SEISMIC PERFORMANCE OF IRREGULAR REINFORCED CONCRETE BUILDING FRAME

A Dissertation

Submitted in Partial Fulfillment of the Requirement

for the Award of Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

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Candidate’s Declaration

I, Neda Rasoly (Roll No 2K22/STE/22), student of M.Tech (Structural Engineering), hereby declare that the project Dissertation titled " **Seismic Performance Of Irregular Reinforced Concrete Building Frame**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of and Degree, Diploma Associateship, fellowship or other similar title or recognition.

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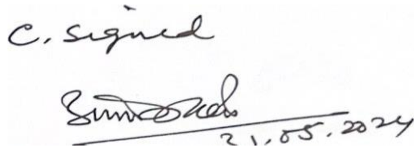
CERTIFICATE

I hereby certify that the project dissertation titled "Seismic performance of frame building through plan and elevation irregularities" which is submitted by Neda Rasoly, Roll no 2K22/STE/22, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by her under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.



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Date: 31/05/2024

ABSTRACT

A structure is considered irregular if it exhibits uneven mass, stiffness, and strength distributions or has an irregular shape. Most structures exhibit irregularity for functional and aesthetic reasons. One significant reason for a structure's collapse during past earthquakes is the irregular configuration of the structure, either in its plan or elevation, as a building's performance during a seismic event is largely determined by its configuration. Therefore, Irregular structures in areas with high seismic activity raise significant concerns. Structures may have one or more types of structural irregularities.

Selecting the type, placement, and extent of irregularities is vital in structural design. According to IS Code 1893 (Part 1): 2016, it is advisable to minimize irregularities by updating architectural designs and structural layouts. However, the concept of "perfect regularity" is an idealized representation., as real structures inevitably contain irregularities due to various needs and demands, and these irregularities are a significant part of modern urban infrastructure. Hence, structural irregularities have become inevitable, and this study aims to analyse their performance.

A G+9 storey regular (Square-Shaped) RCC frame building is developed, and two L-shaped models with plan asymmetric and two setback models with vertical geometric irregularities were created by reducing a specific percentage from the regular (square-shaped) reference model. All models are subjected to earthquake loading, and their responses are computed using CSI ETABS software. The objective will be achieved by comparing the responses of the various models through Response Spectrum Analysis.

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ABBREVIATIONS

R= Model with regular configuration

L_1= L shape model with Plan geometric irregularity

L_2= L shape model with Plan geometric irregularity

S_1= Model with vertical geometric irregularity

S_2= Model with vertical geometric irregularity

RSA=Response Spectrum Analysis

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Structural systems designed to withstand seismic forces are referred to as lateral force resistance systems. Typically, damage within a building initiate at the points of structural weakness. These vulnerabilities can exacerbate structural deterioration, potentially resulting in a collapse. Structural irregularities within a building often contribute to these weak points. Buildings with consistent layouts and evenly distributed strength, mass, and stiffness in both plan and elevation have historically suffered less damage during seismic events, in contrast to structures with irregular geometries.

Structural irregularities can appear as either plan or vertical irregularities, depending on whether there's a deviation in the distribution of mass, stiffness, or strength in the plan or elevation. As per IS 1893 (Part 1): 2016, a floor in a building demonstrates mass irregularity if its seismic weight surpasses 150% of that of the floor below. When the lateral stiffness of a specific floor is inferior to that of the floor above, it's referred to as stiffness irregularity (soft story). Similarly, if a floor's lateral strength is lower than that of the floor above, it's labelled as strength irregularity (weak story). In practical terms, the notion of perfect regularity is merely an idealization since real structures inevitably contain irregularities due to various factors. Numerous existing buildings contain irregularities due to functional and aesthetic considerations. Some structures were designed with irregularities to fulfill specific purposes. Additionally, variations in usage of a particular storey as compared to the adjacent storey can also result in irregularity. Moreover, numerous structures unintentionally acquire irregularities during the construction phase due to factors like inconsistencies in construction practices and variations in the quality of raw materials used.

After examining various seismic codes, it becomes evident that most of them suggest similar criteria for defining irregularities based on their magnitude, often overlooking the aspect of where the irregularity occurs. Nonetheless, considering the type, placement, and extent of irregularities in structural design holds importance. Making informed decisions in this regard can contribute to improving both the functionality and appearance of structures. While irregular buildings are favoured for their functional and aesthetic qualities, historical earthquake data reveals their subpar seismic performance. Nevertheless, irregularities in structures are frequently inevitable. Hence, it's crucial to intentionally choose and position irregularities in a way that doesn't undermine the structure's overall performance.

1.2 TYPES OF IRREGULARITIES

As per IS 1893 (Part 1), the detailed classification of different structural irregularities is presented is presented in Table 1.1 and code limits have been shown in Table 1.2

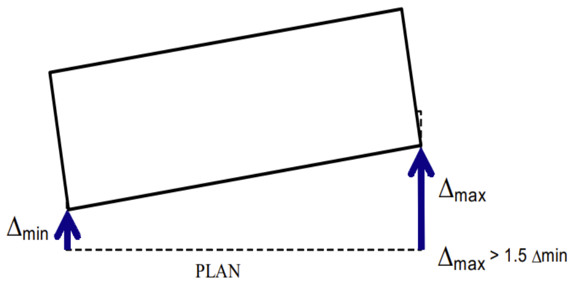
Table 1.1: Types of irregularity as per IS 1893(part 1): 2016

TYPES OF IRREGULARITIES	
PLAN IRREGULARITIES	VERTICAL IRREGULARITIES
1. Torsional irregularity The building rotates around its vertical axis when the centre of mass and centre of resistance are not aligned. Fig.1 (a) illustrates the scenario of torsional irregularity. 2. Re-entrant irregularity This describes a situation where a section of a building or structure protrudes inward, causing an irregularity in its geometric layout, which may result in localized stress concentrations or uneven distribution of forces during seismic events. Fig. 1 (b) illustrates this condition and type of irregularity. 3. Floor slabs having excessive cut outs or openings	1. Stiffness irregularity Soft-story is a story whose lateral stiffness is less than that of the story above. 2. Mass irregularity The seismic weight of any floor exceeding 150% of the floor below can result from heavy equipment, water tanks, or swimming pools, among other factors. 3. Strength irregularity Otherwise known as a weak story, it refers to a level in a building where the lateral strength is inferior to that of the story situated above it 4. Vertical geometric irregularity 5. In plane discontinuity in vertical elements resisting lateral force

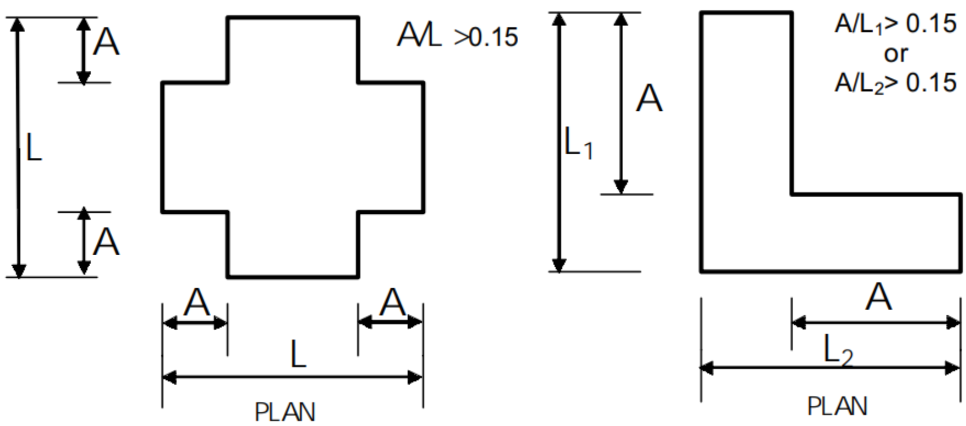
4. Out-of-plane offsets in vertical elements 5. Non parallel lateral force system	6. Floating or stub column 7. Irregular modes of oscillation in two principal directions

Table 1.2: Irregularity limits as per IS 1893 (Part 1): 2016

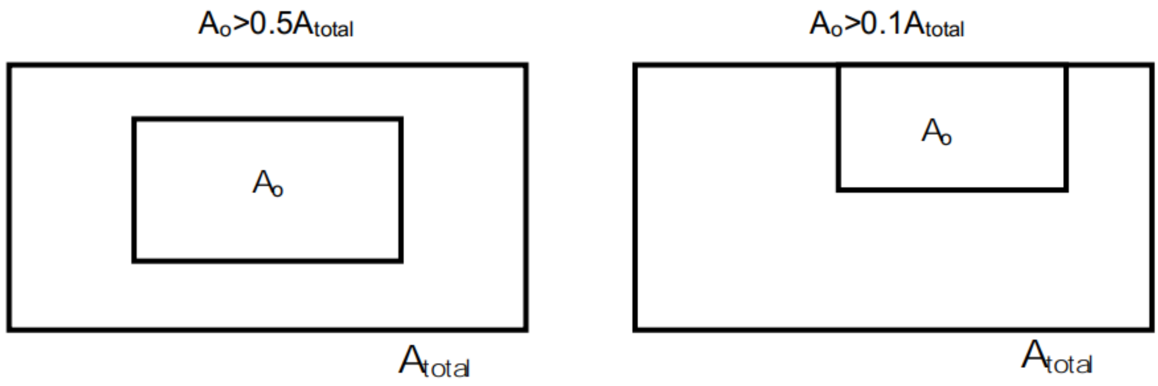
Irregularity	Type	Limits
Mass	Vertical Irregularity	Mi+1 > 1.5 Mi
Stiffness	Vertical Irregularity	Si < Si+1
Torsion	Plan Irregularity	Δmax/Δavg=1.5 to 2.0 >2.0 extreme irregularity
Vertical Geometry	Vertical Irregularity	L2 > 1.25L1



