

The Effect of Water Tank Load Position on the Seismic Response of Pile-Supported Concrete High-Rise Buildings

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ABSTRACT

Analyzing the seismic response of multi-story buildings in detail has gained increasing attention, with the main issue being whether and how to account for the Soil-Structure Interaction (SSI) effect during this analysis. In this study, a numerical investigation was conducted to examine how the different positions of water tank loading affect a 15-story reinforced concrete building on a piled foundation. Three different water tank load distributions were applied at various locations on the building. For the seismic analysis, the ground acceleration caused by the James RD El Centro earthquake (1979), with a Peak Ground Acceleration (PGA) of 0.5502 g, was used as a representative dynamic load. It was found that the presence of the distributed load on the top floor increased the induced acceleration compared to the first floor. That is, the maximum acceleration on the top floor rose from 40.32% when the load covered only a quarter of the floor area to 41.62% when the load extended across the entire floor. A slight increase of about 12.5% and 22.2% was observed when the load distribution area grew from a quarter to half and a full floor area, respectively. The maximum column load showed a limited increase when the water load was partially or fully distributed on the top floor, while the maximum shear force and bending moment were only slightly affected.

Keywords- multistory building; finite elements; earthquake; distributed load

I. INTRODUCTION

Most civil structures have components that are directly connected to the ground, making them susceptible to external forces like seismic loading. In such cases, the movement of the structure and the ground are interdependent. This interaction is

referred to as SSI, which describes the relationship between the soil and structural responses during dynamic events. One of the key challenges in structural engineering is to accurately assess the inelastic dynamic behavior of multistory buildings under seismic loads, a topic that has been widely studied. Although

Three-Dimensional Finite Element Models (3D FEMs) are proposed for simulating these nonlinear dynamic responses with high accuracy, they are computationally intensive and require advanced expertise. As a result, it becomes difficult to perform comprehensive seismic vulnerability assessments across large seismically active regions using such complex models. Therefore, there is a need for simplified, less computationally demanding methods that can still provide reliable and accurate assessments on a larger scale [1].

An earthquake can damage buildings in different ways, resulting in building collapse and even fatalities. One method used to reduce the structural reaction is the development of damping systems for buildings, which gradually lowers the system's energy until all vibrations are eliminated, and the system is brought to rest. Although several methods are available, passive control systems are more cost-effective [2, 3]. SSI is a critical factor in seismic design and assessment of multistory buildings. While it can offer beneficial effects, such as period lengthening and added damping, it also introduces challenges, including increased displacements and design complexity. Engineers must evaluate the SSI effects, especially for buildings on soft soils, to ensure safety, serviceability, and compliance with the modern performance-based seismic design standards. Studying the effects of SSI on different types of structural systems is crucial for fully comprehending their seismic response. The response of a structure-soil system to seismic loading depends on several factors, such as the geometry of the superstructure, natural period, soil modulus, foundation type and depth, input motion, and shear wave velocity [4]. During seismic events, the inertial forces of the superstructure can lead to increased soil deformation and internal forces at the top of the foundation, thereby further modifying the input motion of the foundation [5, 6]. Furthermore, the influence of the inertial interaction is more noticeable for heavy structures [7]. Additionally, the characteristics of the supported structure could potentially affect the impact of SSI. The reaction of a multistory building to the intense seismic activity is contingent upon the way in which the structure's weight, stiffness, and strength are distributed in both the horizontal and vertical directions. The design of structures with homogeneous dispersions has gained the confidence of structural engineers. A regular structure is thought to sustain far less damage than an irregular building because it has a uniformly distributed mass and stiffness in both the plan and elevation. Structural irregularities are commonly observed because of several factors, such as architectural and service requirements during the design phase, errors and adjustments made during the development stage, and alterations in building use over time. Because of the uneven distribution of masses, stiffness, and strength caused by these structural designs, the structures are more vulnerable to earthquake damage [8].

Authors in [9] developed a model for assessing the building behavior by combining a shear beam with a parabolic stiffness variation and a Bernoulli beam with quartic stiffness variation trends, as expected for structures designed for earthquake actions. Following the solution of the partial differential equation of motion which regulates the model's behavior, analytical equations (closed-form solutions) for the mode

shapes were obtained in terms of Legendre functions. The implications of the non-uniformity of stiffness were evaluated in a generalized manner, and these closed-form solutions were verified through analyses using finite element models. Period lengthening was shown to be minor for the first mode but can be much more noticeable for higher modes if the shear stiffness at the top of the beam is less than 20% of its base value. Additionally, mode shapes are known to be altered for reductions that go beyond the same limit, which may result in significant floor acceleration needs in unexpected places. Authors in [10] observed that, despite the potential increases in damping, SSI tends to amplify the seismic response of structures during earthquakes. They highlighted that buildings with 10 to 12 stories constructed on soft clay experienced a significant increase in the vibration period from approximately 1 sec to nearly 2 sec due to the SSI effects. Numerous researchers have investigated how SSI impacts a building's seismic performance [11–13]. For the design objectives, authors in [14] used numerical modeling of high-rise buildings, which reduced the stiffness and full stiffness for vertical element-strength analysis and serviceability-drift analysis, respectively. An investigation was conducted utilizing the elastic response spectrum and nonlinear time-history analysis approaches on a high-rise building with vertical imperfections using a 3-D numerical model. The impact of the transfer floors on the internal forces created by the seismic drift and the drift of the buildings was investigated, with a close examination of the decision to adopt full or decreased stiffness for the vertical elements. Authors in [2] used SAP2000 to determine the optimal location for water tanks that would lower the peak response of the structure subjected to seismic pressures and to assess the viability of utilizing several water tanks as passive Multiple-Tuned Liquid Dampers. A fifteen-story concrete building with five water tanks located in three distinct locations was considered. Many scenarios were used to investigate the depth ratio parameter, such as $\frac{1}{4}$ tanks for all tanks, $\frac{1}{2}$ tanks for all tanks, and $\frac{3}{4}$ tanks for all tanks. The findings indicate that when considering different water tank locations and water levels, Position 2, which is filled with $\frac{3}{4}$ water, has the most significant reduction in structural displacement, measuring 12.6 mm. Torsional flexible buildings are frequently more susceptible to eccentricities of mass and stiffness and the magnitude of an earthquake's torsional component. An increase in these parameters leads to an increase in displacement and force. For various amounts of mass eccentricity, the building performance level under a design-basis earthquake (475-year return period) was established in [15]. The results demonstrated that the asymmetric mass distribution in the plan accounts for the strong seismic reliability of the analyzed system under torsions. Even when moving the center of mass up to 20% of the plan, all models maintained the immediate occupancy performance level in the structures under study. There was also no decline in the building Design Basis Earthquake (DBE) performance level. Authors in [16, 17] employed a shaking table system to conduct dynamic tests aimed at investigating the Soil-Structure-Soil Interaction (SSSI). The study focused on evaluating the dynamic behavior of two adjacent steel structures supported on sandy soil. Four newly designed small-scale, multi-degree-of-freedom steel models were used, representing three-, four- and five-story structures placed next

