ANALYSIS OF IRREGULAR STRUCTURE

A Thesis Submitted

In Partial Fulfilment of the Requirements for the

Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

VARUN GOYAL

(Roll No. 2K23/STE/18)

Under the Supervision of

Prof. NIRENDRA DEV

Professor, Civil Engineering Department

Delhi Technological University

Department of Civil Engineering

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Shahbad Daulatpur , Main Bawana Road,Delhi 110042

May, 2025

M.Tech (Structural Engineering)

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CANDIDTATE' S DECELARATION

I, **VARUN GOYAL** , (M.Tech Structural Engineering) student, having **Roll no:2K23/STE/18** hereby certify that the work which is being presented in the thesis entitled "**ANALYSIS OF IRREGULAR STRUCTURE**" in partial fulfilment of the requirements for the award of the Degree of **Master of Technology in Structural Engineering** , submitted in the **Department of Civil Engineering, Delhi Technological University** is an authentic record of my own work carried out during the period from August 2024 to May 2025 under supervision of Dr. Nirendra Dev, Professor, Department of Civil Engineering , Delhi Technological University , Delhi.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

Varun

(VARUN GOYAL)

This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

Nirendra Dev 30/05/2025

Signature of Supervisor **Signature of External Examiners**

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CERTIFICATE BY THE SUPERVISOR

Certified that VARUN GOYAL (2K23/STE/18) has carried out his research work presented in this thesis entitled "**ANALYSIS OF IRREGULAR STRUCTURE**" for the award of **Master of Technology in Structural Engineering** from the Department of Civil Engineering, Delhi Technological University, Delhi, under our supervision. The thesis embodies the results of original work and studies are carried out by the student himself. The contents of the thesis do not form the basis for the award of any degree to the candidate or to anybody else from this or any other University/Institution.

Nirendra Dev
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ABSTRACT

Structures possess irregular characteristics—either of form, mass, stiffness, or strength—mainly to fulfil functional needs or aesthetics. While being common practice in modern construction, these can have a significant impact on the behaviour of a building under earthquake loads. Experience has shown that structures with irregular plans or elevations tend to get damaged or collapse. For this reason, structural irregularities are a significant concern in earthquake regions.

Design of a building is making deliberate choices regarding where and how to use such irregularities since they have a direct impact on the building's stability. IS 1893 (Part 1): 2016 states that irregularities must be avoided wherever possible through proper planning of architectural and structural arrangement. In fact, in actuality, there is no building that is entirely regular. Irregularities tend to be unavoidable in the context of actual design limitations and demands of urban development.

The aim of this research is to examine how various irregular building forms resist seismic loads through the use of STAAD Pro software. The research begins by modelling a G+3 storey reinforced concrete L-shaped frame and then extending other models of other various different irregular forms. Through the use of the Response Spectrum Analysis approach, the models are loaded with earthquake loading to see how they perform against each other. The aim is to identify which of the forms is most resistant to seismic loads and which is most susceptible.

ACKNOWLEDGEMENT

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VARUN GOYAL
(2K23/STE/18)

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ABBREVIATIONS

M-1 = Model 1 (L shape with plan geometric irregularity)

M-2 = Model 2 (T shape model with plan geometric irregularity)

M-3 = Model 3 (irregular model with vertical geometric irregularity)

M-4 = Model 4(irregular model with asymmetric plan)

RSA=Response Spectrum Analysis

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Seismic force-resistant design can also be termed as lateral force resistance systems. The collapse initiation in a building usually starts from structural weak areas. The weak areas tend to become structural weaknesses, which eventually lead to failure. Architectural irregularities are primarily responsible for the creation of such vulnerabilities. Buildings with regular plan configuration and similar strength, weight, and stiffness in plan and elevation have, to a large extent, experienced very little damage in earthquakes, compared to irregularly configured buildings.

Irregularities may occur structurally by means of either plan or vertical deviations in accordance with changes in the distribution of strength, stiffness, or mass along the floor plan or elevation. A floor is considered to have mass irregularity if its seismic weight is more than 150% of the seismic weight of the floor below, as per IS 1893 (Part 1): 2016. If the lateral stiffness of a given floor is less than the floor above, the condition is termed a stiffness irregularity, or a soft storey. Likewise, if the lateral strength of a floor is less than the floor above, it is termed a strength irregularity, or a weak storey. In reality, absolute regularity is an idealization only, since actual structures always have irregularities due to an incalculable number of variables. The majority of existing buildings have irregularities due to functional and aesthetic purposes. Some structures have been specifically designed with irregularities in order to meet certain requirements. Additionally, variations in the use of a given storey with regard to the immediately superior storey can also lead to the possibility of irregularities. Additionally, most structures unintentionally acquire irregularities during construction, owing to variations in construction practice and changes in the quality of raw materials utilized.

After analysing different seismic codes, it is clear that they all suggest the same parameters for the identification of irregularities in size but mostly neglecting the exact location of such irregularities. But the character, location, and size of building design irregularities are important issues. Proper decision-making in this respect can increase the utility and aesthetic value of the buildings.

Irregular buildings are mostly preferred for their functional and aesthetic benefits. Even though historical evidence of earthquakes reports their adverse seismic performance, it is mostly by design that building irregularities occur. It is hence necessary to intentionally choose and place such irregularities in such a way that it will not deteriorate the overall behaviour of the building.

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

<table>
<tr><th colspan="2">TYPES OF IRREGULARITIES</th></tr>
<tr><th>PLAN IRREGULARITIES</th><th>VERTICAL IRREGULARITIES</th></tr>
<tr><td>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.

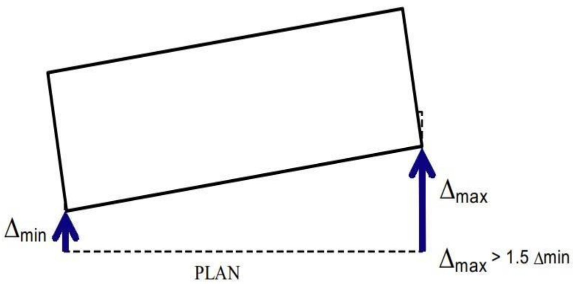
2. Re-entrant irregularity
This describes a situation where a section of a building or structure protrudes inward, causing an irregularity in its geometric layout, which may result in localized stress concentrations or uneven distribution of forces during seismic events.</td><td>1. Stiffness irregularity
Soft-storey is a storey whose lateral stiffness is less than that of the storey 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 Storey, it refers to a level in a building where the lateral strength is inferior to that of the Storey situated above it</td></tr>
</table>

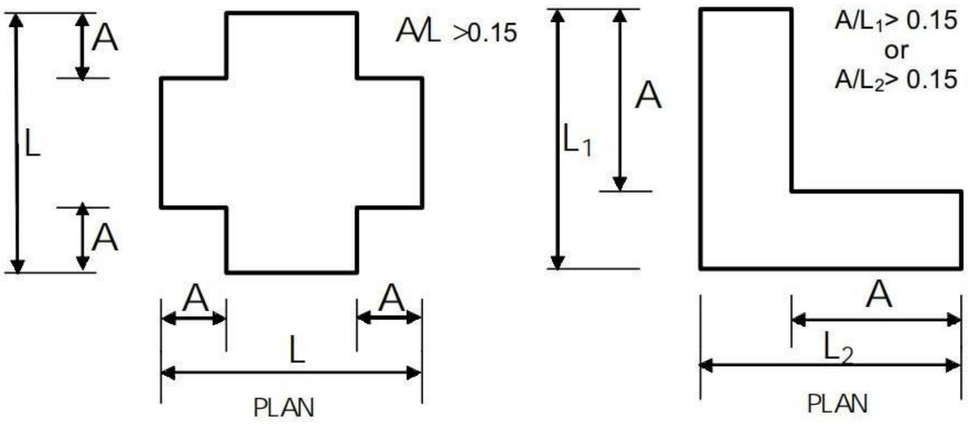
Fig. 1 (b) illustrates this condition and type of irregularity. 3. Floor slabs having excessive cut outs or openings. 4. Out-of-plane offsets in vertical elements. 5. Floor slabs having excessive cut outs or openings	4. Vertical geometric irregularity 5. In plane discontinuity in vertical elements resisting lateral force 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

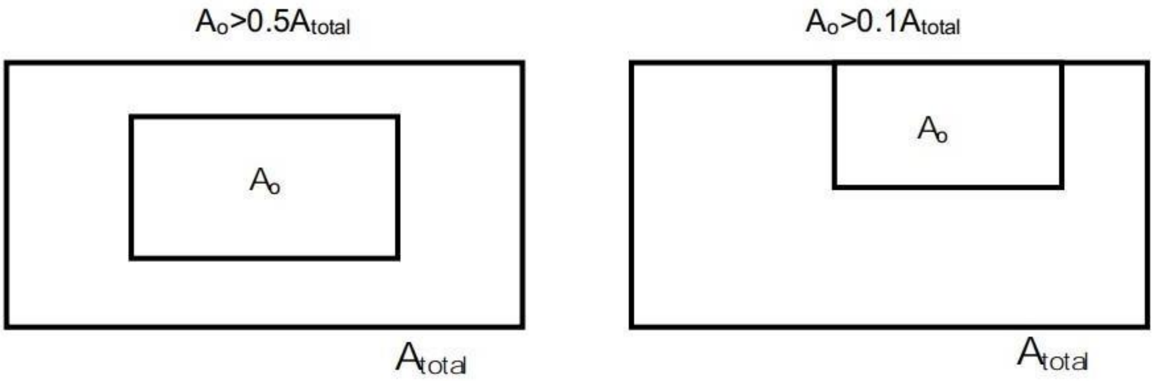
Irregularity	Type	Limits
Mass	Vertical Irregularity	Mi+1 > 1.5 Mi
Stiffness	Vertical Irregularity	Si < Si+1
Torsion	Plan Irregularity	□max/□avg=1.5 to 2.0 >2.0 extreme irregularity
Vertical Geometry	Vertical Irregularity	L2 > 1.25L1



