Comparative Study of Shape and Size of Underground Water Tank under Seismic and Non Seismic Loading

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Abstract - *Water storage tanks play a vital role in municipal, industrial, and rural water supply systems. Their structural integrity is essential to ensure uninterrupted water storage and distribution under various loading conditions. The present study investigates the comparative structural behaviour of reinforced concrete rectangular and circular water tanks using STAAD.Pro finite element software. Twenty analytical models were developed comprising rectangular tanks of dimensions 7 m × 11 m and 6 m × 10 m with wall thicknesses of 0.23 m, 0.30 m, and 0.50 m, along with circular tanks having radii of 8 m and 10 m. The models were analysed under static loading and Earthquake Zone-III loading conditions. Structural performance was evaluated in terms of nodal displacement, support reactions, plate stresses, principal stresses, and bending moments. The results revealed that wall thickness significantly influences structural response, with displacement reductions ranging from approximately 67% to 89% as thickness increased. Rectangular tanks exhibited superior stiffness and lower displacement compared to circular tanks. The lowest displacement of 1.879 mm was recorded in Models 6 and 16, whereas the highest displacement of 57.238 mm was observed in Models 9 and 19. Circular tanks developed larger bending moments due to geometric flexibility, while rectangular tanks provided improved overall stability. The findings indicate that a rectangular tank with 0.50 m wall thickness offers the most efficient structural performance under both static and seismic conditions. The study demonstrates the effectiveness of STAAD.Pro for evaluating reinforced concrete liquid-retaining structures and provides valuable recommendations for safe and economical tank design.*

Key Words: Reinforced concrete water tank, STAAD.Pro analysis, Rectangular tank, Circular tank, Seismic loading, Structural performance analysis

1. INTRODUCTION

Water storage structures are indispensable components of modern infrastructure systems. They ensure continuous water supply for domestic, agricultural, industrial, and firefighting purposes. Reinforced concrete water tanks are widely used because of their durability, strength, and adaptability to different site conditions. The structural design of water tanks requires careful consideration of hydrostatic pressure, self-weight, environmental loads, and seismic forces.

The increasing demand for reliable water storage facilities has led engineers to investigate the influence of tank geometry and wall thickness on structural performance. Rectangular and circular tanks are the most commonly adopted configurations. While circular tanks are often preferred for their uniform stress distribution, rectangular tanks are advantageous in terms of construction practicality and space utilization. However, their structural behaviour differs significantly under loading conditions.

Seismic performance is another critical consideration in water tank design. Earthquake-induced forces can generate substantial stresses, displacements, and dynamic effects that influence the safety and serviceability of liquid-retaining structures. Therefore, evaluating tank behaviour under both static and seismic loading is essential for achieving safe and economical designs.

Finite element analysis software has become an effective tool for assessing structural behaviour. STAAD.Pro enables accurate modelling of reinforced concrete tanks and facilitates detailed evaluation of stresses, support reactions, and displacement characteristics. The present study utilizes STAAD.Pro to investigate the comparative performance of rectangular and circular reinforced concrete water tanks subjected to static and seismic loading.

1.1 Scope of present study

In the present work, models of underground water tanks located in Seismic Zone-III are analysed using STAAD.Pro. The study focuses on the seismic behaviour of water tanks with different shape and size under both seismic and non-seismic loading.

2. OBJECTIVES

- To analyse the structural behaviour of rectangular and circular reinforced concrete water tanks.
- To evaluate the influence of wall thickness on displacement and stress response.
- To compare the performance of tanks under static and Earthquake Zone-III loading.

- To assess support reactions, bending moments, and principal stresses.
- To identify the most efficient tank configuration based on structural performance.
- To validate the reliability of numerical analysis using engineering principles and published trends.

