:**

- Different global generals for earthquake-engineering by different Prof's, Engr's and Developer's around the world.
- Diverse by-laws-governed by-regional MC (Municipal-Corporation) for Str. Building-construction.
- Codes stated by Indian standard IS-1893-2016(PART-1), IS-13920, IS-456-2000, IS-875-(Part -1, 2 & 3) and IS-16700-2017.

C. **MODE OF ANALYSIS OF DATA:**

- Mode used for analysis of data is RSM.

4. CONCLUSION

Structural abnormalities in buildings, whether vertical or horizontal, significantly impact their seismic resilience. Irregularities in mass, stiffness, and strength disrupt the uniform distribution of forces, leading to unpredictable responses and potential collapse during earthquakes. Codal definitions, such as those provided in IS 1893:2016, emphasize the need to identify and rectify these abnormalities during design and construction. Ensuring proper connectivity among structural elements and maintaining consistent load paths are essential strategies to mitigate seismic risks and enhance overall structural stability.

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