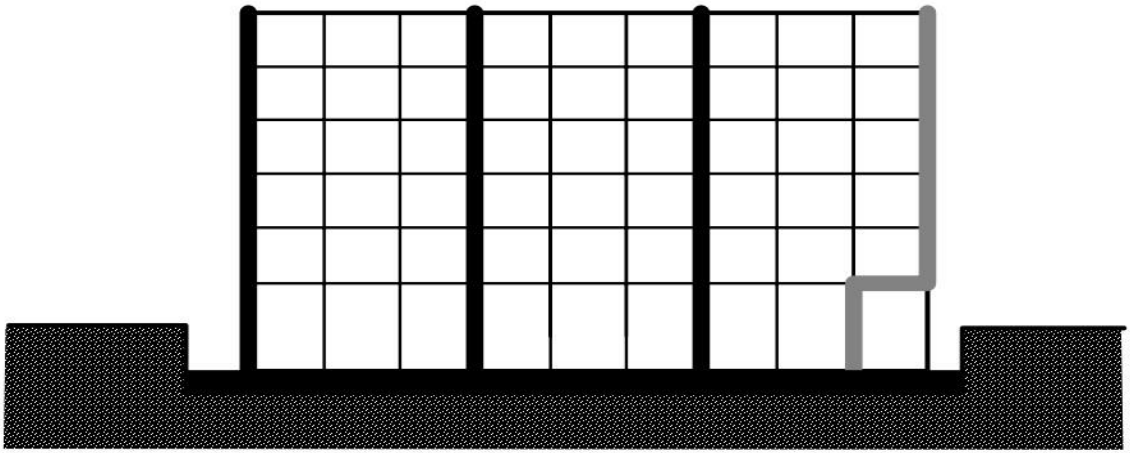
(a) Torsional Irregularity



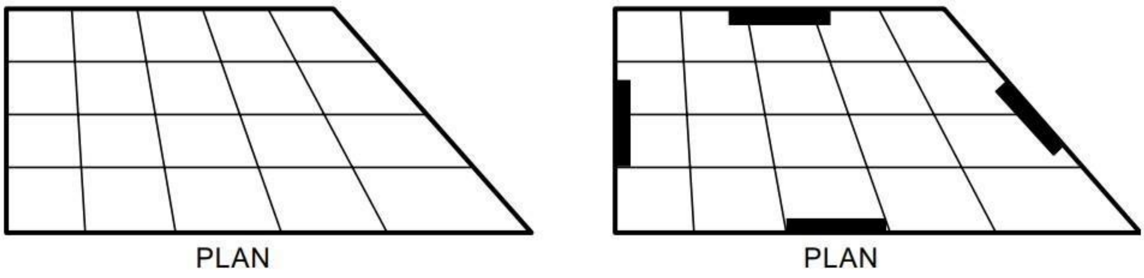
(b) Re-entrant Corners



(c) Excessive cut-out or opening

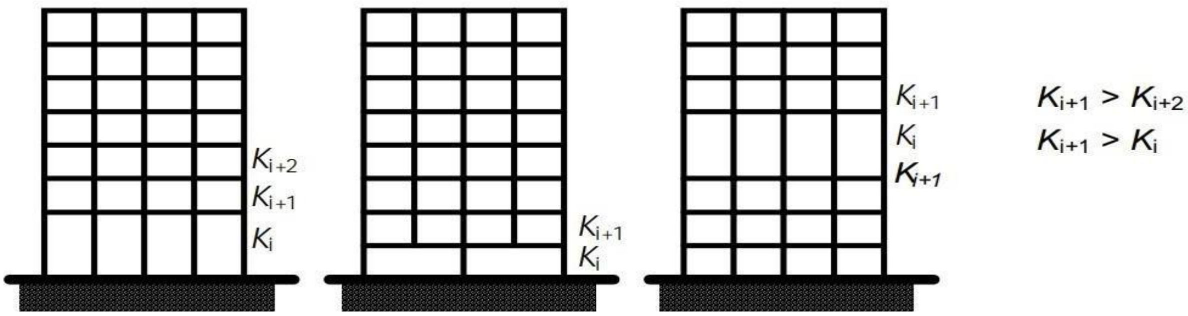


(d) Out of plane offset

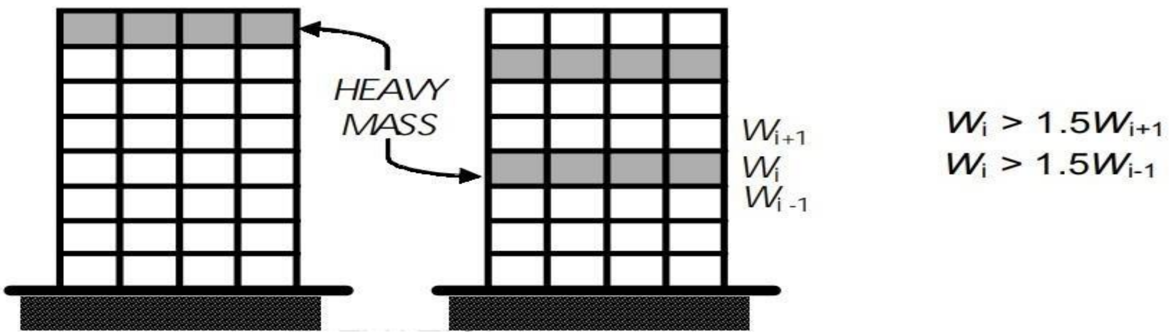


(e) Non parallel lateral force system

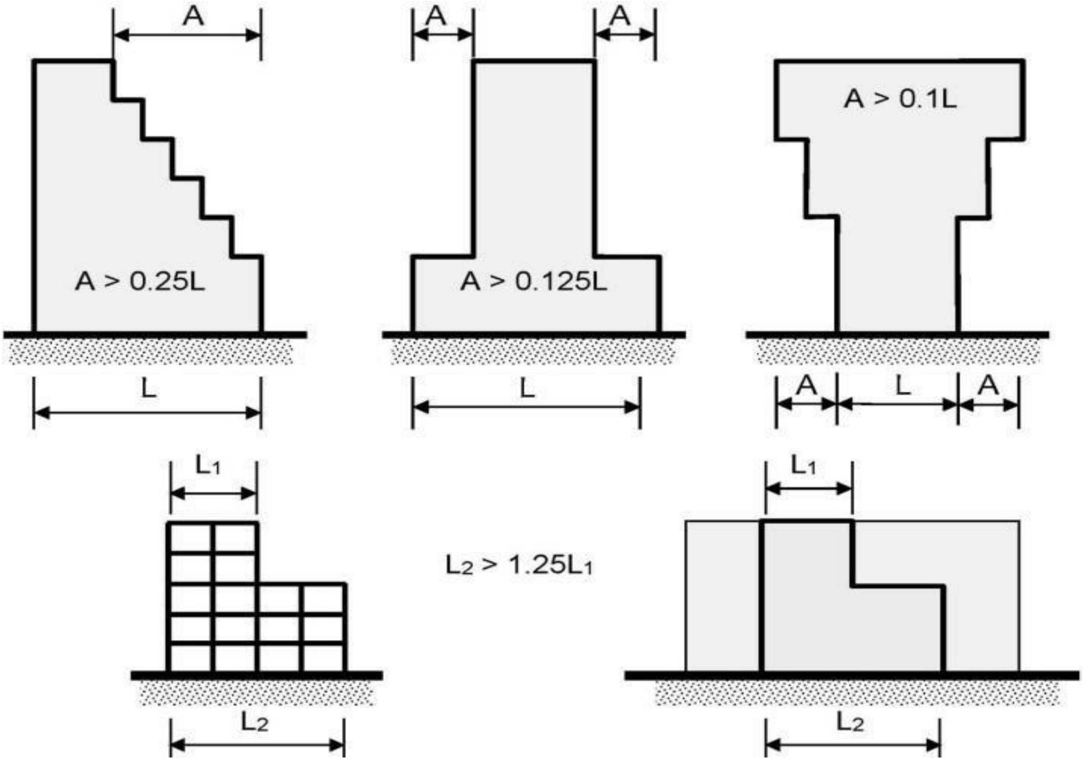
Fig 1.1 Irregular Buildings (Plan Irregularity)



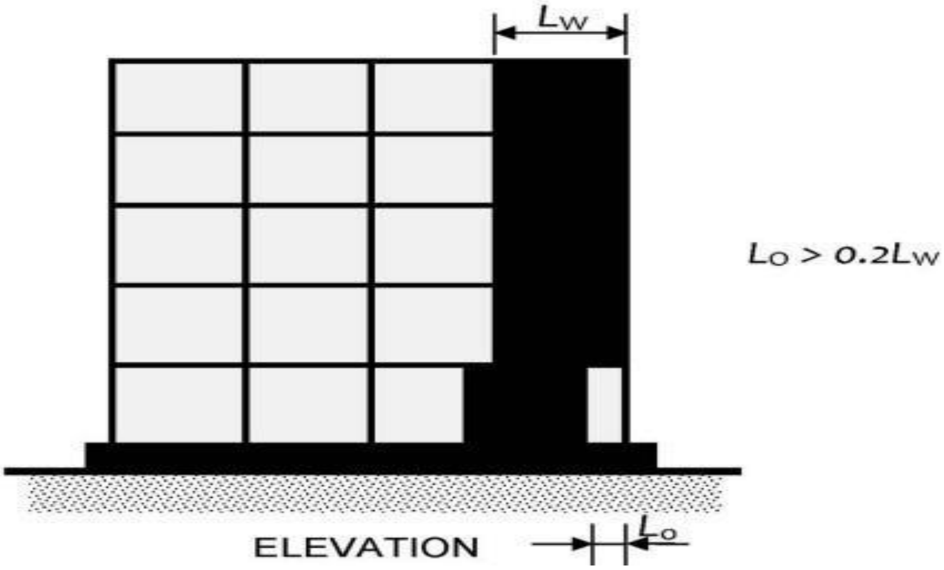
(a) Stiffness Irregularity (Soft storey)



