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Seismic Performance Evaluation of an Irregular Five-Story Reinforced Concrete Building Under Various Shear Wall Placement Configurations Using Pushover Analysis

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ABSTRACT

Earthquakes pose significant risks to buildings in seismically active regions, and evaluating structural performance under lateral loads is essential, particularly for irregular buildings that are more susceptible to torsional effects and nonuniform deformation. This study contributes comparative evidence on the influence of shear wall placement on seismic response parameters of irregular reinforced concrete buildings using nonlinear pushover analysis. Structural parameters were modeled in ETABS v19 in accordance with ACI 318-19, AISC 360-10, and NSCP 2015. Pushover curves in both the X and Y directions were generated to identify first-hinge formation, performance-point capacities, plastic-hinge distribution, and performance indicators such as displacement demand, acceleration response, and fundamental period. Statistical tests (ANOVA and Post Hoc) were conducted to determine significant differences among the three designs. Findings show that the corner configuration achieved the highest base shear capacity but was more torsionally sensitive. The inner-center layout produced the largest displacements and longest time periods, indicating higher flexibility but reduced drift control. The outer-center configuration demonstrated the most balanced response, with efficient drift reduction, moderate stiffness, fewer critical hinges, and performance consistently within Immediate Occupancy limits. These results confirm that shear wall placement significantly influences structural behavior, especially in irregular building forms. Overall, the outer-center layout demonstrated the most balanced seismic response among the configurations assessed.

Keywords: *lateral deformation, pushover capacity, structural irregularity, drift performance, nonlinear seismic assessment*

INTRODUCTION

Earthquakes remain among the most destructive natural hazards, capable of causing severe structural damage, loss of life, and significant economic losses. This threat is especially critical in the Philippines, a country situated along the Pacific Ring of Fire, where frequent seismic activities expose buildings to intense ground shaking that compromises structural stability. When structures experience lateral forces during seismic events, horizontal distortions occur, increasing the likelihood of collapse if buildings are not adequately designed to resist such loads. Recognizing this vulnerability, Themelis (2008) emphasized that earthquake-resistant design requires structures to sustain and safely resist diverse ground motions, which produce unique impacts on structural response.

Reinforced Concrete (RC) shear walls have long been established as an effective lateral load-resisting system due to their strength, stiffness, and ductility. RC structural elements carry substantial lateral and shear forces generated by seismic loads, making stiffness a vital parameter for the safety of medium- to high-rise buildings. Batth and Titiksh (2017) noted that shear walls are the most common lateral-resistance mechanism used in such structures because they possess high in-plane rigidity and can sustain significant lateral forces while supporting gravity loads during earthquakes. As engineering practices evolve, modern analysis techniques such as Performance-Based Engineering Design (PBED) and nonlinear assessment tools have improved the accuracy of predicting structural behavior during seismic events. With advanced tools such as the Extended 3D Analysis of Building Systems (ETABS), engineers can now conduct nonlinear pushover analyses to identify failure mechanisms, evaluate ductility demands, and determine structural performance levels (Prusinski, 2015).

The existing literature consistently demonstrates the importance of correctly locating shear walls to enhance seismic performance. Prior studies reveal that structures with strategically placed shear walls show increased ductility, reduced deformation, and improved resistance to lateral loads (Hanafiah et al., 2017; Parishith & Preetha, 2017). Research further highlights that incorrect placement may introduce torsional irregularities, leading to structural twisting and increased stress concentrations (Tajzadah et al., 2019). Similarly, comparative investigations show that shear walls can significantly increase base shear capacity, limit story drift, and improve overall structural stability (Bongilwar et al., 2018; Chandak & Vaishya, 2022). Studies also emphasize the role of plastic hinge formation, drift limits, and time-period behavior as indicators of structural performance under severe seismic actions (Sapkota, 2018; Ravikumara et al., 2015; Fazileh & Humar, 2012; Anushri & Swamy, 2016). While these findings demonstrate the general effectiveness of shear walls, most existing research focuses on regular building configurations. Limited work has been conducted on irregular structural layouts, such as L-shaped buildings, which tend to exhibit complex, nonuniform seismic responses.

