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Analysis and Design of Multistoried Building By Using Software For Different Earthquake Zones

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Abstract: This study presents a comprehensive analysis and design of a multistoried G+16 L-shaped building using structural analysis software under different seismic zones (II to V), focusing on the impact of shear wall inclusion on structural performance. Five models were developed: one without shear walls and four with shear walls placed in zones of increasing seismic intensity. The investigation evaluates storey drift and storey shear parameters to assess lateral load resistance. Results reveal that the model without shear walls (Model-1) exhibits the highest storey drift and lowest shear resistance, indicating poor seismic performance. In contrast, models with shear walls (Models 2–5) show substantial improvements in both drift control and shear resistance, with Model-3 (Zone III) demonstrating the most balanced performance. The study confirms that the inclusion of shear walls significantly enhances the structural stability and seismic resilience of multistoried buildings, with increased efficiency in higher seismic zones.
Keywords: Seismic analysis, Multi-story buildings, Shear walls, Irregular structures, Dynamic analysis, Seismic codes

I. INTRODUCTION

In the context of rapidly expanding urban centers worldwide, the escalating demand for residential, commercial, and infrastructural spaces has become a defining characteristic of modern development. This surge, primarily driven by relentless urbanization and burgeoning population figures, necessitates innovative solutions to address the increasing spatial requirements. With the finite nature of horizontal land availability, the concept of vertical expansion through the construction of multi-story buildings has evolved from a mere architectural possibility to a practical and indispensable strategy. These towering structures, which encompass a wide spectrum from medium-rise apartment complexes providing much-needed housing to colossal skyscrapers serving as hubs for commerce, administration, and mixed-use developments, play a critical role in effectively mitigating the challenges posed by land scarcity while simultaneously accommodating a diverse array of functional needs that underpin modern urban life. The efficient utilization of vertical space not only optimizes land use but also contributes to the creation of compact, interconnected urban environments that can support a higher density of activities and populations.

The meticulous design of multi-story buildings demands a profound and holistic understanding of a multitude of interconnected factors, all of which are paramount to ensuring the long-term safety, structural durability, and overall usability of these complex edifices. Among the most critical considerations is structural integrity, which encompasses the building's fundamental ability to effectively bear and distribute both vertical loads, such as the inherent weight of the building itself (dead loads) and the weight of occupants and movable objects (live loads), as well as horizontal loads originating from environmental forces, most notably wind pressures and the dynamic forces induced by seismic activity. Secondly, safety is of paramount importance, requiring the integration of robust design features and construction practices to protect occupants from a wide range of potential hazards. This is particularly crucial in regions that are geographically prone to earthquakes or experience extreme weather conditions, necessitating the incorporation of structural enhancements like reinforced concrete frames, strategically placed shear walls designed to resist lateral forces, and comprehensive bracing systems that enhance overall stability. Furthermore, functionality plays a key role in the design process, focusing on the creation of internal layouts that not only maximize the efficient utilization of available space but also maintain optimal structural efficiency. This involves the judicious placement of load-bearing elements such as columns, beams, and walls to seamlessly align with both the architectural vision and the specific operational requirements of the building, ensuring that the structural framework supports the intended use without compromising spatial utility or aesthetic appeal.

In geographical regions characterized by significant seismic activity, the design and construction of multi-story buildings present a unique and complex set of engineering challenges.

Earthquakes generate powerful and unpredictable dynamic forces that can inflict substantial structural damage on buildings if these forces are not adequately anticipated and addressed during the design phase. Therefore, the incorporation of specific earthquake-resistant features into the fundamental design of multi-story structures is not merely an option but an absolute necessity to prevent catastrophic structural collapse and minimize the extent of potential damage to both the building itself and its occupants. Among the key structural principles employed in earthquake-resistant design are flexibility and ductility. Flexibility refers to the building's ability to undergo significant deformations without losing its structural integrity, allowing it to sway and move in response to ground shaking. Ductility, on the other hand, is the capacity of the structural materials and connections to deform beyond their elastic limit without experiencing a sudden and brittle failure. By incorporating these properties, the structure can effectively absorb and dissipate the immense energy imparted by seismic waves through controlled yielding and deformation, thereby reducing the forces transmitted to the primary structural elements and enhancing the overall resilience of the building during an earthquake.

II. LITERATURE REVIEW

Research extensively explores the design and analysis of earthquake-resistant structures to lessen seismic risks. This overview examines existing studies on how multi-story buildings, both regular and irregular, behave during earthquakes. Key findings on static and dynamic analyses, the impact of soil types, and the influence of seismic zones are highlighted. Various methods, tools, and design strategies used to assess and improve building performance under seismic loads are also discussed, providing a foundation for identifying research gaps and defining the scope of further investigation.

Studies have investigated the complex behavior of multi-story buildings with regular and irregular shapes under earthquake and wind loads, utilizing software like ETABS and STAAD-Pro. These analyses consider different seismic zones and soil conditions (hard, medium, soft) to evaluate responses such as story drift, displacements, and base shear. Research also emphasizes the critical need for well-designed and constructed multi-story buildings to prevent collapse during earthquakes, advocating for seismic analysis in the design process, considering ordinary and special moment resisting frames through equivalent static and response spectrum analysis.

