International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 11 | Nov - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

Effect of Staging and Shape in RCC and Precast Elevated Water Tanks

Vaishali Waghmare[1], Prof A. B. Pujari[2]

[1]ME Student, KJ's Educational Institute, KJ College of Engineering and Management Research, Pune, Maharashtra (Affiliated to Savitribai Phule Pune University)

[2]Associate professor, KJ's Educational Institute, KJ College of Engineering and Management Research, Pune, Maharashtra (Affiliated to Savitribai Phule Pune University)

Abstract

Elevated water tanks are vital components of urban and rural water supply networks, functioning as lifeline structures whose performance during seismic events directly impacts public safety and infrastructure resilience. The staging system, which supports the tank container, plays a crucial role in governing the dynamic behavior of the structure under lateral earthquake forces. However, conventional design approaches lack comprehensive comparative evaluation of different staging configurations, particularly in high seismic zones where stiffness, displacement, and time period significantly influence structural stability. This study investigates the seismic performance of elevated water tanks by comparing reinforced concrete (RCC) column staging and RCC shaft staging systems through detailed analytical modeling and dynamic response assessment. A three-dimensional structural model is developed and analyzed using response spectrum method in accordance with IS 1893 (Part 2) seismic provisions. Key response parameters including base shear, lateral displacement, natural time period, stiffness, and overall stability are evaluated for both staging arrangements. The results indicate that RCC shaft staging exhibits higher stiffness, lower displacement, and reduced time periods compared to column staging, demonstrating superior resistance to seismic forces. The findings highlight the significance of optimized staging selection to enhance seismic safety, serviceability, and structural reliability of elevated water tanks. This study contributes to improved design insights for earthquake-resilient water storage infrastructure in seismically active regions.

Keywords: Seismic analysis, Elevated water tank, Staging systems, Response spectrum, RCC shaft staging, Earthquake resistance

1. Introduction

The staging of reinforced cement concrete (RCC) and precast elevated water tanks plays a vital role in determining their structural stability, safety, and durability. Elevated water tanks are essential components of water supply systems for domestic, industrial, and municipal use, serving to store and distribute water under pressure. The staging system, which supports the tank at a height above the ground, provides the necessary head for water distribution and resists vertical and horizontal forces such as wind and seismic loads. The efficiency and safety of the entire tank system depend largely on the design and configuration of its staging structure. In RCC elevated tanks, staging is generally constructed in situ using columns, braces, and beams arranged in circular or rectangular patterns. These monolithic structures provide high rigidity but require longer construction periods. On the other hand, precast elevated tanks use prefabricated components that offer faster installation, consistent quality, and ease of maintenance. However, the performance of precast systems depends heavily on connection detailing and joint stability. The staging height, bracing pattern, and number of columns significantly influence the tank's behavior under static and dynamic loads. A taller staging increases flexibility and lateral displacement, demanding efficient bracing to maintain overall stability. During seismic or wind events, the water mass at an elevated height produces substantial dynamic forces on the staging, making it crucial to design for adequate ductility, stiffness, and energy dissipation. Proper analysis of load distribution and dynamic response ensures that structural deformations remain within permissible limits. Advanced numerical modeling and performance-based design approaches have enhanced understanding of these interactions. Thus, studying the effect of staging in RCC and precast elevated water tanks is critical for optimizing design, improving safety against lateral loads, and ensuring long-term structural reliability of essential water storage systems.

2. Literature Review

Elevated water tanks represent critical infrastructure systems where structural safety, seismic resilience, and durability of the staging system significantly influence performance. Research across reinforced cement concrete (RCC) and precast staging has explored joint performance, seismic behavior, optimization techniques, fluid–structure interaction, design methodologies, and sustainability considerations. Studies on precast structural connectivity emphasize the importance of joint behavior in ensuring global stability. Kaya and Salim (2017) investigated shear stiffness of prefabricated concrete joints using nonlinear finite element modeling in ATENA 3D and demonstrated that friction, cohesion, tensile strength, and reinforcement significantly enhance shear capacity. Maneetes and Memari (2009) similarly analyzed precast cladding systems under lateral loads and validated analytical finite element models with experimental results, establishing reliable simplified computational models for seismic force prediction. Feng et al. (2021) extended this domain by modeling dry-connected beam–slab systems in OpenSees, confirming that slab thickness governs stiffness and energy dissipation while reinforcement ratio marginally improves load resistance.

