

Seismic Response of Soft Storey Buildings with Shear Walls

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ABSTRACT:

Soft-storey irregularity is a critical vertical irregularity in reinforced concrete buildings, particularly under seismic loading, as it can lead to excessive lateral deformation and concentration of seismic forces at the soft-storey level. The present study investigates the seismic behaviour of irregular reinforced concrete buildings with soft-storey conditions and evaluates the effectiveness of different shear wall configurations in improving their seismic performance. Two plan-irregular building configurations, namely L-shaped and C-shaped G+9 buildings, were considered for the study. The analytical models were developed and analysed using ETABS software in accordance with IS 1893 (Part 1):2016 using the Response Spectrum Method. Thirty vibration modes were extracted to achieve adequate cumulative modal mass participation in both principal directions, while seismic responses were evaluated for different loading directions. Various structural configurations were developed, including buildings without shear walls, buildings with shear walls at both corners, adjacent sides, and one corner, as well as alternate soft-storey models with corresponding shear wall arrangements. The influence of centrally located openings in corner shear walls was also investigated. Soft-storey conditions were simulated by reducing the flexural stiffness of columns at alternate floor levels using stiffness modifiers. A comparative assessment was carried out to identify the shear wall arrangement that provides the most effective improvement in lateral stiffness and seismic response. The study particularly focuses on the ability of shear walls to control displacement and inter-storey drift while mitigating the adverse effects of vertical and plan irregularities. The principal response parameters considered were fundamental natural time period, maximum storey displacement, inter-storey drift, base shear, storey shear, and modal mass participation ratio.

Keywords: *Soft Storey, Storey Lateral Displacement, Storey Shear, Storey Drift, ETABS, Shear Wall.*

1. INTRODUCTION

Irregular reinforced-concrete buildings are common where site planning, circulation and architectural functions produce re-entrant C- or L-shaped plans. Their centres of mass and rigidity may not coincide, so earthquake excitation can generate translation and torsion simultaneously. A soft storey further introduces a vertical stiffness discontinuity and concentrates relative floor deformation at the weakened level. These mechanisms must be evaluated together because a wall arrangement that appears adequate in a principal direction may perform poorly under diagonal excitation.

Shear walls provide a direct lateral-load path and can reduce period, displacement and drift. Their benefit, however, depends on symmetry, continuity and distance from the centre of rigidity. The present work therefore compares controlled perimeter-wall layouts while retaining the common frame, staircase and lift-core system. The purpose is not merely to show that walls are beneficial, but to identify which location produces balanced response in both irregular plans.

1.1 Research Need and Scope

Published studies consistently identify soft-storey vulnerability and the value of shear walls, but comparisons often use different geometries, seismic zones, infill assumptions or analysis methods. Direct numerical transfer is therefore difficult. This study closes that comparison gap through one traceable model family in which only the intended soft-storey and perimeter-wall variables change. The investigation is limited to comparative linear-elastic response-spectrum analysis and does not constitute construction design or certification.

2. OBJECTIVES OF THE STUDY

The main objectives of this study are to:

- To analyse a G+9 RC building model in ETABS under earthquake loads as per IS 1893 (Part 1):2016 including the effect of soft storey at different levels.
- Compare seismic performance indicators such as Time period, Modal mass participation ratio, storey displacement, storey drift, and base reactions.
- To compare the seismic response of buildings with and without shear wall.
- Find out the effect of opening in the wall.
- To identify the most effective shear wall configuration for improving the seismic performance of the buildings with soft storey.

3. LITERATURE REVIEW

Mallikarjuna et al. (2025) experimentally retrofitted a damaged half-scale open-ground-storey RC frame with partial infill RC shear walls and reported improvements in strength, stiffness, energy dissipation and deformation capacity, preventing a soft-storey mechanism. Patel and Sinha (2025) compared steel bracing, RC jacketing and RC shear walls using pushover and time-history analysis; RC infill walls produced the strongest base-shear improvement and drift control. Timsina et al. (2024) evaluated feasible soft-storey mitigation and showed that ground-floor RC walls can improve weak-storey stiffness while preserving usability. Shabala et al. (2024) analysed a G+14 ETABS model across Zones III–V and found corner walls most effective in reducing displacement and drift. Krishnan and Sivakumar (2023) used response-spectrum analysis of regular and irregular RC structures and confirmed that shear-wall geometry and location significantly reduce period and improve lateral stiffness.

Simon et al. (2023) compared centre, side, peripheral, corner and combined wall arrangements in a ten-storey ETABS model; peripheral walls provided effective deflection and drift control, while poor placement could increase torsional eccentricity. Balakrishna and Saishanker (2022) demonstrated the use of ETABS for optimized shear-wall design through comparison of drift, stiffness, base shear and displacement. Ahamad and Pratap (2021) analysed a G+20 building in different seismic zones and concluded that symmetrical wall placement performs better than absent or unsymmetrical walls. Al Agha and Umamaheswari (2021) compared irregular RC frame and dual wall-frame systems using equivalent-static and response-spectrum methods and observed lower displacement and increased lateral resistance. Bhat and Azam (2020) varied the shear-wall-area ratio in five-, nine- and twelve-storey soft-ground-storey buildings and showed that increasing wall area reduces displacement and drift while increasing lateral stiffness.

