4. Chapter 4: Comparative study of hybrid and conventional Intze tanks

4.1. Introduction

As explored in previous chapters, CWT can be designed following two distinct criteria outlined in IS 3370:2021, known as type I and type II tanks. type I tanks are designed to keep steel stresses below 130 N/mm², thereby eliminating the need for crack width calculations. On the other hand, type II tanks allow for increased steel stresses up to the ultimate stress limit, which necessitates the inclusion of crack width calculations. In this chapter, Conventional type I and II Intze tanks are compared with Hybrid Intze tanks in terms of cost efficiency and structural performance. Three different tanks representing low (200 kL), medium (600 kL), and high (1000 kL) capacities are selected for analysis and design using a novel approach.

The tanks of different capacities (200 kL, 600 kL, and 1000 kL) were designed 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 Hybrid design.

The comparative analysis aims to demonstrate the cost and structural superiority of the Hybrid methodology over Conventional RCC tanks. Table 4 outlines the principles and guidelines used in the design, while Figure 4.1 illustrates the general flow chart of the methodology for the comparison criteria (Only the clauses change for type I and type II CWT as per IS 3370 rest the process is same). Section 4.2 discusses the application and comparison criteria chosen for the study. The following studies are included:

- Section 4.3: Comparative study of Hybrid and Conventional type I Intze tanks
- Section 4.4: Comparative study of Hybrid and Conventional type II Intze tanks
- Section 4.5: Combined comparative study of Hybrid, Conventional type I, and type II Intze tanks.

In Section 4.5, the input parameters such as seismic zone and wind speeds are modified from the first two studies. It has been found that despite significant steel savings in CWT II compared to CWT I, the overall cost difference between CWT I and CWT II is only 5-16%. This section aims to investigate the underlying reasons for this relatively small cost variation, considering the increased use of concrete in CWT II and other contributing factors. Additionally, this chapter introduces new conditions—Seismic Zone III and a wind speed of 47 m/sec—to provide further insights into the cost implications for HWTs. By altering these parameters, the section seeks to offer a more comprehensive understanding of the cost dynamics and identify potential areas for cost optimization in tank construction.

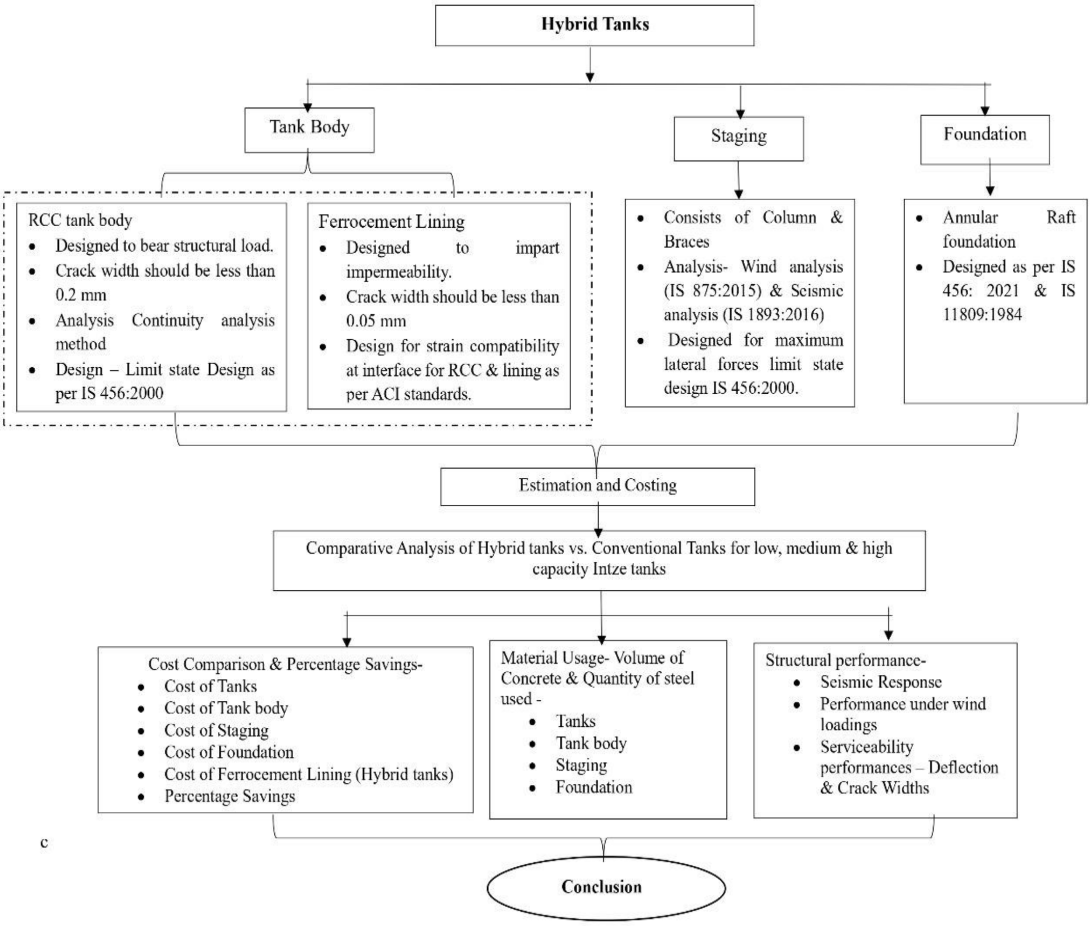


Fig. 4.1: Flow chart of the methodology of comparative study

Table 4.1: Design standard used in hybrid and conventional design approaches

Element/ Parameter	**Hybrid design**	**Conventional design**	
		Type I	Type II
Tank body	IS 456:2000 (Reaffirmed 2021)	IS 3370:2021 (clause no 4.4.3.1.)	IS 3370:2021 (clause no 4.4.1.1.)
Ferrocement lining	American concrete institute standards	-	
Crack width	In ferrocement lining the crack width should be less than 0.05 mm	Less than 0.2 mm in tank body	
Analysis and design for tank body	Continuity analysis approach & Limit state design method		
Staging and foundation	Same for both Hybrid and Conventional design approach.		

4.2. Application & comparison criteria's

For this investigation, deliberate consideration was given to the selection of three tanks, each exemplifying distinct capacity: low, medium, and high. The specific details pertaining to each tank are delineated in Table 4.2. 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.

The Cylindrical H/D Ratio is selected in each case to ensure that the maximum height of the cylindrical wall, including the free board, remains around 4 meters. Parametric studies were conducted for Intze tanks, incorporating practical considerations. These studies indicated that a cylindrical wall height exceeding 4 meters poses construction difficulties, particularly in rural areas. Consequently, the height of the cylindrical wall in Intze tanks is limited to 4 meters.

Table 4.2: Specifications of Intze water tanks used for the study.

Parameters	**Specifications**		
Quantity (in kilo liters)	200	600	1000
Staging height (m)	14	16	18
Concrete grade & steel	M 30 & Fe 500		
Foundation depth	1.8		
Net safe soil bearing capacity	80 kN/m^2		
Wind and seismic parameters	39 m/s, Terrain category 2, non-coastal region, seismic zone II		
Number of Bracings	4 Nos		
Lining only for HWT	1:2 cement sand mortar. Cement- OPC 43 or PPC Grade. Mesh- HB wires 1mm diameter square steel welded mesh (The tensile strength of bars in no case should be less than that of mild steel).		

4.2.1. Cost efficiency parameters

Cost efficiency has been accessed through following parameters-

- 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.

4.2.2. Structural efficiency parameters

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- Leakage is the most important phenomenon to be checked while designing a water retaining structure. Hence the crack width calculation is to be done to check the structural integrity of the tanks.
- Comparative analysis of annular raft footing.

4.3. Results and discussions: Comparative study of HWT and CWT I Intze type tanks

A comprehensive comparative study was undertaken to evaluate the economic and structural aspects of a HWT design in comparison with conventional methods. Results are focused on specific criteria for evaluation, such as structural integrity metrics, cost breakdowns, and leakage resistance, to ensure a rigorous and systematic comparison. Results encompass detailed cost and quantity evaluations, including the total water tank, tank body, lining, staging, and foundation (4.3.1-4.3.5). Structural performances are analyzed by calculation of Crack width, deflection, performance under Wind and seismic loading in both full & empty tank conditions, Raft area requirement (4.3.6-4.3.9) etc. The results underscored substantial advantages of the Hybrid design, emphasizing its economic and structural superiority over conventional practices.

