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Analyzing the Effects of Soil-Structure Interaction and Geometric Configuration on Structure

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Abstract

This study investigates how varying soil types impact the seismic performance of a 30-story building, simulated using ETABS software. The research focuses on key parameters such as soil type, different shapes of structure, base shear, and inter-story drifts under different soil conditions, ranging from soft clay to dense sand. By comparing fixed-base models with those incorporating soil-structure interaction (SSI), the analysis highlights significant differences influenced by soil type. The findings reveal that softer soils tend to amplify ground motion effects, resulting in higher displacements and inter-story drifts within the structure. In contrast, stiffer soils provide greater stability but may transmit higher forces to the building. These insights underscore the critical role of local soil conditions in structural behavior during seismic events. They emphasize the necessity of considering SSI and soil variability in the design and analysis of tall buildings to ensure their safety and performance under dynamic loads. In conclusion, integrating SSI into structural analysis proves essential for accurate seismic assessment and resilient design, particularly in regions with diverse geotechnical profiles. By understanding how different soil types interact with building structures, engineers can optimize designs to mitigate risks and enhance the overall seismic resilience of high-rise constructions.

Keywords: Soil-structure interaction, soil type, structural shape, lateral displacement, base shear, response spectrum method, tall structures, comparative study

INTRODUCTION

Soil-structure interaction (SSI) is a critical consideration in structural engineering, particularly during seismic events like earthquakes. Unlike traditional analyses that assume foundations are rigid and fixed, SSI recognizes that a building's behavior is profoundly influenced by the characteristics of the soil beneath it. During seismic activity, the soil can deform, absorb energy, and transmit forces in complex ways, significantly impacting how the structure responds. Understanding these interactions is essential for accurately predicting and mitigating potential damage to buildings, especially tall structures vulnerable to dynamic forces.

Key factors influencing SSI include soil type, stiffness, foundation design, and the structural properties of the building itself. Soft soils, for example, tend to amplify ground motions, leading to increased displacements and stresses within the structure. In contrast, stiffer soils may enhance stability but can also intensify forces transmitted to the building. Integrating SSI into structural analysis involves sophisticated modeling and simulation techniques that simulate these interactions under varying load conditions. This approach allows engineers to design buildings that are more resilient and better equipped to withstand seismic events, particularly in regions with high seismic activity.

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By accurately accounting for SSI, engineers can optimize structural designs to mitigate risks associated with soil variability and improve overall safety and performance. This proactive approach ensures that buildings are not only structurally sound but also capable of enduring the dynamic forces exerted during earthquakes, thereby enhancing their resilience and longevity in seismic-prone areas.

SOIL–STRUCTURE INTERATION

SSI refers to the complex interplay between the soil beneath a structure and the structure itself, particularly under dynamic loads such as earthquakes or machinery vibrations. It involves the mutual influence where the stiffness, damping, and inertial properties of the soil affect the dynamic response of the structure, and vice versa. SSI is crucial in seismic engineering and geotechnical analysis as it can significantly alter the structural behavior and performance during seismic events, influencing factors such as displacements, accelerations, and internal forces.

SSI is crucial in structural engineering for distributing loads effectively from a structure to the soil, ensuring stable foundations and preventing structural failures. It is essential for designing foundations that can withstand seismic activity and other environmental forces, optimizing construction costs while enhancing safety. SSI analysis also predicts how structures will behave under various conditions, helping engineers mitigate risks like settlements and ensuring long-term performance and stability. Overall, SSI integrates soil behavior with structural design to safeguard buildings against dynamic forces and ensure their resilience over time.

SSI is indispensable in structural engineering because it directly influences the stability, safety, and performance of buildings. By considering how a structure interacts with the underlying soil, engineers can effectively distribute loads, mitigate risks such as settlements and structural failures, and optimize foundation designs for different soil conditions and environmental factors. SSI analysis is particularly crucial in seismic regions, where it helps dampen vibrations and minimize earthquake-induced damage. Ultimately, SSI ensures that structures are robust, resilient, and capable of withstanding various dynamic forces over their lifetime (Figure 1).

SCOPE OF STUDY

The scope of the research is:

- To understand the behavior of building structure with SSI.
- Analyze the impact of type of soil and geometric configuration such as different shape building (e.g., moment frames), and architectural features on structural performance and dynamic behavior.

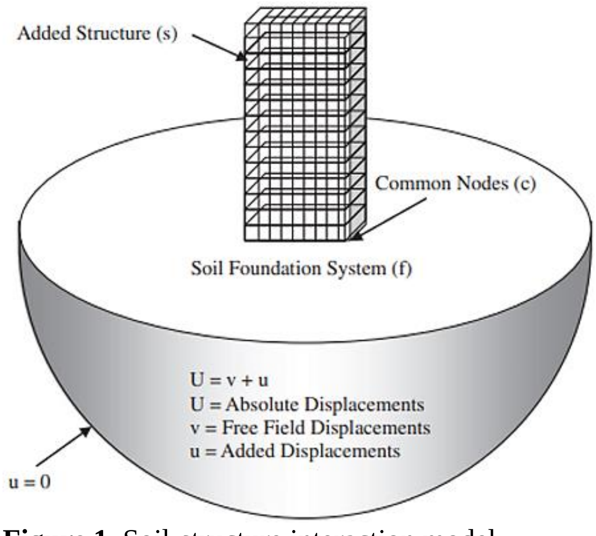

Figure 1. Soil-structure interaction model.

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LITERATURES REVIEW

Seismic studies on SSIs for various structures, such as bridges and towers, generally employ two methods: correlation analysis of bore hole soils to identify structural changes, and internal analysis assuming uniform soil movement above foundation depth. Research has delved into different aspects of seismic SSI, including the impact of course and loose sand on the seismic response of soil structures.

Nazarimofrad and Zahrai [1] Investigated the performance of towers and high-rise buildings against severe earthquakes and strong winds, focusing on the unique challenges posed by irregular floor plans and torsional responses during seismic events. Unlike traditional two-dimensional shear frame models, real buildings exhibit complex dynamics that amplify vibrations, particularly in structures on soft soil, necessitating consideration of SSI effects.

Their research involved developing a mathematical model tailored for calculating the seismic response of irregular multi-story buildings equipped with active tendons. This model incorporated SSI effects by modifying mass, stiffness, and damping matrices. For instance, in their application to a 10-story building using the LQR (linear quadratic regulator) algorithm, the authors represented the structure with rigid floor diaphragms providing three degrees of freedom per story. The study concluded that while active tendons were implemented to reduce structural response, their effectiveness was limited on soft soils due to the complex interplay of dynamic behavior parameters such as natural frequencies, damping ratios, and mode shapes influenced by SSI effects.

