SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V12I7P112

Volume 12 Issue 7, 130-144, July 2025
© 2025 Seventh Sense Research Group®

Original Article

Comparative Analysis of a Square Tall Building for Dominating Effect of Earthquake or Wind

Digvijay S Hada[1], S K Nagar[2], A K Dwivedi[3]

[1,2,3]*Civil Engineering Department, Rajasthan Technical University, Kota.*

[1]*Corresponding Author : digvijaysingh.hada@outlook.com*

Received: 09 May 2025 Revised: 14 June 2025 Accepted: 12 July 2025 Published: 31 July 2025

***Abstract -** In recent years, structural engineering has experienced a crucial transformation, marked by substantial progress in the design of tall buildings. These tall buildings must be designed to withstand wind-induced lateral loads and seismic forces. However, analysing tall buildings for these forces individually can be time-consuming. By identifying the dominant forces (wind or seismic) at specific building heights, designers can prioritize during the design process, ultimately reducing time and resources. This research analyses buildings from 26 to 104 meters under hard and loose soil types in Seismic Zones IV and V, along with wind speeds of 55, 50, and 47 m/s. To assess how building height, soil type, seismic intensity, and wind loads collectively influence structural behaviour. The results show that in Earthquake Zone V with loose soil, wind forces dominate in buildings with heights of more than 64 m, 84 m, and 92 m for wind speeds of 55, 50 and 47 m/s, respectively. In comparison, in Zone IV, wind forces dominate in buildings with heights of more than 48 m and 56 m for wind speeds of 50 m/s and 47 m/s, respectively. For hard soil in Zone V, wind forces dominate in buildings with heights of more than 35 m and 44 m for wind speeds of 50 m/s and 47 m/s, respectively. Wind forces dominate at lower building heights in harder soils and lower seismic zones, making wind force consideration mandatory for shorter buildings in areas with higher wind speeds. Soil conditions have a greater influence than seismic zone on buildings shorter than 64 m in seismic Zones IV and V.*

***Keywords -** Tall buildings, Earthquake force, Wind force, Base shear, Soil conditions.*

1. Introduction

As metropolitan areas grow and land becomes more scarce, high-rise structures are becoming more essential components of modern cities, providing vital residential, commercial, and mixed-use spaces in densely crowded neighbourhoods. These tall structures maximize land use, promote economic development, improve architectural identity, and frequently become cultural landmarks. High-rise structures are defined as taller than 50 meters and further classified into skyscrapers (150-300 m), supertall (300-600 m), and mega tall (over 600 m). High-rise buildings facilitate urban growth by reducing space while improving the economics, culture and design.

Analysis of building loads is essential in design, including vertical loads from imposed dead and live loads, and lateral loads from wind and earthquakes [1-2] Wind effects vary with height and local conditions, making them crucial for tall buildings, especially in stormy areas. Seismic loads are significant in earthquake-prone regions to ensure serviceability. Accurate estimation of these forces ensures high-rise structures remain safe, stable and durable under extreme loading conditions. Wind and seismic forces must be carefully studied because they cause shear, bending, displacement and twisting in tall structures.

Wind load depends on wind speed, building shape, and local topography and must be carefully considered during the design phase. In India, wind speeds are computed using the Extreme Value Type 1 distribution based on peak 3-second gusts, categorized into six zones ranging from 33 m/s to 55 m/s during a 50-year period. Design wind speed varies with location, height and terrain [1].

Earthquake forces can significantly affect structural stability, particularly in areas with high seismic activity and loose soil conditions. During an earthquake, abrupt ground shaking produces horizontal and vertical accelerations that cause structures to sway, vibrate and slide laterally.

The intensity of an earthquake's impact is determined by its magnitude, distance from the epicentre, structural design, materials and mass of structure. To ensure that structures can withstand seismic events, earthquake loads are calculated using parameters such as seismic zone, soil type and structural geometry. India is classified into four seismic zones depending on seismic intensity: Zone II (zone factor 0.10), Zone V (0.36), Zone IV (0.24) and Zone III (0.16), with Zone V posing the greatest seismic risk [2].

A tall building's response to earthquake and wind pressures varies greatly in frequency, magnitude and behavior with tallness. Wind forces occur gradually and continuously, rising with height due to higher wind speeds, resulting in consistent lateral displacement that peaks at the upper stories. In contrast, earthquake forces are abrupt and dynamic, originating at the base and spreading upward with tremendous acceleration over a short period of time, frequently creating fast and fluctuating motion. While wind loads normally decrease comfort and serviceability, seismic loads represent a bigger threat to structural integrity, particularly at the foundation level, where base shear is greatest. The wind forces increase with height, making them more important for tall buildings, while earthquake forces act uniformly across all levels. Earthquake loads are sudden and unpredictable, mainly affecting low-rise structures, whereas wind loads are steady, unidirectional, and critical in high-rise design. Earthquake design emphasizes the ability to absorb rapid movement without collapsing, whereas wind design focuses on reducing lateral deflection and assuring occupant comfort. Wind events are more common and prolonged, although earthquakes are not common but potentially significantly more fatal. Both risks require careful consideration in structure design, particularly in areas where they coexist. A well-balanced methodology ensures that buildings remain safe, resilient, and functional in both wind and seismic situations, which place distinct demands on structural performance [1-3].

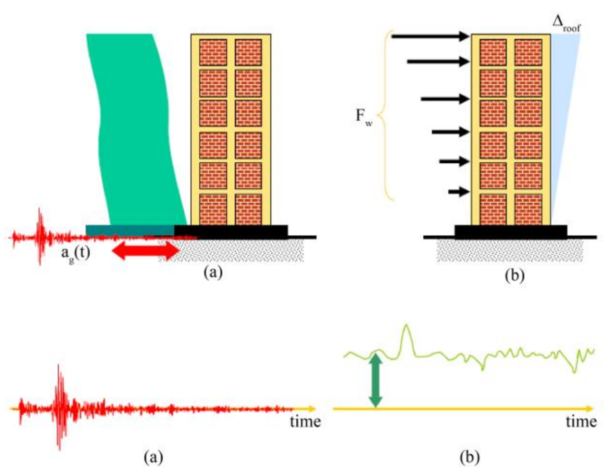

Fig. 1 Behavior of Building (Earthquake v/s Wind)

Figure 1 depicts the differences between how buildings respond to wind and earthquake forces. Earthquake forces cause sudden and dynamic shaking over a short period of time, resulting in sharp lateral movements, whereas wind forces apply steady, unidirectional pressure over a longer period of time, resulting in gradual sway at higher elevations.

Alfonso Vulcano (1998) investigated the dynamic response of RC buildings against earthquakes and wind loads. The researchers discovered that base isolation, particularly with HDLRBs, efficiently minimizes seismic forces and ductility demand. However, the increased flexibility causes wind-induced displacements and floor accelerations, which affect serviceability. Wind-induced accelerations tend to rise with higher isolation ratios, while seismic accelerations decrease [4]. T. Balendra et al. (2001) developed a low-cost system using knee-braced frames and slotted bolted connections to control wind and seismic vibrations. KBF offered hysteretic damping for strong quakes, while SBC provided frictional damping for moderate loads without damage. Tests showed effective energy dissipation and minimal damage, mainly at the knee, enabling easy repairs [5]. Khaled M. Heiza et al. (2012) analysed the effects of wind and seismic forces on reinforced concrete high-rise buildings using the Egyptian Codes of 1993 and 2003.They discovered that earthquake effects frequently prevail, depending on the seismic zone and structural type.

A bespoke program examined building reaction under both loads, indicating that seismic effects vary greatly depending on weight and system type characteristics. For lateral resistance, ductile frames and shear walls performed well. Wind is dominant under minimal design variables, while earthquakes are predominant under maximum factors. The report advises conducting separate design evaluations for wind and earthquake pressures in both directions [6]. S. Mahesh et al. (2014) used ETABS and STAAD PRO V8i to investigate the seismic and wind loads on a G+11 residential building. Linear static and dynamic studies were performed in seismic zones with different soil types. The results showed that the largest base shear occurred in Zone 5 with soft soil, and irregular configurations resulted in higher base shear. Because of their symmetry, regular layouts have higher total base shear and tale drift. The irregular structure's peak story drift happened on the 12th level, whereas the regular structure was on the 13th. STAAD PRO V8i produced more results using 5-10% more steel area than ETABS [7]. A. Gottala et al. (2015) used STAAD-Pro to conduct static and dynamic studies of a G+9 RC frame building under seismic loads in accordance with IS 1893:2002.

Dynamic analysis shows 35-45% higher bending moments and 40-45% larger column displacements than static analysis. Torsion in columns was positive in dynamic and negative in static analysis. Dynamic analysis revealed a 50% increase in nodal displacements in the Z direction. While beam stresses were comparable in both methods, seismic excitation in dynamic analysis resulted in much higher bending moments and displacements [8]. MD. Mahmud Sazzad et al. (2015) investigated how building design influences wind and earthquake responses using the BNBC (2006). Three shapes were investigated, with Building C exhibiting the greatest displacement and story drift under both earthquake (y-direction) and wind (x-direction) stresses. While wind caused more lateral displacements, earthquake forces were more important overall. Building A was deemed the safest under all situations [9]. G.G. Kakpure et al. (2016) examined static and dynamic earthquake analysis of multi-story reinforced concrete buildings and concluded that static analysis is insufficient for high-rise structures. Dynamic analysis provided more accurate findings, particularly for upper floors with considerable displacement variances. Irregular buildings, particularly those with re-entrant corners, exhibited more drift and deformation, emphasizing the benefits of regular designs. Static analysis was also considered unprofitable due to overestimated displacement values [10]. Chenyang Yuan et al. (2017) studied the wind turbines under combined seismic and aerodynamic loads in two scenarios: regular operation with the Baseline Control System (BCS) operating and parked. Fragility curves were developed using IEC 61400-1 standards and pushover analysis, considering tower top displacement and base moment [11]. Rabi Akhtar et al. (2017) analyzed high-rise buildings using STAAD Pro V8i to study their behavior under static and dynamic loading. The key aspects include resonant frequencies, gust factors, accelerations and deflection. The research emphasized the value of varying modelling techniques. The shear wall played a crucial role in limiting deflections, with a noted 25% difference between systems. Due to lower K_2 values, dynamic forces (Fx and Fz) are found to be less than static forces. Earthquake loads are more influential than wind, highlighting the need for extra shear walls to manage seismic deflections.