While numerous studies have demonstrated the effectiveness of shear walls in improving seismic performance, most investigations focus on regular building configurations. Limited research has examined how different shear wall placements influence the nonlinear seismic response of irregular L-shaped reinforced concrete buildings using pushover analysis. Consequently, uncertainty remains regarding which shear wall configuration provides the most balanced combination of strength, stiffness, and drift control for such irregular structures.

Addressing this gap is critical, given that many commercial and mid-rise buildings in the Philippines and globally are constructed with irregular floor plans due to architectural or functional requirements. Without clear evidence on the optimal placement of shear walls for such configurations, design decisions may not fully support structural safety under strong seismic motions. Therefore, understanding the pushover performance of multiple shear wall layouts in an irregular structure becomes essential for minimizing seismic vulnerability and enhancing structural reliability.

Thus, this study evaluates the seismic performance of three shear wall placement configurations—shear walls at the corners, at the inner center, and at the outer center—applied to an irregular five-story L-shaped reinforced concrete building. By generating pushover curves, performance point coordinates, and drift-based performance levels for each configuration, the study identifies the shear wall placement that provides the most effective resistance against lateral seismic forces. This research provides valuable insights for structural engineers, educators, and local designers to improve seismic design strategies for irregular building structures. Furthermore, this research aligns with SDGs 9 and 11 by providing technical evidence to support the design of resilient infrastructure in seismically active regions. The analytical findings of this study may support engineering decisions that contribute to safer and more resilient structural design. In future planning, it mitigates the problems encountered in designing irregularly shaped buildings; hence, the conducted study provides technical insights that may inform future seismic design strategies for irregular reinforced concrete buildings.

Objectives of the Study

The study aims to evaluate the seismic performance of an irregular five-story L-shaped reinforced-concrete building using nonlinear pushover analysis across three shear-wall placement configurations—shear walls at the corners, at the inner center, and at the outer center. Specifically, it aims to: (1) determine the geometric, load, and seismic parameters required for the analysis; (2) determine the first hinge formation and performance point of the structure in both the X and Y directions of the three designs ; (3) identify and compare the number of plastic hinges formed at different damage levels across the three designs; (4) determine the performance point coordinates of each design in both directions, specifically base shear, global displacement, spectral acceleration, spectral displacement, and time period; (5) Is there a significant difference in the pushover analysis results among the three designs based on base shear, global displacement, spectral acceleration, spectral displacement, and time period; and (6) evaluate the performance levels of the three designs in terms of maximum total drift and maximum inelastic drift.

METHODOLOGY

Research Design. This study is analytical and comparative in nature and does not establish causal relationships or real-earth Quake performance. This study employed a quantitative comparative analysis to examine the seismic performance of an irregular five-story reinforced-concrete L-shaped building using nonlinear pushover analysis. The design guided the researchers in acquiring, assessing, documenting, and interpreting the structural conditions generated from the analysis. Comparative research, as described by Mills et al. (2006), may involve quantitative assessments used to identify differences among multiple conditions or configurations. In this study, three shear wall placement configurations were compared to determine their relative effectiveness in resisting seismic loads.

The study used a computational structural model of a five-story L-shaped reinforced-concrete building. No human participants were involved, as the research relied solely on numerical simulation and analysis. The structure served as the conventional design from which three configurations—Design 1 (shear walls at the corners), figure 1, Design 2 (shear walls at the inner center), figure 2, and Design 3 (shear walls at the outer center), figure 3—were developed. The 2nd through 5th floors are typically identical to the ground-floor plan.