4. METHODOLOGY

In this chapter the methodology adopted for G+9 L-shaped and C-shaped RC building was investigated using ETABS software as per IS1893(Part1):2016. Analysis was performed by varying soft-storey conditions, shear wall locations, and wall openings while maintaining other modelling parameters constant. The models were analysed using the Response Spectrum Method, and analysis parameters including time period, base shear, storey displacement, inter-storey drift, and storey stiffness were evaluated. The results were systematically compared to assess the effectiveness of different shear wall configurations in improving the seismic performance of irregular buildings.

1. Model G+9 L-shaped and C-shaped reinforced-concrete buildings using ETABS software.



2. Develop the model configurations for the L-shaped and C-shaped buildings: no shear walls; shear walls at both corners, on adjacent sides, and at one corner; alternate soft-storey models with the corresponding shear-wall arrangements; and shear walls at both corners with openings.



3. Assign dead loads, live loads, and seismic loads to all building models.



4. Perform structural analysis and evaluate the modal mass participation ratio, fundamental time period, storey displacement, storey drift, base reactions, and directional response cases.

Figure 1: Flowchart of the Study

4.1 Problem statement

Both buildings are interpreted as G+9 with analytical storeys above the base. Storey height and uniform bay spacing are 3.0 m, producing a total structural height of 33 m.

Table 1: Material Grades

Grade of Concrete	M25/30
fck	25/30 N/mm ²
Grade of Main reinforcement steel	FE415/500
Grade of lateral ties or stirrups	FE415

Table 2: Material Properties

Column size	300X600mm
Primary beam size	230x450mm
Main beam size	300x550mm
Slab thickness	125mm
Thickness of Shear / Lift wall	200mm
Stairs flight / landing	150mm

Table 3: Seismic Load

Standard IS Code	IS 1893 (Part 1): 2016
Zone Factor	0.16
Importance Factor	1.5
Response Reduction Factor	5
Damping	5%
Soil	Medium / Type II
Modes	30
Eccentricity	5%
Zone	IV

Table 4: Load Considered

Self-Weight	Software generates automatically
Superimposed Dead Load	1.5 kN/m ²
Live Load	1.5 kN/m ²
Staircase Super Imposed Dead Load	1.0 kN/m ²
Live Load in addition to self-weight.	3 kN/m ²
Soft Storey Analytical levels	Analytical levels 2, 4, 6, and 8 are considered.
Modifiers considered for Column	I2 and I3 modifiers of 0.30, Axial, shear, mass, and weight modifiers remain 1.0.

Both L-shaped and C-shaped reinforced-concrete buildings are modelled as G+9 structures in ETABS, with analytical storeys above the base. A uniform storey height and bay spacing of 3.0 m are adopted, resulting in a total structural height of 33 m. Concrete grades M25/M30 and reinforcement grades Fe415/Fe500 are considered. The structural

components include 300×600 mm columns, 230×450 mm primary beams, 300×550 mm main beams, 125 mm slabs, 200 mm shear/lift walls, and 150 mm stair flights and landings. Seismic analysis is performed according to IS 1893 (Part 1): 2016 for Zone IV, considering a zone factor of 0.16, importance factor of 1.5, response reduction factor of 5, 5% damping, medium soil, 30 modes, and 5% eccentricity. Dead, live, staircase, and superimposed loads are applied. Soft-storey conditions are introduced at analytical levels 2, 4, 6, and 8, with appropriate column stiffness modifiers.

4.2 FOUR DIRECTION STATIC ANALYSIS

1. Four Response Spectrum Cases evaluate principal and diagonal demand.
2. RSX uses global U1 at 0 degrees, RSY uses global U2 at 90 degrees, RS45 uses U1 at 45 degrees, and RS135 uses U1 at 135 degrees.
3. The acceleration scale factor is 9.80665 and 5% eccentricity is included.
4. The governing drift and displacement are selected across all four cases rather than from RSX and RSY alone.
5. Diagonal excitation is especially relevant for irregular plans because principal structural axes do not necessarily align with the global coordinate axes.
6. The RS45 and RS135 cases govern several updated L-shaped model responses.

