

Comparative Analysis of Various Bracing Systems for Elevated Water Tank with Varying Staging Heights

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Abstract – Elevated water tanks play a vital role in providing a continuous water supply and are considered important lifeline structures, especially in earthquake-prone regions. During seismic events, the staging system of the tank significantly influences its overall stability and performance. Therefore, selecting a suitable bracing arrangement is essential for improving the earthquake resistance of elevated water tanks. In the present study, a comparative seismic analysis of elevated square water tanks was carried out using STAAD.Pro under Seismic Zone IV conditions. Five different bracing systems, namely Diagonal Bracing, X-Bracing, V-Bracing, Inverted-V Bracing, and Mid-Diagonal Bracing, were considered. The analysis was performed for two staging heights, 9 m and 15 m, under both empty and full tank conditions. The seismic performance of the models was evaluated in terms of base shear and top displacement. The results showed that staging height, tank condition, and bracing type significantly influence the seismic behaviour of elevated water tanks. Among all bracing systems, X-Bracing exhibited the best performance by producing the lowest base shear and top displacement values under both empty and full tank conditions. Compared to conventional Diagonal Bracing, X-Bracing reduced base shear by approximately 32–44% and top displacement by approximately 4–10%. Based on the analytical results, X-Bracing with a 9 m staging height is recommended for improved seismic stability, stiffness, and structural safety.

Key Words: Elevated Square Water Tank, Bracing Types, Staging Height, Empty and Full Tank Condition, Top Displacement, Base Shear, Seismic Zone IV, STAAD.Pro.

1. INTRODUCTION

Elevated water tanks are lifeline structures and are important for the continuous supply of water. Their performances are critical during and after strong earthquakes. Elevated water tanks have experienced significant damage during past earthquakes due to inadequate understanding of staging behaviour and unsuitable structural configurations. This may be due to the lack of knowledge regarding the behavior of supporting system of the tank, and also due to improper selection of geometry of staging patterns.

The seismic behaviour of elevated water tanks is greatly influenced by staging height and water storage condition. Variation in staging height affects the stiffness and stability of the supporting structure, while the empty and full tank conditions change the seismic mass acting on the tank during earthquake loading. Due to these variations, the structural response such as top displacement and base shear may differ significantly. Therefore, it is important to study the performance of elevated water tanks under different staging heights and water level conditions to achieve a safer and more efficient design.

Different bracing systems provide varying levels of lateral stiffness and seismic resistance. Therefore, a comparative evaluation of different bracing configurations is necessary to identify the most effective bracing system for improving the seismic performance of elevated water tanks. In the present study, elevated square water tanks are analysed using STAAD.Pro under empty and full conditions for different staging heights and bracing systems.

1.1 Scope of present study

In the present work, models of elevated square water tanks located in Seismic Zone-IV analysed using STAAD.Pro. The study focuses on the seismic behaviour of elevated water tanks with different bracing systems and staging heights under both empty and full tank conditions. The analysis includes evaluation of parameters such as top displacement and base shear for the given structures in order to determine the most effective bracing configuration and staging height for improved seismic performance.

2. OBJECTIVES

- To perform seismic analysis of square elevated water tanks.
- To analyze and compare the performance of different bracing types, specifically Diagonal bracing, X-bracing, V-bracing, Inverted-V bracing and Mid-diagonal bracing.
- To investigate the impact of staging height on the seismic behaviour of elevated water tanks.

- To study and compare the seismic response of elevated water tanks under empty and full tank conditions.
- To compare key structural parameters such as base shear and top displacement.
- To recommend the most effective bracing and staging system for earthquake resistant square elevated water tanks based on analytical results.

3. TYPES OF BRACING PATTERNS AND STAGING HEIGHTS

Bracings help distribute loads more evenly between the columns, reducing the chances of failure under dynamic loads. Braced frames can absorb and dissipate earthquake energy, reducing the risk the risk of collapse or severe damage during seismic events. Adding bracings can allow for smaller column and beam sizes, which can save material costs while still maintaining the required structural strength.