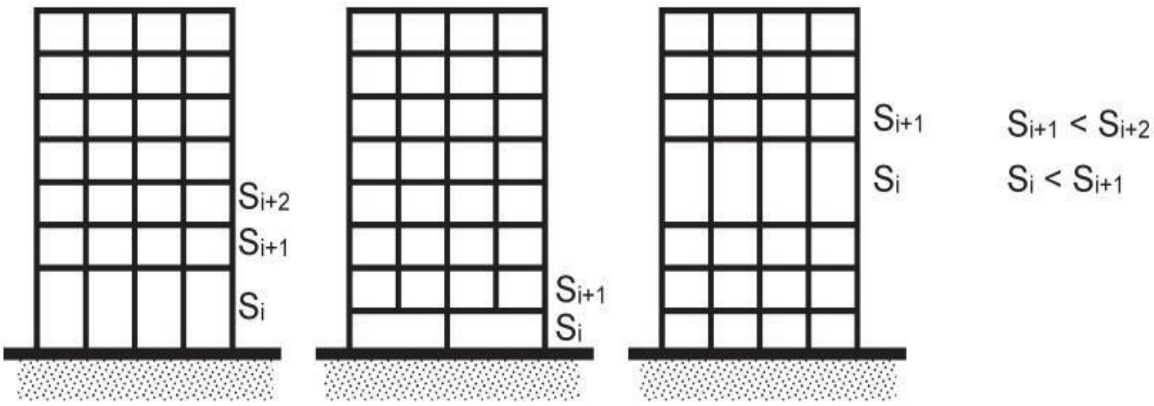
(b) Mass Irregularity



(c) Vertical Geometry Irregularity



(d) In Plane Discontinuity



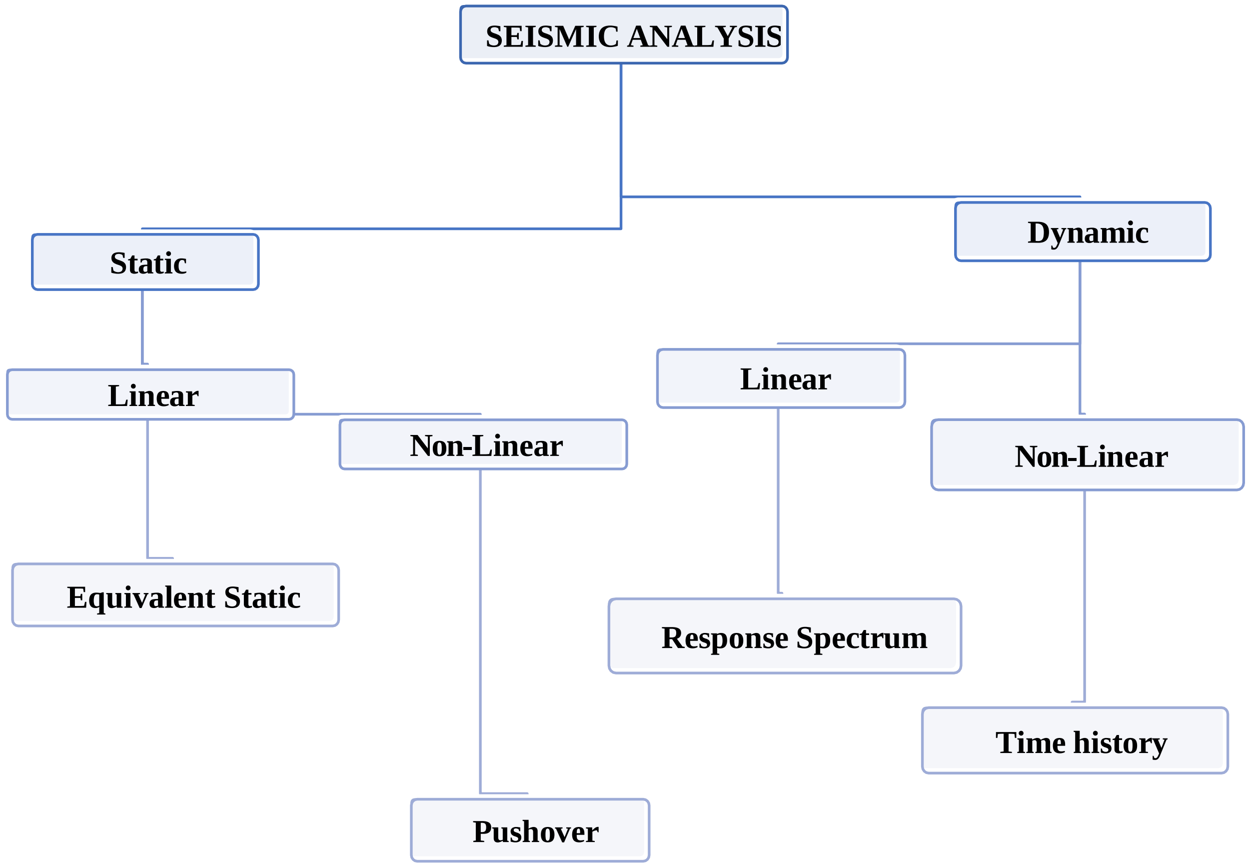
(e) Strength Irregularity (Weak Storey)

Fig 1.2 Irregular Building (Vertical Irregularity)

1.3 METHODS OF SEISMIC ANALYSIS

Seismic response shown by the building structure largely depends on the seismic analysis technique utilized. In the past, the analysis techniques were largely based on the linear static technique because of its ease of application, lack of complexity in computation, and simplicity of interpretation. Although these techniques provided designs that were considered safe, they were eventually found to be excessively conservative.

The development of advanced computing systems and analysis programs allowed scientists to simulate real seismic activity in computer models, which gave a higher degree of authenticity of seismic responses. These kinds of methods are known as dynamic analysis. Static and dynamic analyses are then classified as linear and nonlinear methods on the basis of force-deformation behaviour of structural members. Structural irregularities are incorporated and influence the dynamic response through altering the fundamental period and modifying the mode shapes.



1.3.1 Equivalent Lateral Force Method

Seismic analysis is usually performed under the assumption that the lateral forces are the true load conditions. As per IS 1893 (Part 1): 2016, the linear static method is sufficient for regular structures with a height of 15 meters or less for seismic zone II, and regular structures with an approximate estimate of the fundamental period Ta of 0.4 seconds or less. The method requires less computational effort since it does not require the analysis of higher modes' periods and configurations. The calculation of base shear includes, first, the calculation of the structure's mass, its fundamental period, and its configuration in terms of the relevant code. The base shear is then distributed over the structure's height in terms of lateral forces.

1.3.2 Response Spectrum Analysis (RSA)

This method is recommended for such models where structural response from high vibrational modes is considerable. It is usually used to study dynamic response in asymmetrical structures or structures with discontinuity in linear behavior. It can, in specific, be used to study the forces and displacements experienced by high-rise structures when subjected to ground vibrations of moderate amplitude, resulting in predominantly linear structural responses of large magnitude.

This technique calculates the response of independent natural vibration modes with a particular damping mode included. These modal responses may be combined to calculate the overall response of the structure. According to IS 1893 – 2016 (Part 1), this technique is to be applied to all buildings except regular structures not exceeding 15 m in seismic zone II.

1.3.3 Pushover Analysis (PoA)

Pushover analysis is a static analysis technique that combines non-linear behavior in the structure and thus enables inelastic response analysis. The technique gives information on structural ductility, deformation, strength, and demand distribution. It also determines possible weaknesses in the structure and helps in determining the critical elements most likely to reach their limit states. Determination of the critical elements enables engineers to improve the design and detailing procedures at the initial design stage. In existing structures, pushover analysis can be utilized for seismic retrofitting to meet existing standards or to improve seismic resistance capacity deficiencies. The technique is, however, limited to some extent due to the fact that it does not account for changes in loading patterns, higher vibration modes, or resonance effects. Pushover analysis is also not covered in the IS code.

The Capacity Spectrum Method (ATC-40) and the Displacement Coefficient Method (FEMA 356) are two popular methods of performing Pushover Analysis (PoA) of structures. During Pushover Analysis, the importance factor described in Table 8 of IS 1893 (Part 1): 2016 is not taken into account. Instead, the performance level of a structure is the same as the demands for the importance factor.

1.3.4 Time History Method

This technique may be used for both inelastic and elastic analysis. The most precise technique to describe the real seismic response of a structure is time history analysis, which is one of the non-linear dynamic techniques. Structural response over a series of time intervals is calculated as part of it. Because of the high computational efforts and the requirement that interpretive skills must be present, this technique is usually recommended for special structure design only.

1.4 EARTHQUAKE

An earthquake involves the sudden shaking of the Earth's surface due to the sudden release of energy within the Earth's crust. The release of energy is mainly caused by the dynamics of tectonic plates—gigantic bodies of rock that form the outer layer of the Earth. The plates are in perpetual motion, and as they collide or ride over one another in a haphazard manner, the stored stress is released as seismic waves traveling through the earth that cause the surface to vibrate.

1.4.1 Seismic Classification in India for assessment and control of earthquake risk

India has been classified into four seismic zones based on the intensity and frequency of earthquakes:

Zone 2: It is the zone of lowest seismicity. Earthquakes here are generally small, and seismic hazard is very low.

Zone 3: ZONES in this category experience a moderate level of seismic action. Seismic forces are stronger than in Zone 2 and cause a slightly higher zone factor.

Zone 4: This zone consists of areas having a higher likelihood of earthquake damage. It is defined by moderate intensity earthquakes and a corresponding increase in the zone factor.

Zone 5: The most seismically active zone in the country, Zone 5 has very strong earthquakes. The potential for damage is highest here, and the zone factor reflects the high seismicity.

1.5 OBJECTIVES OF THE STUDY

- To generate irregular configurations buildings through the plan, and elevation irregularities.
- Modelling the 3D models with STAAD PRO software and conducting Response Spectrum Analyses.
- To analyze and distinguish between various responses, such as Storey displacement, storey drift, and base shear.
- To comprehend the structural-behaviour under the application of lateral-loads i.e. on irregular structures.
- To determine the most vulnerable model among the candidate configurations.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Vaishali Sahu et al. (2022) This research evaluated the effect of shear wall position on seismic performance in a G+14 reinforced concrete plus-shaped building. Using STAAD Pro and P-delta analysis, results showed that shear wall position in the core improved stability by decreasing displacement, drift, and base shear. Of all the models evaluated, the closed-loop shear wall pattern was the best, and the unreinforced building was the worst in terms of efficiency in resisting seismic forces. Results highlight the necessity of placing shear walls in a reasonable way to improve earthquake resistance in irregular high-rise buildings.

