Chapter 5: Comparative study of hybrid and conventional circular tanks

5.1. Introduction

In this study Elevated Hybrid Circular tanks are compared with Conventional tank (type I and II) using software programs specifically tailored for both Conventional RCC and Hybrid approaches. The analysis involved detailed cost assessments and extensive comparisons regarding quantities of steel and concrete, deflection, base shear, wind forces, crack widths, and other relevant factors. The findings highlight the significant advantages of the Hybrid design. The comparative analysis is conducted to demonstrate the cost and structural superiority of the Hybrid methodology over Conventional RCC tanks. For this study five tanks with capacities of 100 kL, 150 kL, 200 kL, 250 kL, and 300 kL have been selected for the study.

Before commencing the comparative study between Hybrid and Conventional type I and type II Circular water tanks, a parametric study was conducted to assess the Optimum H/D Ratio and Number of Columns. This study aimed to achieve the Optimum Cost and provided insights into the structural preferences for Intze tanks over Circular tanks as capacity increases. These findings informed the subsequent comparative study, highlighting the structural and economic advantages of Intze tanks in larger water storage applications.

5.2. Application and comparison criteria for parametric study

For this investigation, deliberate consideration was given to the selection of tanks, keeping the above-mentioned points in mind. Therefore, Hybrid Circular tanks with capacities ranging from 100 kL to 300 kL, in intervals of 50 kL, are analyzed in this study, each with varying staging heights. The specific details pertaining to each tank are delineated in Table 5.1. The study focuses on specific criteria for evaluating the optimum H/D ratio and the optimum number of columns for further comparative studies.

Table 5.1: Specifications of Circular water tanks used for the study

Parameters	**Specifications**				
Quantity (in kL)	100	150	200	250	300
Staging Height (m)	12	14	14	14	14
Column Variations	4,6, 8	4,6,8	4,6,8,10	4,6,8 and 10	4,6,8,10 and 12
Foundation depth	2				
Net safe bearing capacity of soil	80 kN/m^2				
Wind and seismic parameters	47 m/s, Terrain category 4, Non-Coastal region, Seismic zone II.				

5.3. Result and discussions: Parametric study of hybrid circular tanks

Before the comparative study, parametric study has been done to comprehensively investigate the influence of varying Cylindrical Height-to-Diameter (H/D) ratios on the design of Hybrid Elevated Circular water tanks, as well as to determine the optimum number of columns necessary for further studies. Elevated Circular water tanks are typically not preferred for capacities above 200 or 250 kL. This is due to the fact that, beyond such capacities, the height of the tank body (container) often exceeds 5-6 meters when H/D ratios are greater than 0.6, making construction both challenging and, at times, impractical. Maintaining a lower H/D ratio, around 0.2-0.4 or even less, can effectively control the height of the tank. However, this adjustment leads to an increase in the diameter, which in turn requires a greater number of supporting columns. The need for additional columns significantly raises the overall construction costs, making it far more expensive compared to Elevated Intze water tanks. Given these considerations, it is more feasible and cost-effective to focus on the study of tanks with capacities up to a maximum of 300 kL. This range allows for a manageable height while avoiding the excessive costs and construction difficulties associated with larger circular tanks. Therefore, this study aims to explore and establish the most efficient design parameters for Hybrid Elevated Circular water tanks within this capacity range. The main objective of this study is to determine whether HWTs (Intze or Circular) are cost-effective and structurally superior to CWT. After identifying the minimum cost structure at the optimum number of columns, a comparative study with CWT will commence. Given the practical significance of this topic and considering the points mentioned above, only tanks with capacities up to 300 kL will be examined against CWT. Hybrid Circular tanks are analyzed to determine the optimum H/D ratio and the optimum number of columns for capacities ranging from 100 to 300 kL, as detailed in Table 5.2. Additionally, 400 kL, 500 kL, and 600 kL tanks are examined to assess the feasibility of their construction.

Table 5.2: Parametric study of Circular HWTs

Cost of hybrid circular tanks						
Capacity	H/D	Column				
		4	6	8	10	12
100 Kl	0.2	-	15.86	16.74	-	-
	0.4	10.66	11.47	12.1	-	-
	0.6	9.88	10.43	11.16	-	-
	0.8	**9.06**	9.71	10.44	-	-
150 Kl	0.2	-	19.33	19.35	-	-
	0.4	13.34	12.92	13.52	-	-
	0.6	11.9	12.07	12.76	-	-
	0.8	**11.12**	**11.59**	11.179	-	-
200 kL	0.2	-	22.69	19.33	21.29	-
	0.4	-	15.36	15.73	16.8	-
	0.6	14.47	13.64	14.78	15.56	-
	0.8	**13.03**	**13.13**	14.78	15.9	-
250 Kl	0.2	-	-	26.45	22.6	-
	0.4	-	18.33	18.27	18.92	-
	0.6	-	16.48	16.76	17.48	-
	0.8	15.91	**15.64**	**15.95**	16.79	-
300 Kl	0.2	-	-	28.9	28.69	28.53
	0.4	-	-	20.18	20.44	21.21
	0.6	-	18.55	18.65	19.08	19.89
	0.8	-	**17.49**	**17.8**	18.37	19.26

5.3.1. 100 kL hybrid circular tanks

This analysis covers H/D ratios from 0.2 to 0.8 using 4, 6, and 8 columns. At an H/D ratio of 0.2, the radius of the top ring beam is 5.8 meters, resulting in a circumference of 36.4 meters. Each span would be approximately 18.3 meters. Therefore, it is impractical to use a small number of columns for perimeters of this size. Similarly, for a 100-kL tank, using 10 or 12 columns is not cost-effective due to the rising costs involved.

The Optimum Cost is observed at H/D 0.8 with 4 columns for a 100 kL tank.

5.3.2. 150 kL hybrid circular tanks

The optimum cost is observed at an H/D ratio of 0.8 with both 4, showing minimal cost difference between the two configurations. Therefore, this study recommends using 4 and even 6 columns for structural safety and stability. This analysis spans H/D ratios from 0.2 to 0.8 using 4, 6, and 8 columns. At an H/D ratio of 0.2, similar issues as observed in the 100 kL tank can occur, making it impractical to use a small number of columns for larger perimeters such as those required for 200 kL tanks. Similarly, for a 200 kL tank, using 10 or 12 columns is not cost-effective due to increased costs.

5.3.3. 200 kL hybrid circular tanks

The optimum cost is observed at an H/D ratio of 0.8 with both 4 and 6 columns, showing minimal cost difference between the two configurations. Therefore, this study recommends using 6 columns for structural safety and stability. This analysis spans H/D ratios from 0.2 to 0.8 using 4, 6, and 8 columns. At an H/D ratio of 0.2, similar issues as observed in the 100 kL tank can occur, making it impractical to use a small number of columns for larger perimeters such as those required for 200 kL tanks. Similarly, for a 200 kL tank, using 10 or 12 columns is not cost-effective.

5.3.4. 250 kL hybrid circular tanks

The optimum cost is observed at an H/D ratio of 0.8 with both 6 and 8 columns, showing minimal cost difference between the two configurations. Therefore, this study recommends using 8 columns for structural safety and stability. This analysis spans H/D ratios from 0.2 to 0.8 using 4, 6, 8 and 10 columns. At an H/D ratio of 0.2, similar issues as observed in the 100 kL tank can occur, making it impractical to use a small number of columns for larger perimeters such as those required for 200 kL tanks. Similarly, for a 250 kL tank, using 12 columns is not cost-effective.