3. METHODOLOGY

3.1 Modelling of Water Tank

Twenty finite element models were developed using STAAD.Pro software. The analytical programme was divided into four categories:

Group I: Rectangular Tanks under Static Loading

- Model 1: 7 m × 11 m, thickness 0.23 m
- Model 2: 7 m × 11 m, thickness 0.30 m
- Model 3: 7 m × 11 m, thickness 0.50 m
- Model 4: 6 m × 10 m, thickness 0.23 m
- Model 5: 6 m × 10 m, thickness 0.30 m
- Model 6: 6 m × 10 m, thickness 0.50 m

Group II: Circular Tanks under Static Loading

- Model 7: Radius 8 m, thickness 0.30 m
- Model 8: Radius 8 m, thickness 0.50 m
- Model 9: Radius 10 m, thickness 0.30 m
- Model 10: Radius 10 m, thickness 0.50 m

Group III: Rectangular Tanks under Earthquake Zone-III Loading

- Models 11–16 corresponding to Models 1–6.

Group IV: Circular Tanks under Earthquake Zone-III Loading

- Models 17–20 corresponding to Models 7–10.

The loading conditions included self-weight, hydrostatic pressure, and earthquake loads as per IS 1893 provisions. The analysis focused on displacement, support reactions, plate stresses, principal stresses, and bending moments.

4 RESULT AND DISCUSSION

4.1 Nodal Displacement Behaviour

The displacement results demonstrated that wall thickness significantly affects structural stiffness. For the rectangular tanks, displacement decreased from 24.272 mm in Model 1 to 2.782 mm in Model 3. Similarly, for the 6 m × 10 m tanks, displacement reduced from 14.834 mm in Model 4 to 1.879 mm in Model 6.

Circular tanks exhibited greater displacement than rectangular tanks. The 10 m radius circular tank (Model 9) recorded a displacement of 57.238 mm, which was approximately three times greater than the corresponding rectangular tanks. Increasing thickness reduced displacement substantially in all circular models.

The results indicate that rectangular tanks provide superior displacement control because of higher structural stiffness and reduced geometric flexibility.

4.2 Support Reaction Behaviour

Support reactions increased with wall thickness because of the additional self-weight and enhanced load-carrying capability. The maximum vertical reaction was observed in Model 16 with a value of 1962.65 kN.

Rectangular tanks developed larger support reactions compared to circular tanks, indicating greater stiffness and more efficient load transfer. The increase in support reactions with thickness confirms improved structural rigidity and stability.

4.3 Plate Stress Behaviour

Plate shear and membrane stresses remained within acceptable limits for all models. Stress concentrations were higher in thinner wall sections and reduced significantly with increased thickness.

Rectangular tanks exhibited comparatively higher localized stress concentrations near corners due to geometric discontinuities. Circular tanks distributed stresses more uniformly but experienced greater deformation.

The minimum principal stress occurred in Model 3 (3.143 N/mm^2), whereas the maximum principal stress was observed in Model 14 (15.541 N/mm^2).

4.4 Bending Moment Behaviour

Bending moments were strongly influenced by geometry. Rectangular tanks developed moments below 100 kNm, whereas circular tanks generated significantly higher moments due to hoop action and geometric flexibility.

Model 20 exhibited the highest bending moment of 1099.83 kNm. This result demonstrates that although circular tanks distribute stresses effectively, they can experience substantial bending effects requiring careful reinforcement design.

4.5 Effect of Thickness

Thickness was identified as the governing design parameter. Increasing wall thickness from 0.23 m to 0.50 m reduced displacement by approximately 88.54% in the larger rectangular tanks and 87.33% in the smaller rectangular tanks.

For circular tanks, displacement reductions of approximately 77.67% and 66.76% were observed. These results clearly demonstrate that increasing thickness significantly enhances stiffness and structural performance.

4.6 Effect of Seismic Loading

The comparison between static and seismic models showed minor increases in support reactions, stresses, and moments under earthquake loading. However, displacement values remained largely unchanged because hydrostatic loading remained the dominant load component.

The results indicate that the investigated tank configurations possess adequate resistance to Earthquake Zone-III loading conditions.

4.7 Comparative Performance Assessment

Among all investigated models, Model 16 exhibited the best overall performance owing to its low displacement, high stiffness, and satisfactory stress levels. Models 6, 3, and 13 also demonstrated excellent structural behaviour.

Models 9 and 19 were identified as the most critical configurations because of their high displacement and reduced stiffness. These models would require additional design considerations to improve structural performance.