Shelja Jain and Rahul Sathbhaiya et al. (2020) The study was intended to find out how the location of shear walls affects the seismic performance of an irregular, plus-shaped G+14 RCC building. Owing to the building's irregular plan, it is more prone to lateral forces during seismic activity. Various positions of shear walls at corners, exterior perimeters, and at the central core were analysed using STAAD. Pro and IS 1893:2002 codes. The results indicated that the irregular building is significantly improved with shear walls positioned strategically, especially in a central closed-loop position. Such an arrangement resulted in maximum improvement in structural stability through displacement, drift, and internal stress minimization. The poorest performance was exhibited by the irregular model without shear walls, which highlights the fact that shear walls should be positioned correctly to offset the adverse effects of irregularity in high-rise buildings subjected to seismic loading.

Pathan Irfan Khan et al. (2016) 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 Storey shear, Storey displacement, and Storey drift. The analysis findings reveal that buildings with mass irregularity displayed higher values of maximum Storey shear, Storey displacement, and Storey drift compared to both regular buildings and those with irregularities in vertical geometry. Moreover, a sudden change in Storey shear was observed at the setback level in the irregular building.

Lovneesh Sharma et al. (2019) The study was intended to dynamic seismic analysis of multi-storey RCC structures with different plan shapes—H, L, and O—and vertical mass irregularities introduced at selected floor levels. STAAD. Pro was utilized for response spectrum analysis for Zone V with V-type bracing to examine its effect on performance. Analysis indicated that irregular configurations, particularly L-shape constructions, are defined by greater lateral displacement and reduced seismic resistance with L-shape model recording a maximum displacement of 82.405 mm. Mass irregularity increased bending moment and shear force by 1.46 and 1.50 times respectively. Though the structure's response was varied, the cost was influenced very minimally by the variation of heavy mass's location overall. The study brought to the limelight that plan and vertical irregularities significantly contribute towards a building's seismic performance, and effective bracing and design techniques must be used to counter the latter in seismically active zones.

Jayakrishna et al. (2018) conducted comparative seismic analysis of regular and irregular G+7 RCC buildings using STAAD. Pro and the response spectrum method. The study tried to study the impact of plan irregularity on the performance of a structure under different seismic zones. The results indicated that the irregular models consistently yielded higher base shear, higher displacement, and higher storey drift—especially in high-seismic zones like Zone V. The findings confirmed that structural irregularity significantly affects the response of a building under earthquake loading and needs to be treated with caution during design to avoid performance shortcomings.

Puppala Sesha Pavani et al. (2020) Seismic response of G+10 RCC buildings with vertical irregularity was examined by STAAD. Pro and Time History Analysis. Research revealed vertical irregularities—soft stories and mass discontinuities—result in non-uniform stiffness distribution, resulting in increased deformation and instability under dynamic loads. By comparing regular and irregular models, the research concluded that vertically irregular buildings experience higher responses, particularly at transition floors. The authors emphasized careful design and detailing of vertically irregular buildings to ensure seismic resilience.

Verma et al. (2023) Seismic performance of irregular G+10 multi-storey buildings was investigated using STAAD. Pro for three different irregular configurations. The results showed that building plan irregularity yields higher storey drift, base shear, and torsion responses, particularly in seismic Zone IV. Maximum behaviour was found in L-shaped and H-shaped models, which showed that plan and elevation irregularities both negatively impact seismic performance. The study finally concluded that such irregularities necessitate the application of advanced modelling and design techniques to improve safety and structural efficiency against lateral loads.

Rajendra Kumar et al. (2017) A comparative analysis was conducted between regular and irregular G+10 RCC buildings using equivalent static and response spectrum analysis methods in the STAAD.Pro software. The outcome showed that irregular configurations had higher Storey drifts and lateral displacements under all seismic zones, especially following response spectrum analysis. In addition, the irregular buildings were more sensitive to seismic responses caused by the irregular mass and stiffness distribution, resulting in higher seismic responses. The research finally concluded that structural irregularities reduce performance drastically under seismic loading and should be checked carefully by dynamic analysis methods.

Mahesh et al. (2014) Seismic performance of regular and irregular G+11 structures was investigated in this study using ETABS and STAAD.Pro, taking various seismic zones and soils into account. The results showed that irregular plans experience higher Storey drifts, non-symmetric base shear, and instability, particularly in soft soil. Irregularity caused eccentricity and disturbed load paths and therefore enhanced seismic vulnerability. The study highlighted the requirement of accurate modelling and proper structural layout in order to achieve safety and performance under seismic zones.

Karma Tempa et al. (2019) A 3D seismic analysis was conducted on several irregular building shapes in Bhutan using STAAD.Pro. Four types of irregular configurations—winged plans, split elevations, L-shaped buildings, and twin buildings—were analyzed under dynamic loading conditions. The findings showed that irregular shapes play a significant role in the modification of load paths and the enhancement of structural response, particularly in the case of storey drift and base shear. The research demonstrated that under functional and architectural limitations, as common as irregular structures are, they need to undergo extensive dynamic analysis to confirm stability in areas with high seismicity such as Bhutan.

2.2 RESEARCH GAP

- Most of the research effort is focused on regular structures since they offer more convenience in modelling and analysis; irregular buildings—although common in real design practice—are not yet as widely studied due to their complex behaviour to lateral loads.
- The literature available generally talks about one type of irregularity and does not have comparative studies on different irregular geometries through a software like STAAD Pro.
- Therefore, very little is known about how different irregular configurations affect primary structural responses, including displacement, storey drift, and base shear—highlighting the need for a comprehensive comparison that this study seeks to provide.

CHAPTER 3

METHODOLOGY

3.1 DEFINITION OF BUILDING MODELS

The current work takes an irregular G+3 building model as a reference model for comparison. In addition, diversified models with diversified types of irregularities are also analyzed. A concise description of these irregularities is as follows.

3.1.1 Plan geometric irregularity Model (PG)

According to Is 1893: 2016 a building is considered to possess geometric irregularity if;

A/L1 > 0.15

A/L2 > 0.15

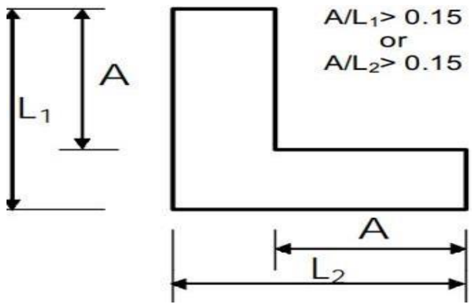


Fig 3.1 Plan geometry irregularity

3.1.2 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

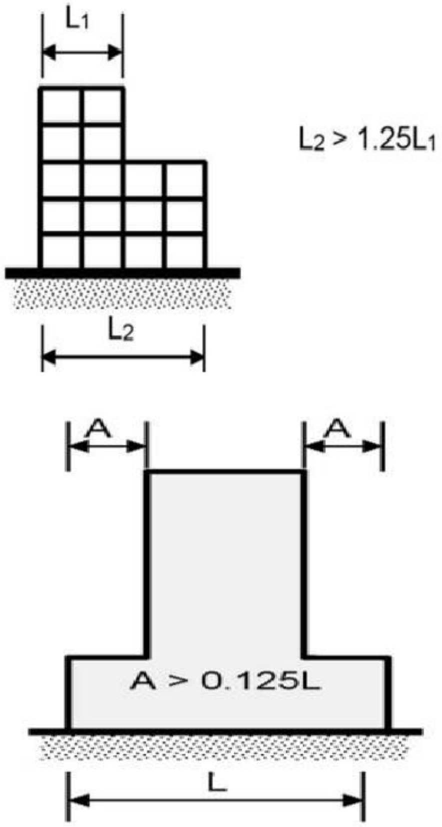


Fig 3.2 Vertical geometry irregularity

3.2 CODES AND STANDARDS

- The modelling and analysis are carried out in STAAD PRO.
- The structure properties are designed and detailed as per IS 456:2000
- 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

Structural modelling was done with the help of STAAD Pro, a structural analysis and design program, which was offered by Bentley Systems. Model generation involved the assignment of building geometry, assignment of material properties, specification of cross-sections, application of support conditions, and the generation of correct load cases. As this study includes Response Spectrum

Analysis, the following steps involved the definition of the response spectrum function in terms of seismic parameters and the definition of the associated dynamic load case according to IS 1893:2016.

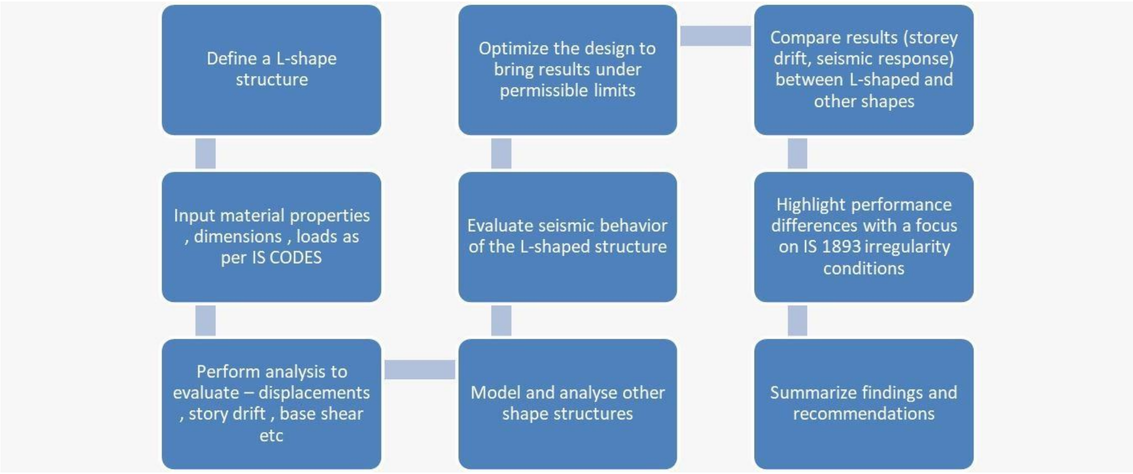


Fig 3.3 Flowchart of Methodology used

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	III
Importance Factor	1.5
Damping Ratio	0.05
Soil Type	II (Medium)
Response Reduction factor I	5
Importance Factor (I)	1
Type of support	Fixed
Method of seismic analysis	Response Spectrum analysis
Geometric parameters	
No storey	G+3 (4)
Storey height	3.3m
Over all height of the building	13.2m