[12] Zheng Lu et al. (2018) investigated the effectiveness of Particle Dampers (PD) and Tuned Mass Dampers (TMD) for vibration control in structures. PD shows superior performance by limiting plastic hinge formation, enhancing energy dissipation, and reducing relative displacement. PD also maintained stability under varying stiffness and seismic conditions, showing its reliability in earthquake resistance [13]. Raffaele De Risi et al. (2018) studied the seismic response of monopile-supported offshore wind turbines on loose soils under crustal and interface earthquakes. The finite element analysis using unscaled seismic data revealed that ignoring Soil-Structure Interaction (SSI) overestimates seismic capacity by 60–70%. The research stressed the importance of accurate modelling near the tower base and buckling zones so that earthquakes often push turbines beyond the serviceability limit [14]. Piguang Wang et al. (2018) investigated the dynamic response of Offshore Wind Turbines (OWT) on clay foundations under combined wind, wave and seismic loads. A 3D finite element model in OpenSees is used to simulate interactions between the tower, monopile, soil and water. The author assessed how factors like wind speed, wave period, peak ground acceleration and soil characteristics affect structural performance [15]. Ghanbari et al. (2019) analysed a 58-story building in Dallas, USA, comparing Tube in Tube (TiT), Braced Bundled Tube (BBT) and Bundled Tube (BT) systems under wind and seismic loading. The BBT system has a lower displacement of 45% and a reduced structural weight of 71% compared to BT. While BBT distributes loads in BT, they raise displacement on the upper floors. Overall, BBT shows the most efficient in load resistance [16]. Yang et al. (2019) created a Seismic Analysis Framework (SAF) by integrating the QuakeDyn module into FAST to assess Offshore Wind Turbines (OWTs) with fixed and flexible foundations under combined wave, wind and seismic loads. Using nonlinear p-y curves for soil modelling, the author observed that flexible foundations had much higher seismic responses, including a 34% rise in mudline bending moment during emergency shutdowns. The soil-structure interaction and ground motion direction reduce seismic risks and enhance turbine performance [17]. Xiao-Wei Zheng et al. (2019) developed a multihazard framework to assess high-rise buildings under combined earthquake and wind loads. This study found that combined loading greatly increased damage probabilities, particularly under extreme conditions. Wind speed had a strong influence on structural response, and neglecting simultaneous consideration of seismic load led to underestimated risks.

[18] Wei Jing et al. (2019) developed a 3D wind-shell-liquid interaction model to study the dynamic response of liquid storage tanks under earthquake, wind and combined loading, considering material nonlinearity and sloshing. The author shows that high wind speeds alone could trigger stronger responses than earthquakes, and combined loading produces greater strain, especially in upper unfilled and lower filled wall zones. Wind interference of tank groups further increases the tank design’s displacement and internal stress [19]. Zhang et al. (2019) proposed the Tuned Parallel Inerter Mass System (TPIMS) to control seismic vibrations in wind turbine towers. Combining a mass, spring and inerter, this system served as a lightweight retrofit that reduces top displacement, base shear and moments more efficiently than traditional dampers. TPIMS control the vibration and shows high robustness under different seismic conditions, making it a practical and cost-effective solution [20]. Zhao et al. (2019) find a scissorjack braced Viscous Damper System (VD-SJB) to reduce vibrations in wind turbine towers, particularly in areas with strong wind and seismic activity. Finite element analysis showed VD-SJB outperformed conventional dampers under both operating and parked conditions. It was optimised using a multi-objective genetic algorithm and artificial neural networks. The system enhanced the damper stroke and reduced damping force, proving to be an effective and promising solution for vibration control [21]. Biswas Ankon et al. (2020) assessed 15-story regular and irregular buildings using ETABS 2015 under static, wind, and seismic loads in Dhaka’s seismic zone 2. Irregular forms showed greater displacements, drifts, and time periods, indicating higher vulnerability. The rectangular model performed best, while the L-shaped had the highest seismic response, proving irregular shapes are less stable [22]. Kazemi Esfeh et al. (2020) found that liquefaction increases foundation rotation in offshore wind turbines, with reduced effects using larger caissons or longer monopiles. The replacement of liquefiable sand with non-liquefiable material around monopiles reduced

displacements. Asymmetrical wind and seismic stresses threaten the OWT foundation's stability [23]. Wang et al. (2020) proposed a pushover analysis-based approach for evaluating the performance of low- and medium-rise concrete structures under combined earthquake and wind stresses. The study analyses various soil types and winds with speeds ranging from 0.5 to 20 m/s and found that linked loading greatly increases displacement needs, particularly in flexible-base systems. It was determined that current seismic-focused design regulations may understate dangers in earthquake-prone locations. The study emphasized the need to include both wind and seismic effects in structural design and suggested additional research on other wind regimes and combined loading situations [24]. The author compares shear walls, braced frames, diagrids, outriggers and framed tubes. The findings revealed that shear walls are excellent for mid-rise buildings, whereas framed tube systems are better suited for large constructions. Diagrids resist displacement and drift; outriggers give the best resistance for mid-height to the top of the structure.

Composite constructions showed higher ductility and lower base shear than RCC. Overall, shear walls and framed tubes were found to be the most suitable in terms of building height [25]. Maha Al-Soudani et al. (2021) analyzed the effects of wind and seismic loads on a 12-story concrete building using SAP2000 and compared results with various international codes. The study found significant differences, with the Romanian code being the most conservative and the Italian code the least. It emphasized the importance of considering horizontal forces in structural design and recommended using shear walls and international standards, especially in earthquake-prone regions [26]. Huaxiao Wu et al. (2021) analyzed two adjacent high-rise buildings connected by passive control devices to study their relative dynamic responses under wind and earthquake loads. Using wind tunnel tests and 44 seismic records, they found that wind-induced responses, especially in the across-wind direction, showed higher and more stable opposite-sign response factors than those from earthquakes. The results suggest that wind loads are less sensitive to variations in natural frequency ratios, offering useful insights for designing vibration mitigation systems in adjacent tall buildings [27]. Shinyoung Kwag et al. (2021) presented a performance-based framework to evaluate whether building design is governed by single or multiple hazards, focusing on wind and earthquake. The study integrates site-specific hazard data with structural performance criteria and supports both probabilistic and deterministic approaches. Case studies across U.S. locations show that multihazard considerations significantly affect design and retrofit solutions, especially in urban settings, where designs effective for one hazard may not perform well under another [28]. Zhu et al. (2022) developed a dynamic model to evaluate wind turbine tower responses under wind and earthquake loads using a generalized global spatial discretization method. Validated by ANSYS, the model analyzed transient vibrations and stress distributions. A hybrid mutation particle swarm optimization algorithm was then applied to reduce tower top vibrations while meeting weight and stress constraints. Results showed improved vibration control and structural performance after optimization [29]. Gujjewar et al. (2022) studied a four-legged square transmission tower under different seismic zones as per IS 1893 Part 3 for three heights: 40m, 50m, and 60m using STAAD.Pro software. The analysis showed that the 60m tower had the highest deflection up to 37.6mm, support reaction up to 1862 kN, and support moment up to 111 kN-m in seismic zone V. The axial stress was highest for the 60m tower in zone V, while the 50m tower had the highest bending stress, 58 N/mm². Overall, the 60m tower was most critical except for bending stress, where the 50m tower was more vulnerable, emphasizing the influence of seismic loads on tower performance [30]. Abdulateef et al. (2023) invented a Fuzzy Logic Multi-Verse Optimal Control (FLMVOC) system for vibration control of structures under wind and earthquake loads. Using a magnetorheological damper, the system reduced story drifts by up to 60% and floor acceleration by up to 38% during earthquakes. For wind-induced structures, FLMVOC maintained comfort limits while reducing drift. The system achieved significant reductions in drift (51%) and acceleration (22%) under seismic loads and 12-16% under wind loads, proving effective in managing uncertainties and saving power.

Further research on online optimization is recommended [31]. Lin et al. (2024) studied the dynamic response of offshore jacket platforms under wave, wind, current, and earthquake loads using CFD-FEA coupling. Their results showed that earthquakes had a greater impact than waves, with the structural response being underestimated when wave effects were neglected. The aftershock-mainshock sequence increased platform stress and displacement. The study emphasizes the importance of protective measures and suggests further research on two-way coupling and extreme marine conditions like tsunamis [32]. Wang et al. (2024) investigated the impact of the same loading interactions on wave height and hydrodynamic pressure using CFD. They found that wind and current increased wave height, while earthquake effects on wave behavior were minor. The combined forces led to higher wave heights and hydrodynamic pressures than individual loads, particularly in wave-current-earthquake interactions [33]. Wang et al. (2024) studied the failure of wind turbines at Japan's Kugino wind farm during the Kumamoto earthquake using a beam-on-model with a new QzSimple6 soil footing interaction. Their analysis showed that while all three pile groups cracked, only the No.2 tower buckled at 13.9 m due to a sudden thickness reduction. The study revealed that footing rigidity controls pile bending, while softer soils under No.1 and No.3 likely reduced tower damage, highlighting the role of local soil conditions in seismic resilience [34]. Ishihara et al. (2024) investigated the dynamic loads on a 2.4 MW wind turbine supported by a gravity foundation under combined wind and earthquake effects using both coupled and uncoupled analysis methods. A simplified lumped mass model showed strong agreement with the aeroelastic model in predicting modal responses. Their results showed that maximum base moments occur during emergency stops when wind and earthquake are aligned (0°), while normal operation dominates at 90° misalignment. To simplify design, they proposed vector sum and SRSS methods for combining loads in uncoupled analysis, which matched well with coupled analysis results [35].

Few researchers have compared the earthquake force in the peak zones with the wind force on tall buildings for peak wind speeds with varying heights of the buildings.

Also, very little research data is available for comparative analysis of earthquake forces with wind forces for different soil conditions.

Very few studies are available for wind load analysis on tall buildings with a constant aspect ratio and varying wind speed.