to a three-story structure. The results showed that the taller buildings had a significant impact on the shorter one, particularly in terms of the top displacement (up to 3.82 mm), top acceleration (around 0.2 g), and foundation rotation (approximately 1°). The effects of the dead loads on the seismic response were found to be mixed, producing both beneficial and adverse outcomes. However, increasing the embedment level of the structures consistently reduced the influence of the earthquake waves on their seismic behavior.

Authors in [1] developed an equivalent non-uniform inelastic beam-like model to evaluate the nonlinear behavior of multi-story buildings subjected to seismic loadings. The proposed beam can be employed to model structures with non-uniform mass and stiffness distributions. The model was designed to anticipate a building's nonlinear dynamic response following a thorough calibration based on the results of the pushover analysis performed on a nonlinear FEM model. The number of degrees of freedom corresponds to the number of floors in the building. The proposed inelastic equivalent beam-like model was validated and demonstrated a good agreement with the results obtained through accurate 3D FEM frame modeling on the benchmarks under consideration for varying earthquake loadings. This model could find applications in the seismic assessment of building structures. For all seismic vulnerability approaches that require multiple nonlinear dynamic analyses, such as those related to large-scale applications or those expressed in terms of the probability of failure, typically represented by fragility curves, the low computational cost of the beam-like model can be particularly advantageous. However, the main goal of this study is to examine how the location and distribution of loads affect the response of the multistory buildings during earthquakes. According to [18, 19], the placement and distribution of tank loads significantly impact a building's seismic performance. Tanks placed on rooftops or at higher levels increase the mass and height of a building's center of gravity, which raises the seismic stresses and the likelihood of resonance with ground motion frequencies. Therefore, this study aims to analyze how the load placement and distribution influence the seismic response of multistory buildings. These findings emphasize the importance of strategically distributing and positioning the tank loads to reduce the adverse seismic reactions and enhance structural resilience.

II. CASE STUDY

This study examined the effect of water tank loading on the seismic response of a 15-story reinforced concrete building supported by a piled foundation, utilizing numerical modeling. The building footprint measures 40 m \times 36 m, with five bays spaced 8 m apart in one direction and six bays in the other direction. The latter included three bays on each side, divided by a 12 m courtyard. Each story has a height of 4 m. The self-weight of the structure and a typical floor load of 2 kN/m² were considered as the gravity dead loads. Given that the building is designated for office use, the live load was specified as 4 kN/m². Figure 1 illustrates the building's dimensions along with the distribution of the dead and live loads, whereas Table I details the structural material properties.

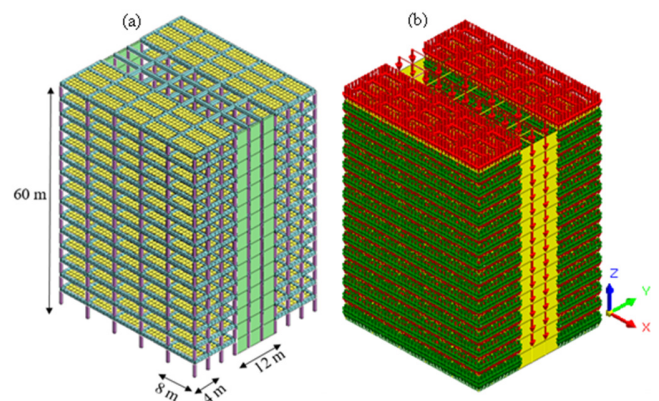


Fig. 1. 3D plan of 15-story building: (a) building dimensions, (b) dead and live loads distribution.

Additionally, the building is supported by a rectangular pile cap foundation with dimensions of 41 m \times 37 m and a depth of 1.40 m. This pile cap rests on piles with a diameter of 0.60 m and a length of 30 m. Figure 2 depicts the typical dimensions of the piled foundation, and the structural characteristics of both the pile and pile cap foundations are summarized in Table I.