4.3.1. 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 4.2. clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs.

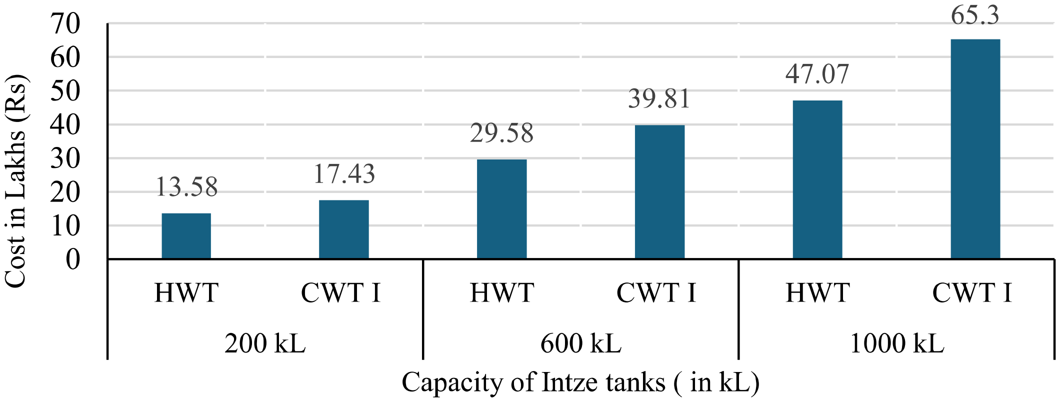


Fig. 4.2: Cost analysis of Hybrid & Conventional type I Intze tanks

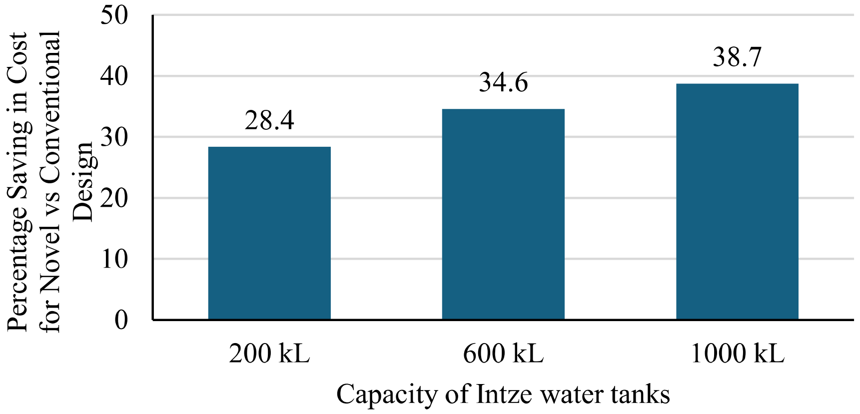


Fig. 4.3: Percentage Saving of Cost for Hybrid vs Conventional type I Intze tanks

The outcomes are summarized as follows:

- The percentage difference in cost savings, as depicted in Figure 4.3, falls within the range of 28.4-38.7%, a substantial margin.
- The cost of the HWT includes the lining cost. On average, there is a savings of about 33%, which is equivalent to one-third 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 28.4 % for a capacity of 200 kL, 34.6% for 600 kL, and 38.7% for 1000 kL, indicating a linear increase in savings with the tank capacity. It's important to note that these savings include the cost of ferrocement lining.

4.3.2. Cost of ferrocement lining

Table 4.3 provides details on the linings designated for each tank, encompassing the top, bottom, conical Section, and cylindrical wall—essentially, all parts in contact with water. The lining design prioritizes factors like strain compatibility, thickness, and the specified reinforcement layers, as outlined in Table 4.3. Fig. 4.4 Shows the Cost of ferrocement lining used in Hybrid design approach and variations. Cost of lining includes cost of mortar and steel required. lining is also optimized to give minimum cost and Details are given in Annexure A.

Table 4.3: Specifications of ferrocement lining provided in tanks

tank	**Thickness (mm)**	**Reinforcement**	**Percentage of Cost of lining over Total cost of structure**
200 kL	12	3 Layers	3.74
600 kL	15	3 Layers	3.49
1000 kL	15	3 Layers	3.12

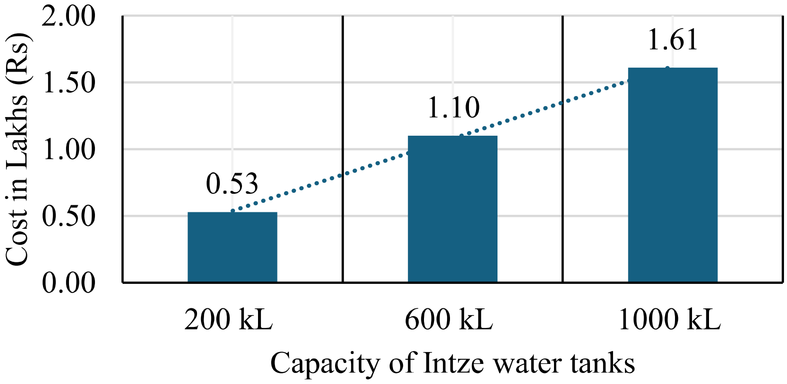


Fig. 4.4: Cost of ferrocement lining used in Hybrid design approach.

The outcomes are summarized as follows:

- Cost of the ferrocement lining ranges from 0.5 lakhs – 1.7 lakhs which is about 3.1-3.7 % of the overall cost.
- Thickness of the ferrocement lining & number of steel mesh requirement depends on the strain occurring at the interface of the RCC tank body and lining.
- For a 200 kL tank, the strain at the interface is minimal, leading to a reduced thickness requirement for the lining and 3 layers of steel mesh are required. In contrast, the maximum strain occurring at the interface in 600 kL and 1000 kL tanks is nearly. Therefore, thickness of 15 mm is provided, as per calculations, with the 4 layers of square steel mesh.
- The increase in tank capacity is directly correlated with a consistent rise in lining costs.
- This trend underscores the impact of the water-contacting surface area on the overall expenditure associated with the lining as shown in Fig.4.4.

- The average percentage of Cost of lining over Total cost of tank is approximately 3.45 %.

4.3.3. Comparison of Cost of tank body and Total cost of tank in both Hybrid and Conventional type I Intze tank

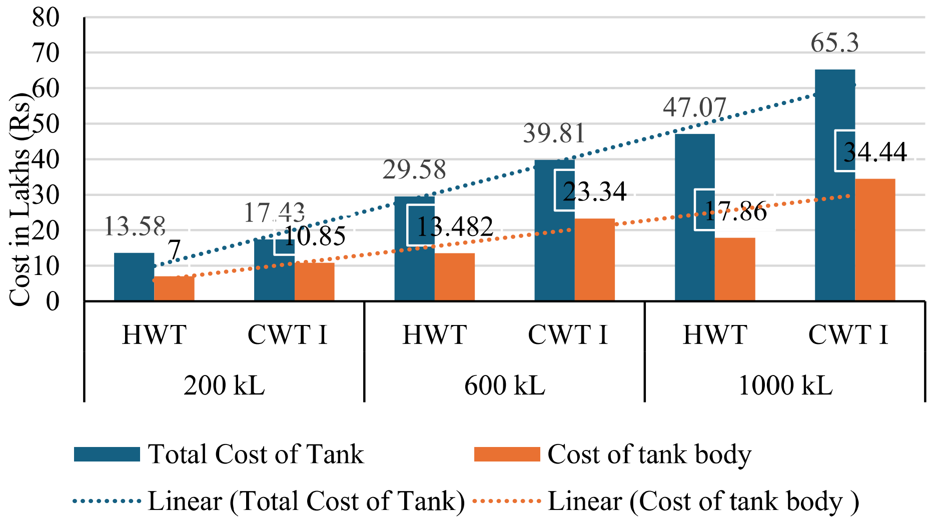


Fig. 4.5: Comparative analysis of tank body and Total tank Costs in HWT and CWT I

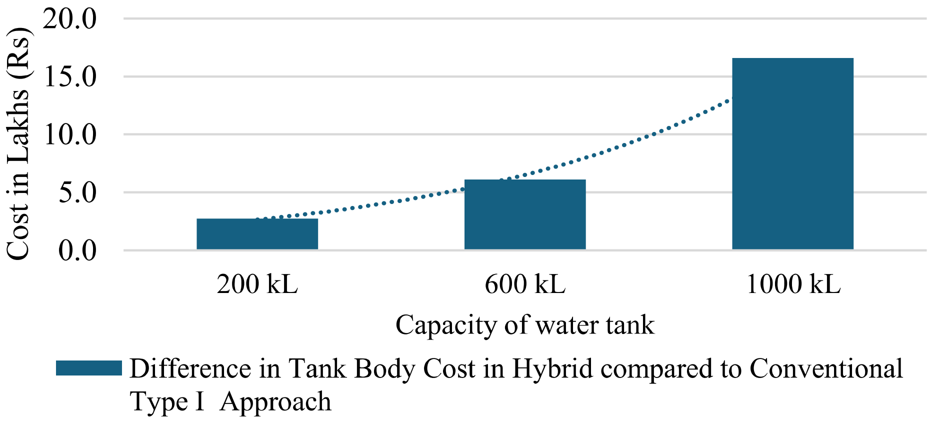


Fig. 4.6: Difference in cost of tank body of hybrid vs conventional approach.