This study aims to identify the dominant forces at specific heights to help designers prioritize which forces to consider during the design process, thereby reducing time and resources.

The current study considers the peak wind and seismic forces acting on buildings ranging from 26 to 104 meters in height for both hard and loose soil types in Seismic Zones IV and V. It also includes wind speeds of 47, 50, and 55 m/s.

2. Methodology

The following methodology is used to evaluate the dominance between wind and seismic pressures on tall buildings using STAAD Pro.

2.1. Modelling

Seven square-shaped base models (D1 to D7) are developed with building heights ranging from 26 meters to 104 meters, increasing in 13-meter constant intervals.

Table 1. Model details (D1 to D7)

Model	Description	Height (m)	Lateral Dimension (m)
D1	G+7	26	8.67
D2	G+11	39	13
D3	G+15	52	17.33
D4	G+19	65	21.67
D5	G+23	78	26
D6	G+27	91	30.33
D7	G+31	104	34.7

Table 1 outlines the specifications of seven square-based building models (D1 to D7) with varying elevations and lateral dimensions. Each model features a constant aspect ratio of 3, four bays, a floor height of 3.25 meters, and a slab thickness of 0.2 meters. To ensure consistency across all models, uniform beam and column sizes are kept uniform at each corresponding depth.

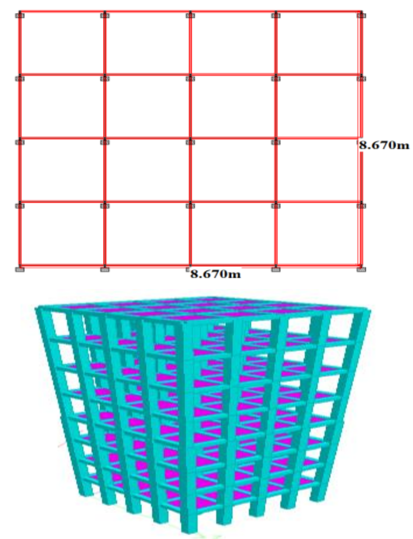

Fig. 2 Modelling (D1)

Figure 2 illustrates the 3D model (D1), which includes the building's plan.

2.2. Data Input in STAAD Pro

The data inputs for wind and earthquake analysis in STAAD Pro are presented in the following tabular format.

Table 2. Data input for earthquake analysis

IS CODE	1893 Part 1		
Year of publication	2016		
Zone	IV and V		
Z	0.24 and 0.36		
Response reduction factor	5	RC building with a moment resisting frame	
Importance factor	1	For all other structures	
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 2 provides seismic design parameters as per IS 1893 Part 1 (2016) for RC MRF buildings in Zones IV and V, considering both loose and hard soil strata. It uses the coefficients of ±1 in X and Z directions for analysis [2].

Table 3. Data input for wind analysis

IS CODE	875 Part 3		
Year of publication	2015		
Maximum height	26, 39, 52, 65, 78, 91 and 104 m		
Ground level elevation	0		
Height Interval for Intensity	3.25 m		
Basic wind speed (V_B)	47,50,55 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 3 represents wind load data as per IS 875 Part 3 (2015) for buildings up to 104 m high, using custom wind speeds (47, 50, 55 m/s) and evaluated every 3.25 m interval from ground level. The Terrain factor (k2) is auto-calculated in STAAD Pro by assigning Terrain Category 1 with 0.002 aerodynamic roughness. Pressure coefficients for 0° wind angle are 0.8 (X), 0.25 (–X), 0.8 (Z) and -0.8 (–Z) [1].

A total of 49 structural models are analyzed to evaluate their behavior under wind and seismic loading conditions. It includes 21 wind load models, developed by applying three different peak wind speeds to each of the seven base models (D1 to D7), and 28 seismic load models, obtained by subjecting the same set of models to seismic forces corresponding to two peak ground acceleration zones, IV and Zone V.

All models are designed with consistent loading parameters: a wall dead load of 15 kN/m, a floor dead load of 4 kN/m², and an imposed live load of 3 kN/ m².

Table 4. Load combinations

S No.	Load combination	Dead load	Live load	Wind load
1	DL	1	-	-
2	LL	1	-	-
3	WL/EQ	1	-	-
4	DL + LL	1.5	1.5	-
5	DL + LL + WL/EQ	1.2	1.2	1.2
6	DL + LL + WL/EQ	1.2	1.2	-1.2
7	DL + LL	1.2	1.2	-
8	DL + WL/EQ	1.5	-	1.5
9	DL + WL/EQ	1.5	-	-1.5
10	DL	1.5	-	-
11	DL + WL/EQ	0.9	-	1.5
12	DL + WL/EQ	0.9	-	-1.5
13	DL	0.9	-	-

Table 4 represents the load combinations with their corresponding factors as per IS 456: 2000, which are assigned in STAAD Pro. 2023 [3].

3. Results and Discussions

3.1. General

A static wind and earthquake analysis was carried out on square-shaped building models with heights varying from 26 m to 104 m. The primary results include the top storey displacement, which reflects the overall lateral movement of the structure under applied loads. The maximum forces and moments are obtained at the base, which are critical for evaluating the internal stresses and foundation reactions.

Each model is evaluated under three different wind speeds, 55, 50 and 47 m/s, to observe wind-induced responses. Additionally, seismic analysis is conducted under both Zone IV and Zone V conditions. For each seismic zone, models are analysed for both hard and loose soil types to observe the effect of soil variability. This comprehensive approach provides in-depth insight into how building height, wind speed, seismic intensity, and soil type affect the structural behaviour of high-rise buildings.

The bending Moment (Mx) is related to the lateral force component Fz. Wind forces are applied primarily in the x-direction; hence, pressure coefficients in the z-direction are zero, resulting in low bending Moment (Mx) values under wind loading. In contrast, earthquake forces produce considerable lateral components, resulting in higher Mx values in all figures. As a result, more meaningful comparisons between wind and earthquake effects are made with the bending Moment (Mz), which corresponds to the lateral force component Fx, representing base shear in the x-direction.

3.2. Loose Soil Condition

The results of the analysis of wind and earthquake forces under loose soil, including twisting, bending, and top storey displacement, are compared for different wind speeds in Zone IV and then in Zone V.

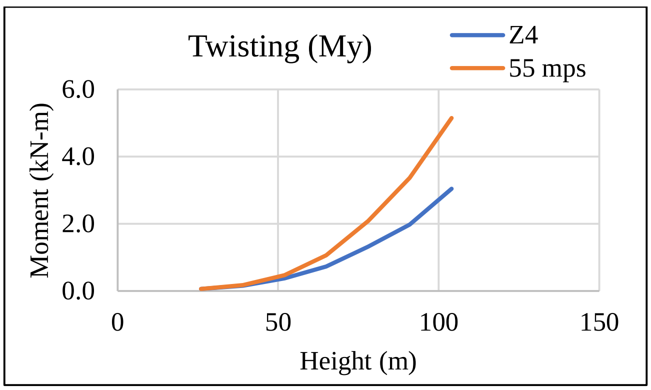

Fig. 3 Twisting (earthquake zone iv with loose soil & 55 mps)

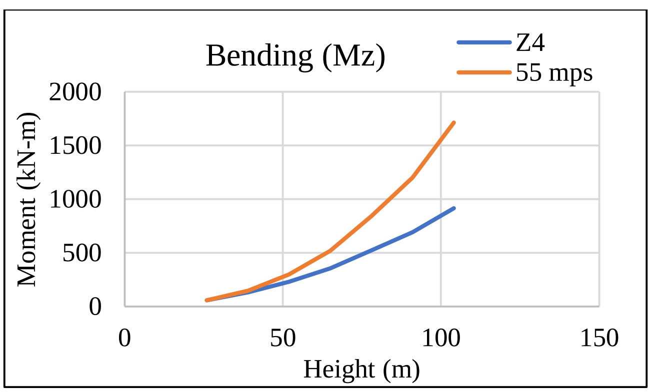

Fig. 4 Bending (earthquake zone iv with loose soil & 55 mps)

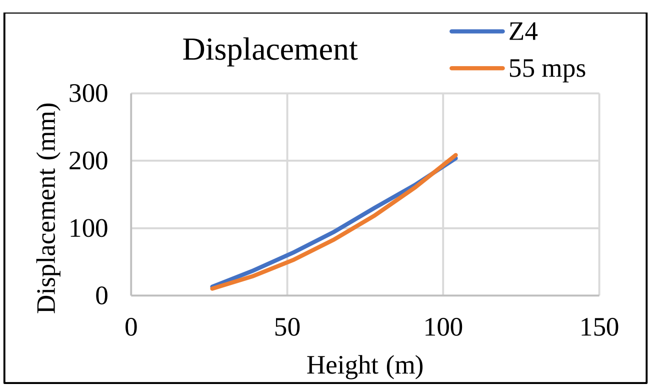

Fig. 5 Displacement (earthquake zone iv with loose soil & 55 mps)

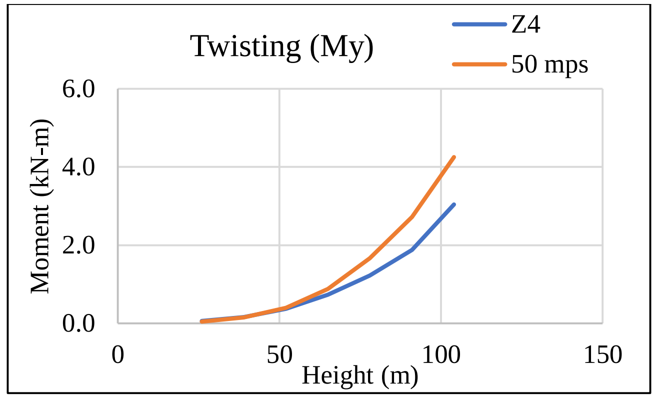

Fig. 6 Twisting (earthquake zone iv with loose soil & 50 mps)

