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Torsional Irregularity Control in Irregular Plan RC Buildings through Optimized Shear Wall Placement: A Parametric Study

Birendra Kumar Bohara[1*], Deepak Bahadur Kunwar[2] , Bhim Kunwar[3]
[1]Assistant Professor, School of Engineering, Far Western University, Mahendranagar, Nepal, bbohara2@gmail.com
[2]Lecturer, Lalitpur Engineering College, Lalitpur, Nepal, deepak@lec.edu.np
[3]School of Engineering, Far Western University, Mahendranagar, Nepal, bhimkunwar070@gmail.com
[*]Corresponding author, e-mail: bbohara2@gmail.com

Abstract— Irregular buildings, particularly those with L-shaped plans, are more vulnerable during seismic events due to their asymmetric geometry and torsional irregularity. This study investigates the seismic performance of L-shaped reinforced concrete (RC) structures with various shear wall configurations under lateral loading. A total of 12 L-shaped six-story building models were analyzed using ETABS software, applying both Equivalent Static Method (ESM) and Response Spectrum Analysis (RSA) as per IS 1893:2016. The effect of shear wall positioning on fundamental time period, base shear, displacement, torsional irregularity and diaphragm rotation was evaluated. Results showed that shear walls significantly enhance structural performance by reducing displacement, increasing base shear, and controlling torsional behavior when placed effectively. Improper or asymmetric wall placement, however, led to increased torsional amplification and irregular seismic responses. Among all models, those with shear walls aligned along both X and Y directions performed best in terms of seismic resistance. The study highlights the importance of optimal shear wall positioning in irregular RC buildings for enhancing seismic safety and structural efficiency.

Keywords: L-shaped buildings, shear wall configuration, torsional irregularity, diaphragm rotation

1. Introduction

Earthquakes remain among the most devastating natural hazards, particularly in tectonically active regions such as Nepal [1]–[3]. Situated at the collision boundary of the Indian and Eurasian plates, Nepal is highly vulnerable to frequent moderate-to-severe seismic events [4]. These earthquakes pose significant threats to human life, infrastructure, and economic stability. A building's seismic performance is highly influenced by its structural configuration [5]. Irregular buildings—those exhibiting asymmetry in mass, stiffness, or geometry—tend to perform poorly during earthquakes compared to regular configurations [6]. In Nepal, L-shaped buildings are commonly adopted due to spatial limitations and aesthetic preferences; however, such layouts inherently increase seismic risk due to horizontal irregularity [7]. Typical issues associated with L-shaped plans include stress concentration at re-entrant corners and torsional responses due to asymmetrical stiffness and mass distribution [8].

A well-recognized strategy for improving seismic resistance in buildings is the incorporation of shear walls—vertical elements designed to resist lateral forces [9], [10]. These elements contribute significantly

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to structural stiffness and strength, and are typically constructed from reinforced concrete and extended through the full height of the building. While the effectiveness of shear walls in regular or high-rise buildings has been widely documented, limited studies have evaluated their impact in irregular buildings, particularly those with L-shaped configurations [11]–[13]. Such irregularities lead to differential displacements and concentrated torsion, which can be exacerbated by improper shear wall placement [14]–[16]. The literature consistently affirms that while shear walls enhance seismic response, their effectiveness is highly dependent on optimal placement [17].

Given the prevalence of L-shaped structures in Nepal and other seismic zones, and the insufficient research addressing their dynamic performance with varied shear wall placements, there is a critical need to investigate how shear wall configurations influence seismic behavior. The absence of such studies contributes to uncertainty in design strategies for irregular RC buildings, potentially leading to unsafe or inefficient constructions.

This research addresses the existing gap by conducting a parametric study involving 12 six-story L-shaped RC building models analyzed under various shear wall configurations. Using both Equivalent Static Method (ESM) and Response Spectrum Analysis (RSA) as per IS 1893:2016, the study evaluates key seismic performance indicators, including fundamental time period, base shear, displacement, torsional irregularity, and diaphragm rotation. The novelty lies in the focus on shear wall positioning in irregular plan buildings and its correlation with torsional effects—a topic that remains underexplored in current literature.

The primary objective of this study is to determine the most effective shear wall configurations for minimizing torsional irregularity and maximizing seismic resilience in L-shaped reinforced concrete buildings. To support this analysis, a comparative literature review is provided in Table 1 to contextualize previous research findings and highlight the specific research gap addressed in this work.

Table 1. Summary of some literature on seismic performance of L-shaped and irregular RC buildings.

