

# Seismic Performance and Cost Optimization of Asymmetrical RC Buildings: A Performance-Based Approach

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## Abstract

Asymmetrical reinforced concrete (RC) structures exhibit irregular mass and stiffness distributions, leading to torsional effects and complex seismic responses. This study examines the seismic performance and cost implications of three configurations, rectangular (symmetrical), L-shaped, and T-shaped, modelled and analysed in ETABS according to the IS 1893:2016 provisions. Key performance parameters, including base shear, story shear, story drift, and displacement, were evaluated for each model. It has been seen that asymmetrical forms demonstrate higher vulnerability, about 25-30% compared to a symmetric structure, when subjected to ground motion; however, their performance can be improved through strategically undertaken countermeasures such as optimal placement of shear walls, strengthening of diaphragm cores, and strategic stiffness balancing. Cost analysis was done based on material quantity and reinforcement estimates, which revealed that asymmetry generally increases construction costs due to greater concrete and steel requirements. Nevertheless, optimisation strategies such as selective shear wall installation or enlargement of the core column can also reduce displacement by 40% and increase cost by up to 11%. The research culminates in a design framework integrating performance-based analysis with cost efficiency, enabling the development of seismically safe, cost-effective asymmetrical RC buildings. The proposed approach offers practical guidance for residential construction in earthquake-prone regions, ensuring that architectural asymmetry can coexist with structural resilience and economic feasibility.

**Keywords:** Symmetric structures, Asymmetric structures, Cost implications, Seismic performance.

## 1 Introduction

In the realm of civil engineering, the design of RC structures has long been a subject of structural engineering research, particularly due to the catastrophic effects of earthquakes, which are more prone to irregular and asymmetric configurations. While symmetrical structures typically perform better under seismic excitation due to uniform stiffness and mass distribution, asymmetrical buildings are more prone to torsional irregularities, stress concentrations, and uneven displacement demands, thereby increasing their vulnerability to structural damage [1]. In practice, a symmetric structure is seldom constructed nowadays. Different types of variation in functional requirements, architectural aesthetics, and urban

planning constraints result in an asymmetric structure either in plan or in elevation [2]. The irregularities in the plan, such as in the L and T-shaped layout, lead to eccentricity between the centre of mass (CM) and centre of rigidity (CR), producing torsional coupling during ground motion. Analogously, vertical asymmetries arise from uneven stiffness or mass distribution along the height, which can trigger story failure and amplify the seismic demands [3, 4]. Earlier studies have shown that the asymmetrical structure not only amplifies story drift and displacement but also complicates the design of lateral force resisting systems (LFRS) [5]. It has been proven that the asymmetrical structure not only amplifies story drift and displacement but also complicates the design of LFRS. This further suggests that the shear wall can reduce the impact to a considerable level. The strategic use of shear walls, diaphragmatic strengthening, and optimised column layouts can significantly mitigate torsional irregularities and enhance seismic resilience [6]. These countermeasures inevitably increase the utilisation of materials, and that can lead to higher construction costs, which cause challenges to the financially constrained environments. In seismic-prone countries like India, architects often pursue unique structural designs for aesthetics and space optimisation; asymmetry is often unintentionally introduced (IS 1893, 2016) [7]. The inevitable increase in the utilisation of materials can lead to higher construction costs, which cause challenges in the financially constrained environments. In seismic-prone countries like India, architects often pursue unique structural designs for aesthetics and space optimisation, and asymmetry is often unintentionally introduced (IS 1893, 2016) [7]. This demands a balance between architectural freedom, structural safety, and cost-effectiveness. While performance-based seismic design (PBSD) provides a rational framework for evaluating nonlinear behaviour, there remains a gap in establishing cost-optimised strategies for asymmetrical RC buildings that meet both safety and economic feasibility [8, 9].