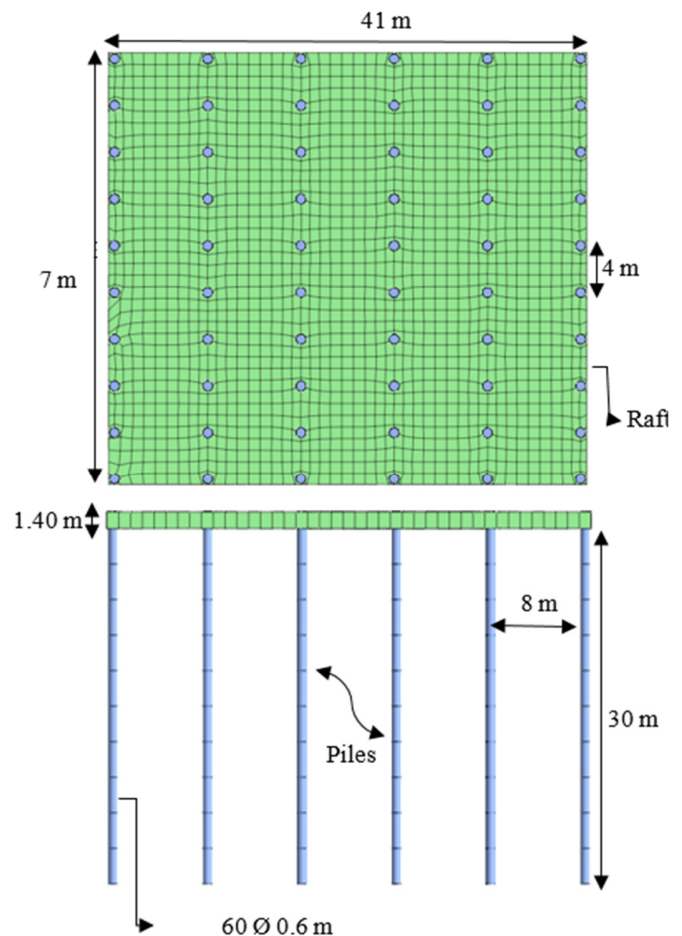


Fig. 2. The dimensions of the piled foundation (elevation and plan).

TABLE I. STRUCTURAL MATERIAL PROPERTIES

Member	Beam	Column	Slab	Pile cap	Pile
Cross section (mm)	400×700	500×700	200	410×370	600
Member density γ , (kN/m ³)	23.5				
Elastic modulus E, (kN/m ²)	26.7×10 ⁶				
Poisson's ratio ν ,	0.20				
Compressive strength f_c , MPa	56				

III. NUMERICAL MODELING

A. Finite Element Method

In this research, a numerical study was conducted using the Midas GTS-NX program to investigate the effects of different positions of water tank loadings on multistory buildings resting on piled foundations subjected to seismic impact. To minimize the impact of the reflexive wave, the foundation's distance from the vertical border should be two to three times the foundation radius, and the distance from the soil's horizontal limit should be three to four times the base radius [20]. Additionally, most seismic activity occurs within the first 30 m of the soil profile [21]. Increasing the soil boundary from five to ten times the structure's width causes a 5% difference in the results. The soil dimensions were extended to 160 m, 160 m, and 80 m in the X, Y, and Z directions, respectively. Since a larger mesh size did not affect the analysis results, these dimensions were sufficiently large to reduce the boundary effects in the numerical model. The total number of nodes and elements used in the analysis were 24213 and 32696, respectively. Furthermore, the lateral boundary conditions were modeled as free-field elements to minimize the wave reflection, while the soil bottom was assumed to be a fixed end. Figure 3 presents the perspective view of the numerical model. For larger values of the depth-to-diameter ratio and a group of four piles with large spacing ($s/d = 5$), the problem dimensions of the current study fully satisfy the influence zone identified from the theory of elasticity utilized in [22] and fall within the influence zone found in [23, 24].

B. Constitutive Models and Loading Applied

A crucial element in determining the performance and accuracy of the numerical simulation employed in soil dynamics is the constitutive model of soil [25, 26]. In this study, the Mohr-Coulomb model was used to simulate the soil nonlinearity. This model is considered a linear elastic-perfect plastic model and is commonly used in finite element analyses because of its simplicity and accuracy [27-31]. The piles and the pile cap foundation were simulated using a linear elastic model. The required parameters for the piled foundation and soil are listed in Tables I and II, respectively.

The current study investigates three different distributions of water tank loading applied at two distinct positions in the building, as depicted in Figure 4. Figures 4(a-c) represent the full, half, and quarter uniformly distributed loads applied on the last floor, respectively. Similarly, Figures 4(d-f) depict the same distribution patterns applied on the first floor. In all cases, the magnitude of the applied load is 10 kN/m².

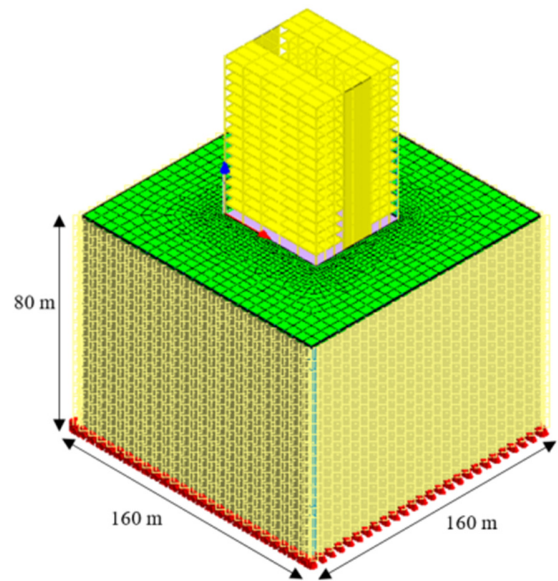


Fig. 3. 3D FEM.

TABLE II. SOIL PROPERTIES

Parameters	Sandy soil layer
Unit density γ , (kN/m ³)	20
Modulus of elasticity E, (kN/m ²)	70000
Poisson's ratio ν ,	0.3
Friction angle [°]	36
Dilation angle [°]	6

C. Design Earthquake

In structural and seismic engineering, selecting an appropriate earthquake design is essential for accurate analysis and ensuring the structural safety during seismic events. This selection defines the seismic parameters a structure must withstand, based on factors, such as the geographic location, building function, and associated risk. Design earthquakes are typically characterized by a return period, which reflects the probability of occurrence within the structure's lifespan. Longer return periods correspond to rarer but more severe events. Critical structures (e.g., hospitals and bridges) often require more conservative seismic criteria than standard buildings, as reflected in the building codes that assign higher performance requirements to essential or high-occupancy structures. In this study, seismic analysis was performed using the ground acceleration record from the 1979 James RD El Centro earthquake, which has a PGA of 0.5502 g and is available in the Midas GTS-NX library. The analysis was conducted using nonlinear time-history simulation, incorporating material nonlinearity and implicit time integration. A damping ratio of 0.05 was adopted, with damping applied by aligning the dominant vibration modes with the highest mass participation. Static loads were converted into equivalent masses for eigenvalue analysis, as both the stiffness and mass influence the dynamic behavior.