5.3.5. 300 kL hybrid circular tanks

The optimum cost is observed at an H/D ratio of 0.8 with both 6 and 8 columns, showing minimal cost difference between the two configurations. Therefore, this study recommends using 8 columns for structural safety and stability. This analysis spans H/D ratios from 0.2 to 0.8 using 4, 6, 8, 10 & 12 columns. At an H/D ratio of 0.2-0.4, similar issues as observed in the 100 kL tank can occur, making it impractical to use a small number of columns for larger perimeters such as those required for 200 kL tanks. Similarly, for a 300 kL tank, using 12 or more columns is not cost-effective due to increased costs. This large perimeter poses a general construction challenge because supporting such a span with a small number of columns would compromise the structural integrity and stability of the tank. Therefore, it becomes impractical to use a limited number of columns for tanks designed with such proportions, as they are unable to adequately support the structural requirements imposed by the large perimeter.

5.3.6. Checking the feasibility of 400 – 600 kL hybrid circular or general elevated circular tanks

Table 5.3 presents an analysis of cylindrical height and diameter for various capacities of Circular tanks across different H/D ratios. These dimensions play a crucial role in evaluating the feasibility and practicality of constructing Hybrid Circular or General Elevated Circular tanks within these capacity ranges. At smaller H/D ratios, it is possible to achieve a lower height of construction, but this results in a larger diameter. This increase in diameter necessitates the use of more columns, thereby escalating costs and rendering the construction impractical. Conversely, higher H/D ratios make it challenging to construct tanks of such Cylindrical heights for construction. Therefore, based on this study, it is recommended to opt for Intze tanks for capacities beyond 300 kL to ensure practicality and cost-effectiveness in construction**.**

Table 5.3: Cylindrical height and diameter analysis for different capacity circular tanks

Capacity	H/D Ratio			
	0.2		0.8	
	Height of cylindrical tank	Diameter of TRB	Height of cylindrical tank	Diameter of TRB
400 KL	3.71 m	18 m	7.8 m	9.4 m
500 KL	4 m	19.4 m	8 m	10 m
600 Kl	4.4	20.6 m	8.5	10.6

Therefore, the subsequent study comparing hybrid circular tanks with Conventional Circular tanks will exclusively focus on tanks within the 100-300 kL capacity range.

5.3.7. Concluding remarks

The study investigated the impact of height-to-diameter (H/D) ratios on Hybrid Elevated Circular water tanks ranging from 100 kL to 300 kL capacities. It identified that H/D ratios around 0.8 effectively balance cost and structural integrity across different tank sizes. Specifically, for 100 kL tanks, optimal cost-efficiency and stability were achieved with 4 columns at H/D 0.8, while 6 columns at the same ratio were suitable for 150 kL to 200 kL tanks. Larger capacities (250 kL and 300 kL) benefited from 8 columns at H/D 0.8, providing robust support without excessive construction costs. Challenges were noted for capacities beyond 300 kL, where extreme H/D ratios either increased column requirements and costs (at lower ratios) or posed impractical construction challenges (at higher ratios). The study underscores the practicality and cost-effectiveness of hybrid circular tanks within the 100-300 kL range compared to conventional designs, with recommendations favoring Intze tanks for capacities exceeding 300 kL due to their lower construction heights and reduced column needs. These insights are crucial for optimizing the design and construction of water storage tanks to meet both structural demands and economic considerations.

5.4. Application and comparison criteria for comparative study

After the parametric study, Selection of tanks, H/D Ratios and Optimum number of Columns are selected for the comparative study. The specific details pertaining to each tank are delineated in Table 5.4. as obtained from section 5.3. The study is focused on specific criteria for evaluation, such as structural integrity metrics, cost breakdowns, and leakage resistance, to ensure a rigorous and systematic comparison.

Table 5.4: Specifications of Intze water tanks used for the study.

Parameters	**Specifications**				
Quantity (kL)	100	150	200	250	300
Staging height (m)	12	14	14	14	16
Number of columns	4	6	6	8	8
Foundation depth	2 m				
Net safe bearing capacity of soil	80 kN/m^2				
Wind and seismic parameters	47m/s, Terrain category 2, Non-Coastal region, Seismic Zone IV				

a). Cost efficiency: Cost efficiency has been assessed through following same parameters as done in previous chapters

- Cost of CWT vs Cost of HWT (including ferrocement lining).
- Calculation of cost of ferrocement lining is important to assess the percentage of lining cost as compared to that of overall cost of tank.
- comparative Evaluation of tank body and Total tank Cost in HWT and CWT.
- Comparison of quantity & cost of steel and concrete in both HWT and CWT is also required to get an overview of saving in steel and concrete in HWTs.

b). **Structural efficiency**

- Structural Efficiency has been accessed through following parameters-
- Deflection in both the tanks in both full & empty tank conditions.

- Seismic and wind analysis of Hybrid and Conventional designs to access the performance of both tanks under impact of wind & seismic forces and to ascertain the maximum lateral forces in both full & empty tank conditions.
- Crack width analysis
- Comparative analysis of annular raft footing

5.5. Results and discussions: Comparative study of hybrid and Conventional (type I) Elevated Circular type tanks

In this study Elevated Hybrid Circular tanks are compared with Conventional tank (type I) using software programs specifically tailored for both Conventional RCC and hybrid approaches. The analysis involved detailed cost assessments and extensive comparisons regarding quantities of steel and concrete, deflection, base shear, wind forces, crack widths, and other relevant factors. The findings highlight the significant advantages of the Hybrid design. The comparative analysis is conducted to demonstrate the cost and structural superiority of the Hybrid methodology over Conventional RCC tanks. In examining the practical applicability of circular tanks as discussed in Chapter 8, five tanks with capacities of 100 kL, 150 kL, 200 kL, 250 kL, and 300 kL have been selected for the study.

5.5.1. Cost comparison of Hybrid & Conventional tanks

The total cost of the water tank encompasses the expenses related to the steel and concrete utilized in the entire tank structure, including materials for the tank body, staging, and foundation. Figure 5.1. clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs.