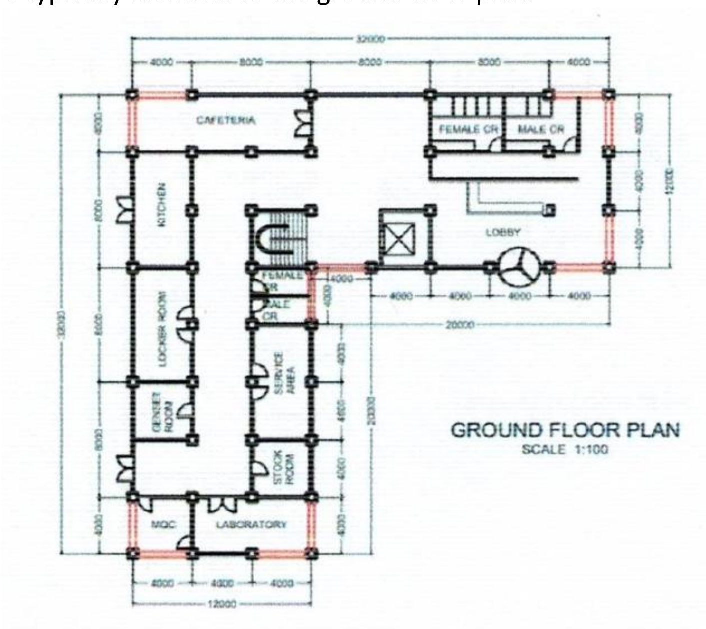

Figure 1
Design 1- shear walls at the corners

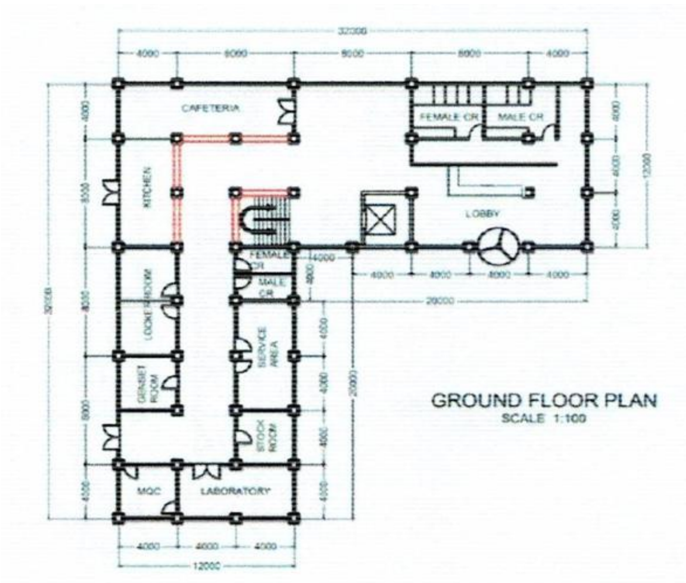

Figure 2
Design 2 (shear walls at the inner center)

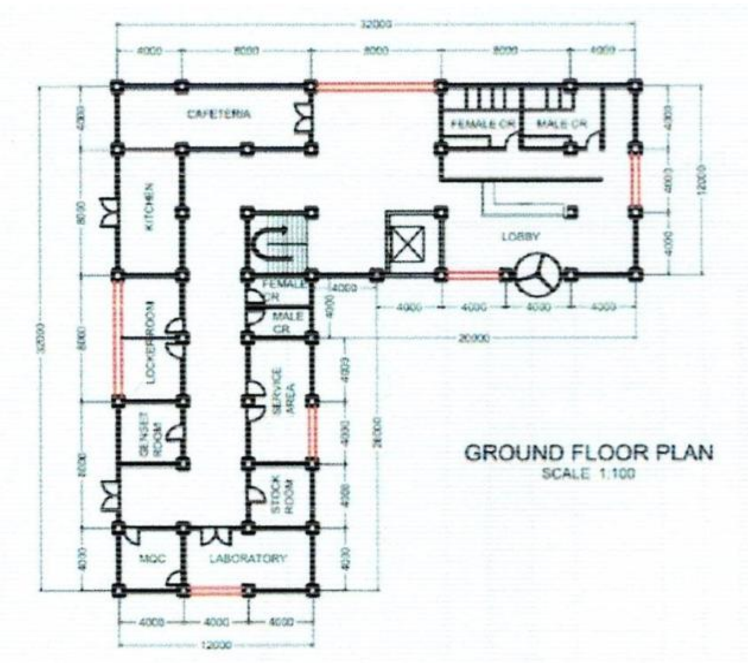

Figure 3
Design 3 (shear walls at the outer center)

Research Instrument. The researchers used ETABS, a widely recognized engineering software validated by numerous structural studies, as the primary tool for data generation. ETABS v19 was used to construct the model, define material and section properties, apply loads, perform nonlinear pushover analysis, and generate the output parameters necessary to evaluate structural performance.