S.N.	Author(s) & Year	Study Title / Focus	Methodology	Key Findings
1	Ravikumar et al. (2012) [18]	Seismic performance of irregular RC buildings	Analytical (RSA, ESM)	Irregular buildings are more vulnerable than regular ones.
2	Abdel Raheem et al. (2018) [8]	Effects of plan irregularity on seismic demands	Time history & pushover analysis	The L-shaped structure shows increased torsional irregularity.
3	Khanal & Chaulagain (2020) [7]	L-shaped buildings through plan irregularities	Response Spectrum Analysis	Identified high torsional irregularity and stress at corners.
4	Banerjee & Srivastava (2019) [19]	Optimal shear wall position in irregular buildings	Static, RSA, Time History	Proper shear wall placement improves lateral resistance.
5	Wiyono et al. (2018) [20]	Shear wall configuration in hotel buildings	Dynamic analysis	Shear walls on both axes improve seismic performance.
6	Singh (2015) [21]	Shear wall in RC open ground story buildings	Static & dynamic analysis	Shear walls improve ground-story building performance.
7	Raghunandan & Kumar (2017) [22]	Irregular high-rise with shear walls	RSA under various soil conditions	Positioning of shear walls affects behavior in irregular buildings.

S.N.	Author(s) & Year	Study Title / Focus	Methodology	Key Findings
8	Prajwal et al. (2017) [23]	Re-entrant corner L-shaped buildings	Pushover & Time History	Bracing reduces displacement and drift in irregular buildings.
9	Özmen et al. (2014) [24]	Torsional irregularity in RC buildings	Comparative study	High torsional amplification is found in irregular layouts.
10	Vielma et al. (2025) [25]	Design Factors in Reinforced concrete Shear Wall structure	FEMA Methodology	Optimize the seismic performance of the buildings
11	Aslani M, Tehrani P (2025) [26]	Vertical irregularities in shear walls	Numerical	collapse capacity assessment of dual RC
12	Poudel, Chaulagain (2024) [27]	Jajarkot Earthquake: Revealed the Vulnerability	Case study	Load-bearing structure failure.
13	Dutta et al. (2015) [28]	Sikkim earthquake structural failures	Case study	Soft-story and irregular buildings were highly affected.

Irregular structures with uneven mass and stiffness distributions are particularly susceptible to seismic forces due to torsional irregularities and stress concentrations at re-entrant corners. While previous research has primarily focused on vertically irregular or symmetric buildings, this study investigates a six-story L-shaped reinforced concrete building using ETABS, utilizing both the ESM and RSA according to IS 1893:2016. A total of twelve models with different shear wall configurations are analyzed to evaluate base shear, drift, fundamental time period, torsional irregularity, and diaphragm rotation. The findings indicate that symmetrically placed shear walls in both the X and Y directions significantly mitigate displacements and torsional effects, whereas irregular placements heighten vulnerability. This research is particularly pertinent for Nepal, where L-shaped buildings are prevalent but often lack adequate seismic detailing.

2. Method

This study aims to investigate the seismic behavior of L-shaped RC structures with and without shear walls, focusing on different wall configurations under lateral loads. The analysis is conducted using ETABS 2018 software, employing linear dynamic and linear static approaches in compliance with IS 1893:2016. A six-story commercial RC building with an L-shaped plan is selected for modeling, representing common irregular building typologies in Nepal. The building incorporates a soft story at the base (4.0 m floor height), while the remaining floors maintain a standard height of 3.2 m. The total height of the structure is 20 m, and each bay spans 6 m in both X and Y directions as shown in Figure 1. The slab thickness is 120 mm, with two-way action considered.

For analysis purposes, 12 different structural models (L1–L12) were prepared:

a. L1 represents a bare frame without any shear walls and serves as the reference model.
b. Case I: L2–L8 are partially shear-walled configurations where walls are applied asymmetrically or unidirectionally.
c. Case II: L9–L12 represent more uniform and symmetrical shear wall distributions, designed to enhance lateral load resistance in both directions.

The building is assumed to be fixed at the base, and P-Delta effects are included. Live loads are taken as 5 kN/m^2 for general floors and 2 kN/m^2 on the roof. Seismic mass calculations consider 100% of the dead load and 50% of the live load (for loads >3 kN/m^2). Concrete grade M25 and steel grade Fe500 are used.