This study investigates the seismic response of the asymmetrical RC structures, focusing on L-shaped and T-shaped configurations, and compares them against symmetrical structures. ETABS has been used throughout the analysis and is evaluated as per the guidelines of IS 1893:2016 provisions. Additionally, the study has investigated the cost implications of incorporating shear walls and diaphragm strengthening, recommending an optimised design framework for occupant safety as well as affordable asymmetrical RC buildings in seismic-prone regions.

## **2 Methodology**

The configurations of the three buildings are rectangular (symmetrical), T-shaped (asymmetric), and L-shaped (asymmetric), and were modelled as four-story RC structures (height 12 m) with moment-resisting frames, as shown in Figs. 1 & 2. All models had uniform story heights (3 m) and consistent material properties (M30 concrete, Fe500 steel) to isolate the effect of plan irregularity.

### **2.1 Analytical procedure**

Pushover, static and dynamic analyses were conducted, including P–Delta effects. Checks for plan and vertical irregularities, stiffness imbalance, and torsional response were performed. Key parameters extracted included base shear, story shear, drift ratios, and displacements.

### **Design and Optimization**

Structural members were designed for combined load cases as per the IS codes. Where irregular responses exceeded code limits, mitigation strategies were tested—such as adding shear walls in different orientations and enlarging core columns.

### Manual calculation

This formula distributes the total seismic base shear proportional to the floor's weight and height squared, ensuring realistic lateral force allocation during earthquakes

$$Q_i = V_b [(W_i \cdot h_i^2) / (\sum_{j=1}^n (W_j \cdot h_j^2))] \quad (1)$$

Where,

$Q_i$  = Story shear at the  $i$ th floor

$V_b$  = Base shear

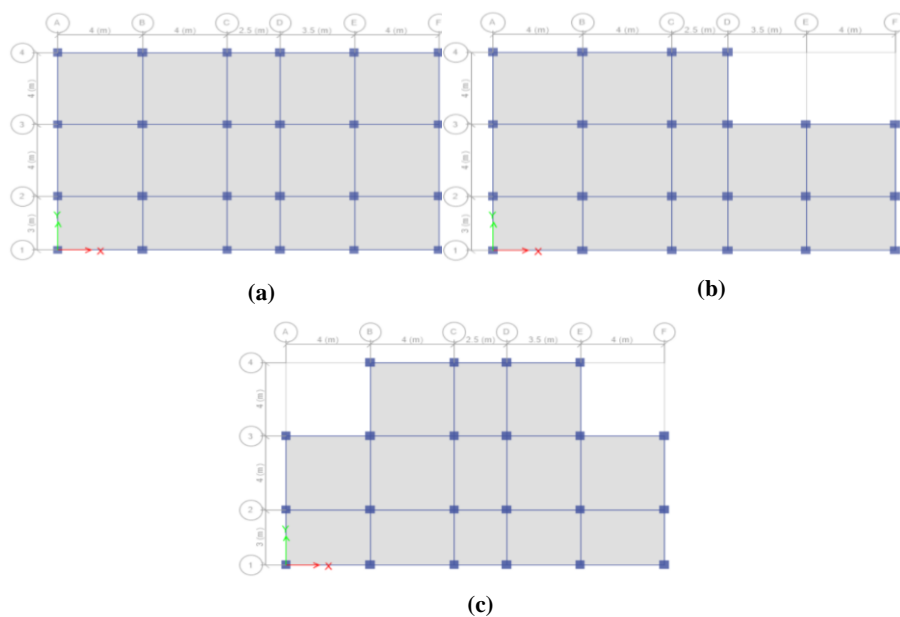
$W_i$  = Seismic weight of the  $i$ th floor