There are various bracing types as shown in Fig 1. Like diagonal bracing, x-bracing, v-bracing, Mid-diagonal bracing. In this study five types of bracing patterns are considered. They are diagonal bracing, X-bracing, V-bracing, inverted V-bracing and Mid-diagonal bracing.

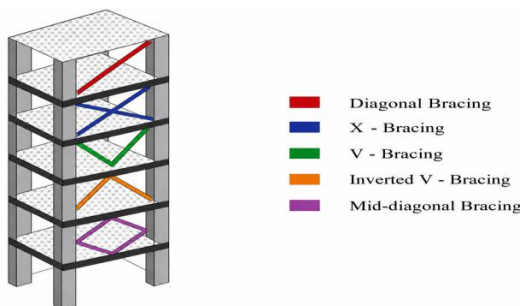


Fig 1: Types of Bracing

In this study, two different staging heights, 9m and 15m, are analysed to understand their effect on the water tank's stability. Staging height is a very important factor because as the height increases from 9m to 15m, the structure becomes more flexible and its vibration time changes during lateral loads. Testing these two heights helps us find out how much the height increases structural risk and how effectively different bracing systems can control this side-to-side movement.

4. METHODOLOGY

4.1 Modelling of Water Tank

To perform the structural analysis, STAAD.Pro v8i was utilized as the primary software tool. The software enables efficient 3D modeling, structural analysis, and design of reinforced concrete structures under static and dynamic

loading conditions. Its user-friendly interface and accurate analytical capabilities make it suitable for seismic analysis of elevated water tanks.

In the present study, elevated square water tank models were analyzed under Seismic Zone IV conditions using STAAD.Pro v8i. The models were evaluated for two staging heights, namely 9 m and 15 m, with five different bracing systems: Diagonal bracing, X-bracing, V-bracing, Inverted-V bracing and Mid-diagonal bracing. Seismic loading was applied in accordance with IS 1893 provisions for liquid retaining structures. The seismic performance of the tanks was compared under empty and full tank conditions based on important structural parameters such as base shear and top displacement.

4.2 Elevated Water Tank Models

- **Square Elevated Water Tank**

The design parameters adopted for the analytical modelling of elevated square water tanks are presented in Table 1 and Table 2. The same geometrical and material properties were maintained for all analytical models to ensure uniformity in comparative analysis. However, the staging height was varied from 9 m to 15 m, and accordingly, the column size was increased to maintain structural stability, stiffness, and load-carrying capacity. As the staging height increases, the structural flexibility also increases; therefore, larger column dimensions were provided for the higher staging model.

Table 1: Design Parameters of Tank

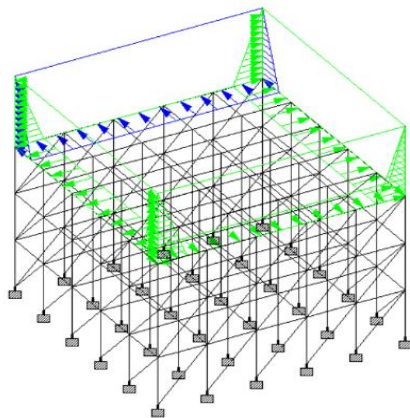
Capacity of Tank	1000 m ³
Tank size	15 m × 15 m
Height of container	4.5 m
Seismic Zone	Zone IV
No. of columns	36
Beam size	300 mm x 300 mm
Bracing size	250 mm x 250 mm
Plate thickness	200 mm
Zone Factor (Z)	0.24
Importance Factor (I)	1

Table 2: Staging Height and Member Dimensions of Tank

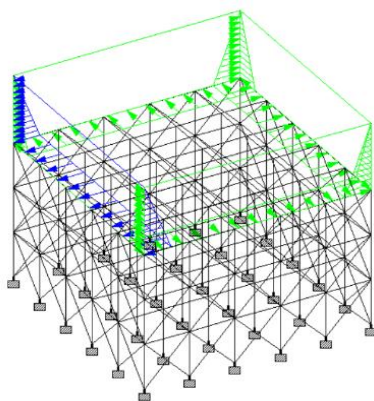
Staging Height	Column size
9m	350 mm x 350 mm
15m	500 mm x 500 mm

Fig. 2 and Fig. 3 display the square elevated water tank configurations for a 9 m and 15 m staging height. It highlights five individual models integrated with Diagonal, X, V, Inverted-V and Mid-diagonal bracing systems to compare their structural performance.