The outcomes are summarized as follows:

- Figure 4.5 depicts a consistent divergence between the overall cost and the specific tank body cost, incorporating staging and foundation expenditures.

- Figure 4.6 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.
- Cost difference in the tank body in Hybrid & Conventional tank is about 3.85 – 16.58 lakhs ranging from 200 – 1000 kL tanks.
- 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 HWT and CWT is experiencing exponential growth with increase in the tank capacity.

4.3.4. Comparison of cost of steel and concrete in both Hybrid and Conventional type I tanks

A comparative analysis, shown in Figure 4.7, examines the costs of concrete and steel in both the tank body and the complete tank for both HWT and CWT.

The outcomes are summarized as follows:

- Figure 4.7 clearly illustrates that the cost of concrete & steel in both Complete tank & tank body substantially lower in the hybrid approach compared to the conventional one the cost of concrete and steel is nearly equal for HWTs, while in the case of CWT, the cost of concrete is significantly higher for both medium and low-capacity tanks. For high capacity CWT the cost of steel exceeds the cost of concrete.
- It is evident that, across all tank types, the cost of concrete exceeds that of steel for HWTs but for High-capacity conventional ones steel cost can exceed the cost of concrete.

- The disparity in the cost of concrete between HWT and CWT is more pronounced than the difference in steel costs.
- Additionally, the cost of staging and foundation is similar for both tank types, with the primary distinction in overall cost arising from the costs of concrete and steel in the tank body when compared to the complete tank structure.

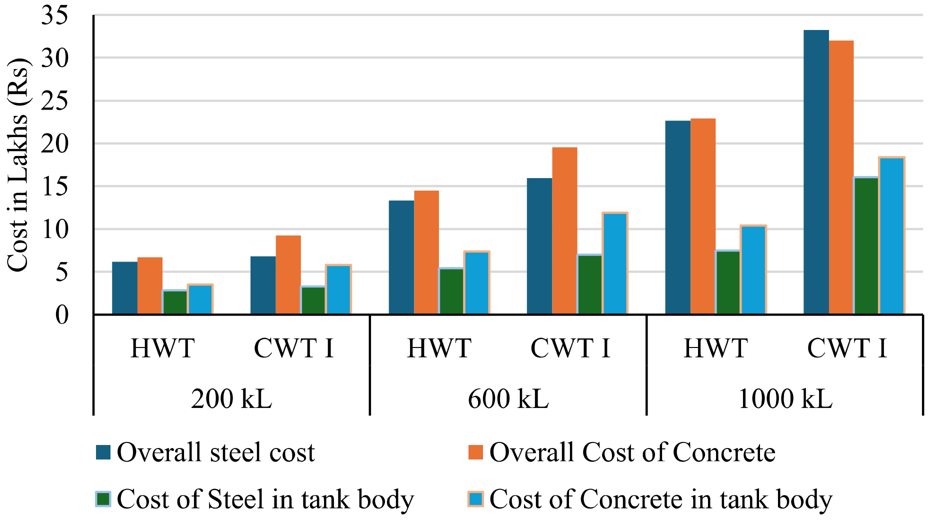


Fig. 4.7: Cost comparison of steel and concrete in both HWT and CWTs

4.3.5. Material consumption

Table 4.4 provides a comprehensive breakdown of concrete and steel quantities, accounting for the tank body, staging, and foundation in each tank. Steel and concrete constitute the primary components of water tanks, with the quantity of steel and the volume of concrete playing a significant role in determining the overall cost of the tanks.

Table 4.4: Consumption of materials in tanks

Capacity	Concrete used (cum)		Steel used (Tonnes)	
	HWTs	CWT I	HWTs	CWT I
200 kL	65.77	85.98	6.93	9.42
600 kL	140.6	181.15	15.49	23.3
1000 kL	219.47	306.6	25.31	37.08

The outcomes are summarized as follows:

- Remarkably, the Hybrid design consistently demonstrates lower concrete and steel requirements compared to the conventional design for all tanks.
- Steel and concrete constitute the primary components of water tanks, with the quantity of steel and the volume of concrete playing a significant role in determining the overall cost of the tanks.
- Concrete savings range from 23-39%, while steel savings vary between 26-32%, showcasing a substantial and consistent reduction across low to high-capacity tanks.
- This highlights the robust effectiveness of the Hybrid design approach in achieving significant material savings across various tank capacities.
- Percentage savings in Concrete and steel quantities increases with increase in capacity of water tanks.

4.3.6. 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.

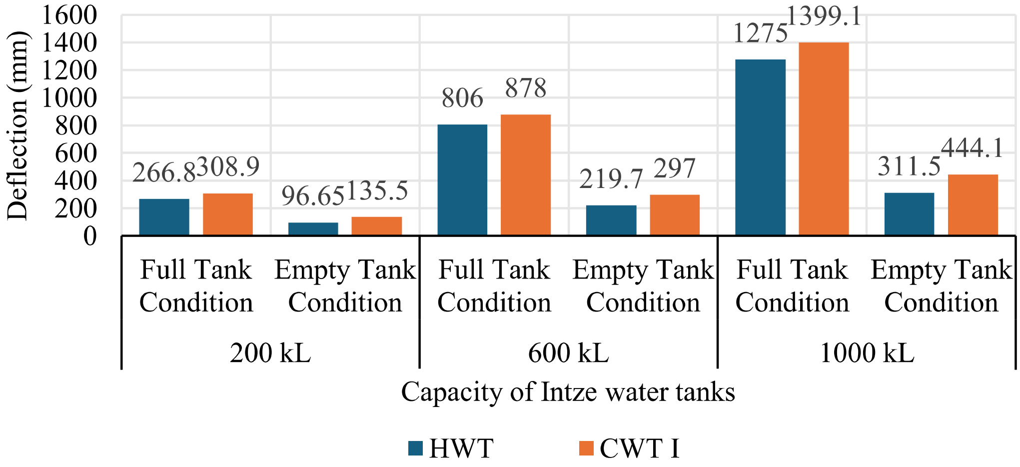


Fig. 4.8: Deflection in both full & empty tank condition for HWT and CWT I

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%-12% lower in the full tank condition.
- Deflection is significantly reduced, ranging from 32% to 43%, in the empty tank condition in comparison to the conventional approach.
- HWTs performs better in case of seismic activity as compared to CWT.

4.3.7. 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 4.9.

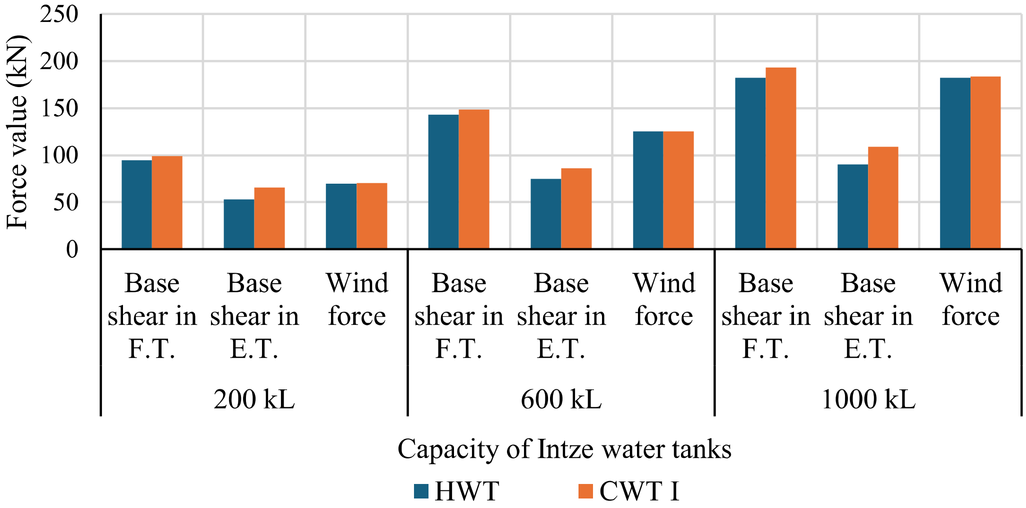


Fig. 4.9: Comparative analysis of seismic and wind forces

The outcomes are summarized as follows:

- Figure 4.9 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 7-15% for full tanks.
- Additionally, for empty tanks, the Hybrid approach exhibits a substantial reduction in seismic base shear, ranging from 14-21%.