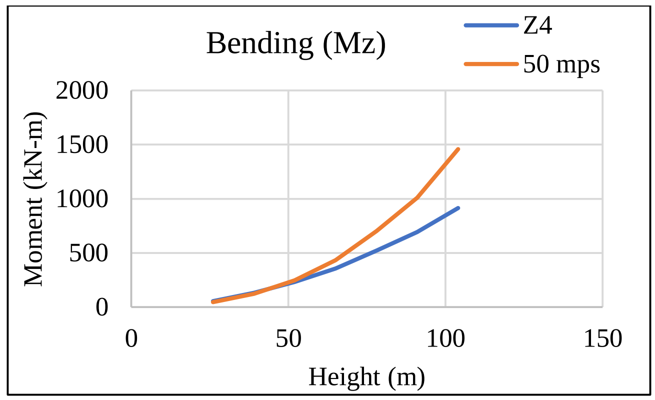

Fig. 7 Bending (earthquake zone iv with loose soil & 50 mps)

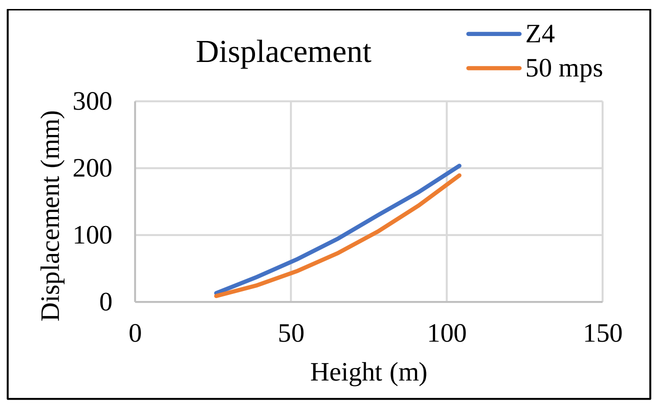

Fig. 8 Displacement (earthquake zone iv with loose soil & 50 mps)

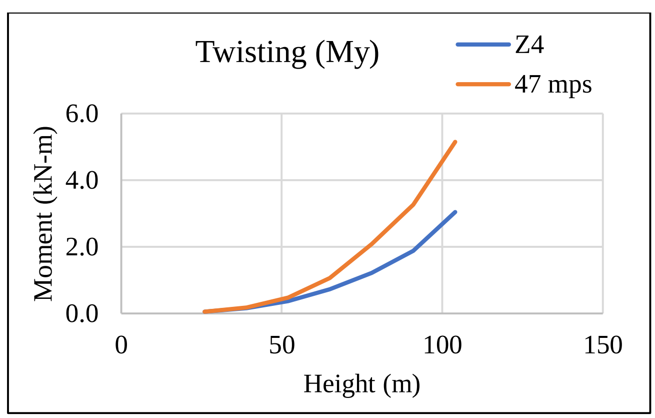

Fig. 9 Twisting (earthquake zone iv with loose soil & 47 mps)

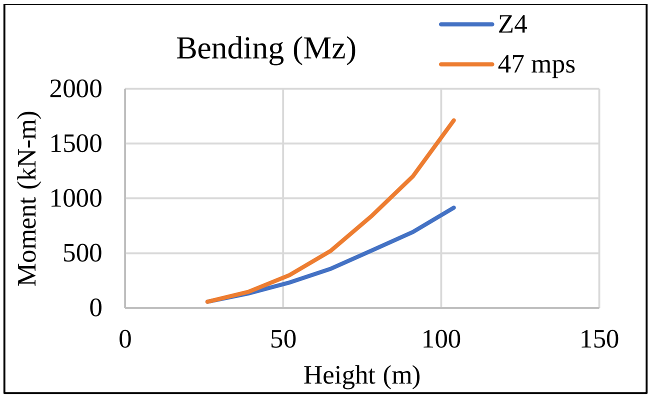

Fig. 10 Bending (earthquake zone iv with loose soil & 47 mps)

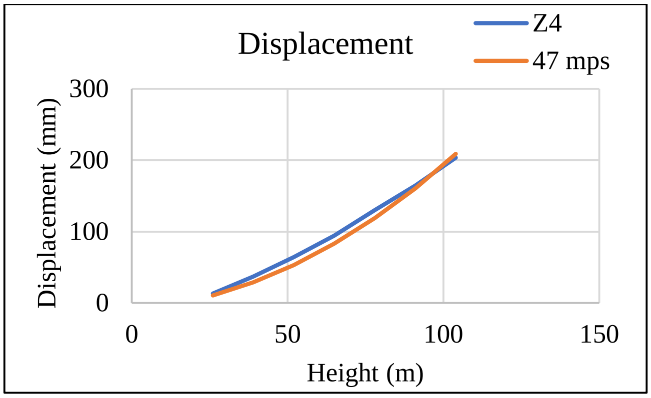

Fig. 11 Displacement (earthquake zone iv with loose soil & 47 mps)

The twisting and bending moment comparison between Earthquake Zone IV with loose soil and wind speeds of 55 m/s is shown in Figures 3 and 4**.** These figures reveal that the effect is similar for low building heights, but the wind force dominates for tall buildings, making wind resistance crucial in buildings taller than 39 meters.

Figure 5 makes it evident that, at 26 m height, the displacements are similar. However, for large height buildings, earthquake forces in Zone IV begin to dominate, and around 85 m, wind forces generated by the maximum wind speed become the governing force for top displacement of the building.

Figures 6 and 7 show that beyond 42 m, wind-induced bending and twisting moments exceed seismic moments, signaling a crucial shift in design focus from seismic to wind resistance at greater heights. Figure 8 declared that the top displacement due to the earthquake force in zone IV with loose soil is greater than the wind force generated by the wind speed of 50 m/s throughout the heights.

From Figures 9 and 10, a comparison of bending and twisting moments shows that, in Earthquake Zone IV with loose soil and wind force due to wind speed of 47 m/s, both forces have similar effects at 26 m height. However, for taller buildings, wind-induced moments grow more rapidly, and by 56 m, they drastically exceed seismic moments. This indicates that beyond 56m height, wind becomes the dominant factor in structural design, particularly for lateral and torsional stability.

From Figure 11, displacement due to earthquake forces in Zone IV dominates over wind forces at 47 m/s up to 98 m, after which the difference starts to decrease. For tall buildings, wind-induced effects such as lateral and torsional moments increasingly surpass seismic effects, especially in areas with high wind speeds.

Seismic forces are more significant in low-rise buildings due to their direct exposure to ground motion, while wind forces become dominant at greater heights. This shift calls for a change in design priorities from seismic to wind resistance for tall buildings.

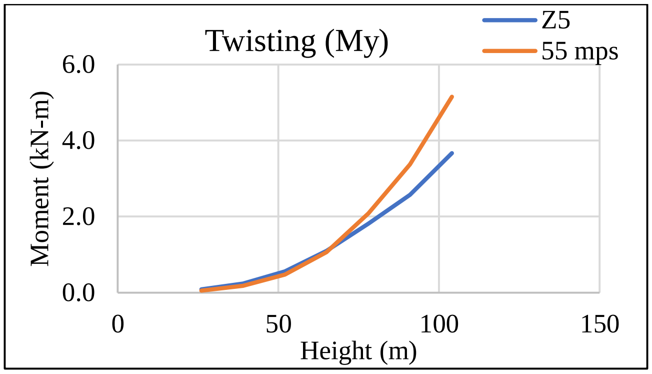

Fig. 12 Twisting (earthquake zone v with loose soil & 55 mps)

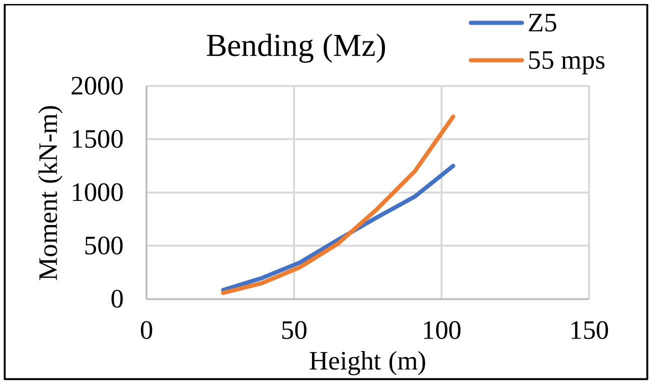

Fig. 13 Bending (earthquake zone v with loose soil & 55 mps)

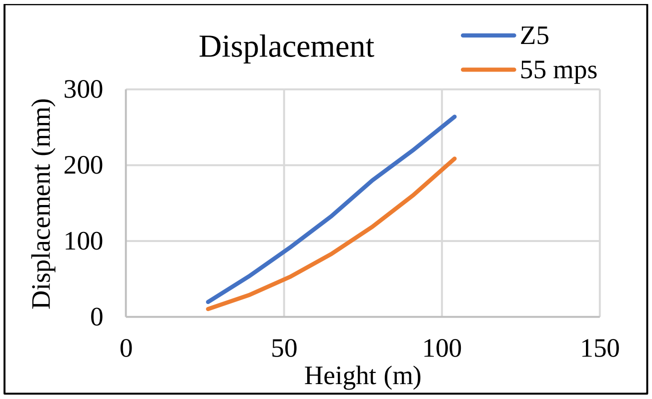

Fig. 14 Displacement (earthquake zone v with loose soil & 55 mps)

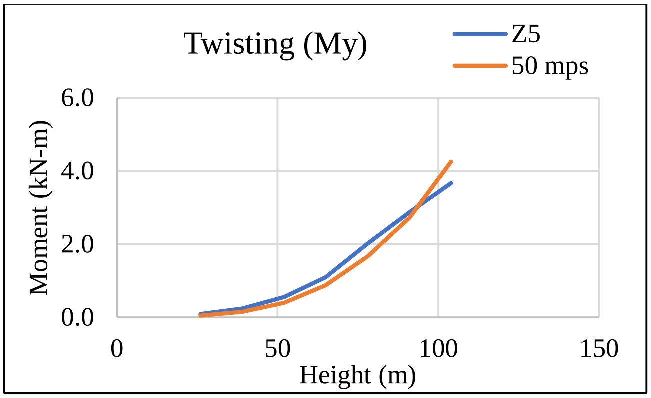

Fig. 15 Twisting (earthquake zone v with loose soil & 50 mps)