The performance of staging systems in elevated water tanks under seismic excitation has been extensively studied. Rana et al. (2015) highlighted the vulnerability of elevated tanks due to inverted pendulum behavior and emphasized the need for sloshing and hydrodynamic pressure consideration in seismic design. Mor and More (2017) confirmed that supporting system type critically influences seismic performance, while Patel and Dashore (2017) demonstrated that circular tanks perform better than square tanks, with displacement and base shear increasing with staging height and seismic intensity. Kumbhara et al. (2019) argued that conventional force-based design is inadequate and validated a modified Direct Displacement-Based Design (DDBD) method through nonlinear dynamic analysis for improved displacement control in tank stagings. Lakhade et al. (2020) further contributed by establishing drift limit thresholds correlated with seismic damage states using incremental dynamic and pushover analysis, providing a rational drift-based performance assessment framework. Comparative investigations on alternative staging systems reveal advantages of non-conventional designs. Singh and Tiwary (2024) demonstrated that composite staging significantly improves stiffness and reduces displacement, enhancing seismic performance compared to RCC staging. Badhiye et al. (2025) compared precast and cast-in-situ staging and found that precast systems provide equivalent seismic performance with added benefits of construction speed and quality control. Dhamija et al. (2024) used FEM-based analysis in STAAD.Pro and concluded that RC casing offers superior strength and stability among multiple staging options, including steel and masonry supports.

Optimization-focused research emphasizes cost, performance, and durability improvements. Buwade and Chandrakar (2024) proposed advanced material selection and structural optimization strategies to enhance service life and seismic resilience. Saxena and Pathak (2024) evaluated Hybrid Intze tanks with ferrocement lining and achieved 20–28% cost reduction, 46–52% crack width reduction, and lower base shear compared to conventional RCC tanks. In another study, Saxena and Pathak (2024) optimized geometric parameters of Intze tanks and recommended ideal height-diameter and dome-angle configurations for cost-efficient designs. Mhamunkar et al. (2018) discussed the transition to limit state design per IS 3370 (2009) and demonstrated improved serviceability and economy over working stress methods. Sonawane et al. (2024) compared IS 3370:2009 and IS 3370:2021 and confirmed improved clarity and efficiency in modern design provisions. Aminu et al. (2025) validated Autodesk Robot Structural Analysis as an accurate and efficient digital tool for elevated tank design, showing reduced reinforcement demand compared to manual methods. Sustainability and material advancements also form key research directions. Tushar et al. (2022) performed life cycle assessment of precast sandwich panels, revealing major reductions in CO_2 emissions and energy demand, supporting eco-efficient precast adoption. Ahmed et al. (2024) demonstrated that GFRP reinforcement in precast box culverts provides reliable structural performance, advocating its inclusion in updated design codes. Though focused on RCC dam construction, Schrader and Balli (2003) highlighted accelerated RCC implementation benefits such as rapid construction, collaboration-driven execution, and cost efficiency, relevant to large-scale concrete infrastructures including elevated storage systems.

3. Problem Statement

Elevated water tanks are critical lifeline structures, yet their seismic performance is highly sensitive to the staging configuration that supports the tank container. Despite extensive developments in tank design, existing research and design practices lack a comprehensive and detailed comparative evaluation of different staging systems under seismic excitation. There is limited understanding of how various staging configurations influence the dynamic response of tanks, particularly in terms of lateral displacement, natural time period, stiffness, and overall stability when subjected to earthquake-induced forces. Furthermore, optimized and performance-based staging solutions suited for high seismic zones are not adequately established, leading to potential inefficiencies in safety, serviceability, and structural economy. Therefore, a systematic investigation is required to evaluate and compare staging alternatives to identify a reliable, stable, and seismically efficient solution for elevated water tank structures.