5. STRUCTURAL MODELLING

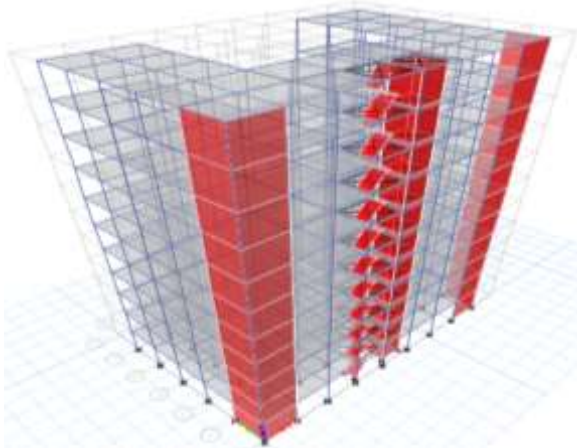


Figure 2: C-Type Building with Both Corner Walls – 3D View

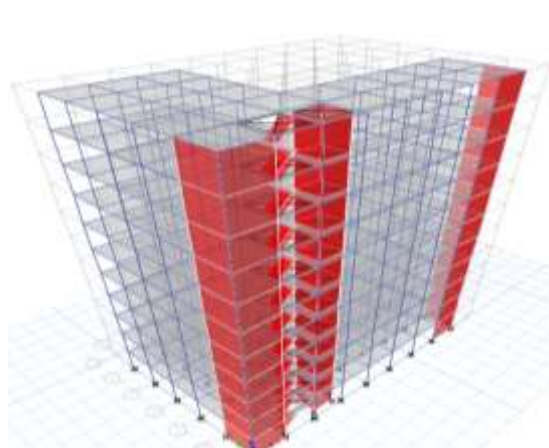


Figure 3: L-Type Building with Both Corner Walls – 3D View

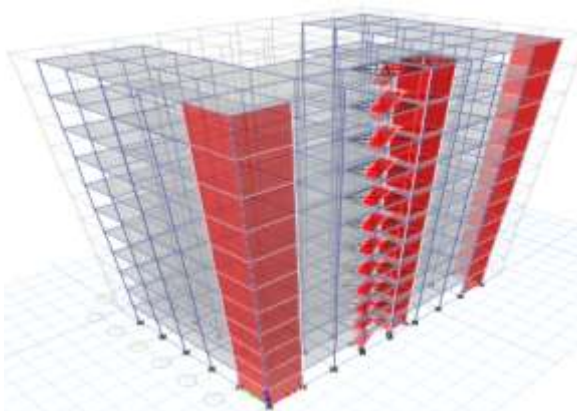


Figure 4: C-Type Building with Alternate Soft Both Corner Walls – 3D View

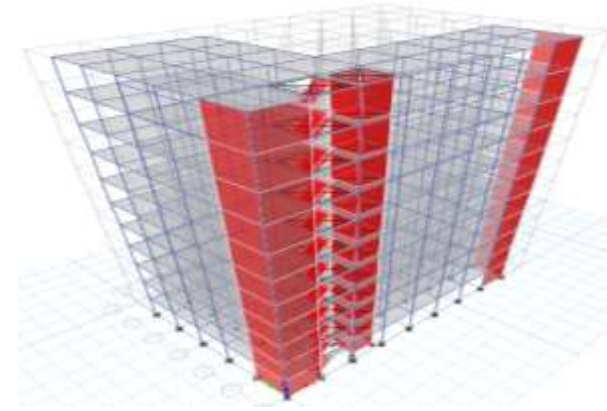


Figure 5: L-Type Building with Alternate Soft Both Corner Wall – 3D View

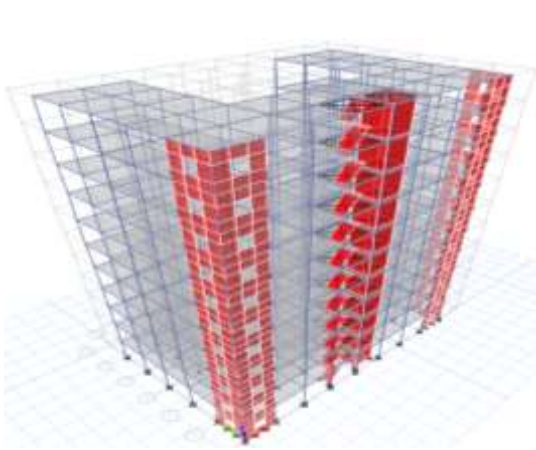


Figure 6: C-Type Building with Both Corners Opening Wall – 3D View

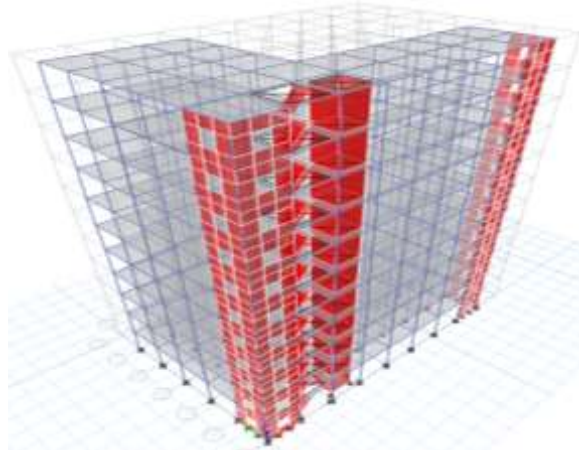


Figure 7: L-Type Building with Both Corners Opening Wall – 3D View

6. RESULTS AND DISCUSSION

The updated results are interpreted using the governing values from Four Directional Response Spectrum Cases. Force and Deformation are considered together because a stiffer structure may attract higher force while experiencing lower displacement and drift.