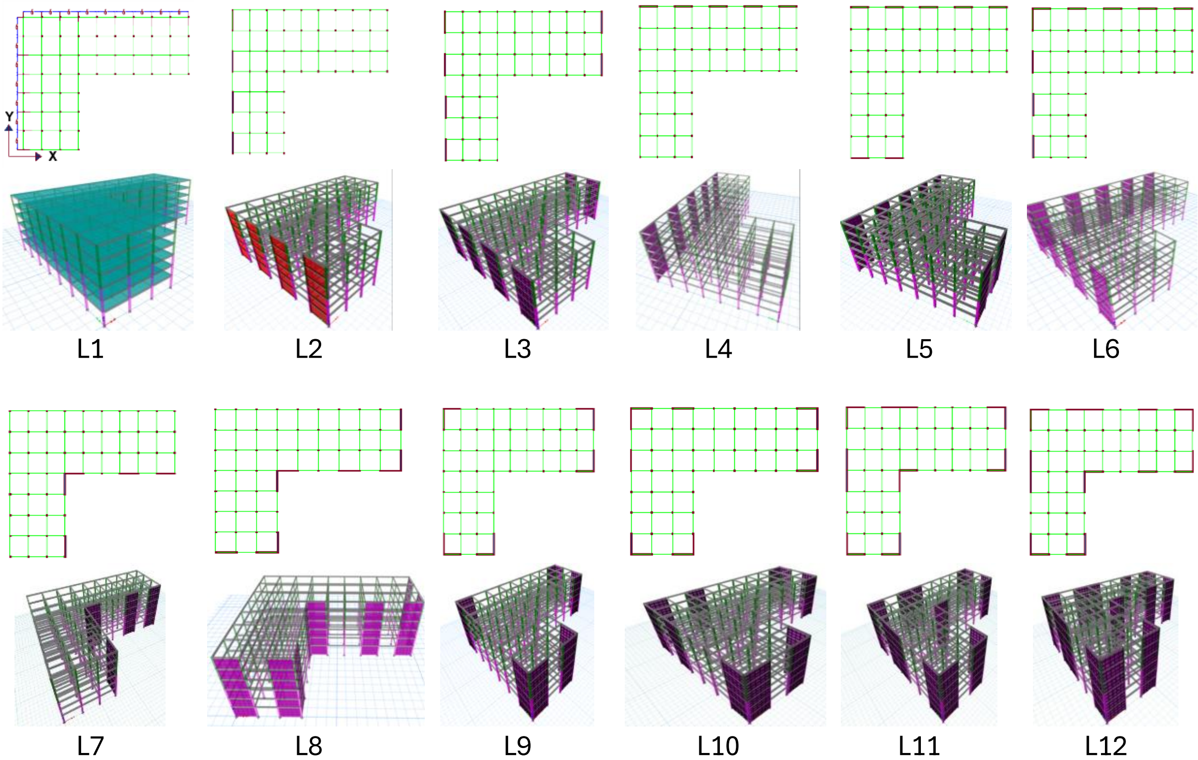

Figure 1. Plans and 3D views of proposed buildings

The columns taper from 400 x 400 mm (lower three floors) to 350 x 350 mm (upper three floors), and beams are 300 x 400 mm. For seismic analysis, both ESM and RSA are conducted. The RSA is performed using sufficient modes to capture at least 90% of the total modal mass, and the Complete Quadratic Combination (CQC) method is applied for modal response combination. Design base shear from the RSA is scaled to match the base shear from the static method if found lower, as per the IS code guidelines. All structural elements are modeled with appropriate boundary conditions. Columns and beams are treated as frame elements, while shear walls and slabs are modeled using shell elements. Rigid diaphragms are applied at each floor to distribute lateral loads effectively. The different shear wall configurations are designed to examine their impact on the seismic performance of irregular L-shaped buildings. These configurations include shear walls placed at the re-entrant corners, along one or both wings of the building, and symmetrically across both axes as shown in Figure 1.

Through comparative evaluation of all models, the study identifies configurations that effectively control lateral displacement, minimize torsional irregularity, and reduce seismic demand on columns. The findings contribute to improved design strategies for irregular RC buildings in high seismic zones.

3. Results and Discussion

3.1 Fundamental period

The vibration periods for different shapes of models were computed by the Etabs finite element software. Normally, to calculate the fundamental time period (FTP) of the buildings, the code provides the empirical formula. However, the formula is only for regular structures; the code-provided formula does not give accurate FTP for structures when the buildings are irregular [29], [30]. Figure 2 illustrates the variation in the FTP along the X and Y axes for different models. The presence of shear walls significantly reduces the FTP in the direction they are applied. For instance, in model L1 (without shear walls), the FTP is 1.44 s, while in model L12 (shear walls in both directions), it drops to 0.286 s an 80% reduction is observed. This decrease corresponds to increased stiffness and base shear. The trend confirms that as the number of shear-walled bays increases, the time period decreases, especially along the direction of wall placement.