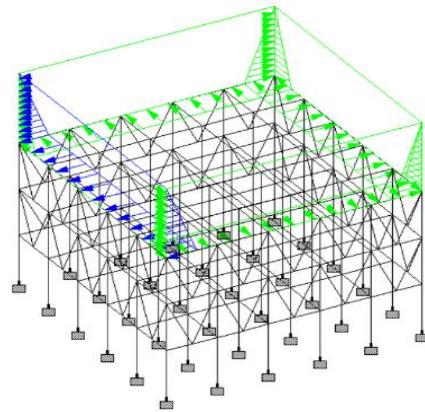
- **Staging Height 9 m**



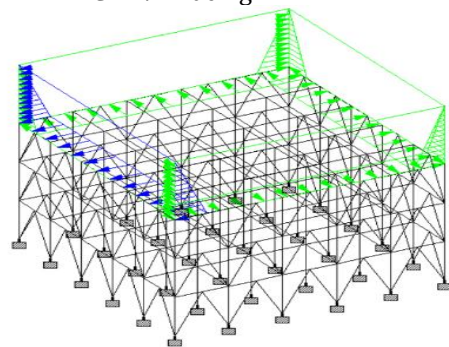
A. Diagonal Bracing



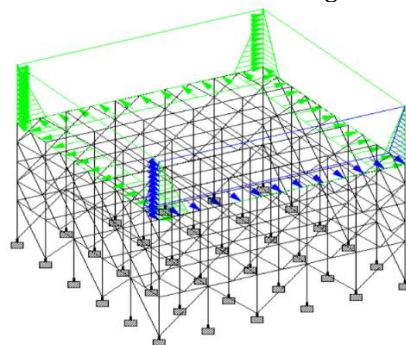
B. X-Bracing



C. V-Bracing



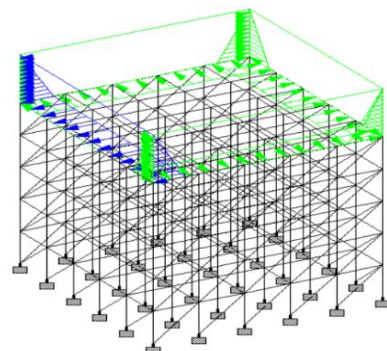
D. Inverted V-Bracing



E. Mid-diagonal Bracing

Fig. 2: Square Water Tank with 9 m Height of Staging

- **Staging Height 15 m**



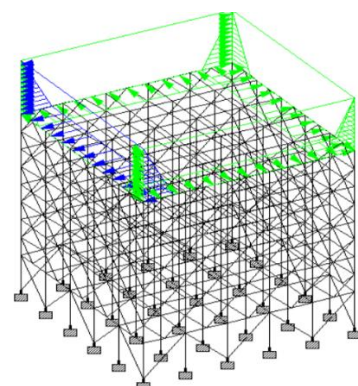
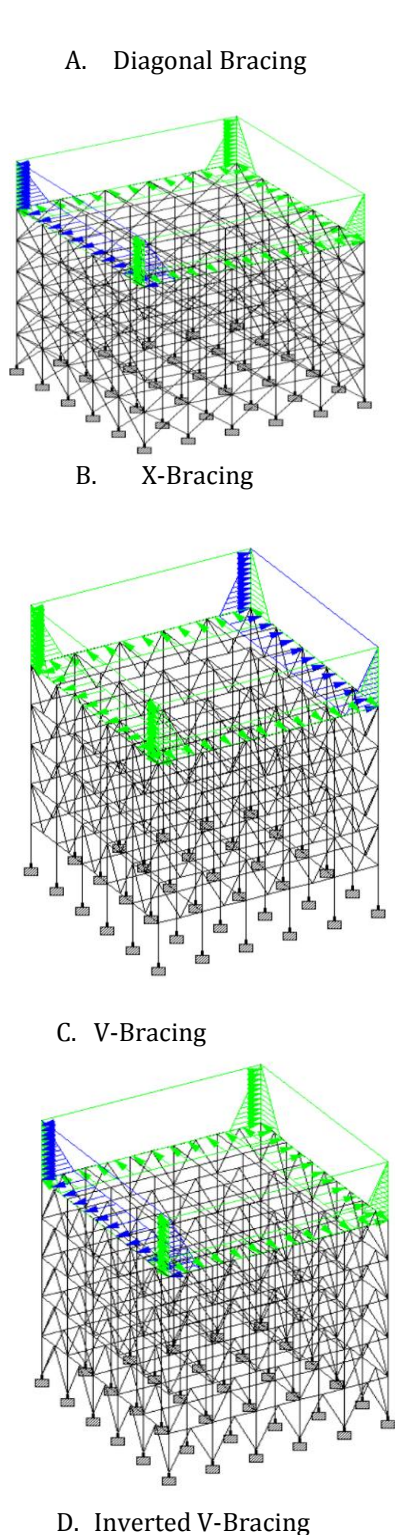


Fig. 3: Square Water Tank with 15 m Height of Staging

5 RESULTS AND DISCUSSION

In this section, the analytical results obtained from the structural models simulated in STAAD.Pro v8i under Seismic Zone IV are presented and discussed. The study focuses on the comparative seismic analysis of elevated square water tanks with staging heights of 9 m and 15 m under empty and full tank conditions. Five different bracing systems, namely Diagonal bracing, X-bracing, V-bracing, Inverted-V bracing and Mid-diagonal bracing are considered to evaluate their effectiveness under earthquake loading. The structural performance of the models is assessed using two important seismic parameters: base shear and top displacement. The obtained results are compared to understand the effect of bracing type, staging height, and tank condition on the seismic behaviour of elevated water tanks.

5.1 Base Shear