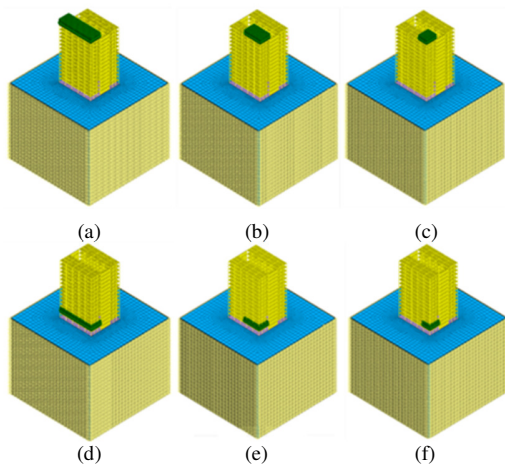


Fig. 4. Water tank load positions.

beam (building). The position of a Uniformly Distributed Load (UDL), such as water tank loading, affects the earthquake response of a multistory building by altering the distribution of the mass and stiffness across the floors, which in turn influences the behavior of the building under seismic forces. When a UDL is positioned at a higher floor, the additional mass increases the inertial forces at that level. Earthquake-induced accelerations generate greater forces at the upper stories, amplifying the lateral demands on these floors. The mass distribution directly affects the fundamental natural frequency and mode shape of the building. Concentrating UDLs on the upper stories generally lower the building's natural frequency, making it more susceptible to long-period seismic waves. Buildings with non-uniform mass distributions (e.g., owing to varying UDL positions across floors), and particularly taller buildings, can exhibit more pronounced higher-mode responses. This can lead to complex deformation patterns and stress concentrations, specifically at the mass change points.

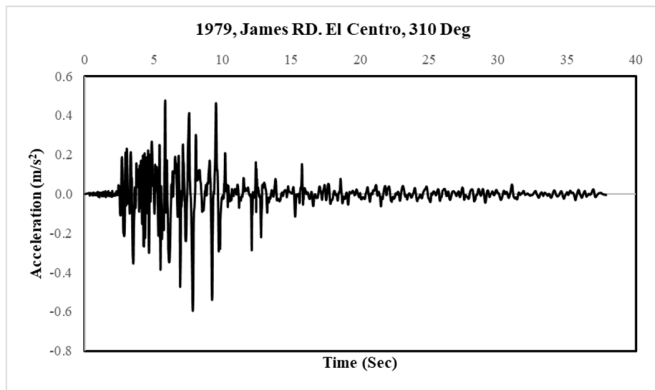


Fig. 5. Acceleration time history of the earthquake used in the analysis.

IV. RESULTS AND DISCUSSION

A 3D modeling analysis was conducted to evaluate the seismic response of high-rise buildings supported by piled foundations under varying positions and distributions of applied loads. The structural responses were measured at three key locations: the top floor (Node 1), the first floor (Node 2), and the ground level at the base of the foundation (Node 3).

A. Effect of Different Positions of Water Tank Loadings on the Last Floor

1) Acceleration

Figure 6 presents the acceleration-time history of Node 1 on the last floor of the building under different conditions of the distributed loads. It can be observed that the position of the load had a minimal effect on the acceleration response of the upper floor. In addition, the maximum accelerations of Nodes 2 and 3 on the first floor and base ground, respectively, were measured (Table III) to understand the effect of the existing water tank loadings on the last floor at different positions in the building. The results show that the maximum acceleration of Node 1 is higher than that of the other Nodes owing to its position at a higher level. On the other hand, Node 3 is affected more than Node 2 when the water tank is loaded on the last floor. This is because Node 3 is located within the piled foundation, which acts as a semi-fixed support for a cantilever

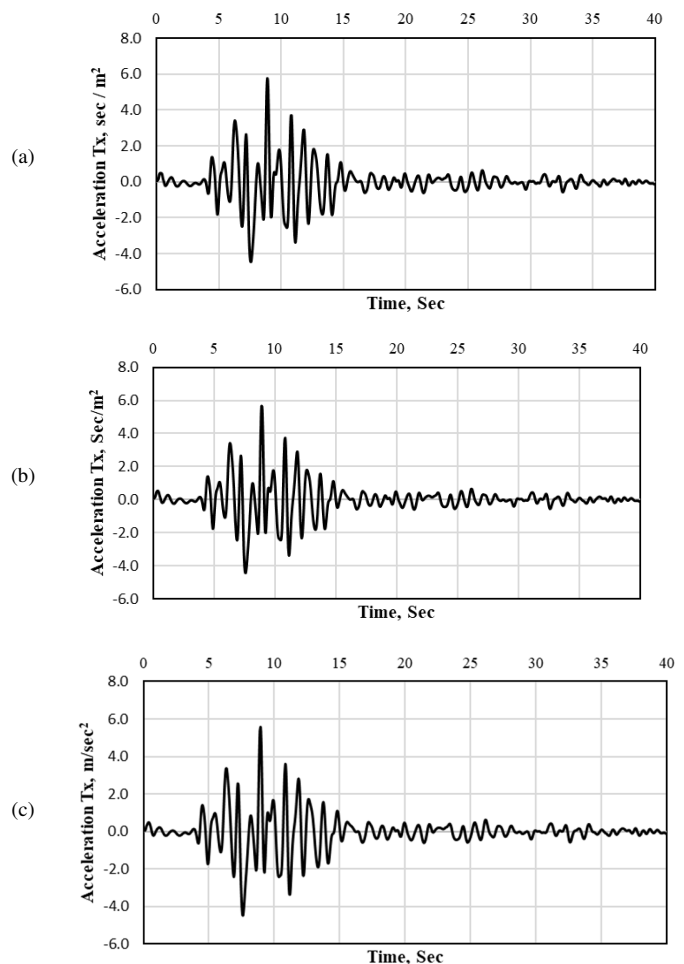


Fig. 6. Acceleration time history for Node 1 in the last floor with: (a) full, (b) half, and (c) quarter load distributions.

