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Comparative Analysis of Square Building of Varying Height with Constant Aspect Ratio Corresponding to Peak Wind and Earthquake Loads

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Abstract- **As urban areas continue to expand and the demand for space intensifies, tall buildings have emerged as a crucial solution for optimizing land use in cities. The design of skyscrapers, however, necessitates careful consideration of various structural loads, with wind-induced lateral forces and seismic forces being among the most critical. A key challenge lies in determining the optimal building height at which the effects of wind and seismic forces are nearly equivalent, allowing for an economical and resilient design. This study seeks to identify this "optimal height," enabling engineers to design structures that effectively resist both wind and seismic forces while minimizing material usage and associated costs.**

In this research, buildings with heights ranging from 26 meters to 104 meters are analyzed to evaluate the relative impact of wind and earthquake forces. Two distinct soil conditions—loose and hard soil—are considered, with the analysis conducted in Earthquake Zone V under extreme wind conditions of 55 m/s. Structural parameters such as base shear, moments, shear forces, and building displacement are assessed for each scenario to identify the height at which wind and earthquake forces exert nearly equivalent effects on the structure.

The findings indicate that for buildings on loose soil in Earthquake Zone V under a wind speed of 55 m/s, the optimal height is 64 meters. Conversely, for buildings on hard soil under the same conditions, wind forces dominate across all building heights analyzed.

Keywords: Base shear, Earthquake force, Soil conditions, Tall buildings, Wind force

I. INTRODUCTION

As cities grow and land becomes scarce, tall buildings have become essential for accommodating more people and businesses within limited urban space. However, their design requires careful consideration of environmental forces, particularly wind and earthquakes, to ensure safety and stability. Wind forces, which increase with height, can cause swaying and structural stress, while earthquakes induce horizontal forces that challenge the building's ability to withstand ground shaking. Factors such as building height, shape, and soil conditions further influence these forces. To address these challenges, engineers must design structures capable of resisting both wind and seismic loads, ensuring safety, stability, and cost-effectiveness while optimizing material usage.

High-rise structures are essential to accommodate growing urban populations and maximize limited land resources in cities. These buildings must be designed to withstand various loads, including dead loads (weight of the structure itself), live loads (occupants and movable objects), wind loads (lateral forces from wind pressure, especially at greater heights), seismic loads (horizontal and vertical forces caused by ground movements during earthquakes), and environmental loads (temperature changes, snow, and rain). Proper analysis and integration of these loads ensure the safety, stability, and longevity of high-rise structures while maintaining cost-effectiveness and structural efficiency.

The classification of soil types based on the Sa/g ratio (spectral acceleration divided by gravitational acceleration) is essential for understanding how soil conditions influence the seismic response of structures. This categorization helps engineers evaluate the risks associated with a site's ground characteristics, enabling more precise design and construction practices. By understanding the effects of soil on seismic behavior in earthquake-prone regions, engineers can select appropriate foundation systems, materials, and reinforcement methods to ensure that buildings and infrastructure can withstand earthquake forces, enhancing public safety and resilience.

Hard soils generally exhibit lower Sa/g ratios, indicating reduced amplification of seismic waves and less shaking of structures during an earthquake. Medium soils have moderate Sa/g ratios, reflecting a moderate amplification of seismic waves and resulting in more noticeable shaking. In contrast, soft soils have higher Sa/g ratios, significantly amplifying seismic waves, which leads to greater vibrations and an increased risk of structural damage.

Wind pressure distribution on a building depends on factors such as height, shape, orientation, and exposure to wind. At greater heights, wind speeds and pressures are typically higher due to reduced ground friction, resulting in a non-uniform distribution of pressure across the building's surface. The windward face experiences positive pressure, while the leeward and side faces experience negative (suction) pressure. Tall buildings must be designed to resist these lateral forces to prevent excessive swaying, discomfort for occupants, and structural damage.