4.3.8. Crack width calculations

In a comparative study of hybrid and conventional tank designs, crack widths were analyzed and are shown in Table 5. 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.

Table 4.5: Crack width calculations for CWT I and HWTs.

Quantity in Kl	Crack width (in mm)	
	CWT I	HWT
200	0.006866	0.01384
600	0.047	0.022
1000	0.0371	0.022

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.
- In a 200 kL tank, the conventional design displays lower crack width due to nearly double material consumption in the tank wall. The higher thickness, meeting minimum standards, results in increased use of steel and concrete, contributing to a substantial material volume. Due to the extensive use of materials in CWT, the crack width consistently remains within permissible limits, even for high-capacity tanks. In contrast, HWTs achieve low crack width with less material and reduced thickness, primarily attributed to the use of ferrocement lining.

4.3.9. 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 4.10. The investigation aims to provide insights into the potential savings of the hybrid design over the conventional approach under varying soil conditions.

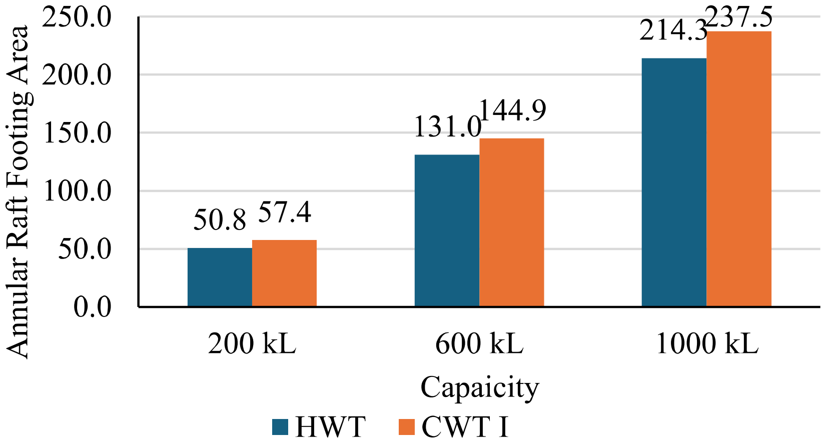


Fig. 4.10: Comparative analysis of area of annular raft footing designed as per hybrid and conventional approach.

Hybrid consistently demonstrates a reduction in designed area compared to conventional across all loading conditions (200 kL, 600 kL, and 1000 kL), with the percentage savings ranging from 10% -15 %.

4.3.10. Concluding remarks

The research findings highlight that HWTs offer substantial cost savings, ranging from 28% to 38%, along with enhanced structural performance. They demonstrate significant reductions in crack widths (48–54%), concrete usage (35–40%), and steel consumption (11–46%). Additionally, HWTs achieve minimized foundation area (10–15%) and lower seismic shear (7-15% when full, 14-21% when empty), as well as reduced deflection (11-12% when full, 32-43% when empty), making them a highly promising option for water supply.

4.4. Result and discussion: Comparative study of HWT with CWT II Intze tanks

A comprehensive comparative study was undertaken to evaluate the economic and structural aspects of a HWT design in comparison with Conventional type II Intze tanks of varying capacities (200, 600 & 1000 kiloliters) were meticulously designed using a specialized software program developed for both Hybrid and conventional approaches. Results encompass detailed cost evaluations and Quantity evaluations, including the total water tank, tank body, lining, staging, and foundation (4.4.1-4.4.5). Structural performances are analyzed by calculation of Crack width, deflection, performance under Wind and seismic loading in both full & empty tank conditions, Raft area requirement (4.4.6-4.4.9) etc. The results underscored substantial advantages of the Hybrid design, emphasizing its economic and structural superiority over conventional practices.

4.4.1. Cost comparison of Hybrid & Conventional tanks

Figure 4.11 clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs.

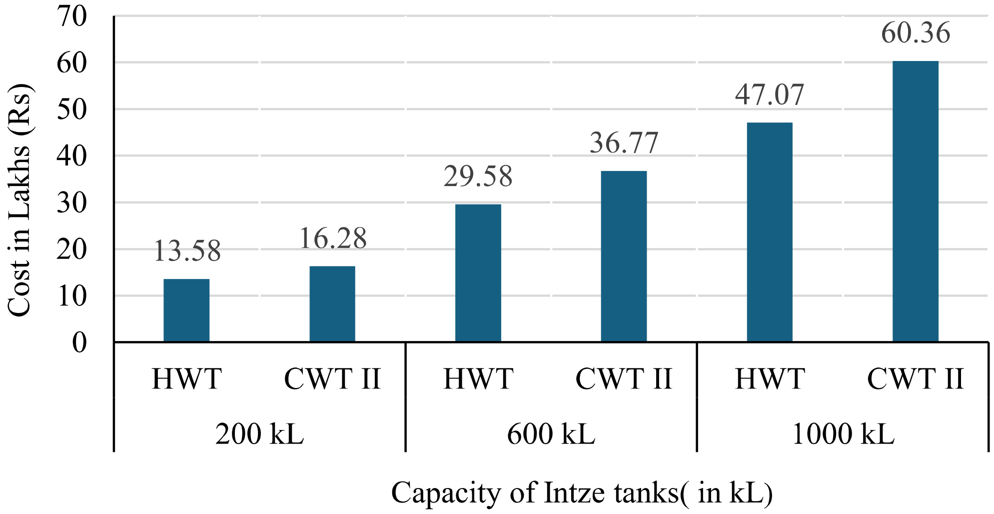


Fig. 4.11: Cost Comparison of HWT and CWT II Intze water tanks

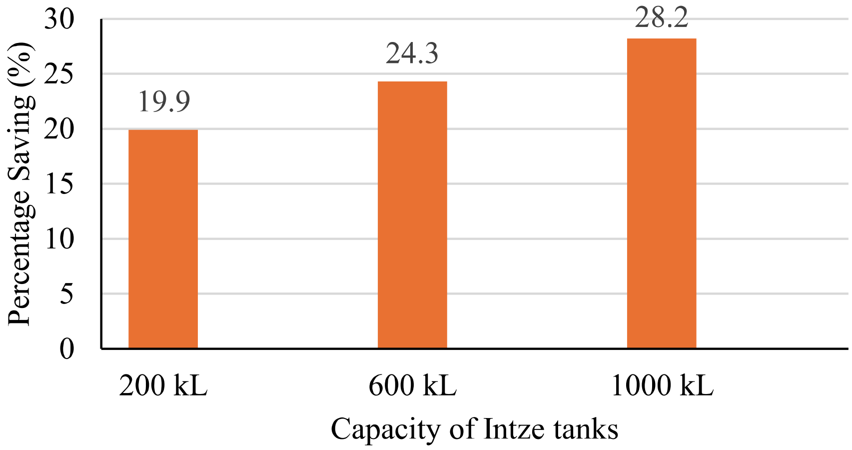


Fig. 4.12: Percentage saving in cost for hybrid vs conventional design

The outcomes are summarized as follows:

- The percentage difference in cost savings, as depicted in Figure 4.12, falls within the range of 20-29%, 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-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% for a capacity of 200 kL, 24% for 600 kL, and 28% for 1000 kL, indicating a linear increase in savings with the tank capacity. It's important to note that these savings include the cost of ferrocement lining.

4.4.2. Comparison of cost of tank body and total cost of tank in both HWT and CWT II-

Cost of tank body (water Retaining Container) is compared with Total costs of the tanks in Both Hybrid and Conventional type II tanks.