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	3.0
Roof Load	1.5
Wall Load	5.0

CHAPTER 4

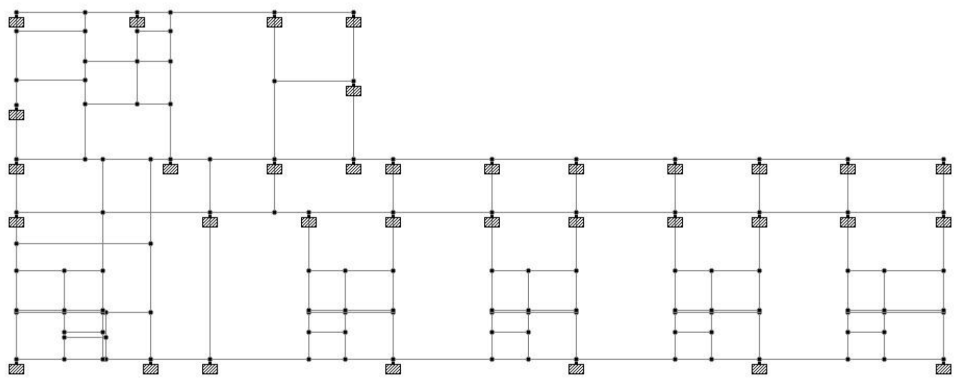
ANALYSIS and RESULTS

4.1 RESPONSE SPECTRUM ANALYSIS

All the different models are seismically designed through Response Spectrum Analysis, as specified by the IS code in irregular structures. The model responses, as ascertained by RSA, are given and explained below:

4.1.1 Model 1 (M-1)

This is an L-shaped structure with plan irregularity because of the asymmetrical configuration. This type of geometry results in non-uniform seismic response and augmented torsional effects during earthquake excitation. This structure is considered as a base structure so that rest of all other irregular models will be compared to it.



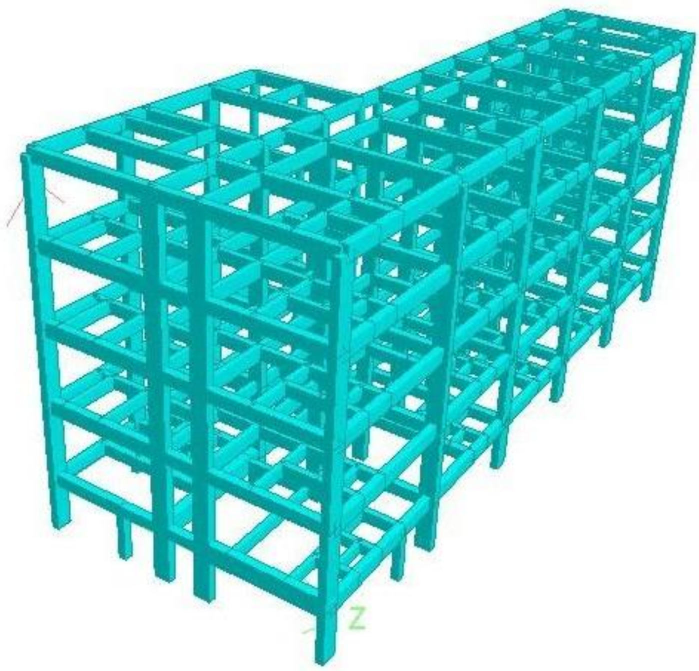


Fig 4.1 Plan and 3D view of M-1

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.3818	0.3552	L / 1454	L / 1563	PASS	PASS
2	7.05	0.2772	0.2804	L / 1191	L / 1177	PASS	PASS
3	10.35	0.2050	0.2184	L / 1610	L / 1512	PASS	PASS
4	13.65	0.1085	0.1320	L / 3042	L / 2500	PASS	PASS

Fig 4.2 Storey drift EQX of M-1

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.3748	0.3546	L / 1481	L / 1565	PASS	PASS
2	7.05	0.2737	0.2780	L / 1206	L / 1188	PASS	PASS
3	10.35	0.1964	0.2215	L / 1680	L / 1490	PASS	PASS
4	13.65	0.0978	0.1415	L / 3375	L / 2333	PASS	PASS

Fig 4.3 Storey drift EQZ of M-1

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	435	321 (DL+0.25	**19.353**	-1.922	9.131	21.485	0.000	0.000	-0.001
Min X	453	325 (DL+0.25	**-20.898**	-2.317	-1.005	21.050	-0.000	-0.000	-0.000
Max Y	267	345 (DL+ELZ	5.304	**0.524**	15.956	16.823	0.001	0.000	0.001
Min Y	389	320 (DL+LL+	-0.611	**-16.081**	1.625	16.174	0.001	-0.000	-0.003
Max Z	448	329 (DL+0.25	7.385	-2.009	**29.206**	30.192	0.002	-0.000	0.000
Min Z	432	349 (DL-ELZ-	-7.703	-3.068	**-18.109**	19.916	-0.001	-0.001	0.001
Max rX	164	320 (DL+LL+	0.348	-2.638	0.451	2.699	**0.006**	-0.000	-0.000
Min rX	371	320 (DL+LL+	-1.045	-5.750	1.623	6.065	**-0.006**	-0.000	-0.000
Max rY	510	345 (DL+ELZ	7.678	-5.162	21.695	23.585	0.000	**0.001**	0.001
Min rY	434	333 (DL+0.25	-7.740	-1.193	-16.700	18.445	-0.000	**-0.001**	-0.000
Max rZ	223	329 (DL+0.25	3.003	-6.714	7.752	10.686	0.001	0.000	**0.003**
Min rZ	230	320 (DL+LL+	0.150	-2.110	0.298	2.136	0.000	-0.000	**-0.005**
Max Rst	479	329 (DL+0.25	6.852	-4.948	29.187	**30.386**	0.000	0.000	0.000

Fig 4.4 Storey displacement of M-1

```
                                    ---------------------------
TOTAL SRSS  SHEAR     112.09      0.00      0.00
TOTAL 10PCT SHEAR     156.44      0.00      0.00
TOTAL ABS   SHEAR     214.28      0.00      0.00
TOTAL CSM   SHEAR     213.71      0.00      0.00
TOTAL CQC   SHEAR     155.31      0.00      0.00
```

```
**********************************************************
* UNITS - MTON  METE                                     *
* TIME PERIOD FOR X 1893 LOADING =    0.58446 SEC        *
* SA/G PER 1893=    2.327, LOAD FACTOR= 1.000            *
*      FACTOR V  PER 1893=    0.0558 X   2781.10         *
*                                                        *
**********************************************************
```

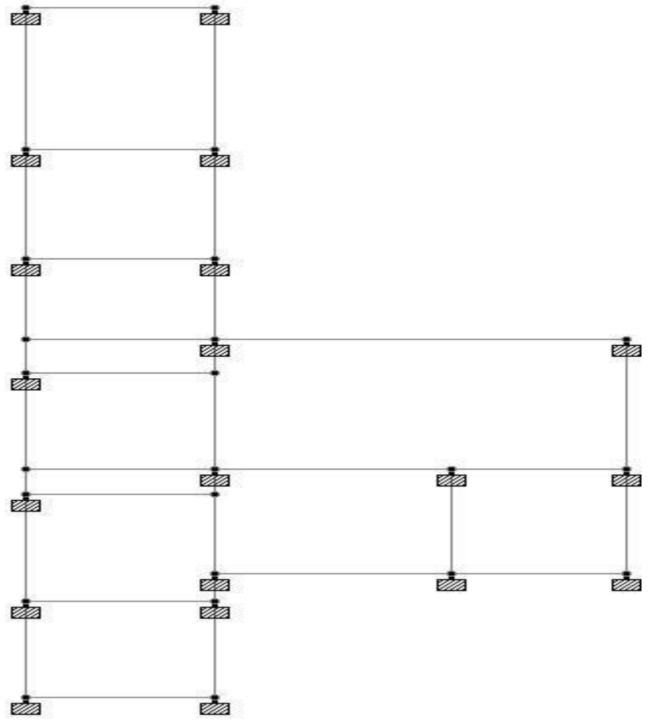
Fig 4.5 Base Shear of M-1

Table 4.1 Response of M-1

Seismic response parameter	**Value**	**Limit**
Max storey displacement	29.206mm	NA
Max Storey drift	3.818mm	0.015 (0.004*3.75)
Base Shear	155.31 metric ton	NA
Remark	L-Shaped Structure	

4.1.2 Model 2 (M-2)

Model 2 is a T-shaped building with plan irregularity by virtue of its asymmetrical plan. The irregular mass and stiffness distribution can result in torsional effects during an earthquake. These irregularities can influence the seismic performance of the building.