Lu et al. [2] focused on assessing how towers and high-rise buildings perform under severe earthquakes and strong winds, particularly considering the challenges posed by irregular floor plans and torsional responses during seismic events. They underscored the complex dynamics inherent in real buildings, contrasting them with simplified two-dimensional models typically used. Emphasizing the impact of soft soil conditions, they stressed the critical need to account for SSI effects in their mathematical model. This model, tailored for irregular multi-story buildings with active tendons, adjusted mass, stiffness, and damping matrices to incorporate SSI dynamics. Despite efforts to reduce structural response with active tendons, their study revealed limitations in effectiveness on soft soils due to the intricate interdependencies of natural frequencies, damping ratios, and mode shapes influenced by SSI effects.

Ghandil and Behnamfar [3] explored the nonlinear response of moment-resisting frames on soft soils, incorporating SSI through a direct modeling approach that encompasses both the structure and the soil down to the bedrock. Traditionally, soil behavior has been simplified using the equivalent linear method, but the study proposed adjustments to more accurately represent soil responses under large strains. Nonlinear structural behavior was centered around plastic hinges at member ends, and the analysis included computation of drifts, shear forces, and ductility demands through nonlinear time-history methods. Findings emphasized that SSI significantly increases drifts and ductility demands, particularly affecting lower stories of buildings. To evaluate this impact, the study introduced interim modification factors, which compare ductility demands with and without SSI, providing insights into the substantial influence of SSI on nonlinear dynamic responses in structural analysis.

Vicencio and Alexander [4] investigated structure-soil-structure interaction (SSSI) effects between two buildings during seismic events, taking into account various building parameters, inter-building spacing, and soil types. It proposed an extended simplified reduced-order model capable of considering higher mode interactions, which facilitated analysis even with substantial height differences between buildings. Using a comprehensive database of strong ground motion records, including far-field, near-field without pulse, and near-field pulse-like motions, the research analyzed over 3 million system/ground motion scenarios. The findings demonstrated that the extended model effectively captured significant interactions, particularly in displacement responses, particularly noting the effects when a smaller building is positioned close to a much taller one.

Elwi et al. [5] Explored the influence of SSI on multi-story buildings during earthquakes, highlighting the often over looked impact of this interaction by designers. It emphasized how the type of soil can significantly alter seismic wave propagation, affecting ground motion and ultimately shaping the behavior of the entire structure-soil system. Adhering to IS 1893:2002 guidelines, which offer response spectra tailored to different soil types, the research focused on multi-story buildings with diverse foundation systems. Using SAP2000 software, the study conducted analyses under seismic forces, considering both rigid and flexible foundations. It assessed parameters such as lateral deflection, story drift, base shear, axial force, and column moment values across varying soil conditions, including hard, medium, and soft soils.

Anand and Satish Kumar [6] investigated into SSI, where the mutual influence between soil and structures impacts seismic response. Traditionally viewed as advantageous, ignoring SSI can lead to overly conservative designs, reflected in seismic codes that either allow reductions in seismic coefficients due to SSI or recommend its neglect. However, events like the 1989 Loma Prieta and 1995 Kobe earthquakes demonstrated that SSI can also have detrimental effects. Despite recent research highlighting these potential drawbacks, design guidelines remain inconsistent. While strides have been made in understanding and addressing SSI, its practical integration into design practices remains limited. The paper provides an overview of various SSI approaches in structural analysis, reviews guidelines from prominent seismic codes, underscores the importance of appropriate selection methods, and concludes with an examination of current SSI research trends.

Chen et al. [7] examined the previously underestimated impact of SSI on structures equipped with an inert system. It employed an enhanced fixed-point method to determine inert system parameters and derived foundation characteristics from a sub-structure model. Through frequency- and time-domain analyses, the research compared dynamic responses with and without SSI. The findings indicated that SSI amplified dynamic responses in inert system-equipped structures, suggesting potential safety concerns with conventional design methods. To enhance inert system performance while accounting for SSI, the study utilized the simulated annealing algorithm, which effectively mitigated dynamic responses. Emphasizing the importance of incorporating SSI effects, especially for structures on flexible soil, the research underscored the utility of optimization algorithms in optimizing inert system designs.

Han et al. [8] investigated dynamic SSSI effects with large separation distances, using the Millikan Library Building as a case study. Numerical results from two-dimensional anti-plane and in-plane models, employing the indirect boundary element method (IBEM) for various seismic wave directions, revealed that SSSI effects can be either detrimental or beneficial. Structural response amplification and reduction compared to a stand-alone structure reached up to 40% and 30%, respectively. The study highlighted the sensitivity of structural response to the parameters of adjacent buildings, noting that more similar or heavier buildings had a greater influence. SSSI effects were shown to persist over large distances, with amplification reaching 36% at separation distances of approximately 2.5 times the equivalent wavelength. These effects alternated with variations in separation distance, underscoring the need for comprehensive consideration in seismic response prediction during the design process.

Vicencio and Alexander [9] explored the influence of SSSI between two buildings, focusing on one with an asymmetrical plan prone to seismically induced coupled torsion and sway motions. Using a reduced-order parametric model validated through finite element analysis and 15 strong ground motion records, over 3 million system/ground motion cases were analyzed. Results indicated significant impacts of SSSI on displacement and acceleration responses, particularly affecting buildings with unsymmetrical plans. Torsion increased building responses across various parameters where SSSI effects were pronounced. Interestingly, scenarios involving a taller, torsionally irregular building adjacent to a smaller one sometimes resulted in adverse effects, contrasting with findings for non-torsional, plan-regular buildings where taller structures typically benefit from smaller adjacent ones.

Scarfone et al. [10] investigated SSI effects on a 20-story building using 3D nonlinear dynamic analyses with an elasto-plastic soil model. They examined three foundation systems (shallow, deeply embedded, and pile foundations) and two soil profiles, focusing on site amplification, kinematic interaction, and inertial effects. Comparisons between complete 3D models and building-only analyses highlighted that more deformable foundations reduced maximum base shear forces without significantly increasing structural displacements. The research cautioned against decoupled substructure approaches in cases involving deep foundations through soft soil layers, advocating instead for embedded pile elements to streamline computational complexity in 3D simulations of dynamic SSI scenarios.

Liu et al. [11] investigated SSI phenomena under seismic loadings through shaking table tests and numerical modeling. It utilized a finite element model incorporating both bounding surface plasticity and equivalent linear methods to simulate soil nonlinear behavior, with closer agreement found using the bounding surface plasticity model. Parametric analysis highlighted that SSI effects significantly reduce structural dynamic responses, especially when the superstructure's frequency aligns with soil frequency. Higher shear wave velocities in the soil were associated with reduced SSI influence. These findings contribute valuable insights for engineering design, particularly in seismic-prone areas, by elucidating the complex interactions between soil and structure.

Dhadse et al. [12] comprehensively examined ongoing research in nonlinear analysis of SSI, focusing on advancements in interface elements for soil-soil and soil-structure interactions. They discuss coupled finite element modeling of SSI systems that integrate soil nonlinearity and interface element behavior. The review covers various constitutive models for soil nonlinearity and explores interface modeling techniques such as zero thickness and thin layer elements developed from the 1970s to present. Special attention is given to challenges like interface thickness issues and the selection of stiffness parameters, along with the benefits and drawbacks of different methods in terms of accuracy and applicability to real-world structural and soil conditions.