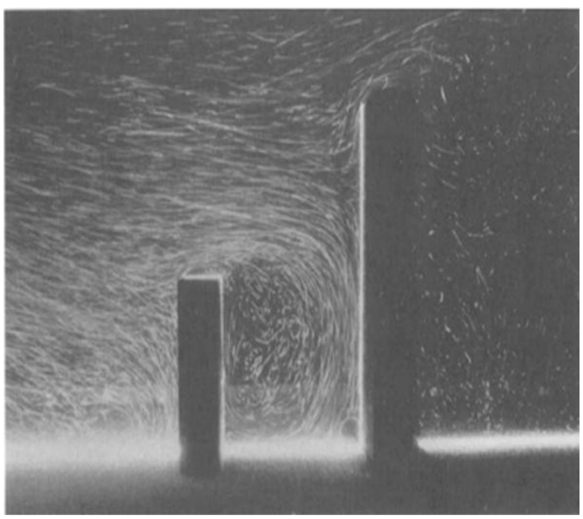

Fig. 1 Wind Flow around Tall Buildings

The seismic behavior of a building is governed by its ability to withstand horizontal and vertical forces generated by ground motion during an earthquake. Factors such as height, mass distribution, structural stiffness, and the type of soil beneath the foundation play a crucial role. Taller buildings are more prone to sway due to their higher flexibility, which can amplify seismic effects. The seismic response is also influenced by resonance, where the building's natural frequency aligns with earthquake vibrations. Proper seismic design ensures energy dissipation, stability, and prevention of structural collapse.

Objective of Study

- To analyze the impact of soil conditions on earthquake forces acting on buildings with heights ranging from 26m to 104m, maintaining a constant aspect ratio.
- To evaluate how variations in building height influence wind forces while keeping the aspect ratio constant.
- To compare the earthquake forces experienced in Zone V for loose and hard soil conditions with wind forces at a wind speed of 55 m/s, for buildings of varying heights and a constant aspect ratio.

II. LITERATURE REVIEW

Recent research emphasizes the significant potential of Wind and Seismic analysis to study structures to maximize their structural performance.

Arif, S. Jangde, and V. Kumar (2024) demonstrated that STAAD Pro is an effective tool for designing earthquake-resistant multi-story buildings. Their study shows that higher seismic zones require increased concrete volume (1.94%–8.91%) and reinforcement (5.21%–21.92%), leading to cost increases of 3.20%–27.16%. However, in lower seismic zones, the additional cost is under 4%, highlighting that earthquake-resistant designs are both feasible and essential for safety. Yadav et al. (2023) analyze irregular 20-story buildings for bending moments, shear forces, and drift under wind and seismic loads, using IS 875 (Part 3): 2015 and IS 1893 (Part 1): 2016. Suthar and Goyal (2021) compare wind load impacts for a G+11 building using older (1987) and updated (2015) codes in Zone 4, emphasizing safety and cost-efficiency. Verma et al. (2022) compare RCC and composite (CFST) columns under seismic loads, finding composite columns reduce floor displacement by 55% and storey shear by 17%-19%, making them superior for seismic performance. Pimpalkar and Padmawar (2022) use STAAD-Pro to design a building for lateral wind loads with a basic wind speed of 50 m/s, evaluating displacement, story drift, and load combinations.

B. S. Chauhan et al. (2021) analyzed wind interference effects on buildings, showing that the primary building experiences a 31% reduction in drag force at a 0° interior angle. As the angle increases from 90° to 180°, the along-wind force gradually rises, peaking at 10%. At 180°, twisting moments (KMZ) and across-wind forces (KFY) are at their highest. Suction on the leeward face (Face C) intensifies with angle increases, amplifying along-wind forces. At 30°, Face B has the highest mean wind pressure coefficient (C_p = 1.55), while Face A shows the largest percentage increase in C_p (86.67%). Jafari and Alipoura (2021) emphasize damping systems and aerodynamic modifications for tall buildings, advocating advanced technologies like AI and CFD to mitigate wind effects. G Ramesh (2021) underscores the utility of STAAD-Pro for designing multi-story buildings to handle static and seismic loads, emphasizing civil engineers' role in ensuring safety and integrity. Dr Shinde (2020) studied the performance of G+12 and G+16 RCC buildings using equivalent static and response spectrum analyses, based on the updated IS 1893: 2016 code. The analysis covers seismic zones II, III, IV, and V using ETABS software, comparing how different seismic conditions and methods affect structural performance. Pal et al. (2020) focus on soil types, noting that hard soil offers maximum stability, medium soil moderate stability, and soft soil requires adaptable foundations.