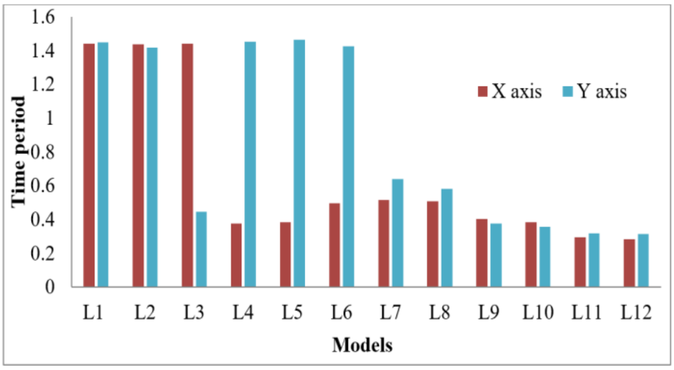

Figure 2. Fundamental time periods of the different models

3.2 Vibration mode shapes

The mode shape of oscillation associated with a natural period of a building is the deformed shape of the structure when shaken at the natural period. Hence, a building has as many mode shapes as the number of natural periods. Figure 3 illustrates the mode shapes of the building at various natural periods. The first mode shape corresponds to the fundamental time period, while higher modes represent the second, third, and so on. Regular buildings exhibit pure translational and rotational modes; however, in irregular buildings, such as L-shaped structures, these modes often mix due to uneven mass and stiffness distribution. Improper shear wall placement increases torsional behavior, causing deviation from pure modes. To minimize early torsional modes, torsional stiffness must be enhanced by adding in-plane stiffness using shear walls or braces symmetrically along both X and Y directions to avoid stiffness eccentricity.

3.3. Design Base shear variations

The base shear of the structures depends upon the plan shape of the structures, fundamental time periods, and soil types of the sites. The base shear is affected by the plan asymmetry of the building or due to lateral-torsional coupling phenomena. In the study, the two cases are analyzed where in case I, the shear walls are used such that it only applied in an incomplete way or only added the shear wall in a single axis of the structure and in case II the bracings are applied in both directions. The models having more seismic weight have more base shears as expected. In both cases, the design base shear is observed in both directions as shown in Figure 4. It is observed that adding the shear wall in the models increases the base shear values of the models [31] . In model L3, the shear walls are added such that bracing is used to resist the lateral load along the y-axis. So, in the L3 models the base shear values are more along the y-axis as compared to the x-axis. In models L4 and L5, shear walls are added to resist the lateral load along the x-axis only, so that only along the x-axis, the base shear values are more as compared to the y-axis. However, in the model L1, which is represented without shear-walled frame L-shaped buildings. In the L1 model, almost the same design shear forces are observed (see Figure 4). In the models, L9 to L12 (case II), almost similar base shear values are observed in both the x and the y-axis.