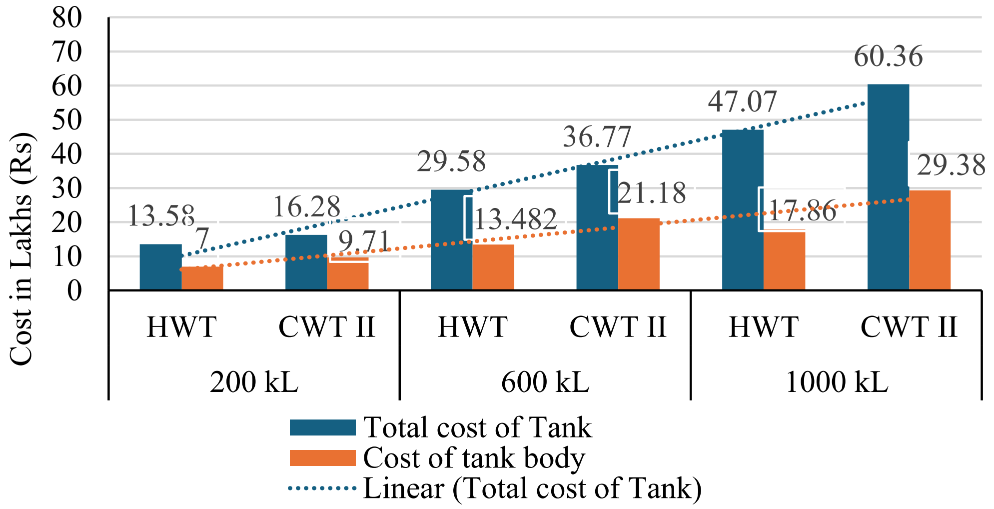


Fig. 4.13: Comparative analysis of tank body and total tank costs in hybrid and conventional approaches

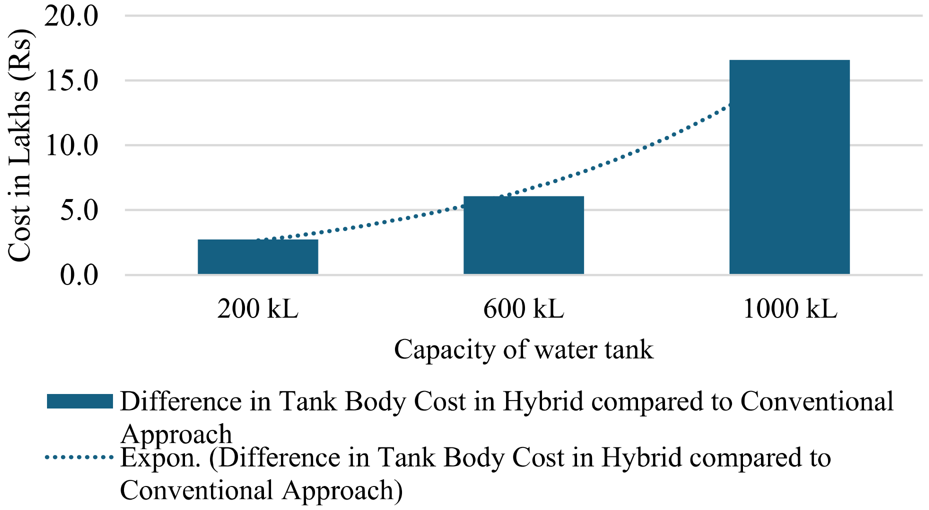


Fig. 4.14: Difference in cost of tank body of hybrid vs conventional approach.

The outcomes are summarized as follows:

- Figure 4.13 depicts a consistent divergence between the overall cost and the specific tank body cost, incorporating staging and foundation expenditures.
- Figure 4.14 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.
- 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 HWT and CWT is experiencing exponential growth with increase in the capacity of tank.
- Cost difference in the tank body in Hybrid & Conventional tank is about 2.5 – 11.5 lakhs ranging from 200 – 1000 kL tanks.

4.4.3. Cost of ferrocement lining

This section is same as that of 4.3.2 section as same capacity tanks are used only conventional designed are changed. Ferrocement lining used is same.

4.4.4. Comparison of cost of steel and concrete in both HWT and CWT II

A comparative analysis has been conducted based on the costs of concrete and steel in both the tank body and the complete tank for both hybrid and conventional approaches as shown in Fig 4.15.

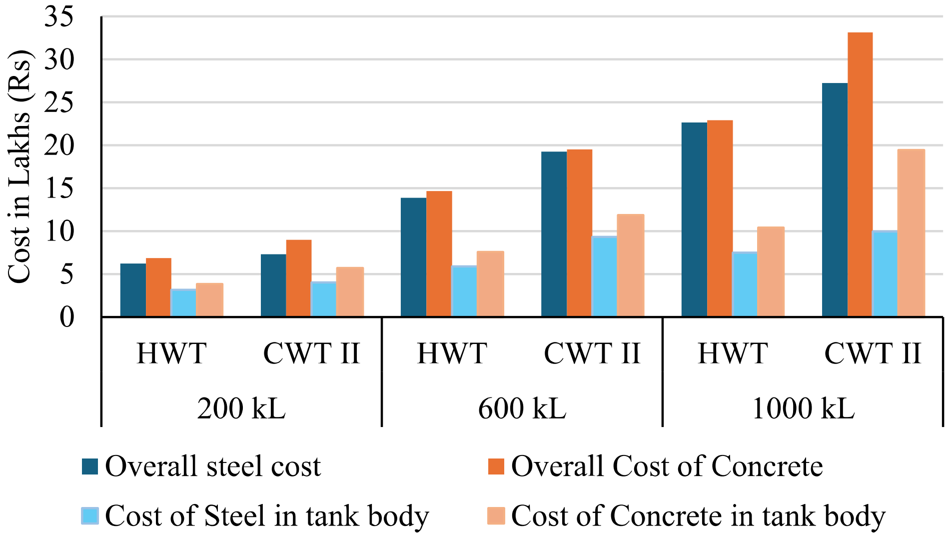


Fig. 4.15: Cost comparison of steel and concrete in HWT and CWT II

The outcomes are summarized as follows:

- Figure 4.15 clearly illustrates that the cost of concrete & steel in both Complete tank & tank body substantially lower in the hybrid approach compared to the conventional one the cost of concrete and steel is nearly equal for HWTs, while in the case of CWT, the cost of concrete is significantly higher for both high and low-capacity tanks.
- For medium-sized tanks, the costs of steel and concrete are roughly equivalent.
- It is evident that, across all tank types, the cost of concrete exceeds that of steel.
- The disparity in the cost of concrete between HWT and CWT is more pronounced than the difference in steel costs.
- Additionally, the cost of staging and foundation is similar for both tank types, with the primary distinction in overall cost arising from the costs of concrete and steel in the tank body when compared to the complete tank structure.

4.4.5. Material consumption

Table 4.6 provides a comprehensive breakdown of concrete and steel quantities, accounting for the tank body, staging, and foundation in each tank.

Table 4.6: Quantity of steel and concrete used in tanks

Capacity	Tank type	Complete concrete quantity in cum	Complete steel quantity in tonnes
200 kL	HWT	65.77	6.93
	CWT II	85.98	8.14
600 kL	HWT	140.6	15.49
	CWT II	186.86	17.25
1000 kL	HWT	219.47	25.31
	CWT II	317.26	30.36

The outcomes are summarized as follows:

- Remarkably, the Hybrid design consistently demonstrates lower concrete and steel requirements compared to the conventional design for all tanks.
- Steel and concrete constitute the primary components of water tanks, with the quantity of steel and the volume of concrete playing a significant role in determining the overall cost of the tanks.
- Concrete savings range from 30-36%, while steel savings vary between 11-20%, showcasing a substantial and consistent reduction across low to high-capacity tanks.
- This highlights the robust effectiveness of the Hybrid design approach in achieving significant material savings across various tank capacities.
- Percentage savings in Concrete and steel quantities increases with increase in capacity of water tanks.

4.4.6. Deflection of tanks

The deflection of all three tanks has been computed under both full and empty tank conditions, employing both Hybrid and conventional Intze tanks, and is shown in Fig. 4.16.