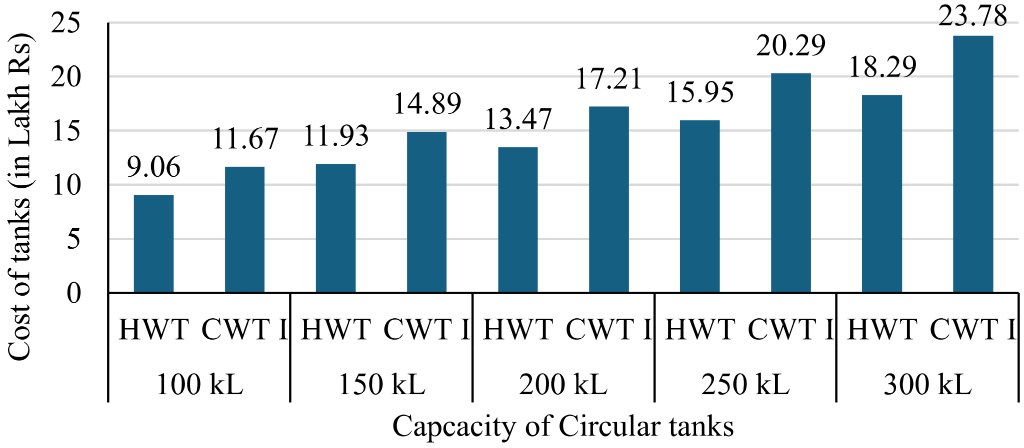

Fig. 5.1: Comparative cost analysis of HWT and CWT I Circular tanks

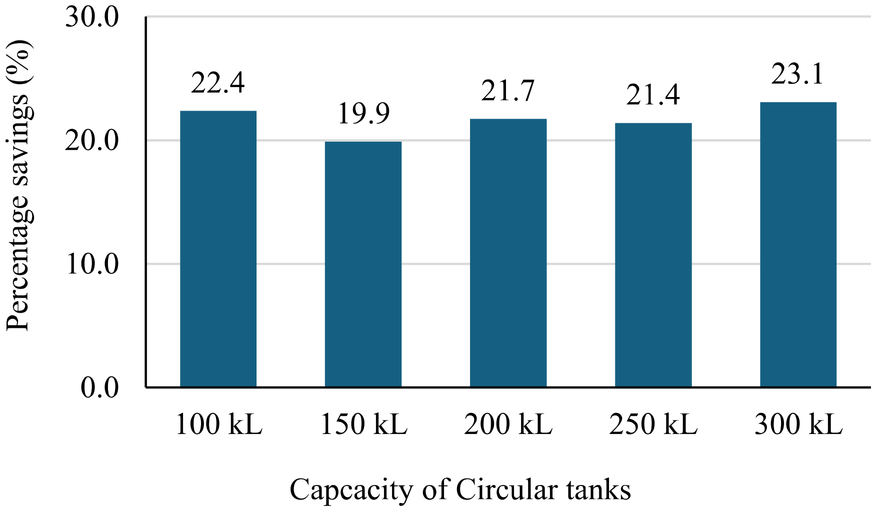

Fig. 5.2: Percentage Saving in cost for HWT and CWT I Circular tanks

The outcomes are summarized as follows:

- The percentage difference in cost savings, as depicted in Figure 5.2, falls within the range of 19%- 24%, a substantial margin.
- The cost of the HWT includes the lining cost. On average, there is a savings of about 25%, which is equivalent to one-fifth to one -fourth of the total cost, specifically in material expenses which is huge.
- Additionally, it's evident that the percentage of savings increases with the increase in the capacity of the tank.
- The percentage savings were approximately 20- 24%. It's important to note that these savings include the cost of ferrocement lining.

5.5.2. Cost of ferrocement lining

The lining design prioritizes factors like strain compatibility, thickness, and the specified reinforcement layers. Strain is very less, Hence Nominal lining is provided which can be 12 mm or 15 mm thick with nominal reinforcement in 3 layers can be provided. For additional safety 15 mm lining is provided. Shows the Cost of ferrocement lining used in Hybrid design approach and variations. The cost of lining includes the cost of mortar and steel required.

Table 5.5: Specifications of ferrocement lining provided in tanks

Capacity (kL)	Strain	Cost of ferrocement lining
100	-0.00146	0.5
150	-0.00003	0.6
200	0.00013	0.6
250	0.000287	0.68
300	0.00046	0.88

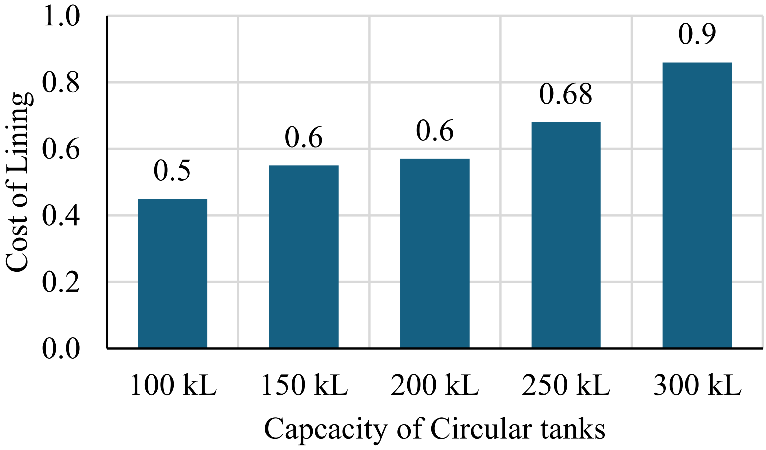

Fig. 5.3: Cost of ferrocement lining used in Hybrid design approach.

- The outcomes are summarized as follows:
- The cost of the ferrocement lining ranges from 0.4 to 0.8 currency units, which is about 4.14% to 4.3% of the total cost of the tank.
- The cost of the lining includes both mortar and steel required for construction.
- The ferrocement lining design prioritizes factors like strain compatibility, thickness, and the specified reinforcement layers.
- Due to very minimal strain, a nominal lining of 10 mm or 12 mm thick with three layers of nominal reinforcement is provided.
- There is a direct correlation between tank capacity and the cost of the ferrocement lining.

- As the tank capacity increases, the cost of the lining also increases consistently, reflecting the larger water-contacting surface area.
- The thickness of the ferrocement lining and the number of steel mesh layers required depend on the strain occurring at the interface between the RCC tank body and the lining.
- This efficient use of materials ensures that the lining is cost-effective while maintaining structural integrity.
- The average percentage of the cost of the lining relative to the total cost of the tank is approximately 4.24%.

5.5.3. Comparison of cost of tank body and total cost of tank in both HWT and CWT I Circular tanks

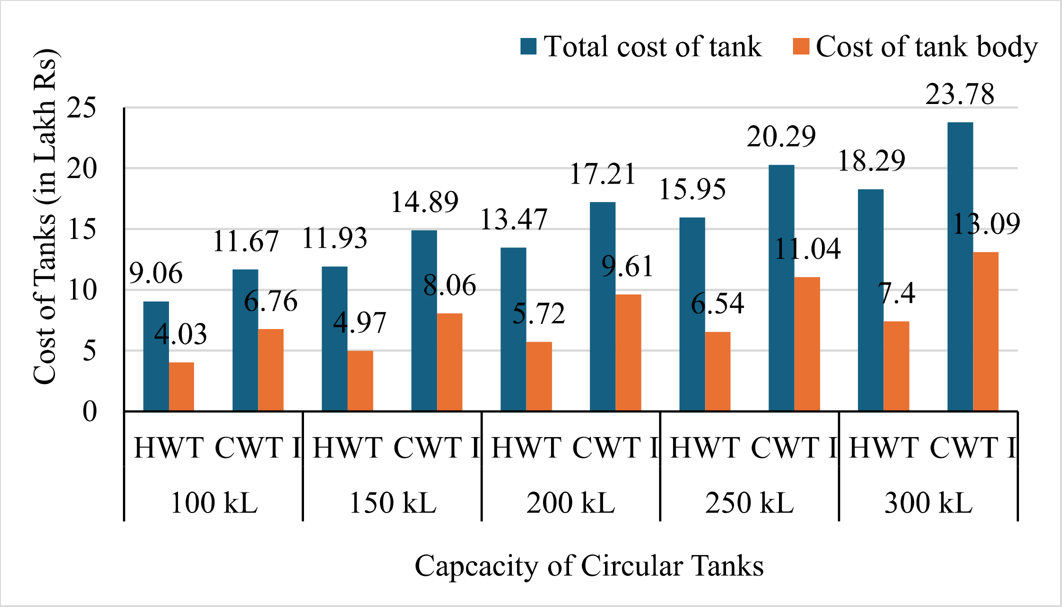

Fig. 5.4: Comparative analysis of tank body and total tank costs in HWT and CWT I