6.1 Normal Building Displacement

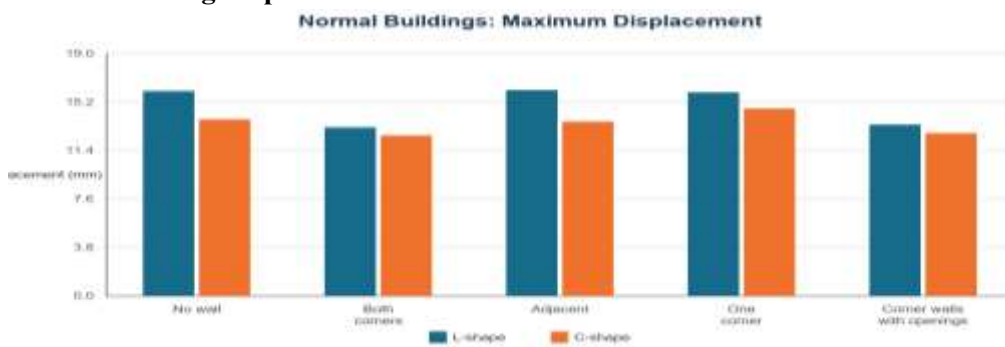


Figure 8: Maximum Displacement of Normal L and C Shaped Buildings

Figure 8 Shows Maximum Displacement of Normal L and C shaped Buildings. The normal building comparison shows that the solid both corner configuration gives the lowest displacement among the principal wall arrangements in both plan shapes. The diagonal cases govern several L-shaped configurations after the service core update. The updated lift core reduces the absolute difference between some layouts, but the relative ordering remains meaningful. Both corner perimeter walls continue to provide the most consistent translation control.

6.2 Normal Building Storey Drift

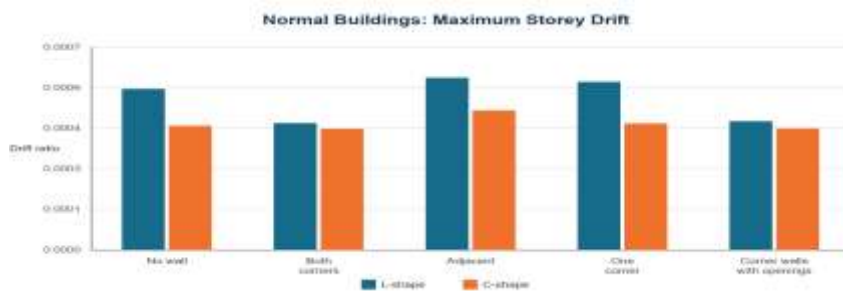


Figure 9: Maximum Drift of Normal L and C Shaped Buildings

Figure 9 Shows Maximum Drift of Normal L and C Shaped Buildings. Both corner walls provide the strongest normal building drift control. Adjacent and one corner arrangements are less balanced and may not improve both global directions consistently. Storey drift measures relative floor displacement and is more closely related to local deformation demand than roof displacement alone. The critical storey changes with wall layout because the added stiffness modifies

the vertical distribution of curvature and shear. The updated normal models remain below the commonly referenced linear drift limit used for preliminary checking, but final compliance should be verified using the exact applicable code combinations and modelling assumptions.

6.3 Soft Storey –Storey Displacement

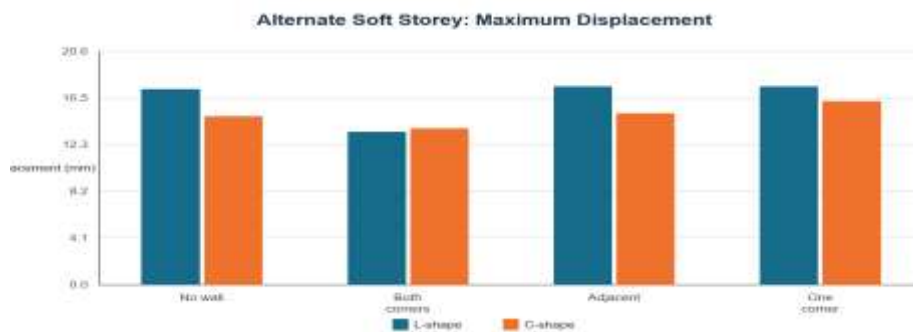


Figure 10: Maximum Displacement of Alternate Soft Storey Buildings

Figure 10 Shows Maximum Displacement of Alternate Soft Storey Buildings. The alternate soft storey condition increases deformation relative to the matching normal building. Both corner walls reduce maximum displacement, while adjacent and one corner walls provide weaker control. The soft storey modification increases flexibility at selected levels, which changes both the global period and the location of peak drift. Maximum displacement alone does not identify the concentration mechanism, so it is interpreted together with the storey drift output. The both corner arrangement provides the clearest reduction because it supplements the common central core with balanced perimeter resistance. Adjacent and one-corner walls offer a less uniform load path.

6.4 Soft Storey - Storey Drift

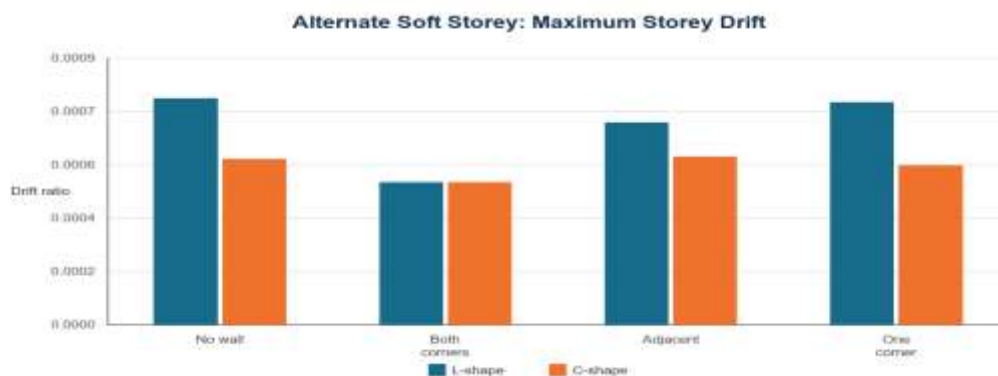


Figure 11: Maximum Drift of Alternate Soft Storey Buildings

Figure 11 Shows Maximum Drift of Alternate Soft Storey Buildings. The soft storey drift comparison confirms the benefit of balanced walls. For the updated L shaped models, both corner walls reduce drift by approximately 37.35% relative to the matching without shear wall model. The corresponding updated C shaped reduction is approximately 13.9%. Although the updated C shaped percentage reduction is smaller than the L-shaped reduction, the both corner layout still provides the lowest soft storey drift among the compared C shaped alternatives.