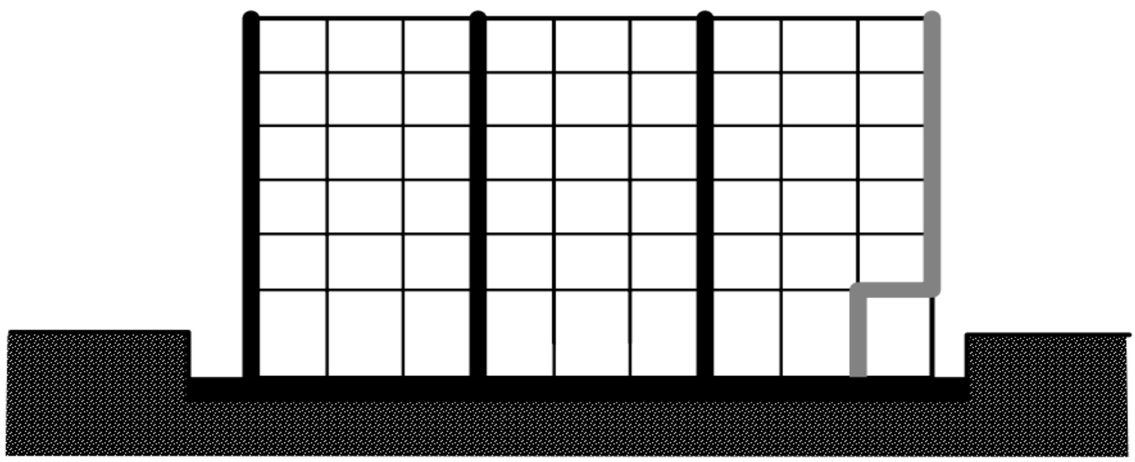
(a) Torsional Irregularity



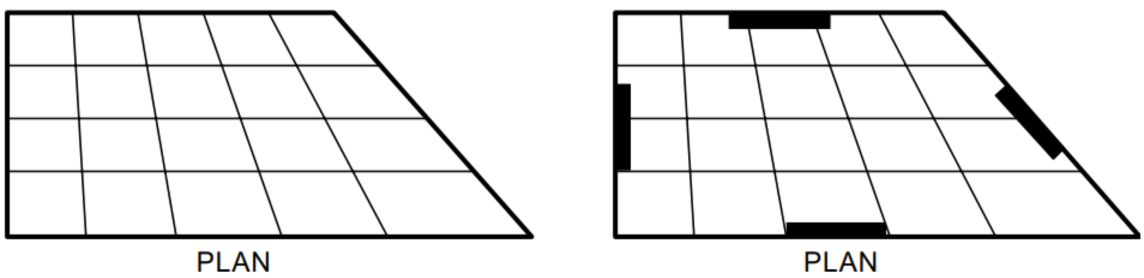
(b) Re-entrant Corners



(c) Excessive cut-out or opening

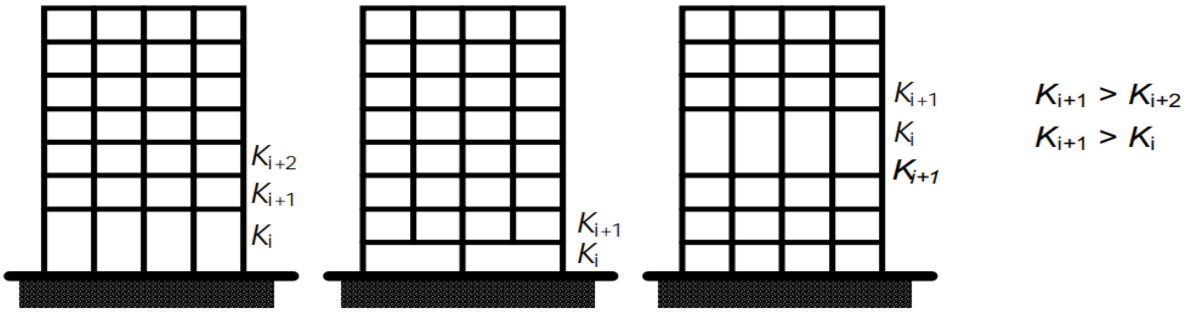


(d) Out of plane offset

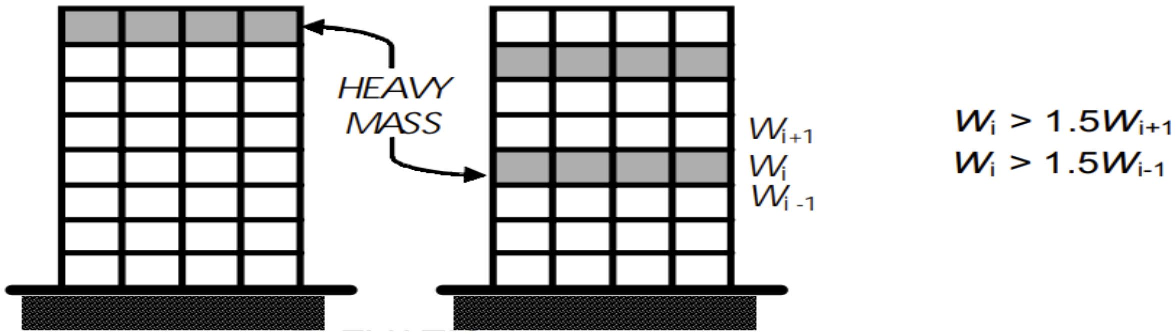


(e) Non parallel lateral force system

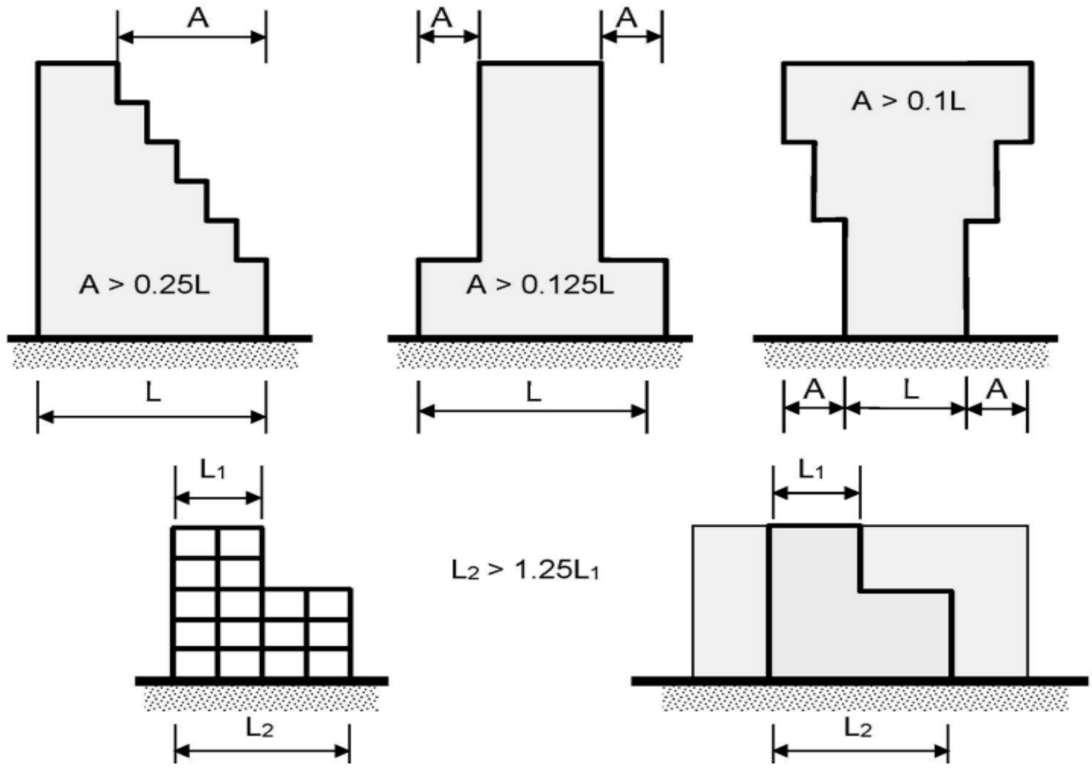
Fig 1.1 Irregular Buildings (Plan Irregularity)