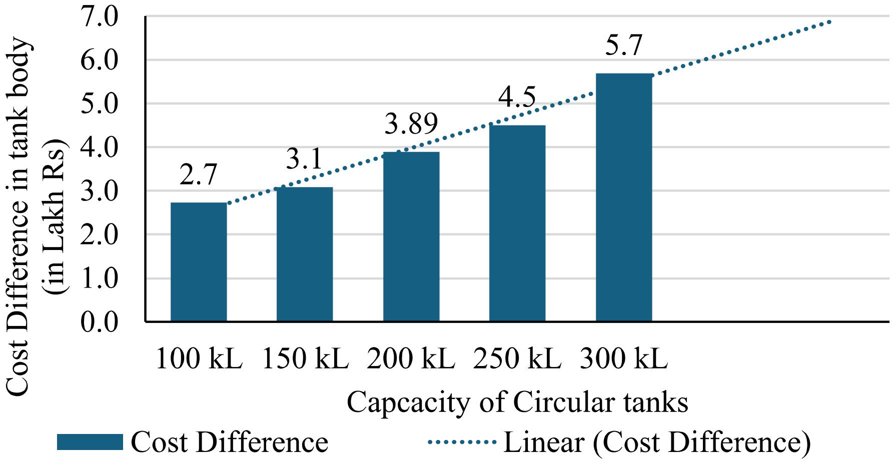

Fig. 5.5:Difference in cost of tank body of hybrid vs conventional approach.

The outcomes are summarized as follows:

- Figure 5.4 depicts a consistent divergence between the overall cost and the specific tank body cost, incorporating staging and foundation expenditures.
- Figure 5.5 emphasizes substantial savings specifically in the cost of the tank body in hybrid & conventional tank design. The cost lines for the tank body and the total tank costs run parallel to each other. This underscores that the predominant contributor to the difference in the total structure cost disparity is solely the tank body cost.
- The staging and foundation costs exhibit relative constancy or marginal reduction owing to the weight diminution in the tank body, an outcome attributed to the innovative design. This weight reduction culminates in a diminished seismic base shear, consequently yielding savings in both staging and foundation expenses.
- The cost difference in the tank body between the Hybrid and Conventional approaches is experiencing linear growth with increase in the capacity of tank.
- The cost of the tank body in hybrid designs is significantly lower across all capacities (100 kL to 300 kL), with reductions ranging from 2.73 to 5.03 currency units, underscoring the material and design efficiency inherent in the hybrid approach.

5.5.4. Material consumption

Table 5.6 provides a comprehensive breakdown of concrete and steel quantities, accounting for the tank body, staging, and foundation in each tank.

Table 5.6: Consumption of materials in tanks

Sr.No	Capacity	Concrete used (cum)		Steel used (Tonnes)	
		HWTs	CWT I	HWTs	CWT I
1	100 kL	45.74	59.41	4.36	6.1
2	150 kL	61.56	79.15	5.61	7.39
3	200 kL	69.58	90.43	6.29	8.66
4	250 kL	83.17	107.7	7.38	11.04
5	300 kL	94.11	122.57	8.6	12.78

The outcomes are summarized as follows:

- The Hybrid design consistently requires less concrete, and steel compared to the conventional type I design for all tank capacities.
- For 100 kL tanks, the Hybrid design uses 45.74 cubic meters of concrete and 4.36 tonnes of steel, compared to 59.41 cubic meters of concrete and 6.1 tonnes of steel for the conventional design. This represents concrete savings of approximately 23% and a steel savings of approximately 28%.
- For 150 kL tanks, the Hybrid design uses 61.56 cubic meters of concrete and 5.61 tonnes of steel, whereas the conventional design requires 79.15 cubic meters of concrete and 7.39 tonnes of steel. This represents concrete savings of approximately 23% and steel savings of approximately 25%.
- For 200 kL tanks, the Hybrid design uses 69.58 cubic meters of concrete and 6.29 tonnes of steel, while the conventional design uses 90.43 cubic meters of concrete and 8.66 tonnes of steel. This represents concrete savings of approximately 23% and steel savings of approximately 27%.
- For 250 kL tanks, the Hybrid design uses 83.17 cubic meters of concrete and 7.38 tonnes of steel, compared to 107.7 cubic meters of concrete and 11.04

tonnes of steel for the conventional design. This represents concrete savings of approximately 23% and steel savings of approximately 33%.

- For 300 kL tanks, the Hybrid design uses 94.11 cubic meters of concrete and 8.6 tonnes of steel, whereas the conventional design requires 122.57 cubic meters of concrete and 12.78 tonnes of steel. This represents concrete savings of approximately 23% and steel savings of approximately 33%.
- Concrete savings across all capacities are consistently around 23%, and steel savings range from 25% to 33%.
- These results underscore the significant material efficiency of the Hybrid design approach, achieving substantial reductions in both concrete and steel usage across various tank sizes.
- The percentage savings in concrete and steel quantities are consistent across different capacities, demonstrating the scalability and effectiveness of the Hybrid design for various tank sizes.

5.5.5. Deflection of tanks

The deflection of tanks has been computed under both full and empty tank conditions, employing both Hybrid and conventional approaches, and is shown in Fig 5.6

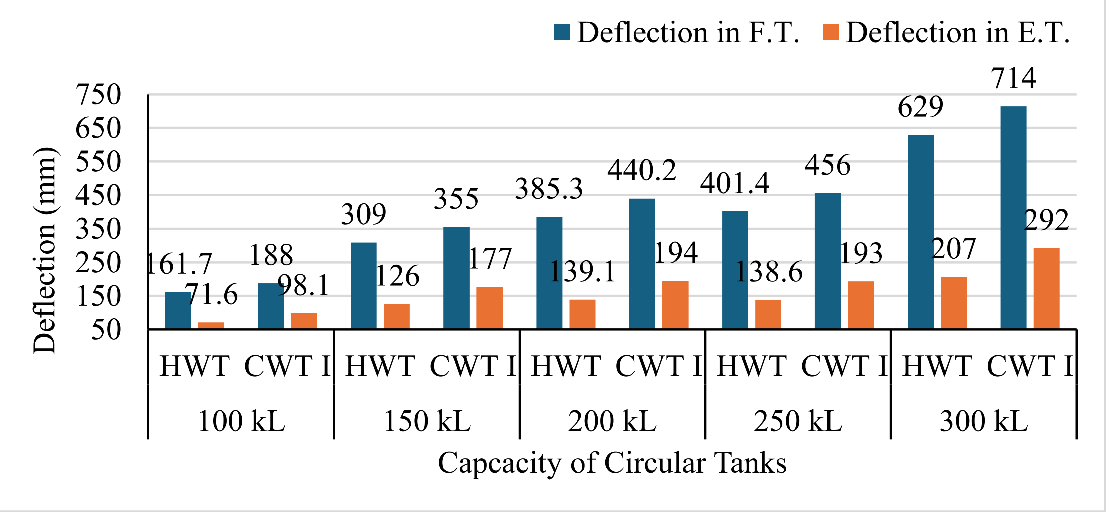

Fig. 5.6: Deflection in both F.T. and E.T. condition for HWT and CWTs

The outcomes are summarized as follows:

- The results indicate that the deflection is consistently lower in the Hybrid design tank for both full and empty tank conditions.
- The deflection is nearly 11%-14% lower in the full tank condition.
- Deflection is significantly reduced, ranging from 27% to 30%, in the empty tank condition in comparison to the conventional approach.
- HWTs performs better in case of seismic activity as compared to CWT.

5.5.6. Seismic and wind analysis of Hybrid and Conventional designs

A comparison of seismic and wind forces acting on tanks designed with both Hybrid and Conventional approaches, shown in Figure 5.7.

