**Comparative Analysis of steel water tank with different shapes**

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**ABSTRACT**: Elevated water tanks are vital infrastructure in earthquake-prone regions, essential for maintaining water supply during and after seismic events. Analysis of steel water tanks reveals that circular tanks experience the highest maximum bending moment in columns, reaching 200 kNm, indicating significant structural stress during earthquakes. Additionally, circular tanks also bear the highest maximum axial load in columns, at 1225 kN, highlighting their critical role in supporting vertical loads. Ensuring these tanks are robustly designed and reinforced is crucial for their resilience and uninterrupted function in supplying water for drinking and firefighting purposes in seismic zones.

**Keywords:** elevated, water tank, supporting structure, moment and hydrodynamic pressure

**Introduction:**

In many municipalities across India, the water supply infrastructure relies heavily on elevated water storage tanks. These tanks are strategically elevated to ensure consistent water pressure throughout the distribution system. They serve as critical components of urban water supply networks, facilitating efficient water distribution to homes, businesses, and public facilities.

An elevated water tank typically consists of a large storage container supported by a slender structure, often a steel or reinforced concrete tower. This design, while effective for maintaining water pressure, also renders the structure vulnerable to horizontal forces, particularly during seismic events. The substantial mass of water stored at the top of the tower can exert significant lateral forces on the supporting structure during earthquakes, posing a risk of structural failure if not adequately designed and reinforced.

The primary objective of projects focusing on elevated water tanks is to analyze and mitigate the effects of dynamic forces, especially seismic forces, on these structures. Seismic analysis is crucial because earthquakes can induce strong ground motions that impart forces on the tank, potentially causing displacement, stress, and structural damage. These analyses consider various factors such as hydrodynamic pressure acting on the sides of the tank, inertia forces exerted by the water mass, and the vertical acceleration of the soil beneath the tank.

Hydrodynamic pressure, generated by the movement of water inside the tank during seismic events, affects the structural integrity of both the tank walls and the base plate. The inertia forces from the water mass can cause significant sway and bending moments in the supporting structure, leading to potential failure if not adequately restrained. Moreover, the vertical acceleration of the soil, which varies with seismic activity, adds another layer of complexity to the structural response analysis.

Design parameters crucial to ensuring the structural stability and safety of elevated water tanks under seismic conditions include:

* **Material Strength and Durability:** Choosing materials such as high-strength concrete or steel that can withstand seismic forces and resist corrosion over the tank's operational lifespan.
* **Structural Configuration:** Optimal design of the tank's support structure to distribute loads evenly and minimize stress concentrations.
* **Foundations:** Ensuring robust foundation design to withstand both vertical and horizontal seismic forces transmitted from the tank structure to the ground.
* **Dynamic Analysis:** Performing rigorous dynamic analysis using advanced computational tools to simulate earthquake effects and predict structural behavior under various seismic scenarios.
* **Safety Measures:** Implementing appropriate safety measures such as seismic retrofitting of existing tanks and incorporating damping devices or base isolators to mitigate seismic vibrations.

By studying and understanding these design parameters and conducting comprehensive seismic analyses, engineers can effectively enhance the resilience of elevated water tanks against seismic hazards. This ensures the continued reliability of water supply systems and reduces the risk of damage or disruption during earthquakes, safeguarding communities' access to clean water even under adverse conditions

**Literature Review:**

**Algreane, G.A., et al. (2011):** Algreane and colleagues conducted a seismic analysis of a round elevated tank using response spectrum and ETABS 9.7.1 software, following IS 1893:2002 guidelines. Their study focused on a tank with a capacity of 900 m3 and a height of 16 m. They considered different soil conditions (soft, medium, and hard) and seismic zones (II, III, IV, V) with zone coefficients ranging from 0.1 to 0.36. The tank was analyzed in both empty and full conditions, and hydrodynamic forces were calculated according to IS 1893:2002 Part II.

**Brunesi, E., et al. (2015):** Brunesi and co-authors reviewed the limitations and shortcomings of IS 1893-1984 in the seismic design of liquid storage tanks. They proposed revisions based on IS 1893 (part 1) -2002, suggesting updated horizontal seismic coefficients and reduction factors for different tank types. Their recommendations aimed to enhance the seismic safety and design accuracy of liquid storage tanks.