$h_i$  = Height of the  $i$ th floor from base

The denominator sums over the  $n$ th storey

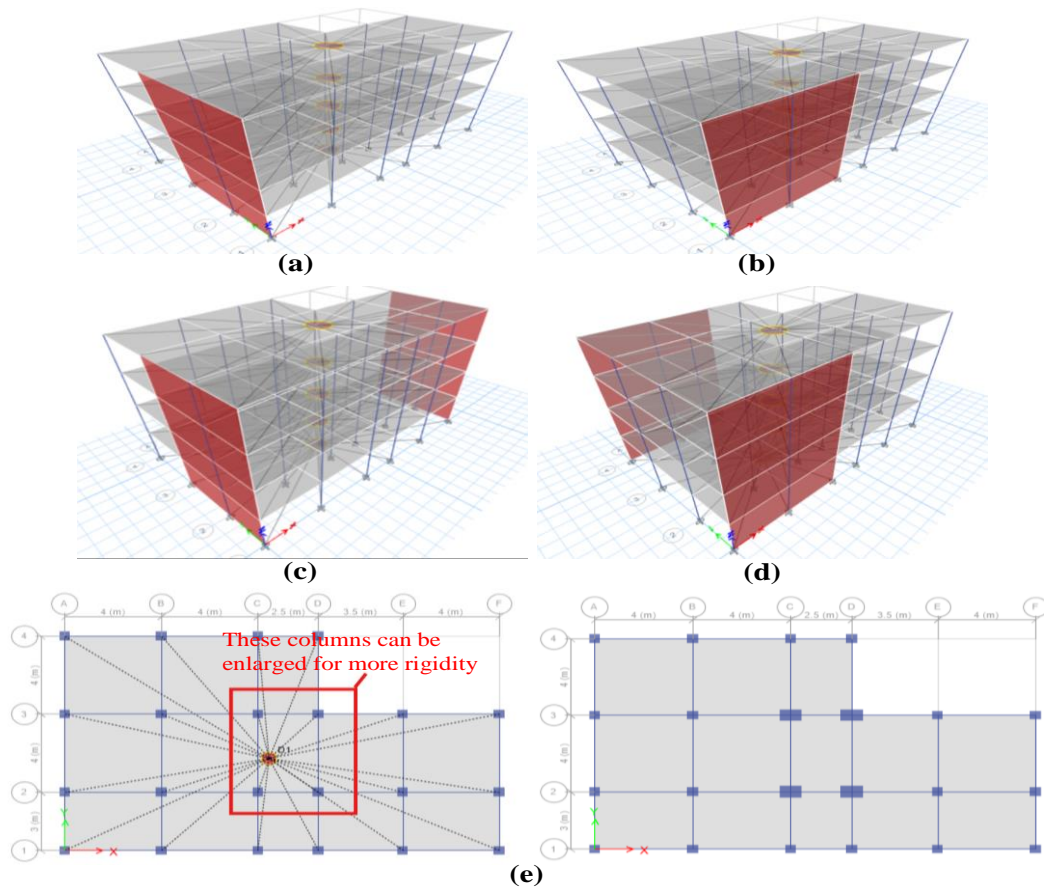
### 2.2 Layout of all models

The load calculation of all the models is done according to the following: Gravity loads and load combinations (IS 875 Part 1 & 2), dead load (DL) 11.877 kN/m<sup>2</sup>, Live load (LL) 25% of DL 0.625 kN/m<sup>2</sup>, column load (0.45x0.45x25)= 5.0625 kN/m<sup>2</sup>, Beam load (0.35x0.35x25)= 3.0625, Slab dead load (0.15x25)= 3.75, Total load = 12.502 kN/m<sup>2</sup> and seismic loads were assigned using the response spectrum method. Zone V seismic parameters, medium soil conditions (type II), accidental eccentricity ( $\pm 5\%$ ), Importance factor (I) 1.0, and response reduction factor (R) 5.0, Spectral Acceleration ( $S_a/g$ )  $\sim 4.0$ , were incorporated to capture torsional effects. The model mentioned in Fig. 1(a, b, and c) below is the plan of the model to be analysed. Num-ber of floors 4, Floor height 3m, plan dimension 11 m  $\times$  18.5 m = 203.5 m<sup>2</sup>



**Fig. 1.** Layout of (a) rectangular model, (b) T-shaped model, (c) L-shaped model

## 2.3 Recommended L-shaped models (Shear wall involvement) & core strengthening model



**Fig. 2.** Recommended L-shaped model (a) L1, (b) L2, (c) L3 (d) L4 (e) Strengthened core with diaphragm L5

Fig 2 represents the recommended models where the position of shear walls is placed strategically, the single shear wall is placed in X & Y directions alternately in Fig. 2 (a&b), and double shear walls are in X&Y directions alternately in Fig. 2 (c&d).

