

Seismic Performance of Irregular RC Building Frame

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ABSTRACT

The current study emphasises on comparing the manner in which irregular reinforced concrete (RC) building frames under earthquake loading with that of regular building configurations. Architectural and functional requirements frequently cause plan irregularities in modern construction practices, which have a significant influence on the seismic performance of structures. The main goal of this investigation is to evaluate and compare the seismic response of conventional and irregular multi-storey RC buildings by employing the analysis method known as the Response Spectrum.

The study uses a G+9-storey reinforced concrete building frame. ETAABS was used to model and analyze four distinct plan configurations: a regular rectangular plan, an L-shaped plan, a T-shaped plan, and a plus (+) shaped plan. Utilising the Response Spectrum Method, analysis was conducted in compliance with relevant Indian Standard code provisions. The overall lateral stiffness of the columns and load intensity was maintained approximately the same for each building configuration to ensure a fair comparison between all structural models. Modal mass, foundation shear, storey displacement and storey drift participation proportion were all evaluated and compared for all building models' structural response parameters.

The research looks into the influence of abnormality in the plan on the seismic behavior of RC framed structures. Despite having a similar overall lateral stiffness of columns, the analytical results show that irregular buildings are more susceptible to torsional effects, larger lateral displacements, and higher storey drifts than regular buildings. Due to the irregular plan geometry, the structures are significantly influenced by seismic forces. The study concludes that proper consideration of plan irregularities is essential in the evaluation and structure plan of earthquake-resistant buildings to ensure structural stability, safety, and serviceability during seismic events.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

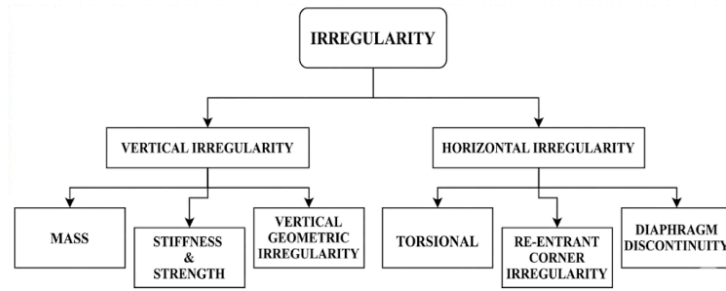
The term "lateral force resistance systems" refers to structural systems that are intended to withstand seismic forces. Usually, damage within a building starts at the points of structural weakness, which can worsen structural deterioration and possibly lead to a collapse. Structural irregularities within a building frequently contribute to these weak points. Historically, buildings with consistent layouts and equally dispersed strength, stiffness and mass, in both plan and elevation have suffered. A building's structural weak areas are usually where damage starts. These weaknesses may worsen structural deterioration, possibly leading to a breakdown. These weak areas are frequently caused by structural imperfections within a building. In contrast to constructions with variable geometries, buildings with consistent layouts and evenly dispersed strength, stiffness and mass, in both plan and elevation have historically sustained less damage during seismic events.

According to IS 1893 (Part 1): 2016, a floor in a building exhibits abnormality of mass when its seismic weight exceeds 150 percent as that of the floor beneath; inconsistency in stiffness (soft storey) occurs when floor's lateral rigidity is lower as compared to the floor above; and strength irregularity (weak storey) occurs when a floor's lateral strength is less than that of the floor above. A floor in a structure exhibits mass abnormality if its seismic weight exceeds 150 percent of the floor below, according to IS 1893 (Part 1): 2016. Irregularity or abnormality of stiffness (soft storey) occurs when floor's lateral rigidity is lower as compared to the floor above. Similarly, a floor is said to as having a strength irregularity (weak storey) if its lateral strength is less than that of the floor above.

Practically speaking, the concept of complete regularity is merely idealisation because actual buildings inevitably possess or have irregularities because of a variety of factors. For example, many existing buildings have anomalies as a result of practical and decorative factors; some structures were designed with irregularities to fulfil specific purposes; variations in the use of a specific floor as opposed to the next storey may potentially cause irregularities; and many structures unintentionally acquire irregularities during the construction phase due to factors like inconsistent construction practices and variations in the quality of raw materials used. Upon closer inspection, it is clear that most seismic codes suggest similar criteria for defining irregularities based on their magnitude, frequently ignoring the location of the irregularity. Due to both functional and aesthetic factors, many existing buildings have abnormalities. Certain structures were made with flaws to serve particular functions. Irregularity can also arise from differences in how a specific storey is used in comparison to its neighbouring storey. Furthermore, many constructions inadvertently develop abnormalities during the building process as a result of things like inconsistent construction methods and differences in the quality of raw materials utilised. It is clear from looking at several seismic codes that most of them provide comparable standards for characterising anomalies based on their magnitude, frequently ignoring the location of the anomaly.

However, it is crucial to take into account the kind, location, and degree of irregularities in structural design. Making wise choices in this area can help make structures more aesthetically pleasing and practical. Although irregular buildings are preferred for their aesthetic and functional aspects, historical earthquake data 1 shows that they have poor seismic performance. However, structural imperfections are often unavoidable. Hence, it's vital to consciously choose and arrange abnormalities in a way that doesn't compromise the structure's overall performance.

1.2 TYPES OF IRREGULARITIES IN BUILDING



"Irregularity" in structural engineering, particularly seismic design, is a measure of how unexpectedly a building could react during an earthquake rather than only an aesthetic decision. **Plan irregularities** and **vertical irregularities** are the two basic categories into which most building regulations (such as ASCE 7 or IS 1893) divide these.

1.2.1 PLAN (HORIZONTAL) IRREGULARITIES

These occur when the layout of the building in the horizontal plane is asymmetrical or disconnected.

- **Torsional Irregularity:** This happens when the core of mass doesn't line up with the stiffness center. This causes the building to twist rather than just sway.
 - It is measured by the proportion of greatest possible displacement ($\delta_{\max}$) to average displacement (δ_{avg}).
 - $\eta = \delta_{\max} / \delta_{\text{avg}}$
 - If $\eta > 1.2$, it's considered irregular.
- **Re-entrant Corners:** Think of L, T, U, or H-shaped buildings. The "inside" corners are stress concentration points where the wings of the building might vibrate differently, potentially tearing the structure apart at the seams.

- **Diaphragm Discontinuity:** When floors have large cut-outs (like massive atriums or elevator shafts) which surpass 50% of the entire floor space, the floor can no longer effectively transfer lateral forces to the walls or columns.
- **Offsets Outside of the Plane:** A "hitch" in the path of lateral force, like a shear wall that exists on the top floors but is shifted over on the bottom floors.
- **Non-parallel Systems:** When the vertical load-resisting elements (walls/frames) aren't parallel to the major orthogonal axes of the building.

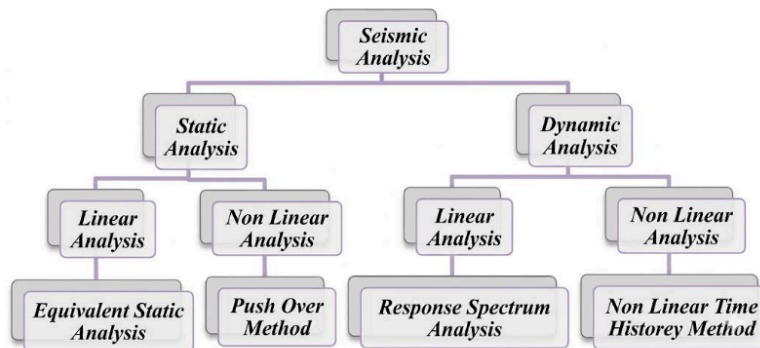
1.2.2 VERTICAL IRREGULARITIES

These occur when the building's properties change abruptly as you move from the ground floor to the roof.

TYPES OF VERTICAL IRREGULARITIES

- **SOFT STOREY:** a floor that is substantially less rigid than the one above it (for example, an open parking lot on the ground floor as opposed to several walls on the upper floors).
- **MASS IRREGULARITY:** The term "mass irregularity" describes a notable vertical discontinuity in the weight distribution throughout a building's height. It happens when a single storey's seismic weight is significantly higher than that of a nearby storey.
- **VERTICAL GEOMETRY:** When the lateral force-resisting system's horizontal dimension at any level differs noticeably from that of a nearby storey, this is known as a vertical geometric irregularity.
- **IN-PLANE CONTINUITY:** When a lateral force-resisting element, like a shear wall or braced frame, experiences a physical lateral offset or shift within the same plane instead of continuously running from the roof down to the foundation, it is known as an In-Plane Continuity Irregularity (more frequently referred to by building codes as an In-Plane Discontinuity or In-Plane Offset).
- **WEAK STOREY:** A floor that has a cumulative lateral design strength of less than 70% of the storey immediately above it is referred to as a "weak storey."

18 1.3 SEISMIC ANALYSIS METHODS



1.3.1 STATIC ANALYSIS

- **Equivalent Lateral Force Method**

One of the most straightforward methods for calculating seismic forces is this one. It is frequently applied to structures having a symmetrical, regular layout and a comparatively small height. It is appropriate to take into account to simply the first mode shape of the structure for such structures since the first mode's contribution is usually dominant and the modal participating mass ratio of the first mode shape frequently exceeds 70–80%. Therefore, based on the first mode shape, the base shear is distributed across each floor to establish the loading values. This is accomplished by creating a static force that is based on the first mode's characteristics.

- **Pushover Analysis Method**

Another static approach is the pushover analysis method, which is also nonlinear since it combines non-linear analysis with the application of a static load. The positions of plastic hinges are found iteratively while the structure is subjected to unit forces in the form of the first mode. This study yields the capacity spectrum, which represents the actual performance level of the

structure when compared to the chosen response spectrum. The modal pushover analysis should be applied if the structure is tall or uneven, indicating that higher modes are important. Both the first mode shape and higher modes are taken into account in this instance (similar to modal analysis).

1.3.2 DYNAMIC ANALYSIS

- **Analysis of Response Spectrum**

Analysis of Response Spectrum combines the corresponding accelerations from the response spectrum with the structure's eigenmodes. A structural state, including the ensuing deformations and internal forces, can be obtained without the need to generate equivalent loads by applying the accelerations and weighting the mode forms with their effective modal masses. The SRSS (Square Root of the total of the Squares) rule is most popular combining approach used to combine the results from the separate modes.

Multiple degrees of freedom in structures result in a variety of mode forms. The modal participation mass ratio, which is calculated by dividing the mass of each mode shape by structure's overall mass, is commonly used to define contribution of each mode shape. Design regulations permit the total participating modal mass ratio to exceed a specified percentage because it is typically impossible to calculate for every mode; nevertheless, the precise threshold may differ based on the code or annexe being used.