Andrew William Lacey et al. (2020) investigated the structural behavior of modular buildings under lateral dynamic loads, emphasizing the role of inter-module connections. Their study found that the translational stiffness of vertical inter-module connections, particularly in the load direction, significantly influences the building's overall response, whereas rotational stiffness has a lesser effect. They advocate for developing more accurate models to better represent the shear behavior of inter-module connections, as existing simplified models may not fully capture their effects. Zheng, Xiao-Wei, et al. (2019) proposed a multi-hazard framework to estimate the damage risk of high-rise buildings subjected to earthquakes and wind forces, both independently and concurrently. The framework was applied to a 42-story steel frame-RC core tube structure in Dali, China, using earthquake and wind data from 1971 to 2017. It integrates fragility analysis and damage probability assessments to evaluate the structural performance under combined hazard scenarios.

III. METHODOLOGY

The methodology process involves to compare and analyze the impacts of static wind and seismic forces on tall buildings by using STAAD Pro, considers different heights, seismic zones, wind speeds, and soil conditions with following building models are varying height from 26m to 104m in the equal interval of 13m. The aspect ratio of each model is constant. The number of bays is also constant.

The model is meshed with medium element sizing, generating 580 elements and 1039 nodes. Structural loads and boundary conditions are applied, including fixed support at the base (indicated by dark blue arrows) and a downward force of 965N at points E and D. Following the application of boundary conditions, solver settings are configured, and the simulation is executed.

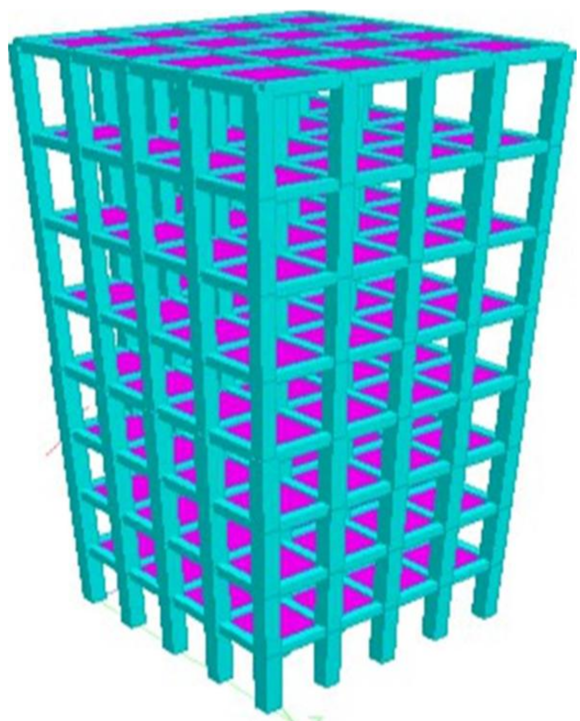

Fig. 2 View of Structure Model

The size of beams and column at each four storeys are constant. The aspect ratio is 3 and number of bays are four, for each model. The dimension with description of each model of different height is given below in table 3.

TABLE 1 DATA IN STAAD PRO FOR WIND LOAD CALCULATION

IS CODE	875 Part 3		
Year of publication	2015		
Maximum height	26,39,52,65,78, 91,104 m		
Ground level elevation	0.00		
Height Interval for Intensity	3.25 m		
Basic wind speed (V_B)	55 m/s	Use custom	
Risk coefficient Factor (k_1)	1	Class 1 General building	
Terrain roughness and height factor (k_2)	-	Terrain category 1	
		Aerodynamic roughness height 0.002	
Topography factor (k_3)	1		
Importance factor for cyclonic region (k4)	1	Other structure	
Pressure coefficients	0.8	X	direction
	0.25	(-X)	direction
	0.8	Z	direction
	-0.8	(-Z)	direction

TABLE 2 DATA FOR EARTHQUAKE CALCULATION

IS CODE	1893 Part 1		
Year of publication	2016		
Zone	V		
Z	0.36		
Response reduction factor	5	RC building with moment resisting frame	
Importance factor	1	For all other structure	
Rock/ Soil type	Hard soil/soft soil		
Structure type	RC MRF buildings		
Damping ratio	5%		
Coefficients	1	X	direction
	-1	X	direction
	1	Z	direction
	-1	Z	direction