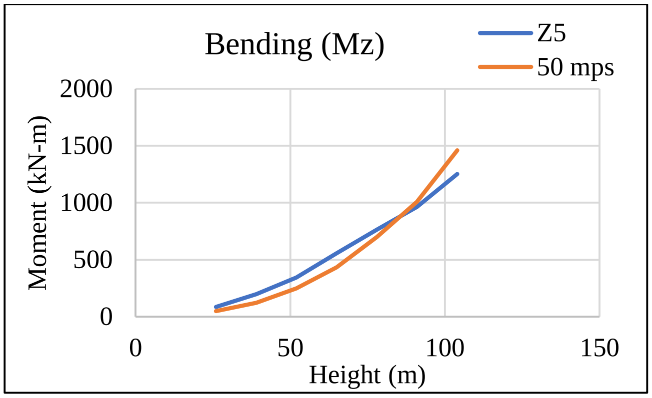

Fig. 16 Bending (earthquake zone v with loose soil & 50 mps)

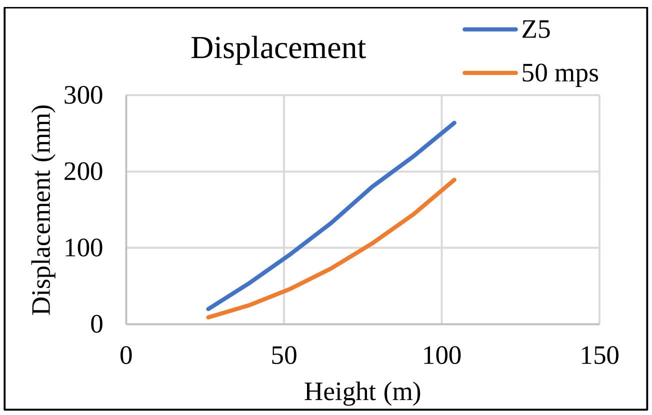

Fig. 17 Displacement (earthquake zone v with loose soil & 50 mps)

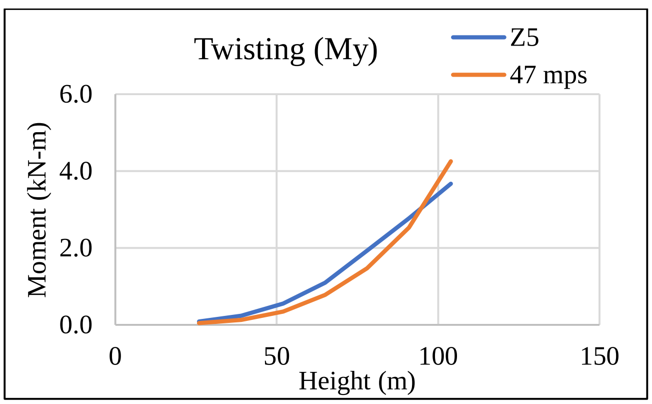

Fig. 18 Twisting (earthquake zone v with loose soil & 47 mps)

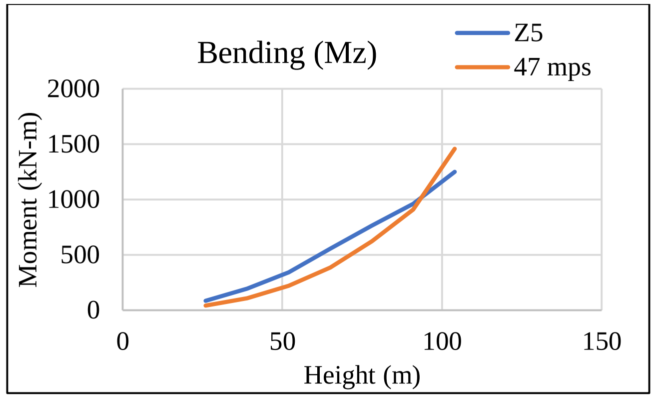

Fig. 19 Bending (earthquake zone v with loose soil & 47 mps)

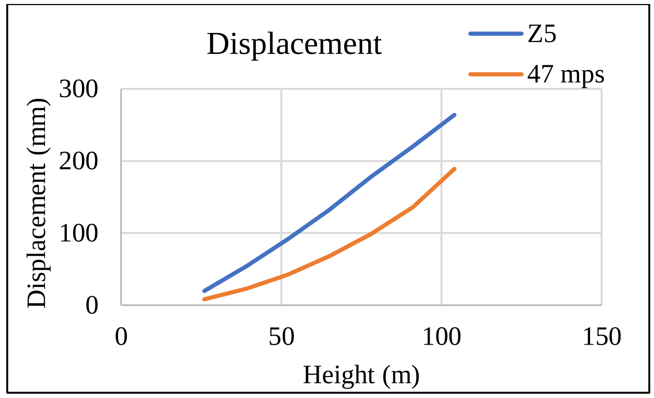

Fig. 20 Displacement (earthquake zone v with loose soil & 47 mps)

The twisting and bending moment comparison between earthquake Zone V with loose soil and wind speeds of 55 m/s indicates that, In Figure 12, this shift of torsional moment occurs between 60 m to 70 m, with wind pressure becoming more significant at 78m, 91 m and 104 m, this indicates that wind resistance becomes more critical than seismic resistance in tall buildings.

Similarly, in Figure 13, the shift in bending moment occurs between 60 m and 78 m, with seismic forces dominating below 65 m, and wind forces surpassing seismic moments in buildings taller than 65 m. Figure 14 shows that the earthquake-induced displacement consistently exceeds wind-induced displacement at all buildings. Figures 15 and 16 reveal that at a height of 26 meters, the difference between earthquake forces in Zone V with loose soil and wind forces caused by a wind speed of 50 m/s remains constant. However, as the greater height buildings, wind forces begin to dominate, particularly around an approximate building height of 78 m, where the moments developed due to wind forces become dominant. Figure 17 discloses that the displacement due to the earthquake force in zone V dominates the wind force.

Figures 18 and 19 declared that, at 26 m height, earthquake forces in Zone V dominate over wind forces with wind speed 47 m/s, as seismic loads depend on the building's mass and respond strongly at lower heights. However, as the height increases, wind-induced bending and twisting moments grow rapidly due to increased exposure area and greater moment arms. Around 91 m, both forces are nearly equal, and beyond this point, wind becomes the dominant force, making it the primary concern for designing tall buildings for lateral and torsional stability. Figure 20 shows that the displacement due to earthquake force in zone V is dominating with the wind force generated by wind speed 47 m/s. The difference also increases for tall buildings up to 91 m in height. Then, above 91m height, it starts decreasing.

3.3. Hard Soil Condition

The results obtained under hard soil conditions in Zones IV and V are compared for different wind speeds, 55, 50 and 47 m/s, as shown below.

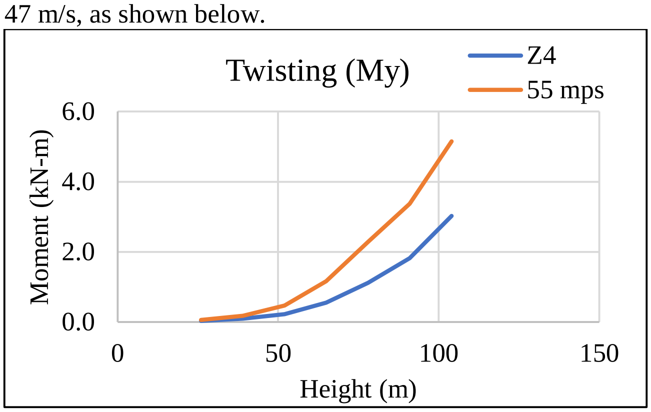

Fig. 21 Twisting (earthquake zone iv with hard soil & 55 mps)

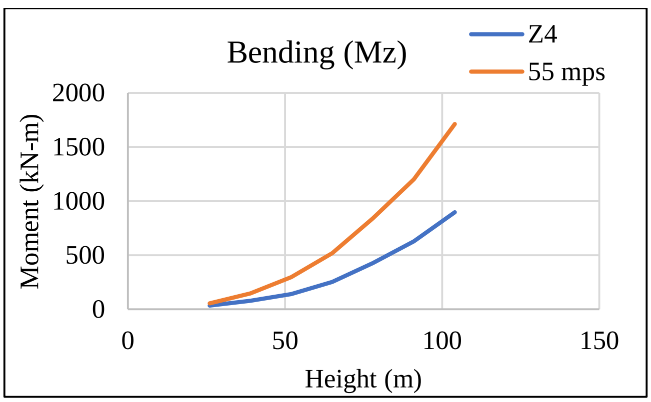

Fig. 22 Bending (earthquake zone iv with hard soil & 55 mps)

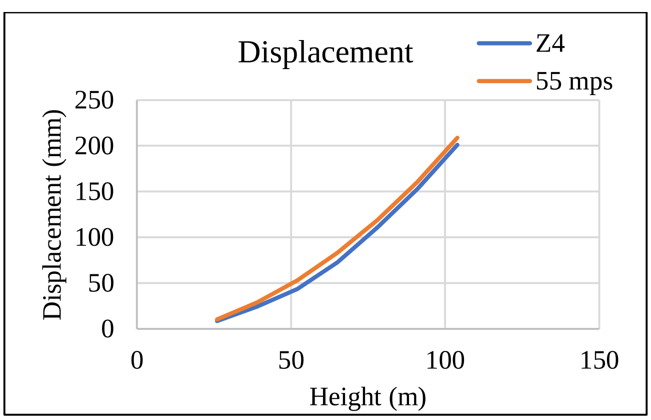

Fig. 23 Displacement (earthquake zone iv with hard soil & 55 mps)

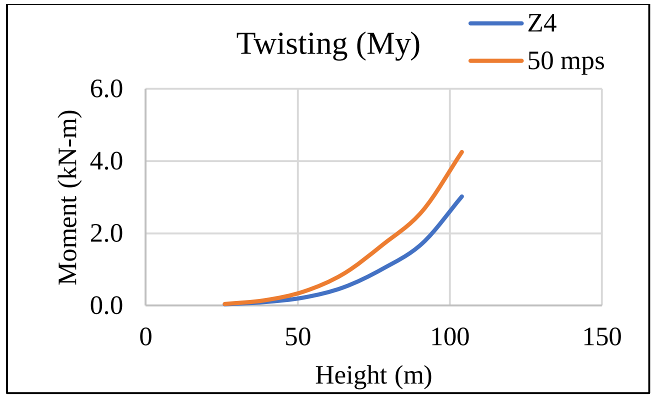

Fig. 24 Twisting (earthquake zone iv with hard soil & 50 mps)