TABLE III. MAXIMUM ACCELERATION AT DIFFERENT POSITIONS AFTER APPLYING LOADS ON THE LAST FLOOR

Load distribution	Node 1 (last floor)	Node 2 (first floor)	Node 3 (base ground)
Full	5.79	3.24	4.5
Half	5.68	3.17	4.45
Quarter	5.58	2.99	4.36

The distribution of the water tank load over the roof of a building can have significant effects on the building's response to an earthquake. Some key considerations are:

- If the load is distributed over the entire roof, the mass spreads more evenly, potentially lowering the center of mass. This can slightly alter the natural frequency of the building, but the overall effect on acceleration might not be significant.
- Concentrating the load on a specific part of the roof creates an uneven mass distribution, causing the building to twist during an earthquake. This twisting, or torsional vibration, can increase the building's overall movement, leading to stronger shaking in certain areas of the structure.
- Adding mass (water tank) increases the inertia of the building. According to Newton's second law ($F = m a$), for a given force, an increase in mass results in a decrease in the acceleration. However, the increased mass also means that the building may experience higher base shear forces during an earthquake.
- The additional mass can affect the damping characteristics of a building. If the damping is increased, the acceleration may be reduced. Conversely, if the dampness decreases, the acceleration could be higher.
- Distributing the load evenly may not significantly alter the stiffness of the building or maintain its original dynamic properties. A localized load can create points of increased stress and potential deformation, locally affecting stiffness. This can lead to non-uniform deformation patterns and potentially higher local accelerations.
- The addition of mass to the roof can change the mode shape of the building. Higher mode shapes, which are more complex vibration patterns, may become more significant, leading to higher accelerations in certain areas. An unevenly distributed load can induce torsional motion, which can significantly increase the lateral accelerations and forces in structural elements, particularly those far from the center of mass.

In summary, the effect of the water tank load on the acceleration of a building during an earthquake depends on the distribution of the load. An evenly distributed load may slightly alter the dynamic response of the building, whereas a concentrated load can introduce torsional effects, potentially leading to higher accelerations and stresses in certain parts of the building. Structural engineers must carefully analyze these effects to ensure the safety and performance of the buildings during seismic events.

2) Horizontal Displacements

Figure 7 illustrates the horizontal displacement-time history of Node 1, located on the top floor, under varying distributed load conditions. The results indicate that the position of the applied load has a minor influence on the horizontal displacement at the upper floor. Specifically, the maximum displacement increased by approximately 2.38% and 4.01% when the load distribution expanded from a quarter to half and full floor coverage, respectively. Table IV summarizes the maximum horizontal displacements recorded at Nodes 1 (top floor), 2 (first floor), and 3 (ground base). Under full load distribution on the top floor, the displacement at Node 1 was approximately 91% and 93.65% greater than at Nodes 2 and 3, respectively.

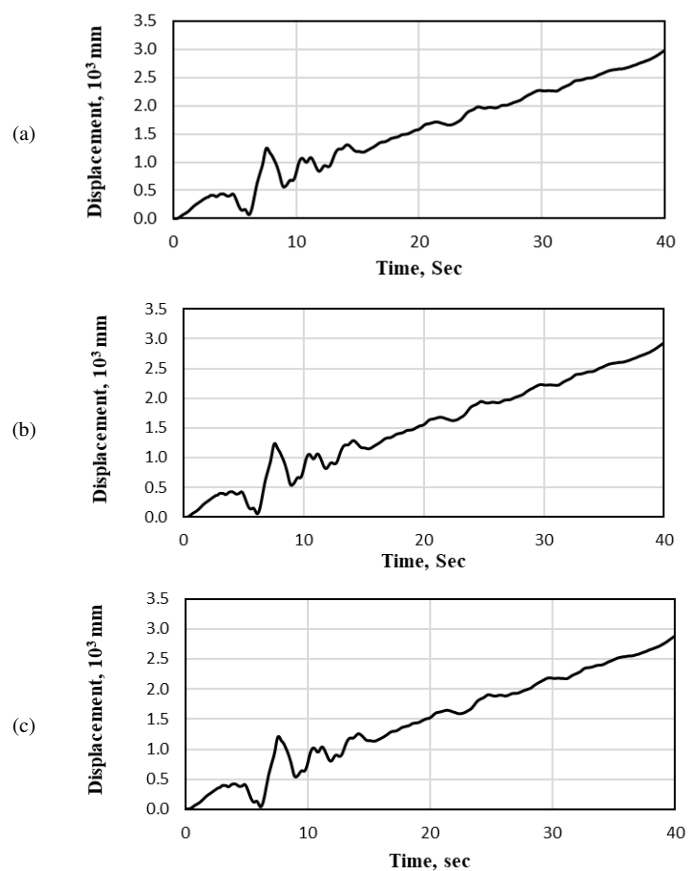


Fig. 7. Relative displacement relationships for the last floor with: (a) full, (b) half, and (c) quarter load distributions.

This significant difference is attributed to the constraint of horizontal movement at lower levels, which limits their displacement response. The additional mass from the water tank increases the base shear forces during the seismic activity, resulting in larger story drifts, particularly in upper stories, where cumulative displacements are more pronounced. When the load is distributed uniformly across the entire roof, the mass and inertia increase evenly, which can enhance the damping and lead to a more uniform displacement pattern throughout the structure. Conversely, when the load is concentrated in one part

of the roof, it creates localized mass increases and potential torsional effects. These can result in higher horizontal displacements at specific points, especially those farther from the building's center of mass, leading to asymmetrical deformation. Accurately assessing these effects requires advanced dynamic analysis tools, such as finite element modeling. Structural engineers must consider the implications of both the load magnitude and distribution to ensure that buildings can safely accommodate the resulting seismic displacements.