- **Base Shear under Empty Tank Condition**

Table 3 shows the base shear values under empty tank condition for different bracing systems and staging heights. Base shear increases with increase in staging height. X-bracing gives the minimum base shear, while diagonal bracing shows the maximum value.

Table 3. Base Shear under Empty Tank Condition

Model	Base Shear (kN)	
	For Staging Height 9m	For Staging Height 15m
X-Bracing	397.99	510.15
Diagonal Bracing	574.4	675.39

Inverted V-Bracing	517.58	631.784
V-Bracing	404.27	513.109
Mid-diagonal bracing	541.37	671.706

Fig. 4 shows that X-Bracing produced the minimum base shear under the empty tank condition for both staging heights. At 9 m staging height, the base shear values of Diagonal, Inverted-V, V, and Mid-Diagonal bracing were 44.33%, 30.05%, 1.58%, and 36.03% higher than X-Bracing, respectively. Similarly, at 15 m staging height, the increase was 32.39%, 23.84%, 0.58%, and 31.67%, respectively, indicating the superior seismic performance of X-Bracing.

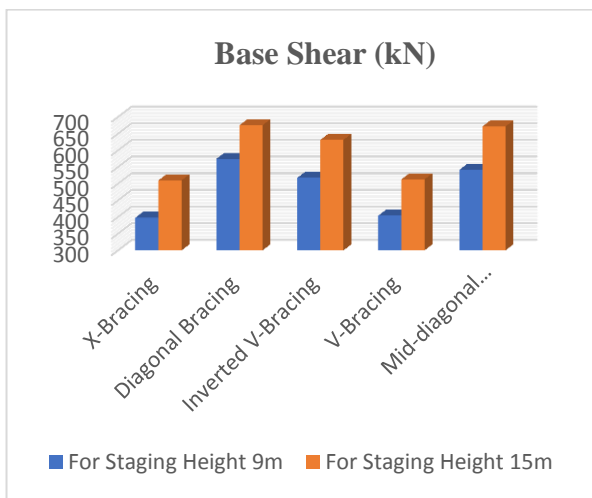


Fig. 4: Base Shear for Empty Tank Condition

• **Base Shear under Full Tank Condition**

Table 4 presents base shear values under full tank condition. Due to the increased water mass, base shear values are higher than those in the empty tank condition. X-bracing shows the lowest base shear, while diagonal bracing shows the highest.