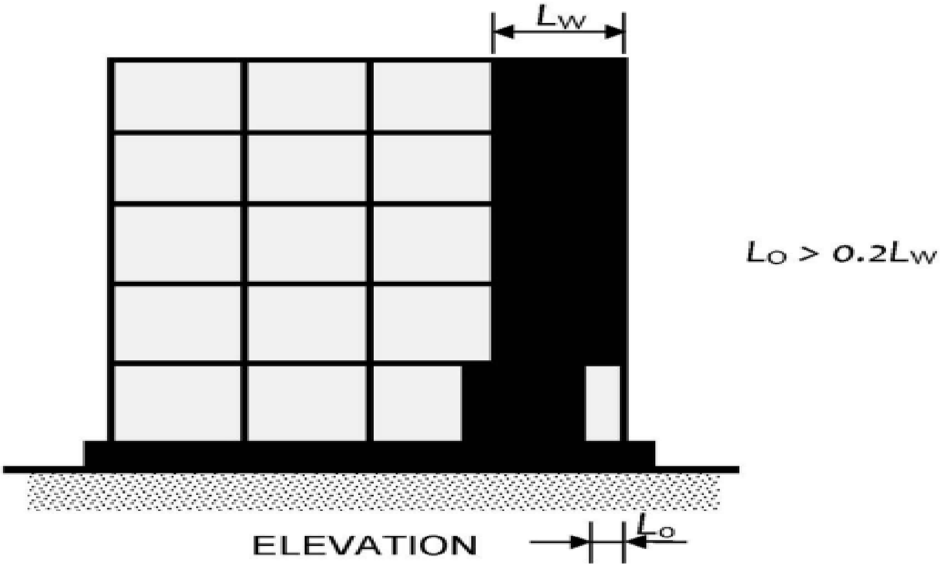
(a) Stiffness Irregularity (Soft story)



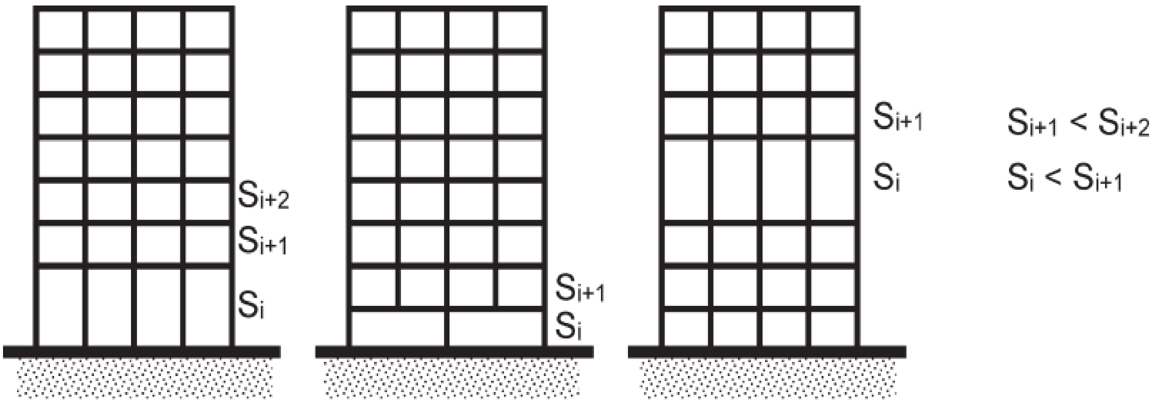
(b) Mass Irregularity



(c) Vertical Geometry Irregularity



(d) In Plane Discontinuity



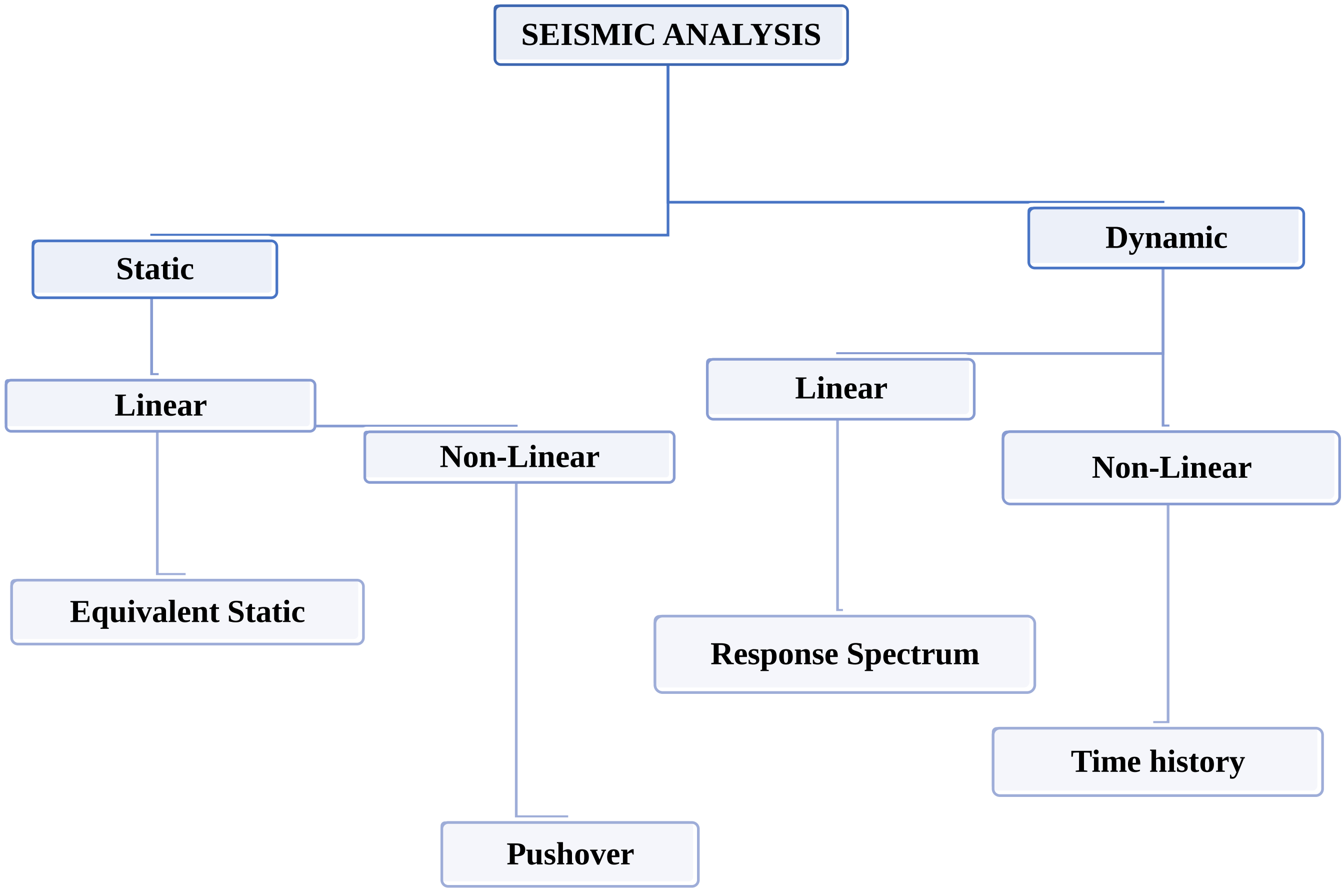
(e) Strength Irregularity (Weak Story)

Fig 1.2 Irregular Building (Vertical Irregularity)

1.3 METHODS OF SEISMIC ANALYSIS

The seismic response of the building system is highly influenced by the seismic analysis method applied. In the past, analysis methods were primarily limited to the linear static approach because of its ease of application, computational, and interpretation simplicity. Although these methods resulted in safe designs, they were found to be over-conservative.

Advanced computers and analysis software have enabled researchers to simulate real earthquakes on models, leading to more realistic seismic responses. These techniques are known as dynamic analysis. Both static and dynamic analyses can be further classified into linear and nonlinear methods, depending on the force-deformation behaviour of structural members. The introduction of structural irregularities impacts the dynamic response by altering the fundamental period and shifting the mode shapes.



1.3.1 Equivalent Lateral Force Method

Seismic analysis is conducted under the assumption that the lateral force is equivalent to the actual loading. According to IS 1893 (Part 1): 2016, the linear static method is suitable for regular buildings with a height under 15 m in seismic zone II and for regular structures with an approximate natural period Ta below 0.4 s. This method demands less computational effort as it does not account for the periods and shapes of higher modes. The determination of base shear involves computing the structure's mass, its fundamental period, and its shape using the formula specified in the code. Following this, the base shear is distributed along the height of the structure in terms of lateral forces.

1.3.2 Response Spectrum Analysis (RSA)

This approach is recommended for structures where the impact of higher vibration modes on the structural behaviour is notable. It is typically used for analysing dynamic responses in irregular structures or those displaying discontinuities in their linear behaviour. Specifically, it can be utilized to assess the forces and deformations experienced by tall buildings under moderate-intensity ground vibrations, resulting in predominantly linear structural responses of moderately large magnitude.

This method computes the response of each natural vibration mode independently, considering a specific damping mode. Subsequently, these modal responses can be integrated to determine the overall structural response. As per IS 1893 – 2016 (Part 1), this method is suitable for all buildings except regular structures lower than 15 m in seismic zone II.

1.3.3 Pushover Analysis (PoA)

Pushover analysis is a static analysis method that incorporates non-linear behaviour within the structure, allowing for the exploration of inelastic responses. This technique offers understanding into the structural strength, deformation, and ductility, as well as the distribution of demands. Furthermore, it anticipates potential points of weakness within the structure and assists in pinpointing critical members that are prone to reaching their limit states. This identification of critical members enables engineers to refine the design and detailing process during the initial design stage. For existing structures, Pushover analysis can be utilized for seismic retrofitting purposes to meet current demands or to address deficiencies in seismic resistance capacity. However, this method has its limitations, as it does not account for variations in loading patterns, higher vibration modes, or resonance. Additionally, the pushover analysis is not part of IS code.

The Capacity Spectrum Method (ATC-40) and the Displacement Coefficient method (FEMA 356) are two widely accepted procedures for conducting Pushover Analysis (PoA) on buildings. In Pushover Analysis, the importance factor specified in Table 8 of IS 1893 (Part 1): 2016 is not taken into account. Instead, the performance level of a building addresses the criteria of the importance factor.