Data Gathering Procedure. Research data were collected through a sequence of modeling and analysis steps performed in ETABS. The procedure began with preparing the architectural and structural plans for the five-story building, which served as the basis for all shear wall configurations. The geometric and load parameters were obtained from the plans and assigned in accordance with applicable engineering standards. Concrete parameters followed the American Concrete Institute 318-19 (ACI 318-19), steel properties were based on the American Institute of Steel Construction 360-10 (AISC 360-10), and load combinations were guided by the National Structural Code of the Philippines (NSCP 2015). Seismic parameters were adopted from NSCP provisions and maps developed for the Uniform Building Code 1997 (UBC, 1997) and NSCP 2015.

After collecting the required data, the researchers installed ETABS v19 and initiated the modeling phase. The grid system was set, material properties were defined, and the building geometry was plotted. Shear walls were drawn, assigned properties, and integrated into each design. Pin supports were placed at the base, diaphragm constraints were defined, load patterns and mass sources were assigned, and the response spectrum function was established. The model was analyzed and iteratively redesigned until all structural members satisfied ETABS design checks.

For pushover analysis, hinge properties and hinge overwrites were assigned to beams, columns, and walls. Pushover load cases in both the X and Y directions, along with gravity load cases, were defined. Nonlinear cases were executed to observe the building's behavior under increasing lateral loads. The resulting pushover curves were generated, and performance point coordinates—base shear, global displacement, spectral acceleration, spectral displacement, and time period—were extracted. The number of plastic hinges at various damage levels was recorded and evaluated using the Applied Technology Council (ATC) performance descriptions. The performance of the three configurations was assessed from their load–deformation curves.

Data Analysis. The data collected from this study were rigorously analyzed through descriptive and inferential statistical procedures. Descriptive analysis, specifically the arithmetic mean, was used to summarize the computed values of base shear, global displacement, spectral acceleration, spectral displacement, and time period. Inferential analysis employed Analysis of Variance (ANOVA) to determine significant differences among the three shear wall configurations in both X and Y directions.

When ANOVA results were significant, Post Hoc Analysis was conducted to identify which specific configurations differed. These statistical tools together supported the comparison of seismic performance and the identification of the most effective shear wall placement for the irregular structure.

RESULTS AND DISCUSSION

This section summarizes the key outcomes of the seismic performance evaluation of the three shear wall placements—Design 1 (Corners), Design 2 (Inner Center), and Design 3 (Outer Center)—based on pushover analysis. The discussion integrates results with relevant literature to highlight implications on structural behavior.

1. Parameters of the Five-Story Reinforced Concrete Building

Tables 3. a, 3.b, and 3.c summarize the geometric data, load data, and seismic data used to model the structure. These parameters were derived from the building's architectural and structural plans.

Table 3. a

Geometric Data of the Five-Story Reinforced Concrete Building

Parameter	Value
Column Dimension	600 mm × 600 mm
Primary Beam 1	450 mm × 600 mm
Primary Beam 2	600 mm × 700 mm
Secondary Beam 1	400 mm × 500 mm
Secondary Beam 2	500 mm × 700 mm
Slab Thickness	150 mm
Floor Height	3200 mm
Concrete Density	23.56 kN/m^3
Exterior Wall Thickness	150 mm CHB
Shear Wall Thickness	200 mm

Using ETABS, four concrete frames were modified from the originally designed beams to meet the design check requirements of the National Structural Code of the Philippines (NSCP 2015).

Table 3.b
Load Data Used in the Structural Model

Load Type	Value
Live Load – Ground Floor	4.8 kPa
Live Load – Upper Floors	2.4 kPa
Dead Load – Slab GF	4.48 kPa
Dead Load – Slab 2F–4F	4.72 kPa
Dead Load – Roof Deck	4.98 kPa
Dead Load – Stairs	5.844 kPa
Dead Load – Beam (450×600)	6.36 kN/m
Dead Load – Beam (600×700)	4.71 kN/m
Dead Load – Beam (400×500)	8.25 kN/m
Dead Load – Beam (500×700)	9.9 kN/m
Dead Load – Column (600×600)	8.48 kN/m
150 mm CHB Wall	9.95 kN/m
100 mm CHB Wall	9.54 kN/m
Glass Parapet Wall	0.456 kN/m
Movable Partition	0.36 kN/m
Superimposed Dead Load	1.52 kPa