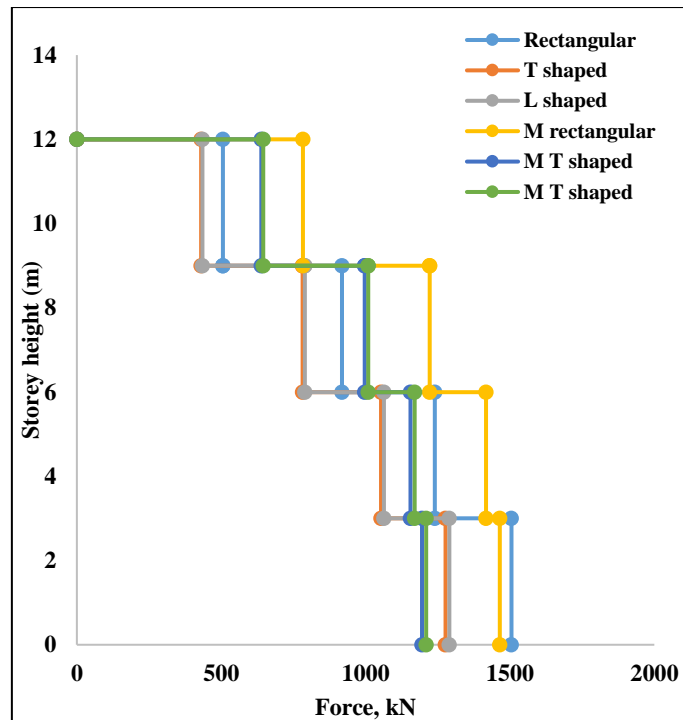
### Cost–Performance Assessment

Concrete volumes for each configuration were computed from ETABS output to compare structural performance improvements against material usage, identifying the most cost-effective seismic strengthening solution.

## 3 Results and discussions

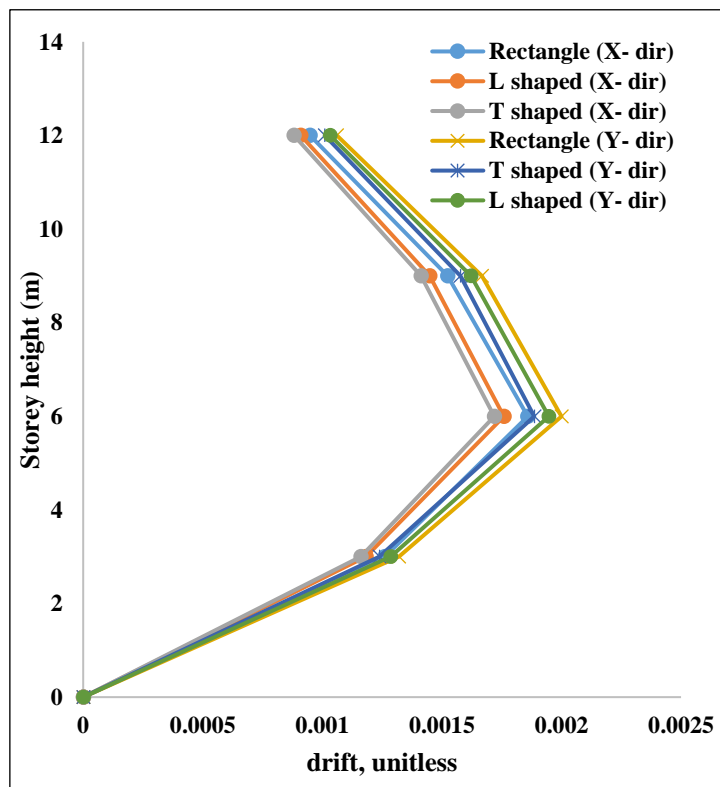
### 3.1 Analytical procedure of T, L, and rectangle-shaped model