Table 7: Fundamental Period Comparison for L Type and C Type of Building

MODEL	T1 (s)	MAX DISP. (mm)
01. C Type Building with Base No Wall	0.8981	13.80
01. L Type Building with Base No Wall	0.9059	16.03
02. C Type Building Both Corners Wall	0.8007	12.52
02. L Type Building Both Corners Wall	0.7610	13.17
03. C Type Building Adjacent Wall	0.8122	13.62
03. L Type Building Adjacent Wall	0.8412	16.09
04. C Type Building One Corner Wall	0.8646	14.66
04. L Type Building One Corner Wall	0.9031	15.92
05. C Type Building Alt Soft No Wall	1.0426	14.80
05. L Type Building Alt Soft No Wall	1.0340	17.21
06. C Type Building Alt Soft Both Corners Wall	0.8695	13.74
06. L Type Building Alt Soft Both Corners Wall	0.8232	13.43
07. C Type Building Alt Soft Adjacent Wall	0.8866	15.08
07. L Type Building Alt Soft Adjacent Wall	0.9102	17.42
08. C Type Building Alt Soft One Corner Wall	0.9609	16.14
08. L Type Building Alt Soft One Corner Wall	1.0108	17.44
09. C Type Building Both Corners Openings	0.8103	12.70
09. L Type Building Both Corners Openings	0.7710	13.39

Table 6 Shows the fundamental time period (T1) and maximum displacement of L and C type buildings under normal and alternate soft-storey conditions. The results show that shear wall location significantly affects structural stiffness and lateral response. The **both-corner wall configuration** provides the lowest time period and displacement for both building shapes, indicating superior stiffness and seismic performance. In contrast, buildings without shear walls, particularly with soft storeys, show higher time periods and larger displacements. Shear wall openings cause a slight reduction in stiffness compared with solid walls. Overall, properly located shear walls, especially at both corners, effectively reduce structural flexibility and lateral displacement, while soft-storey conditions increase the seismic response.

6.5 Base Reaction And Directional Response

Increased stiffness can increase force attraction while reducing deformation, so member capacities and foundation demand must be checked alongside drift and displacement.

Table 8: Base Reaction and Directional Response for L and C Type of Building

MODEL	RSX FX	RSY FY	GOV. CASE
01. C Type Building with Base No Wall	743.3	896.1	RS45
01. L Type Building with Base No Wall	681.8	689.3	RS135
02. C Type Building Both Corners Wall	855.0	1087.0	RSX
02. L Type Building Both Corners Wall	811.6	946.6	RS135
03. C Type Building Adjacent Wall	1067.4	847.7	RSY
03. L Type Building Adjacent Wall	1040.5	733.9	RSY
04. C Type Building One Corner Wall	745.7	816.1	RS135
04. L Type Building One Corner Wall	691.6	616.9	RS135
05. C Type Building Alt Soft No Wall	640.3	804.8	RS45
05. L Type Building Alt Soft No Wall	574.8	626.7	RS135
06. C Type Building Alt Soft Both Corners Wall	798.5	998.0	RSX
06. L Type Building Alt Soft Both Corners Wall	747.6	878.0	RS135
07. C Type Building Alt Soft Adjacent Wall	997.4	786.6	RSY
07. L Type Building Alt Soft Adjacent Wall	973.7	689.4	RSY
08. C Type Building Alt Soft One Corner Wall	663.2	720.2	RS135
08. L Type Building Alt Soft One Corner Wall	609.5	548.2	RS135
09. C Type Building Both Corners Openings	844.9	1064.3	RSX
09. L Type Building Both Corners Openings	799.7	925.3	RS135

Table 8 shows base reaction and directional response for L-type and C-type buildings under different shear wall configurations. The table reports principal base reactions while the governing displacement case may be diagonal. The results indicates that the magnitude of base reaction varies significantly with the location and configuration of the shear walls. Models with adjacent shear walls (model 03 and model 07) generally exhibits the highest base reactions, indicating increased lateral stiffness and greater transfer of seismic forces to the foundation. In contrast, the no wall and one corner wall configurations show comparatively lower base reactions due to reduced lateral stiffness.

6.6 Effect Of Wall Openings

Openings cause a modest loss of stiffness compared with the solid both corner walls. Nevertheless, both opening models retain substantially better global control than the corresponding no variable wall baselines.