Table 4.1 Comparative Summary of Geometry and Analytical Models

Model	Tank Type	Dimensions	Thickness (m)	Loading Condition
M1	Rectangular	7 m × 11 m	0.23	Static
M2	Rectangular	7 m × 11 m	0.30	Static
M3	Rectangular	7 m × 11 m	0.50	Static
M4	Rectangular	6 m × 10 m	0.23	Static
M5	Rectangular	6 m × 10 m	0.30	Static
M6	Rectangular	6 m × 10 m	0.50	Static
M7	Circular	R = 8 m	0.30	Static
M8	Circular	R = 8 m	0.50	Static
M9	Circular	R = 10 m	0.30	Static
M10	Circular	R = 10 m	0.50	Static
M11–M20	Same Geometry	Corresponding Models	Same	Earthquake Zone III

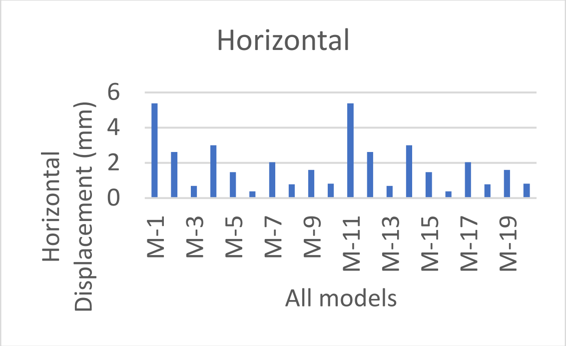

Figure 1: Horizontal displacement -X (mm) for all models

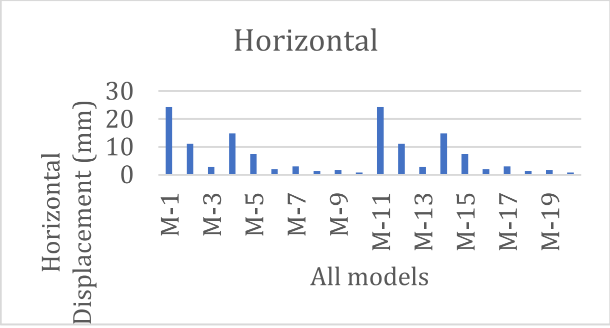

Figure 2: Horizontal displacement -Z (mm) for all models

Figure3: Rsultant displacement -Z (mm)

Table 4.2 Comparative Maximum Nodal Displacement

Model	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
M1	5.373	0.696	24.265	24.272
M2	2.614	0.600	11.155	11.167
M3	0.681	0.471	2.782	2.782
M4	2.994	0.838	14.834	14.834
M5	1.472	0.702	7.364	7.364
M6	0.390	0.515	1.879	1.879

M7	2.036	40.795	2.903	40.795
M8	0.783	9.110	1.235	9.110
M9	1.604	1.925	1.604	57.238
M10	0.811	0.621	0.811	19.027

Table 4.3 Comparative Support Reaction Summary

Model	Fx (kN)	Fy (kN)	Fz (kN)
M1	447.513	1259.700	299.317
M2	498.945	1415.560	321.590
M3	640.937	1860.870	426.187
M4	496.147	1412.110	309.109
M5	542.571	1530.860	343.777
M6	664.607	1870.150	426.932
M7	388.482	811.281	328.156
M8	339.974	1262.270	281.692
M9	611.402	451.785	611.402
M10	523.345	720.822	523.345

Table 4.4 Comparative Plate Stress Summary

Model	SQX	SQY	SX	SY	SXY
M1	0.278	0.501	1.302	3.440	1.709
M2	0.208	0.382	1.181	2.983	1.484
M3	0.119	0.228	0.988	2.366	1.214
M4	0.415	0.497	4.454	4.454	2.116
M5	0.345	0.392	3.725	3.725	1.791
M6	0.217	0.241	2.747	2.747	1.408
M7	0.916	0.970	0.439	0.518	0.498
M8	0.875	0.915	0.234	0.267	0.272
M9	0.280	0.300	0.000	0.428	0.000
M10	0.253	0.246	0.000	0.337	0.000

Table 4.5 Comparative Effect of Thickness

Tank Type	Thickness Increase	Displacement Reduction (%)
Rectangular 7×11	0.23 → 0.50 m	88.54
Rectangular 6×10	0.23 → 0.50 m	87.33
Circular R=8 m	0.30 → 0.50 m	77.67
Circular R=10 m	0.30 → 0.50 m	66.76