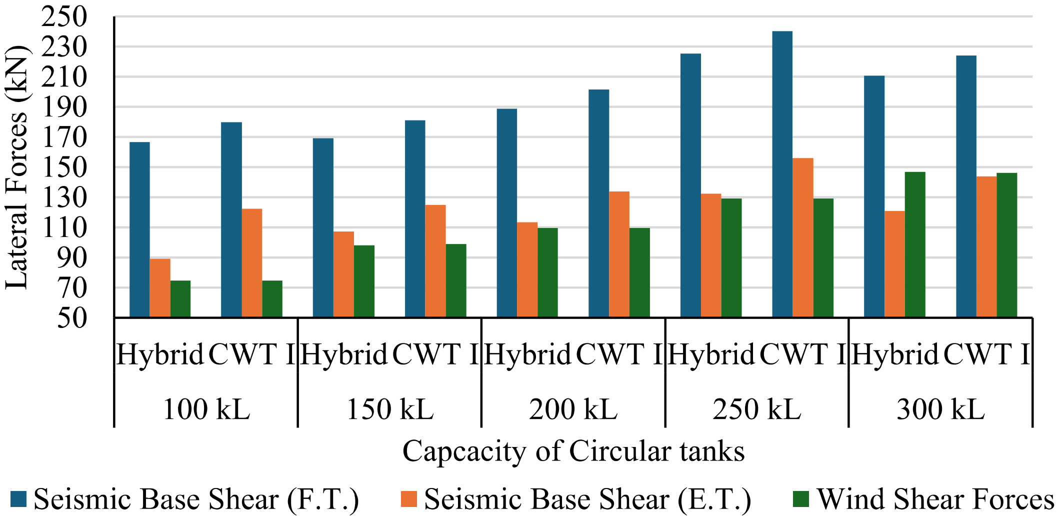

Fig. 5.7: Comparative analysis of seismic and wind forces

The outcomes are summarized as follows:

- Figure 5.7. indicates that wind forces are similar due to consistent tank size and staging height.
- This decrease is attributed to the reduced dead weight of the tank body in the hybrid design.
- Hence HWTs perform better in case of seismic activity as compared to CWT.

- Figure indicates that Base shear is always higher for all the tanks in all the zones in Full tank (F.T.) Conditions as compared to Empty tank conditions (E.T.).
- Figure indicates that HWTs have lower seismic base shear in both full & empty tank conditions as compared to CWT.
- The seismic base shear is notably lower in the Hybrid approach for both empty and full tank conditions, with reductions of 6-8 % for full tanks.
- Additionally, for empty tanks, the Hybrid approach exhibits a substantial reduction in seismic base shear, ranging from 14-28%.
- Wind shear forces increase with tank capacity.
- Wind shear forces become more significant for larger tanks (300 kL), where they exceed seismic base shear forces for empty tanks in both HWT and CWT I types.
- For tanks with 300 kL capacity, wind shear forces are higher than seismic base shear forces for empty tanks, indicating the necessity to consider wind shear in the design of larger tanks.

5.5.7. Crack width calculations

In a comparative study of Hybrid and Conventional tank designs, crack widths were analyzed and are shown in Table 5.7.

Table 5.7: Crack width calculations

Quantity in kL	Crack width in RCC (in mm)	
	Circular HWT	Circular CWT I
100	-0.00146	-0.1752
150	-0.00003	-0.0036
200	0.00013	0.0156
250	0.000287	0.03444
300	0.000387	0.04644

While clause 4.4.3.1 of IS 3370: 2021, used for the Conventional tank type I design of tanks, stipulates that an RCC member exposed to direct tension and flexural tension can be considered satisfactory without crack width calculations, provided stresses in steel reinforcement don't exceed 130 N/mm² for serviceability limits, it's noteworthy that crack width calculations were conducted for study purposes even for Conventional type 1 tanks. The outcomes are summarized as follows:

- The conventional tank's crack width is well below the IS 3370:2021 limit of 0.2 mm.
- For HWTs, crack width calculations for RCC and lining parts were performed, and results are below the ACI standard of 0.05 mm.
- HWTs exhibit significantly less crack width compared to CWT, especially with larger capacities.
- Ferrocement lining Crack width comes out to be 0.022 mm which is an additional safety factor to the tanks.
- The minimum dimensions, stresses, and exposure criteria have been enhanced in IS 3370:2021 compared to IS 3370:2009 and are greater than those in IS 456:2000 due to the need to reduce crack width and prevent leakage in water tanks. However, the excessive material quantities required by the stringent criteria of IS 3370:2021 are unnecessary, as the crack width in RCC as per IS 456:2000 is already minimal. Consequently, adhering to IS 3370:2021 leads to material wastage, particularly in tanks with lower capacities.

5.5.8. Comparative analysis of annular raft footing

A comparative assessment has been carried out on the annular raft footing, analyzing the designed area using both Hybrid and Conventional approaches, as depicted in Figure 5.8. The investigation aims to provide insights into the potential savings of the hybrid design over the conventional approach under varying soil conditions.

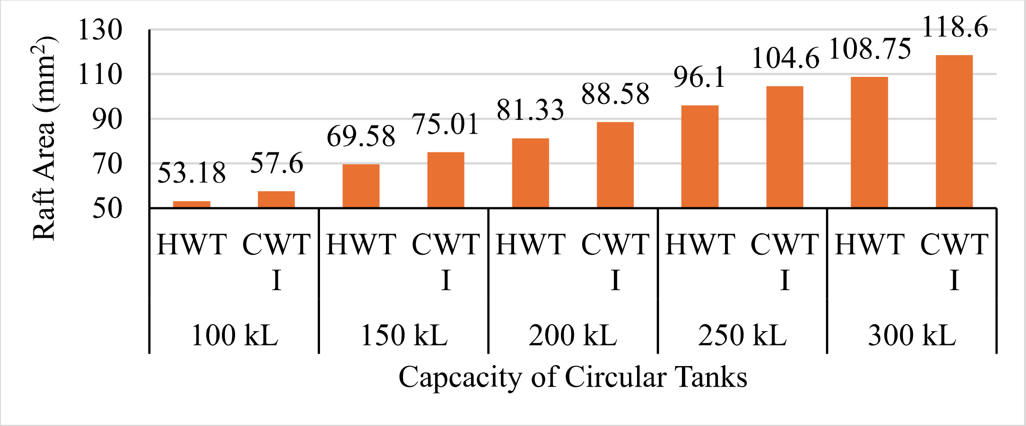

Fig. 5.8: Comparative analysis of area of annular raft footing

The outcomes are summarized as follows:

Hybrid consistently demonstrates a reduction in designed area compared to Conventional across all loading conditions, with the percentage savings ranging from 8-9 % which is good as these are Low-Capacity tanks

5.5.9. Concluding remarks

In conclusion, the comparative study underscores the superiority of Hybrid Circular tank designs over Conventional type II tanks across capacities ranging from 100 to 300 kL. HWTs offer significant cost savings, averaging 19% to 24%, with material expenses reduced by about 25%. Concrete savings are approximately 23%, and steel requirements are lowered by 25% to 33%. The cost of ferrocement lining is minimal, comprising only 4.14% to 4.3% of the total tank cost. Structural benefits include lower deflection (11%-14% for full tanks, 27%-30% for empty tanks), reduced seismic base shear (6%-8% for full tanks, 14%-28% for empty tanks), and less crack width compared to CWT, particularly noticeable in larger capacities. Hybrid designs also optimize annular raft footing area by 8%-9%. These findings affirm that Hybrid Circular tanks are not only cost-effective but also offer enhanced structural integrity, making them the preferred choice for efficient water tank construction across varying capacities.