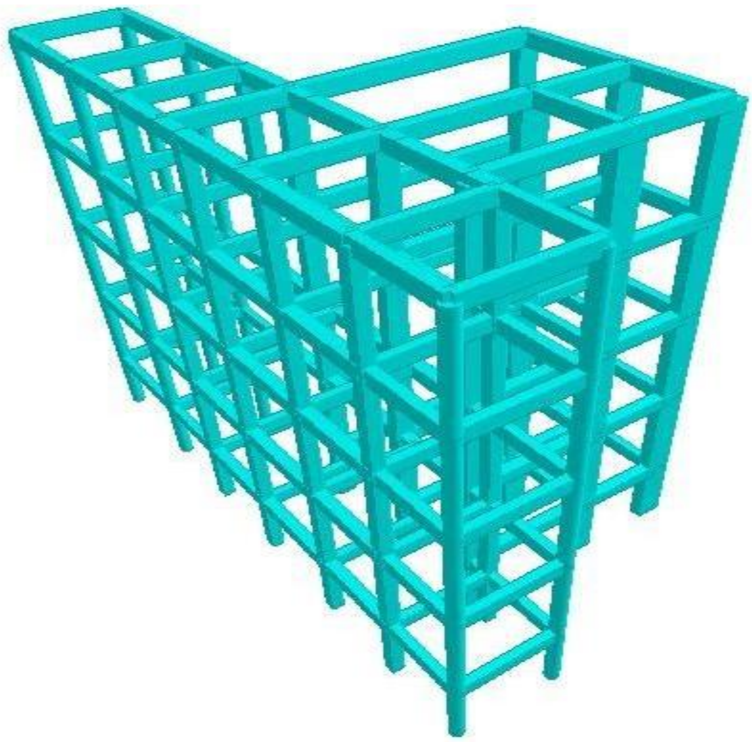


Fig 4.6 Plan and 3D view of M-2

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.2001	0.1389	L / 2774	L / 3997	PASS	PASS
2	7.05	0.1527	0.0945	L / 2161	L / 3491	PASS	PASS
3	10.35	0.1207	0.0735	L / 2734	L / 4493	PASS	PASS
4	13.65	0.0825	0.0567	L / 4002	L / 5823	PASS	PASS

Fig 4.7 Storey Drift EQX of M-2

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.1196	0.3109	L / 4639	L / 1785	PASS	PASS
2	7.05	0.0909	0.2163	L / 3630	L / 1526	PASS	PASS
3	10.35	0.0738	0.1630	L / 4474	L / 2025	PASS	PASS
4	13.65	0.0554	0.0944	L / 5955	L / 3498	PASS	PASS

Fig 4.8 Storey Drift EQZ of M-2

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	3108	337 (DL+ELX	25.805	-0.386	9.536	27.514	0.001	0.002	0.000
Min X	3119	325 (DL+0.25	-26.613	-1.462	-6.439	27.420	0.000	-0.002	-0.000
Max Y	3056	337 (DL+ELX	4.157	0.017	4.944	6.459	0.001	0.001	0.001
Min Y	3127	320 (DL+LL+	-0.706	-2.005	-0.538	2.193	-0.000	0.000	0.000
Max Z	3108	345 (DL+ELZ	11.051	-0.549	14.041	17.877	0.001	0.001	0.000
Min Z	3124	333 (DL+0.25	-5.450	-0.945	-15.225	16.198	-0.000	-0.001	-0.000
Max rX	3057	345 (DL+ELZ	2.043	-0.628	5.392	5.800	0.001	0.000	0.001
Min rX	3057	333 (DL+0.25	-2.322	-1.006	-5.642	6.184	-0.002	-0.000	-0.000
Max rY	3121	321 (DL+0.25	15.237	-1.015	5.594	16.263	0.000	0.002	0.000
Min rY	3121	341 (DL-ELX-	-16.382	-1.497	-6.428	17.662	-0.000	-0.002	-0.000
Max rZ	4042	321 (DL+0.25	2.975	-0.497	2.990	4.247	0.001	0.000	0.001
Min rZ	4042	341 (DL-ELX-	-3.141	-0.726	-3.065	4.449	-0.001	-0.000	-0.001
Max Rst	3108	325 (DL+0.25	-26.611	-1.413	-10.225	28.543	0.000	-0.002	-0.001

Fig 4.9 Displacement of M-2

```
TOTAL SRSS   SHEAR     35.32     0.00     0.00
TOTAL 10PCT SHEAR     36.80     0.00     0.00
TOTAL ABS    SHEAR     66.43     0.00     0.00
TOTAL CSM    SHEAR     48.05     0.00     0.00
TOTAL CQC    SHEAR     38.84     0.00     0.00
```

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* UNITS - MTON  METE                                     *
* TIME PERIOD FOR X 1893 LOADING =    0.58446 SEC        *
* SA/G PER 1893=    2.327, LOAD FACTOR= 1.000            *
*      FACTOR V  PER 1893=    0.0558 X    695.48         *
*                                                        *
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```

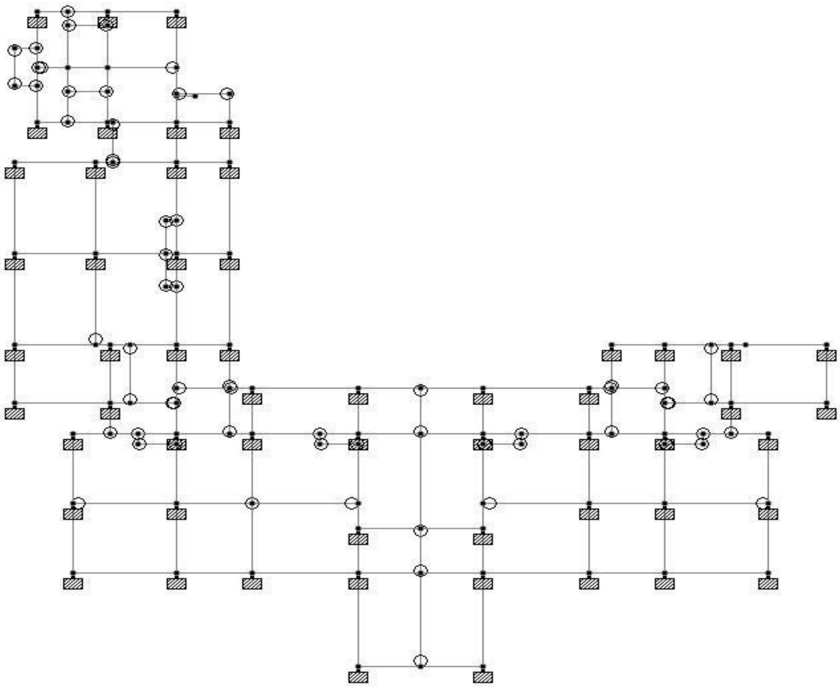
Fig 4.10 Base Shear of M-2

Table 4.2 Response of M-2

Seismic response parameter	Value	Limit
Max storey displacement	26.613 mm	NA
Max Storey drift	3.109 mm	0.015 (0.004*3.75)
Base Shear	38.84 metric ton	NA
Remark	T-Shaped Structure Model 2	

4.1.3 Model 3 (M-3)

Model 3 exhibits vertical irregularity through sharp transitions in stiffness or mass along its height. Such irregularity can lead to uneven distribution of forces between floors during earthquake, which may contribute to structural damage.



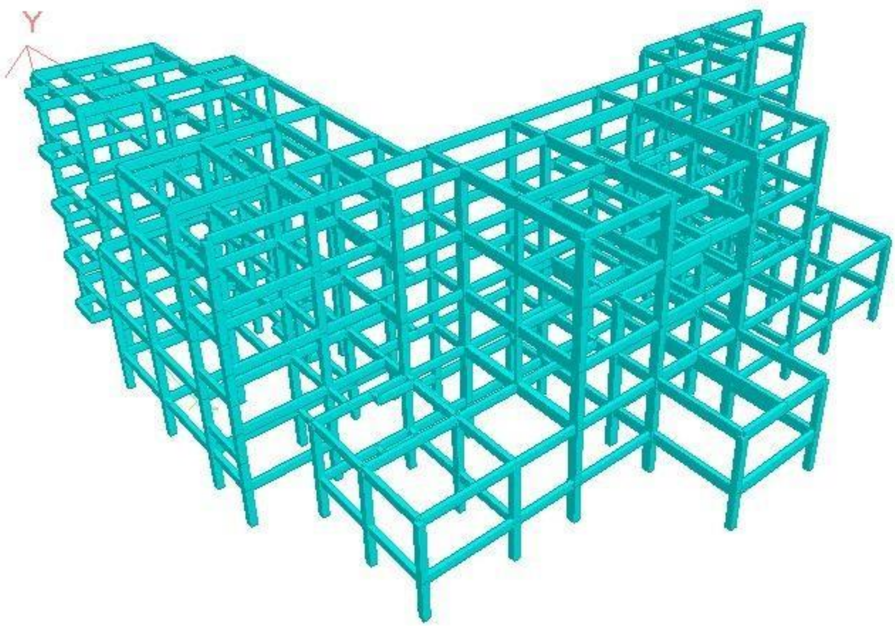


Fig 4.11 Elevation and 3D view of M-3

STORY DRIFT CHECK

STORY	HEIGHT (METE)	INTERSTORY DRIFT(CM) X	INTERSTORY DRIFT(CM) Z	RATIO X	RATIO Z	STATUS X	STATUS Z
BASE	-2.25						
1	3.30	0.3989	0.2649	L / 1391	L / 2095	PASS	PASS
2	6.60	0.2983	0.2172	L / 1107	L / 1519	PASS	PASS
3	9.90	0.2645	0.1635	L / 1248	L / 2019	PASS	PASS
4	13.20	0.1521	0.1082	L / 2170	L / 3049	PASS	PASS

Fig 4.12 Storey Drift EQX of M-3

STORY DRIFT CHECK

STORY	HEIGHT (METE)	INTERSTORY DRIFT(CM) X	INTERSTORY DRIFT(CM) Z	RATIO X	RATIO Z	STATUS X	STATUS Z
BASE	-2.25						
1	3.30	0.2812	0.3404	L / 1974	L / 1631	PASS	PASS
2	6.60	0.1880	0.2695	L / 1755	L / 1225	PASS	PASS
3	9.90	0.2081	0.2255	L / 1586	L / 1463	PASS	PASS
4	13.20	0.1057	0.1453	L / 3122	L / 2272	PASS	PASS

Fig 4.13 Storey Drift EQZ of M-3

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	350	51 DL+EQX	**17.222**	-2.396	1.216	17.430	0.000	0.000	0.001
Min X	282	54 DL+LL-EQ	**-17.710**	-2.164	-0.167	17.843	0.001	-0.000	-0.002
Max Y	175	51 DL+EQX	2.316	**0.559**	0.280	2.399	0.000	0.000	0.000
Min Y	347	50 DL+LL	-0.321	**-7.126**	0.213	7.137	0.000	0.000	-0.000
Max Z	346	57 DL+LL+EQ	12.537	-1.562	**19.378**	23.133	0.002	0.001	0.001
Min Z	346	56 DL-EQZ	-13.221	-1.824	**-19.057**	23.266	-0.001	-0.001	-0.001
Max rX	183	57 DL+LL+EQ	1.213	-0.427	9.810	9.894	**0.003**	0.000	-0.000
Min rX	179	58 DL+LL-EQ	-4.357	-1.479	-13.099	13.884	**-0.003**	-0.001	-0.001
Max rY	194	55 DL+EQZ	1.396	-0.186	5.675	5.847	0.001	**0.002**	-0.000
Min rY	194	58 DL+LL-EQ	-1.360	-0.227	-5.542	5.711	-0.000	**-0.002**	-0.001
Max rZ	604	53 DL+LL+EQ	5.714	-0.445	0.507	5.754	-0.000	0.000	**0.003**
Min rZ	610	52 DL-EQX	-5.871	-0.559	-1.069	5.994	-0.000	-0.000	**-0.003**
Max Rst	346	56 DL-EQZ	-13.221	-1.824	-19.057	**23.266**	-0.001	-0.001	-0.001