- **Time-History Analysis**

This technique simulates a structure model's response over time by applying time-dependent ground motion records, or accelerograms. At every time step, it offers comprehensive findings that include displacements, accelerations, and internal forces. Depending on how the material behaviour and structural reaction are taken into account throughout the loading process, the analysis might be either linear or nonlinear. In the nonlinear situation, the analysis takes into consideration both material and geometric nonlinearities, whereas in the linear case, the structure is modelled under the assumption of linear elastic

behaviour. Consequently, the most sophisticated method is nonlinear time history analysis, which captures the entire spectrum of geometric and material nonlinearity under time-dependent seismic pressures.

1.4 THE STRATEGIC IMPORTANCE OF SEISMIC DESIGN CODES

Structural engineering and the creation of surroundings resistant to tectonic action are based on seismic loading rules. These rules provide minimal standards for ground motion parameters and building behaviour, mandating that structures possess the energy dissipation capacity, stiffness, and lateral stability required to endure seismic shocks.

Basic objectives of seismic codes

- **Occupant Protection:** Preserving life is the main goal of any earthquake requirement. During high-intensity incidents, these standards allow the residents to safely evacuate without the building collapsing.
- **Force resistance and structural integrity:** ASCE 7 and IS 1893 standards outline specifications for foundation engineering and material qualities. As a result, the building frame may effectively transfer the inertial forces brought on by quick ground acceleration.
- **Economic Mitigation:** In addition to providing immediate safety, these standards also serve as a means of managing financial risk. By adhering to standardised design norms, post-disaster downtime and the enormous expenses associated with infrastructure breakdown and structural restoration are decreased.
- **Functional Reliability:** Today's engineering fad is "Performance-Based Design." By employing an Importance Factor that is more conservative than the ratios used for typical residential units, this clause ensures the continuous operation of vital services, particularly hospitals and emergency centers.
- **Regulatory Compliance:** Adhering to codes ensures that your design satisfies the consensus-based safety standards necessary for certification by regulatory bodies, providing you with a professional and legal safety net.

1.5 ASSESSMENT OF SEISMIC AND STRUCTURAL CHARACTERISTICS

Using two distinct parameter sets, the analysis assesses the performance differences between the irregular (L, T, and +) and regular (Square) plan configurations. The IS 1893 (Part 1): 2016 design constants are the initial set used to calculate seismic demand. The performance of each geometry under a fixed total column stiffness budget is assessed using the second set of structural response metrics that were taken from the Response Spectrum Analysis (RSA).

1.4.1. DESIGN GROUND PARAMETERS AND INPUT

The design basis earthquake's features and intensity are determined by these criteria. All four models are affected by these factors and are therefore suitable for a scientifically-controlled comparison:

- **Zone factor (Z):** The zone factor is a measurement of the structure's geographic location's effective peak ground acceleration (EPGA). It describes the minimum amount of ground motion expected over the lifespan of the design of the structure at G+9.
- **Importance Factor (I):** A factor that weighs the importance of buildings based on their occupancy status. It improves the safety margin by multiplying the design lateral forces of critical and densely populated civil infrastructure.
- **Response Reduction Factor (R):** This metric assesses the structural frame system's ductility and capacity to dissipate energy. Assuming that the RC joints are made to withstand plastic deformation without brittle failure, a value of $R = 5$ is employed for a Special Moment Resisting Frame (SMRF).
- **Average Response Acceleration Coefficient (Sa/g):** The primary component of the Response Spectrum Analysis is the Average Response Acceleration Coefficient (Sa/g). It shows the building's normalised spectral acceleration. It is computed using the local foundation soil type (Hard, Medium, or Soft) and the building's fundamental natural period (T).

1.4.2. STRUCTURAL RESPONSE PARAMETERS IN EARTHQUAKE

- **SHEAR AT THE BASE :** As stated in (Part 1), design shear at the base (V_b) is entire design lateral force anticipated during an earthquake. It is determined by multiplying the building's total seismic weight (W) by the design horizontal seismic coefficient (A_h).

- **Base Shear Formula**

$$V_b = A_h \times W$$

In which:

V_b = Design Base Shear

W = The building's total seismic weight

A_h = Design horizontal acceleration coefficient

- **STOREY DRIFT:** The maximum drift of storey in any storey shouldn't be greater than 0.004 times the height of the storey (0.4% of height of storey) under design lateral force, according to IS 1893:2016 (Part 1), Clause 7.11.1. Ensuring seismic safety, preventing structural damage, and safeguarding non-structural components all depend on this inspection.
- **STOREY DISPLACEMENT:** In structural engineering, storey movement is the lateral (horizontal) motion of a structure's floor or storey with respect to its initial, unloaded location at ground level. This absolute deviation, which is usually brought on by wind or seismic forces, rises as you ascend the structure, creating a curved shape.
- **MODE SHAPE:** It is the unique and natural vibrational patterns of a structure if it oscillates at the specific resonance frequencies. They are very crucial to comprehend the dynamics of a framework or building and preventing failures, as they reveal the movement of each part of a system relative to the others, not a physical shift.

- **Natural Period (T):** The amount of time (measured in seconds) required for the building to go through one complete free vibration cycle. It is basically determined by the weight and stiffness of the structure.
- **Modal mass participation ratio:** The percentage of a building's total seismic mass that vibrates and reacts within a particular mode of vibration is indicated by the Modal Mass Participation Ratio (MMPR), a crucial dynamic parameter in structural engineering. In essence, it quantifies the relative contributions of each dynamic mode to the absorption and resistance of seismic energy along the principal global axes (X, Y, and Z).

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

- **Khanal and Chaulagain (2020)** explored the effect of irregularity in the structural plan on the seismic elastic performance of a baseline regular frame structure along with six different L-shaped reinforced concrete structures by applying equivalent static lateral force approach and dynamic response spectrum approach. The buildings have asymmetric layouts; this creates severe re-entrant corners and torsional weaknesses. As a result, these geometric imperfections lead to a cascading loss of earthquake resistance, based on the fundamental phenomenon of increasing stress concentrations, structural twist and significantly variable inter-storey drift distributions.
- **Lingeswaran et al. (2021)** have studied the impact of geometric configuration on the vulnerability of a G+9 storey building by finite element modelling software (ETABS). These variations of storey drift and lateral displacement were systematically mapped for both the symmetric and asymmetric plans, with specific emphasis on the rectangular, L, T and H-shaped plans designed with due consideration to the earthquake forces prescribed by IS 1893 (Part 1): 2016. The symmetrical geometry exhibited a significantly higher seismic stabilisation resistance as well as a much greater performance when compared to the irregular geometries. The plan-irregular model with the T-shape was discovered to be the most susceptible of the plan-irregular models studied with the maximum peak storey displacement in response to the dynamic lateral loads. However, the L and H shapes had similar patterns of floor to floor movements, suggesting that a common structural response archetype might exist for these same seismic conditions.
- **Munni and Chandra Mohan Rao (2022)** compared a standard regular structure with a plan irregular L shaped structure based on a G+9 storey building subjected to extreme lateral loading. These structures were mapped within Seismic Zone-V with ETABS through the use of Response Spectrum

analysis. The simulation considered the various real world variables such as hard soil, medium soil, soft soil, as per the classification done by Indian standard IS 1893. Their tracking parameters included vital parameters of structural integrity, such as storey shear, stiffness, displacement, drift pattern and modal mass participation factor. What is interesting is that the base shear of the regular building was 83% greater than the L-shaped building, as a direct result of its larger plan area and heavier seismic weight.

- **Annapurna et al. (2023)** performed a linear dynamic analysis to evaluate seismic performance of multi-storey reinforced concrete frames. The study compared regular structures with the structures with a variety of structural irregularities. For their research framework, they considered G+10 and G+20 tall building models located in seismic zone II and IV in India respectively, with a particular emphasis of medium soil conditions throughout all their numerical simulations. The authors mapped the impact of adding mass anomalies, local stiffness variations, vertical geometric setbacks and asymmetric floor plans by capturing important engineering demand parameters: storey lateral loads, shear forces, stiffness distributions, floor displacements and inter-storey drift ratios. This data revealed a significant difference in performance across the buildings due to the building layout. Interestingly, the most extreme peak loads for storey lateral loads, cumulative storey shear and overall storey stiffness were obtained with regular structural configurations. Irregular layouts, on the other hand, incurred the highest structural risk of damage, with the floor displacements being amplified and the inter-storey drift concentrations being critical. In order to address these vulnerabilities, the researchers compared a targeted structural intervention. They have demonstrated that the structural shear walls placed in strategic locations within asymmetric or soft-storey structures can offset the geometric deficiencies. This addition properly reduces the lateral loading requirements and prevents excessive drift ratios, thus negating the structural dangers associated with sudden setbacks in elevation and/or a weak storey at a specific location.
- **Sivakumar et al. (2023)** used the response spectrum method to evaluate a G+9

reinforced concrete structure situated in seismic zone III was conducted by. The researchers used ETABS software to monitor seismic metrics with a particular emphasis placed on the floor deflections, the storey drifts and the storey internal shear distributions, with a view to ensuring compliance with the regulatory benchmarks specified in IS 1893 (Part 1): 2016. A structural design which integrated additional shear walls around the elevator cores and stairs was adopted for lateral force resistance. The dynamic simulation results were used and it was concluded that the design met the requirements of Indian design codes regarding safety. The absolute inter-storey drift ratio, which is always less than the required compliance of 0.004 times H_s (localized storey height), was used to demonstrate compliance. The finite element model results showed that dynamic force balance resulted in maximum storey shear forces building up directly at the plinth level, which created a direct opposing reaction to the base shear.

2.2 LITERATURE GAP

- The majority of the previous studies compare regular and irregular buildings having different column sizes, member arrangements or overall stiffness distributions, and therefore it is difficult to isolate the actual effect of plan irregularity alone. One big hole in the research is to hold the total lateral stiffness of the columns exactly the same in all models.
- Studies normally analyse only one irregular form (L-shape or T-shape). A comparative parametric research on L-shape, T-shape, plus-shape with equalised stiffness is still limited.
- Many studies have been carried out to compare the seismic performance of regular and irregular plan buildings but very few studies have been done where the overall lateral stiffness of columns is constant for all the structural models. Thus, the independent effect of plan irregularity on seismic response parameters such as torsion, storey drift, displacement, modal behaviour and force redistribution is not well understood yet.

CHAPTER 3

METHODOLOGY

The primary aim of this study is to investigate the single effect of plan configuration geometry and re-entrant corners on seismic performance of multi-storey reinforced concrete structures. To establish a fully controlled baseline, no changes are introduced in the structural configuration of the vertical supporting members. This is done by fixing the total lateral stiffness of the columns for each evaluation model but varying the architectural floor plan boundaries.