1.3.4 Time History Method

This approach is suitable for both elastic and inelastic assessments. Time history analysis, recognized as a non-linear dynamic technique, is regarded as the most precise method for depicting a structure's real seismic performance. It involves calculation of structural response at number of time intervals. However, due to its intensive computational requirements and the need for expert interpretation skills, this method is typically recommended only for designing special structures.

1.4 OBJECTIVES OF THE STUDY

- To generate regular, and irregular configurations buildings through the plan, and elevation irregularities.

- To create 3D models using ETABS software and perform Equivalent Static and Response Spectrum Analyses.

- To analyse and contrast various reactions, such as storey displacement, storey drift, and base shear.

- To assess the seismic behaviour of various irregular structures situated in a high seismic risk area (Zone IV).

- To identify the most vulnerable model among the studied configurations.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Bharat Khanal et al (2020) The seismic elastic behaviour of G+8 symmetric and L-shaped buildings, featuring plan irregularities, was simulated using finite element (FE) software, ETABS 2015. Initially, a bare frame reference model was created, followed by the development of several models with plan irregularities achieved by reducing a certain percentage of the area from the regular reference model through Linear Elastic and Response Spectrum methods. The findings reveal that the time period derived from standard codes is lower than the value calculated through finite element (FE) analysis. As the building's plan irregularity increases, there is a corresponding rise in inter-story drift response, absolute overturning moment, and shear force. These heightened values could potentially compromise the building's stability.

M. S. Azad et al (2019) The study was conducted considering four different shapes of six-story building configurations to determine the effect of vertical geometric irregularity. Two models were asymmetric along the height and two models were asymmetric along the vertical axis. Pushover analysis was conducted to assess the building's capacity and define its limit states of damage. Additionally, fragility curves were developed to examine the differences resulting from the setbacks. The capacity curves of all models show that Model-3 (33.33% setback) has the highest maximum value, indicating its lower stiffness compared to the others. In contrast, Model-2 (66.66% setback) exhibits the lowest maximum value, indicating its greater stiffness. Notably, Model-3 (33.33% setback) demonstrates the highest base shear capacity, making it the strongest model. Additionally, there is a similarity in behaviour between Model-1 and Model-3, as their setback percentages are the same. From the pushover analysis, it is observed that the effects of the setback locations are negligible, which is why the pushover curves with the same setback percentages are close to each other. However, in contrast, the fragility curves and probability curves are not as close due to the influences of inertia and induced torsion resulting from the irregularity.

Nilesh Kumar et al (2022) A G+14 building with regular stories and another building with irregularities in mass and vertical geometry, situated in zone III, were examined using static and dynamic methods in ETABS v18.0.0, following IS-1893:2016 guidelines. The comparison between the irregular and regular buildings was conducted based on maximum story shear, story displacement, and story drift. The analysis findings reveal that buildings with mass irregularity displayed higher values of maximum story shear, story displacement, and story drift compared to both regular buildings and those with irregularities in vertical geometry. Moreover, a sudden change in story shear was observed at the setback level in the irregular building.

Priyanka Singh et al (2020) The seismic behaviour of a G+7 RC regular building frame was studied alongside six irregular structures in both plan and elevation, which were derived from the regular model. The Response Spectrum method, following IS-1893:2016 guidelines, was employed for the analysis. The results were presented in terms of Base shear, Fundamental period, Storey Stiffness, Lateral displacement, Storey Drift, Eccentricity, and Torsional irregularity. Among the structures with individual irregularities, the horizontally irregular model was found to be the most vulnerable during the earthquake under consideration. In contrast, the vertically irregular model showed better seismic performance. Moreover, the building models with a combination of geometric irregularities demonstrated improved seismic performance, suggesting that specific combinations of irregularities could mitigate a building's seismic response.

Anitha Kumar et al (2019) The study investigates how reinforced concrete structures respond to seismic forces when they possess different combinations of irregularities. A regular nine-storey frame is modified by introducing irregularities in plan and elevation, resulting in 34 configurations with single irregularities and 20 cases with combinations of irregularities. Alongside the regular configuration, a total of 54 irregular configurations were analysed and compared. Seismic loads were applied to all frames, and their responses were calculated numerically. It was observed that irregularities have a significant impact on the seismic response. Among the various types of single irregularities examined, stiffness irregularity was identified as having the most pronounced influence on the response. Among the cases with combinations of irregularities, the configuration incorporating mass, stiffness, and vertical geometric irregularities displayed the highest response. These findings can contribute to the careful design of irregular structures without compromising their performance.

Milind V. Mohod (2015) Seismic analysis was carried out on a 12-story building situated in zone III, initially with a regular configuration. Subsequently, nine additional models were created from the regular shape, each having the same plan area but differing in geometry. These irregular configurations include shapes like T, E, H, L, C, Plus, square with core, and rectangular with core. The seismic analysis utilized the Equivalent Static method in Staad Pro V8i software, and the results were presented in terms of storey drift and lateral displacement.

Examining the impact of lateral displacement on various structure shapes, it was observed that Plus-shaped, L-shaped, H-shaped, E-shaped, T-shaped, and C-shaped buildings exhibited higher displacement in both the X and Y directions compared to other simpler shaped buildings (Core-rectangle, Core-square, Regular building). Story drift, a crucial parameter for understanding the drift demand of the structure, was considered while gathering results from both software, aligning with IS 1893-2002 standards. The prescribed drift limit for the given structure, as per section 7.11.1, is 16 cm, which was not surpassed in any of the structures. However, the L-shaped and C-shaped models displayed larger drift compared to other shaped models.

S. Sidhardhan and M. T. Ragavi (2021) The primary focus of the study was to investigate different types of building irregularities and their response to seismic forces. The objective was to identify the key parameters for evaluating a structure's response to seismic forces. Various structural behaviour parameters, such as displacement, base shear, storey drift, stiffness, and strength, were examined using Response Spectrum Analysis and Time History Analysis. The findings of this study indicate that a building's behaviour during an earthquake is influenced by factors such as stiffness, strength, ductility, and notably, the configuration of the structure. Irregularities in buildings can result in eccentricity between the mass and stiffness centres, leading to adverse effects on the building's performance. Buildings with plan irregularities often sustain significant damage during seismic events. Plan asymmetric structures, when subjected to lateral ground motions, are particularly vulnerable to torsional coupling. To address these challenges, structures should be designed with careful consideration of seismic loads, aiming to improve their seismic behaviour and resilience.

B D F Chandra Mohan Rao and M. S. Kanya (2015) This study examined three reinforced concrete RC buildings including one regular, one Plus-shape, and one H-shape. All buildings, with the same equal floor plan area, were modelled to facilitate a comprehensive comparative analysis. Each building was exposed to ground accelerations from the Northridge earthquake record in twelve directions, ranging from 0 to 180 degrees, with increments of 15 degrees. Linear Time History Analysis (LTHA) was conducted using ETABS v15 Software.

The study noted the input angle of incidence changes the angle of the structural response. Various response parameters were evaluated, including axial forces in the columns, maximum storey displacement, and storey shear. The findings indicate that the angle of seismic input motion significantly affects the response of RC buildings.

Nitin Verma and Kashif Javaid (2023) The research aimed to evaluate how Buckling Restrained Braces and Viscous Dampers impact the seismic behaviour of irregular 15-story steel-concrete composite moment-resisting frames. A thorough response spectrum analysis was conducted to assess the influence of these devices on seismic performance. The results indicated that both Buckling Restrained Braces and Viscous Dampers significantly reduced seismic responses, with VDs proving particularly effective in decreasing the time period 65-73% and base shear by 80-90%. Conversely, BRBs excelled in decreasing the maximum overturning moment, especially in building with irregular configurations.

Furthermore, both led to noticeable reductions in the inter-story drift ratio and maximum displacement. However, their implementation also resulted in increment of columns compression force.

Ravikumar M et al (2013) The study investigated two types of irregularities in building models: plan irregularity with geometric and diaphragm discontinuity, and vertical irregularity with setbacks and sloping ground, in accordance with clause 7.1 of IS 1893 (Part 1): 2002. The aim was to determine the most vulnerable building among the considered models by employing various analytical approaches to assess seismic demands using both linear and nonlinear methods. Additionally, the analysis examined the impact of three different lateral load patterns on the performance of various irregular buildings through pushover analysis. This comprehensive approach enabled a detailed evaluation of how these irregularities affect seismic performance and identified the building configurations most susceptible to seismic demands.

The study's findings reveal that pushover analysis using the codal type of vertical distribution of lateral force was more detrimental for low-rise building models. This was evidenced by the formation of a greater number of hinges at a given displacement level compared to the other two lateral load patterns. This outcome suggests that low-rise buildings with the codal vertical distribution pattern are more prone to structural damage during seismic events, underscoring the importance of carefully considering load distribution methods in the design and analysis of such structures.

2.2 LITERATURE GAP

- The lack of experimental studies defines the current state of research in the field of irregular structures.

- Research on seismic performance has frequently focused on general irregularities, overlooking specific configurations such as L-shaped and setback structures. This thesis addresses this gap by conducting a comprehensive investigation into these particular irregularities, which are prevalent in real-world construction.

- Typically, real structures exhibit a combination of both plan and elevation irregularities. However, much of the existing literature and seismic codes tend to categorize irregularities separately based on their plan or elevation characteristics.