**Ekbote, P.S., et al. (2013):** Ekbote and team studied the behavior of soil and water in elevated concrete tanks under seismic loads. Their research involved generating artificial seismic excitations using Gasparini and Vanmark's approach at the tank base. Nonlinear local site effects were considered in their seismic analyses to simulate realistic seismic conditions and evaluate the structural response of elevated tanks.

**Kwag, S., et al. (2014):** Kwag and collaborators investigated the response of a simple steel water tank during earthquakes and vibration tests. They calculated the tank's vibration periods considering soil yield and water inundation effects. Their study demonstrated a close agreement between measured and calculated results, validating the accuracy of their seismic analysis methods for steel water tanks.

**Moslemi, M., et al. (2011):** Moslemi and colleagues focused on a circular elevated RCC tank constructed with M-20 concrete and using SMRF Fe-415 for structural analysis. They examined tanks ranging from 50,000 liters to 100,000 liters in capacity, with heights varying from 12 m to 28 m. Their study included analyzing the seismic response and behavior of the tanks under different loading conditions, emphasizing structural integrity and seismic resilience.

These studies collectively contribute to the understanding of how elevated water tanks respond to seismic forces, incorporating various factors such as tank shape, construction materials, soil conditions, and seismic zone specifications. Each research effort aims to improve the design standards and safety measures for elevated water tanks, ensuring resilience against seismic events and enhancing structural performance in earthquake-prone regions.

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**Modeling**:

The modeling of the different water tank is performed in the ETABS software and the parameters as well as the shape is considered as follows:

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| Figure 1: Plan of Circular water tank |
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| Figure 2: 3D Model of Circular water tank generated in ETABS |

Table 1: Parameters for the steel water tank

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| Parameters | Circular | Rectangular | Square |
| Capacity of Tank | 200000 lit | 200000 lit | 200000 lit |
| Plane dimensions  | 8 m dia | 6x8.3 m | 7.1x7.1 m |
| Total height of Staging | 20 m | 20 m | 20 m |
| Height of each storey of Staging | 4m | 4m | 4m |
| Height of Water  | 4m | 4m | 4m |
| Free board  | 0.2m | 0.2m | 0.2m |
| Depth of foundation  | 1.5m | 1.5m | 1.5m |
| Size of tie beams  | ISMB 450 | ISMB 450 | ISMB 450 |
| Size of Tank bottom Slab lvl beams | ISMB 600 | ISMB 600 | ISMB 600 |
| Size of Tank top Slab lvl beams | ISMB 450 | ISMB 450 | ISMB 450 |
| size of columns  | ISMB 600 | ISMB 600 | ISMB 600 |
| Thickness of tank Bottom slab | Steel Deck 100 mm | Steel Deck 100 mm | Steel Deck 100 mm |
| Thickness of tank top slab | Steel Deck 100 mm | Steel Deck 100 mm | Steel Deck 50 mm |
| Thickness of tank walls | 50mm | 50mm | 50mm |
| Seismic zone  | III  | III  | III  |
| Soil condition  | Medium | Medium | Medium |
| Response reduction factor  | 5 | 5 | 5 |
| Importance factor  | 1 .5 | 1 .5 | 1 .5 |
| Floor finishes at top slab | 3 kN/m2 | 3 kN/m2 | 3 kN/m2 |
| Live load at top slab | 1.5 kN/m2 | 1.5 kN/m2 | 1.5 kN/m2 |
| Grade of Concrete  | M30 | M30 | M30 |
| Grade of Steel  | Fe500 | Fe500 | Fe500 |
| Density of Concrete  | 25 kN/m3  | 25 kN/m3  | 25 kN/m3  |
| Density of brick masonry  | 20 kN/m3 | 20 kN/m3 | 20 kN/m3 |

**Results**:

Lateral displacement measures the horizontal movement of the structure due to applied loads. In the analysis, different shapes of steel water tanks were subjected to lateral forces, and the results indicate variations in displacement. Typically, the lateral displacement is lower in tanks with more compact shapes, such as square or rectangular tanks, compared to circular tanks. This lower displacement signifies greater resistance to lateral forces and better stability in response to external loading.

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| Figure 4: Lateral Displacement- X dirn of steel water tank |

From the above figure it is observed that the lateral displacement (X-dir) in the case of steel water tank is found to be maximum in the circular water tank and the maximum value observed to be 37 mm.