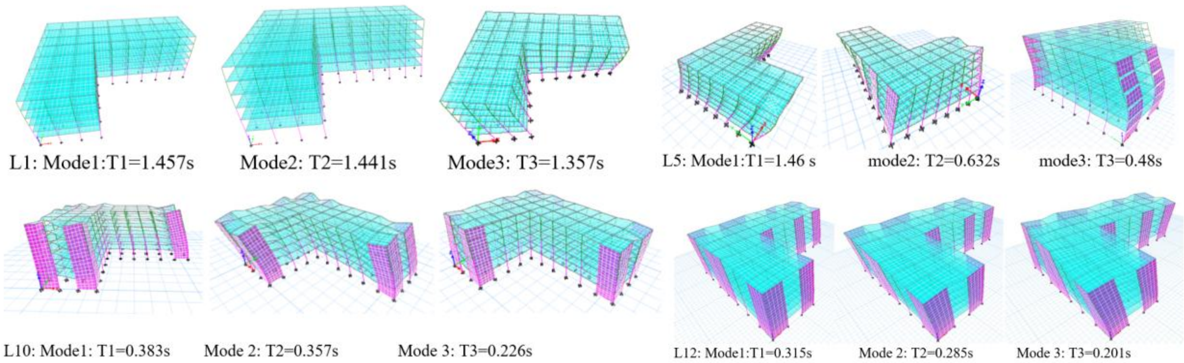

Figure 3. Different mode shapes for selected buildings

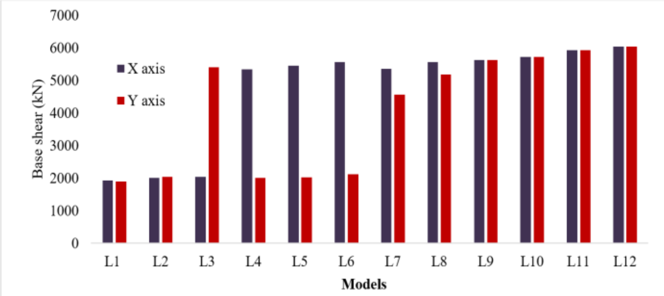

Figure 4. Base shear variations along the x and y-axis in different models

3.4 Maximum displacement response

The story displacements of irregular structures subjected to lateral loads are crucial parameters in building design. The top story displacement responses provide insight into the damage levels sustained by structures. When designing, lateral deformation and drift must be carefully controlled to prevent excessive damage to structural and nonstructural components. Figures 5 illustrate the maximum displacements in L-shaped buildings under lateral loading. Figures 5 compare maximum displacements in various models along the x and y directions. The addition of shear walls at different positions significantly influences displacement behavior. In Case I (models L2 to L8), adding shear walls in model L1 had a limited impact on reducing maximum displacements. Due to torsional effects, model L4 even experienced increased displacements along the x-axis compared to the reference L1 model. Conversely, in Case II (models L9 to L12), shear walls effectively reduced maximum displacements, as seen in Figures 5. Specifically, models L9 through L12 showed reductions in lateral displacements along the x-axis by 74%, 77%, 83%, and 83%, and along the y-axis by 74%, 78%, 81%, and 80%, respectively, compared to the L1 model. Shear walls placed strategically along both axes significantly improved seismic performance by reducing lateral displacement. In Case I, the maximum displacement reached 44 mm along the x-axis, linked to lateral-torsional vibration in the soft-story L-shaped buildings. In Case II, displacements ranged from 6.9 mm in model L9 to 4.3 mm in model L12 along the x-axis, with similar trends observed in the y direction (Figure 5).

3.5 Torsional irregularity ratio

The torsional irregularity ratio of the structures gives the most important information about buildings' damage levels during earthquake loading. It is an analytical index, created based on the structural response and, multidirectional response of the asymmetry structure. The different studies studied the limit of torsional irregularity ratio, which is 1.2 [32]. When the torsional irregularity ratio surpasses the allowable limit, the structure undergoes differential movements across its plan, adversely affecting its performance during seismic events. Seismic design guidelines state that a torsional irregularity ratio below 1.2 signifies the absence of significant torsional irregularity. According to IS 1893 (Part 1, 2016), a re-entrant corner exists when the projection of a building's plan exceeds 15% of the overall dimension in a given direction. In this study, the L-shaped building has a projection of 66% along the x-direction and 57% along the y-direction, both exceeding the 15% threshold, confirming the presence of re-entrant corners in the plan configuration.

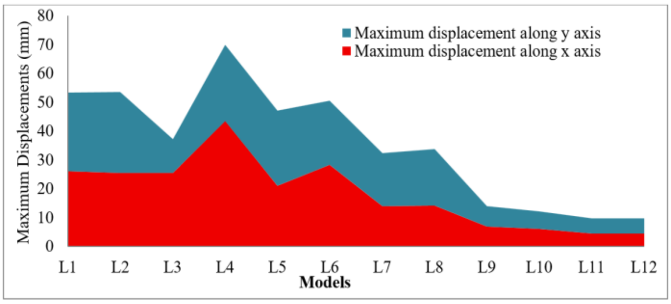

Figure 5. Maximum top story displacements along the x and y-axis

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Torsional irregularity is assessed by evaluating the drift at the corners of a 3D structural model. Most seismic codes, including IS 1893:2016 and ASCE 7-10, define similar methods to quantify torsional irregularity, particularly for irregular plan geometries like L-shapes. To account for accidental torsion, the torsional amplification factor (Ax) is considered as per ASCE 7-10. The maximum (Δmax), minimum (Δmin), and average (Δavg) story drifts are determined (refer to Figure 6). The torsional irregularity coefficient (ηt) is defined as (ηt=Δmax/Δavg). Based on ηt, the following conditions apply:

a. When η_t is less than or equal to the 1.2, then no torsional irregularity exists and Ax is equal to 1;
b. When η_t is between 1.2 to 2.083, the torsional irregularity exists and Ax is calculated as given formula;
c. When the η_t is greater than 2.083, then ηt=2.083 and Ax is equal to 3.

$$A_x = \left(\frac{\Delta_{max}}{1.2\Delta_{avg}}\right)^2 \quad (1)$$

Figures 7 and 8 depict the changes in torsional irregularity ratios throughout the building height for L-shaped models both with and without shear walls. The torsional irregularity ratio fluctuates between different stories, with the lower levels typically exhibiting higher values, likely due to the soft-story phenomenon and the geometry of the L-shaped plan. Under unidirectional spectrum loading along the x-axis (Case I), the peak torsional irregularity ratios for models L2 to L8 are 1.02, 1.001, 1.92, 1.53, 1.858, 2.654, and 1.458, respectively. Model L7 records the greatest torsional irregularity in Case I, while Model L1 stays within safe limits (<1.2). In Case I, models L4–L8 exceed the 1.2 threshold along the x-axis, while models L2, L6, L7, and L8 go beyond the limit along the y-axis. These models feature incomplete or asymmetric shear wall designs, which heighten torsional effects, particularly in L7. In contrast, the models in Case II (L9–L12), which include well-distributed shear walls in both the x and y directions, show improved torsional behavior, with all torsional irregularity ratios staying within acceptable limits. These results indicate that well-placed shear walls in L-shaped RC buildings significantly enhance torsional stability, minimize displacements and drifts, and improve overall seismic resilience. Such designs are beneficial not only for new constructions but also offer practical solutions for retrofitting torsionally vulnerable, irregular structures [34].