Long et al. [13] concluded that two-dimensional finite element analysis was employed to investigate SSSI) effects among identical high-rise buildings with pile-raft foundations and varying spacing. Static-dynamic coupled simulations revealed significant influences of adjacent buildings on the peak acceleration and response spectra of the middle building, particularly at heights between 1/4 to 1/2 of its total height. These effects were most pronounced in inter-story drifts at the top, bottom, and basement levels of the middle building. The study also highlighted how adjacent buildings redistributed horizontal shear forces among pile foundations, impacting seismic safety. Insights into spacing configurations were discussed, emphasizing their implications for seismic design and safety assessments in high-rise structures.

Requena-Garcia-Cruz et al. [14] concluded the often overlooked SSI effects in seismic vulnerability analyses of reinforced concrete (RC) buildings, particularly in Portugal where older buildings lack adequate seismic design. European seismic codes mandate SSI analyses for structures with significant second-order effects or mid/high-rise buildings, characteristics common in Portugal's RC building stock. The study aimed to quantify SSI effects using two methods: the beam on nonlinear Winkler method (BNWM) and direct soil modeling. It emphasized the need for realistic soil and foundation modeling to improve seismic performance assessments. The methodology was applied to a mid-rise RC building in Lisbon, focusing on clay-type soil under undrained conditions, employing advanced finite element techniques to capture complex soil behavior.

After conducting a thorough and comprehensive literature review, several innovative approaches have emerged to enhance the seismic performance and efficiency of soil structure interaction in high-rise buildings., the following factors have been identified as critical considerations in structural analysis and design, that is, type of soil and geometrical configuration. These findings underscore the importance of thoughtful soil structure interaction in enhancing building safety and resilience.

SYSTEM DEVELOPMENT

To adapt the study to changes in soil type and geometric configuration, the approach begins with a thorough assessment of how varying soil types impact foundation bearing capacity and stiffness. Conducting detailed soil testing allows for precise determination of parameters such as soil bearing capacity, settlement characteristics, and lateral pressures. This analysis informs adjustments in structural design, including recalculating loads for dead, live, wind, and seismic forces to align with the revised soil conditions. Furthermore, modifications in shear wall dimensions and placement are explored to optimize structural stability against lateral forces specific to each soil type. Evaluating performance metrics such as lateral deflection, drift, shear forces, and moments under updated conditions ensures compliance with regulatory standards, guiding necessary design refinements to enhance safety and performance while managing costs effectively.

In parallel, efforts focus on optimizing shear wall dimensions—lengths and thicknesses—to strike a balance between structural integrity, performance requirements, and economic feasibility. Considerations of life cycle costs and construction practicality play pivotal roles in finalizing design decisions that sustainably meet both regulatory and project-specific objectives, ensuring robust adaptation to varied soil types and geometric configurations within high-rise building frameworks.

1. Modeling
2. Analysis phase
3. Design phase [15]

STRUCTURE DESCRIPTIONS

The study's design considerations for the building structure, which includes varying parameters of structure such as changes in soil type and geometric configuration. Initially planned for a 36 m × 36 m building with multiple 3-m stories in a seismic Zone III on all three types of soils, the design integrates shear walls shaped as T, I, L, and plus. In response to changes in soil type, rigorous soil testing and analysis become imperative to assess the new soil's bearing capacity, settlement characteristics, and lateral pressures. This informs adjustments in the structural analysis, recalibrating loads for dead, live, wind, and seismic forces to align with the revised soil conditions. Geometrically, modifications may involve repositioning or resizing shear walls to optimize stability against lateral forces specific to the updated soil profile (Tables 1 and 2) [16].

LOADS AND LOADING CONDITION

Loads are the external forces or other actions that cause stresses, deformations, or accelerations in a structure. They can be categorized into several types:

1. *Dead loads:* Permanent static forces from the weight of the structure itself and any permanent fixtures.
2. *Live loads:* Temporary or movable forces that the structure supports, such as people, furniture, and vehicles.
3. *Environmental loads:* Forces from natural elements, including wind, snow, rain, earthquakes, and temperature changes.
4. *Dynamic loads:* Loads that involve motion and vary with time, such as moving vehicles or machinery vibrations.

Loading conditions describe the specific scenarios under which loads are applied to a structure. They include:

1. *Static loading conditions:* Scenarios where loads are applied slowly and remain constant or change very slowly over time.
2. *Dynamic loading conditions:* Scenarios involving loads that change rapidly with time, such as those caused by wind gusts, seismic activity, or impacts.
3. *Combination of loads:* Scenarios where multiple types of loads act simultaneously on a structure, requiring careful consideration of their combined effects for safety and performance assessment.

Table 1. Structure descriptions.

S.N.	Specification	Value
1	Size of buildings	36 m × 36 m
2	Building height	87 m
3	Floor to floor height	3 m
4	Bottom story height	1.5 m
5	Number of stories	30
6	Thickness of slab	175 mm
7	Beam size	450 × 450 mm
8	Outer column size	850 × 850 mm
9	Inner column size material property	1000 × 1000 m
10	Material property	M30
11	Grade of steel	HYSD 415, HYSD 500
12	Density of concrete	25 kN/m
13	Density of lightweight brick	10 kN/m
14	Support condition	Fixed support

Table 2. Loading conditions.

1. Dead Load: IS 875: 2000 Part 1.	
i. Self-weight	1 kN/m
ii. Floor finished	1.5 kN/m
iii. Wall load	6 kN/m
2. Live Load: IS 875: 2000 Part 2.	
i. Live load	3 kN/m
3. Wind Load: IS 875: 2000 Part 3.	
i. Terrain category	II
ii. Windward coefficient (Cp)	0.8
iii. Leeward coefficient (Cp)	0.25
iv. Internal coefficient (Cpi)	1
v. Wind speed	44 m/s
vi. Risk coefficient (k_1)	1
vii. Terrain height	87 m, 117 m, 147 m
viii. Topography factor (k_3)	1
ix. Directionality factor	0.85
x. Area overaging factor	0.8
xi. Load combination factor	1.5.
xii. Importance factor	1
4. Earthquake Load: IS 1893: 2016 Part 1.	
i. Seismic zone	III
ii. Zone factor	0.24
iii. Response reduction factor	5
iv. Importance factor	1.2
v. Soil type	Medium
vi. Damping ratio	5%

RESPONSE SPECTRUM ANLYSIS

Response spectrum analysis assesses a structure's dynamic response to seismic or other loads by calculating its maximum response across various natural frequencies and damping ratios, defined by a response spectrum curve. Engineers use historical earthquake data or seismic design codes to define this spectrum, then input it into analysis software to compute maximum displacements, velocities, and accelerations. This method helps evaluate a structure's vulnerability to seismic events, guiding design or retrofitting efforts to ensure safety and performance standards are met, enhancing seismic resilience through comprehensive dynamic analysis.