TABLE IV. MAXIMUM HORIZONTAL DISPLACEMENTS AT DIFFERENT POSITIONS AFTER APPLYING LOADS ON THE LAST FLOOR

Load distribution	Node 1 (last floor), mm	Node 2 (first floor), mm	Node 3 (base ground), mm
Full	2.99	0.24	0.19
Half	2.94	0.23	0.18
Quarter	2.87	0.22	0.17

B. Effect of Different Positions of Water Tank Loadings on the First Floor

1) Acceleration

Figure 8 presents the acceleration-time history at Node 2, located on the first floor, under various distributed load conditions. The results indicate that load positioning has a relatively minor effect on the acceleration response at this level. Specifically, the maximum acceleration increased by approximately 0.6% and 1.5% as the load distribution expanded from a quarter to half and a full floor coverage, respectively. As shown in Table V, the top floor (Node 1) consistently experiences nearly double the acceleration observed on the first floor when the same load distributions are applied at the first-floor level. This is primarily due to the greater freedom of movement at higher elevations. Evenly distributing the load across the entire first floor increases the mass and inertia at the base of the structure, which can slightly reduce acceleration at all levels due to the stabilizing effect of increased inertia. This added mass also shifts the building's center of gravity downward, enhancing the overall stability and reducing the seismic response. Additionally, a larger mass can improve the damping characteristics, further attenuating the acceleration response. Conversely, concentrating the load on a specific area of the first floor introduces an uneven mass distribution, potentially generating torsional effects. These effects may cause localized increases in acceleration, especially at higher stories, as the building experiences asymmetric vibration patterns. As a result, structural engineers must consider both the magnitude and distribution of the applied loads during the seismic design to mitigate the adverse dynamic responses. A comparison between Figures 6 and 8 shows that applying the distributed load on the last floor results in higher induced acceleration compared to when the same load is applied on the first floor, as illustrated in Figure 9. Specifically, the maximum acceleration increased by 40.32% when the load was distributed over a quarter of the top floor area and by 41.62% when distributed across the entire floor. Additionally, Figures 10(a) and 11(b) compare the acceleration response at the ground level under different load distributions on the last and first floors. A slight increase in the ground-level

acceleration is revealed when the load is applied on the first floor.

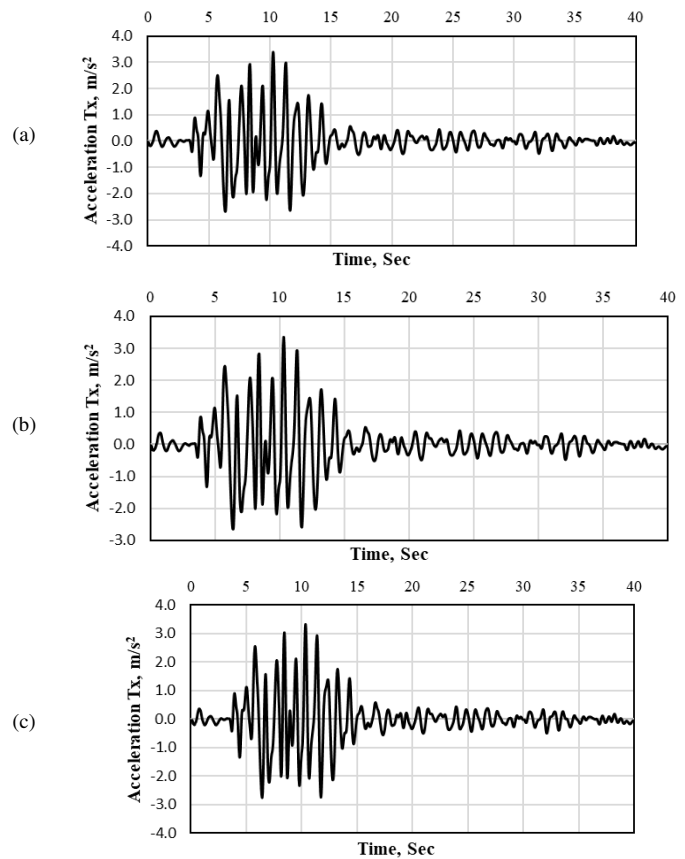


Fig. 8. Acceleration time history for the first floor: with (a) full, (b) half, and (c) quarter load distributions.

TABLE V. MAXIMUM ACCELERATION AT DIFFERENT POSITIONS AFTER APPLYING LOADS ON THE FIRST FLOOR

Load distribution	Node (last floor)	Node 2 (first floor)	Node 3 (base ground)
Full	6.00	3.38	4.57
Half	5.94	3.35	4.53
Quarter	5.90	3.33	4.42

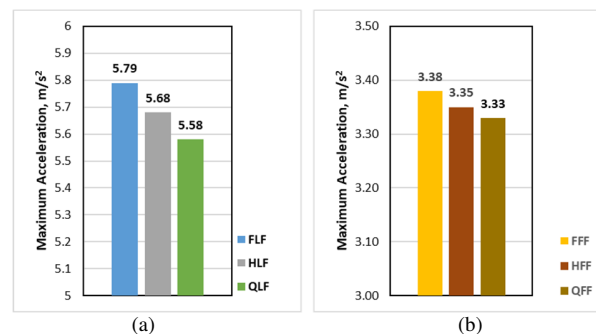


Fig. 9. A comparison between the maximum results of acceleration for: (a) Node 1 and (b) Node 2 with different positions of load distributions on the last and first floors, respectively.

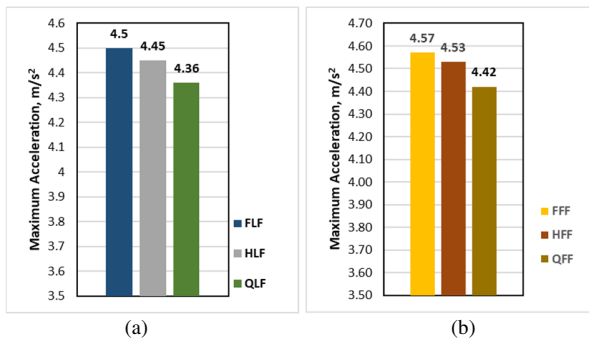


Fig. 10. A comparison between the maximum results of acceleration for Node 3 with different load distributions on: (a) the last floor and (b) the first floor.