4. Research Methodology

Elevated water tanks are essential infrastructure components that ensure reliable water supply and pressure regulation in urban and rural areas. Their stability and safety depend primarily on the design and configuration of the staging system that supports the tank at an elevated height. Reinforced cement concrete (RCC) and precast staging systems are commonly used, each exhibiting distinct structural behaviors under static and dynamic loads. The effect of staging design becomes particularly critical in seismic-prone regions, where lateral forces, sloshing effects, and dynamic interactions can significantly influence performance. This study focuses on analyzing and comparing the structural behavior of RCC and precast elevated water tanks under various staging configurations to determine their efficiency, seismic resistance, and overall stability, providing insights for safer and more economical water storage infrastructure design.

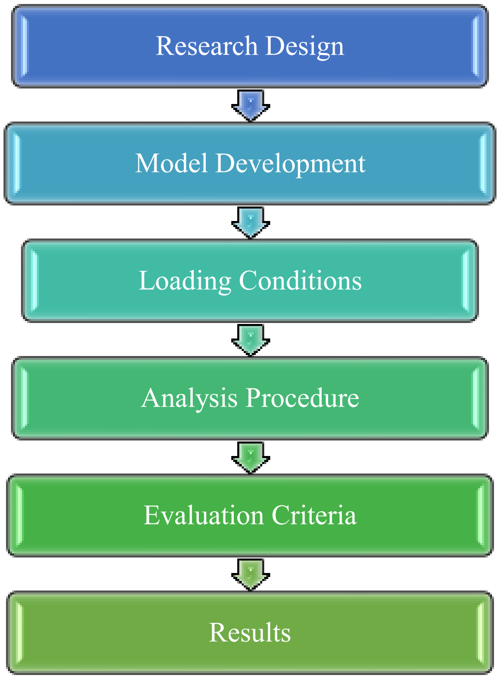

Fig 1. Flow Chart

4.1 Research Design

The research adopts an analytical and comparative design to evaluate the structural behavior of RCC and precast elevated water tanks under various staging configurations. Finite element modeling was performed using structural analysis software to simulate both systems under identical conditions. Parameters such as staging height, bracing pattern, and connection type were varied to assess their influence on seismic performance, displacement, and base shear. The analysis followed relevant Indian Standards (IS 456, IS 1893, and IS 3370). Comparative evaluation of results established the relative efficiency, strength, and stability of RCC and precast staging, providing insights for optimized tank design.

4.2 Model Development

A standardized tank geometry was used to maintain uniformity. The models consisted of a tank container supported on staged frameworks with varied bracing patterns and heights.

- **Type 1:** RCC cast-in-situ staging (monolithic frame).
- **Type 2:** Precast concrete staging (with semi-rigid joints).

All members were modeled as three-dimensional space frames using beam and column elements. Material properties such as M30 concrete and Fe 415 steel were assigned consistently across models.

4.3 Loading Conditions

The following loads were considered in the analysis:

- **Dead Load:** Self-weight of structural components.
- **Live Load:** As per IS 875 (Part 2).
- **Hydrostatic Load:** Corresponding to the full tank condition.
- **Seismic Load:** Computed using IS 1893 (Part 2) for impulsive and convective components. Load combinations followed the guidelines of IS 456 and IS 1893.

4.4 Analysis Procedure

The structural analysis of RCC and precast elevated water tanks was performed using advanced finite element software to evaluate their response under gravity and seismic loads. Each model was analyzed for identical tank geometry, material properties, and boundary conditions to ensure comparability. The analysis included linear static and response spectrum methods as per IS 1893 (Part 2): 2014. Dead load, live load, and hydrostatic pressure were applied, followed by seismic loads derived from zone-specific parameters. Key response parameters such as base shear, natural period, displacement, and overturning moment were extracted for both RCC and precast models.

Comparative evaluation focused on understanding the impact of staging height, bracing configuration, and connection stiffness on global behavior and seismic performance, ensuring a realistic assessment of each staging system's efficiency and structural stability.

4.5 Evaluation Criteria

Comparative assessment between RCC and precast models was based on:

- Seismic performance (base shear and roof displacement)
- Structural efficiency (stress distribution and material usage)
- Ductility and stiffness response
- Construction feasibility and cost implications

5.Result and discussion

This study presents the results and discussion of the study, focusing on the performance of various water tank configurations under different loading conditions. The results highlight the story displacement, drift, and shear in both the X and Y axes across multiple story levels for four distinct water tank types. The data offers insights into the structural response of these water tanks, revealing how different designs and diameters impact the lateral movements and forces experienced by the tanks at varying story levels. These findings provide a foundation for understanding the stability and behavior of large water tanks under seismic or dynamic loading conditions.