TABLE 3 GEOMETRIC DIMENSIONS OF MODEL

			Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
S No	Variables	Description	Dimension	Dimension	Dimension	Dimension	Dimension	Dimension	Dimension
1	Model		G+7	G+11	G+15	G+19	G+23	G+27	G+31
2	Dimensions	Length (4bays)	8.67m	13m	17.33m	21.67m	26m	30.33m	34.67m
		Width (4bays)	8.67m	13m	17.33m	21.67m	26m	30.33m	34.67m
		Height	26m (8storey)	39m (12storey)	52m (16storey)	65m (20storey)	78m (24storey)	91m (28storey)	104m (32storey)
3	Floor height	3.25 m							
4	Column (B*D)	1-4 storey	0.5m*0.5m	0.6m*0.6m	0.8m*0.8m	1m*1m	1.2m*1.2m	1.4m*1.4m	1.6m*1.6m
		4-8 storey	0.4m*0.4m	0.5m*0.5m	0.6m*0.6m	0.8m*0.8m	1m*1m	1.2m*1.2m	1.4m*1.4m
		8-12 storey		0.4m*0.4m	0.5m*0.5m	0.6m*0.6m	0.8m*0.8m	1m*1m	1.2m*1.2m
		12-16 storey			0.4m*0.4m	0.5m*0.5m	0.6m*0.6m	0.8m*0.8m	1m*1m
		16-20 storey				0.4m*0.4m	0.5m*0.5m	0.6m*0.6m	0.8m*0.8m
		21-24 storey					0.4m*0.4m	0.5m*0.5m	0.6m*0.6m
		25-28 storey						0.4m*0.4m	0.5m*0.5m
		29-32 storey							0.4m*0.4m
5	Beam (B*D)	1-4 storey	0.5m *0.3m	0.6m*0.4m	0.8m*0.6m	1m*0.75m	1.2m*0.8m	1.4m*1.1m	1.6m*1.2m
		4-8 storey	0.4m*0.3m	0.5m *0.3m	0.6m*0.4m	0.8m*0.6m	1m*0.75m	1.2m*0.8m	1.4m*1.1m
		8-12 storey		0.4m*0.3m	0.5m *0.3m	0.6m*0.4m	0.8m*0.6m	1m*0.75m	1.2m*0.8m
		12-16 storey			0.4m*0.3m	0.5m *0.3m	0.6m*0.4m	0.8m*0.6m	1m*0.75m
		16-20 storey				0.4m*0.3m	0.5m *0.3m	0.6m*0.4m	0.8m*0.6m
		21-24 storey					0.4m*0.3m	0.5m *0.3m	0.6m*0.4m
		25-28 storey						0.4m*0.3m	0.5m *0.3m
		29-32 storey							0.4m*0.3m
6	Plate thickness		0.2m						

IV. RESULTS AND DISCUSSION

This section presents the results obtained from the experimental investigations and their analysis. The findings are systematically organized to provide clarity and insight into the study's objectives. The static wind and earthquake analysis of square-shaped building models, with heights ranging from 26m to 104m and a constant aspect ratio, has been completed using STAAD Pro. The analysis results, presented in tables and graphs, include key parameters such as top displacement, which reflects the building's lateral movement under loads, and maximum forces and moments, calculated at the base of the building to assess structural stability and load resistance. These outputs provide critical insights into how building height influences structural behavior under wind and seismic forces.