2) Horizontal Displacement

Figure 11 displays the horizontal displacement-time history of Node 2 on the first floor of the building under different conditions of distributed loads. It can be concluded that there was no significant effect on the horizontal displacement under different load distributions on the first floor. Moreover, there was a slight increase of approximately 12.5 % and 22.2 % when the load distribution area increased from a quarter of the floor area to half and a full area, respectively. The maximum horizontal displacements for Nodes 1, 2, and 3 are listed in Table VI. The results indicated that the maximum horizontal displacement of the last floor was greater than that of the other Nodes when a full distribution load was applied on the first floor. In addition, there was no visible effect on the horizontal displacements on the first floor and base ground when different distribution loadings were applied. The increased mass at the lower level will increase the inertia and possibly the damping of the building, leading to reduced overall horizontal displacements. The effect is more pronounced at lower levels, but higher levels may also experience reduced displacement owing to the overall increased stability. In addition, because the load is evenly distributed, the deformation pattern is more uniform, with all floors experiencing a relatively proportional reduction in displacement. Concentrating on one part of the first floor creates areas of higher mass and potentially alters the stiff distribution. This can result in uneven deformation across the structure, with increased horizontal displacements in certain areas. A localized load may also raise the story drift at and above the point of concentration, especially if the torsional effects are significant. As a result, the upper floors may experience larger displacements due to the imbalance in the mass distribution. Non-uniform deformation patterns with potential increases in horizontal displacements and story drift, are especially observed at higher levels. In both cases, a detailed structural analysis, such as a dynamic response analysis, is essential for accurately assessing the effects of acceleration and horizontal displacement. This ensures that the building design can accommodate additional loads and the resulting dynamic behavior during an earthquake.

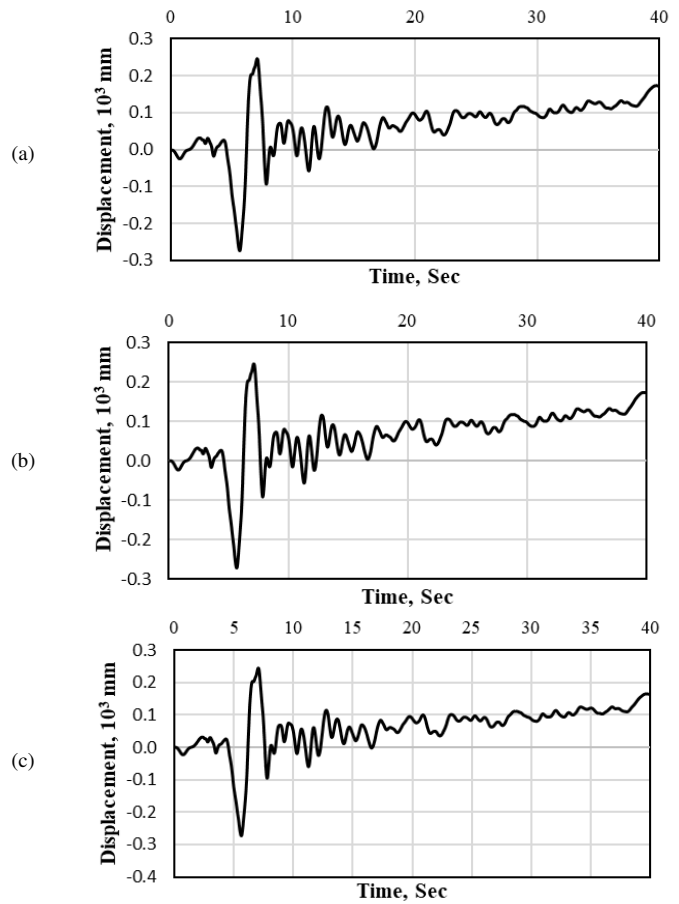


Fig. 11. Relative displacement relationships for the first floor with: (a) full, (b) half, and (c) quarter load distributions.

TABLE VI. MAXIMUM HORIZONTAL DISPLACEMENTS OF DIFFERENT POSITIONS AFTER APPLYING LOADS ON THE FIRST FLOOR

Load distribution	Node 1 (last floor), mm	Node 2 (first floor), mm	Node 3 (base ground), mm
Full	2.99	0.27	0.19
Half	2.95	0.24	0.18
Quarter	2.88	0.21	0.17

Finally, a comparison between Figures 7 and 11 reveals that the presence of the distributed load on the last floor caused an increase in the induced horizontal displacement compared with the first floor, as shown in Figure 12. In addition, a comparison between the results for the last column in Tables IV and VI indicates that there are no visible differences between the maximum displacements at the base ground when loads are applied on the last and first floors. Figure 13 displays the direct results of the relative displacement and acceleration of the full load on the last floor from Midas Gts-Nx.

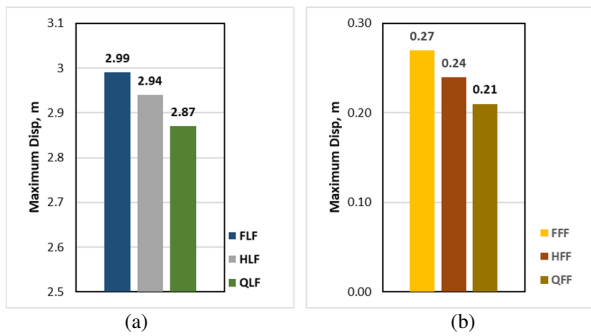


Fig. 12. A comparison between the maximum horizontal displacement results for: (a) the last and (b) first floors with different positions of load distributions.

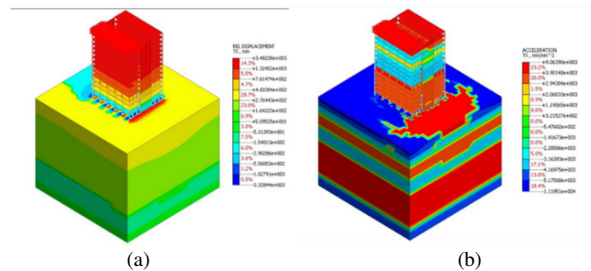


Fig. 13. Direct results from Midas Gts-Nx for (a) relative displacement, (b) acceleration for full load at the last floor (FLF).

C. Maximum Column Load in The Floor Versus Distributed Load Position

Figure 14 exhibits that there was a limited increase in the maximum column load when the water load was partially or fully distributed on the last floor. Additionally, Figures 15 and 16 show that the maximum shear force and maximum bending moment were slightly affected when the water load was partially or fully distributed on the last floor.