Further work has analyzed multi-story buildings for storey drift, base shear, displacement, and torsional irregularity across all Indian seismic zones using software like Etabs. Findings indicate that structures with symmetrically placed shear walls perform better in terms of seismic parameters compared to those without or with asymmetrically placed shear walls, especially on soft soil. Studies on reinforced concrete frame buildings, common in urban India and subject to static and dynamic forces, have used STAAD-Pro for analysis in different seismic zones, summarizing post-processing results.

Observations on storey shear, stiffness, joint displacement, and center of mass displacement in buildings of different shapes (L, rectangular, T, I) reveal that asymmetrical plans tend to deform more than symmetrical ones, suggesting that symmetrical shapes offer better stability in high seismic zones. Seismic performance analysis is recommended for safe building structures, with new design provisions requiring static and dynamic analyses like equivalent static analysis, response spectrum analysis, and time history analysis on regular and irregular RCC building frames using software like ETABS and SAP 2000, considering seismic codes like BNBC.

Computer-aided software like STAAD.Pro is crucial for analyzing the stability of high-rise multi-story buildings by calculating forces and deformations, aiming for economic design of building components. Research concludes that structures should withstand moderate earthquakes with acceptable damage, termed Design Basis Earthquakes (DBE), often modeled as 3D space frames and analyzed using Response Spectrum methods on varying slope ground conditions, adhering to seismic codes like IS 1893 and ductile detailing as per IS 13920.

Analysis of the dynamic responses of multi-story nonlinear structural frames using digital computers and related analytical studies highlight the importance of a wide range of modes in earthquake response and the effect of yielding. Structural responses are compared with earthquake strength measurements, considering bilinear and curvilinear hysteretic behavior and different definitions of ductility factor. Comparisons between static (Seismic Coefficient Method) and dynamic (Response Spectrum Method) linear seismic analyses on multi-story framed structures using STAAD-Pro, based on IS codes, examine parameters like bending moment and nodal displacements.

The objective of earthquake engineering is to minimize structural damage during earthquakes, often achieved through dynamic analysis of symmetrical multi-story RCC buildings using finite element software to determine response parameters like lateral force, base shear, and story drift, employing time history or response spectra methods. Finally, comparisons of seismic analysis on braced and shear wall stiffened multi-story buildings across different seismic zones using software like STAAD-Pro, based on IS codes, aim to understand factors leading to poor structural performance during earthquakes to improve behavior in future seismic events.

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III. METHODOLOGY

The following section gives the modeling in STAAD-PRO software.