PLAN AND 3D VIEW OF MODEL

In the current study, the building structure is designed to consider variations in soil types and geometric configuration in structure. The building plan measures 36 m × 36 m with multiple stories, each having a height of 3.0 m.

DESCRIPTION OF MODELS

The names of the models, plans, and 3D views are listed, and the Figures 2–5 display the models.

- *Model 1:* Structure of 36 m span with L shape.
- *Model 2:* Structure of 36 m span with plus shape.
- *Model 3:* Structure of 36 m span with I shape.
- *Model 4:* Structure of 36 m span with T shape.

RESULTS AND DISCUSSION

Different soil types, such as coarse and loose sand, significantly affect the seismic response of structures. Coarse sand tends to provide better support, reducing the overall structural response compared to loose sand. Therefore, site-specific soil properties are crucial in determining the dynamic behavior of structures during earthquakes. Taller buildings with deeper or more flexible foundations experience more significant SSI effects, with shallow foundations leading to higher seismic demands on the superstructure compared to pile foundations.

The interaction between the structure and the underlying soil can increase base shear forces and foundation rotations. Additionally, plan irregularities and the presence of adjacent buildings significantly influence the seismic behavior of structures. Torsionally irregular buildings adjacent to smaller or similar-sized structures exhibit increased displacement and acceleration responses. Properly spaced and geometrically regular structures perform better under seismic loads, reducing the adverse effects of SSSI.

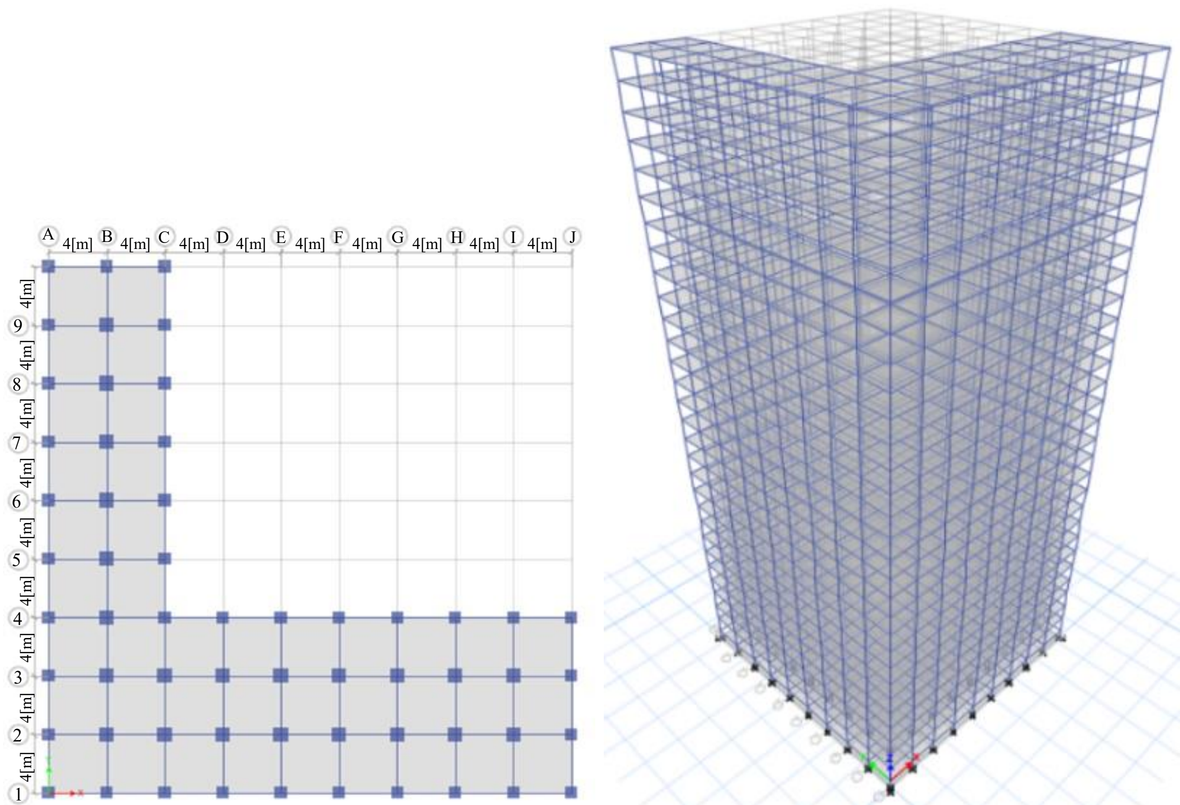

Figure 2. Model 1.

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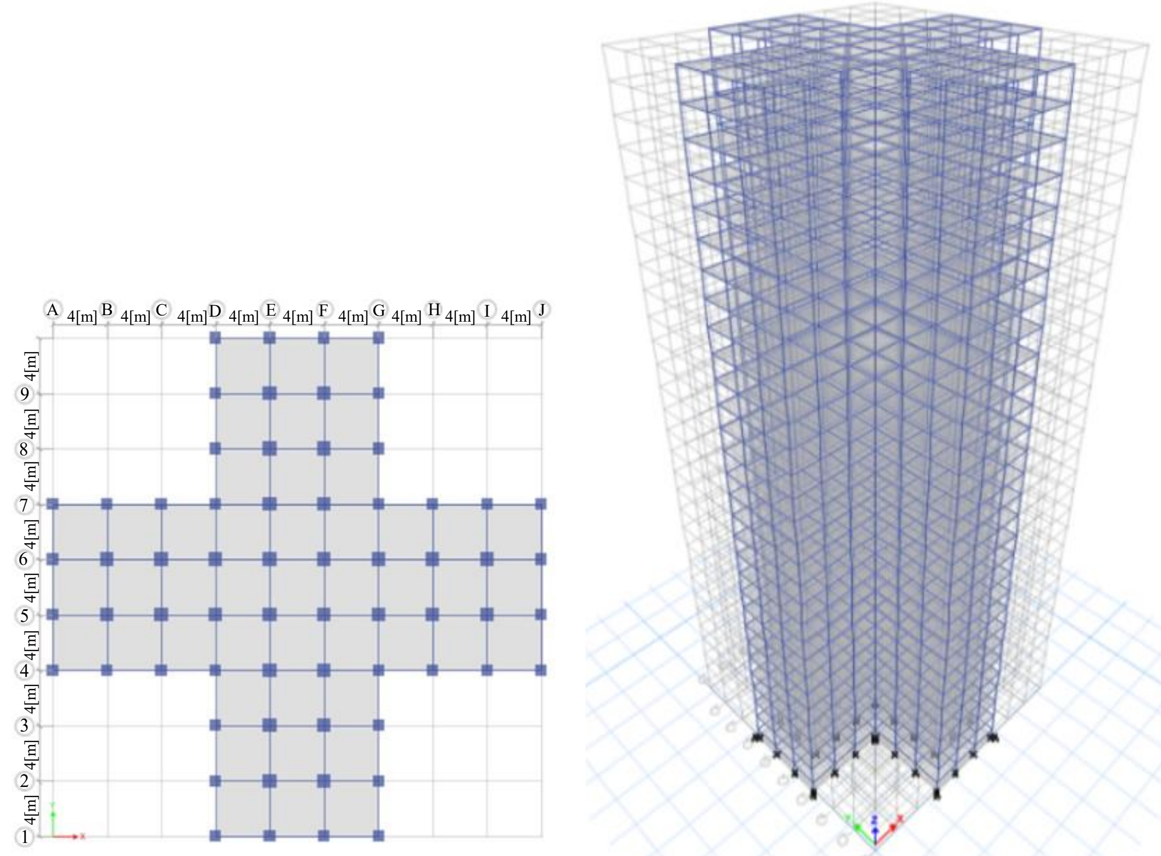

Figure 3. Model 2.