Table 3.c
Seismic Data Used in the Structural Model

Parameter	Value
Seismic Zone	Zone 4
Seismic Zone Factor (Z)	0.4
Ca	0.44
Cv	0.64
Importance Factor	1.0
Soil Type	Type D
Structure Type	RC Building
Seismic Source	Type A
Distance to Source	16.5 km
Response Modification Factor (R)	8.5
Eccentricity Ratio	0.05
Damping Ratio	0.05

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2. Pushover Analysis: First Hinge Formation and Performance Point

Table 4
Summary of First Hinge Formation and Performance Points

Direction	Parameter	Design 1	Design 2	Design 3
X	First Hinge Base Shear (kN)	14,593.77	12,801.23	13,442.55
	First Hinge Disp. (mm)	8.32	5.96	7.41
	Performance Point Base Shear (kN)	37,592.99	25,066.23	22,293.37
	Performance Point Disp. (mm)	24.90	68.64	33.89
Y	First Hinge Base Shear (kN)	13,201.05	13,607.96	12,784.33
	First Hinge Disp. (mm)	7.52	5.96	6.30
	Performance Point Base Shear (kN)	37,930.60	19,499.32	28,140.27
	Performance Point Disp. (mm)	31.26	9.15	23.48

Design 1 (Corners) consistently developed the highest base shear capacity in both loading directions, confirming the findings of Chandak & Vaishya (2022), who reported that shear walls significantly increase lateral load resistance. The higher base shear reflects greater stiffness, although it does not directly imply better ductility.

Design 2 (Inner Center) reached the performance point at the lowest displacement values, indicating early nonlinear behavior and increased ductility demand. This aligns with Sapkota (2018), who emphasized that hinge formation and early yielding are strong indicators of deformation characteristics during seismic loading.

Design 3 (Outer Center) demonstrated balanced behavior, exhibiting moderate displacements while maintaining adequate base shear capacity, suggesting an efficient lateral force distribution for irregular structures. This supports Hanafiah et al. (2017), who showed that shear wall positioning significantly influences drift and strength performance.

3. Plastic Hinge Distribution

Table 5
Plastic Hinges at Different Damage Levels

Damage Level	D1	D2	D3
Not Yielded (NY)	2,954–2,990	2,960–2,990	2,990–2,997
Immediate Occupancy (IO)	40	46	15–20
Life Safety (LS)	5	4	0
Collapse Prevention (CP)	0	0	2

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Damage Level	**D1**	**D2**	**D3**
>CP	14–19	0	4–6

Plastic hinge distributions reinforce the contrast in structural behavior across designs.
Design 3 recorded the highest number of unyielded hinges, indicating delayed yielding and extended elastic response. This observation supports the findings of Sreeram et al. (2017), who demonstrated that corner and mid-wall configurations effectively reduce story drift and lateral deformation.

Design 2 showed the highest counts in Immediate Occupancy and Life Safety, suggesting earlier yielding and higher ductility demand. This behavior is consistent with Ravikumara et al. (2015), who noted that hinge progression closely reflects the structural response to lateral forces.

In contrast, Design 1 had the highest number of hinges beyond Collapse Prevention (>CP), indicating the greatest vulnerability under large-displacement demands. While its stiffness is high, as indicated by its performance point values, the concentration of >CP hinges implies reduced ductility and greater risk of severe damage—consistent with Kalibhat et al. (2014), who associated >CP hinges with near-collapse conditions.

4. Performance Point Coordinates

Table 6
Summary of Performance Indicators

Metric	**Direction**	**D1**	**D2**	**D3**
Base Shear (kN)	X	37,592.99	25,066.23	22,293.37
	Y	37,930.60	19,499.32	28,140.27
Global displacement (mm)	X	24.90	68.64	33.89
	Y	31.26	9.15	23.48
Spectral acceleration (g)	X	0.33	0.33	0.30
	Y	0.86	0.24	0.61
Spectral displacement (mm)	X	18.70	22.72	15.26
	Y	23.48	15.11	18.33
Time Period (sec)	X	0.33	0.52	0.39
	Y	0.33	0.51	0.42

Design 1 demonstrated the highest base shear capacity, indicating greater stiffness. These results demonstrate that stiffness enhancement through shear wall placement must be evaluated alongside ductility and hinge progression. However, its greater y-displacements indicate increased drift under lateral loading. Anushri &

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Swamy (2016) observed similar variations in time period and stiffness for irregular buildings, noting that shear wall placements influence overall dynamic response.