3.1 REGULAR PLAN MODEL

A regular plan model is a building with a very symmetrical and consistent distribution of mass, plan geometry, and lateral stiffness throughout its horizontal footprint is referred to as a regular plan model. The total lack of substantial re-entrant corners is a crucial feature that distinguishes a regular layout in structural and seismic engineering.

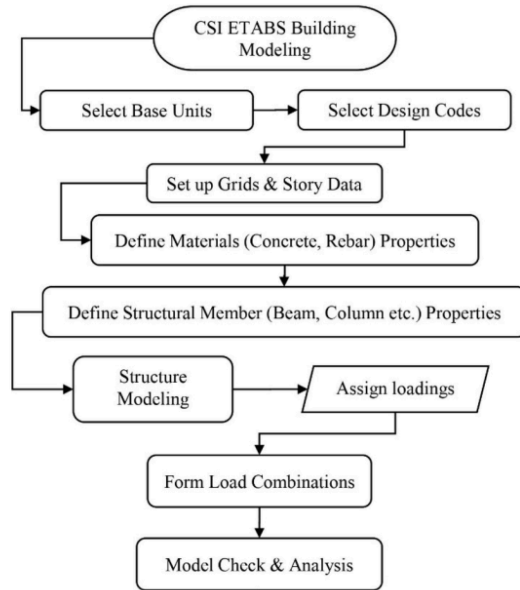
3.2 IRREGULAR PLAN MODEL

A building configuration with notable asymmetry, discontinuity, or differences in its horizontal footprint, mass, or lateral stiffness is referred to as an irregular plan model. The existence of noticeable re-entrant corners is the main characteristic that distinguishes an irregular plan type.

+ shape is symmetrical and its center of mass and center of rigidity also aligns perfectly but because it have reentrant corners it also comes under irregular plan shape model.

3.3 STRUCTURAL MODELING WORKFLOW

The numerical simulation and dynamic analysis are carried out using the finite element software **ETABS**. The workflow encompasses material definitions, geometric modeling of a G+9 storey frame, column stiffness normalization, load assignment, and the execution of linear dynamic analysis.



3.4 MATERIAL AND GEOMETRIC PARAMETERS

The material grades and structural member dimensions are configured to comply with standard Indian code provisions for earthquake-resistant design.

3.4.1. MATERIAL PROPERTIES

- **Concrete Grade:** M30 specified for all structural components to support high seismic performance requirements.
- **Longitudinal Reinforcement:** Fe500 high-strength deformed bars.
- **Confinement Ties:** Fe415 steel bars.

3.4.2. INPUT PARAMETERS OF THE MODELS

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

Seismic Parameters as per IS 1893:2016	
Type of Building	Residential Building
Zone	V
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 storey	G+9 (10)
Storey height	4m
Over all height of the building	40m
No. Bays X-dir	5, 5m
No. Bays Y-dir	5, 5m
Dimensions of structural members	
Beam (mm)	500 x 500
Column (mm)	(500 x 500) _{SQUARE} , (500 x 535) _{L-SHAPE} , (500 x 570) _{T-SHAPE} , (500 x 570) _{-SHAPE}
Slab (mm)	200
Outer Wall (mm)	250
Inner Wall (mm)	125
Properties of Material	
Grade of Concrete	M 30
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
FF	1.5
Roof Load	1.5
Outer Wall Load	15
Inner Wall Load	10

Table 3.1 Input Parameters of the Models

3.5 DESCRIPTION OF EVALUATED MODELS

The study analyzes four distinct structural plan configurations. While the floor plans change, the total summation of individual column lateral stiffnesses (ΣK_i) is mathematically held constant across all models.

3.5.1. MODEL 1: REGULAR SQUARE PLAN

This model is symmetrical along both the major axis. The center of mass (CM) and the center of rigidity (CR) are properly aligned thanks to its uniform grid arrangement, which is free of geometric discontinuities and plan imperfections. The square plan model we have made consists of 49 columns at each floor.

- **Floor Plan Layout**

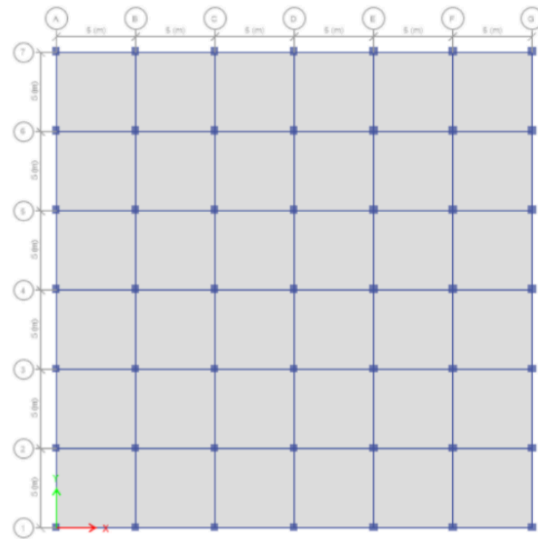
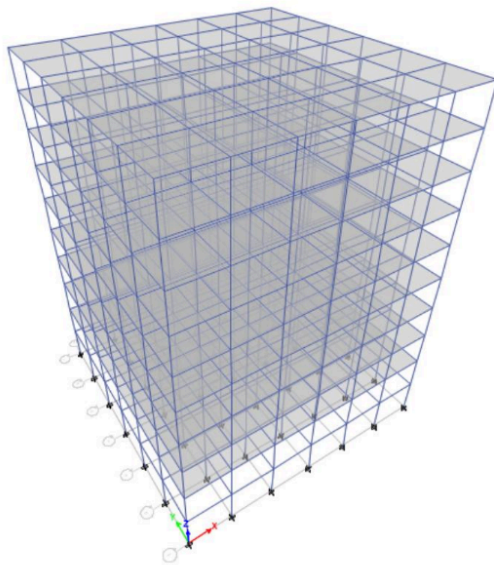


Figure 3.1: Floor Plan Layout of Regular Square Plan

- **3D Model**



²⁷ Figure 3.2 3D Model of Regular Square Plan

3.5.2. MODEL 2: IRREGULAR L-SHAPE PLAN

According to codal norms, this projection results in a plan discontinuity ³that is larger than 15% ⁹of the total structural plan dimensions in that direction. A large baseline offset between the center of mass (CM) and center of rigidity (CR) results from this uneven mass and geometry distribution, which disrupts the structural symmetry. The misalignment increases the frame's vulnerability to rotational amplification and lateral torsional coupling during seismic stimulation. This plan is made by removing 9 columns from our square model on each floor.

- **Floor Plan Layout**

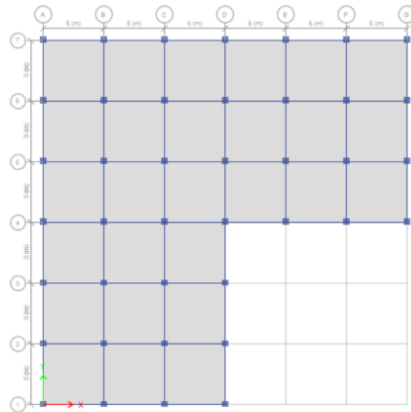


Figure 3.3 Floor Plan Layout of Irregular L-Shape Plan

- 3D Model

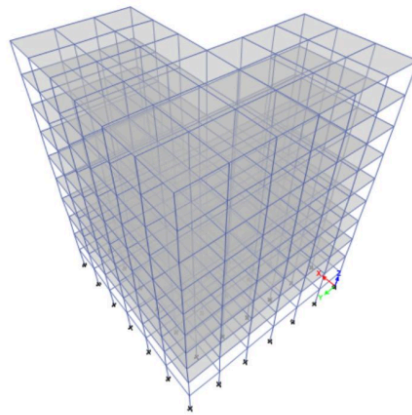


Figure 3.4 3D Model of Irregular L-Shape Plan

3.5.3. MODEL 3: IRREGULAR T-SHAPE PLAN

The T-shaped design induces a substantial lateral-torsional coupling vulnerability along the perpendicular axis while producing symmetric irregularity along one axis. It has two unique re-entrant corners that change the distribution of localised stress. This plan model is made by removing 16 columns from our square plan on each floor.

- **6 Floor Plan Layout**

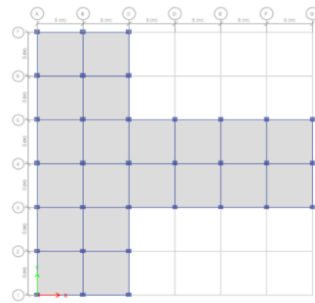


Figure 3.5 Floor Plan Layout of Irregular T-Shape Plan

- **3D Model**

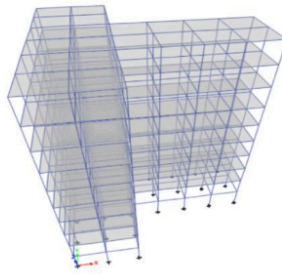


Figure 3.6 3d Model of Irregular T-Shape Plan

3.5.4. MODEL 4: IRREGULAR PLUS (+) SHAPE PLAN

There are several re-entrant corners in the plus-shape model. Its inner core shape results in significant localised stress differences at each inner intersection, despite its globally symmetrical exterior profile. This plan model is made by removing 4 corner columns from every corner of square plan model on every floor.

- **Floor Plan Layout**

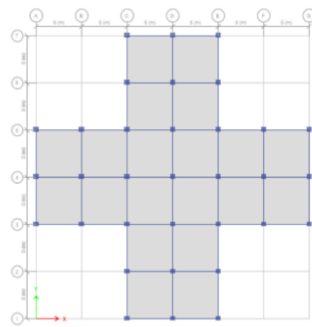


Figure 3.7 Floor Plan Layout of Irregular (+) Shape Plan

- **3D Model:**

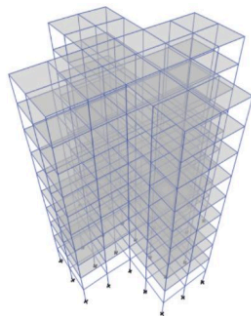


Figure 3.8 3D Model of Irregular (+) Shape Plan

3.6 COLUMN STIFFNESS NORMALIZATION

METHODOLOGY

The lateral stiffness of the vertical frames must not change globally between configurations in order to isolate plan shape as the only independent variable. The structural formula determines a fixed-ended column member's lateral stiffness:

$$K=12EI/L^3$$

Where E represents the concrete modulus of elasticity, I is the moment of inertia ($I = bd^3/12$), and h is the storey height.