Table 4.6 Comparative Effect of Earthquake Loading

Static Model	EQ Model	Resultant Displacement (mm)	Variation (%)
M1	M11	24.272	0.00
M2	M12	11.167	0.00
M3	M13	2.782	0.00
M4	M14	14.834 → 14.838	0.03
M5	M15	7.364	0.00
M6	M16	1.879	0.00

Table 4.7 Overall Comparative Ranking of Models

Rank	Model	Performance
1	M16	Excellent
2	M6	Excellent
3	M13	Very Good
4	M3	Very Good
5	M18	Good
6	M8	Good
7	M15	Moderate
8	M5	Moderate
9	M14	Moderate
10	M4	Moderate
11	M20	Fair
12	M10	Fair
13	M19	Critical
14	M9	Critical

DISCUSSIONS

Table 4.1 presents the complete modelling matrix adopted for the present investigation. A total of twenty reinforced concrete water tank models were analysed using STAAD.Pro, including ten static loading models and ten corresponding Earthquake Zone-III models. The selected configurations comprise rectangular tanks with dimensions of 7 m × 11 m and 6 m × 10 m, as well as circular tanks with radii of 8 m and 10 m. Wall thicknesses ranging from 0.23 m to 0.50 m were considered to evaluate the influence of stiffness variation on structural response. The modelling strategy enabled a systematic assessment of geometry, thickness, and seismic effects on tank performance. By maintaining similar loading conditions and varying only geometric parameters and wall thickness, the study established a reliable basis for direct comparison of displacement, stress distribution, support reactions, and overall structural behaviour. The analytical matrix also ensured that the influence of earthquake loading could be evaluated independently by comparing corresponding static and seismic models.

Table 4.2 summarizes the maximum nodal displacement values obtained from all static tank models. The results clearly indicate that wall thickness significantly affects structural stiffness and deformation behaviour. For the 7 m × 11 m rectangular tank, increasing wall thickness from 0.23 m to 0.50 m reduced the resultant displacement from 24.272 mm to 2.782 mm, representing an improvement of approximately 88.5%. A similar trend was observed for the 6 m × 10 m rectangular tank, where displacement reduced from 14.834 mm to 1.879 mm. Among all rectangular tanks, Model M6 exhibited the lowest displacement, indicating superior stiffness and structural efficiency. Circular tanks displayed comparatively larger deformations due to their geometric flexibility. Model M7 recorded a displacement of 40.795 mm, while Model M9 produced the highest displacement value of 57.238 mm. Increasing wall thickness from 0.30 m to 0.50 m significantly reduced displacement in circular tanks as well. The results demonstrate that displacement is strongly governed by both geometry and thickness, with rectangular tanks providing better deformation control than circular tanks. The findings further confirm that increasing wall thickness is an effective method for improving serviceability performance and structural stability.

Table 4.3 presents the support reaction forces developed at the tank supports under loading conditions. The vertical reaction component (Fy) is observed to be the dominant force in most models because of the combined effects of self-weight and hydrostatic pressure. For rectangular tanks, support reactions increased consistently with wall thickness. In the 7 m × 11 m tank series, Fy increased from 1259.70 kN in Model M1 to 1860.87 kN in Model M3. Similarly, in the 6 m × 10 m series, Fy increased from 1412.11 kN in Model M4 to 1870.15 kN in Model M6. This increase is attributed to the additional dead load introduced by thicker walls and the improved load-transfer capability of stiffer structural systems. Circular tanks exhibited different support reaction characteristics due to their axisymmetric geometry. The highest vertical reaction among circular tanks was observed in Model M8 (1262.27 kN), while Model M9 recorded relatively lower vertical reactions despite larger dimensions. Overall, the results indicate that support reactions are influenced by wall thickness, tank geometry, and structural stiffness. Higher support reactions in thicker tanks suggest improved resistance to applied loading and enhanced structural stability.