5.6. Result and comparative study: Comparative analysis of HWT and CWT II Circular tanks

A comprehensive comparative study was undertaken to evaluate the economic and structural aspects of a HWT design in comparison with conventional methods. CWT of varying capacities (100 to 300 kL) were meticulously designed using a specialized software program developed for both hybrid and conventional approaches. The results encompass detailed cost evaluations, including the total water tank, tank body, lining, staging, and foundation. Additionally, thorough comparisons were made regarding steel and concrete quantities (5.6.1-5.6.5). Structural performance was analyzed by calculating crack width, deflection, performance under wind and seismic loading in both full and empty tank conditions, and raft area requirements (5.6.6-5.6.9). The results underscored substantial advantages of the hybrid design, emphasizing its economic and structural superiority over conventional practices.

5.6.1. Cost comparison of HWT and CWT II

Figure 5.9. clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs.

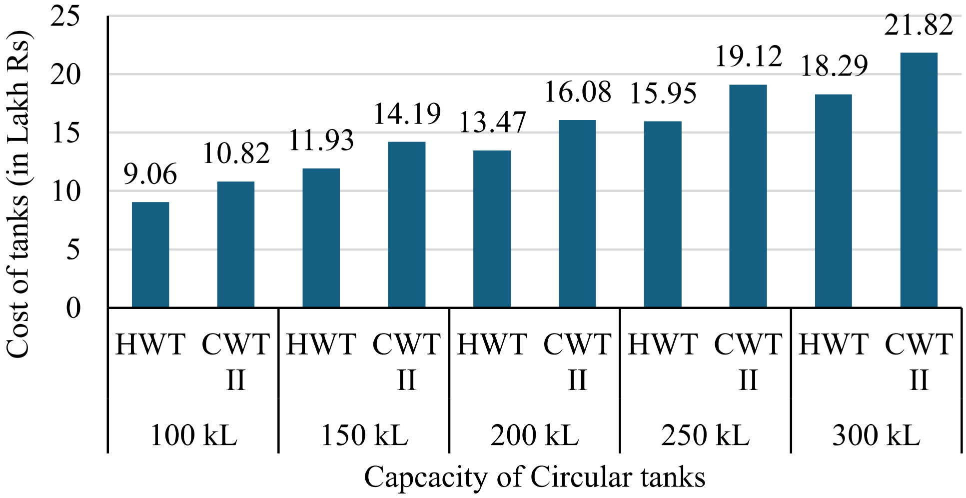

Fig. 5.9: Cost analysis of HWT & CWT II Circular tanks

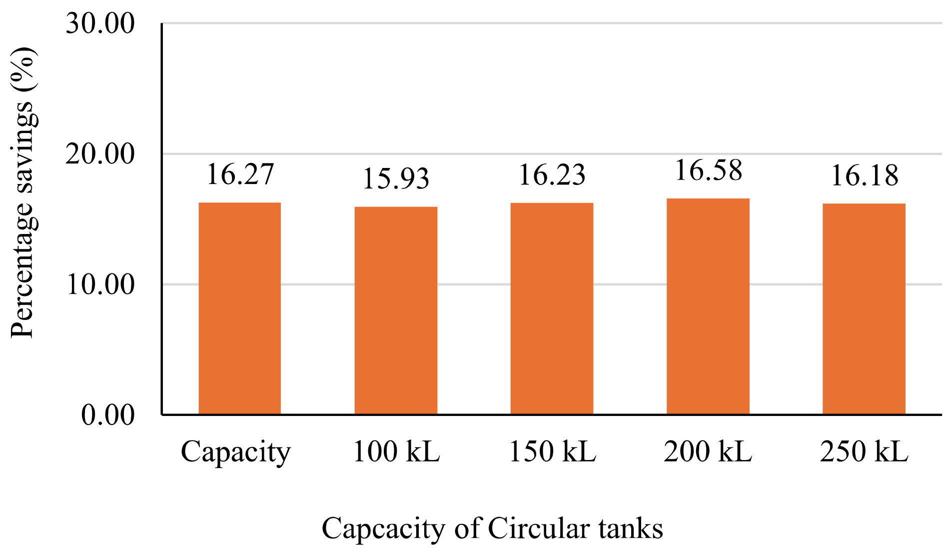

Fig. 5.10: Percentage Saving in cost for HWT and CWT II Circular tanks

The outcomes are summarized as follows:

- The percentage difference in cost savings, as depicted in Figure 5.10, falls within the range of 16%- 18%, a substantial margin.
- The cost of the HWT includes the lining cost. On average, there is a savings of about one-fifth – one sixth of the total cost, specifically in material expenses which is huge.
- Additionally, it's evident that the percentage of savings increases with the increase in the capacity of the tank.
- The average percentage savings were approximately 17%. It's important to note that these savings include the cost of ferrocement lining.

5.6.2. Cost of ferrocement lining

Same as Section 5.5.2.

5.6.3. Comparison of Cost of tank body vs total cost of tank for both HWT and CWT I circular tanks

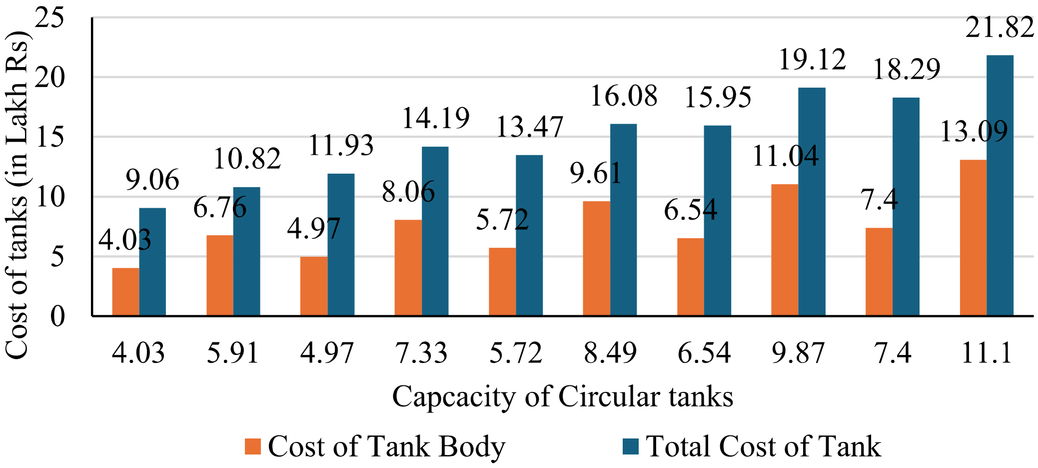

Fig. 5.11: Comparative analysis of tank body and total tank costs in hybrid and conventional approaches

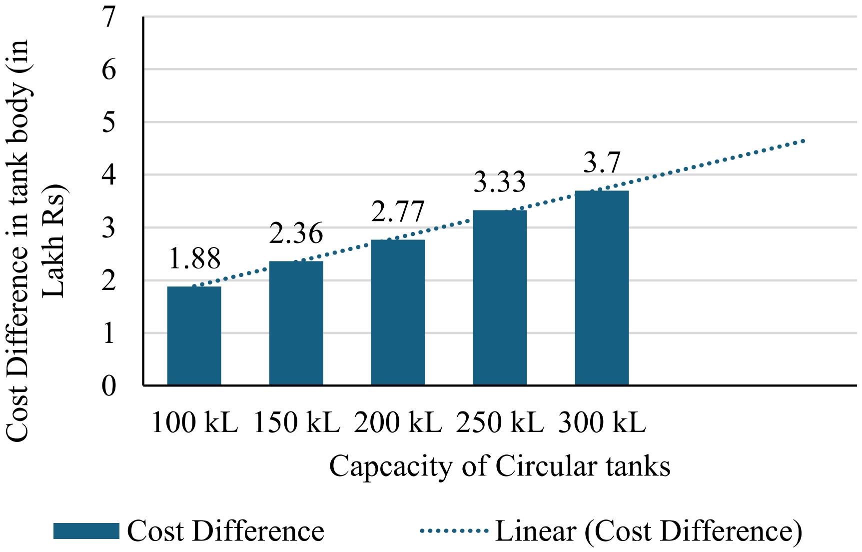

Fig. 5.12: Difference in cost of tank body of hybrid vs conventional approach.