Because E and h and b are held constant throughout the project, the cross-sectional column dimensions (b is kept same and d) for each specific model is calculated such that:

$$\Sigma (k_{\text{square}}) = \Sigma (k_{\text{L,shape}}) = \Sigma (k_{\text{T,shape}}) = \Sigma (k_{\text{+shape}})$$

This mathematical constraint ensures that if a model contains fewer columns due to its reduced floor space configuration, the individual remaining columns are systematically enlarged to preserve the exact total lateral stiffness of columns.

CHAPTER 4

ANALYSIS AND RESULTS

4.1 REGULAR MODEL (SQUARE SHAPE)

4.1.1 ¹ STOREY DRIFT IN X DIRECTION

STOREY	ELEVATION (m)	DRIFT(mm)
Storey10	40	0.000761
Storey9	36	0.001256
Storey8	32	0.001635
Storey7	28	0.001926
Storey6	24	0.00217
Storey5	20	0.002385
Storey4	16	0.002593
Storey3	12	0.002809
Storey2	8	0.002998
Storey1	4	0.00214
Base	0	0

Table 4.1 Storey Drift Of Square Model In X Direction

4.1.2 ¹ STOREY DRIFT IN Y DIRECTION

STOREY	ELEVATION (m)	DRIFT(mm)
Storey10	40	0.000761
Storey9	36	0.001256
Storey8	32	0.001635
Storey7	28	0.001926
Storey6	24	0.00217
Storey5	20	0.002385
Storey4	16	0.002593

Storey3	12	0.002809
Storey2	8	0.002998
Storey1	4	0.00214
Base	0	0

Table 4.2 Story Drift Of Square Model In Y Direction

4.1.3 STOREY DISPLACEMENT IN X DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	76.885
Storey9	36	74.518
Storey8	32	70.579
Storey7	28	65.205
Storey6	24	58.546
Storey5	20	50.703
Storey4	16	41.732
Storey3	12	31.645
Storey2	8	20.491
Storey1	4	8.561
Base	0	0

Table 4.3 Story Displacement Of Square Model In X Direction

4.1.4 STOREY DISPLACEMENT IN Y DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	76.805
Storey9	36	74.446
Storey8	32	70.521
Storey7	28	65.161
Storey6	24	58.513
Storey5	20	50.681
Storey4	16	41.718
Storey3	12	31.638

Storey2	8	20.487
Storey1	4	8.56
Base	0	0

Table 4.4 Story Displacement Of Square Model In Y Direction

4.1.5 BASE SHEAR VALUE

5826.5132 KN

4.1.6 MODAL MASS PARTICIPATION ANALYSIS

MODE	PERIOD	UX	UY	RZ
1	2.284	0.4241	0.4241	0.0028
2	2.283	0.4255	0.4255	0
3	2.084	0.0014	0.0014	0.8471

Table 4.5 Modal Mass Participation Analysis of Square Model

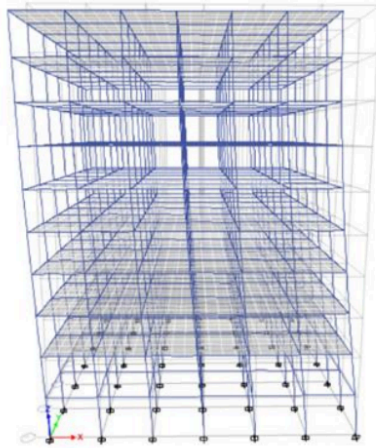


Figure 4.1 Deformed Shape Of Square Model In Mode 1

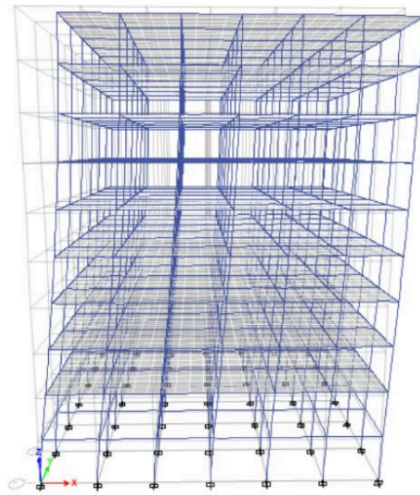


Figure 4.2 Deformed Shape Of Square Model In Mode 2

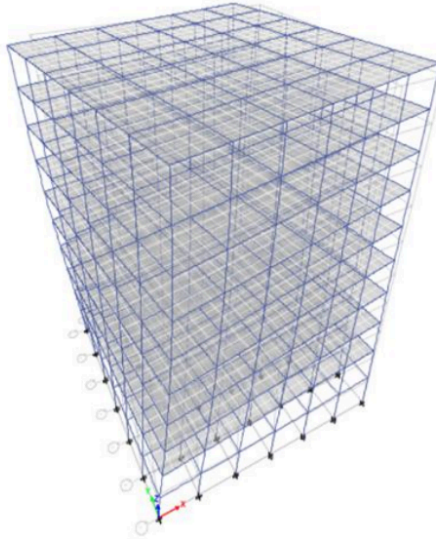


Figure 4.3 Deformed Shape Of Square Model In Mode 3

4.1.7 COLUMN FORCES

OUTER COLUMN

STOREY	AXIAL FORCE(KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-4962.6885	851.6427	-437.1107	422.1522
Storey 2	-4540.4724	736.1804	-297.0508	245.3344
Storey 3	-3984.9633	608.8082	-327.2905	246.6841
Storey 4	-3431.0293	486.9541	-311.9581	242.6556
Storey 5	-2883.9453	372.5756	-299.7775	236.8755
Storey 6	-2347.3246	267.7871	-279.9458	226.9865
Storey 7	-1826.0395	175.3676	-252.7946	211.9991
Storey 8	-1325.7485	98.7410	-217.6521	192.8487
Storey 9	-863.4431	45.2894	-170.9884	157.8022
Storey 10	-420.7067	13.3698	-147.7768	167.0680

Table 4.6 Outer Column Forces of Square Model

INNER COLUMN

STOREY	AXIAL FORCE(KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5721.6778	2.5436	-488.4731	487.2752
Storey 2	-5455.8665	2.6748	-441.4956	441.4954
Storey 3	-4843.8513	2.8499	-440.3082	438.0868
Storey 4	-4231.5397	2.8852	-427.5297	425.3116
Storey 5	-3619.1954	2.7540	-407.1368	404.2586
Storey 6	-3006.8240	2.5518	-375.9995	372.6230
Storey 7	-2394.4783	2.3234	-332.5181	328.6932
Storey 8	-1782.1490	2.0770	-275.1786	270.9544
Storey 9	-1169.9091	1.8280	-201.6356	197.3029
Storey 10	-559.5987	1.5679	-118.9839	114.0872

Table 4.7 Inner Column Forces of Square Model

4.1.8 BEAM FORCES

PERIPHERY BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B31	Storey1	223.36	390.41
B31	Storey2	256.34	427.15
B31	Storey3	253.48	420.42
B31	Storey4	248.27	408.47
B31	Storey5	239.61	388.82
B31	Storey6	226.93	360.19
B31	Storey7	209.59	321.19
B31	Storey8	186.93	270.34
B31	Storey9	159.52	208.71
B31	Storey10	130.4	135.69

Table 4.8 Periphery Beam Forces of Square Model

LONGITUDINAL INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B36	Storey1	207.32	381.24
B36	Storey2	261.47	427.18
B36	Storey3	258.86	421.88
B36	Storey4	253.34	409.82
B36	Storey5	244.55	390.44
B36	Storey6	231.86	362.33
B36	Storey7	214.65	324.1
B36	Storey8	192.31	274.37

B36	Storey9	165.01	213.89
B36	Storey10	144.35	148.82

Table 4.9 Longitudinal Internal Beam Forces of Square Model

TRANSVERSE INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B59	Storey1	206.39	379.59
B59	Storey2	262.03	427.3
B59	Storey3	260.01	422.48
B59	Storey4	254.94	411.3
B59	Storey5	246.41	392.28
B59	Storey6	233.87	364.39
B59	Storey7	216.71	326.22
B59	Storey8	194.45	276.9
B59	Storey9	167.1	215.72
B59	Storey10	147.13	154.93

Table 4.10 Transverse Internal Beam Forces of Square Model

4.2 L SHAPE MODEL**4.2.1 ¹ STOREY DRIFT IN X DIRECTION**

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.000979
Storey9	36	0.001526
Storey8	32	0.001949
Storey7	28	0.002279
Storey6	24	0.002555

Storey5	20	0.002795
Storey4	16	0.003018
Storey3	12	0.003232
Storey2	8	0.003381
Storey1	4	0.002255
Base	0	0

Table 4.11 ¹⁷ Storey Drift in X Direction of L-Shape Model

4.2.2 ¹ STOREY DRIFT IN Y DIRECTION

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.000981
Storey9	36	0.001545
Storey8	32	0.001983
Storey7	28	0.002318
Storey6	24	0.002607
Storey5	20	0.002857
Storey4	16	0.003085
Storey3	12	0.003311
Storey2	8	0.003489
Storey1	4	0.00238
Base	0	0

Table 4.12 ²¹ Storey Drift in Y Direction of L-Shape Model

4.2.3 STOREY DISPLACEMENT IN X DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	88.179
Storey9	36	85.237
Storey8	32	80.534
Storey7	28	74.191

Storey6	24	66.376
Storey5	20	57.217
Storey4	16	46.799
Storey3	12	35.168
Storey2	8	22.422
Storey1	4	8.997
Base	0	0

Table 4.13 Storey Displacement in X Direction of L-Shape Model

4.2.4 STOREY DISPLACEMENT IN Y DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	91.802
Storey9	36	88.648
Storey8	32	83.68
Storey7	28	77.04
Storey6	24	68.899
Storey5	20	59.387
Storey4	16	48.601
Storey3	12	36.591
Storey2	8	23.438
Storey1	4	9.518
Base	0	0