CHAPTER 3

METHODOLOGY

3.1 DEFINITION OF BUILDING MODELS

The current study incorporates a standard G+9 building model as the baseline for comparison. Additionally, different models with various types of irregularities are examined. These irregularities are described briefly below:

3.1.1 Regular model (R)

The regular building model serves as the baseline, characterized by the symmetric geometry, uniform distribution of mass, stiffness, and strength with no irregularities. Various types of irregularities have been introduced into this regular model to create irregular building models.

These irregularities have been introduced by varying geometry in plan and elevation. The base model is used as a reference point for all comparisons and discussions regarding the results.

3.1.2 Plan geometric irregularity Model (PG)

Plan irregularity in buildings refers to deviations from standard floor plans. Portion of the regular I model projects inward, creating an irregularity in its geometric configuration. According to Is 1893: 2016 a building is considered to possess geometric irregularity if;

$A/L1 > 0.15$

$A/L2 > 0.15$

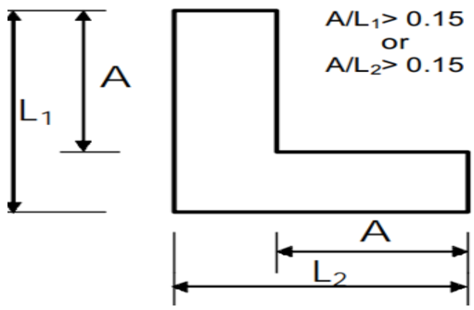


Fig 3.1 Plan geometry irregularity

3.1.3 Vertical geometric irregularity Model (VG)

As per IS 1893: 2016 (part 1) A building is considered to possess geometric irregularity if

L2 > 1.25L1 or A > 0.125L, as per fig 3.2

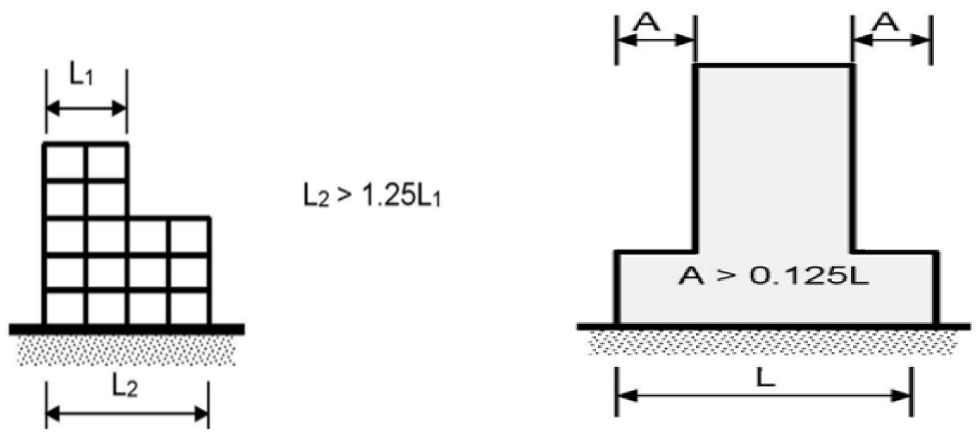


Fig 3.2 Vertical geometry irregularity

3.2 CODES AND STANDARDS

- The modelling and analysis are carried out in CSI software ETABS 2018
- The structure properties are designed and detailed as per IS 456:2000 and IS 800:2007
- The loads considered and load combinations are according to IS 875 (part 2): 1987
- Seismic analysis and seismic loading conform to IS 1893 (part 1): 2016

3.3 MODELLING

The modelling is carried out utilizing CSI, INC's Structural and Earthquake Engineering software, ETABS v 21, which incorporates integrated functionalities for Linear Static Analysis and Response Spectrum Analysis. The initial stages common to both analyses involve defining the geometry, materials, sections, support restraints, and creating load patterns along with load assignments. However, for Response Spectrum Analysis, additional steps include defining the response spectrum function and Response Spectrum load case.

3.4 INPUT PARAMETERS OF THE MODELS

The detailed specifications and input parameters of the model used in the analysis process are presented in Table 3.1 below:

Table 3.1 Input Parameters of the model

Seismic Parameters as per IS 1893:2016	
Type of Building	Residential Building
Zone	IV
Importance Factor	1
Damping Ratio	0.005
Soil Type	II (Medium)
Response Reduction factor I	5
Importance Factor (I)	1
Type of support	Fixed
Type of support	Program calculated
Method of seismic analysis	Response Spectrum analysis
Geometric parameters	
No story	G+9 (10)
Story height	3m
Over all height of the building	30m
No. Bays X-dir	5, 5m
No. Bays Y-dir	5, 5m
Dimensions of structural members	
Beam (mm)	400 x 450
Column (mm)	450 x 450
Slab (mm)	150
Outer Wall (mm)	250
Inner Wall (mm)	120
Properties of Material	
Grade of Concrete	M 25
Grade of steel	Fe 415
Density of brick	19 KN/m^2
Density of Reinforced concrete	25 KN/m^2
Loads (KN/m^2)	
Live load	2.0
FF+CL	1.5
Roof Load	1.0
Outer Wall Load	14.25
Inner Wall Load	7.125

CHAPTER 4

ANALYSIS and RESULTS

4.1 RESPONSE SPECTRUM ANALYSIS

All the various models are seismically analysed using Response Spectrum Analysis, as recommended by the IS code for irregular structures. The responses of the models, as determined by RSA, are detailed and discussed below:

4.1.1 Regular Model (R)

The model's design was adequate based on the concrete frame design check according to IS 456: 2000. The seismic response parameters and their corresponding values, which categorize it as a regular building, are listed in Table 4.1. This model serves as the base model, The standard reference model (RM) is a square-shaped building model devoid of any irregularities in mass, stiffness, and strength distribution. The structures analysed in the study are multi-story reinforced concrete frame buildings. All comparisons are made in relation to this baseline.

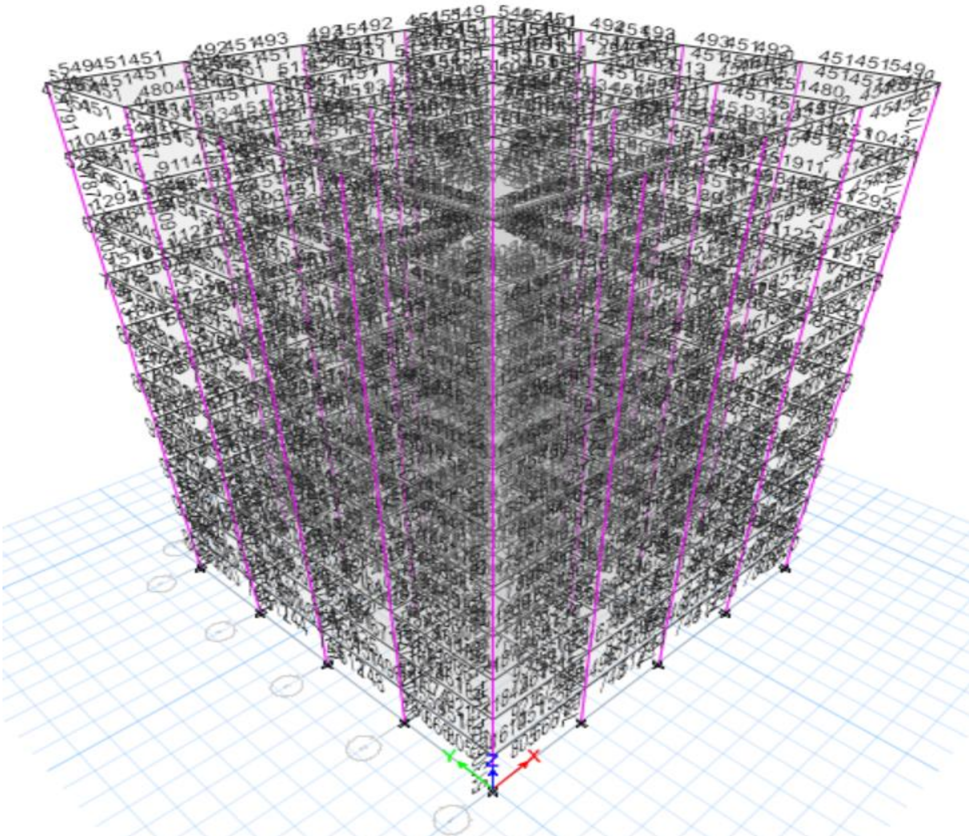


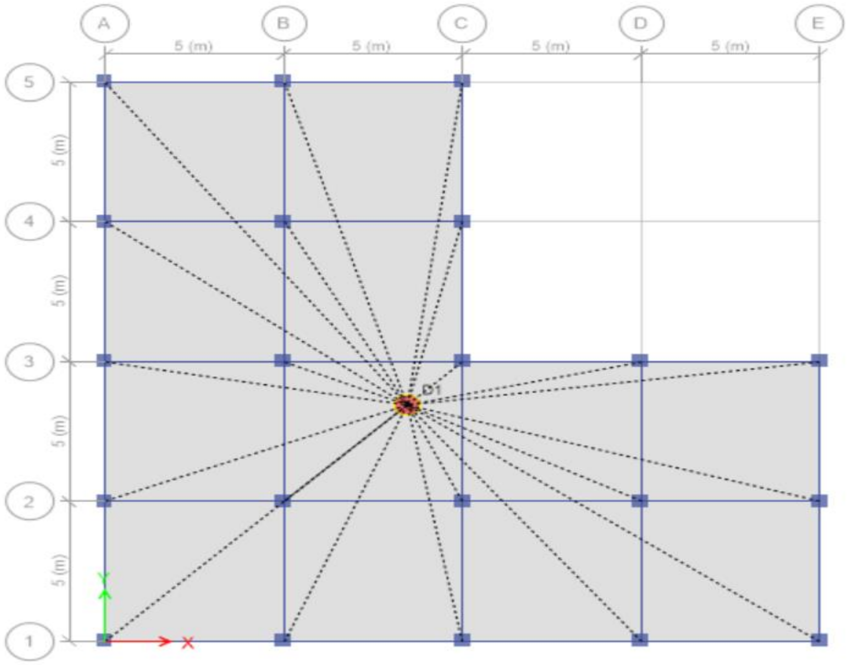
Fig 4.1 Plan and 3D view of regular model (R)

Table 4.1 Response of R model

Seismic response parameter	**Value**	**Limit**
Max storey displacement	25.065mm	120mm
Max Storey drift	0.001105 (storey 3)	0.004
Remark	Regular Structure	

4.1.2 Plan Geometry Irregularity Models

Two L-shaped models with asymmetrical plans were created by reducing a certain percentage of the area from the standard (square-shaped) reference model.