The outcomes are summarized as follows:

- Figure 5.11 depicts a consistent divergence between the overall cost and the specific tank body cost, incorporating staging and foundation expenditures.

- Figure 5.12 emphasizes substantial savings specifically in the cost of the tank body in hybrid & conventional tank design. The cost lines for the tank body and the total tank costs run parallel to each other. This underscores that the predominant contributor to the difference in the total structure cost disparity is solely the tank body cost.
- The staging and foundation costs exhibit relative constancy or marginal reduction owing to the weight diminution in the tank body, an outcome attributed to the innovative design. This weight reduction culminates in a diminished seismic base shear, consequently yielding savings in both staging and foundation expenses.
- The cost difference in the tank body between the Hybrid and Conventional approaches is experiencing linear growth with increase in the capacity of tank.
- The cost of the tank body in hybrid designs is significantly lower across all capacities (100 kL to 300 kL), with reductions ranging from 1.88 to 3.07 Lakh Rs, underscoring the material and design efficiency inherent in the hybrid approach.

5.6.4. Material consumption

Table 5.8 provides a comprehensive breakdown of concrete and steel quantities, accounting for the tank body, staging, and foundation in each tank.

Table 5.8: Consumption of materials in tanks

Sr.No	Capacity	Concrete used (cum)		Steel used (Tonnes)	
		HWTs	CWT I	HWTs	CWT II
1	100 kL	45.74	59.41	4.36	5.15
2	150 kL	61.56	79.15	5.61	6.61
3	200 kL	69.58	90.43	6.29	7.41
4	250 kL	83.17	107.7	7.38	8.77
5	300 kL	94.11	122.57	8.6	10.05

The outcomes are summarized as follows:

- The Circular HWTs consistently requires less concrete and steel compared to the Circular Conventional type II design for all tank capacities.
- For 100 kL tanks, the Hybrid design utilizes 45.74 cubic meters of concrete and 4.36 tonnes of steel, in contrast to the Conventional type II design which requires 59.41 cubic meters of concrete and 5.15 tonnes of steel. This results in a notable concrete savings of approximately 23% and a significant steel savings of approximately 15.34%.
- Moving to 150 kL tanks, the Hybrid design uses 61.56 cubic meters of concrete and 5.61 tonnes of steel, whereas the Conventional type II design necessitates 79.15 cubic meters of concrete and 6.61 tonnes of steel. This configuration translates to a concrete savings of around 23% and a steel savings of about 15.13%.
- For 200 kL tanks, the Hybrid design employs 69.58 cubic meters of concrete and 6.29 tonnes of steel, compared to the Conventional type II design which uses 90.43 cubic meters of concrete and 7.41 tonnes of steel. This results in a concrete savings of roughly 23% and a steel savings of approximately 15.12%.
- In the case of 250 kL tanks, the Hybrid design uses 83.17 cubic meters of concrete and 7.38 tonnes of steel, while the Conventional type II design requires 107.7 cubic meters of concrete and 8.77 tonnes of steel. Consequently, this setup achieves a concrete savings of about 23% and a steel savings of approximately 15.85%.
- Lastly, for 300 kL tanks, the Hybrid design utilizes 94.11 cubic meters of concrete and 8.6 tonnes of steel, whereas the Conventional type II design utilizes 122.57 cubic meters of concrete and 10.05 tonnes of steel. This results in a concrete savings of approximately 23% and a steel savings of about 14.4 %.
- Concrete savings across all capacities are consistently around 23%, and steel savings range from 14% to 16%.
- These results underscore the significant material efficiency of the Hybrid design approach, achieving substantial reductions in both concrete and steel usage across various tank sizes.

- The percentage savings in concrete and steel quantities are consistent across different capacities, demonstrating the scalability and effectiveness of the Hybrid design for various tank sizes.

5.6.5. Deflection of tanks

The deflection of all three tanks has been computed under both full and empty tank conditions, employing both Hybrid and conventional approaches, and is shown in Fig. 5.13.

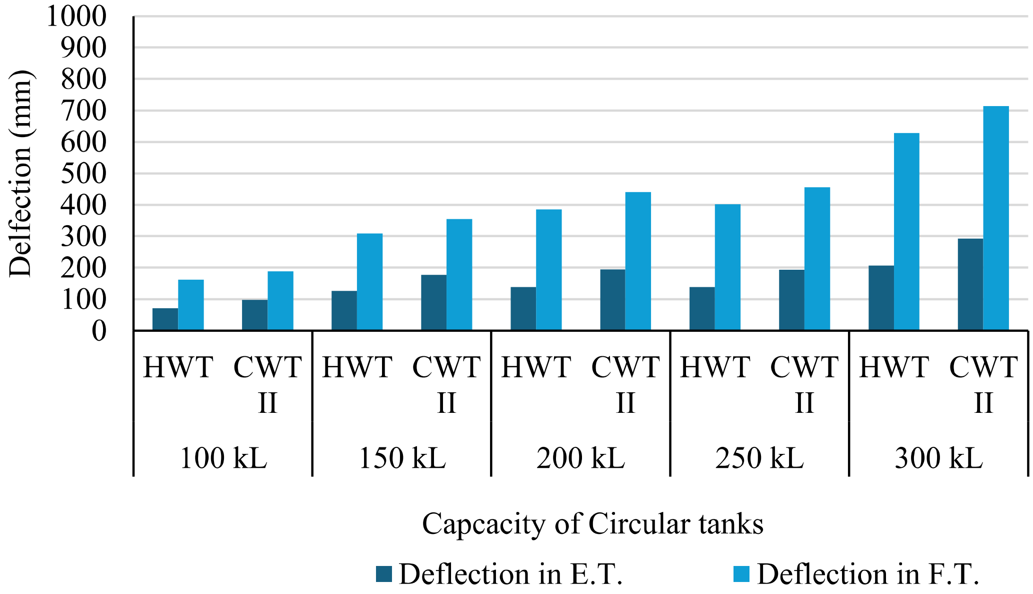

Fig. 5.13: Deflection in both full & empty tank condition for HWT and CWT II

The outcomes are summarized as follows:

- The results indicate that the deflection is consistently lower in the Hybrid design tank for both full and empty tank conditions.
- The deflection is nearly 11%-15% lower in the full tank condition.
- Deflection is significantly reduced, ranging from 27% to 30%, in the empty tank condition in comparison to the conventional approach.
- Circular Conventional type II tanks have similar values or slightly lesser values of Deflection in both Full and Empty tank Conditions.
- HWTs performs better in case of seismic activity as compared to CWT.