Table 4.14 Storey Displacement in Y Direction of L-Shape Model

4.2.5 BASE SHEAR VALUE

6215.6397 KN

4.2.6 MODAL MASS PARTICIPATION ANALYSIS

MODE	PERIOD	UX	UY	RZ
1	2.628	0.0007	0.8538	0.0036
2	2.551	0.8462	0.0004	0.0094
3	2.352	0.0095	0.0042	0.8418

Table 4.15 Modal Mass Participation Analysis of L-Shape Model

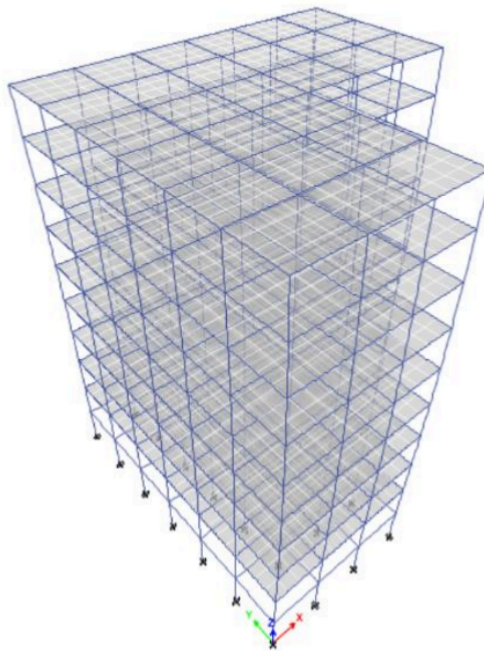


Figure 4.4 Deformed Shape Of L Shape Model In Mode 1

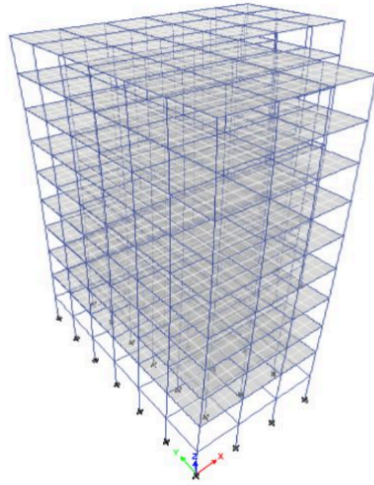


Figure 4.5 Deformed Shape Of L Shape Model In Mode 2

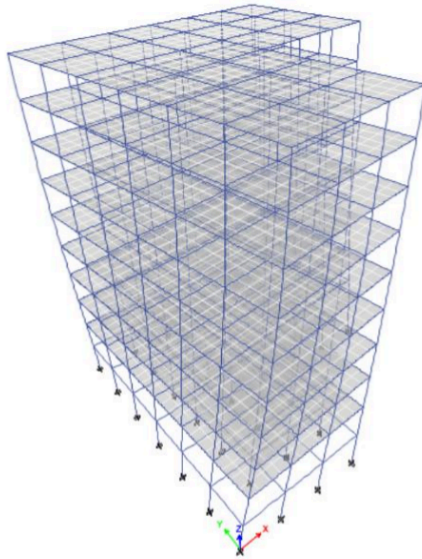


Figure 4.6 Deformed Shape Of L Shape Model In Mode 3

4.2.7 COLUMN FORCES

OUTER COLUMN

STOREY	AXIAL FORCE(KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5440.5715	1143.4234	-593.3329	577.9694
Storey 2	-4966.8439	995.4881	-385.6229	321.5215
Storey 3	-4345.7234	826.9926	-413.5807	287.0047
Storey 4	-3726.4754	664.1732	-391.8529	265.1330
Storey 5	-3116.6776	510.6351	-374.3757	237.1465
Storey 6	-2521.2668	369.3539	-346.7803	202.6086
Storey 7	-1946.7217	244.1666	-309.4338	159.4925
Storey 8	-1400.5777	139.7421	-261.2938	109.1828
Storey 9	-892.5090	61.4235	-196.4237	67.5378
Storey 10	-433.0922	17.9127	-158.9378	21.7590

Table 4.16 Outer Column Forces of L-Shape Model

INNER COLUMN

STOREY	AXIAL FORCE		BENDING MOMENT	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5625.3954	11.1814	-666.4313	667.1658
Storey 2	-5361.3714	11.7922	-593.5713	597.3256
Storey 3	-4750.1562	12.7998	-594.0394	599.2036
Storey 4	-4143.0205	13.1873	-573.6184	583.1718
Storey 5	-3538.7308	12.9340	-544.4198	556.7193
Storey 6	-2936.9621	12.1048	-500.4115	515.3132
Storey 7	-2337.2745	10.7707	-439.6075	456.6568
Storey 8	-1739.2485	8.9753	-359.9790	378.7096
Storey 9	-1142.3322	6.7406	-258.3799	278.4972
Storey 10	-559.1431	4.0005	-145.6782	168.8412

Table 4.17 Inner Column Forces of L-Shape Model

4.2.8 BEAM FORCES

PERIPHERY BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B31	Storey1	273.4	503.16
B31	Storey2	310.73	548.99
B31	Storey3	307.79	542.06
B31	Storey4	300.98	526.54
B31	Storey5	289.53	500.67
B31	Storey6	272.6	462.6
B31	Storey7	249.39	410.5
B31	Storey8	218.92	342.17
B31	Storey9	182.27	260.02
B31	Storey10	140.78	158.56

Table 4.18 Periphery Beam Forces of L-Shape Model

LONGITUDINAL INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B36	Storey1	257.73	494.71
B36	Storey2	314.93	546.58
B36	Storey3	312.94	542.59
B36	Storey4	305.92	527.17
B36	Storey5	294.48	501.91
B36	Storey6	277.67	464.66
B36	Storey7	254.7	413.66
B36	Storey8	224.67	346.8
B36	Storey9	188.37	266.4

B36	Storey10	154.94	172.19
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Table 4.19 Longitudinal Internal Beam Forces of L-Shape Model

TRANSVERSE INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B59	Storey1	253.68	480.68
B59	Storey2	316.01	542.7
B59	Storey3	315.53	540.96
B59	Storey4	309.37	527.25
B59	Storey5	298.36	502.71
B59	Storey6	281.75	465.86
B59	Storey7	258.78	414.97
B59	Storey8	228.69	348.62
B59	Storey9	192.28	267.85
B59	Storey10	160.88	181.99

Table 4.20 Transverse Internal Beam Forces of L-Shape Model

4.3 T SHAPE MODEL**4.3.1 STOREY DRIFT IN X DIRECTION**

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.001112
Storey9	36	0.001681
Storey8	32	0.002119
Storey7	28	0.002462
Storey6	24	0.002753
Storey5	20	0.003008

Storey4	16	0.003233
Storey3	12	0.003437
Storey2	8	0.003574
Storey1	4	0.002314
Base	0	0

Table 4.21 Storey Drift in X Direction of T-Shape Model

4.3.2 ¹ STOREY DRIFT IN Y DIRECTION

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.001294
Storey9	36	0.001978
Storey8	32	0.002498
Storey7	28	0.002906
Storey6	24	0.003256
Storey5	20	0.003546
Storey4	16	0.003809
Storey3	12	0.004067
Storey2	8	0.004209
Storey1	4	0.002763
Base	0	0

Table 4.22 Storey Drift in Y Direction of T-Shape Model

4.3.3 ¹ STOREY DISPLACEMENT IN X DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	92.595
Storey9	36	89.489
Storey8	32	84.535
Storey7	28	77.844
Storey6	24	69.586

Storey5	20	59.891
Storey4	16	48.864
Storey3	12	36.579
Storey2	8	23.138
Storey1	4	9.205
Base	0	0

Table 4.23 Storey Displacement in X Direction of T-Shape Model

4.3.4 STOREY DISPLACEMENT IN Y DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	113.693
Storey9	36	109.462
Storey8	32	103.032
Storey7	28	94.57
Storey6	24	84.284
Storey5	20	72.358
Storey4	16	58.922
Storey3	12	44.04
Storey2	8	27.862
Storey1	4	11.051
Base	0	0

Table 4.24 Storey Displacement in Y Direction of T-Shape Model

4.3.5 BASE SHEAR VALUE

6517.1741 KN

4.3.6 MODAL MASS PARTICIPATION ANALYSIS

MODE	PERIOD	UX	UY	RZ
1	2.998	0.00001	0.8424	0.0188
2	2.835	0.8581	0.00004	0.0191
3	2.66	0.0004	0.0198	0.8557

Table 4.25 Modal Mass Participation Analysis of T-Shape Model

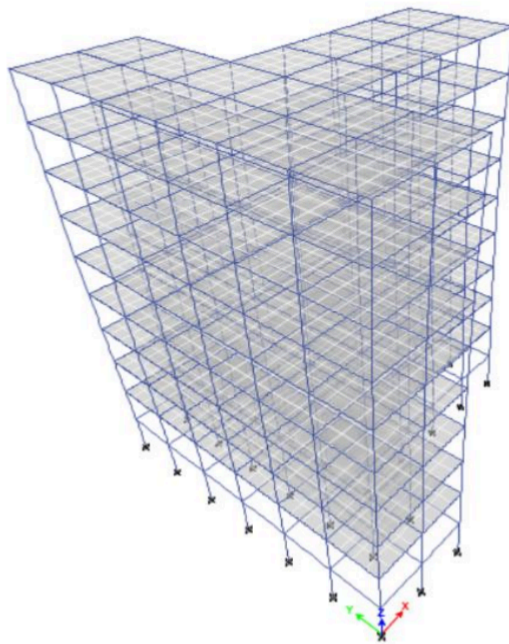


Figure 4.7 Deformed Shape of T-Shape Model in Mode 1

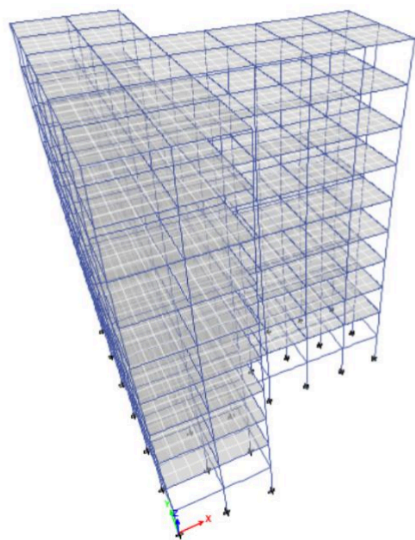


Figure 4.8 Deformed Shape of T-Shape Model in Mode 2

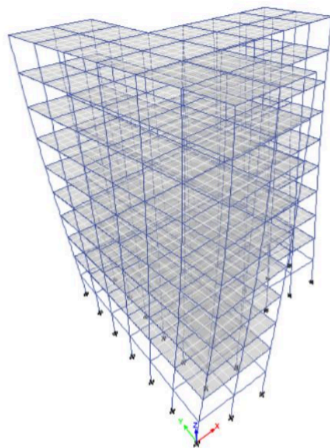


Figure 4.9 Deformed Shape of T-Shape Model in Mode 3

4.3.7 COLUMN FORCES

OUTER COLUMN

STOREY	AXIAL FORCE (KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-6011.4378	1500.7692	-803.9766	785.8188
Storey 2	-5478.6142	1315.2213	-490.3936	426.0277
Storey 3	-4780.5591	1097.6610	-521.8347	390.3996
Storey 4	-4082.5784	884.6501	-487.7093	357.6088
Storey 5	-3397.1952	683.0234	-463.9294	323.0359
Storey 6	-2730.8778	496.7857	-426.2807	278.5659
Storey 7	-2092.1590	331.1305	-376.0184	222.6458
Storey 8	-1490.8713	192.2594	-311.4271	151.8791
Storey 9	-938.8200	87.2200	-226.3665	86.3960
Storey 10	-444.7026	23.8627	-169.2166	27.8764