Table 9: Effect of Wall Openings of L and C type Building

MODEL	PERIOD (s)	DISP. (mm)	DRIFT
02. L Type Building Both Corners Wall	0.7610	13.170	0.0004495
09. L Type Building Both Corners Openings	0.7710	13.385	0.0004553
02. C Type Building Both Corners Wall	0.8007	12.521	0.0004283
09. C Type Building Both Corners Openings	0.8103	12.698	0.0004296

Comparative Graph of Maximum Displacement For C-Shaped Models

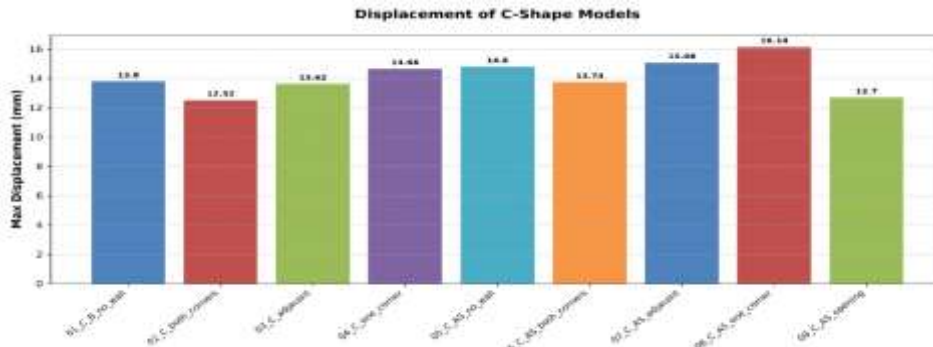


Figure 12: Maximum Displacement Comparison for C-Shaped Models

Table 9 shows that wall openings marginally increased the L-type period from 0.7610 to 0.7710 s and displacement from 13.170 to 13.385 mm, while C-type values increased from 0.8007 to 0.8103 s and 12.521 to 12.698 mm. Figure 12, “Maximum Displacement of C-Shaped Models under Different Structural Configurations,” shows a 12.52–16.14 mm range. Both-corner walls provided maximum stiffness and minimum displacement, whereas the alternate soft-storey one-corner wall produced maximum displacement.

Comparative Graph of Maximum Drift For C-Shaped Models

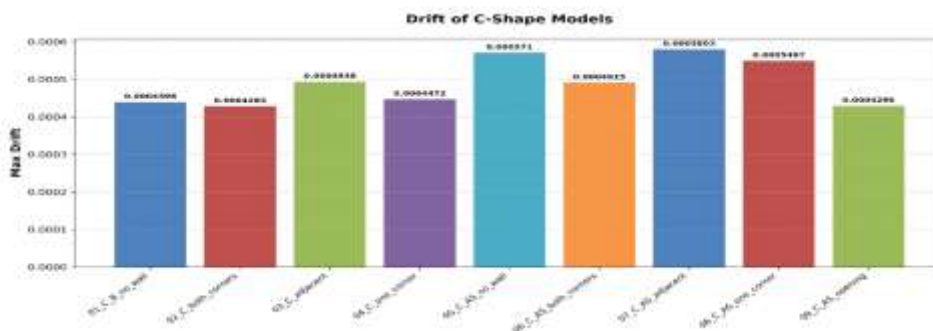


Figure 13: Maximum Drift Comparison for C-Shaped Models

Figure 13 compares the maximum drift of C-shaped models under different structural configurations. The drift values range from 0.0004283 to 0.000583. The **both-corner wall configuration** shows the lowest drift (0.0004283), indicating higher structural stiffness, while the **alternate soft storey with adjacent wall** records the highest drift (0.000583). Overall, the results confirm that shear wall location and configuration significantly influence drift performance, with properly positioned corner walls providing better seismic resistance.

Graph of Stiffness For C-Shaped Models

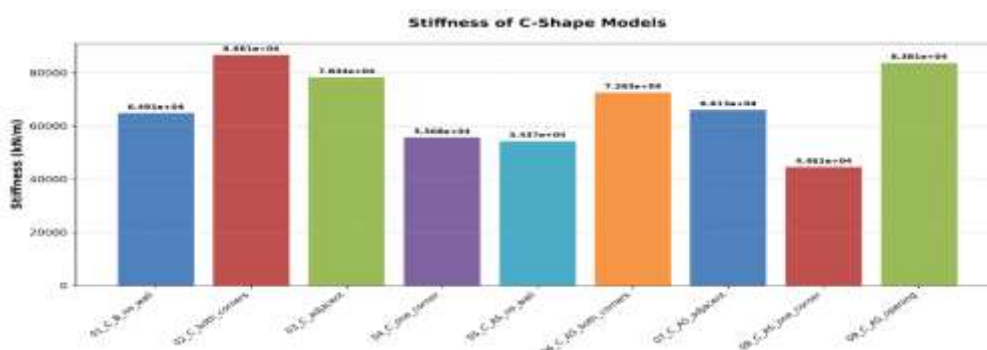


Figure 14: Stiffness Comparison for C-Shape Models

Figure 14 compares the stiffness of C-shaped models under different structural configurations. The stiffness ranges from 4.461×10^4 to 8.681×10^4 kN/m. The **both-corner wall configuration** provides the highest stiffness (8.681×10^4 kN/m), while models without shear walls show lower stiffness. Overall, the results confirm that proper shear wall

placement and optimized openings increase structural stiffness and reduce lateral displacement and storey drift, improving seismic performance.