3.6 Investigation of torsional irregularity coefficient with torsional amplification factor (Ax)

The models L4, L5, L6, L7, and L8 along the x-axis, further studied the torsional amplification factors because the model has a greater torsional irregularity ratio (>1.2). similarly, along the y axis models L2, L6, L7 and L8 are studied for torsional amplification factors. Tables 2 and 3 show the amplification factors for models along the x and y axes, respectively. When the torsional irregularity coefficient is studied, it is noticed that some models show that their values range between 1.2 to 2.083, it means it suggests that eccentricity amplification factors should be computed by using equation (i). It should be less than one as per the code provisions. It is also noticed that model L7 has a torsional irregularity ratio greater than 2.083, so that Ax should be equal to 3. Tables 2 and 3 show that eccentricity amplification factors are higher in models L2, L4, L6, and L7. These models are especially related to the case 1 buildings. However, in this case, one eccentricity amplification factors are assumed because these models are safe against the torsional effects.

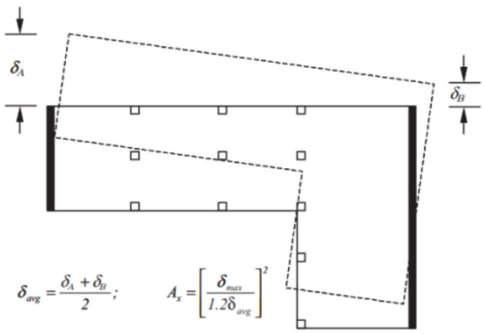
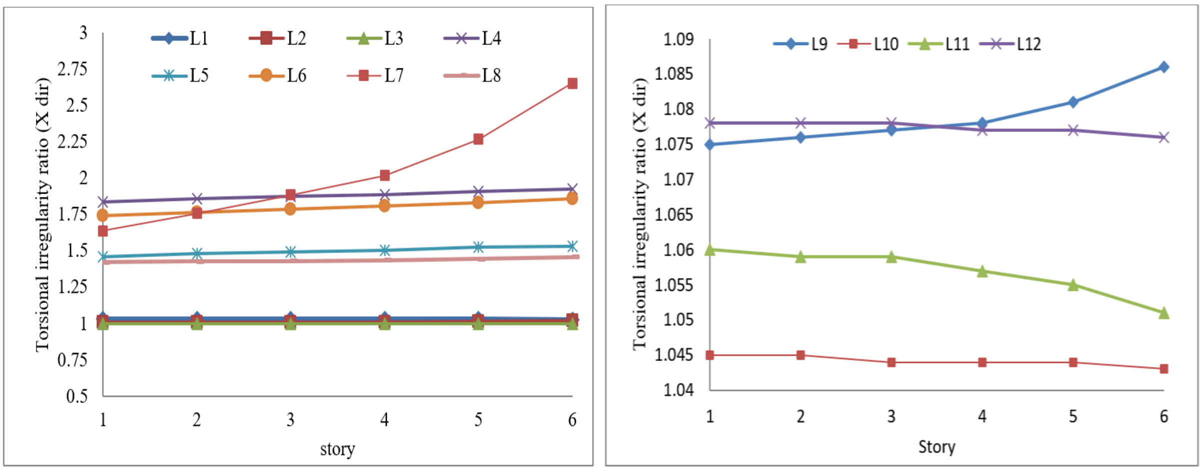
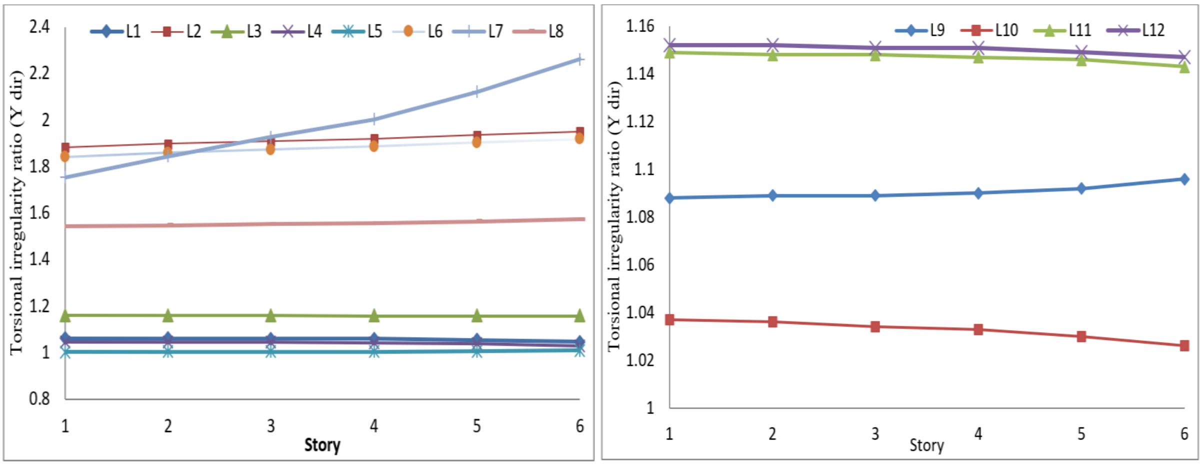