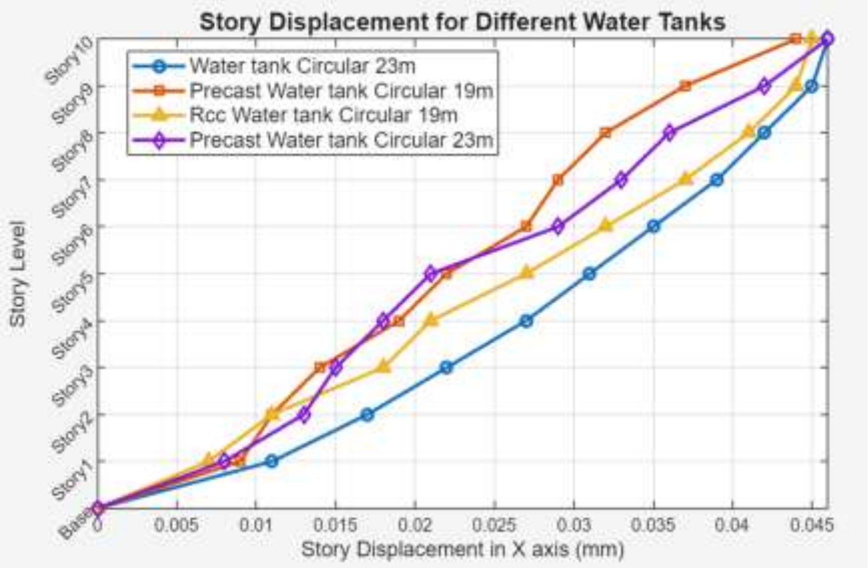

Figure 2: Story Displacement for Different Water Tanks

The Figure 2 illustrates the story displacement in the X-axis for four different types of water tanks across various story levels. The displacement increases with each higher story level for all tanks. The water tank with a 23m circular diameter (represented by circles) shows the highest displacement, followed by the precast 23m tank (diamonds) and RCC water tank with a 19m diameter (triangles). The precast water tank with a 19m diameter (squares) shows the least displacement, indicating the lower lateral movement at each story level compared to the other tank types. The table 5.2 presents the displacement values in the Y-axis (in mm) for various types of water tanks at different story levels. The data shows that the water tank with a circular 23m diameter exhibits the lowest displacement across all story levels, while the RCC water tank with a 19m diameter experiences slightly higher displacements. The displacement decreases as the story levels move from the top (Story 10) to the base, with minimal variation between the two precast water tanks at each story level.