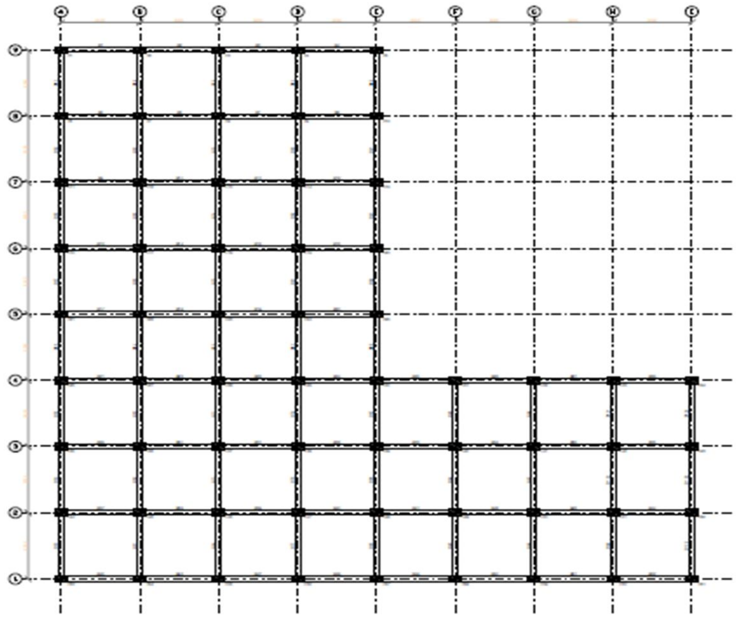

Figure 1: Beam plan

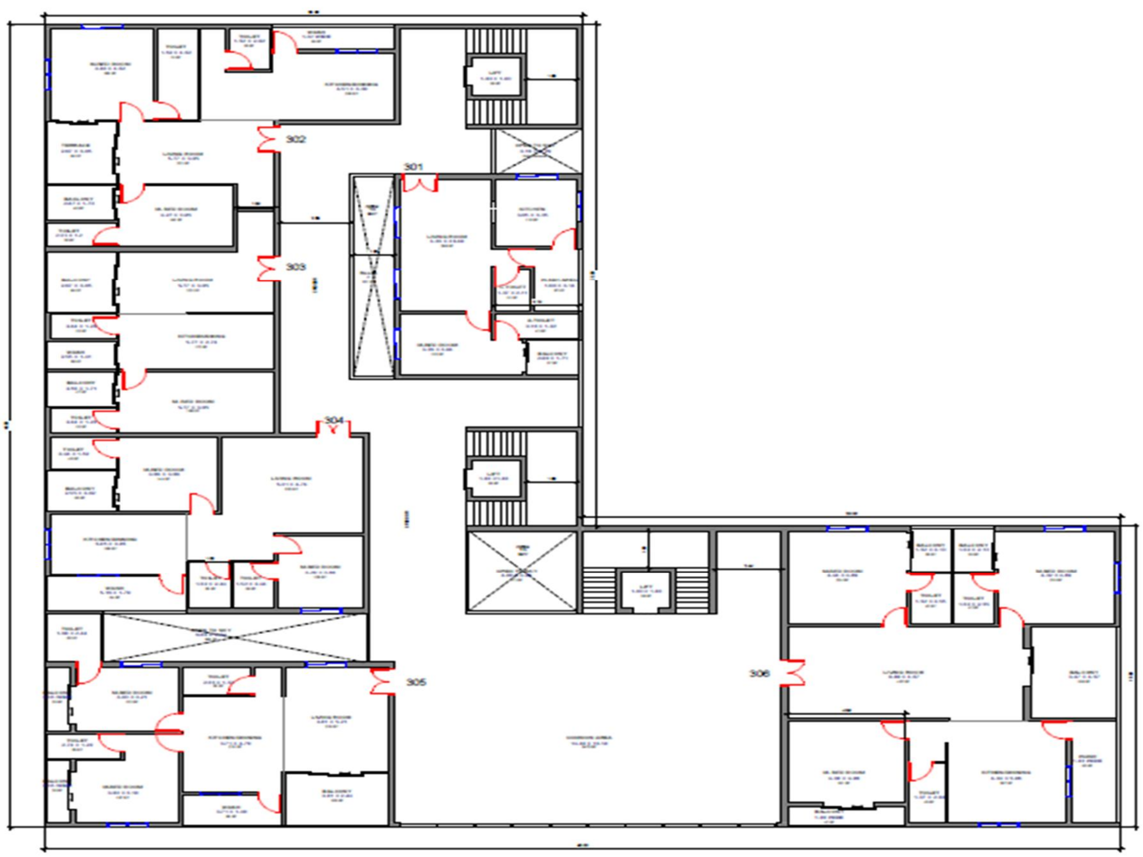

Figure 2: Plan of the structure

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Table **Error! No text of specified style in document.**.1: Properties of the model

Parameters	Dimensions (m)
Grid Spacing (X, Z)	5
Height (Y)	30
Width (X)	25
Depth (Z)	25
Column size	0.75 × 0.50
Rectangular Beam	0.55 × 0.35
Type of Support	Fixed Support
Live load	3 kN/m2
Response reduction factor	5
Importance factor	1
rock and soil site factor	2

The structural model is defined with key parameters that determine its geometry, material properties, and loading conditions. The grid spacing in the X and Z directions is set at 5 meters, providing a uniform layout for the structure. The overall height (Y) of the model is 30 meters, while its width (X) and depth (Z) are both 25 meters, resulting in a cubic-like arrangement.

Table **Error! No text of specified style in document.**.2:Seismic Design Parameters for Different Seismic Zones in India

Parameters	Zone II	Zone III	Zone IV	Zone V
Zone Factor (Z)	0.10	0.16	0.24	0.36
Response Reduction Factor (RF)	5	5	5	5
Importance Factor (I)	1	1	1	1
Rock and Soil Site Factor (SS)	2	2	2	2
Type of Structure (ST)	1	1	1	1
Damping Ratio (DM)	0.05	0.05	0.05	0.05

Table **Error! No text of specified style in document.**.3:Typical Variation of Column and Beam Sizes with Building Height for a G+16 Structure

Storey Level	Column Size (m)	Beam Size (m)
Ground to 4th	0.75 × 0.50	0.55 × 0.35
5th to 8th	0.70 × 0.45	0.50 × 0.30
9th to 12th	0.65 × 0.40	0.45 × 0.30
13th to Terrace	0.60 × 0.40	0.40 × 0.25

The structural elements consist of plates and beams. The plate thickness is specified as 0.75 × 0.50 meters, ensuring sufficient rigidity for floor systems or load-distributing surfaces. The rectangular beams are consistently dimensioned at 0.55 × 0.35 meters, designed to carry and transfer loads effectively throughout the structure. The supports at the base of the structure are modeled as fixed supports, ensuring stability by restricting all degrees of freedom.

The Following models are prepared using STAAD-PRO software:

1) Irregular G+16: L-shaped building without shear wall
2) Irregular G+16: L-shaped building with shear wall-Seismic Zone-II
3) Irregular G+16: L-shaped building with shear wall-Seismic Zone-III
4) Irregular G+16: L-shaped building with shear wall-Seismic Zone-IV
5) Irregular G+16: L-shaped building with shear wall-Seismic Zone-V