For Soft Soil Zone V v/s Wind speed 55 m/s

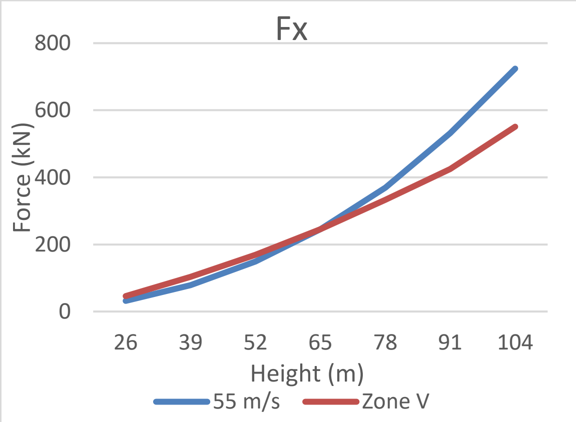

Fig. 3 Shear in X direction v/s height

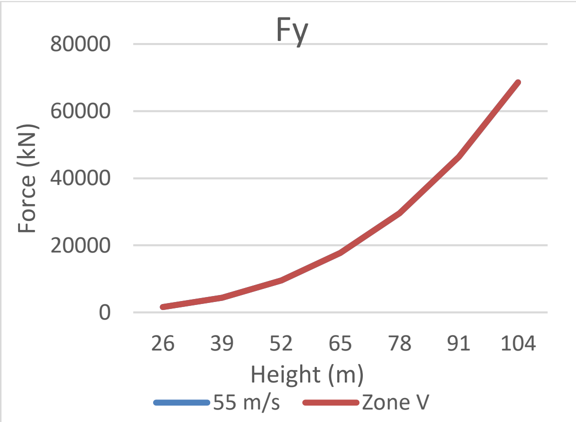

Fig. 4 Reaction in Y direction v/s height

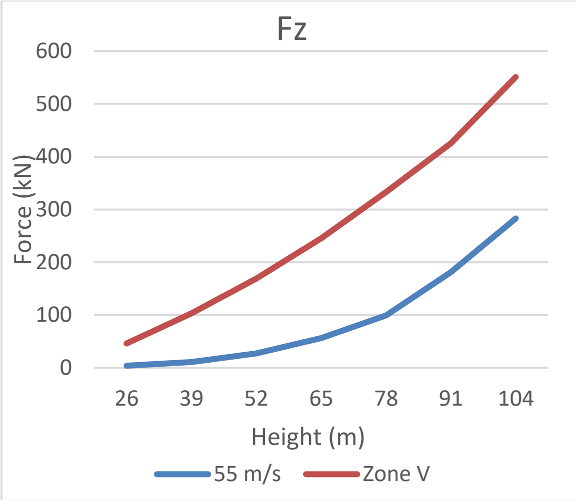

Fig. 5 Shear in Z direction v/s height

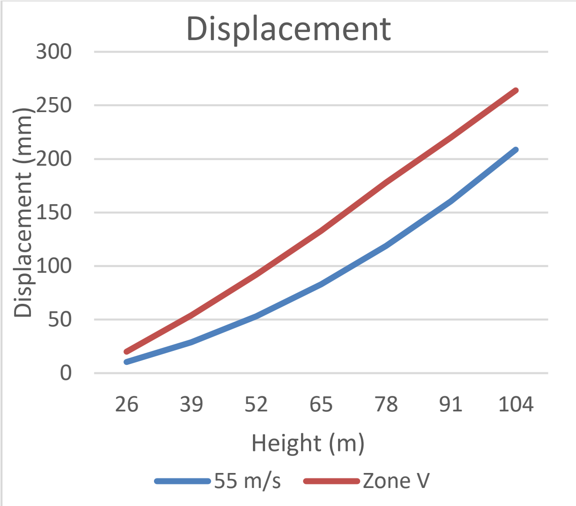

Fig. 6 Displacement v/s height

In **Zone V** with loose soil, base shear analysis shows that earthquake forces dominate up to a height of **64m**, after which wind forces take over for a wind speed of **55 m/s**. Both forces produce similar vertical reactions at the base level, resulting in overlapping curves. In the **Z direction**, earthquake forces dominate as wind pressure coefficients nullify each other's effects. Displacement due to earthquake forces consistently exceeds that of wind forces, with the difference increasing as building height increases.