Table 4.26 Outer Column Forces of T-Shape Model

INNER COLUMN

STOREY	AXIAL FORCE (KN)		BENDING MOMENT (KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5546.5877	6.3889	-904.4601	901.1535
Storey 2	-5283.9424	6.6970	-779.9263	780.3653
Storey 3	-4672.4776	7.4318	-795.2937	795.1004
Storey 4	-4069.0552	7.7699	-769.1376	769.6701
Storey 5	-3471.1138	7.6799	-734.5832	735.6037
Storey 6	-2878.0286	7.1497	-679.1852	680.7278
Storey 7	-2288.9273	6.2225	-600.7540	602.7775
Storey 8	-1703.0163	4.9541	-496.6525	499.2239
Storey 9	-1119.1753	3.3891	-362.6319	365.1085
Storey 10	-549.5688	5.4768	-220.3595	225.7639

Table 4.27 Inner Column Forces of T-Shape Model

4.3.8 BEAM FORCES

PERIPHERY BEAM

Beam	Floor	Max Absolute Shear Force V2 (Kn)	Max Absolute Bending Moment M3 (Kn-m)
B31	Storey1	330.48	631.6
B31	Storey2	373.58	689.59
B31	Storey3	370.56	682.49
B31	Storey4	361.68	662.32
B31	Storey5	346.78	628.72
B31	Storey6	324.73	579.19
B31	Storey7	294.48	511.34
B31	Storey8	254.79	422.32
B31	Storey9	207.05	315.45
B31	Storey10	152.64	185.39

Table 4.28 Periphery Beam Forces of T-Shape Model

LONGITUDINAL INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B36	Storey1	316.75	627.46
B36	Storey2	378.93	689.08
B36	Storey3	378.04	687.42
B36	Storey4	369.34	668.11
B36	Storey5	354.78	635.8
B36	Storey6	333.1	587.56
B36	Storey7	303.25	521.12
B36	Storey8	264.03	433.67
B36	Storey9	216.88	329.14

B36	Storey10	168.67	200.84
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Table 4.29 Longitudinal Internal Beam Forces of T-Shape Model

TRANSVERSE INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B59	Storey1	309.06	600.58
B59	Storey2	381.63	682.32
B59	Storey3	383.81	687.46
B59	Storey4	376.04	670.92
B59	Storey5	361.77	640
B59	Storey6	339.95	592.51
B59	Storey7	309.62	526.33
B59	Storey8	269.83	439.49
B59	Storey9	222.01	334.85
B59	Storey10	176.55	219.02

Table 4.30 Transverse Internal Beam Forces of T-Shape Model

4.4 + SHAPE MODEL**4.4.1 ¹ STOREY DRIFT IN X DIRECTION**

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.001052
Storey9	36	0.001641
Storey8	32	0.002079
Storey7	28	0.002419
Storey6	24	0.002715
Storey5	20	0.002969
Storey4	16	0.0032
Storey3	12	0.003426
Storey2	8	0.003571

Storey1	4	0.002305
Base	0	0

Table 4.31 ¹⁷ Storey Drift in X Direction of + Shape Model

4.4.2 ¹ STOREY DRIFT IN Y DIRECTION

STOREY	ELEVATION (m)	DRIFT (mm)
Storey10	40	0.001065
Storey9	36	0.001681
Storey8	32	0.002139
Storey7	28	0.002493
Storey6	24	0.002809
Storey5	20	0.003085
Storey4	16	0.003329
Storey3	12	0.00357
Storey2	8	0.003779
Storey1	4	0.002554
² Base	0	0

Table 4.32 Storey Drift in Y Direction of + Shape Model

4.4.3 ¹ STOREY DISPLACEMENT IN X DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	94.31
Storey9	36	90.995
Storey8	32	85.817
Storey7	28	78.911
Storey6	24	70.447
Storey5	20	60.566
Storey4	16	49.37
Storey3	12	36.907
Storey2	8	23.29

Storey1	4	9.219
Base	0	0

16
Table 4.33 Storey Displacement in X Direction of + Shape Model

4.4.4 STOREY DISPLACEMENT IN Y DIRECTION

STOREY	ELEVATION (m)	DISPLACEMENT(mm)
Storey10	40	98.304
Storey9	36	94.995
Storey8	32	89.729
Storey7	28	82.657
Storey6	24	73.949
Storey5	20	63.74
Storey4	16	52.15
Storey3	12	39.239
Storey2	8	25.077
Storey1	4	10.215
Base	0	0

Table 4.34 Storey Displacement in Y Direction of + Shape Model

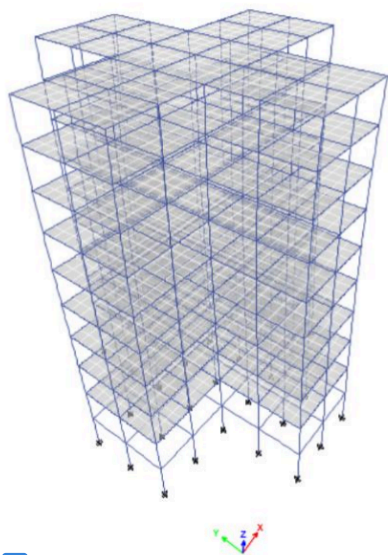
4.4.5 BASE SHEAR VALUE

6522.3101 KN

4.4.6 MODAL MASS PARTICIPATION ANALYSIS

MODE	PERIOD	UX	UY	RZ
1	2.988	0	0.8629	0.0001
2	2.834	0.859	0	0.0003
3	2.594	0.0002	0.0001	0.8559

Table 4.35 Modal Mass Participation Analysis of + Shape Model



12
Figure 4.10 Deformed Shape of (+) Shape in Mode 1

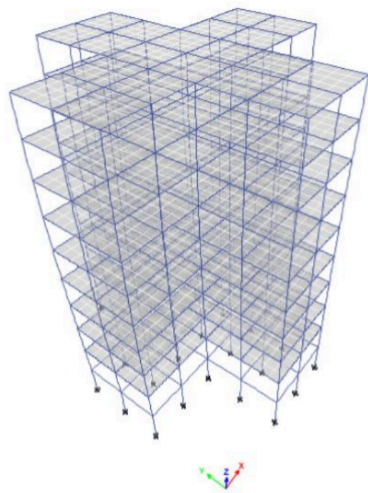


Figure 4.11 Deformed Shape of (+) Shape in Mode 2

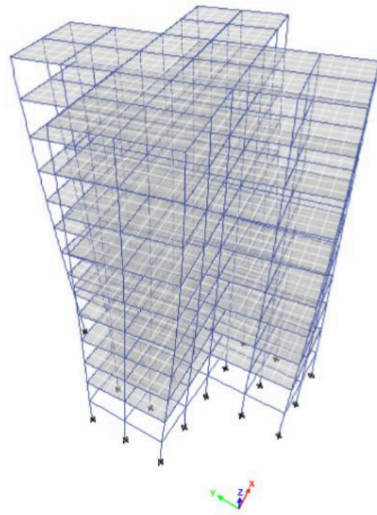


Figure 4.12 Deformed Shape of (+) Shape in Mode 3

4.4.7 COLUMN FORCES

OUTER COLUMN

Storey	AXIAL FORCE(KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5701.9159	1495.0406	-803.2759	786.7838
Storey 2	-5174.1997	1310.2947	-489.0305	427.5383
Storey 3	-4482.4171	1091.5952	-516.9080	391.9571
Storey 4	-3803.0059	878.3354	-482.5474	359.8563
Storey 5	-3144.5641	676.7567	-457.9344	325.7631
Storey 6	-2512.5841	490.8882	-419.7886	281.7316
Storey 7	-1914.2044	325.8672	-369.1629	226.1714
Storey 8	-1358.3286	187.8879	-304.2436	155.7323
Storey 9	-854.5392	84.0063	-219.4648	86.2904
Storey 10	-422.2522	23.8577	-161.6855	26.6141

Table 4.36 Outer Column Forces of + Shape Model

INNER COLUMN

STOREY	AXIAL FORCE(KN)		BENDING MOMENT(KN-m)	
	COMPRESSION	TENSION	-ve BM	+ BM
Storey 1	-5544.6814	16.8486	-903.4390	900.9654
Storey 2	-5282.1013	15.2835	-782.0064	778.5807
Storey 3	-4670.7173	15.4438	-801.1903	790.5046
Storey 4	-4067.4421	14.8796	-776.6389	763.4174
Storey 5	-3469.6869	13.8619	-744.1761	727.4602
Storey 6	-2876.8271	12.1816	-690.5337	670.9382
Storey 7	-2287.9828	9.7926	-613.5988	591.5534
Storey 8	-1702.3552	6.7005	-510.8126	486.6644
Storey 9	-1118.8064	3.0468	-376.9773	352.2144
Storey 10	-549.7121	5.4780	-238.7192	208.5042

Table 4.37 Inner Column Forces of + Shape Model

4.4.8 BEAM FORCES**PERIPHERY BEAM**

Beam	Floor	Max Absolute Shear Force V2 (Kn)	Max Absolute Bending Moment M3 (Kn-m)
B31	Storey1	361.33	740.58
B31	Storey2	403.6	793.28
B31	Storey3	395.44	772.84
B31	Storey4	384.38	745.21
B31	Storey5	366.47	701.43
B31	Storey6	340.95	639.71
B31	Storey7	306.55	557.01
B31	Storey8	261.51	448.94
B31	Storey9	208.06	321.82
B31	Storey10	148.38	162.75

Table 4.38 Periphery Beam Forces of + Shape Model

LONGITUDINAL INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B36	Storey1	347.65	736.23
B36	Storey2	405.88	783.96
B36	Storey3	401.75	773.85
B36	Storey4	391.32	748.13
B36	Storey5	374.53	707.5
B36	Storey6	350.1	648.82
B36	Storey7	316.88	569.38
B36	Storey8	273	464.46
B36	Storey9	221.53	343.08
B36	Storey10	164.71	178.72

Table 4.39 Longitudinal Internal Beam Forces of + Shape Model

TRANSVERSE INTERNAL BEAM

Beam	Floor	Max Absolute Shear Force V2 (kN)	Max Absolute Bending Moment M3 (kN-m)
B59	Storey1	309.67	600.59
B59	Storey2	382.21	685.25
B59	Storey3	384.62	691.51
B59	Storey4	377.16	676.28
B59	Storey5	363.26	646.62
B59	Storey6	341.8	600.27
B59	Storey7	311.79	535.06
B59	Storey8	272.17	448.76
B59	Storey9	224.79	345.16
B59	Storey10	177.72	225.5

Table 4.40 Transverse Internal Beam Forces of + Shape Model

4.5 COMPARISON OF PARAMETERS OF ALL MODELS

4.5.1 BASE SHEAR

The Base shear value is lowest in the Regular (Square) plan model 5826.51. Its structural arrangement minimizes the amplification of seismic design forces by enabling appropriate mass distribution. + shape model has the highest value of base shear followed by T shape and L shape model.