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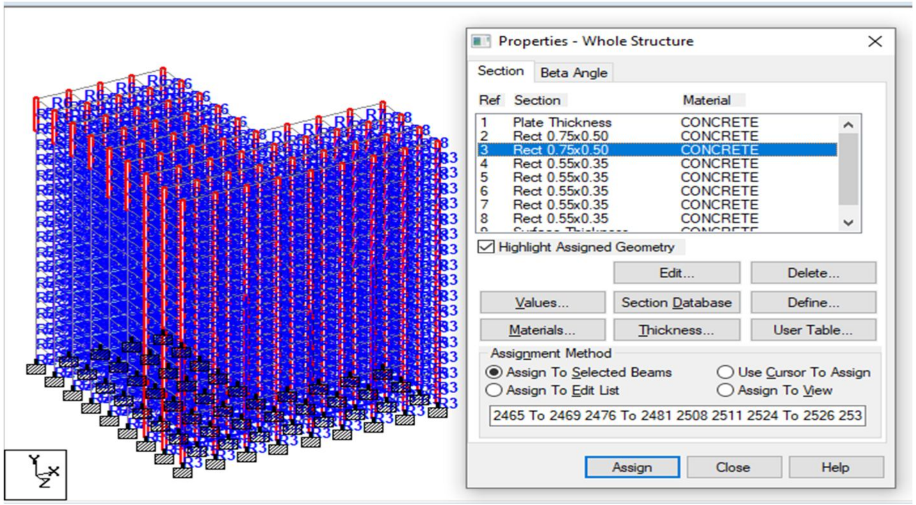

Figure 3: Column properties assigned to the model

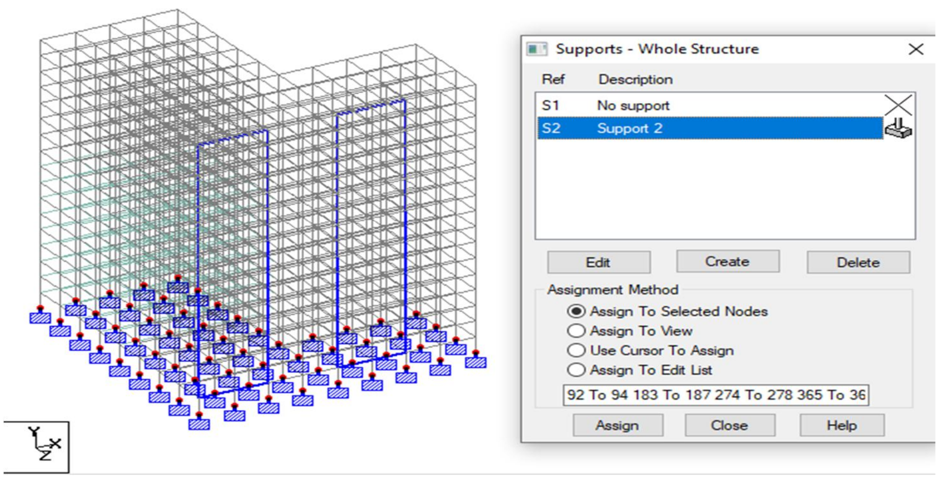

Figure 4: Supports assigned to the model

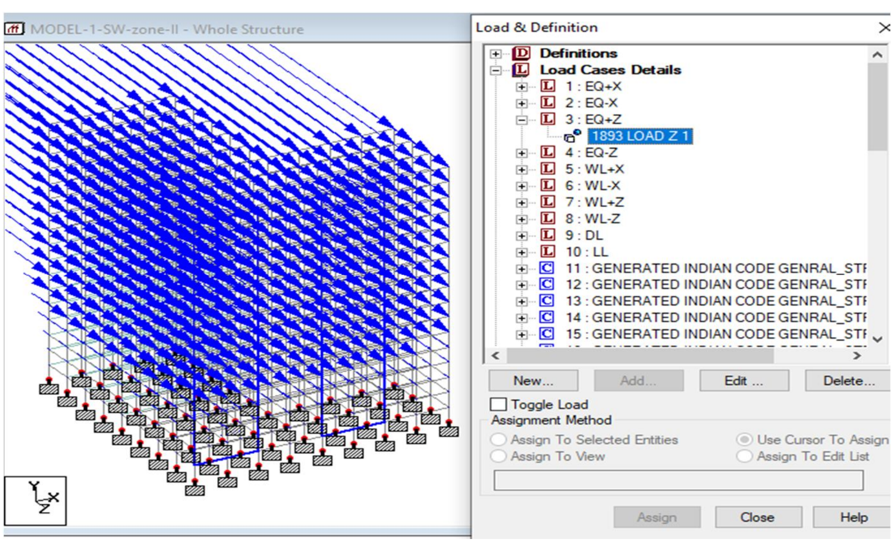

Figure 5: Load assignment to the model

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IV. RESULTS

The results include a detailed evaluation of key structural parameters such as story drift, base shear, displacement, and torsional response. The findings are compared for both regular and irregular building configurations to assess their seismic performance under different loading conditions. Additionally, the impact of varying soil types on the building's behavior is analyzed, providing valuable insights into the structural resilience of buildings in different seismic environments.