From Fig. 3, it can be understood that the comparison between the ETABS analytical result and the manual calculation is in the context of story shear along the X-direction. It elaborates on the distribution of seismic lateral forces among the building height, framing the reliability of the analytical model, and validating the manual calculation approach. The plot reflects higher story shear values in asymmetrical models (L-shaped and T-shaped) compared to the symmetrical rectangular one, where “M” stands for manual. Whereas Fig. 4 shows the analytical evaluation of the story drift in both X & Y directions.

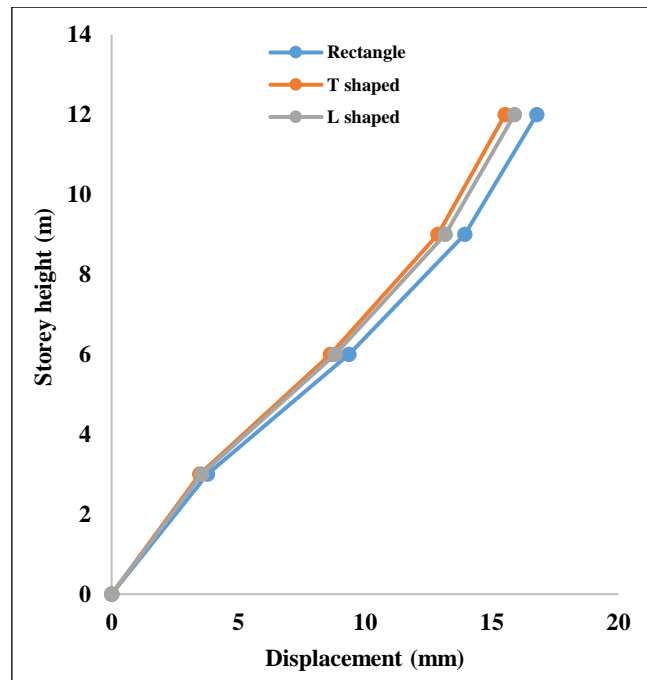


**Fig. 3.** Analytical and Manual calculation of Storey shear of all models (X direction).

It reveals that asymmetrical structures experience a greater drift ratio, resulting in elevated lateral displacements that potentially increase the chance of severe damage under seismic excitation, supporting the argument on torsional irregularities.