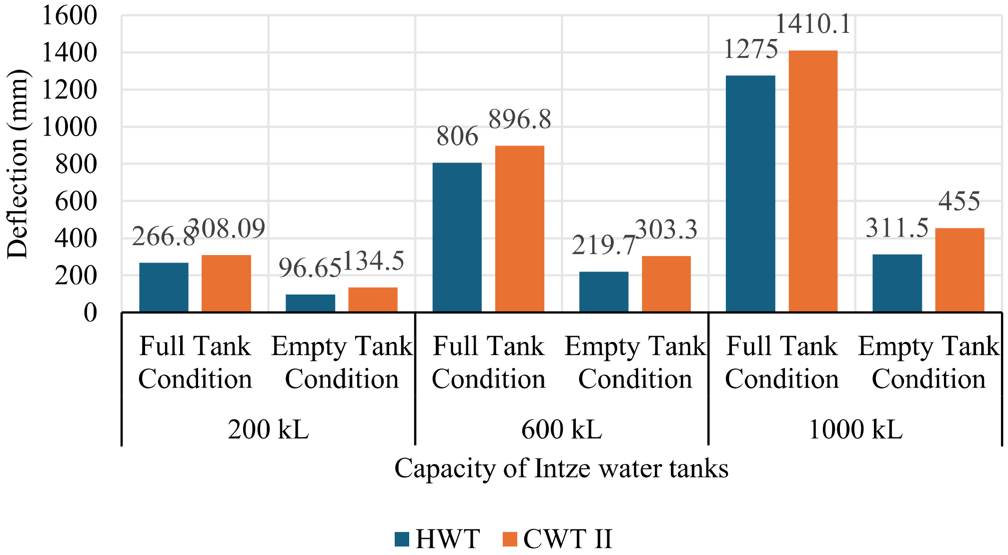


Fig. 4.16: Deflection in both full and empty tank condition for HWT and CWT II

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 10%-16% lower in the full tank condition.
- Deflection is significantly reduced, ranging from 38% to 46%, in the empty tank condition in comparison to the conventional approach.
- HWTs performs better in case of seismic activity as compared to CWT.

4.4.7. Seismic and wind analysis of HWT and CWT II Intze tanks

A comparison of seismic and wind forces acting on tanks designed with both HWT and CWT II approaches, shown in Figure 4.17 (a) & Seismic base shear is also calculated for all the three capacity tanks for all Seismic Zones (II, III, IV & V) in India.

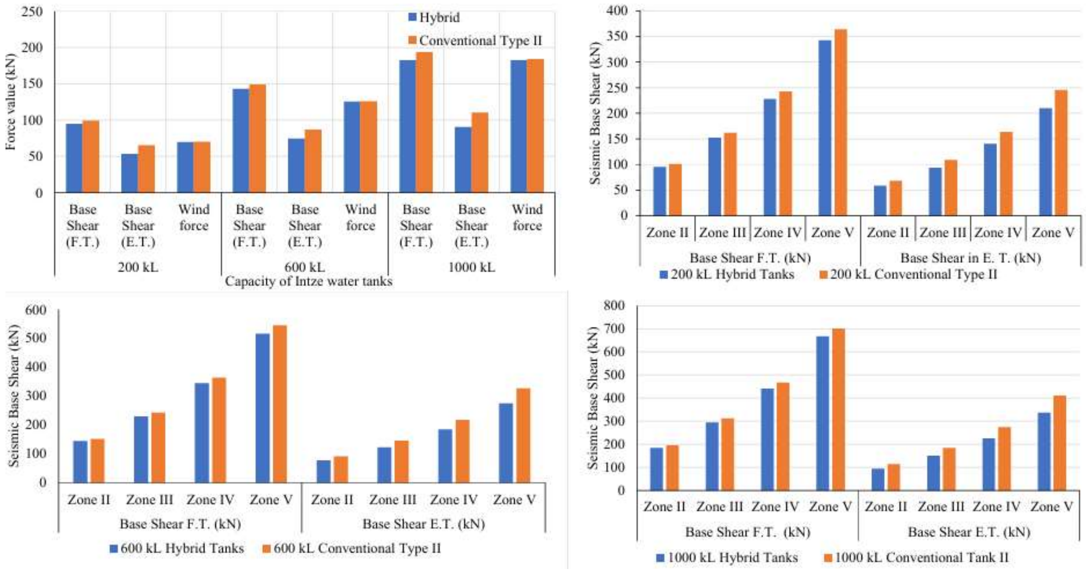


Fig. 4.17 (a)Comparative analysis of seismic and wind forces; (b) Seismic base shear for 200 kL tank for Zone II, III, IV &V; (c) Seismic base shear for 600 kL tank for Zone II, III, IV &V. (d) Seismic base shear for 1000 kL tank for Zone II, III, IV &V.

The outcomes are summarized as follows:

- Figure 4.17 (a) 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 4.17 (b-d) 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 4.17 (b-d) indicates that for all the zones 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 4-6% for full tanks.
- Additionally, for empty tanks, the Hybrid approach exhibits a substantial reduction in seismic base shear, ranging from 16-23%.
- Zone II has the lowest Base shear values in both full & empty tank conditions.

- Zone V has the highest Base shear values in both full & empty tank conditions.
- Base shear increases with increase in seismic zones.

4.4.8. Crack widths calculation

In a comparative study of Hybrid and Conventional tank designs, crack widths were analyzed and are shown in Table 4.7.

Table 4.7: Crack width calculations for HWT and CWT II

Quantity in kL	Crack width (in mm)	
	CWT II	HWT
200	0.006866	0.01384
600	0.047	0.022
1000	0.042	0.022

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.
- In a 200 kL tank, the conventional design displays lower crack width due to nearly double material consumption in the tank wall. The higher thickness, meeting minimum standards, results in increased use of steel and concrete, contributing to a substantial material volume.
- Due to the extensive use of materials in CWT, the crack width consistently remains within permissible limits, even for high-capacity tanks.
- In contrast, HWTs achieve low crack width with less material and reduced thickness, primarily attributed to the use of ferrocement lining.

4.4.9. 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 4.18. The study involves varying the soil bearing capacity at 80, 160, and 240 kN/m² to comprehend the design's response to changes in bearing capacity. The investigation aims to provide insights into the potential savings of the hybrid design over the conventional approach under varying soil conditions.

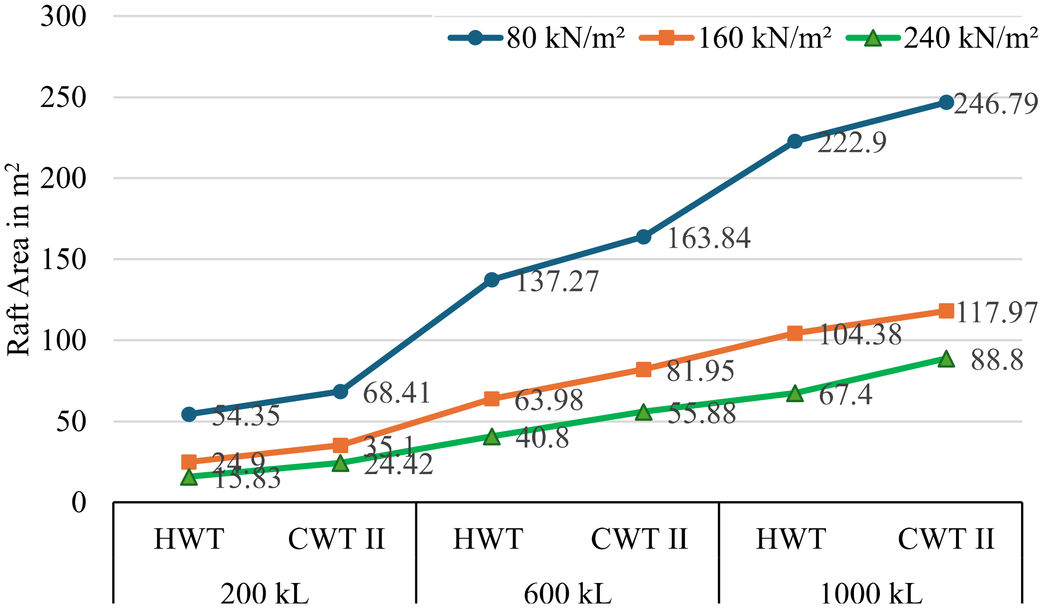


Fig. 4.18: Comparative analysis of area of annular raft footing of HWT and CWT II

The outcomes are summarized as follows:

- At 80 kN/m²: Hybrid consistently demonstrates a reduction in designed area compared to Conventional across all loading conditions (200 kL, 600 kL, and 1000 kL), with the percentage savings ranging from 10% to 20%.
- At 160 kN/m²: The reduction in designed area by Hybrid is more pronounced, with percentage savings ranging from 12% to 29% across different loading conditions.
- At 240 kN/m²: Hybrid exhibits substantial savings, with a percentage reduction in designed area ranging from 24% to 35% as soil bearing capacity increases.
- With a soil bearing capacity of 80 kN/m2, the raft area expands rapidly, particularly in comparison to other capacities, as the tank capacity increases.