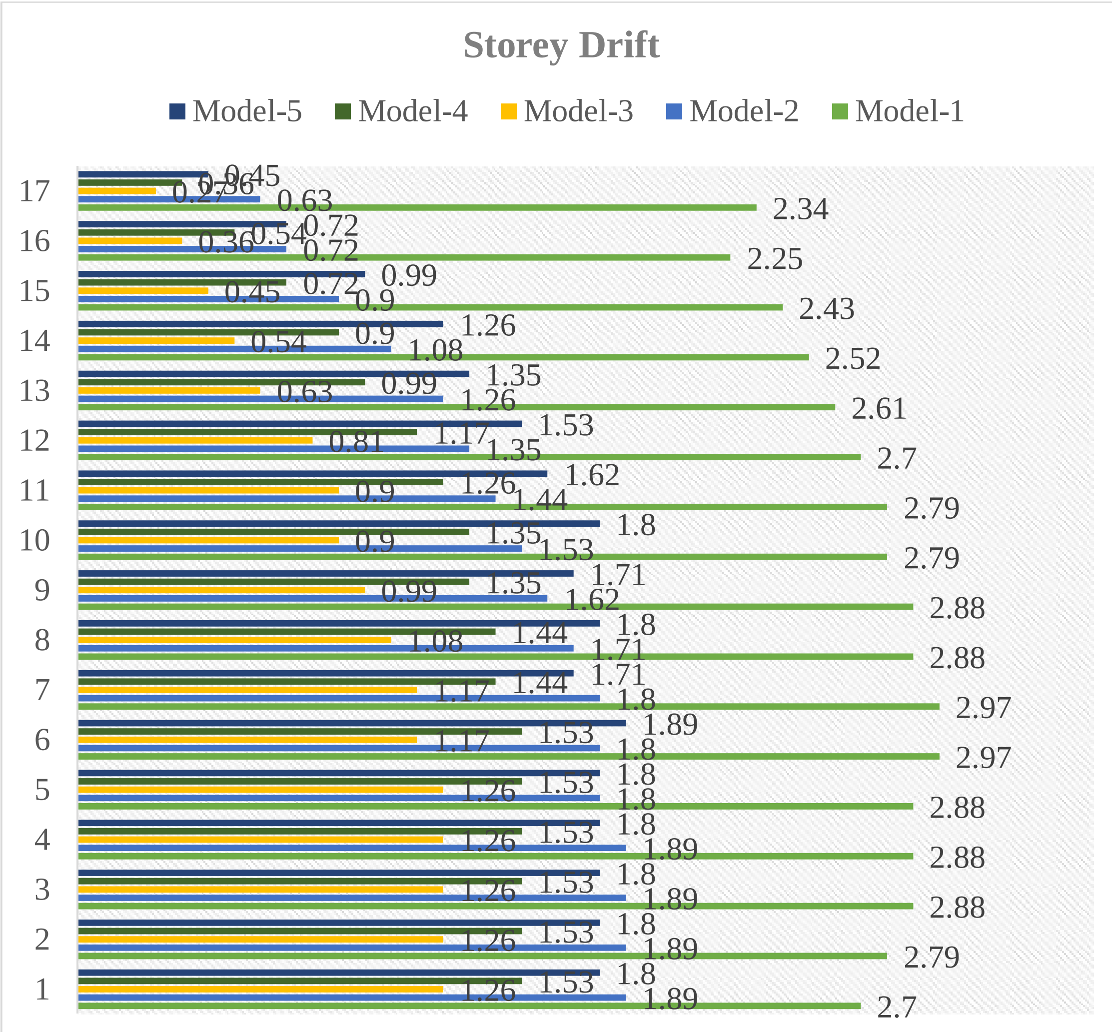

Figure 6: Storey drift for all models

This bar chart compares the storey drift across five different structural models (Model-1 to Model-5) at each story level, from story 1 to story 17. All models are G+16 story L-shaped buildings. Model-1 is without a shear wall, while Models 2-5 include a shear wall and are located in Seismic Zones II, III, IV, and V, respectively. Model-1 consistently exhibits the highest storey drift across all stories, starting at around 2.7 at the base, peaking at 2.97 between stories 6 and 7, and then gradually decreasing to 2.34 by story 17. In contrast, Models 2-5, all incorporating shear walls, demonstrate a significant reduction in storey drift. While their drift values are generally lower, some variation exists: in the lower stories (1-3), all models experience their highest drift, with Model-2 showing 1.89 at stories 1-4, decreasing to 0.63 at the top. Model-5 has the highest drift in the upper stories. Overall, storey drift tends to be greater in the lower stories and decreases towards the upper levels for all models. The presence of shear walls effectively mitigates drift, and increasing seismic zone intensity from Zone II (Model-2) to Zone V (Model-5) is generally associated with a slight increase in storey drift.