Fig 4.14 Displacement of M-3

```
                           --------------------------
TOTAL SRSS  SHEAR    159.99     0.00      0.00
TOTAL 10PCT SHEAR    163.69     0.00      0.00
TOTAL ABS   SHEAR    242.94     0.00      0.00
TOTAL CSM   SHEAR    242.92     0.00      0.00
TOTAL CQC   SHEAR    164.91     0.00      0.00
```

```
*********************************************************
* UNITS - MTON  METE                                    *
* TIME PERIOD FOR X 1893 LOADING =    0.58446 SEC       *
* SA/G PER 1893=    2.327, LOAD FACTOR= 1.000           *
*      FACTOR V  PER 1893=    0.0558 X   2952.93        *
*                                                       *
*********************************************************
```

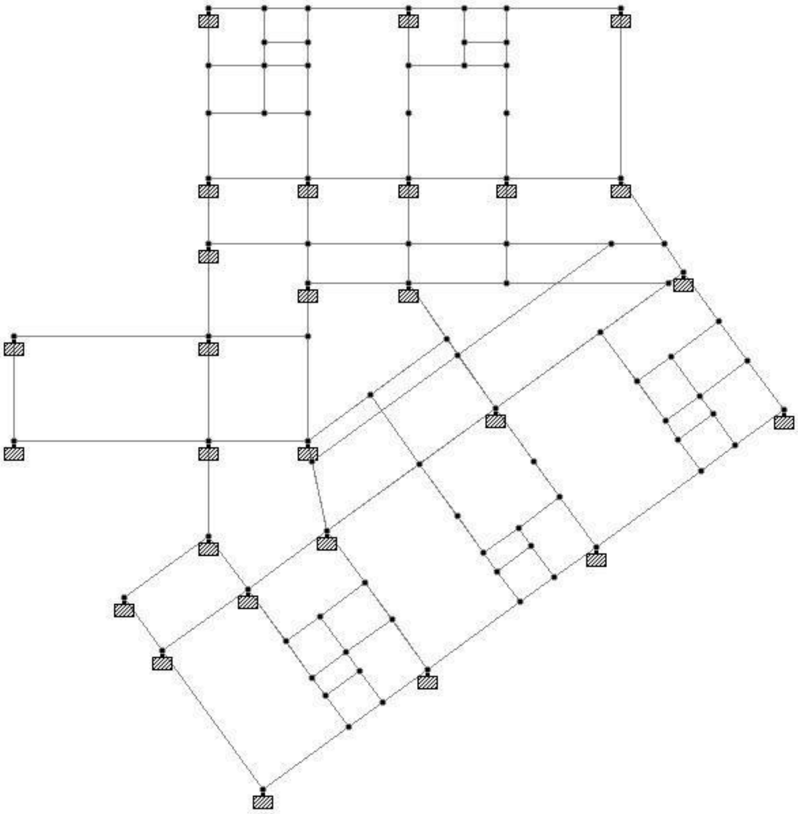
Fig 4.15 Base Shear of M-3

Table 4.3 Response of M-3

Seismic response parameter	Value	Limit
Max storey displacement	19.378 mm	NA
Max Storey drift	3.989 mm	13.2mm (0.004*3.2)
Base Shear	164.91 metric ton	NA
Remark	Vertical Irregular Structure Model 3	

4.1.4 Model 4 (M-4)

This irregular structure consists of an uneven and asymmetrical arrangement that is not distinctly within the ambit of typical plan or vertical irregularities. Its configuration can result in uncertain behavior in an earthquake.



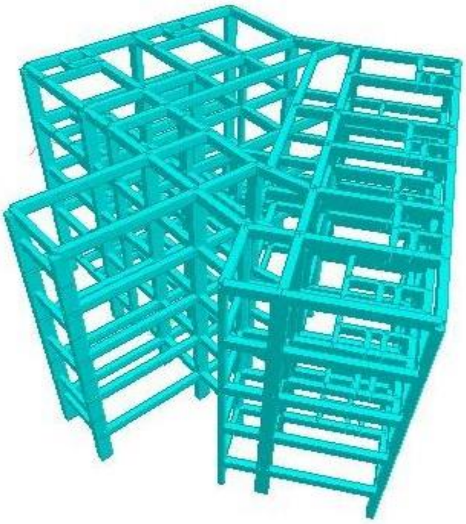


Fig 4.16 Elevation and 3D view of M-4

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.3503	0.1794	L / 1585	L / 3094	PASS	PASS
2	7.05	0.2597	0.1333	L / 1271	L / 2476	PASS	PASS
3	10.35	0.2020	0.1203	L / 1634	L / 2744	PASS	PASS
4	13.65	0.1257	0.0600	L / 2626	L / 5500	PASS	PASS

1893 RESPONSE SPECTRUM LOAD 2

Fig 4.17 Storey Drift EQX of M-4

STORY DRIFT CHECK

STORY	HEIGHT	INTERSTORY DRIFT(CM)		RATIO		STATUS	
	(METE)	X	Z	X	Z	X	Z
BASE	-1.80						
1	3.75	0.1750	0.2943	L / 3171	L / 1886	PASS	PASS
2	7.05	0.1284	0.2193	L / 2570	L / 1505	PASS	PASS
3	10.35	0.1038	0.1866	L / 3179	L / 1768	PASS	PASS
4	13.65	0.0648	0.1028	L / 5093	L / 3211	PASS	PASS

Fig 4.18 Storey Drift EQZ of M-4

	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	Rotational rX rad	rY rad	rZ rad
Max X	88	321 (DL+0.25	**17.224**	-1.017	7.300	18.735	0.001	0.001	0.002
Min X	86	341 (DL-ELX-	**-15.580**	-1.911	-5.744	16.715	0.000	-0.001	-0.002
Max Y	106	345 (DL+ELZ	11.197	**0.326**	12.686	16.924	0.001	0.001	0.000
Min Y	218	333 (DL+0.25	-6.542	**-5.179**	-6.927	10.844	-0.000	-0.001	0.000
Max Z	103	329 (DL+0.25	7.477	-1.859	**17.607**	19.219	0.002	0.001	0.001
Min Z	103	349 (DL-ELZ-	-5.817	-2.077	**-17.223**	18.297	-0.001	-0.001	-0.000
Max rX	67	329 (DL+0.25	4.292	-0.362	7.035	8.249	**0.002**	0.001	0.001
Min rX	66	333 (DL+0.25	-2.911	-0.817	-6.760	7.405	**-0.002**	-0.001	-0.001
Max rY	87	329 (DL+0.25	14.664	-2.142	13.504	20.049	0.001	**0.001**	0.001
Min rY	317	349 (DL-ELZ-	-13.012	-3.138	-13.768	19.202	-0.000	**-0.001**	-0.001
Max rZ	57	321 (DL+0.25	9.803	-0.698	4.159	10.671	0.001	0.000	**0.002**
Min rZ	55	325 (DL+0.25	-8.942	-1.388	-3.402	9.668	0.000	-0.000	**-0.002**
Max Rst	88	329 (DL+0.25	14.671	-1.040	16.531	**22.127**	0.002	0.001	0.001

Fig 4.19 Displacement of M-4

```
                         ---------------------------
TOTAL SRSS   SHEAR     122.90      0.00      0.00
TOTAL 10PCT SHEAR     129.79      0.00      0.00
TOTAL ABS    SHEAR     178.74      0.00      0.00
TOTAL CSM    SHEAR     174.15      0.00      0.00
TOTAL CQC    SHEAR     131.05      0.00      0.00
```

```
**********************************************************
* UNITS - MTON  METE                                     *
* TIME PERIOD FOR X 1893 LOADING =    0.58446 SEC        *
* SA/G PER 1893=    2.327, LOAD FACTOR= 1.000            *
*      FACTOR V  PER 1893=    0.0558 X   2346.63         *
*                                                        *
**********************************************************
```