Table 4. Base Shear under Full Tank Condition

Model	Base Shear (kN)	
	For Staging Height 9m	For Staging Height 15m
X-Bracing	621.313	759.5
Diagonal Bracing	878.621	1014.732
Inverted V-Bracing	792.539	925.181
V-Bracing	633.896	765.955

Mid-diagonal bracing	829.453	980.811
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Fig. 5 shows that X-Bracing exhibited the lowest base shear under the full tank condition. Compared to X-Bracing, Diagonal, Inverted-V, V, and Mid-Diagonal bracing showed increases of 41.41%, 27.56%, 2.03%, and 33.50%, respectively, at 9 m staging height. At 15 m staging height, the corresponding increases were 33.61%, 21.81%, 0.85%, and 29.14%.

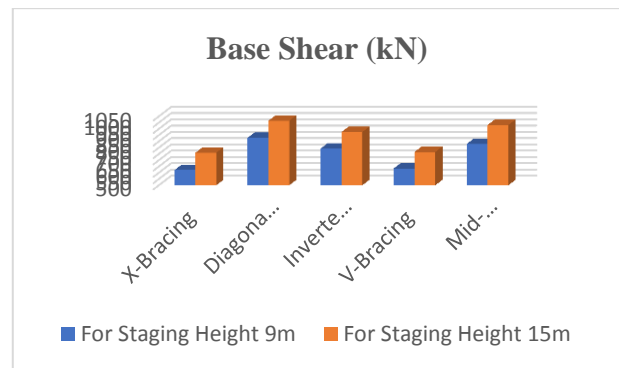


Fig. 5: Base Shear for Full Tank Condition

5.2 Top Displacement

• **Top Displacement under Empty Tank Condition**

Table 5 shows the top displacement values under empty tank condition. Displacement increases with increase in staging height. X-bracing gives the minimum displacement, whereas diagonal bracing shows the maximum displacement.

Table 5. Top Displacement under Empty Tank Condition

Model	Top Displacement (mm)	
	For Staging Height 9m	For Staging Height 15m
X-Bracing	5.34	5.36
Diagonal Bracing	5.88	5.89
Inverted V-Bracing	5.63	5.77
V-Bracing	5.46	5.66
Mid-diagonal bracing	5.47	5.76

Fig. 6 shows that X-Bracing resulted in the minimum top displacement under the empty tank condition. At 9 m staging height, Diagonal, Inverted-V, V, and Mid-Diagonal bracing produced 10.11%, 5.43%, 2.25%, and 2.43% higher displacement values than X-

Bracing, respectively. At 15 m staging height, the corresponding increases were 9.89%, 7.65%, 5.60%, and 7.46%.

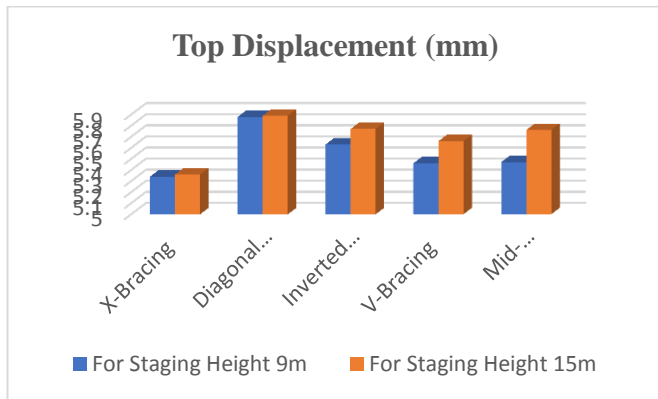


Fig. 6: Top Displacement for Empty Tank Condition

• **Top Displacement under Full Tank Condition**

Table 6 presents top displacement values under full tank condition. The displacement values are higher due to increased water mass. X-bracing shows the minimum displacement, while diagonal bracing shows the maximum.