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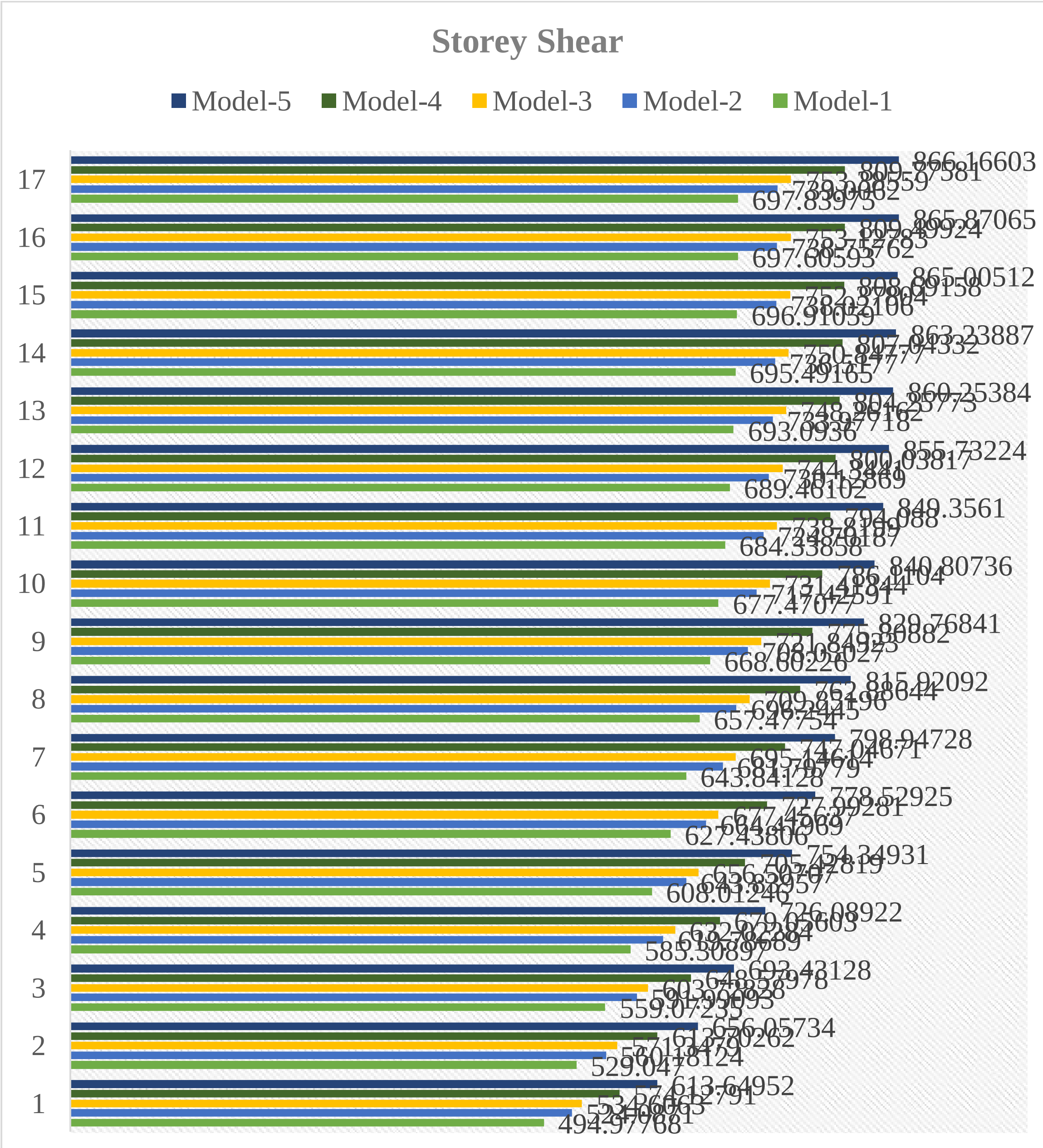

Figure 7: Storey shear for all the models

This bar chart compares the storey shear across five different structural models (Model-1 to Model-5) at each story level, from story 1 to story 17. All models are G+16 story L-shaped buildings. Model-1 is without a shear wall, while Models 2-5 include a shear wall and are located in Seismic Zones II, III, IV, and V, respectively. Model-1 (without shear wall) has the lowest storey shear at story 1, and the storey shear decreases until story 17. Models 2-5 (with shear wall) show significantly higher storey shear compared to Model-1 at all story levels. In the lower stories, Model-5 (Seismic Zone V) has the highest storey shear, followed by Model-4 (Seismic Zone IV), Model-3 (Seismic Zone III), and Model-2 (Seismic Zone II). The storey shear for all models tends to be higher in the lower stories and decreases towards the upper stories.