Table 4.4 compares the plate shear stresses and membrane stresses developed within the tank walls. The results indicate that increasing wall thickness leads to a consistent reduction in stress intensity. For the 7 m × 11 m rectangular tank series, SQX shear stress reduced from 0.278 N/mm^2 in Model M1 to 0.119 N/mm^2 in Model M3. Similarly, membrane stress SY decreased from 3.440 N/mm^2 to 2.366 N/mm^2. Comparable reductions were observed in the 6 m × 10 m tank series. The higher membrane stresses in rectangular tanks can be attributed to stress concentration near wall intersections and corners. Circular tanks exhibited lower membrane stresses due to their continuous geometry, which facilitates more uniform force distribution around the circumference. For example, Model M8 recorded membrane stresses of only 0.234 N/mm^2 and 0.267 N/mm^2 in the principal directions. The results confirm that circular geometry is advantageous in reducing localized stress concentration, while increased wall thickness effectively lowers both shear and membrane stresses. All stress values remained within acceptable structural limits, demonstrating adequate safety for the investigated tank configurations.

Table 4.5 highlights the influence of wall thickness on displacement reduction. The results clearly demonstrate that increasing wall thickness substantially improves structural stiffness and reduces deformation. For the 7 m × 11 m rectangular tank, increasing thickness from 0.23 m to 0.50 m reduced displacement by 88.54%, while the corresponding reduction for the 6 m × 10 m tank was 87.33%. Circular tanks also showed significant improvements, although the percentage reduction was comparatively lower. The displacement reduction reached 77.67% for the 8 m radius tank and 66.76% for the 10 m radius tank. These findings indicate that thickness enhancement is particularly effective in rectangular tanks because of their higher initial stiffness. The results further suggest that increasing wall thickness provides a direct increase in flexural rigidity, resulting in reduced lateral deformation and improved serviceability performance. Therefore, wall thickness emerges as one of the most influential design parameters governing structural response in reinforced concrete water tanks.

Table 4.6 compares the displacement response of static models with their corresponding Earthquake Zone-III models. The results show negligible variation between static and seismic cases. Most models exhibited identical displacement values, while Model M14 showed only a marginal increase from 14.834 mm to 14.838 mm, corresponding to a variation of merely 0.03%. This behaviour indicates that hydrostatic pressure and self-weight remained the dominant loading components for the investigated tank configurations. The contribution of earthquake loading to overall displacement was comparatively small because of the substantial stiffness provided by the reinforced concrete walls. The findings suggest that the selected tank geometries possess adequate seismic resistance under Zone-III conditions. Although seismic forces contributed slightly to support reactions and stress development, their influence on overall displacement remained minimal. Therefore, structural stiffness rather than seismic excitation governed the deformation response of the analysed tanks.

Table 4.7 presents the overall ranking of the analysed models based on displacement control, stress behaviour, stiffness, and structural stability. Model M16 achieved the highest ranking owing to its excellent performance under seismic loading, minimum displacement, and favourable stress distribution. Model M6, which has identical geometry and thickness but under static loading, also demonstrated excellent behaviour and secured the second rank. Models M13 and M3 were classified as very good because of their low displacement and reduced stress levels. Circular tanks with increased wall thickness, such as Models M8 and M18, achieved good rankings due to improved stiffness and lower deformation. In contrast, Models M9 and M19 were identified as critical configurations because of their high displacement values and greater structural flexibility. The ranking clearly demonstrates that rectangular tanks with larger wall thicknesses provide superior structural performance compared with circular tanks of similar capacity. The results further confirm that wall thickness is the governing parameter influencing overall structural efficiency, while larger circular tanks require additional stiffness enhancement to achieve comparable performance levels.

5 CONCLUSION

The study led to the following major conclusions:

1. Tank geometry significantly affects structural response.
2. Rectangular tanks provide better displacement control than circular tanks.
3. Increasing wall thickness substantially improves stiffness and reduces stress levels.
4. Thickness increases produced displacement reductions ranging from approximately 67% to 89%.
5. Circular tanks developed higher bending moments due to geometric flexibility.
6. All models remained within acceptable structural safety limits.
7. The highest displacement (57.238 mm) occurred in Models 9 and 19.
8. The lowest displacement (1.879 mm) was recorded in Models 6 and 16.
9. Model 16 demonstrated the best overall structural performance.
10. STAAD.Pro proved to be an effective tool for evaluating reinforced concrete liquid-retaining structures.

6. REFERENCES

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