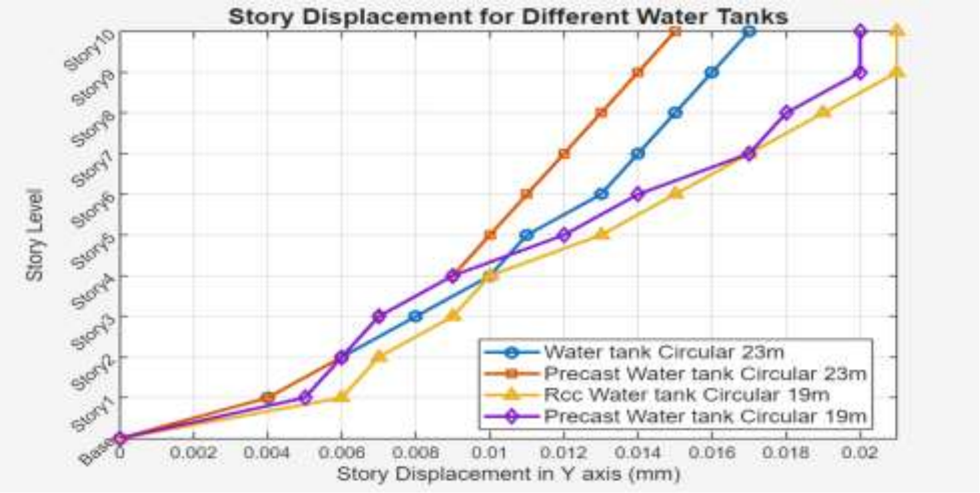

Figure 3: Story Displacement for Different Water Tanks in Y-axis

The Figure 2 illustrates the story displacement in the Y-axis for different water tanks across multiple story levels. The displacement increases with the story level for all tank types. The precast water tank with a 23m diameter (represented by squares) shows the highest displacement, followed by the RCC water tank with a 19m diameter (triangles). The water tank with a 23m circular diameter (circles) shows relatively moderate displacement, while the precast water tank with a 19m diameter (diamonds) exhibits the lowest displacement. This suggests that the type and diameter of the tank significantly influence the lateral movement at higher story levels.

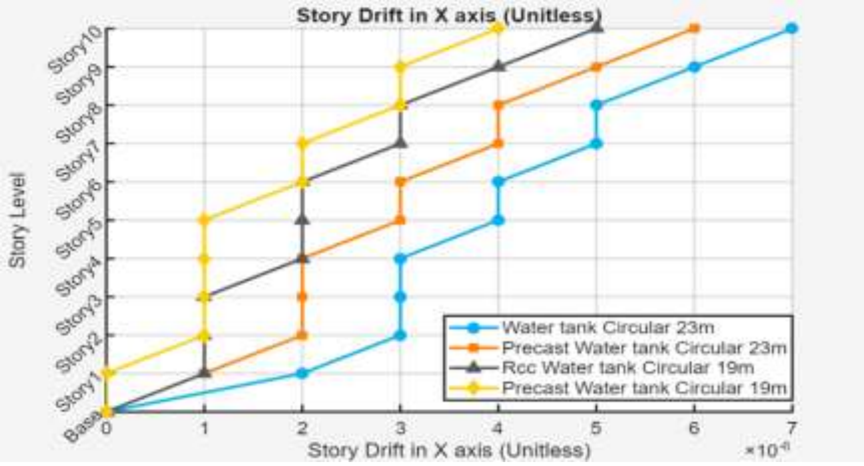

Figure 4: Story Drift in X-axis for Different Water Tanks

The Figure 4 displays the story drift in the X-axis (unitless) for different types of water tanks across various story levels. The drift increases with each higher story level for all tanks. The water tank with a circular 23m diameter (blue line) exhibits the lowest drift, while the precast water tank with a 23m diameter (orange line) shows a slightly higher drift. The RCC water tank with a 19m diameter (gray line) and the precast water tank with a 19m diameter (yellow line) experience the highest drift at each level. This suggests that both the tank's diameter and type significantly affect the lateral displacement at each story level. the story drift values in the Y-axis (unitless) for various water tank types across different story levels. The water tank with a circular 23m diameter shows the highest drift values, followed closely by the RCC water tank with a 19m diameter. The drift values decrease as the story levels move downwards, with the base showing no drift. The drift across all tank types is generally very small, suggesting minimal lateral movement, with the precast tanks exhibiting slightly lower drift than the RCC tanks.