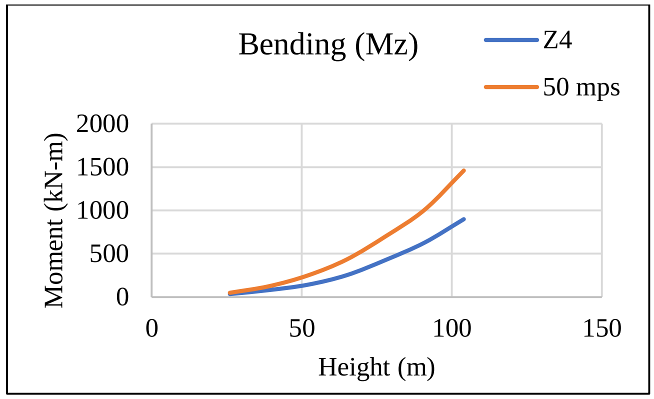

Fig. 25 Bending (earthquake zone iv with hard soil & 50 mps)

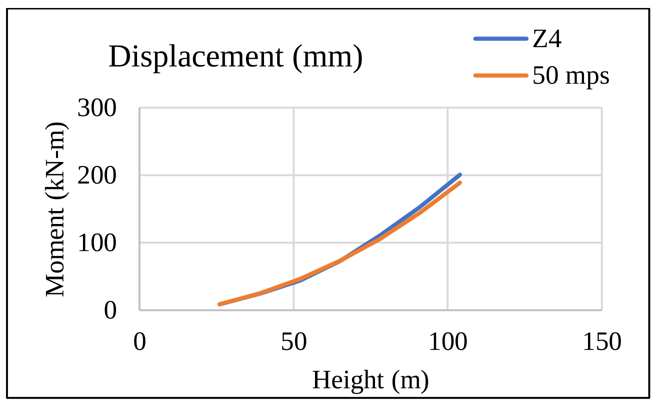

Fig. 26 Displacement (earthquake zone iv with hard soil & 50 mps)

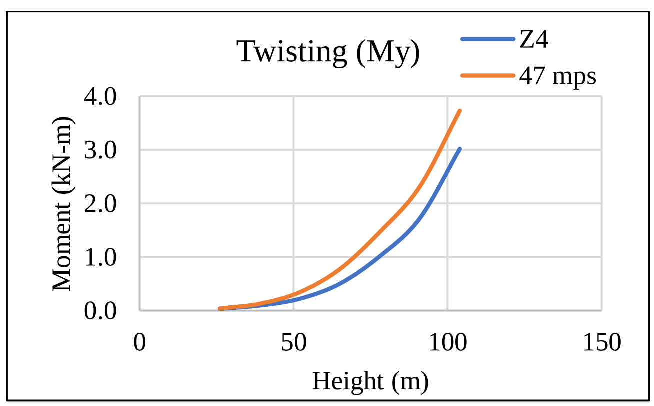

Fig. 27 Twisting (earthquake zone iv with hard soil & 47 mps)

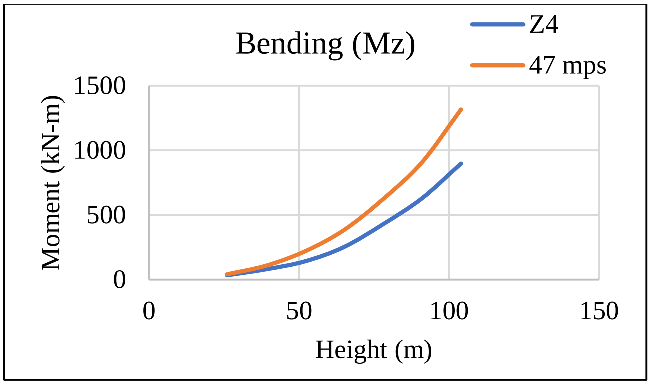

Fig. 28 Bending (earthquake zone iv with hard soil & 47 mps)

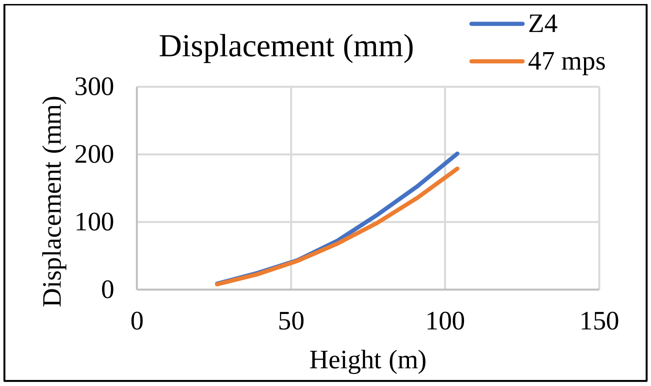

Fig. 29 Displacement (earthquake zone iv with hard soil & 47 mps)

The twisting and bending moment comparison between Earthquake Zone IV with hard soil and wind speeds of 55 m/s is shown in Figures 21 and 22. The wind force is dominant over the earthquake force for all building heights. At a 26 m height building, the effect is similar, but for tall buildings, the wind forces increase sharply. Figure 23 shows that the wind-induced displacement consistently exceeds the earthquake-induced displacement at all building heights.

Figures 24 and 25 show that the wind force is dominant over the earthquake force by comparing Earthquake Zone IV with hard soil and wind speeds of 50 m/s. Figure 26 declares that the displacement curves give almost similar results up to a height of 78 m; for buildings taller than 78 m, the earthquake force dominates.

Figures 27 and 28 declare that the wind force is dominant over the earthquake force. Figure 29 reveals that the displacement due to earthquake force in zone IV is dominating with wind forces generated by wind speed 47 m/s. The differences are increases for buildings of large height.

Seismic forces dominate in low-rise structures due to inertia effects, but in taller structures, wind-induced moments surpass seismic moments, shifting the design focus from seismic resistance to wind resistance. In hard soil conditions, wind dominance occurs at relatively low building heights.

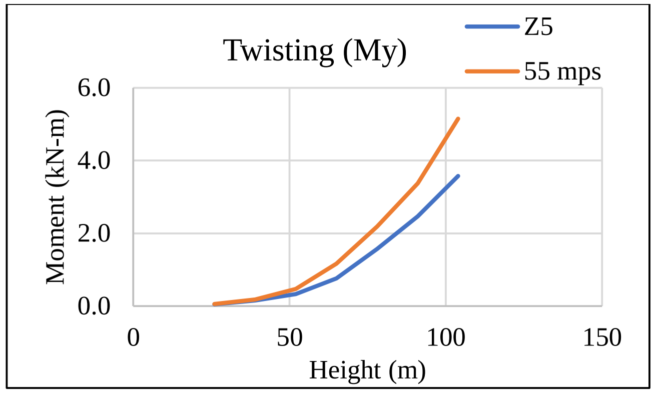

Fig. 30 Twisting (earthquake zone v with hard soil & 55 mps)

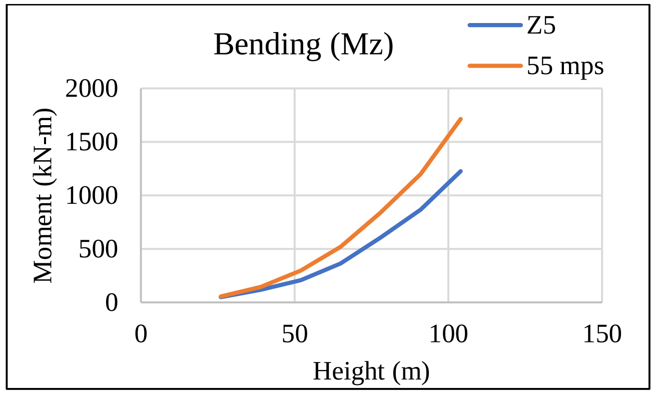

Fig. 31 Bending (earthquake zone v with hard soil & 55 mps)

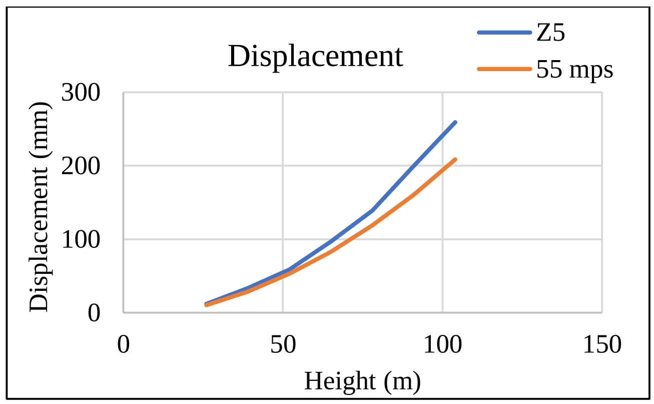

Fig. 32 Displacement (earthquake zone v with hard soil & 55 mps)

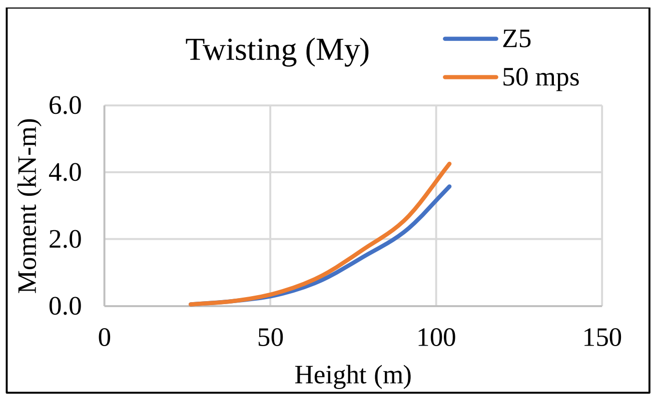

Fig. 33 Twisting (earthquake zone v with hard soil & 50 mps)