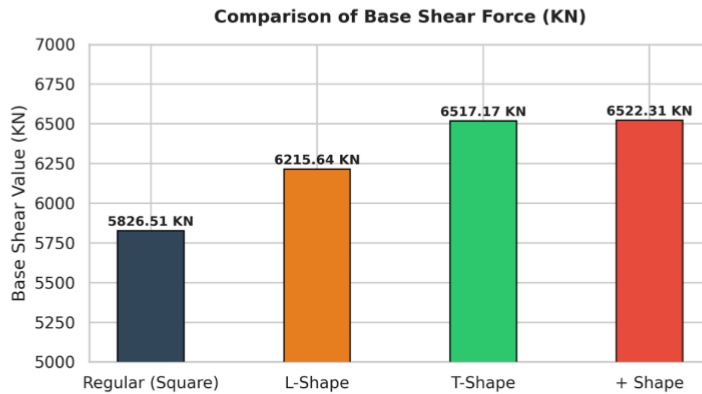


Figure 4.13 Comparison of Base Shear

4.5.2 STOREY DRIFT

The Regular (Square) Model has remarkable structural control when examining the Storey Drift Ratio, maintaining a highly consistent resistance pattern over all stories and limiting the relative shift between adjacent floors to a baseline minimum of 0.00076 at its higher levels. The T-Shape Model, on the other hand, exhibits significant structural deformation and records the highest and most critical inter-storey drift value of 0.00421, which is primarily centred at Storey 2. The Regular Model is without a doubt the safest arrangement in terms of safety.

1 STOREY DRIFT IN X DIRECTION

STOREY	ELEVATION (m)	SQUARE SHAPE	L SHAPE	T SHAPE	+ SHAPE
Storey10	40	0.000761	0.000979	0.001112	0.001052
Storey9	36	0.001256	0.001526	0.001681	0.001641
Storey8	32	0.001635	0.001949	0.002119	0.002079
Storey7	28	0.001926	0.002279	0.002462	0.002419
Storey6	24	0.00217	0.002555	0.002753	0.002715
Storey5	20	0.002385	0.002795	0.003008	0.002969
Storey4	16	0.002593	0.003018	0.003233	0.0032
Storey3	12	0.002809	0.003232	0.003437	0.003426
Storey2	8	0.002998	0.003381	0.003574	0.003571
Storey1	4	0.00214	0.002255	0.002314	0.002305
Base	0	0	0	0	0

Table 4.41 Comparison of ⁵Storey Drift In X Direction

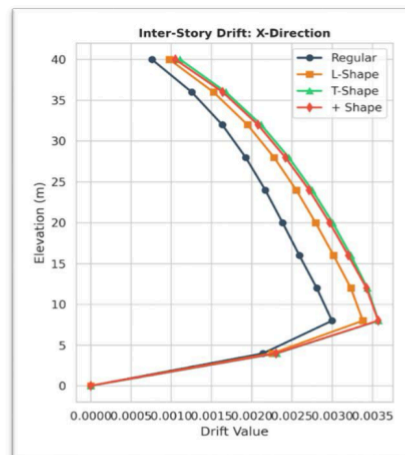


Figure 4.14 Storey Drift In X Direction

STOREY DRIFT IN Y DIRECTION

STOREY	ELEVATION (m)	SQUARE SHAPE	L SHAPE	T SHAPE	+ SHAPE
Storey10	40	0.000761	0.000981	0.001294	0.001065
Storey9	36	0.001256	0.001545	0.001978	0.001681
Storey8	32	0.001635	0.001983	0.002498	0.002139
Storey7	28	0.001926	0.002318	0.002906	0.002493
Storey6	24	0.00217	0.002607	0.003256	0.002809
Storey5	20	0.002385	0.002857	0.003546	0.003085
Storey4	16	0.002593	0.003085	0.003809	0.003329
Storey3	12	0.002809	0.003311	0.004067	0.00357
Storey2	8	0.002998	0.003489	0.004209	0.003779
Storey1	4	0.00214	0.00238	0.002763	0.002554
Base	0	0	0	0	0

Table 4.42 Comparison of Storey Drift In Y Direction

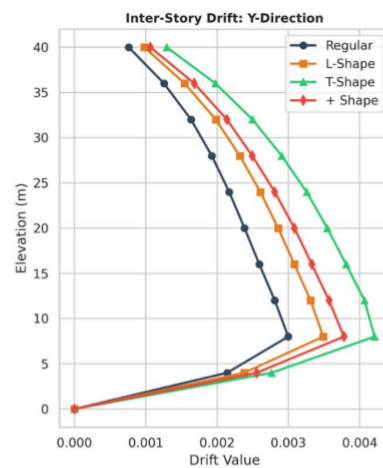


Figure 4.14 Storey Drift In Y Direction

4.5.3 STOREY DISPLACEMENT

With the lowest absolute deflection values of 76.81 mm along the Y-axis and 76.89 mm along the X-axis, the Regular (Square) Model clearly performs the best when assessing Max Storey Displacement. On the other hand, the T-Shape Model, which peaks at a high 113.69 mm in the Y-direction, records the largest and most adverse displacement. Because of its geometric symmetry, which avoids excessive lateral wobbling, the Regular Model is the safest configuration in terms of safety. This limits serious structural collapse under lateral pressure and significantly reduces the possibility of structural pounding against neighboring properties.

¹⁹ STOREY DISPLACEMENT IN X DIRECTION

STOREY	ELEVATION (m)	SQUARE SHAPE	L SHAPE	T SHAPE	+ SHAPE
Storey10	40	76.885	88.179	92.595	94.31
Storey9	36	74.518	85.237	89.489	90.995
Storey8	32	70.579	80.534	84.535	85.817
Storey7	28	65.205	74.191	77.844	78.911
Storey6	24	58.546	66.376	69.586	70.447
Storey5	20	50.703	57.217	59.891	60.566
Storey4	16	41.732	46.799	48.864	49.37
Storey3	12	31.645	35.168	36.579	36.907
Storey2	8	20.491	22.422	23.138	23.29
Storey1	4	8.561	8.997	9.205	9.219
Base	0	0	0	0	0

Table 4.43 Comparison of Storey Displacement In X Direction

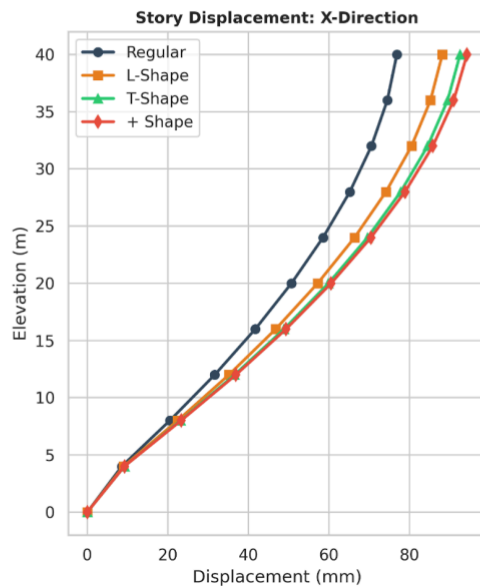


Figure 4.15 Storey Displacement In X Direction

STOREY DISPLACEMENT IN Y DIRECTION

STOREY	ELEVATION (m)	SQUARE SHAPE	L SHAPE	T SHAPE	+ SHAPE
Storey10	40	76.805	91.802	113.693	98.304
Storey9	36	74.446	88.648	109.462	94.995
Storey8	32	70.521	83.68	103.032	89.729
Storey7	28	65.161	77.04	94.57	82.657
Storey6	24	58.513	68.899	84.284	73.949
Storey5	20	50.681	59.387	72.358	63.74
Storey4	16	41.718	48.601	58.922	52.15
Storey3	12	31.638	36.591	44.04	39.239
Storey2	8	20.487	23.438	27.862	25.077

Storey1	4	8.56	9.518	11.051	10.215
Base	0	0	0	0	0

Table 4.44 Comparison of Storey Displacement In Y Direction

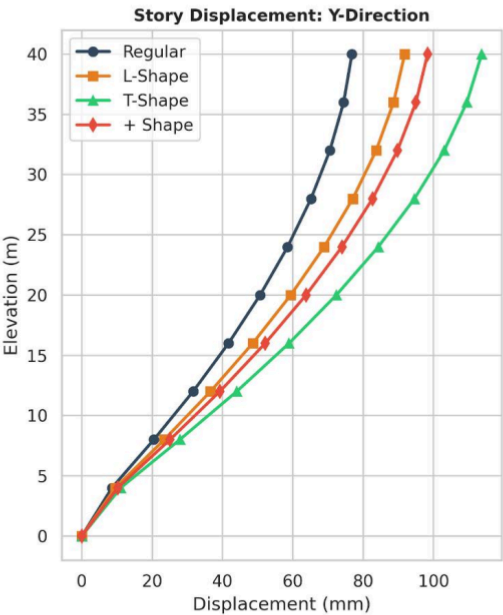


Figure 4.16 Storey Displacement In Y Direction

4.5.4 MODAL MASS PARTICIPATION ANALYSIS

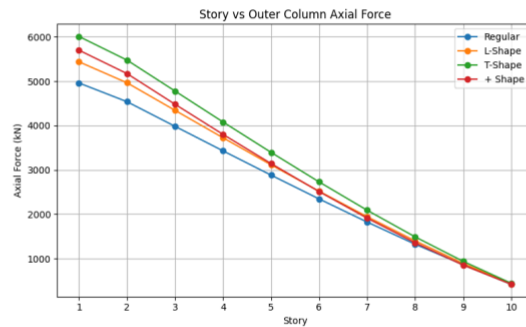
The Regular (Square) Model has the lowest torsional behavior by exactly isolating twisting movements in Mode 3 and maintaining pure and predictable translations in Modes 1 and 2. The T-Shape Model is the most irregular in its main modes of vibration, leading to an immediate dangerous coupling between translation and torsion. The Regular Model is the most secure model as it ensures that the building does not bend when it sways due to the center of mass and stiffness matching. This

avoids the potential for the stresses that could be required at the re-entrant corners of the T-Shape.