Design 2 reported the largest global displacement and longest time periods, indicating higher flexibility. Although flexibility can reduce seismic forces, excessive drift may compromise nonstructural elements. Design 3 recorded the lowest spectral displacements, indicating efficient drift control. Its moderate base shear values, combined with controlled displacements, align with Tajzadah et al. (2019), who emphasized the advantages of optimized shear wall placement for torsional and lateral resistance.

5. Statistical Significance (ANOVA and Post Hoc)

Statistical results confirm that shear wall placement significantly alters seismic response patterns in irregular structures, emphasizing the importance of configuration-specific analysis rather than generalized design assumptions. ANOVA results from Tables 11–30 show that all evaluated parameters exhibited significant differences ($p < 0.01$) across the three configurations in both directions.

Table 7

Summary of Significant Differences (ANOVA + Post Hoc)

Parameter	Direction	ANOVA Result	Which Designs Differ?	Summary Interpretation
Base Shear	X	Sig. (p < .01)	D1 vs D2, D1 vs D3	Shear wall location greatly affects lateral strength
	Y	Sig. (p < .01)	D1 vs D2, D1 vs D3, D2 vs D3	Designs resist loads differently depending on orientation
Global Displacement	X	Sig. (p < .01)	All pairs differ	Inner center shows highest drift
	Y	Sig. (p < .01)	All pairs differ	Corners show highest displacement
Spectral Acceleration	X	Sig. (p < .01)	D1 vs D3, D2 vs D3	Outer center shows most stable acceleration response
	Y	Sig. (p < .01)	All pairs differ	Corners show maximum acceleration
Spectral Displacement	X	Sig. (p < .01)	D1 vs D3, D2 vs D3	Inner center exhibits highest vulnerability
	Y	Sig. (p < .01)	All pairs differ	Corners and Outer Center differ significantly
Time Period	X	Sig. (p < .01)	All pairs differ	Inner center most flexible
	Y	Sig. (p < .01)	All pairs differ	Inner center also most flexible in Y-direction

Base Shear Differences

Design 1 consistently showed the highest base shear capacity, significantly surpassing Designs 2 and 3 in both axes. This supports the findings of Chandak & Vaishya (2022), who found that corner-aligned shear walls provide the greatest lateral stiffness. However, higher stiffness does not necessarily translate to better overall behavior, as indicated by hinge formation results.

Global Displacement Differences

All three designs differed significantly in displacement behavior.

- Design 2 (Inner Center) exhibited the highest displacement, consistent with Anushri & Swamy (2016), who found that central wall placements were associated with increased flexibility.
- Design 1 showed significant y-displacement, reflecting the torsional sensitivity common in irregular structures (Tajzadah et al., 2019).

Spectral Acceleration and Displacement Differences

Design 1 demonstrated the highest spectral acceleration and y-directional displacement, indicating a high torsional response. This aligns with Eccentricity Theory (NSCP 2015), which states that corner walls may increase torsion in irregular plans. Design 3 maintained lower spectral displacement in both directions, suggesting a more stable behavior under increasing lateral demands, consistent with findings by Bongilwar et al. (2018).

Time Period Differences

Design 2 consistently recorded the highest time periods, reinforcing its classification as the most flexible configuration. Design 1 showed the lowest time periods, reflecting stiff behavior—a trend supported by the fundamental period relationships described in ACI and NSCP provisions.

6. Performance Level of the Three Designs

The maximum total drift and maximum inelastic drift obtained from the pushover analysis were evaluated using ATC performance criteria. These performance levels—Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP)—indicate the severity of structural response during seismic loading. Tables 31.a and 31.b summarize the drift values of the three designs.