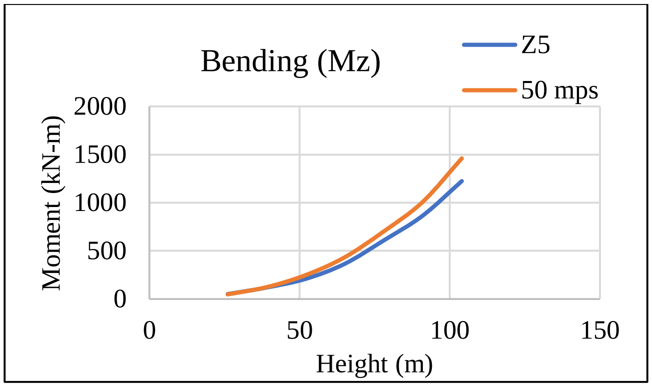

Fig. 34 Bending (earthquake zone v with hard soil & 50 mps)

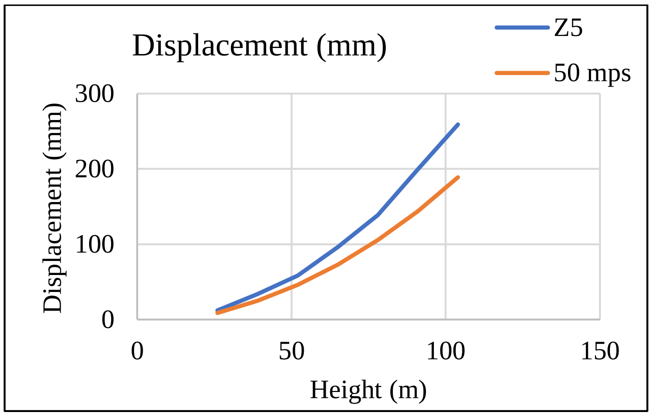

Fig. 35 Displacement (earthquake zone v with hard soil & 50 mps)

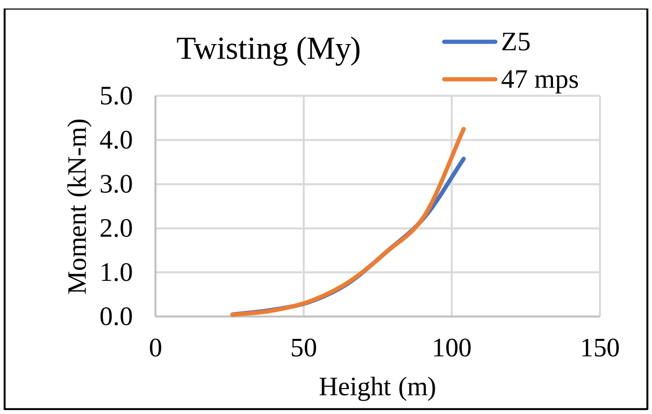

Fig. 36 Twisting (earthquake zone v with hard soil & 47 mps)

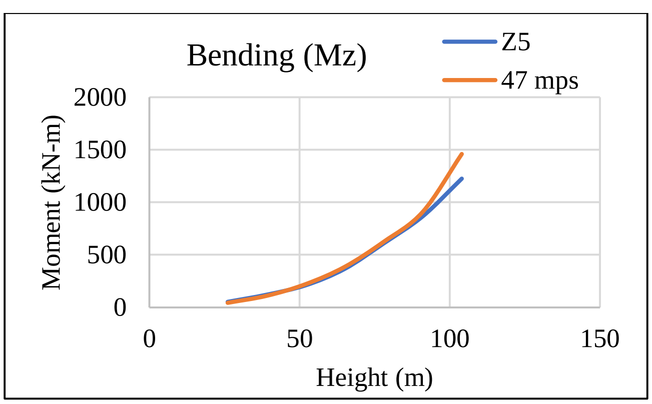

Fig. 37 Bending (earthquake zone v with hard soil & 47 mps)

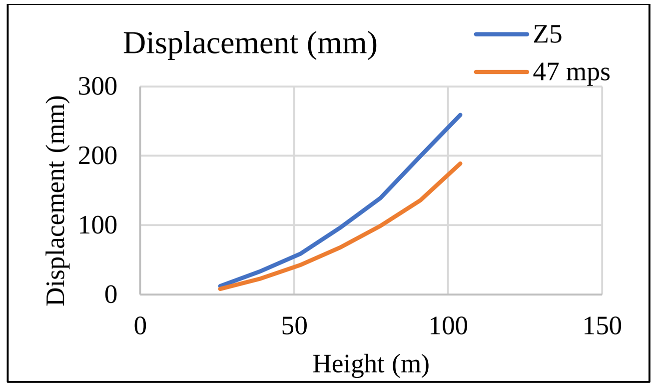

Fig. 38 Displacement (earthquake zone v with hard soil & 47 mps)

The twisting and bending moment comparison between earthquake Zone V with hard soil and wind speeds of 55 m/s is shown in Figures 30 and 31**;** the wind force is dominating for all building heights. Initially, at 26m height, the effect is similar. Figure 32 shows that the displacement due to earthquake force in zone V is dominating with the wind force generated by wind speed 55 m/s. The difference is more for tall buildings.

When compared with wind speeds of 50 m/s, Figures 33 and 34 show that the buildings are up to 39 meters in height, and the variations between twisting and bending behaviors remain relatively small. However, this difference increases for buildings taller than 39 meters, and wind forces increasingly govern the structural response. Figure 35 reveals that the displacement due to earthquake forces is dominating over wind forces.

At a wind speed of 47 m/s, Figures 36 and 37 show that for a building height of 26 meters, earthquake forces are more significant than wind forces. In taller buildings, wind forces begin to dominate around 44 meters and increase sharply beyond 91 meters in building height. Figure 38 declares that the displacement due to earthquake forces is dominating over wind forces for all buildings.

Compared to soft soil, structures founded on hard soil experience lower bending and twisting moments from seismic forces. Because of higher stiffness and reduced ground motion amplification. While seismic effects are less severe, as a result, wind forces become dominant at a lower height than in loose soil, requiring an earlier shift in design focus toward wind resistance. Seismic forces are more dominant at lower heights due to inertia effects because the building's mass near the base responds more strongly to ground acceleration, whereas wind forces become increasingly significant at high-rise buildings, prompting a shift in design focus from seismic to wind.

3.4. Seismic Zone Effect with Soil Conditions

A comparison between the two peak zones, Zone V and Zone IV, shows that Zone V with soft soil always causes the highest base shear, making it the most critical for earthquake design. In contrast, Zone IV with hard soil results in the lowest base shear and displacement, making it the safest condition for the same building.

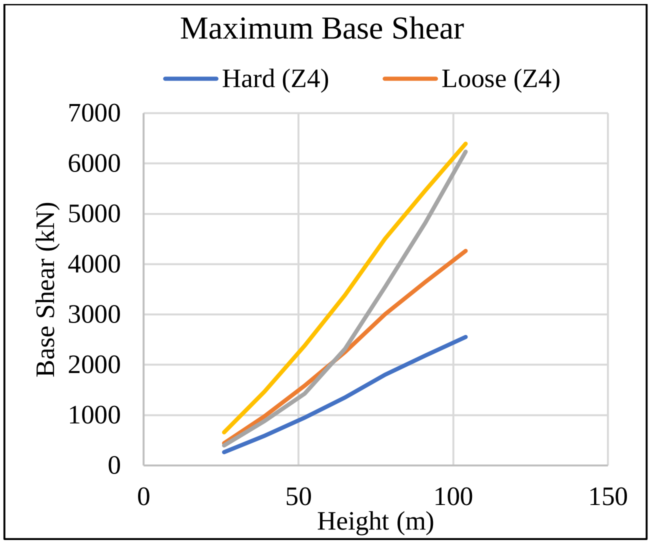

Fig. 39 Maximum base shear

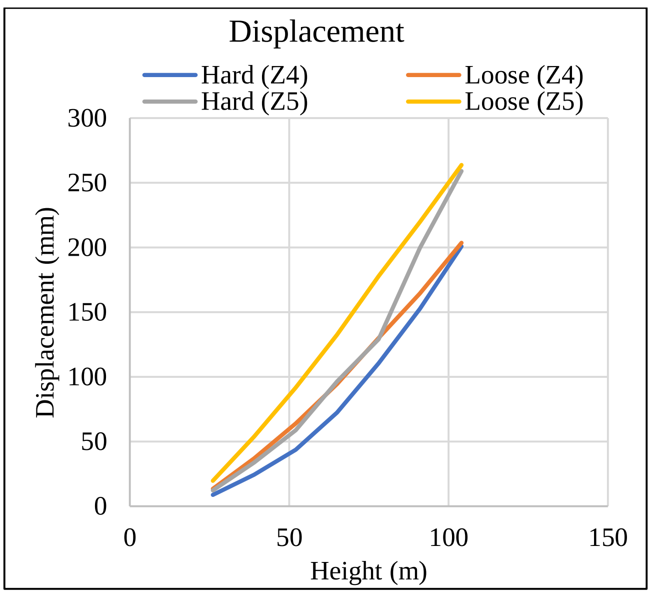

Fig. 40 Seismic displacement

Figure 39 shows that the effect of the earthquake in zone IV for loose soil is even more than the effect of the earthquake in zone V for hard soil due to the amplification of seismic waves in soft ground conditions. For the buildings with a height of more than 64m, the zone effect is dominant over the soil effect.

From Figure 40, it is clear that the effect of soil conditions on building displacement has a more significant impact on buildings with heights below 60 meters. The greatest variation occurs between 60 and 80 meters, while the effect becomes negligible above 100 meters.

4. Conclusion

In the present study, the static results of earthquake forces in zones IV and V for different soil conditions are compared with static wind forces for wind speeds of 55 m/s, 50 m/s and 47 m/s using STAAD Pro 2023. The following key conclusions have been drawn based on the comparative analysis.