Figure 6. Torsional irregularity calculation of the L-shaped buildings [33].



a) Case 1 (b) Case 2

Figure 7. Torsional irregularity ratio for different models along the x-axis



(a) Case 1 (b) Case 2

Figure 8. Torsional irregularity ratio for different models along the y-axis

Table 2. Maximum torsional amplification factor (Ax) for the structure along the x-axis

Number of stories	Types of structure				
	L4	L5	L6	L7	L8
Story6	2.34	1.48	2.10	1.87	1.40
Story5	2.40	1.52	2.17	2.15	1.41
Story4	2.44	1.55	2.22	2.47	1.42
Story3	2.47	1.58	2.27	2.83	1.43
Story2	2.52	1.61	2.33	3.57	1.45
Story1	2.58	1.63	2.40	4.89	1.47

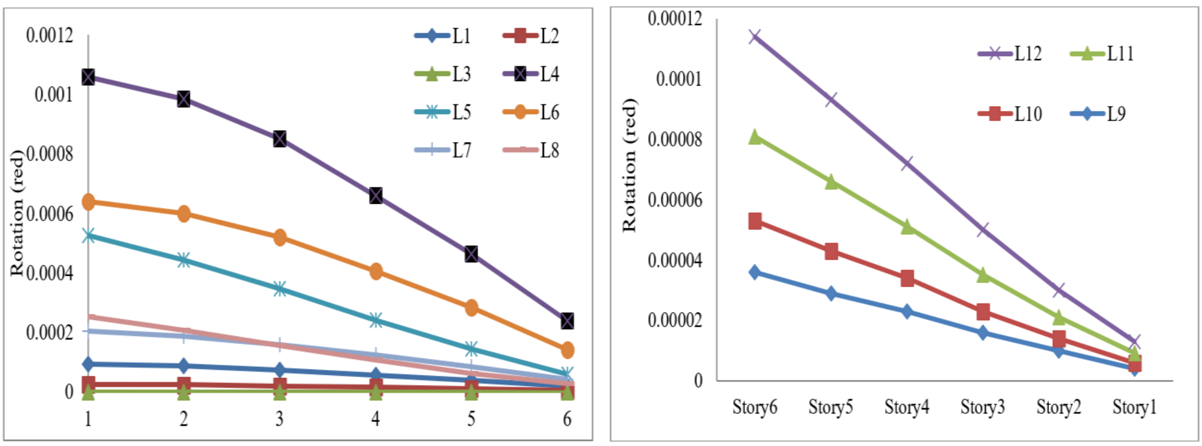
Table 3. Maximum torsional amplification factor (Ax) for the structure along the y-axis

Number of stories	Types of structure			
	L2	L6	L7	L8
Story6	2.46	2.35	2.14	1.65
Story5	2.50	2.40	2.36	1.66
Story4	2.53	2.44	2.58	1.67
Story3	2.56	2.47	2.79	1.68
Story2	2.60	2.51	3.13	1.70
Story1	2.64	2.56	3.55	1.72