- The average savings across all soil bearing capacities show that Hybrid consistently outperforms Conventional in terms of reducing the designed area. The average percentage savings are 15% at 80 kN/m², 21% at 160 kN/m², and 28% at 240 kN/m².
- Percentage savings in Raft areas in Hybrid design as compared to conventional increases with increase in the in Bearing capacity of soil.

4.4.10. Concluding remarks

This study highlights the significant advantages of Hybrid Intze tanks over Conventional type II Intze tanks in terms of cost-effectiveness, material savings, and structural performance. The Hybrid design, integrating a ferrocement lining, achieves substantial reductions in concrete and steel consumption, leading to overall cost savings of 20-28%. HWTs show significant reductions in concrete usage (30-36%) and steel consumption (11-20%).

In terms of performance, HWTs demonstrate superior structural integrity with lower deflection (10-16% in full tanks, 38-46% in empty tanks), enhanced resistance to seismic and wind forces, reduced crack widths (46-52%), and lower base shear (4-6% in full tanks, 16-23% in empty tanks), ensuring better durability and serviceability. The innovative approach also optimizes the design of annular raft footings, resulting in more efficient land usage with minimized raft area (10-35%).

Overall, Hybrid Intze tanks represent a more economical, durable, and sustainable solution for elevated water tank construction, proving to be efficient alternatives for water storage.

4.5. Result and discussion: Comparative study of HWT with CWT II Intze tanks

A comprehensive comparative study was conducted to evaluate the cost and structural aspects of HWTs versus CWT I & II, with a particular focus on the cost differences between CWT I and CWT II. Intze tanks with capacities of 200, 600, and 1000 kiloliters were meticulously designed using specialized software. While previous findings in Section 4.4 highlighted significant steel savings in CWT II compared to CWT I, the overall cost difference remained minimal. This study delves deeper into this issue. Additionally, HWTs were assessed under various seismic zones and wind speeds to examine the performance of 200, 600, and 1000 kL tanks under different conditions. The study also includes a comparative analysis of HWT and CWT. Specifications of Intze water tanks used for the study are given in Table 4.8.

Table 4.8: Specifications of Intze water tanks used for the study.

Sr. No	Parameters	Specifications
1	Quantity, Staging height, Net safe bearing capacity and Foundation depth	Same as in Section 4.1
2	Wind speed	47 m/s
3	Terrain category and region type	Terrain category 3, Non-Coastal
4	Seismic parameters	Seismic zone III

4.5.1. 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 tank structure, including materials for the tank body, staging, and foundation. For HWTs, the cost of ferrocement lining is also included in the total cost. Fig. 4.19 shows a comparative cost analysis of HWT and CWT.

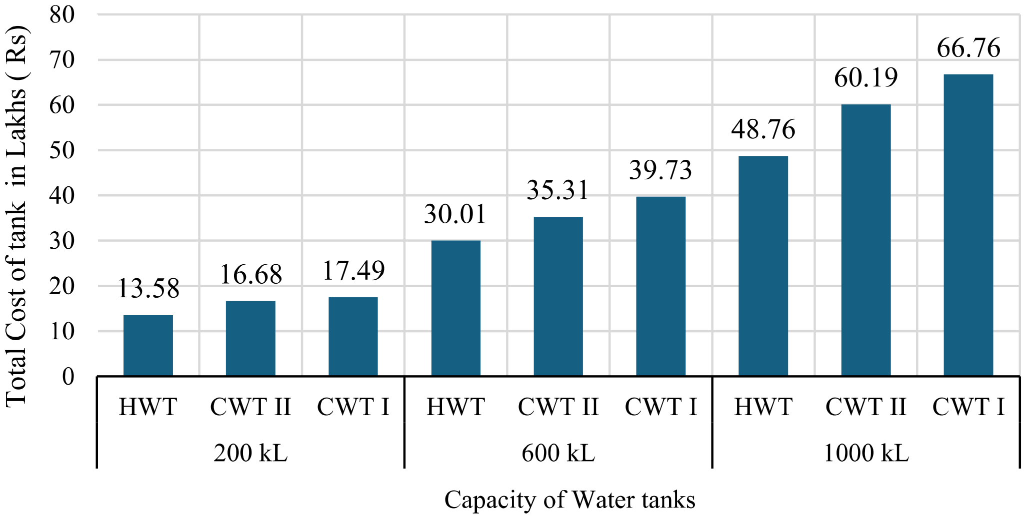
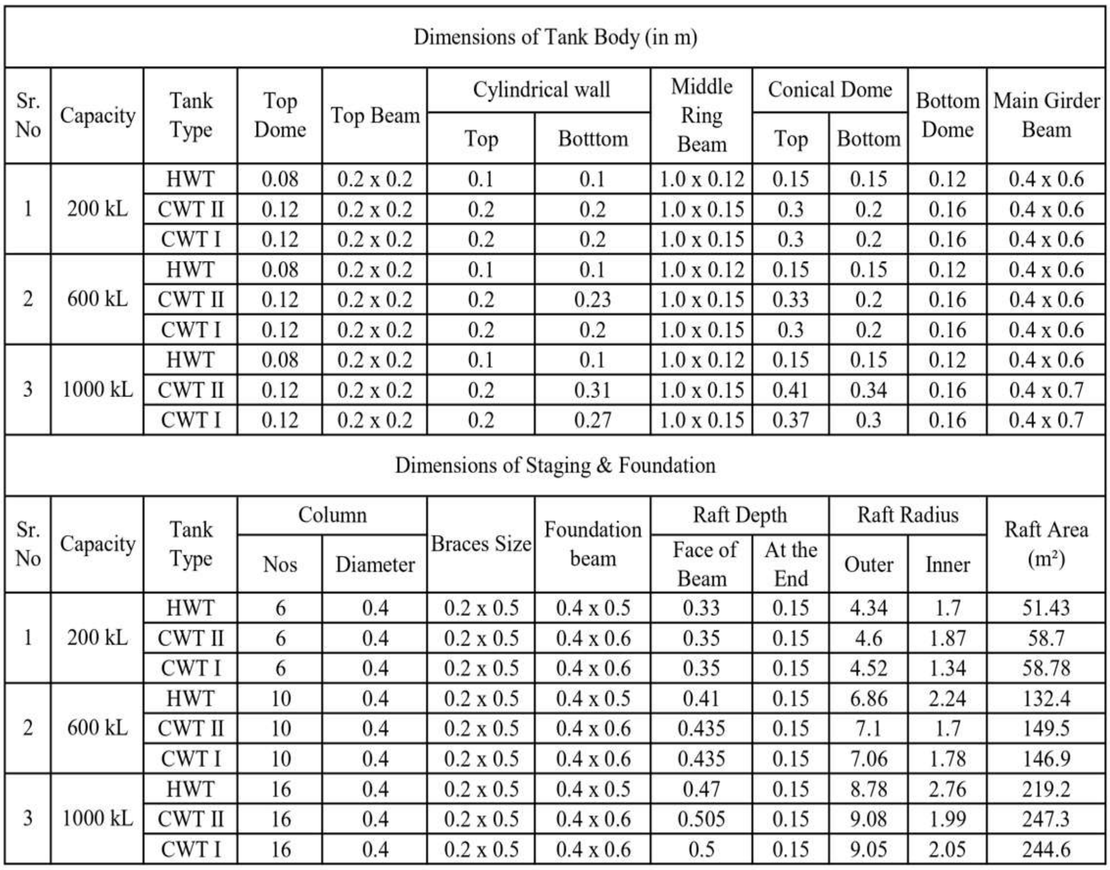


Fig. 4.19: Comparative Cost analysis of Hybrid, Conventional type I & type II Intze water tanks.

- Figure 4.19 illustrates that HWTs are considerably more cost-effective than CWT.
- The percentage difference in cost savings between HWT and CWT I falls within the range of 28-37%.
- Similarly, the difference in cost savings between and CWT II ranges between 17-24%, indicating a significant margin in both cases. The cost of the HWT includes the lining cost.
- The percentage of savings increases with the increase in the capacity of the tank.
- CWT II is more cost-effective as compared to CWT I.
- A savings range of 4.85% to 13% can be achieved in CWT II compared to CWT I.