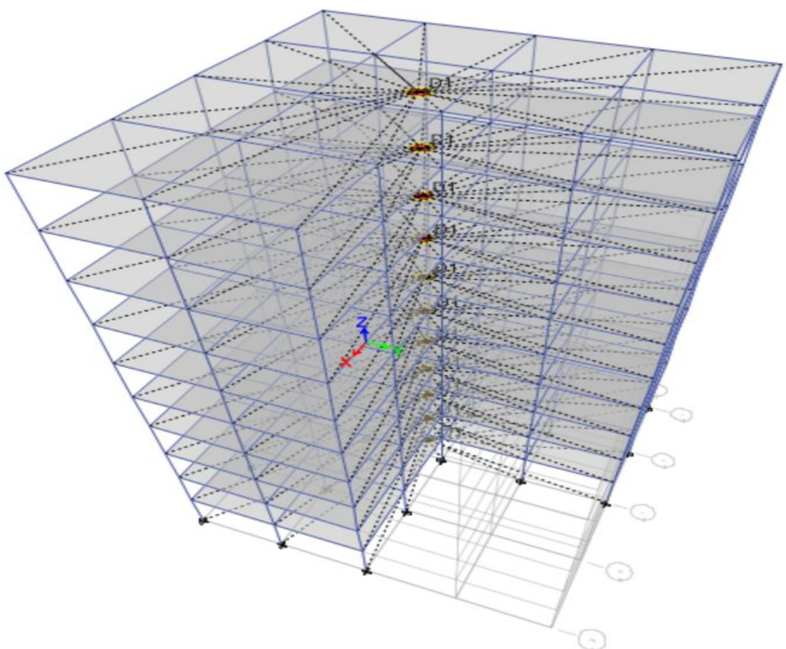


Fig 4.2 Plan and 3D view of Plan Irregular model (L_1)

Table 4.2 Response of L_1 model

Seismic response parameter	**Value**	**Limit**
Max storey displacement	38.744 mm	120 mm
Max Storey drift	0.001697 (storey 3)	0.004
PG limit	0.5	A/L1 > 0.15
Remark	L_ Shaped Plan Irregular Structure	

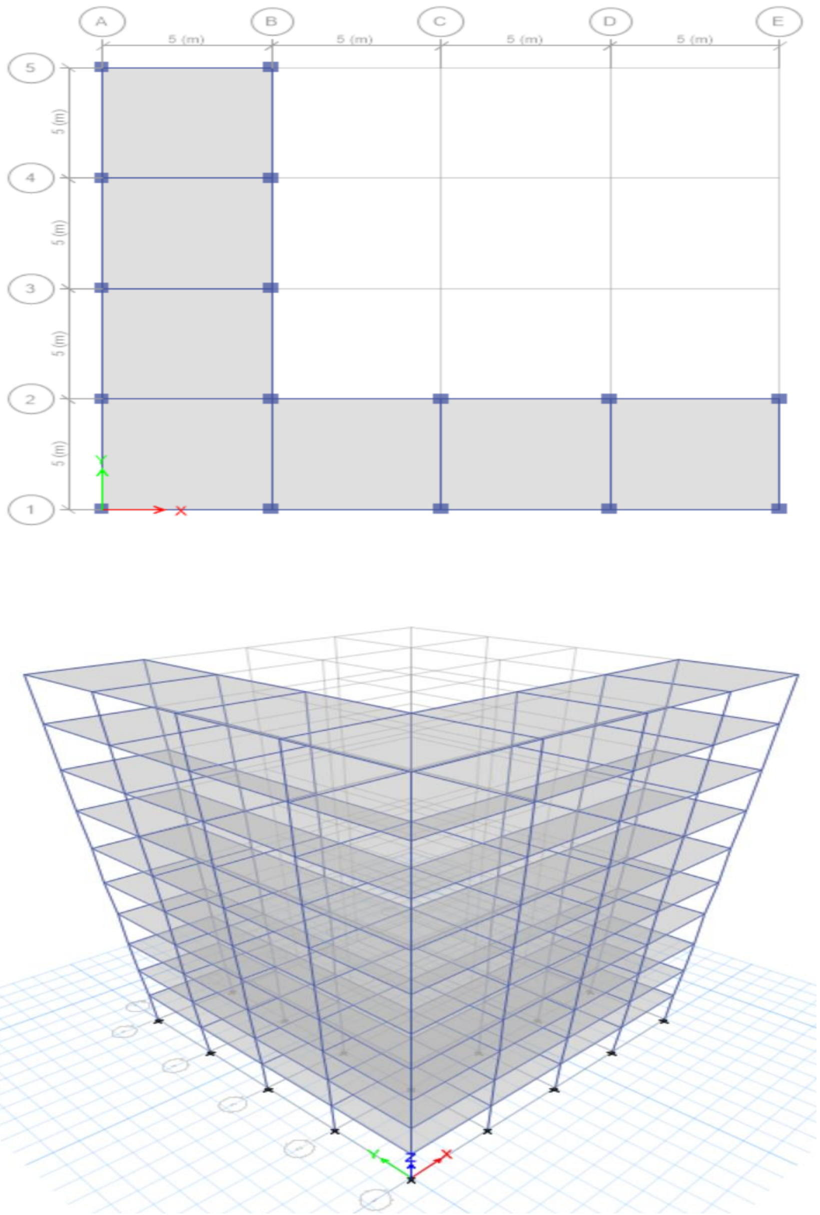


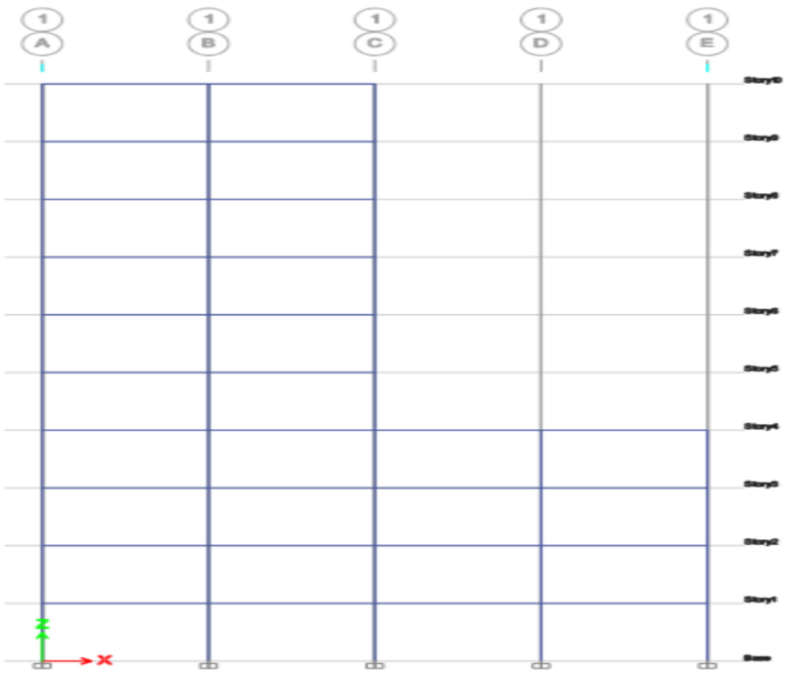
Fig 4.3 Plan and 3D view of Plan Irregular model (L_2)

Table 4.3 Response of L_2 model

Seismic response parameter	**Value**	**Limit**
Max storey displacement	43.142 mm	120 mm
Max Storey drift	0.001842 (storey 4)	0.004
PG limit	0.75	A/L1 > 0.15
Remark	L_ Shaped Plan Irregular Structure	

4.1.3 Vertical Geometry Irregularity Models

Two different building shapes were adopted to assess the impact of vertical geometric irregularity, featuring setbacks at various positions.