Comparative graph of base shear for c-shaped models

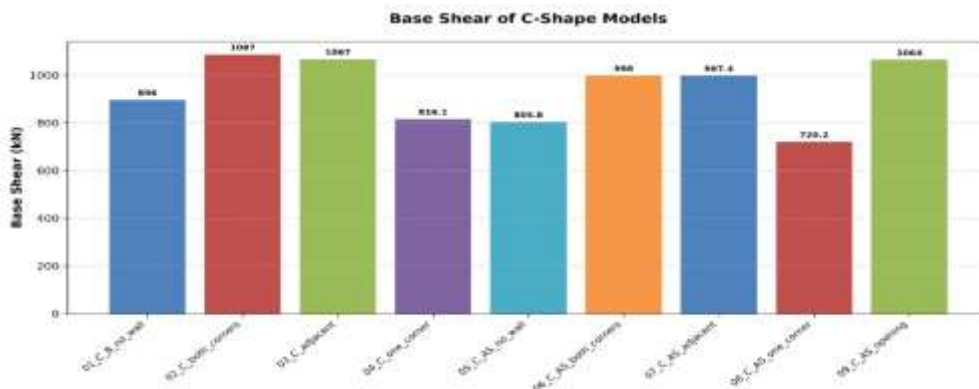


Figure 15: Base Shear Comparison for C-Shape Models

Figure 15 compares the base shear of C-shaped models under different structural configurations. The **both-corner wall configuration** shows the highest base shear (1087 kN), indicating greater lateral stiffness and seismic resistance. In contrast, the **alternate soft storey with one corner wall** records the lowest value (720.2 kN). Overall, the results confirm that properly positioned shear walls, particularly at both corners, enhance the structure's ability to resist earthquake-induced lateral forces.

Comparative Graph of Maximum Displacement For L-Shaped Models

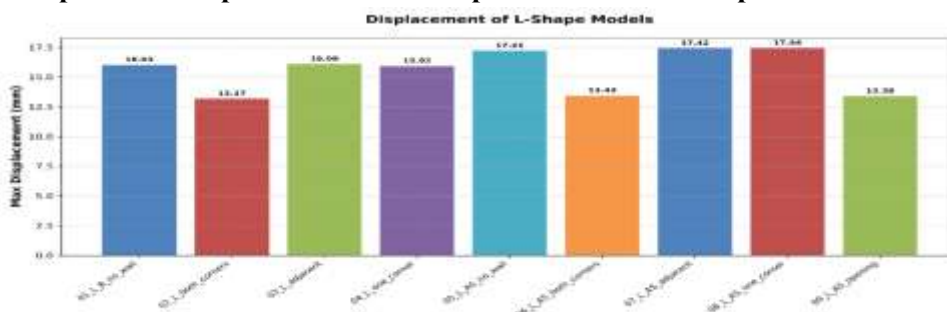


Figure 16: Maximum Displacement Comparison for L-Shape Models

Figure 16 compares the maximum displacement of L-shaped models under different structural configurations. The displacement ranges from 13.17 mm to 17.44 mm. The **both-corner wall configuration** shows the lowest displacement, while the **alternate soft storey with one corner wall** records the highest displacement (17.44 mm). Overall, the results confirm that proper shear wall placement significantly reduces lateral displacement and improves the seismic performance of L-shaped buildings.

Comparative graph of maximum drift for l-shaped models

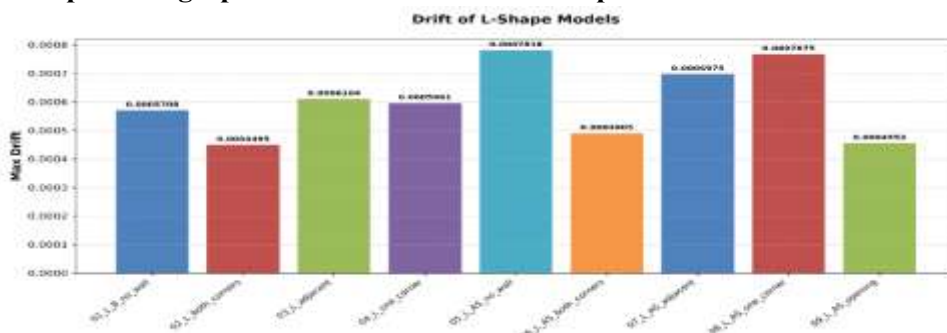


Figure 17: Maximum Drift Comparison for L-Shape Models

Figure 17 compares the maximum drift of L-shaped models under different structural configurations. The drift ranges from **0.0004495 to 0.0007818**. The **alternate soft storey with no wall** shows the highest drift (0.0007818), followed by the one-corner wall configuration (0.0007675). Overall, the results indicate that proper shear wall placement significantly reduces storey drift, while soft-storey and less effective wall configurations result in greater lateral deformation.