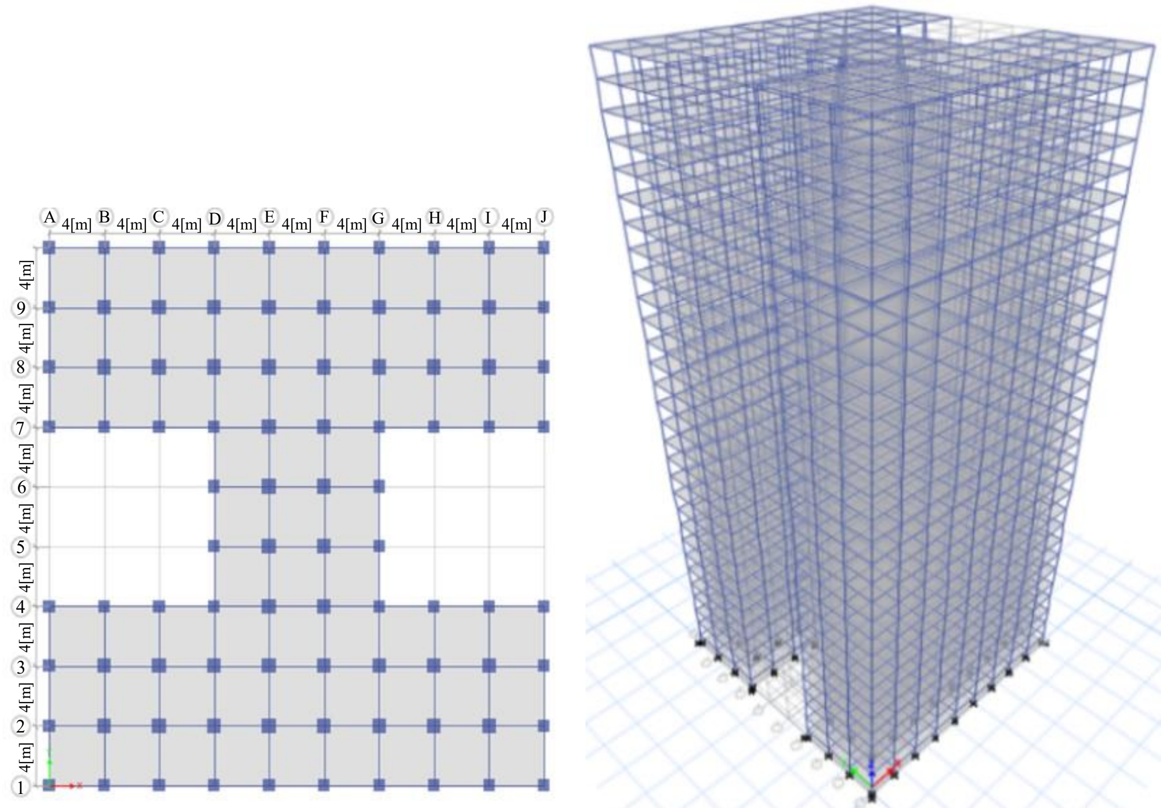

Figure 4. Model 3.

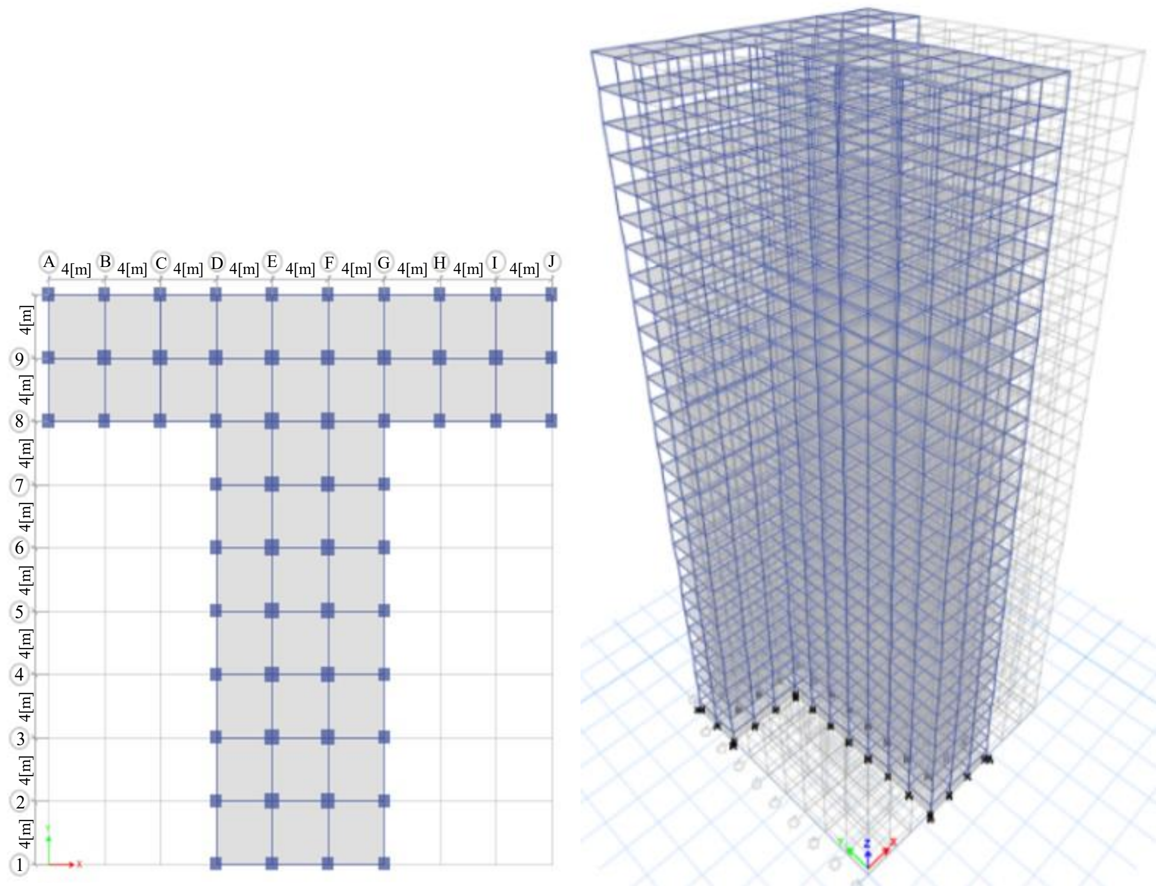

Figure 5. Model 4.