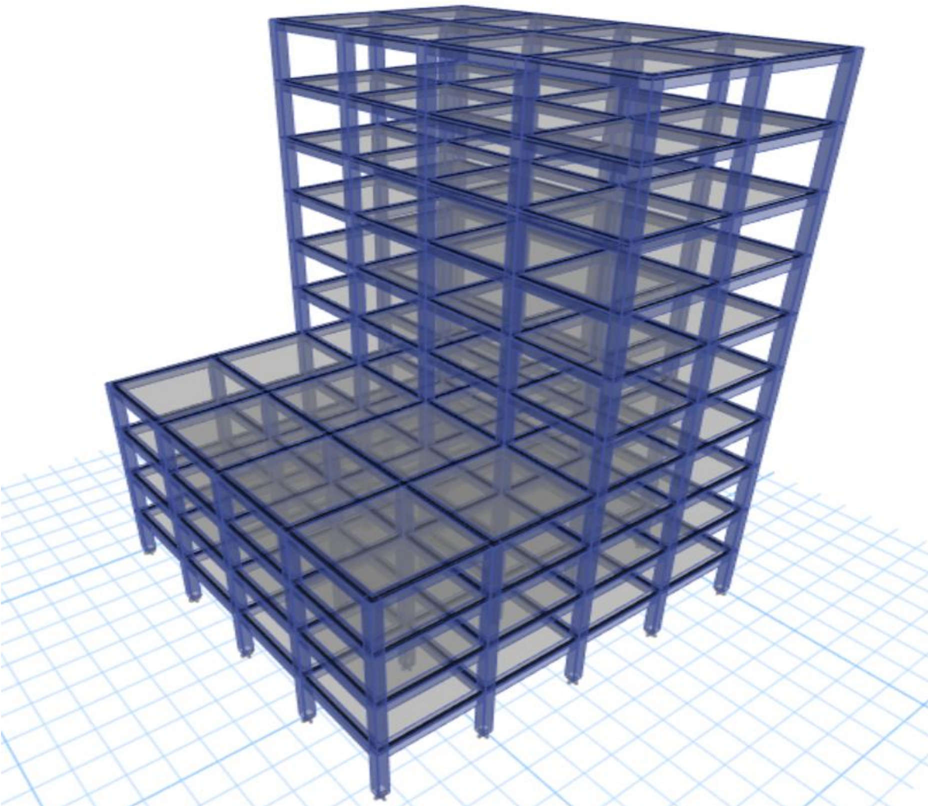


Fig 4.4 elevation and 3D view of vertical geometric irregularity model (S_1)

Table 4.4 Response of S_1 model

Seismic response parameter	Value	Limit
Max storey displacement	44.28 mm	120 mm
Max Storey drift	0.002178 (storey 6)	0.004
PG limit	L1=10 L2 = 20	L2 > 1.25L1
Remark	Vertical Irregular Structure	

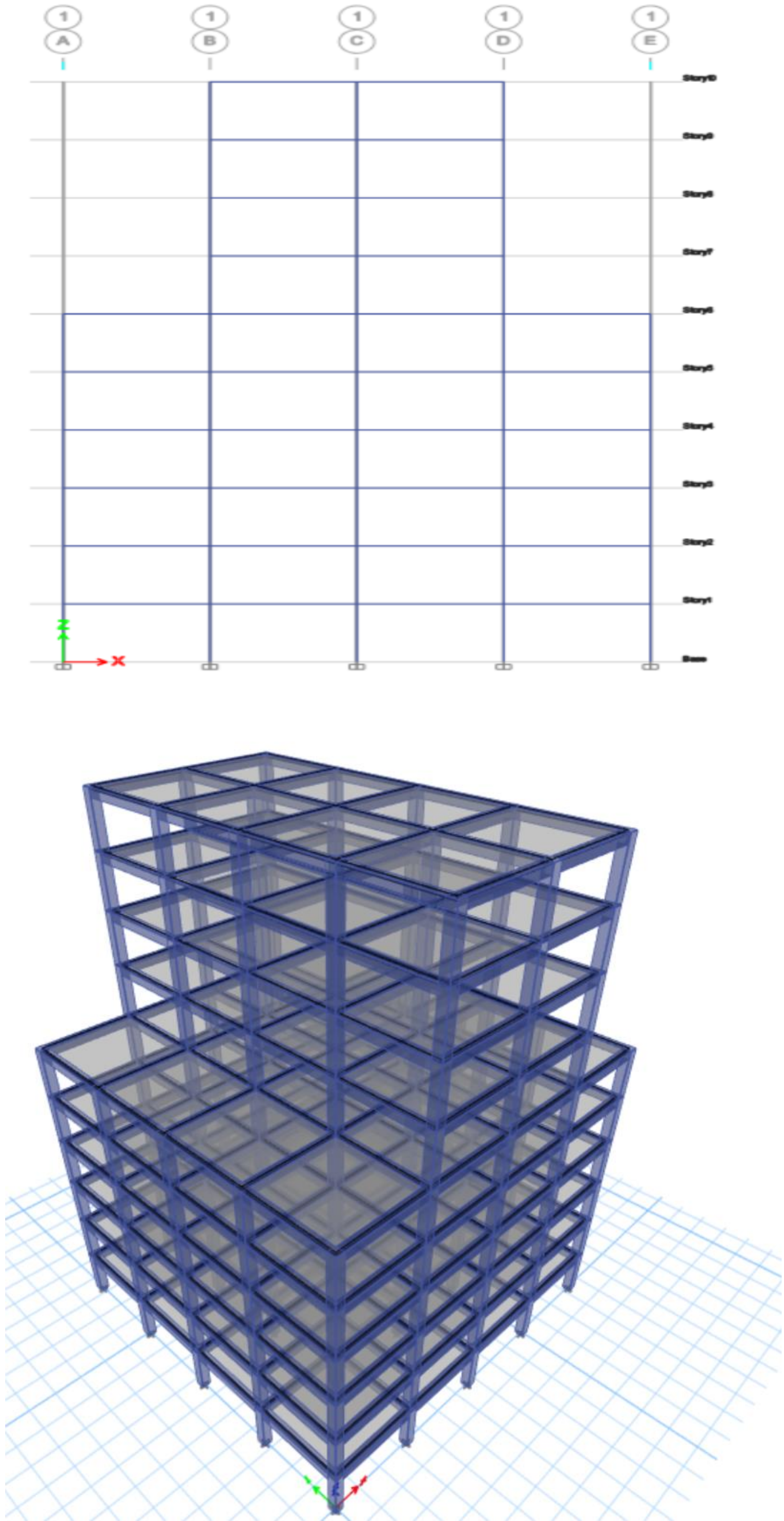


Fig 4.5 elevation and 3D view of vertical geometric irregularity model (S_2)

Table 4.4 Response of S_2 model

Seismic response parameter	Value	Limit
Max storey displacement	39.45 mm	120 mm
Max Storey drift	0.001582 (storey 3)	0.004
PG limit	A = 5 L = 20	A > 0.125L
Remark	Vertical Irregular Structure	

4.2 COMPARISON OF THE RESPONSES OF ALL MODELS AS DERIVED

The outputs of the models are illustrated in either tabular or graphical format.

4.2.1 Base Shear

The base shear reaches its maximum value in the vertical geometry irregularity model (S_2), while its minimum value is observed in the plan geometry irregularity model (L_2). The base shear values for the (L_1) and (S_1) models exceed those of the regular model.

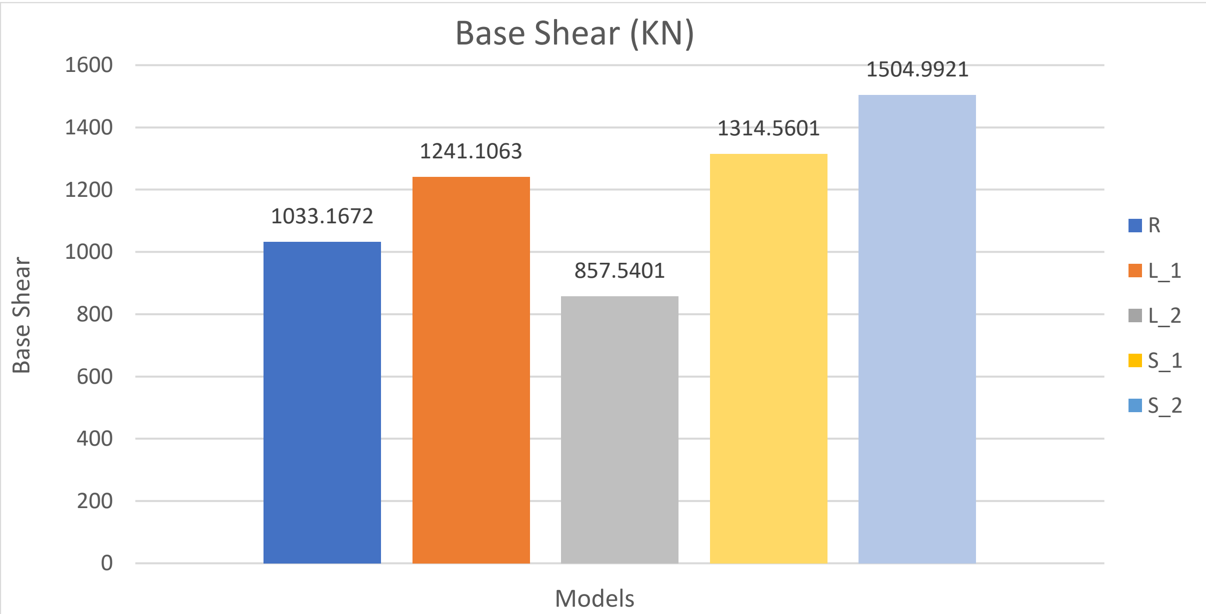


Fig 4.6 Base shear of models in x direction

Table 4.5 Base Shear

Building Model	R	L_1	L_2	S_1	S_2
Base Shear	1033.17	1241.1063	857.5401	1314.5601	1504.9921

4.2.2 Maximum storey displacement (mm)

According to Fig 4.7, the Regular model (R) demonstrates the best performance with an overall top storey displacement of 25.065 mm, On the other hand, the vertical irregular model (S_1) shows the poorest performance, recording a top storey displacement of 44.28 mm. However, all models meet the maximum displacement requirement, which is 0.004 times the storey height (equivalent to 120 mm for all models).