- Under Loose soil in seismic zone IV, initially, the earthquake forces are slightly higher, but for tall buildings, the wind forces dominate for building heights more than 42m and 56m for wind speeds of 50 m/s and 47 m/s, respectively. The wind force for wind speed 55 m/s dominates for all building heights.
- Under loose soil in seismic zone V, initially, the earthquake forces are slightly higher, but for tall buildings, the wind forces dominate for building heights of 64m, 78m, and 92m for wind speeds of 55 m/s, 50 m/s, and 47 m/s, respectively.
- For hard soil conditions in seismic zone IV, the wind forces dominate over the earthquake forces at all heights of the building with wind speeds of 55 m/s, 50 m/s, and 47 m/s.
- For hard soil conditions in seismic zone V, initially, the earthquake forces are slightly higher, but for the large building heights, wind forces dominate at heights of 35m and 44m for wind speeds of 50 m/s and 47 m/s, respectively. Wind forces with a wind speed of 55 m/s dominate over the earthquake forces for all building heights.
- The displacement in soft soil in Zone IV is governed by earthquake forces at wind speeds of 50 m/s and 47 m/s, but for wind speed 55 m/s, wind forces dominate for buildings taller than 95 m. In Zone V, earthquake forces dominate at all building heights.
- The displacement in hard soil in Zone IV is governed by earthquake forces compared to wind speed 47 m/s, but with wind speed 50 m/s, wind forces dominate for buildings taller than 65 m, and with wind speed 55 m/s, wind forces dominate across all building heights.
- Soil conditions in earthquake zones IV and V are critical for buildings up to approximately 64 meters in height. The impact of earthquake forces due to soil conditions is more significant in zone IV with loose soil compared to zone V with hard soil. However, for buildings taller than 64 meters, the effect of the earthquake zone becomes more significant than the soil condition.

Acknowledgment

The author gratefully acknowledges the support and guidance provided by the Department of Civil Engineering, Rajasthan Technical University, Kota, for providing access to the licensed version of Bentley Systems software, which was essential for conducting this study.

References

[1] IS 875 (Part 3): 2015, "*Design Loads (Other than Earthquake) for Buildings and Structures - Code of Practice Part 3 Wind Loads*," Bureau of Indian Standards, 2015. [Google Scholar] [Publisher Link]

[2] IS 1893-1: (2002), "*Criteria for Earthquake Resistant Design of Structures*," Part 1 General Provisions and Buildings, Bureau of Indian Standards, pp. 1-45, 2002. [Google Scholar] [Publisher Link]

[3] IS 456: (2000), "*Plain and Reinforced Concrete - Code of Practice*," Bureau of Indian standards, pp. 1-114, 2000. [Google Scholar] [Publisher Link]

[4] Alfonso Vulcano, "Comparative Study of the Earthquake and Wind Dynamic Responses of Base-Isolated Buildings," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 74-76, pp. 751-764, 1998. [CrossRef] [Google Scholar] [Publisher Link]

[5] T. Balendra, C.H Yu, and F.L. Lee, "An Economical Structural System for Wind and Earthquake Loads," *Engineering Structures*, vol. 23, no. 5, pp. 491-501, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[6] Khaled Mohamed Heiza, and Magdy A. Tayel, "Comparative Study of The Effects of Wind and Earthquake Loads on High-Rise Buildings," *Challenge Journal of Concrete Research Letters*, vol. 3, no. 1, pp. 386-405, 2012. [Google Scholar] [Publisher Link]

[7] S.Mahesh, and B.Panduranga Rao, "Comparison of Analysis and Design of Regular and Irregular Configuration of Multi Story building in Various Seismic Zones and Various Types of Soils using ETABS and STAAD," *IOSR Journal of Mechanical and Civil Engineering*, vol. 11. no. 6, pp. 45-52, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] Anirudh Gottala et al., "Comparative Study of Static and Dynamic Seismic Analysis of a Multistoried Building," *International Journal of Science Technology & Engineering*, vol. 2, no. 1, pp. 173-183, 2015. [Google Scholar] [Publisher Link]

[9] Mahmud Sazzad, and Samdani Azad, "Effect of Building Shape on the Response to Wind and Earthquake," *International Journal of Advanced Structures and Geotechnical Engineering*, vol. 4, no. 4, pp. 232-236, 2015. [Google Scholar] [Publisher Link]

[10] Gauri G. Kakpure, and Ashok R. Mundhada, "Comparative Study of Static and Dynamic Seismic Analysis of Multistoried RCC Building by ETAB: A Review," *International Journal of Emerging Research in Management &Technology*, vol. 5, no. 12, pp. 16-20, 2016. [Google Scholar] [Publisher Link]

[11] Chenyang Yuan et al., "Fragility Analysis of Large-Scale Wind Turbines Under the Combination of Seismic and Aerodynamic Loads," *Renewable Energy*, vol. 113, pp. 1122-1134, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[12] Rabi Akhtar, Shree Prakash, and Mirza Aamir Baig, "Study of Comparison between Static and Dynamic Analysis Subjected to Wind and Earthquake Load," *International Research Journal of Engineering and Technology*, vol. 4, no. 7, pp. 3009-3014, 2017. [Google Scholar] [Publisher Link]

[13] Zheng Lu, Kun Li, and Ying Zhou, "Comparative Studies on Structures with a Tuned Mass Damper and a Particle Damper," *Journal of Aerospace Engineering*, vol. 31, no. 6, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Raffaele De Risi, Subhamoy Bhattacharya, and Katsuichiro Goda, "Seismic Performance Assessment of Monopile-Supported Offshore Wind Turbines Using Unscaled Natural Earthquake Records," *Soil Dynamics and Earthquake Engineering*, vol. 109, pp. 154-172, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Piguang Wang et al., "Wind, Wave and Earthquake Responses of Offshore Wind Turbine on Monopile Foundation in Clay," *Soil Dynamics and Earthquake Engineering*, vol. 113, pp. 47-57, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[16] Ghanbari Hamid et al., "Performance Assessment of Different Tabular Systems for Tall Buildings Against Dynamic Wind and Earthquake Effects," *8th Internal Conference on Seismology & Earthquake Engineering*, Tehran, Iran, pp. 1-2, 2019. [Google Scholar]

[17] Yang Yang et al., "Analysis of Seismic Behaviour of an Offshore Wind Turbine with a Flexible Foundation," *Ocean Engineering*, vol. 178, pp. 215-228, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] Xiao-Wei Zheng et al., "Damage Risk Assessment of a High-Rise Building Against Multihazard of Earthquake and Strong Wind with Recorded Data," *Engineering Structures*, vol. 200, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[19] Wei Jing, Huan Feng, and Xuansheng Cheng, "Dynamic Responses of Liquid Storage Tanks Caused by Wind and Earthquake in Special Environment," *Applied sciences*, vol. 9, no. 11, pp. 1-16, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ruifu Zhang, Zhipeng Zhao, and Kaoshan Dai, "Seismic Response Mitigation of a Wind Turbine Tower Using a Tuned Parallel Inerter Mass System," *Engineering Structures*, vol. 180, pp. 29-39, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[21] Zhi Zhao et al., "Studies on Application of Scissor-Jack Braced Viscous Damper System in Wind Turbines Under Seismic and Wind Loads," *Engineering Structures*, vol. 196, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[22] Swagato Biswas Ankon, "A Comparative Study of Behavior of Multi-Storied Regular and Irregular Buildings under Static and Dynamic Loading," *Open Journal of Civil Engineering*, vol. 10, no. 4, pp. 337-352, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Pourya Kazemi Esfeh, and Amir M. Kaynia, "Earthquake Response of Monopiles and Caissons for Offshore Wind Turbines Founded in Liquefiable Soil," *Soil Dynamics and Earthquake Engineering*, vol. 136, pp. 1-22, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[24] Zijun Wang, Pedro Martinez-Vazquez, and Boming Zhao, "Pushover Analysis of Structures Subjected to Combined Actions of Earthquake and Wind," *Engineering structures*, vol. 221, pp. 1-25, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[25] Hussin Ahmad Hasrat, "Comparative Study of Various High Rise Building Lateral Load Resisting Systems for Seismic Load & Wind Load: A Review," *International Research Journal of Engineering and Technology*, vol. 8, no. 1, pp. 291-297, 2021. [Google Scholar] [Publisher Link]

[26] Maha Al-Soudani, Hesham Aamer Najim Abbas, and Hesham A. Numan, "Assessment of Reinforced Concrete Structures Under Wind and Earthquake Using Different Design Methods," *Journal of Engineering Research*, vol. 11, no. 1B, pp.1-13, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[27] Huaxiao Wu et al., "Comparison of Dynamic Responses of Parallel-Placed Adjacent High-Rise Buildings under Wind and Earthquake Excitations," *Shock and Vibration*, vol. 2021, pp. 1-14, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[28] Shinyoung Kwag et al., "Significance of Multi-Hazard risk in Design of Buildings Under Earthquake and Wind Loads," *Engineering Structures*, vol. 243, pp. 1-14, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[29] Hao Zhu, Deyu Li, and Jun Xu, "Dynamic Analysis and Optimization of a Wind Turbine Tower Subject to Wind and Earthquake Loads," *The Structural Design of Tall and Special Buildings*, vol. 31, no. 15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[30] Praful P. Gujjewar, S.S. Rathore, and Aasif M. Baig, "Static and Dynamic Analysis of Transmission Tower to Wind and Seismic Loads," vol. 4, no. 6, pp. 3925-3933, 2022. [Google Scholar] [Publisher Link]

[31] Wisam S. Abdulateef, and Farzad Hejazi, "Fuzzy Logic Based Adaptive Vibration Control System for Structures Subjected to Seismic and Wind Loads," *Structures*, vol. 55, pp. 1507-1531, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[32] Hong Lin et al., "Hong LinA CFD-FEA Coupled Model for Simulating Dynamic Response of Offshore Jacket Platform Under Earthquake Considering Wind, Wave, Current and Aftershock Loads," *Ocean Engineering*, vol. 300, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[33] Piguang Wang et al., "Effects of Wind-Wave-Current-Earthquake Interaction on the Wave Height and Hydrodynamic Pressure Based on CFD Method," *Ocean Engineering*, vol. 305, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[34] Lilin Wang, and Takeshi Ishihara, "Failure-Mechanism for Wind Turbines Supported by Pile Groups at the Kugino Wind Farm in the Kumamoto Earthquake," *Structures*, vol. 69, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[35] Takeshi Ishihara, Yoshihisa Iida, and Lilin Wang, "Numerical Study of Combined Seismic and Aerodynamic Loads on Wind Turbine Support Structures by Coupled and Uncoupled Approaches," *Structures*, vol. 60, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]