Table 8

Performance Level Summary

Direction	Design	Max Total Drift	Max Inelastic Drift	Performance Level
X	D1 (Corners)	0.00313	0.00301	IO
	D2 (Inner Center)	0.00313	0.02419	LS
	D3 (Outer Center)	0.00570	0.00558	IO
Y	D1 (Corners)	0.00403	0.00391	IO
	D2 (Inner Center)	0.00410	0.00401	IO
	D3 (Outer Center)	0.00535	0.00523	IO

Results show that Designs 1 and 3 remained within the Immediate Occupancy (IO) level in both directions, indicating minimal structural damage and retention of lateral strength after seismic loading. This behavior is consistent with Sapkota (2018), who noted that structures performing at IO remain functional with little or no repair.

Design 2, however, reached the Life Safety (LS) level in the x-direction due to its significantly higher inelastic drift. LS performance indicates noticeable damage but no collapse, aligning with Ravikumara et al. (2015), who observed that centrally placed walls can lead to greater ductility demand.

Among the designs, Design 3 (Outer Center) provided the most balanced and reliable performance by maintaining IO levels while effectively controlling drift. While Design 1 also achieved IO, its earlier hinge results suggest a tendency toward brittle behavior under higher displacement demands. Design 2 performed adequately but showed greater flexibility and higher drift, making it less favorable for irregular configurations.

Overall, the performance evaluation indicates that Design 3, with shear walls at the outer center, exhibited the most balanced seismic response among the configurations evaluated for the five-story irregular L-shaped building. Design 3 recorded the lowest spectral displacements, indicating efficient drift control. It's moderate base shear values combined with controlled displacements. Limiting lateral displacement is a very important factor in the design and construction of mid-rise buildings.

CONCLUSIONS

The study achieved its aim of assessing the seismic performance of an irregular five-story L-shaped reinforced-concrete building with three different shear wall placements. The geometric, load, and seismic parameters were successfully identified and applied to develop accurate structural models for nonlinear pushover analysis. The generated pushover curves in both the X and Y directions clearly showed variations in the first hinge formation and performance points, indicating that shear wall placement significantly influences stiffness, yielding behavior, and displacement capacity. The findings demonstrate that shear wall placement significantly influences stiffness, drift demand, hinge formation, and overall seismic response in irregular reinforced concrete buildings.

The comparison of plastic hinges across different damage levels revealed distinct behavioral patterns among the three configurations, with the outer center placement showing delayed hinge formation and lower damage accumulation. The performance point coordinates further demonstrated how base shear, global displacement, spectral acceleration, spectral displacement, and time period varied across designs, highlighting the structural implications of each wall location. Statistical analysis confirmed significant differences among configurations for all major parameters, reinforcing the conclusion that shear wall placement directly affects seismic response.

Evaluating the performance levels based on drift criteria showed that the outer center placement consistently met Immediate Occupancy requirements, while the inner center placement exhibited higher drift demands that reached the Life Safety level in one direction. The results provide analytical evidence supporting the consideration of outer-center shear wall placement to improve drift control and balance seismic behavior in L-shaped buildings. Design 3 recorded the lowest spectral displacements, indicating efficient drift control. It is moderate base shear values combined with controlled displacements. Limiting lateral displacement is a very important factor in the design and construction of mid-rise buildings.

RECOMMENDATIONS

Based on the findings and conclusions of this study, several recommendations are proposed to enhance future research and structural design practices involving irregular reinforced concrete buildings subjected to seismic loading.

First, future studies may explore other types of irregular building geometries beyond the L-shaped configuration used in this research. Irregularities in plan and elevation—such as T-shaped, U-shaped, or setback structures—may exhibit different seismic responses, and examining these can broaden understanding of how structural irregularity influences overall performance.

Second, designers and engineers are encouraged to investigate taller and more complex structures, particularly those exceeding five stories. Mid- to high-rise buildings often experience amplified lateral forces and dynamic effects; thus, analyzing these structures using nonlinear pushover analysis in ETABS can provide valuable insights. Further, additional shear wall configurations—beyond the three considered in this study—should be evaluated to identify more optimized and practical wall layouts. Alternative materials, such as structural steel systems, may also be examined to compare their behavior with reinforced concrete under similar seismic demands.