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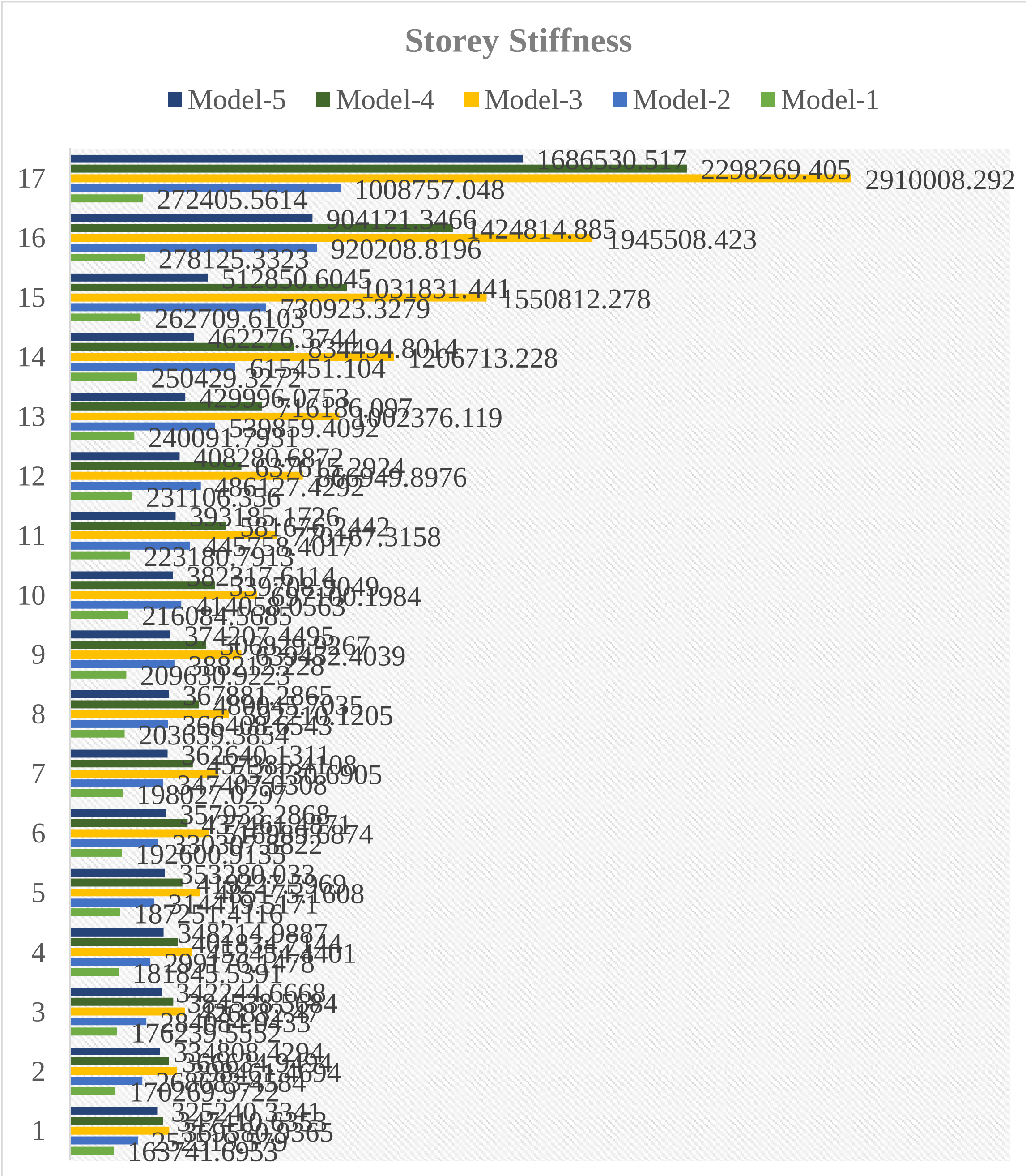

Figure 8: Storey stiffness for all the models

The bar chart compares the storey stiffness of five models of a G+16 irregular L-shaped building, revealing that the model without shear walls (Model-1) exhibits the lowest stiffness across all storeys, underscoring the significant stiffening effect of shear walls present in Models 2-5 (designed for Seismic Zones II-V). Generally, the models with shear walls show higher stiffness, with a trend of increasing stiffness in upper storeys and decreasing towards the base, and a noticeable influence of seismic zone design intensity, where higher seismic zones (IV and V) tend to result in greater stiffness, particularly in the upper levels, to enhance resistance against larger lateral forces.