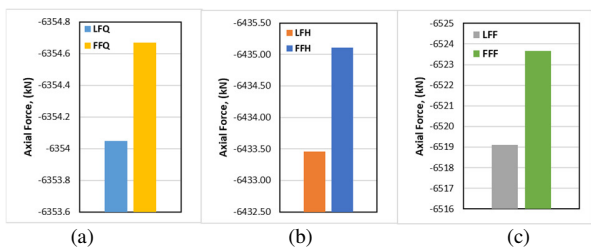


Fig. 14. Maximum axial force for the last and first floors at different: (a) quarter load, (b) half load, and (c) full load distributed positions.

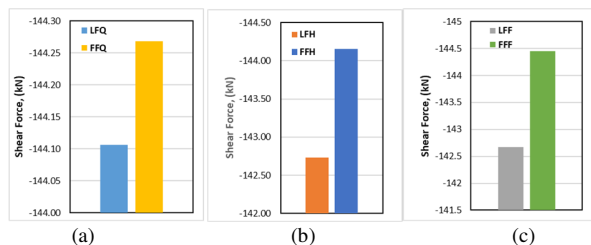


Fig. 15. Maximum shear force for the last and first floors at different: (a) quarter load, (b) half load, and (c) full load distributed positions.

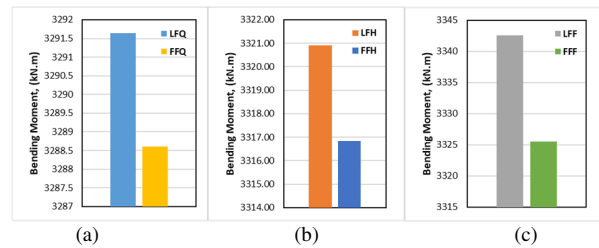


Fig. 16. Maximum bending moment for the last and first floors at different: (a) quarter load, (b) half load, and (c) full load distributed positions.

Evenly distributing the water tank load across the entire roof leads to a uniform increase in the vertical loads on all columns throughout the building. This added mass increases the axial forces from the roof down to the foundation, requiring each column to carry additional weight. As a result, it may be necessary to reassess the column design to ensure sufficient load-carrying capacity. During seismic events, the increased roof mass also contributes to higher inertial forces, which are transmitted through the structural system. These forces can elevate the bending moments and shear forces in the columns particularly in those near the roof due to their proximity to the added mass.

- **Localized Load Increase:** Concentrating the load on a specific part of the roof results in a non-uniform distribution of the vertical loads. Columns directly under the loaded area experience significantly higher axial loads than columns away from the load.
- Columns under the loaded area must support the concentrated load, leading to increased axial loads and potentially higher bending moments and shear forces. Columns away from the loaded area show less of an increase in the load. A concentrated load can create eccentricity, causing torsional effects and differential settlement issues. This can result in additional bending moments in the columns as they resist the torsional forces.
- All columns experienced increased axial loads due to the added weight of the water tank. During an earthquake, these added masses contribute to higher inertial forces, which in turn raise the bending moments and shear forces within the columns. When the load is uniformly distributed, the increased demand is spread more evenly, potentially requiring a re-evaluation and strengthening of the columns throughout the structure. In contrast, when the load is concentrated in a specific area, the columns directly beneath the load experience significantly higher axial forces, while those farther away are less affected. This uneven loading can also introduce torsional effects due to mass eccentricity, further increasing the bending moments and shear forces in certain columns.
- A non-uniform load distribution can cause asymmetry in the structural response, leading to differential settlement and potential structural issues. In both scenarios, structural engineers must carefully analyze the load distribution to ensure that the columns are designed to handle the additional loads and resulting forces during an earthquake. This may involve reinforcing the existing columns or

redesigning parts of the structural system to accommodate the increased demand.

Placing a higher UDL in a building increases the story shear and overturning moments due to the longer lever arm from the base. This adds extra demand on the lateral force-resisting system, which must be designed to accommodate the higher base shear and overturning forces. Concentrated UDLs on upper floors often result in larger story drifts during the seismic events. Uneven mass distribution leads to irregular story displacements, which can cause localized damage and increase the stress on the nonstructural components. When UDLs are not symmetrically positioned, they create eccentric mass distributions. This asymmetry induces torsional (twisting) effects under seismic loading, amplifying the seismic forces and causing uneven displacement across the building width. These effects are especially pronounced in buildings with irregular shapes or asymmetrical mass layouts. Additionally, the load distribution affects how energy is dissipated throughout the structure. Higher UDLs on the upper floors can result in greater displacements, causing structural components, such as dampers, to absorb more energy. Over time, this may lead to increased wear and reduced performance of these components.

V. CONCLUSIONS

A numerical study was conducted by using the Midas GTS-NX program. This study focused on the response of piled foundation-supported high-rise buildings subjected to different positions and load distributions. Based on the findings and discussion, the following conclusions were drawn:

- Placing the distributed load on the top floor led to higher induced acceleration compared to placing it on the first floor. The maximum acceleration increased by 40.32% when the load covered a quarter of the top floor, and by 41.62% when it was spread across the entire floor.
- There was no significant change in the horizontal displacement when different load distributions were applied to the first floor. However, a slight increase of about 12.5% and 22.2% was observed as the load coverage expanded from one-quarter to one-half and then to the full floor area, respectively.
- There was a limited increase in the maximum column load when the water load was partially or fully distributed on the last floor, whereas the maximum shear force and maximum bending moment were slightly affected.

In general, placing Uniformly Distributed Loads (UDLs) on higher floors or distributing them unevenly across the building height tends to increase the seismic demand. This can lead to higher inertial forces, greater story drifts, increased torsional effects, and added strain on the isolation and damping systems. To ensure an accurate seismic analysis and a safe structural design, it is essential to carefully account for UDL placement in the building's mass model. This study has some inherent limitations. For instance, it did not explore the effects of different soil types in depth. Future research is encouraged to examine how the Soil-Structure Interaction (SSI) influences high-rise buildings under varying conditions, such as different

soil profiles, layered or complex soil systems, structural irregularities, and alternative foundation types.

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