Third, the use of other structural analysis software is recommended to validate and compare the results obtained from ETABS. Programs such as SAP2000, Perform-3D, or OpenSees may offer different modeling capabilities, which can help verify consistency in performance predictions and strengthen the reliability of the findings.

Lastly, future research may incorporate additional performance variables beyond base shear, global displacement, spectral acceleration, spectral displacement, and time period. Parameters such as interstory drift ratios, torsional irregularity indices, energy dissipation capacity, and ductility factors can provide a more comprehensive understanding of structural behavior under nonlinear seismic loading.

These recommendations aim to support continuous improvement in seismic design practices and to support improved seismic design strategies for irregular reinforced concrete buildings, especially in earthquake-prone regions.

ETHICAL STATEMENT

This study was carried out in full compliance with the ethical guidelines prescribed by the Vector Publication and Research Ethics Committee of the University of Northern Philippines (UNP). The research protocol was reviewed and approved before data processing and analysis. All individuals who provided technical input or data were informed of the study's purpose, procedures, and their rights. Participation was entirely voluntary, with the option to withdraw at any time without penalty. Strict confidentiality and anonymity were maintained throughout the research process, and all collected information was used exclusively for academic and research purposes. The researchers affirm adherence to the principles of integrity, transparency, and respect for all persons as mandated by the Vector Publication and Research Ethics Committee.

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REFERENCES

Anushri, C., & Swamy, S. (2016). Study on the performance of regular and L-shape plan irregular buildings with dampers, shear walls, and infill walls. *International Research Journal of Engineering and Technology, 3*(10), 618–625.

Batth, G., & Titiksh, A. (2017). *Optimum positioning of shear walls for minimizing the effects of lateral forces in multistorey buildings*. ResearchGate.

Bongilwar, R., Hame, V. R., & Chopade, A. (2018). Significance of shear wall in multi-storey structures with seismic analysis. *IOP Conference Series: Materials Science and Engineering, 330*(1), 012131. https://doi.org/10.1088/1757-899X/330/1/012131

Chandak, R., & Vaishya, P. K. (2022). An analysis and comparative study of replacement of shear wall with intermediate beams. *International Journal of Advanced Engineering Research and Science*.

Fazileh, F., & Humar, J. L. (2012). Displacement-based seismic design of torsionally unbalanced shear structures. In *Proceedings of the 15th World Conference on Earthquake Engineering*.

Hanafiah, H., Saloma, H., Idris, Y., & Yahya, J. (2017). Behavior study of shear walls on concrete structures using pushover analysis. *International Journal on Advanced Science, Engineering and Information Technology, 7*(4), 1127–1133. https://doi.org/10.18517/ijaseit.7.4.2495

Kalibhat, M. G., Kumar, A. Y., Kamath, K., Prasad, S. K., & Shetty, S. (2014). Seismic performance of RC frames with vertical stiffness irregularity from pushover analysis. *IOSR Journal of Mechanical and Civil Engineering*, 61–66.

Mills, M., Bunt, G., & Bruijn, J. (2006). *Comparative research: Persistent problems and promising solutions*. ResearchGate.

Parishith, J., & Preetha, V. (2017). Pushover analysis on RC frames with and without shear walls. *International Journal of Intellectual Advancements and Research in Engineering Computation*.

Prusinski, K. (2015). *Automated nonlinear pushover analyses of reinforced concrete buildings* (Master's thesis). University of Colorado.

Ravikumara, H., Kulkarni, S. R., & Babu Narayan, K. S. (2015). A study on plastic hinge formation in RC frames by nonlinear static analysis. *International Journal of Research in Engineering and Technology*.

Sapkota, S. (2018). *Seismic capacity evaluation of reinforced concrete buildings using pushover analysis* (Master's thesis). University of Toledo.

Sreeram, K. V. G. M., Singh, R. P., Siva, S., & Sai Kumar, B. (2017). Effective location of shear walls and bracings for multistoried buildings. *International Research Journal of Engineering and Technology*.

Tajzadah, M., Ghafory-Ashtiany, M., & Davoodi, M. (2019). Seismic performance of irregular structures considering torsional effects.

P-ISSN: 0119-3058
E-ISSN: 2945-4093

Themelis, S. (2008). *Pushover analysis for seismic assessment and design of structures*. Semantic Scholar.