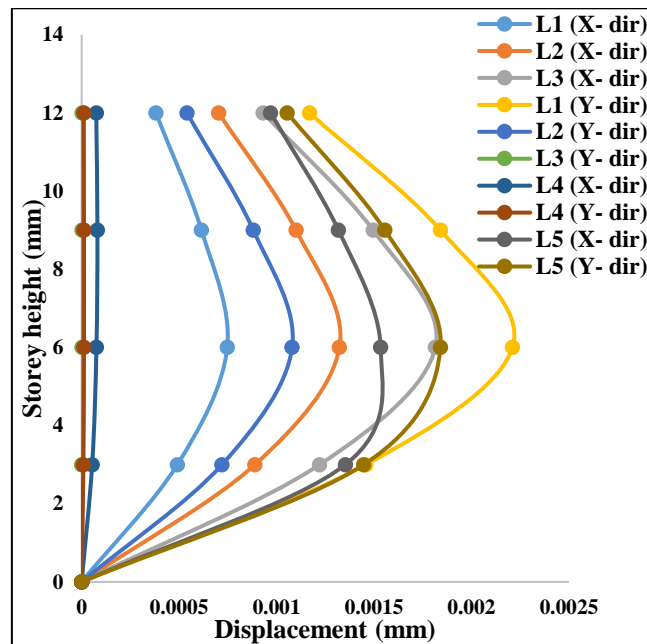


**Fig. 4.** Analytical calculation of Storey drift of all models (X & Y direction).



**Fig. 5.** Analytical calculation of Storey displacement of all models (X direction).

### 3.2 Recommended L-shaped models and strengthened L-shaped model



**Fig. 6.** Analytical result of Storey drift of all recommended models (X & Y direction).

Fig. 5 provides a critical insight into the graph of story displacement along X direction. It complements the story drift findings from Fig. 4, showing the highest displacement in the T-shaped model, then the L-shaped, and the lowest in the rectangular building. These displacement shows the vulnerability levels and the necessity for targeted mitigation measures.

Fig. 6 compares the results of story drift of the recommended L-shaped models, including those with various shear wall configurations from L1 to L5 and strengthened core designs L6. This

result demonstrates the effectiveness of different shear wall placements in mitigating seismic deformations. The shear wall of model L4 particularly shows the greatest drift reduction, emphasising the importance of strategic strengthening in asymmetrical buildings.

### 3.3 Overall storey drift and cost estimation of the recommended structure

The models in Fig. 7, show that incorporating double shear walls demonstrated the highest improvements in drift and displacement reduction, particularly in the model L4 configuration. However, these improvements were done at the cost of significantly increased concrete usage, with volumes exceeding 245 m<sup>3</sup> per story, making them less economical.

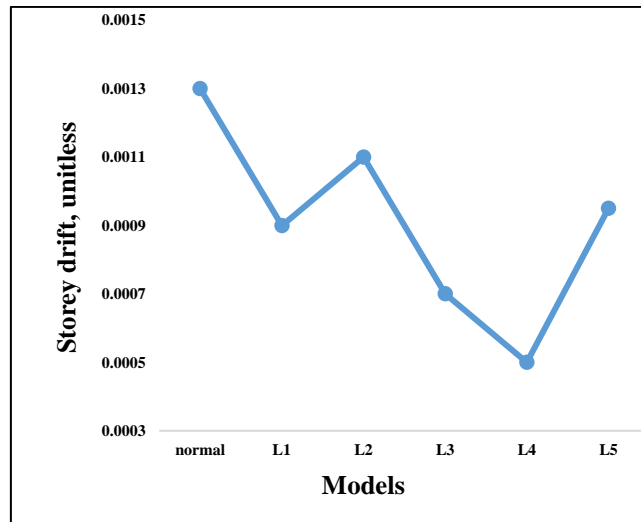


Fig. 7. Average Storey drift of L-shaped structure

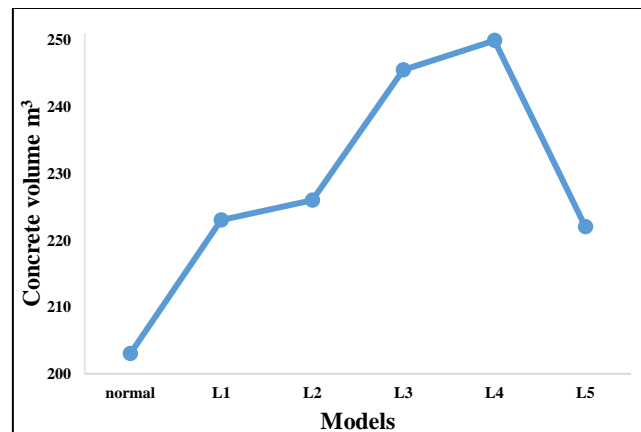


Fig. 8. Average concrete volume of L-shaped structure

The Fig. 8 graphically represents the concrete volume requirements for various structural models, providing insight into the financial implications of seismic strengthening strategies. This trend shows an additional strengthening of countermeasures, such as shear walls and core strengthening reinforcement incorporated (notably in models L1 through L4), the required concrete volume increases substantially, peaking at over 245 m<sup>3</sup> for L4.