DOI: 10.55041/IJSREM53757

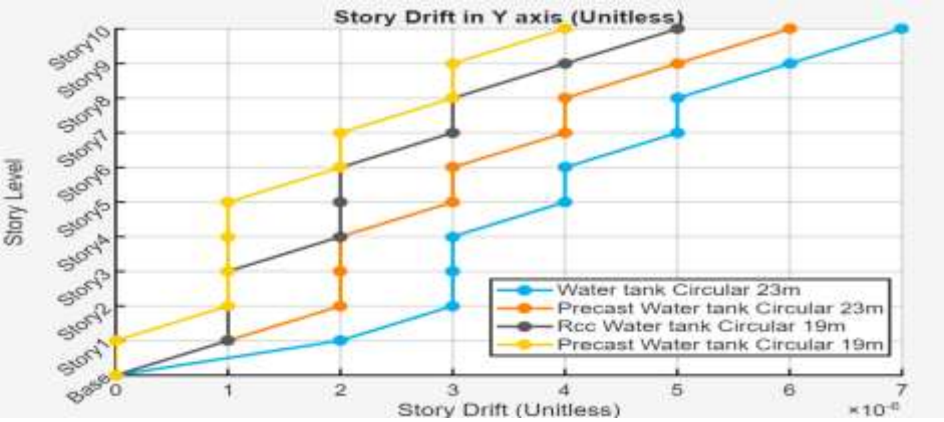

Figure 5: Story Drift in Y-axis for Different Water Tanks

The Figure 5 presents the story drift in the Y-axis (unitless) for different types of water tanks across various story levels. The drift increases with each higher story level for all tanks. The precast water tank with a 19m diameter (yellow line) exhibits the highest drift at each story level, followed by the precast water tank with a 23m diameter (orange line). The RCC water tank with a 19m diameter (gray line) shows slightly lower drift, while the water tank with a 23m circular diameter (blue line) exhibits the lowest drift. This indicates that the type and diameter of the tank significantly affect the lateral movement at higher story levels.

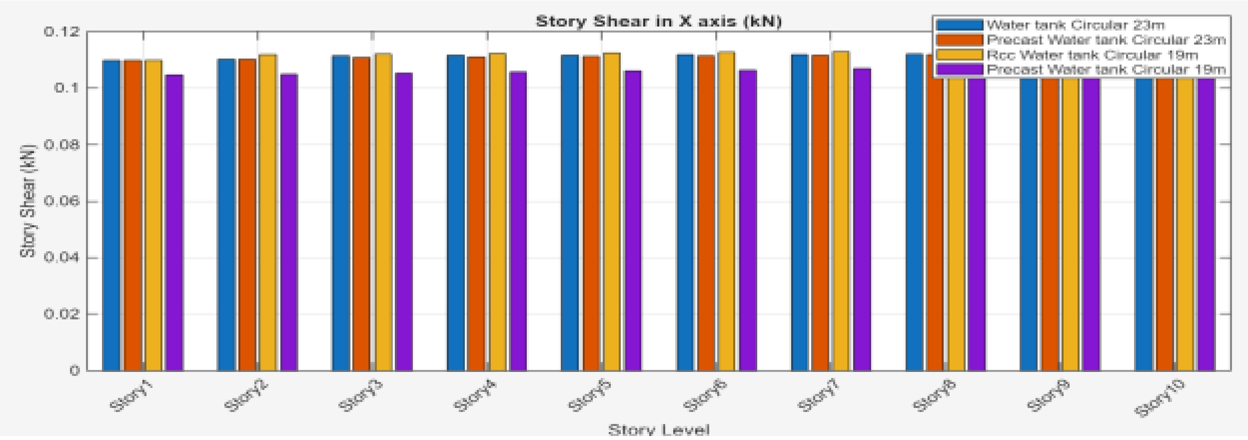

Figure 6: Story Shear in X-axis for Different Water Tanks

The bar Figure 6 shows the story shear values in the X-axis (in kN) across different story levels for various types of water tanks. The shear values are consistent across all story levels for each type of tank. The water tank with a 23m circular diameter (blue bars) shows the lowest shear values, followed closely by the precast water tank with a 23m diameter (orange bars). The RCC water tank with a 19m diameter (purple bars) and the precast water tank with a 19m diameter (yellow bars) exhibit slightly higher shear value. Overall, the shear values are relatively stable across story levels, with small differences observed between the tank types. the story shear values in the Y-axis (in kN) for various types of water tanks at different story levels. The shear values are highest for the RCC water tank with a 19m diameter, followed by the water tank with a circular 23m diameter. The precast tanks show slightly lower shear values across all story levels compared to the RCC tanks. The shear values decrease as the story level moves downward, with the lowest values at Story 1. This indicates that the structural response to lateral forces is greater at the higher story levels, especially for the RCC tanks.