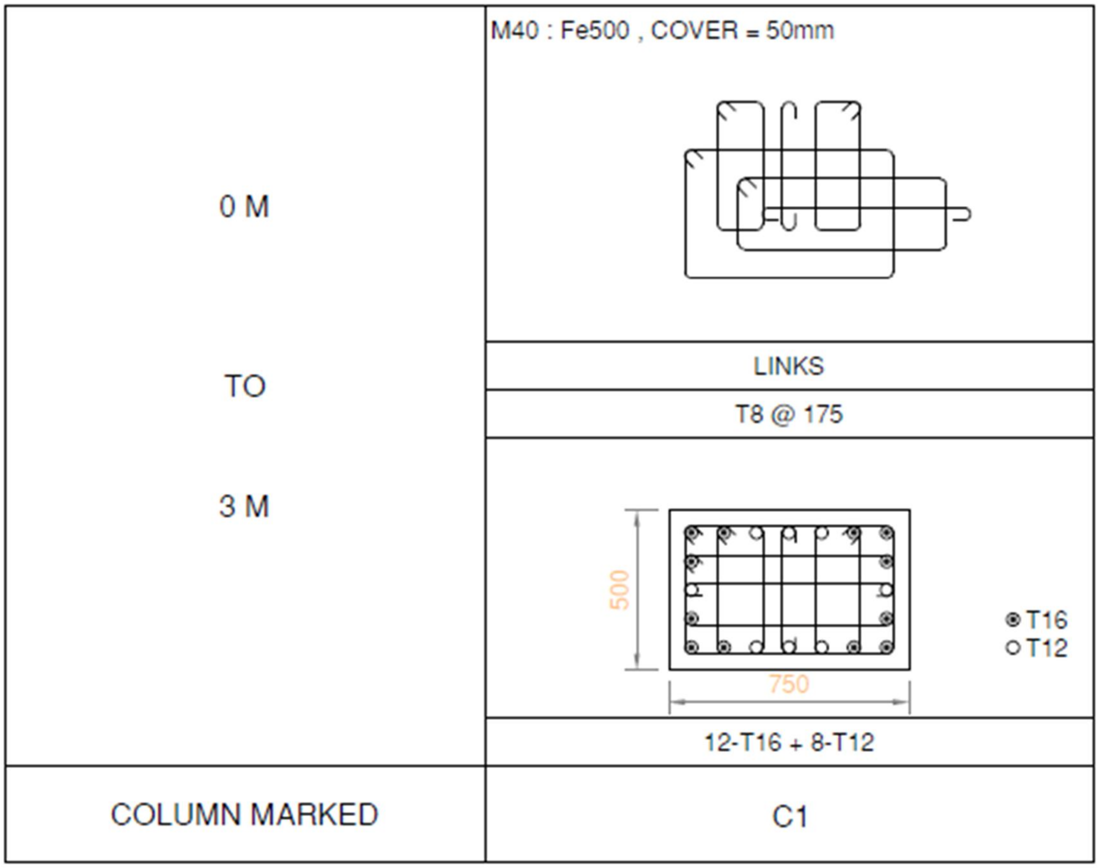

Figure 9:Column Design

Flexure Design						
	Beam Bottom			Beam Top		
	Left	Mid	Right	Left	Mid	Right
Critical L/C - Analysis	28	28	32	16	32	28
Critical L/C - RCDC	18	18	22	6	22	18
Mu (kNm)	137.14	69.83	132.09	139	69.83	132.09
Tu (kNm)	0.58	0.58	0.58	0.12	0.58	0.58
M_{Tu} (kNm)	0.88	0.88	0.88	0.19	0.88	0.88
Mud (kNm)	138.02	70.71	132.97	139.18	70.71	132.97
MuLim (kNm)	456	456	456	456	456	456
R	1.609	0.825	1.55	1.623	0.825	1.55
Ptmin (%)	0.2	0.2	0.2	0.2	0.2	0.2
Ptclc (%)	0.389	0.2	0.374	0.392	0.2	0.374
Pcclc (%)	0	0	0	0	0	0
PtPrv (%)	0.457	0.326	0.457	0.464	0.261	0.464
AstCalc (sqmm)	673.92	346.5	647.97	679.91	346.5	647.97
AstPrv (sqmm)	791.7	565.5	791.7	804.24	452.4	804.24
Reinforcement Provided	5-T12 2-T12	5-T12	5-T12 2-T12	4-T16	4-T12	4-T16

Shear Design	Left	Mid	Right
Critical L/C - Analysis	16	16	12
Critical L/C - RCDC	6	6	2
PtPrv (%)	0.464	0.261	0.464
Vu (kN)	65.85	58.53	57.84
Tu (kNm)	0.12	0.12	0.81
V_{Tu} (kN)	0.57	0.57	3.68
Vut (kN)	66.42	59.09	61.52
Tv (N/sqmm)	0.38	0.34	0.36

Figure 10:Shear and Flexure Design of Beam

V. CONCLUSIONS

Based on the analysis and design of a G+16 irregular L-shaped multi-story building across different seismic zones using advanced structural analysis software, the following conclusions are drawn:

1) Effectiveness of Shear Walls

The inclusion of shear walls significantly enhances the seismic performance of the structure. Model-1, which lacks shear walls, exhibits the highest storey drift and the lowest shear resistance, indicating inadequate lateral stability. In contrast, Models 2 to 5 (incorporating shear walls) demonstrate greatly improved performance, particularly in drift control and shear capacity.

2) Storey Drift Observations

- Model-1 shows maximum storey drift across all levels, highlighting its poor resistance to seismic lateral loads.
- The introduction of shear walls in Models 2 to 5 results in a considerable reduction in drift values.
- Model-3 (Seismic Zone III) records the lowest overall drift, suggesting optimal structural behavior under moderate seismic intensity.
- Although Models 4 and 5 (Zones IV and V) show a slight increase in drift compared to Model-3, they still maintain acceptable performance and demonstrate improved resistance over Model-1.

3) Storey Shear Trends

- Storey shear values increase progressively from top to bottom in all models, consistent with expected seismic behavior.
- Model-1 records the lowest shear values, underscoring its limited ability to resist lateral forces.
- Models 2 to 5 show significantly enhanced shear resistance, with Model-5 (Zone V) experiencing the highest shear values due to higher seismic demand.
- Model-3 displays peak shear values at lower levels, indicating effective lateral force transfer through shear wall action in a moderate seismic zone.

4) Impact of Seismic Zone Variation

- As the seismic zone intensity increases from Zone II to Zone V, both storey drift and shear values reflect corresponding changes in structural demand and response.
- The trend confirms the importance of adapting design strategies according to regional seismicity to ensure structural resilience.

5) Structural Stability and Design Implications

The strategic placement of shear walls proves to be a critical factor in enhancing structural stability. The study confirms that properly designed and positioned shear walls are highly effective in reducing drift and increasing shear resistance, thereby contributing to the overall seismic resilience of multi-story buildings in various earthquake-prone regions

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