MODEL	MODE	PERIOD(SEC)	UX	UY	RZ
SQUARE	1	2.284	0.4241	0.4241	0.0028
	2	2.283	0.4255	0.4255	0
	3	2.084	0.0014	0.0014	0.8471
L SHAPE	1	2.628	0.0007	0.8538	0.0036
	2	2.551	0.8462	0.0004	0.0094
	3	2.352	0.0095	0.0042	0.8418
T SHAPE	1	2.998	0.00001	0.8424	0.0188
	2	2.835	0.8581	0.00004	0.0191
	3	2.66	0.0004	0.0198	0.8557
+ SHAPE	1	2.988	0	0.8629	0.0001
	2	2.834	0.859	0	0.0003
	3	2.594	0.0002	0.0001	0.8559

Table 4.45 Comparison of Modal Mass Data

4.6 COMPARISON OF COLUMN FORCES



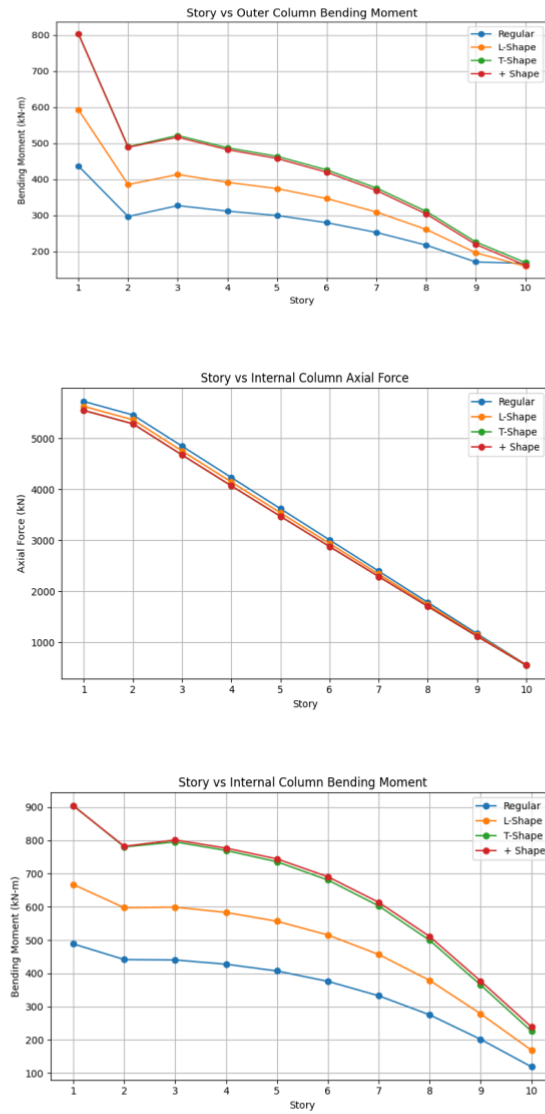
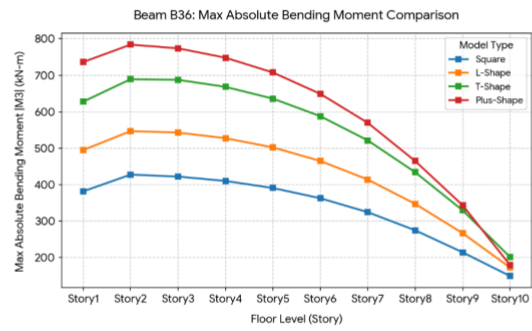
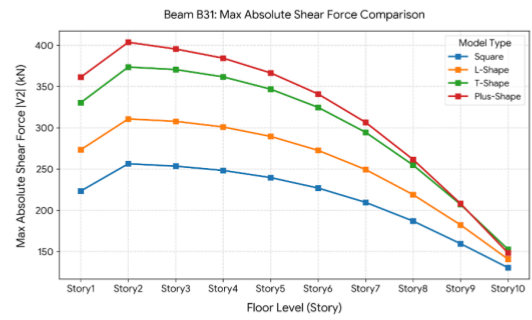
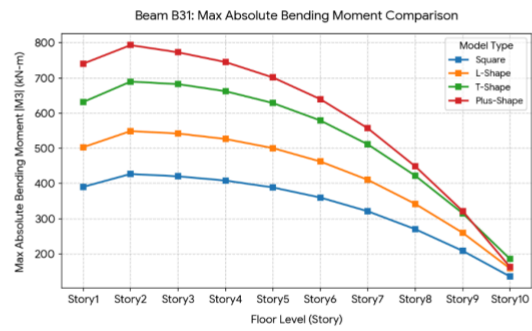


Figure 4.17 Comparison of Column Forces

4.7 COMPARISON OF BEAM FORCES



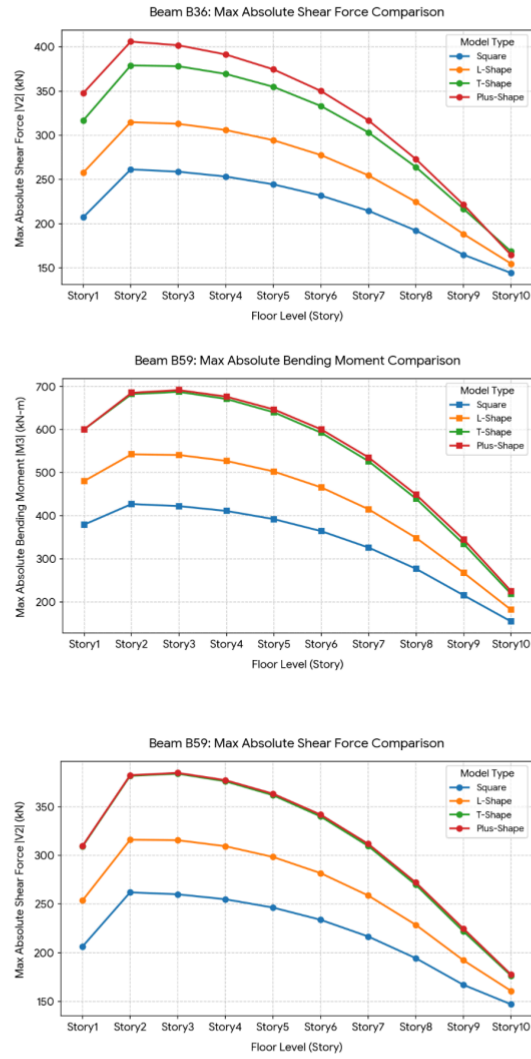


Figure 4.18 Comparison of Beam Forces

CHAPTER 5

CONCLUSION

- The Regular (Square) model showed the lowest ²²storey drift values in both the X and Y directions. It has a maximum drift of 0.002998 mm at Storey 2. In contrast, the T-shape model has the highest critical inter-storey drift at 0.004209 mm, occurring at Storey 2 in the Y direction. From all the irregular models, the T-shape is the most at risk for drift-related damage, with the Plus and L-shape models following in vulnerability.
- As per the specifications of IS1893:2016, the drift values of all models are within the prescribed limit of 0.004h.
- The T-shape model showed the highest displacement which is about 48% more than the Regular model. The Plus shape and L-shape models displayed intermediate displacement behavior. The large increase in displacements for irregular models mainly results from torsional amplification and stress concentrations at re-entrant corners.
- ⁷The Plus (+) shape model recorded the highest base shear value followed by T shape and L shape model whereas the square shape model witnessed the least value. This shows that irregular shapes increase the seismic demand on a structure.
- In their primary modes, all three irregular models (L, T, and +) displayed notable translational-torsional interaction. The structure starts to twist even in its fundamental translational modes, as displayed by the T-shape model's maximum torsional irregularity and significant RZ contributions in Modes 1 and 2. The Regular model showed a clear, dissociated translational response, with Mode 3 being exclusively torsional and Modes 1 and 2 being purely translational, suggesting very little torsional coupling.
- This study has proved that strong seismic performance is showed by symmetrical regular(square) shape model. Due to stress concentrations at its

four re-entrant corners, the Plus (+) shape showed more storey drifts and displacements than the regular model, while being globally symmetric with coincident centers of mass and stiffness. This demonstrates that, after having overall geometric symmetry, re-entrant corners generally degrade seismic response.

- Irregularity has a significant effect in increasing the column forces, when compared to the Regular (Square) model in all models. The largest increases are displayed on the inner column bending moments (~36% increase in L-shape, ~85% increase in T-shape and Plus shape). These findings validate that the irregular shapes have an excessive requirement for axial and moment forces on columns, with the T-shape and Plus shape geometry being the worst configurations.
- Irregularity will always make the beam shear forces and beam bending moments larger on each floor level. Periphery beam bending moments at Storey 2 are found to be ~28%, ~61%, and ~86% higher in the periphery of the beam, for L shape, T shape and Plus shape respectively, compared to the Regular model. The same is true for the internal longitudinal and transverse beams, which experience increases of ~27–28% (L-shape) and ~60–83% (T and Plus shapes), respectively. This indicates that the plan geometry of the houses will have to be designed to be much heavier, with the Plus (+) and T-shape designs being the most complex.
- The regular square configuration turns out to be the most safe configuration because it has the best potential of reducing the seismic demand and preventing undesirable twisting phenomena. Regular geometry provides the ultimate level of structural stability by providing a clean, predictable response to loading rather than having localized stress points like irregular shapes.

FUTURE SCOPE OF WORK

- Under a given column stiffness budget, the current research is focused on plan (horizontal) irregularities. Future studies might incorporate such specific plan geometries and vertical discontinuities as mass irregularities or soft stories, and examine the effects of coupled horizontal-vertical earthquakes.
- Nonlinear Dynamic Analysis: It was carried out using linear dynamic Response Spectrum Analysis (RSA). Rotational, progressive structural degradation, the formation of plastic hinges and actual collapse mechanisms should be examined by future investigations through Nonlinear Time-Historey Analysis (NLTHA) with real and scaled earthquake accelerograms.
- Optimization of Stiffness Redistribution: In this work, total column stiffness of the column is normalized by enlarge the columns symmetrically in reduced-area plans, but in further studies, it is possible to investigate asymmetric optimization of stiffness of the column. Rather than increasing the size or stiffness of the columns throughout the entire structure, it is possible to analyse the effect of strategically increasing the size or stiffness of the columns only in the re-entrant corners to identify if the structure can be made to efficiently minimise the torsional coupling.
- Effect of Structural Wall Configuration: Further studies could examine the effectiveness of the added RC shear walls or steel bracing system. In particular, the effects of shear wall placement (shear wall at re-entrant corners vs at the central cores) on base shear redistribution and on controlling torsional amplification in the T- and Plus-shaped models would be of great value.
- Soil-Structure Interaction (SSI): The analytical models used were medium soil, with fixed base. Further studies have the potential to incorporate flexible foundations to investigate Soil-Structure Interaction (SSI) for different soil profiles (soft, medium and hard) and to calculate the changes in natural periods and torsional response of irregular buildings for different soil compliance.

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