For Hard Soil Zone V v/s Wind speed 55 m/s

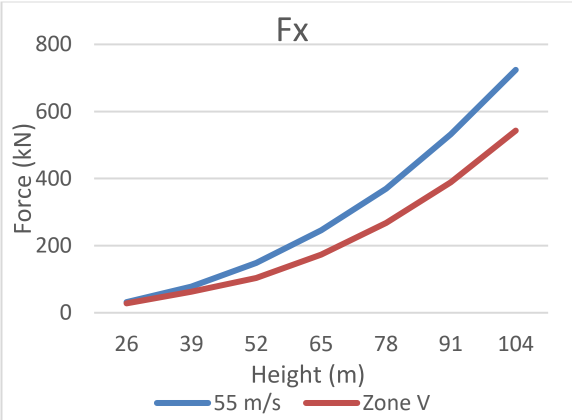

Fig. 7 Shear in X direction v/s height

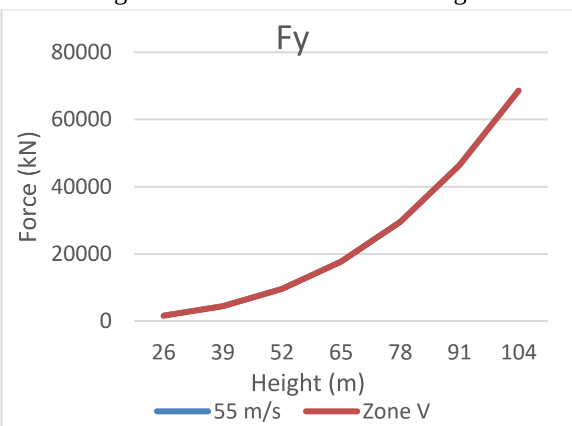

Fig. 8 Reaction in Y direction v/s height

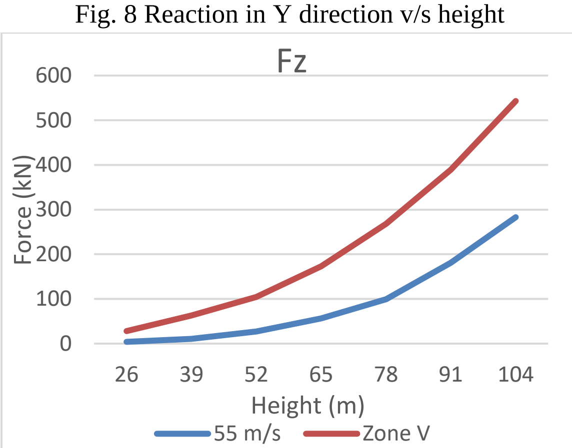

Fig. 9 Shear in Z direction v/s height

In **Zone V** with hard soil, base shear analysis shows that wind forces generated by a wind speed of **55 m/s** dominate throughout the building's height, with a smaller difference at **26m** that increases with height. In the **Z direction**, earthquake forces dominate as wind pressure coefficients cancel each other's effects. Displacement due to earthquake forces exceeds that of wind forces, with the difference widening as height increases.

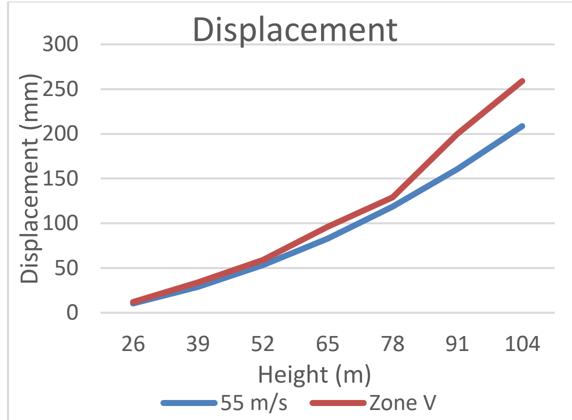

Fig. 10 Displacement v/s height

V. CONCLUSIONS

Here are the inferred conclusions for above analysis.

- In Zone V with loose soil, earthquake forces initially dominate but are overtaken by wind forces at a height of 65m for a wind speed of 55 m/s.
- In Zone V with hard soil, wind forces dominate over earthquake forces throughout the building's height for the same wind speed.
- Forces in the Z direction are primarily governed by earthquake forces, as wind pressure coefficients cancel out in this direction, making wind effects negligible.
- For loose soil, displacements are always governed by earthquake forces compared to wind forces.
- For hard soil, earthquake forces cause more displacement up to 95m, after which wind forces dominate.
- Comparing soil conditions, softer soils amplify seismic forces, requiring stronger structural designs in earthquake-prone areas

The analysis highlights that the behavior of tall buildings under wind and earthquake forces depends significantly on height, soil conditions, and force direction. In **Zone V**, earthquake forces dominate initially for loose soil but are overtaken by wind forces at greater heights, while wind forces consistently govern for hard soil. The **Z direction** forces are negligible under wind, as they are primarily influenced by earthquake forces. Displacement analysis shows that earthquake forces are more critical for loose soil, while wind forces dominate at higher elevations for hard soil. Additionally, softer soils amplify seismic forces, underscoring the need for robust structural designs in earthquake-prone regions to ensure safety and resilience.

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