LATERAL DISPLACEMENT

Lateral displacement refers to the horizontal movement or shift of a structure or its components due to applied forces such as wind, seismic activity, or other horizontal loads. This type of displacement occurs perpendicular to the vertical axis of the structure and can significantly affect the stability and integrity of buildings, bridges, and other constructions. Measuring and controlling lateral displacement is crucial in structural engineering to ensure safety and performance, especially in regions prone to earthquakes or strong winds.

Type I Soil: Rock or Hard Soil

Includes well-graded gravel, sand, gravel-sand mixtures with or without clay binder, and clayey sands poorly graded or sand-clay mixtures (GB, CW, SB, SW, and SC, respectively) with a standard penetration value (N) above 30. The comparison of maximum lateral displacements for type I soil are detailed in Table 3 while Figure 6 is the graphical representation of value given in Table 3.

Type II Soil: Medium Soil

Encompasses all soils with N values between 10 and 30, and poorly graded sands or gravelly sands containing minimal fines (SP) with N greater than 15. The comparison of maximum lateral displacements for type II soil is detailed in Table 4 while Figure 7 provides a graphical representation of the values given in Table 4.

Type III Soil: Soft Soil

Covers all soils other than SP with N values less than 10. Table 5 presents the detail values of the maximum lateral displacement for type III soil in both direction, with Figure 8. providing a graphical representation.

Table 3. The comparison of maximum lateral displacement for all structures in both directions: type I soil.

Maximum Lateral Displacement		
Story	***X-Direction***	***Y-Direction***
Plus shape	116.536	116.536
I shape	111.179	131.17
T shape	158.306	119.52
L shape	166.329	163.306

Table 4. The comparison of maximum lateral displacement for all structures in both directions: type II soil.

Maximum Lateral Displacement		
Story	***X-Direction***	***Y-Direction***
Plus shape	71.491	71.491
I shape	68.216	74.56
T shape	97.039	73.159
L shape	102.051	92.533

Table 5. The comparison of maximum lateral displacement for all structures in both directions: type III soil.

Maximum Lateral Displacement		
Story	***X-Direction***	***Y-Direction***
Plus shape	88.378	88.378
I shape	84.316	92.188
T shape	120.119	90.447
L shape	126.361	114.528

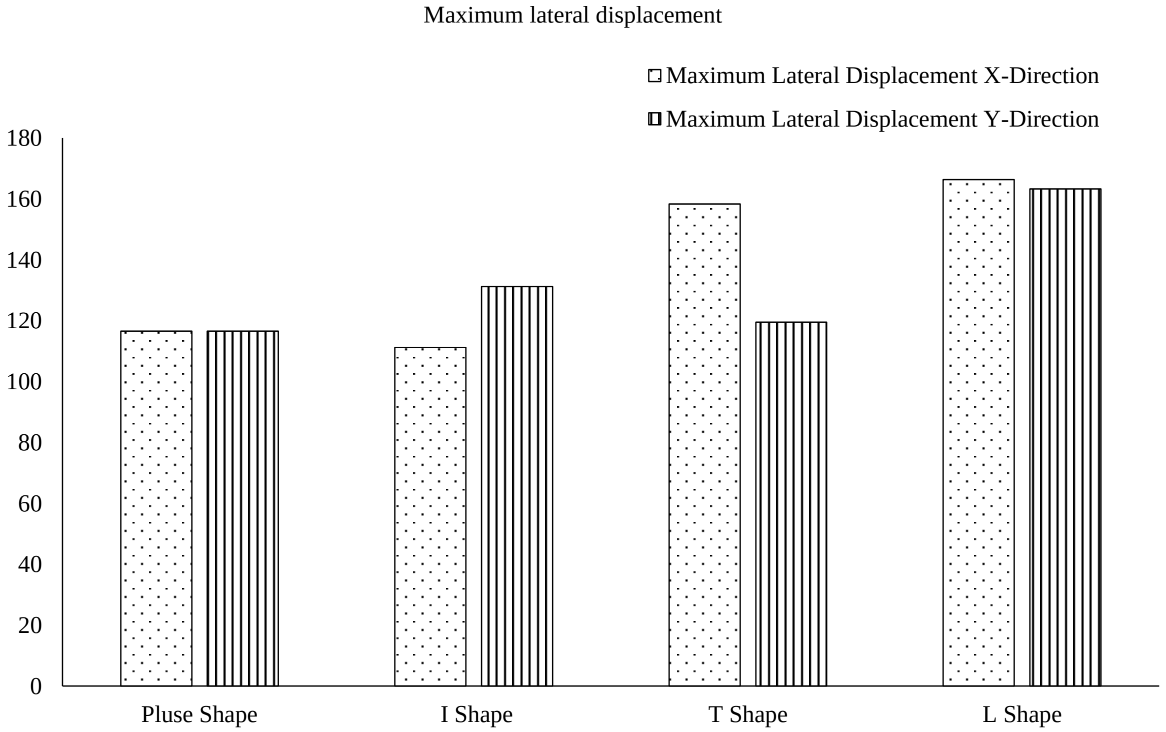

Figure 6. The comparison of maximum lateral displacement for type I soil.

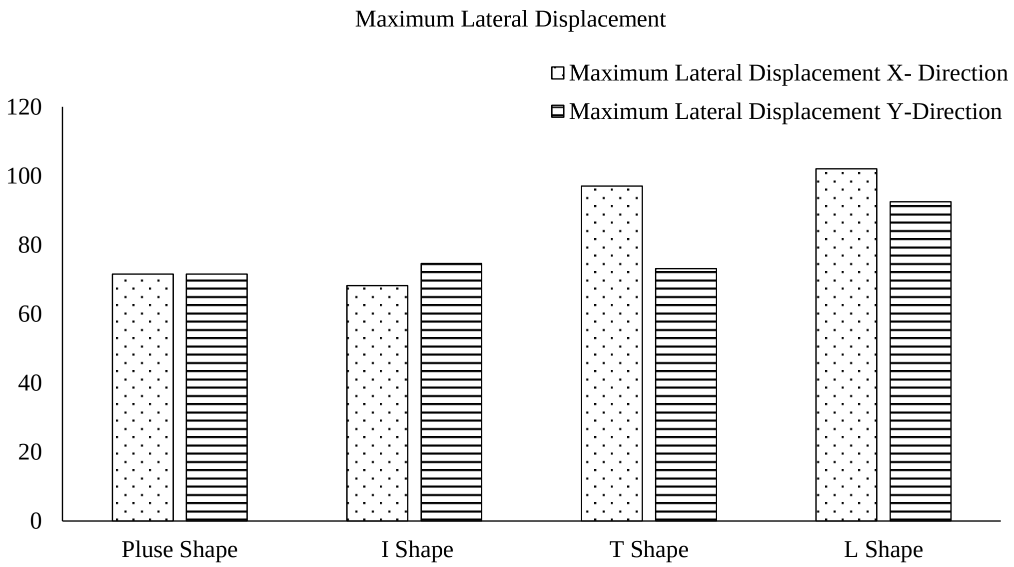

Figure 7. The comparison of maximum lateral displacement for type II soil.