3.7 Torsional diaphragm rotation

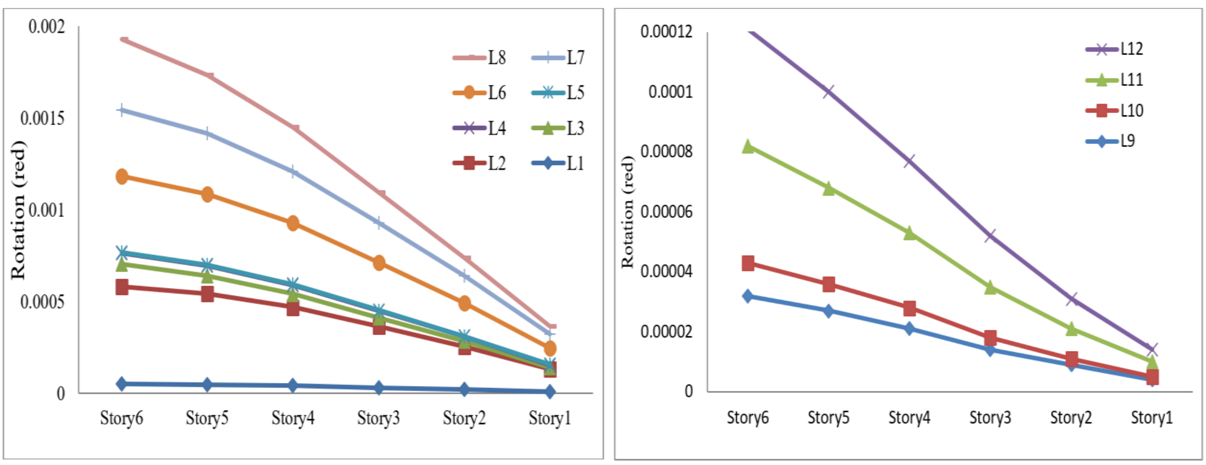
Torsional seismic impacts arising from irregular building layouts are a significant issue in seismic design, as emphasized in multiple building regulations. In structures with intricate geometries, such as L-shaped designs, torsional effects lead to twisting accompanied by lateral movements. A critical factor for assessing this behavior is the torsional rotation of the diaphragm, which reflects the in-plane rotation of floor slabs caused by differential displacements at the edges of the slabs. This rotation can result in localized failures in peripheral structural components, jeopardizing the overall structural stability. The relative stiffness between vertical and horizontal structural systems and the effectiveness of the floor diaphragms influence the degree of torsional rotation.

Figures 9 and 10 show that, in L-shaped reinforced concrete buildings, torsional diaphragm rotation typically escalates with the height of the building. In Case I models (L1–L8), elevated torsional rotations are noted, ranging from 0.000001 to 0.001058 radians, especially in scenarios where shear walls are unevenly distributed. In contrast, Case II models (L9–L12), which have more evenly distributed shear wall arrangements, display diminished rotations (0.000017–0.000036 radians), suggesting enhanced torsional control. The findings indicate that inadequate shear wall positioning amplifies torsional effects, while a symmetric and consistent shear wall layout reduces diaphragm rotation. A similar pattern is observed along the Y-axis, with the maximum rotation typically occurring at the highest floor.



(a) Case 1, (b) Case 2

Figure 9. Variation of floor rotations for structures with x axis



(a) Case1 b) Case 2

Figure 10. Variation of floor rotations for structures with y axis

4. Conclusion

This study investigated the seismic performance of a six-story L-shaped RC structure with and without shear walls using linear static and dynamic analyses in ETABS. A total of 12 models were developed to assess the influence of different shear wall configurations on various seismic parameters, including fundamental period, base shear, maximum displacement, torsional irregularity, and diaphragm rotation. The findings confirm that shear wall placement significantly affects the lateral behavior of irregular buildings. Models with shear walls aligned in both X and Y directions (Case II: L9–L12) demonstrated superior performance across all parameters. In contrast, incomplete or asymmetrically placed shear walls (Case I: L2–L8) introduced torsional irregularities and inconsistent seismic responses, especially in models L4 to L8. The reference model without shear walls (L1) showed the highest displacement and highlighting the vulnerability of unreinforced irregular structures. Key conclusions drawn from the study include:

- The addition of shear walls reduces the FTP and increases base shear due to enhanced stiffness and mass.
- Proper shear wall placement decreases lateral displacement by up to 83%, significantly improving seismic resilience.
- Torsional irregularity ratios and amplification factors exceed acceptable limits when walls are placed asymmetrically, leading to unpredictable responses in some models.
- Diaphragm rotation increases with height but is well controlled in buildings with symmetric shear wall arrangements.

Overall, the study demonstrates that strategic shear wall positioning can mitigate the adverse effects of plan irregularity in RC structures. Properly designed and symmetrically distributed shear walls not only improve structural stiffness and strength but also ensure better control of torsional behavior and displacement demands. The results are particularly relevant for seismic-prone regions like Nepal, where L-shaped structures are common due to architectural and site constraints.

This research highlights the importance of integrated structural design in irregular buildings and encourages engineers to evaluate torsional effects and stiffness distribution carefully during the planning phase. Future work can expand on these findings using nonlinear analysis methods or experimental validation to capture damage mechanisms more accurately and assess retrofitting techniques for existing irregular structures.

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