Table 6. Top Displacement under Full Tank Condition

Model	Top Displacement (mm)	
	For Staging Height 9m	For Staging Height 15m
X-Bracing	13.42	14.09
Diagonal Bracing	14.18	14.62
Inverted V-Bracing	13.78	14.45
V-Bracing	13.55	14.3
Mid-diagonal bracing	13.5	14.34

Fig. 7 shows that X-Bracing provided the least top displacement under the full tank condition. At 9 m staging height, the displacement values of Diagonal, Inverted-V, V, and Mid-Diagonal bracing were 5.66%, 2.68%, 0.97%, and 0.60% higher than X-Bracing, respectively. At 15 m staging height, the increases were 3.76%, 2.56%, 1.49%, and 1.77%, respectively.

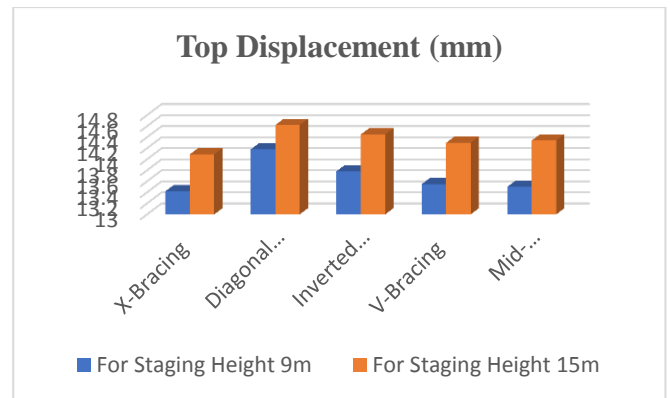


Fig. 7: Top Displacement for Full Tank Condition

6. CONCLUSION

The present study carried out the seismic analysis of elevated square water tanks located in Seismic Zone IV using STAAD.Pro. Five different bracing systems, namely Diagonal Bracing, X-Bracing, V-Bracing, Inverted-V Bracing, and Mid-Diagonal Bracing, were analyzed for staging heights of 9 m and 15 m under empty and full tank conditions. The performance of the models was evaluated based on base shear and top displacement.

- A. Effect of Bracing Systems: The comparative seismic analysis of Diagonal Bracing, X-Bracing, V-Bracing, Inverted-V Bracing and Mid-Diagonal Bracing showed that the bracing configuration significantly affects the seismic performance of elevated square water tanks in Seismic Zone IV. Among all the bracing systems, X-Bracing exhibited the minimum base shear and top displacement values under both empty and full tank conditions, indicating superior seismic performance. Mid-Diagonal Bracing performed better than conventional Diagonal Bracing but was less effective than X-Bracing in controlling seismic response. Furthermore, compared to conventional Diagonal Bracing, X-Bracing reduced base shear by approximately 32–44% and top displacement by approximately 4–10% for both staging heights, demonstrating its superior lateral stiffness and earthquake resistance.
- B. Effect of Staging Height: The increase in staging height from 9 m to 15 m resulted in higher base shear and top displacement values for all bracing systems. This increase is mainly due to the greater flexibility of the taller staging system. Therefore, tanks with 9 m staging height showed better seismic stability compared to tanks with 15 m staging height.

- C. Effect of Tank Condition: The full tank condition produced higher base shear and top displacement values compared to the empty tank condition. This is because the stored water increases the seismic mass of the structure, leading to greater earthquake-induced forces and displacements.

Based on the analytical results obtained from STAAD.Pro, X-Bracing with a 9 m staging height is recommended as the most effective configuration for elevated square water tanks in Seismic Zone IV. This configuration provides minimum base shear and top displacement and therefore offers better seismic stability, stiffness, and overall structural safety.

7. REFERENCES

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