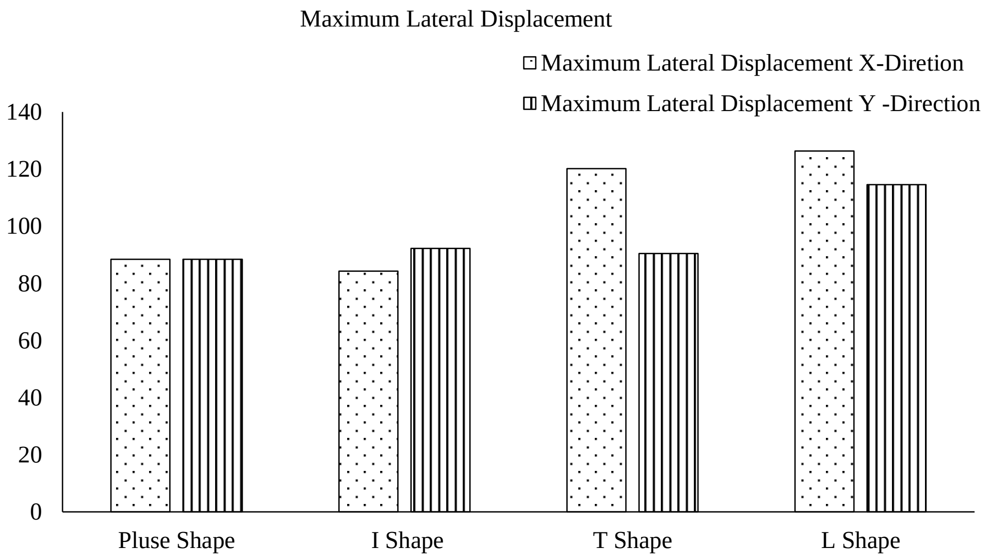

Figure 8. The comparison of maximum Lateral Displacement for type III soil.

BASE SHEAR

Base shear is the total horizontal force exerted at the base of a structure due to seismic activity, crucial for ensuring the structure's stability and safety during an earthquake.

Type I Soil: Rock or Hard Soil

Soil consisting of very dense, solid rock that offers excellent support and stability. The comparison of maximum base shear for all structures in type I soil are given in Table 6. By analyzing all models in ETABS, we know that the maximum base shear obtained at the bottom of high-rise structure and it is represented in graphical form in Figure 9.

Type II Soil: Medium Soil

Soil with moderate stiffness and density, which includes soils like stiff clays, silty clays, and dense sands. Table 7 details the comparison of maximum base shear for all structures in type II soil. By analyzing all models in ETABS, we know that the maximum base shear occurs at the bottom of high-rise structures. This is represented graphically in Figure 10.

Type III Soil: Soft Soil

Soil with low stiffness and poor load-bearing capacity, such as loose sands, silty sands, and soft clays. Table 8 presents the comparison of maximum base shear for all structures in type III soil in both directions. Analysis of all models in ETABS indicates that the maximum base shear is found at the bottom of high-rise structures, as depicted graphically in Figure 11.

Table 6. The comparison of maximum base shear for all structures in both direction: type I soil.

Maximum Base Shear		
Story	***X-Direction***	***Y-Direction***
Plus shape	5878.9818	5878.9818
I shape	8177.4718	8824.2286
T shape	5179.8597	5179.8597
L shape	5179.8648	5608.3973

Table 7. The comparison of maximum base shear for all structures in both directions: type II soil.

Maximum Base Shear		
Story	***X-Direction***	***Y-Direction***
Plus shape	3597.9399	3597.9397
I shape	5004.6155	5004.6231
T shape	3170.0779	3170.0751
L shape	3170.0843	3170.0838

Table 8. The comparison of maximum base shear for all structures in both directions: type III soil.

Maximum Base Shear		
Story	***X-Direction***	***Y-Direction***
Plus shape	4418.0596	4418.0594
I shape	6145.3766	6145.3831
T shape	3892.6664	3892.6664
L shape	3892.6741	3892.6708

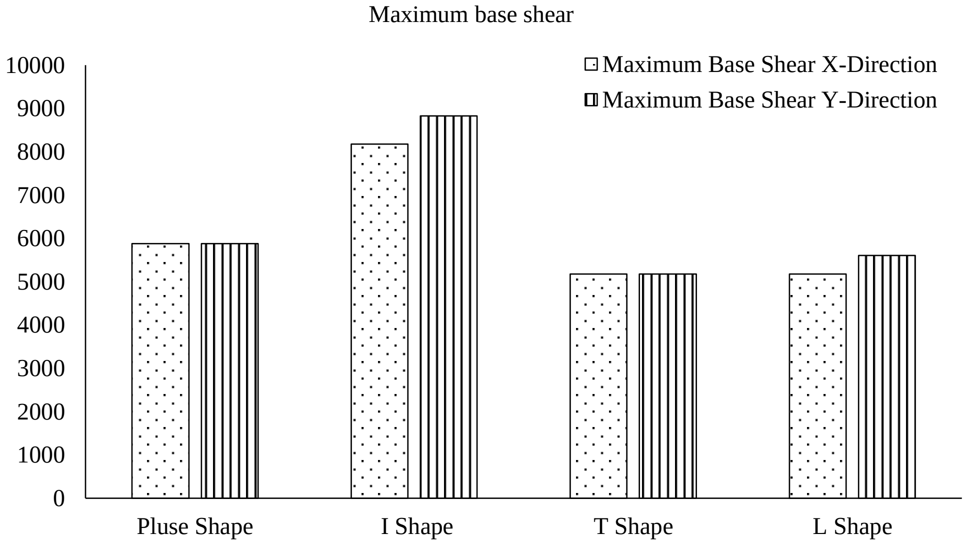

Figure 9. The comparison of maximum base shear for type I soil.