Comparative graph of stiffness for l-shaped models

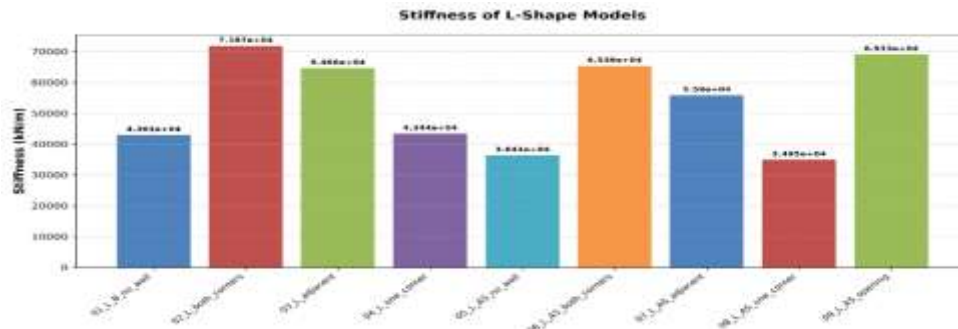


Figure 18: Stiffness Comparison for L-Shape Models

Figure 18 compares the stiffness of L-shaped models under different structural configurations. The stiffness ranges from **3.495×10^4 to 7.187×10^4 kN/m**. The **both-corner wall configuration** shows the highest stiffness (7.187×10^4 kN/m), while models with alternate soft storey and less effective wall arrangements show lower stiffness. Overall, proper shear wall placement and optimized openings increase structural stiffness, thereby reducing displacement and storey drift and improving seismic performance.

Comparative graph of base shear for l-shaped models

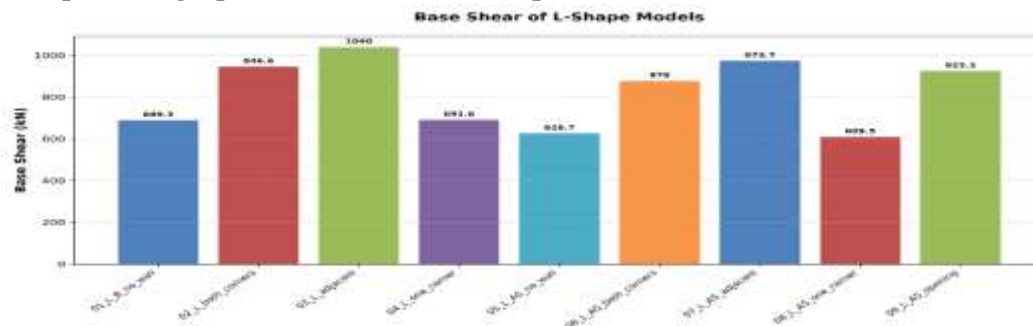


Figure 19: Base Shear Comparison for L-Shape Models

Figure 19 compares the base shear of L-shaped models under different structural configurations. The **adjacent wall configuration** records the highest base shear (**1040 kN**), followed by the **alternate soft storey with adjacent wall** (**973.7 kN**), indicating greater lateral stiffness and seismic resistance. In contrast, the **alternate soft storey with no wall** shows the lowest base shear (**626.7 kN**). Overall, the results confirm that proper shear wall placement enhances the lateral load-resisting capacity of L-shaped buildings.

7. DISCUSSIONS

1. Shear walls significantly improve seismic performance by reducing displacement and storey drift.
2. Both-corner shear walls provide the best overall performance due to higher lateral and torsional stiffness.
3. Adjacent and one-corner walls are less effective because they create stiffness concentration and torsional effects.
4. Alternate soft-storey models show higher flexibility, displacement, and drift than regular models.
5. Both-corner walls effectively control soft-storey effects and reduce lateral deformation.
6. Shear wall openings slightly reduce stiffness and cause a small increase in displacement and drift.

7. Higher stiffness reduces the fundamental time period but increases base shear, creating higher force demand on foundations.
8. L-shaped buildings generally show higher displacement than C-shaped buildings due to their geometry and torsional behaviour.
9. Proper perimeter/corner wall placement is more effective than asymmetric or adjacent wall placement.
10. Overall, both-corner shear walls are the most effective configuration for controlling displacement, drift, torsion, and soft-storey effects in irregular buildings.

8. CONCLUSIONS

1. Vertical stiffness irregularity increases the fundamental time period, displacement, and storey drift.
2. Both-corner solid shear walls provide the most effective and consistent seismic performance for both L- and C-shaped buildings. L-shaped buildings are more vulnerable to displacement and torsional effects than C-shaped buildings due to their irregular geometry.
3. Both-corner shear walls significantly reduce displacement:
L-shape: 16.03 -13.17 mm (17.84% reduction)
C-shape: 13.80 -12.52 mm (9.27% reduction)
4. Soft-storey conditions increase structural flexibility and displacement, while both-corner shear walls effectively control these effects.
5. For alternate soft-storey L-shape, displacement reduced from 17.21-13.43 mm, showing approximately 21.96% improvement.
6. Adjacent and one-corner wall arrangements are less effective because they create unbalanced stiffness and greater torsional effects. Both-corner walls increase structural stiffness significantly and reduce the fundamental time period.
7. All models satisfy the IS 1893:2016 drift limit, but both-corner configurations provide the lowest drift values. Wall openings cause only a slight reduction in performance compared with solid walls and remain effective when properly designed.
8. Higher stiffness increases base shear, creating greater force demand on shear walls and foundations. Four-direction response-spectrum analysis is important, as RS45 and RS135 govern several irregular models. Overall, balanced perimeter/corner shear wall placement is the most effective strategy for controlling displacement, drift, torsion, and soft-storey effects in irregular buildings.

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