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| Figure 5: Lateral Displacement- Y dirn of steel water tank |

Upon analyzing the data presented in the figure, it becomes evident that the lateral displacement in the Y-direction for steel water tanks varies significantly based on tank shape. Specifically, the circular water tank exhibits the maximum lateral displacement among the shapes studied, reaching a substantial value of 210 mm.

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| Figure 6: Drift (X-dir) of steel water tank |

Upon analyzing the figure depicting the structural behavior of steel water tanks, several observations emerge regarding the drift in the X-direction. It is evident that among the different tank shapes studied, the square steel water tank exhibits the least drift. Drift refers to the relative horizontal displacement between different levels or storeys of the structure, indicating how much the floors shift horizontally under lateral loads.

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| Figure 7: Drift (Y-dir) of steel water tank |

The figure highlights that among the various shapes of steel water tanks studied, the rectangular water tank exhibits the minimum drift in the Y-direction. Drift in this context refers to the lateral displacement or movement perpendicular to the direction of the applied force. A lower drift value indicates that the rectangular water tank experiences less lateral movement between its floors or levels when subjected to lateral loads.

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| Figure 8: Storey Shear (X-dir) of steel water tank |

From the analysis of the provided figure, it is evident that the storey shear in the X-direction for steel water tanks varies significantly depending on the tank's shape. Specifically, the square water tank exhibits the highest storey shear among the shapes studied, with a maximum observed value of 300 kN. Storey shear refers to the lateral force that each storey of the structure must resist due to applied loads or environmental forces.

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| Figure 9: Storey Shear (Y-dir) of steel water tank |

From the analysis of the provided figure, several insights regarding the behavior of steel water tanks under vertical (Y-direction) storey shear forces are discerned. The data highlights that among the various shapes studied, the square steel water tank exhibits the highest storey shear in the Y-direction. Storey shear refers to the lateral force that acts along the height of a structure, contributing to its stability and structural integrity.

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| Figure 10: Max Bending Moment in Column for steel water tank |

From the analysis of the figure depicting the maximum bending moment in columns of steel water tanks, it is evident that the circular water tank exhibits the highest values compared to other tank shapes. Specifically, the maximum bending moment observed in the columns of the circular steel water tank reaches 200 kNm.

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| Figure 11: Max shear force in Column for steel water tank |

Upon analyzing the provided figure, several key observations are made regarding the maximum shear force in columns of steel water tanks, specifically comparing different tank shapes. It is noted that the circular water tank exhibits the highest maximum shear force among the shapes studied, with a peak value recorded at 85 kNm.

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| Figure 12: Max axial load in Column for steel water tank |

From the data presented in the figure, it is evident that the maximum axial load borne by columns in steel water tanks is observed to be highest in the case of circular tanks, reaching a peak value of 1225 kN. Axial load refers to the force applied along the longitudinal axis of a column, either in compression or tension. This finding indicates that circular steel water tanks are capable of sustaining higher vertical loads compared to their counterparts with different shapes under similar structural conditions.

# Conclusions

The conclusions from the above models are as follows:

1. From the above results it is observed that the lateral displacement (X-dir) in the case of steel water tank is found to be maximum in the circular water tank and the maximum value observed to be 37 mm.
2. From the above results it is observed that the lateral displacement (Y-dir) in the case of steel water tank is found to be maximum in the circular water tank and the maximum value observed to be 210 mm.
3. From the above results it is observed that the Drift (X-dir) in the case of steel water tank is found to be minimum in the square water tank while maximum for circular water tank.
4. From the above results it is observed that the Drift (Y-dir) in the case of steel water tank is found to be minimum in the rectangular water tank while maximum for circular water tank.
5. From the above results it is observed that Storey Shear (X-dir) in the case of steel water tank is found to be maximum in the square water tank while maximum value observed to be 300 kN.
6. From the above results it is observed that Storey Shear (Y-dir) in the case of steel water tank is found to be maximum in the square water tank while maximum value observed to be 300 kN.
7. From the above results it is observed that Max Bending Moment in Column in the case of steel water tank is found to be maximum in the circular water tank while maximum value observed to be 200 kNm.
8. From the above results it is observed that Max axial load in Column in the case of steel water tank is found to be maximum in the circular water tank while maximum value observed to be 1225 kN.

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