Fig 4.20 Base Shear of M-4

Table 4.4 Response of M-4

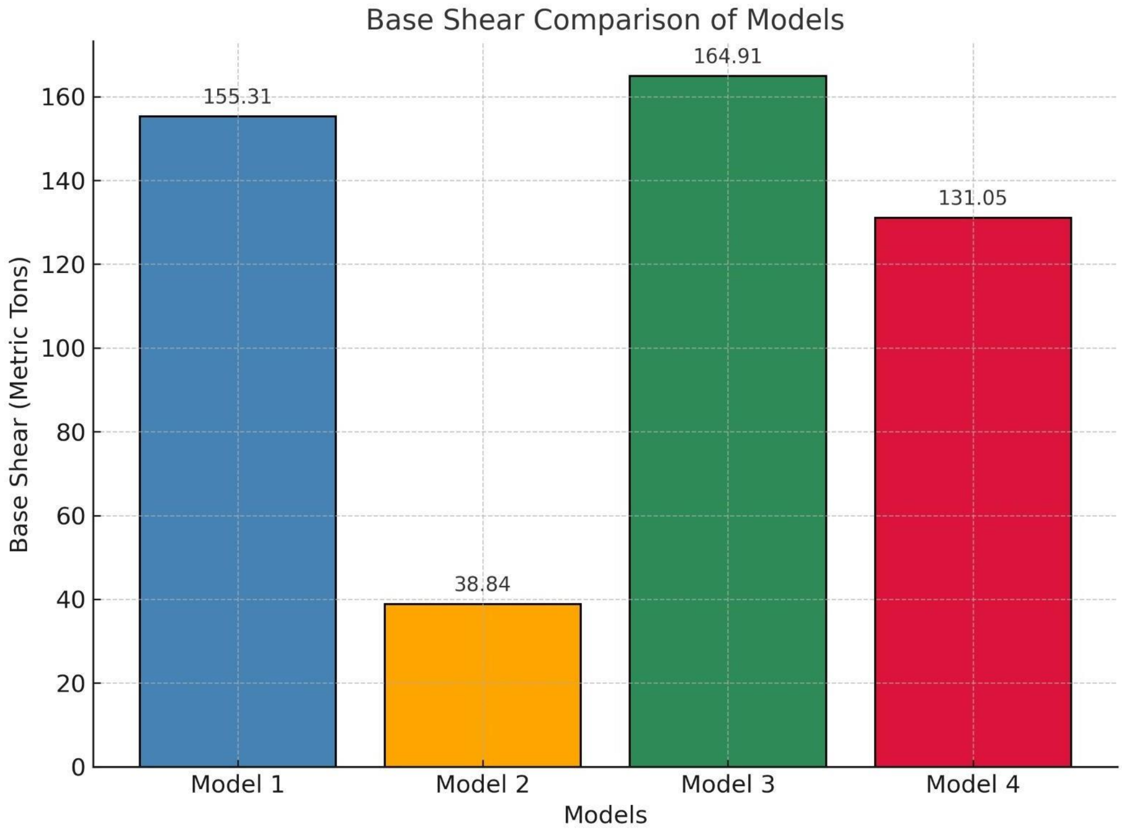
Seismic response parameter	Value	Limit
Max storey displacement	17.607 mm	NA
Max Storey drift	3.503 mm	0.015 mm (0.004*3.75)
Base Shear	131.05 metric ton	NA
Remark	Irregular Structure Model 4	

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 (M-3), while its minimum value is observed in the plan geometry irregularity model (M-2).



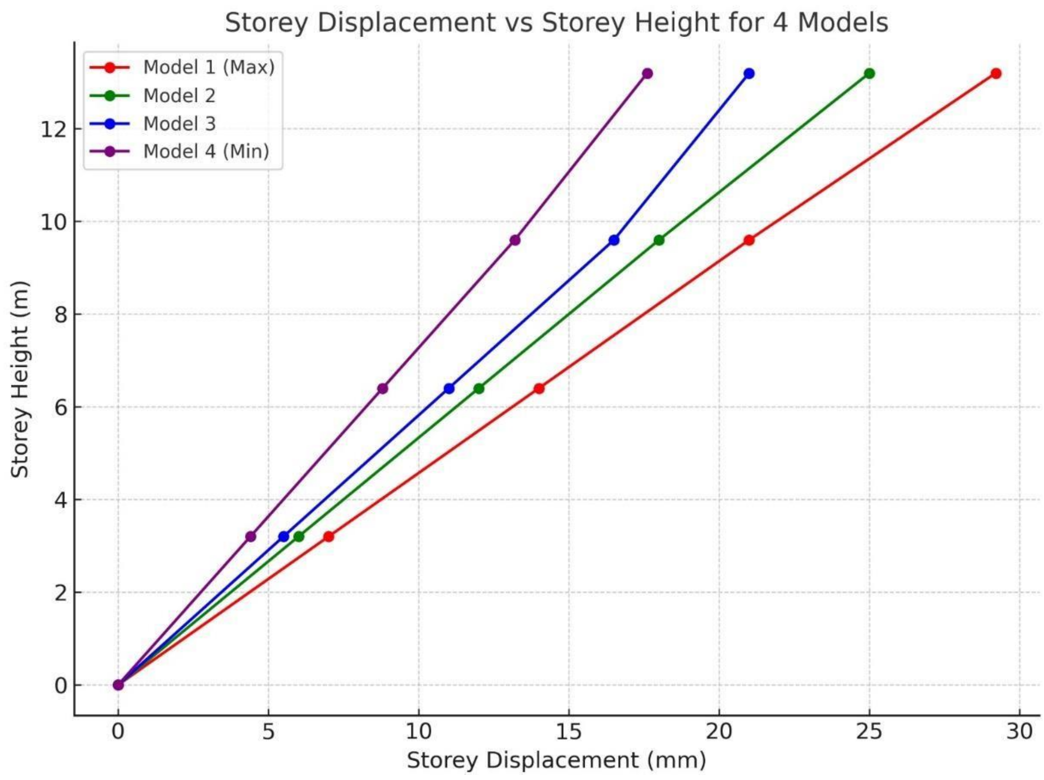
Graph 4.1 Base shear comparison of models

Table 4.5 Base Shear

Building Model	M-1	M-2	M-3	M-4
Base Shear (Metric Ton)	155.31	38.84	164.91	131.05

4.2.2 Maximum storey displacement (mm)

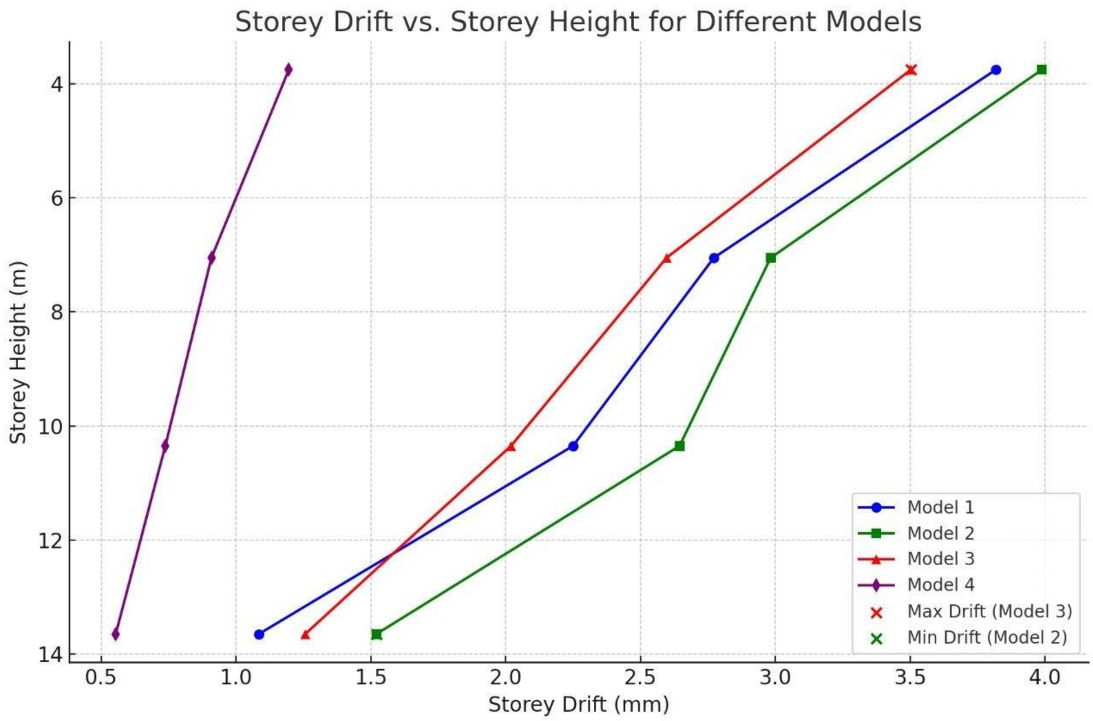
According to Fig 4.7, The storey displacement reaches its maximum value in the Model 1 (M-1), while its minimum value is observed in the Model 4 (M-4).



Graph 4.2 Maximum storey displacement

4.2.3 Storey Drift

As depicted in Figure 4.7, The storey drift reaches its maximum value in the Model 3 (M-3), while its minimum value is observed in the Model 2 (M-2).



Graph 4.3 Storey Drift in x direction

Table 4.6 Storey Drift in X-direction

Storey	Elevation (m)	M-1	M-2	M-3	M-4
Base	0	0.0	0.0	0.0	0.0
Storey 1	3.75	3.818	3.109	3.989	3.503
Storey 2	7.05	2.772	2.163	2.983	2.597
Storey 3	10.35	2.050	1.630	2.645	2.020
Storey 4	13.65	1.085	0.944	1.521	1.257

CHAPTER 5

CONCLUSION

- Model 2 (T-Shaped configuration) exhibited the best seismic response: It recorded the lowest storey drift value (3.109 mm), well within limits.
  Base shear was also minimum (38.84 metric tons), reflecting less structural demand due to seismic forces. Generally, this model can be taken as the most stable and strongest of all.
- Model 3 (Vertical Irregularity) exhibited the worst behavior under seismic loading: It measured the greatest storey drift (3.989 mm), albeit still within the recommended value. Base shear was also the greatest (164.91 metric tons), indicative of its high sensitivity to earthquake forces. Vertical irregularity seems to have adversely affected its performance and must be properly designed.
- Model 1 (L-Shaped design): Posted a relatively higher storey drift (3.818 mm) compared to the majority of other models. The base shear value was similarly higher (155.31 metric tons). To enhance its performance, it can be improved with more lateral resistance elements like bracings or shear walls.
- Model 4 (Irregular Plan): Had the minimum displacement (17.607 mm), indicating good lateral stiffness. The values of drift were within tolerable limits, and base shear was moderate (131.05 metric tons).Although irregular in plan, the model showed an acceptable seismic response, as long as design irregularities are properly resolved.
- 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

This research can be further developed by investigating structures with combined plan and vertical irregularities to achieve a better insight into seismic complex behaviors. Sophisticated analytical methods like time history and pushover analysis could be embraced for more accurate outcomes. Adding soil-structure interaction would enhance response prediction accuracy even further. It is also possible to investigate the efficiency of seismic control devices like base isolators and dampers for the reduction of drift and displacement.

Application of actual earthquake ground motion records for dynamic analysis can also provide useful insights in practice. Finally, cost-performance comparison may assist in choosing the most effective and economically sensible structural layouts. This might entail exploring different methods, e.g., structural retrofitting or advanced design methodologies, to reduce the weaknesses introduced by irregularities and enhance overall structural resilience to seismic loading

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PLAGIARISM REPORT

Seismic force-resistant design can also be termed as lateral force resistance systems.

ORIGINALITY REPORT

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