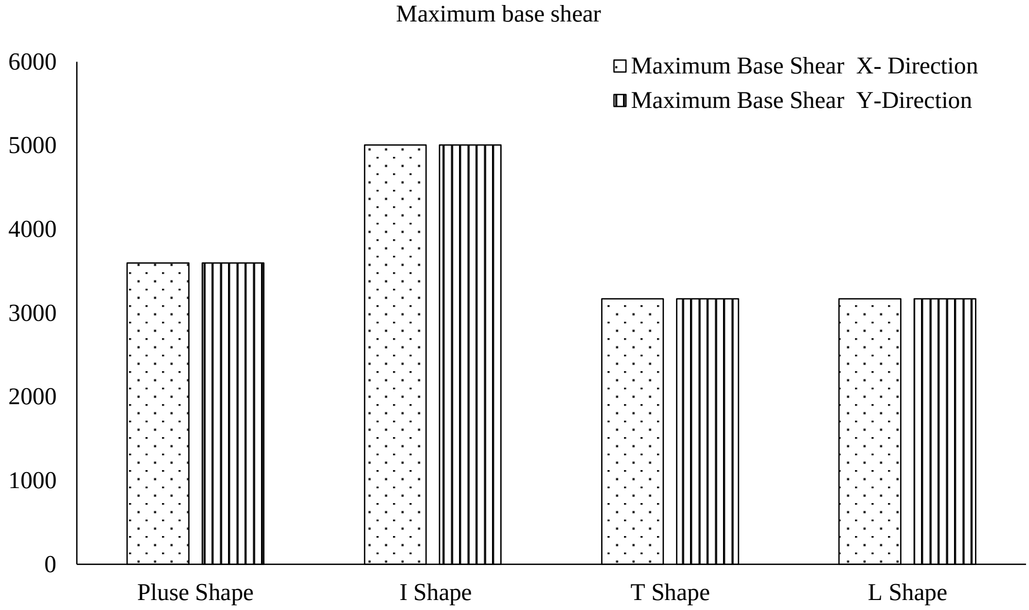

Figure 10. The comparison of maximum base shear for type II soil.

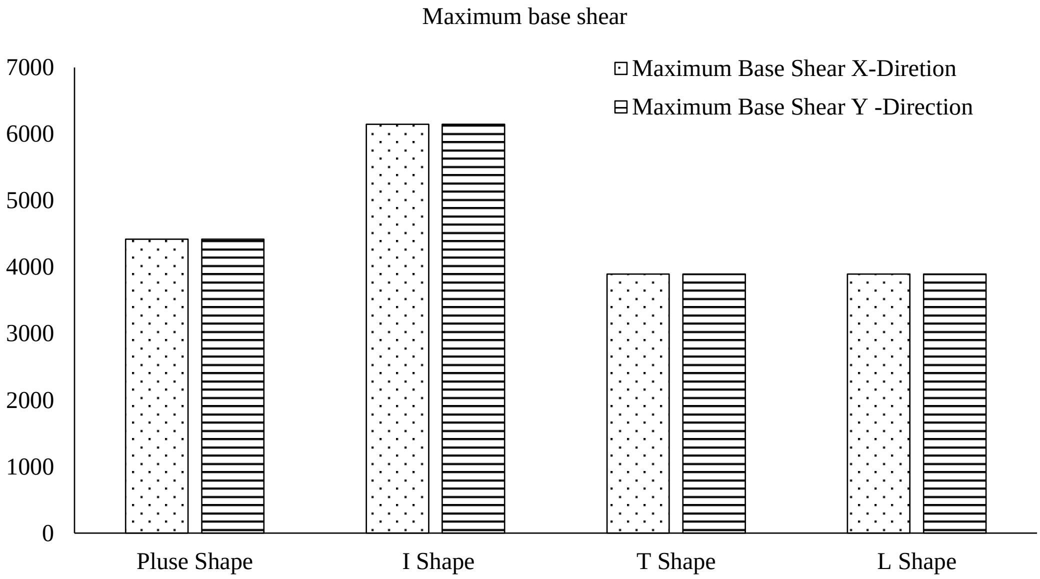

Figure 11. The comparison of maximum base shear for type III soil.

CONCLUSIONS

1. The extent of displacement increases from hard to soft soil. Higher torsional effects and displacement at the extremities are magnified on softer soils. Uniform displacement patterns are observed, but the magnitude of displacement increases with soil softness.
2. Incorporating SSI effects and geometric considerations, such as soil type, building height, foundation system, sand variability, and adjacent structures, into seismic design is crucial for enhancing the safety and resilience of structures, particularly in seismically active regions.
3. This comprehensive understanding aids in developing reliable and accurate models, leading to better informed engineering decisions and improved structural performance during earthquakes.

REFERENCES

1. Nazarimofrad E, Zahrai SM. Seismic control of irregular multistory buildings using active tendons considering soil–structure interaction effect. Soil Dynam Earthquake Eng. 2016; 89: 100–115.

ISSN: 2394-1987

2. Lu Y, Hajirasouliha I, Marshall AM. Performance-based seismic design of flexible-base multi-storey buildings considering soil–structure interaction. Eng Struct. 2016; 108: 90–103.
3. Ghandil M, Behnamfar F. Ductility demands of MRF structures on soft soils considering soil-structure interaction. Soil Dynam Earthquake Eng. 2017; 92: 203–214.
4. Vicencio F, Alexander NA. Higher mode seismic structure-soil-structure interaction between adjacent building during earthquakes. Eng Struct. 2018; 174: 322–337.
5. Elwi M, Muhammed B, Alhussiny N. Evaluation of soil-structure interaction for structures subjected to earthquake loading with different types of foundation. MATEC Web Conf. 2018; 162: 04026.
6. Anand V, Satish Kumar SR. Seismic soil-structure interaction: a state-of-the-art review. Structures. 2018; 16: 317–326.
7. Chen Q, Zhao Z, Zhang R, Pan C. Impact of soil structure interaction on structures with inerter system. J Sound Vibr. 2018; 433: 1–15.
8. Han B, Chen S, Liang J. 2D dynamic structure-soil-structure interaction: a case study of Millikan Library Building. 2020; 113: 346–358.
9. Vicencio F, Alexander NA. Dynamic structure-soil-structure interaction in unsymmetrical plan buildings due to seismic excitation. Soil Dynam Earthquake Eng. 2020; 113: 346–358.
10. Scarfone R, Morigi M, Conti R. Assessment of dynamic soil-structure interaction effects for tall buildings: a 3D numerical approach. Soil Dynam Earthquake Eng. 2020; 128: 105864.
11. Liu S, Li P, Zhang W, Lu Z. Experimental study and numerical simulation on dynamic soil-structure interaction under earthquake excitations. Soil Dynam Earthquake Eng. 2020; 138: 106333.
12. Dhadse GD, Ramtekkar G, Bhat G. Finite element modelling of soil structure intersection on system with interface: a review. Arch Comput Methods Eng. 2021; 28: 3415–3432.
13. Long H, Wang Z, Zhang C, Zhuang H, Chen W, Peng C. Nonlinear study on the structure-soil-structure interaction of seismic response among high-rise buildings. Eng Struct. 2021; 242: 112550.
14. Requena-Garcia-Cruz MV, Bento R, Durand-Neyra P, Morales-Esteban A. Analysis of the soil structure-interaction effects on the seismic vulnerability of mid-rise RC buildings in Lisbon. Structures. 2022; 38: 599–617.
15. Bureau of Indian Standards. IS 1893 (Part 1): 2016, Criteria for Earthquake Resistant Design of Structures. Sixth Revision. New Delhi, India: Bureau of Indian Standards; 2021.
16. Bureau of Indian Standards. IS 16700-2017, Criteria for Structural Safety of Tall Buildings. New Delhi, India: Bureau of Indian Standards; 2018.