**Table 1.** Maximum Base shear among Rectangular, L-shaped, and T-shaped models.

Building Type	Maximum base shear (kN/m <sup>2</sup> )	Different from rectangular model (kN/m <sup>2</sup> ) (%)
Rectangular shaped	505.368	$((a-b)/a)*100$
T-shaped	430.265	14.86
L-shaped	434.503	14

This indicates a clear trade-off: while these measures enhance seismic performance, they lead to higher construction costs. Whereas utilisation of concrete in model L5 shows a decline in concrete usage, it also posed as an optimised design, achieving improved performance with less material. Figure 8 also highlights the economic challenge of balancing seismic safety and material efficiency, emphasising that models with extensive strengthening provide the greatest resistance but at a notably higher cost due to increased concrete demand

Tables 1, 2, and 3 present the % of improvement of base shear, storic drift, and storic displacement compared to the rectangular-shaped building. It has been observed throughout “results and discussions” that the irregular building forms like L- and T-shapes increase seismic vulnerability due to heightened torsional effects, story drift, and displacement compared to symmetrical designs, posing structural and safety challenges. From a perspective of structural engineering, the strategic placement of shear walls and core strengthening effectively mitigates the risks of seismic events, improving resilience. Earthquake engineering insights guide load assignments per IS 1893:2016, emphasising realistic seismic demands. Economically, increased reinforcement and material use raise construction costs, highlighting a tradeoff between safety and affordability. The optimisation framework proposed balances these dimensions, supporting seismic safety without excessive expenses. This integrative approach informs architects and engineers on achieving resilient, economically viable, and aesthetically flexible designs in seismic zones, fostering safer urban development under natural hazards while addressing practical financial constraints.

**Table 2.** Maximum storic drift along X&Y direction.

Building Type	Drift along the X-direction	Drift along the Y-direction	Percentage of improvement compared to rectangle (X,Y direction) (%)
Rectangular shaped	0.001859	0.002	$((a-b)/a)*100$
T-shaped	0.001719	0.001886	7.5, 5.7
L-shaped	0.001759	0.001947	5.3, 2.7

L1	0.000381	0.001169	79.5, 41.6
L2	0.001323	0.00054	28.8, 73
L3	0.001815	0.000002	2.36, 99.9
L4	0.000076	0.000011	95.9, 99.5
L5	0.001534	0.001841	17.5, 8

**Table 3.**Storie displacement.

Building type	Maximum displacement X (mm)	Different from rectangle (mm) (%)
Rectangular shaped	16.778	$((a-b)/a)*100$
T-shaped	15.525	7.5
L-shaped	15.899	5.2
E5	9.362	44.2

#### 4 Conclusion

This study concludes that asymmetrical RC buildings, such as L-shaped and T-shaped configurations, exhibit higher seismic vulnerability due to torsional irregularities and unbalanced load distribution compared to symmetrical structures. The recommended countermeasures reduce the effect of earthquakes by 99.9%, also reduce the cost upto 11% as the requirement of concrete reduces. However, their seismic performance can be significantly enhanced by targeted and strategic structural interventions like the utilisation of shear walls and core strengthening. While these measures improve safety by reducing story drift and displacement, they also significantly increase material consumption, leading to higher construction costs and some-times reducing them. The research proposes a performance-based, cost-optimised design framework that balances structural resilience with economic feasibility, and an approach that enables the development of architecturally flexible and seismically safe as well as affordable buildings, particularly suited for earthquake-prone regions. Hence, the study offers practical guidance for integrating aesthetic design, safety requirements, and cost-effectiveness, ensuring safer urban environments without compromising on architectural creativity or budget constraints. The research can be further continued focusing on the weight of material design, by using recycled material to reduce the seismic effect and can also be analysed in the context of durability..

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