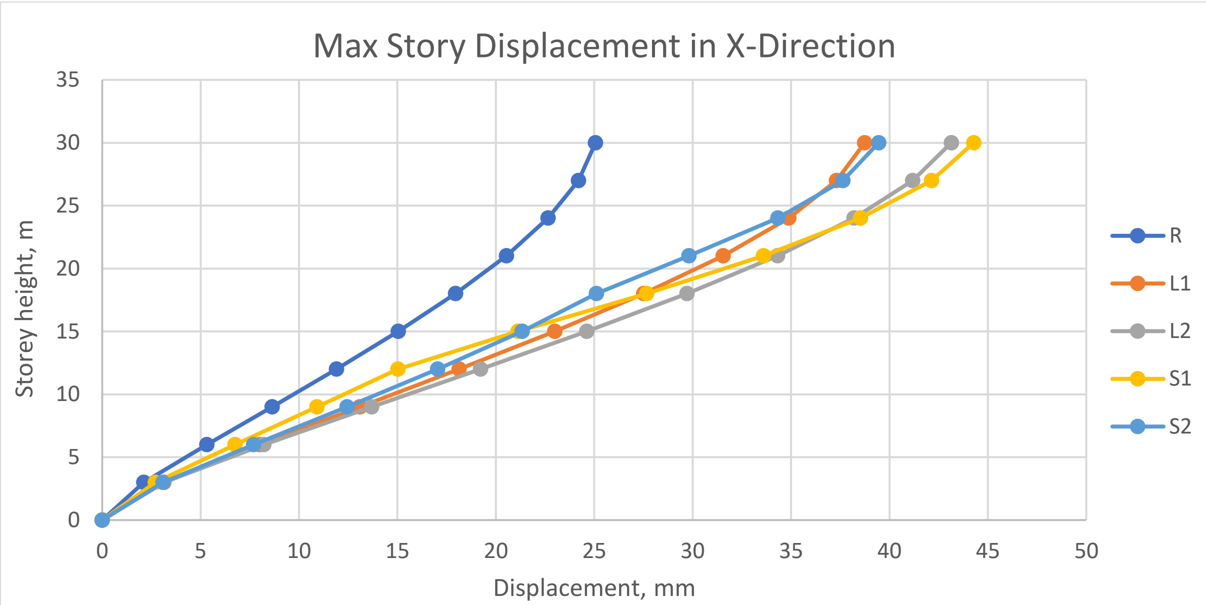


Fig 4.7 Maximum storey displacement in x direction

Table 4.6 Maximum Storey Displacement in X-direction

Storey	Elevation (m)	R (mm)	L_1 (mm)	L_2 (mm)	S_1 (mm)	S_2 (mm)
Base	0	0.000	0.000	0.000	0.000	0.000
Storey 1	3	2.118	3.138	3.113	3.653	3.079
Storey 2	6	5.315	8.001	8.208	9.163	7.679
Storey 3	9	8.630	13.091	13.693	14.856	12.445
Storey 4	12	11.90	18.136	19.221	20.456	17.043
Storey 5	15	15.037	22.994	24.616	26.278	21.332
Storey 6	18	17.952	27.521	29.710	31.825	25.114
Storey 7	21	20.535	31.548	34.311	36.744	29.813
Storey 8	24	22.661	34.881	38.205	40.777	34.332
Storey 9	27	24.197	37.314	41.179	43.660	37.628
Storey 10	30	25.065	38.744	43.142	45.258	39.450

4.2.3 Storey Drift

As depicted in Figure 4.7, the Regular model (R) shows the most favourable performance, recording an overall top storey displacement of 25.065 mm. Conversely, the vertical irregular model (S_1) displays the least desirable performance, registering a top storey displacement of 44.28 mm. Nevertheless, all models adhere to the maximum displacement constraint, which is 0.004 times the storey height (equivalent to 120 mm for all models).

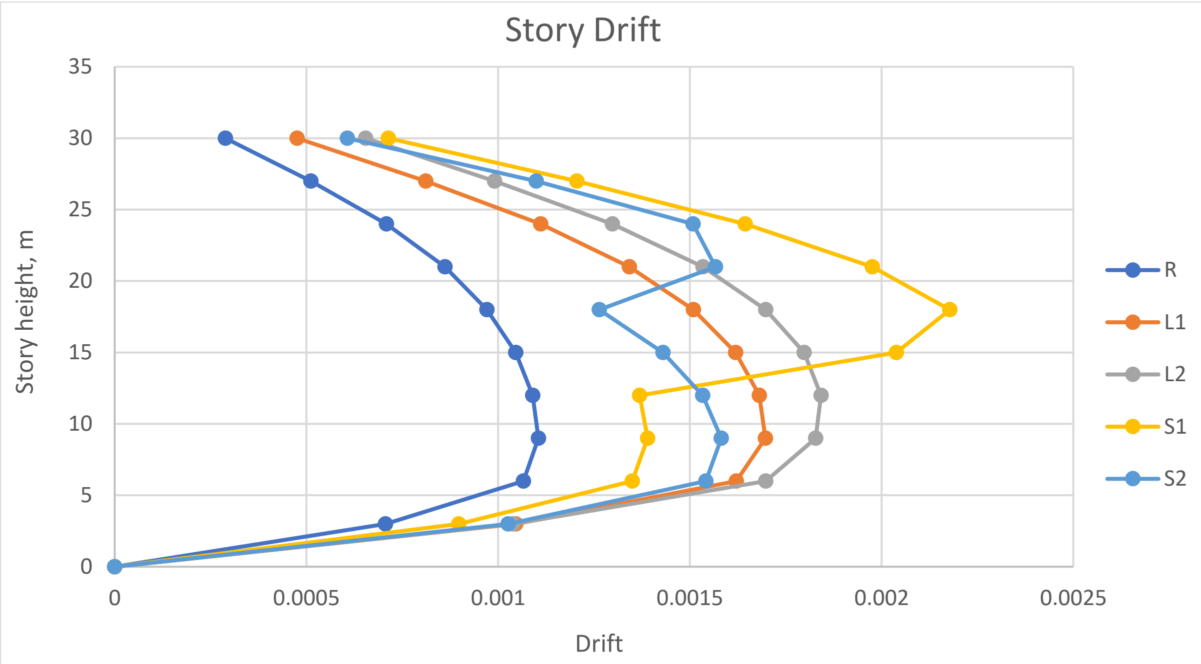


Fig 4.8 Storey Drift in x direction

Table 4.7 Storey Drift in X-direction

Storey	Elevation (m)	R	L_1	L_2 (mm)	S_1 (mm)	S_2 (mm)
Base	0	0.0	0.0	0.0	0.0	0.0
Storey 1	3	0.000706	0.001046	0.001038	0.000897	0.001026
Storey 2	6	0.001066	0.001621	0.001698	0.001350	0.001542
Storey 3	9	0.001105	0.001647	0.001828	0.001390	0.001582
Storey 4	12	0.001090	0.001681	0.001842	0.001369	0.001533
Storey 5	15	0.001046	0.001619	0.001798	0.002038	0.001430
Storey 6	18	0.000971	0.001509	0.001698	0.002178	0.001264
Storey 7	21	0.000861	0.001342	0.001534	0.001976	0.001567
Storey 8	24	0.000709	0.001111	0.001298	0.001644	0.001508
Storey 9	27	0.000512	0.000811	0.000991	0.001205	0.001099
Storey 10	30	0.000289	0.000476	0.000654	0.000714	0.000607

CHAPTER 5

CONCLUSION

- The findings from the analysis show that the Regular structure (R) demonstrates safety, as there are no occurrences of member failures under seismic load. Additionally, it displays the lowest levels of storey drift and displacement.

- The vertical geometric irregularity model (S_1) displays the greatest levels of both storey displacement and drift when compared to other models. This observation implies that (S_1) undergoes more significant vertical movements and lateral shifts, indicating potentially greater vulnerability or structural challenges.

- The plan geometric irregularity model (L_2) demonstrates a storey displacement increase of 11.34% compare to model (L_1), indicating a rise in structural vulnerability attributed to the increased irregularity.

- The vertical geometric irregularity model (S_1) demonstrates a storey displacement increase of 14.72% compare to model (S_2), indicating a rise in structural vulnerability attributed to the change in location of irregularity.

- The outcomes emphasize the significant impact that irregularity magnitude and location have on the seismic behaviour of the buildings.

- The drift values of all models met the prescribed limit of 0.004H as specified in IS 1893 (Part 1): 2016.

- Irregularities in a structure can significantly affect its seismic behaviour and alter the building's performance.

FUTURE SCOPE OF WORK

For the purpose of future work, this study suggests the possibility of expanding its scope by incorporating a wider range of irregularities. Moreover, there is an opportunity to delve deeper into analysing methods aimed at enhancing the seismic performance of irregular structures. This could involve investigating various techniques, such as structural retrofitting or innovative design approaches, to mitigate the vulnerabilities posed by irregularities and improve overall structural resilience against seismic events.

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