5.6.6. Seismic and wind analysis of Hybrid and Conventional designs

A comparison of seismic and wind forces acting on tanks designed with both Hybrid and Conventional approaches, shown in Figure 5.14

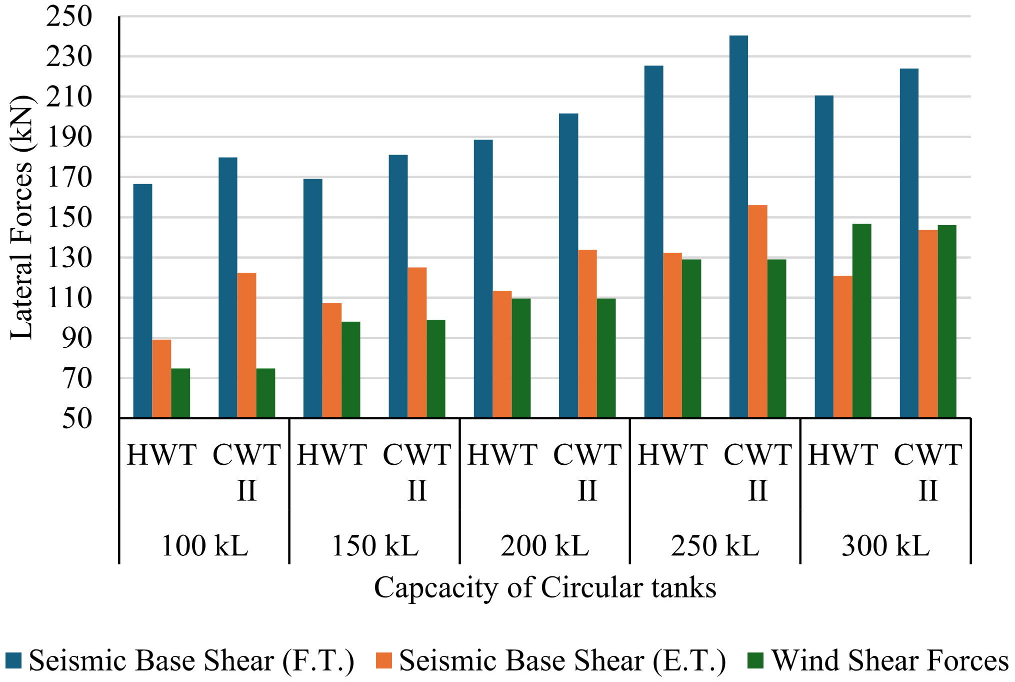

Fig. 5.14: Comparative analysis of seismic and wind forces

The outcomes are summarized as follows:

- Figure 5.14 indicates that wind forces are similar due to consistent tank size and staging height.
- This decrease is attributed to the reduced dead weight of the tank body in the hybrid design.
- HWTs perform better in case of seismic activity as compared to CWT.
- Circular CWT II tanks exhibit values comparable to or slightly lower than those of Circular CWT I tanks, as determined in the previous study.
- Figure indicates that Base shear is always higher for all the tanks in all the zones in Full tank (F.T.) Conditions as compared to Empty tank conditions (E.T.).
- Figure indicates that HWTs have lower seismic base shear in both full & empty tank conditions as compared to CWT.

- The seismic base shear is notably lower in the Hybrid approach for both empty and full tank conditions, with reductions of 6-8 % for full tanks.
- Additionally, for empty tanks, the Hybrid approach exhibits a substantial reduction in seismic base shear, ranging from 14-28%.
- Wind Shear force s increase with tank capacity and Height of the structure.
- Wind Shear forces become more significant for larger tanks (300 kL), where they exceed seismic base shear forces for empty tanks in both HWT and CWT I type, indicating the necessity to consider wind shear in the design of larger tanks.

5.6.7. Crack width calculations

In a comparative study of Hybrid and Conventional tank designs, crack widths were analyzed and are shown in Table 5.9.

Table 5.9: Crack width calculations for conventional & HWTs.

Quantity in kL	Crack width in RCC (in mm)	
	Circular HWT	Circular CWT II
100	-0.1752	-0.0482
150	-0.0036	-0.0203
200	0.0156	0.00552
250	0.03444	0.04644
300	0.0552	0.09432

The outcomes are summarized as follows:

- The conventional tank's crack width is well below the IS 3370:2021 limit of 0.2 mm.
- For HWTs, crack width calculations for RCC and lining parts were performed, and results are below the ACI standard of 0.05 mm.
- HWTs exhibit significantly less crack width compared to CWT, especially with larger capacities.

- Ferrocement lining Crack width comes out to be 0.022 mm which is an additional safety factor to the tanks.
- The minimum dimensions, stresses, and exposure criteria have been enhanced in IS 3370:2021 compared to IS 3370:2009 and are greater than those in IS 456:2000 due to the need to reduce crack width and prevent leakage in water tanks. However, the excessive material quantities required by the stringent criteria of IS 3370:2021 are unnecessary, as the crack width in RCC as per IS 456:2000 is already minimal. Consequently, adhering to IS 3370:2021 leads to material wastage, particularly in tanks with lower capacities.

5.6.8. Comparative analysis of annular raft footing

A comparative assessment has been carried out on the annular raft footing, analyzing the designed area using both Hybrid and Conventional approaches, as depicted in Figure 5.15. The investigation aims to provide insights into the potential savings of the hybrid design over the conventional approach under varying soil conditions**.**

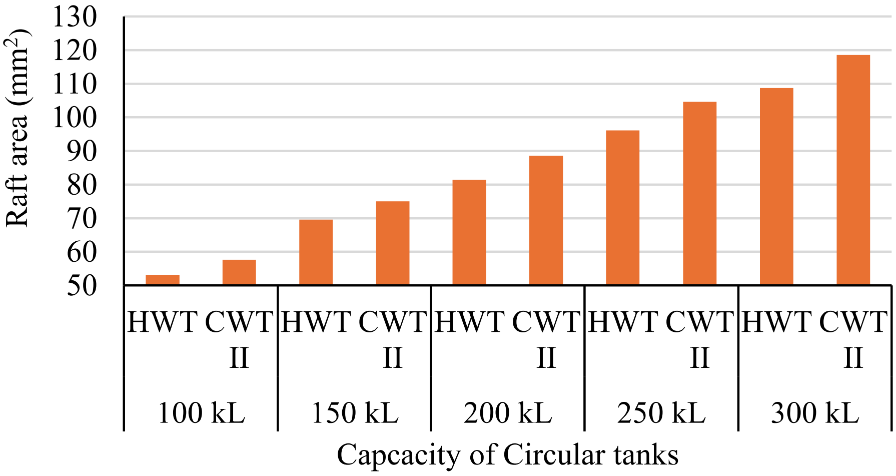

Fig. 5.15: Comparative analysis of area of annular raft footing designed as per hybrid and conventional approach.

The outcomes are summarized as follows:

- Hybrid consistently demonstrates a reduction in designed area compared to Conventional across all loading conditions, with the percentage savings ranging from 8-9 % which is good as these are Low Capacity tanks.

5.6.9. Conclusive remarks

HWT designs demonstrate significant cost-effectiveness, offering savings ranging from 16% to 18% compared to CWT II Circular tanks. Material expenses are reduced by an average of 17%, with savings increasing proportionally with tank capacity. These designs also exhibit lower construction costs due to reduced tank body weight and seismic base shear, resulting in decreased staging and foundation expenses. Concrete savings are approximately 23%, complemented by steel savings ranging from 14% to 16% across all tank capacities. HWTs further excel in structural performance, showing lower deflection (11%-14% for full tanks, 27%-30% for empty tanks) and reduced seismic base shear (6%-8% for full tanks, 14%-28% for empty tanks). The optimized design of annular raft footings also contributes to savings of 8%-9%. These findings reinforce the superiority of Hybrid Circular tanks in terms of both economic efficiency and structural integrity, making them an ideal choice for water tank construction across various capacities.