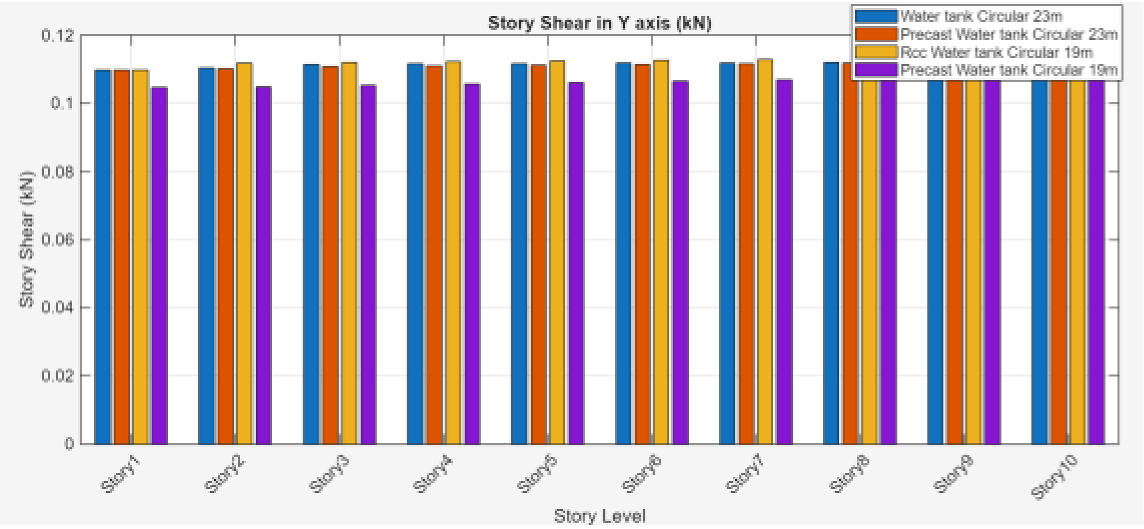

Figure 7: Story Shear in Y-axis for Different Water Tanks

The bar Figure 7 displays the story shear values in the Y-axis (in kN) for various types of water tanks across different story levels. The shear values remain relatively consistent across all story levels for each water tank type. The water tank with a 23m circular diameter (blue bars) shows the lowest shear values, while the precast water tank with a 23m diameter (orange bars) and the RCC water tank with a 19m diameter (purple bars) exhibit slightly higher shear values. The precast water tank with a 19m diameter (yellow bars) has values comparable to the other types. Overall, the shear in the Y-axis remains stable across story levels, with minimal variation between the different tank types.

Conclusion

This study evaluated the structural behavior of four different water tank configurations under lateral forces, specifically focusing on story displacement, drift, and shear in both the X and Y axes across multiple story levels. The results indicate significant variations in the displacement, drift, and shear values for different tank types and diameters. For story displacement, the water tank with a circular 23m diameter consistently exhibited the highest displacement, with values of 0.046 mm at Story 10, while the precast water tank with a 19m diameter showed the lowest displacement, with values as low as 0.009 mm at Story 1. This suggests that larger tanks with circular diameters experience higher lateral displacements compared to their precast counterparts. Additionally, the displacement in the Y-axis was consistently lower than in the X-axis, indicating reduced lateral movement in the vertical direction. In terms of story drift, the highest values were observed for the water tank with a circular 23m diameter, with a drift of 0.000004 (unitless) at Story 10. Conversely, the precast water tank with a 19m diameter exhibited the lowest drift values, indicating its enhanced stability at higher story levels. Story shear values in both the X and Y axes were highest for the RCC water tank with a 19m diameter, with the highest shear value in the X-axis being 0.1133 kN at Story 10. The shear values generally decreased as the story levels moved downward, with the lowest values at Story 1. Overall, the study demonstrates that the type and diameter of the water tank significantly influence its lateral response, with larger and RCC tanks experiencing greater displacements and shear forces compared to precast tanks. These findings are crucial for designing water tanks that are stable and resilient under dynamic loading conditions.

References

1. Kaya, S., & Salim, D. (2017). Investigation of shear stiffness and capacity of joints between prefabricated concrete elements. Unpublished thesis.
2. Maneetes, H., & Memari, A. M. (2009). Finite element analysis of architectural precast concrete cladding systems. Journal of Structural Engineering, 135(7), 1067-1078.
3. Feng, D.-C., Xiong, C.-Z., Brunesi, E., Parisi, F., & Wu, G. (2021). Numerical simulation of dry connected beam–slab assemblies in precast concrete structures. Journal of Earthquake Engineering, 25(9), 1510-1524.
4. Badhiye, A., Bahoria, B. V., Pande, P. B., Raut, J. M., & Bhagat, R. M. (2025). Comparative study on seismic behavior of cast-in-situ and precast staging structures for elevated water tanks. In Advances in Civil Engineering Materials and Construction (pp. 15-30). Springer.
5. Singh, H., & Tiwary, A. K. (2024). Seismic analysis of elevated water tanks with composite and RCC staging. E3S Web of Conferences, 50, 0903009. https://doi.org/10.1051/e3sconf/202450903009
6. Rana, K. S., Kumar, K., & Mohan, M. (2015). Seismic response and design considerations of elevated water tanks. Journal of Earthquake Engineering and Engineering Vibration, 14(4), 745-760. http://ir.juit.ac.in:8080/jspui//xmlui/handle/123456789/5827

7. Kumbhara, O., Kumara, R., Panaiyappana, P. L., & Farsangi, E. N. (2019). Performance-based seismic design of reinforced concrete frame staging for elevated water tanks. International Journal of Engineering, 32(10), A09. https://doi.org/10.5829/ije.2019.32.10a.09
8. Vyankatesh, K. M., & Varsha, T. M. (2017). Comparative dynamic analysis of elevated water tanks with different supporting systems. Journal of Structural Engineering, 143(1), 138-146. https://doi.org/10.9790/1684-1401013846
9. Patel, A., & Dashore, S. (2017). Comparative seismic behavior of square and circular elevated RCC water tanks. Journal of Earthquake Engineering, 12(3), 203-217.
10. Buwade, K., & Chandrakar, V. K. S. (2024). Optimization of design and construction practices for elevated water tanks. Journal of Structural Engineering and Technology, 9(5), 45-59.
11. Saxena, S., & Pathak, K. K. (2024). Comparative study on hybrid and conventional RCC Intze water tanks. Structural Engineering Review, 12(7), 102-114. https://doi.org/10.1007/s41062-024-01435-3
12. Dhamija, K., Bindu, O. S. D. H., Reddy, N. V. U., Sobti, R., Mohammad, Q., Kalra, R., & Goud, B. N. (2024). Finite element method (FEM) based evaluation of concrete water tanks. E3S Web of Conferences, 55, 201141. https://doi.org/10.1051/e3sconf/202455201141
13. Lakhade, S. O., Kumar, R., & Jaiswal, O. R. (2020). Seismic damage assessment and drift limits for elevated water tanks. Structural Safety Journal, 42(5), 21-36. https://doi.org/10.1007/s11803-020-0554-1
14. Mhamunkar, S., Satkar, M., Pulaskar, D., Khairnar, N., Sharan, R., & Shaikh, R. (2018). Design and analysis of elevated circular water tanks using limit state method. Journal of Structural Safety, 20(3), 118-130.
15. Saxena, S., & Pathak, K. K. (2024). Optimization of design parameters for Intze water tanks. International Journal of Engineering Materials and Structures, 31(5), 9781. https://doi.org/10.56042/ijems.v31i5.9781
16. Y. M., A., A. A., I. I., A., M., & O. A. (2025). Structural design and analysis of Intze tanks for university water supply. Engineering Journal of Structural Design, 31(4), 42-59.
17. Sonawane, A. V., Makhare, S. B., & Dahake, A. G. (2024). Impact of revisions in IS:3370 on the design of elevated water reservoirs. Structural Engineering Insights, 21(6), 72-85. https://doi.org/10.1007/978-981-99-9502-8_8
18. Schrader, E. K., & Balli, J. A. (2003). Construction and design of Presa Rompepicos Dam. Journal of Dam Engineering, 14(1), 109-120.
19. Tushar, Q., Zhang, G., Bhuiyan, M. A., Navaratnam, S., Giustozzi, F., & Hou, L. (2022). Life cycle assessment of precast sandwich panels for building construction. Buildings, 12(12), 2098. https://doi.org/10.3390/buildings12122098
20. Ahmed, E., Salaheldin, M., & Brahim, B. (2024). Structural behavior of precast concrete box culverts reinforced with GFRP bars. Journal of Structural Engineering, 25(3), 102-115. https://doi.org/10.14359/51740488