4.5.2. Comparative analysis of RCC member sizes between HWTs, CWT I and CWT II

Figure 4.20 displays the dimensions of all tank components, encompassing the tank body, staging, and foundation. Outcomes are summarized as follows-



Dimensions of Tank Body (in m)

Sr. No	Capacity	Tank Type	Top Dome	Top Beam	Cylindrical wall		Middle Ring Beam	Conical Dome		Bottom Dome	Main Girder Beam
					Top	Botttom		Top	Bottom		
1	200 kL	HWT	0.08	0.2 x 0.2	0.1	0.1	1.0 x 0.12	0.15	0.15	0.12	0.4 x 0.6
		CWT II	0.12	0.2 x 0.2	0.2	0.2	1.0 x 0.15	0.3	0.2	0.16	0.4 x 0.6
		CWT I	0.12	0.2 x 0.2	0.2	0.2	1.0 x 0.15	0.3	0.2	0.16	0.4 x 0.6
2	600 kL	HWT	0.08	0.2 x 0.2	0.1	0.1	1.0 x 0.12	0.15	0.15	0.12	0.4 x 0.6
		CWT II	0.12	0.2 x 0.2	0.2	0.23	1.0 x 0.15	0.33	0.2	0.16	0.4 x 0.6
		CWT I	0.12	0.2 x 0.2	0.2	0.2	1.0 x 0.15	0.3	0.2	0.16	0.4 x 0.6
3	1000 kL	HWT	0.08	0.2 x 0.2	0.1	0.1	1.0 x 0.12	0.15	0.15	0.12	0.4 x 0.6
		CWT II	0.12	0.2 x 0.2	0.2	0.31	1.0 x 0.15	0.41	0.34	0.16	0.4 x 0.7
		CWT I	0.12	0.2 x 0.2	0.2	0.27	1.0 x 0.15	0.37	0.3	0.16	0.4 x 0.7

Dimensions of Staging & Foundation

Sr. No	Capacity	Tank Type	Column		Braces Size	Foundation beam	Raft Depth		Raft Radius		Raft Area (m^2)
			Nos	Diameter			Face of Beam	At the End	Outer	Inner	
1	200 kL	HWT	6	0.4	0.2 x 0.5	0.4 x 0.5	0.33	0.15	4.34	1.7	51.43
		CWT II	6	0.4	0.2 x 0.5	0.4 x 0.6	0.35	0.15	4.6	1.87	58.7
		CWT I	6	0.4	0.2 x 0.5	0.4 x 0.6	0.35	0.15	4.52	1.34	58.78
2	600 kL	HWT	10	0.4	0.2 x 0.5	0.4 x 0.5	0.41	0.15	6.86	2.24	132.4
		CWT II	10	0.4	0.2 x 0.5	0.4 x 0.6	0.435	0.15	7.1	1.7	149.5
		CWT I	10	0.4	0.2 x 0.5	0.4 x 0.6	0.435	0.15	7.06	1.78	146.9
3	1000 kL	HWT	16	0.4	0.2 x 0.5	0.4 x 0.5	0.47	0.15	8.78	2.76	219.2
		CWT II	16	0.4	0.2 x 0.5	0.4 x 0.6	0.505	0.15	9.08	1.99	247.3
		CWT I	16	0.4	0.2 x 0.5	0.4 x 0.6	0.5	0.15	9.05	2.05	244.6

Fig. 4.20: Member sizes/ dimensions of Intze water tanks.

- It is evident that HWTs adhere to the minimum dimension criteria outlined in IS 456:2000 (Reaffirmed 2021) and exhibit the smallest dimensions among all the members.
- CWT adhere to the minimum dimension criteria outlined in the guidelines of IS 3370: 2021, which results in larger Sections when compared to HWTs.
- In the case of CWT I, the limitation of steel stresses to 130 N/mm2 leads to significant quantities of steel and comparatively smaller concrete Sections compared to CWT II.
- The larger sizes observed in CWT II can be attributed to the consideration of steel stresses as ultimate stresses. This approach reduces steel usage, thereby necessitating larger concrete Sections to withstand the Hoop tension experienced by the members.
- The minimum thickness for the top dome of CWT, as per the specifications outlined in IS 3370:2021 for exposure criteria, should be at least 120 mm. In contrast, HWTs,

which adhere to IS 456:2000 (Reaffirmed 2021), have a lower required thickness of 80 mm.

- The top ring beam is the same for all the tanks following minimum specifications as per provisions.
- In comparison to CWT, HWTs have a reduced thickness in their cylindrical walls across all three capacity levels. Additionally, CWT II exhibits a maximum bottom wall thickness in contrast to CWT I and HWTs. The heightened thickness of the cylindrical walls in CWT II, arising from substantial steel savings, results in an augmentation of concrete Sections by the stress criteria for concrete specified in IS 3370:2021. A similar pattern is reflected in conical dome thicknesses at the top & bottom.
- In the analysis of joint continuity, it is observed that the minimum depth of the middle ring beam, Bottom contrasts with CWT I and CWT II. In HWTs, the main girder beam has either the same depth or a lesser depth compared to CWT I and CWT II.
- Column diameter & staging are kept the same for all the tanks although due to the lesser dead weight of the tank body, Steel requirement will be lesser in the case of HWTs as compared to CWT I & II.
- Foundation beam sizes, raft area requirements, and the required diameters for the raft are smaller in HWTs when compared to CWT I and CWT II.
- In summary, there are substantial concrete savings in HWTs compared to both CWT I and CWT II. Furthermore, CWT I exhibit better performance than CWT II in this regard.

4.5.3. Cost of ferrocement lining

Cost of the ferrocement lining is same as Section 4.3.2 in Chapter.

4.5.4. Comparison of cost of tank body and total cost of the tank in both HWT, CWT I, and CWT II

Figure 4.21 depicts a consistent divergence between the overall cost and the specific tank body cost, incorporating staging and foundation expenditures, in both Hybrid and conventional designs.

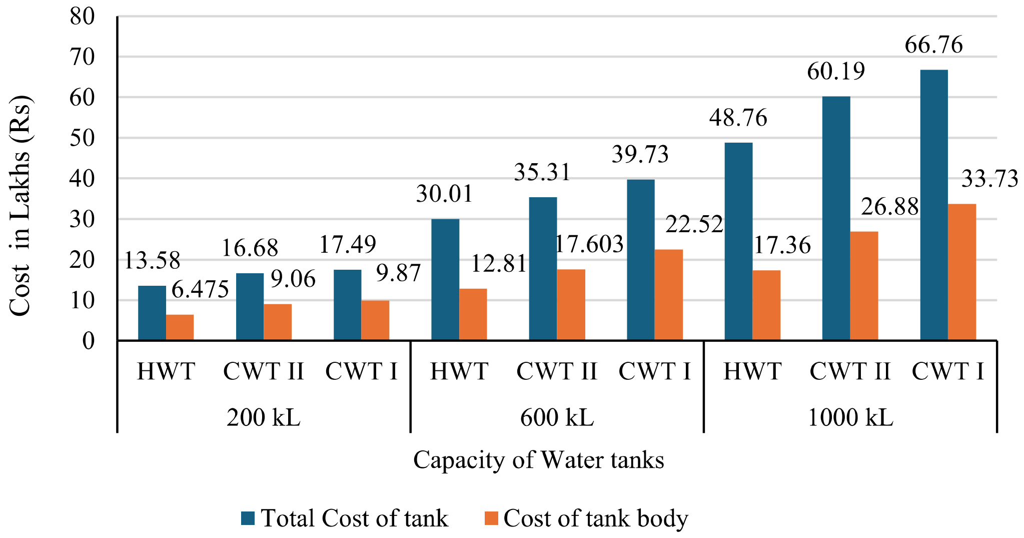


Fig. 4.21: Comparative analysis of tank body and total tank costs in hybrid and conventional tanks

Outcomes are summarized as follows-

- Figure 4.21 emphasizes substantial savings specifically in the cost of the tank body.
- 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 exponential growth.

4.5.5. Material consumption

Table 4.9 provides a comprehensive breakdown of concrete and steel quantities, accounting for the tank body, staging, and foundation in each tank.

Table 4.9: Quantity of steel and concrete used in tanks

Capacity	**Tank type**	**Complete concrete quantity in cum**	**Complete steel quantity in tonnes**
200 kL	HWT	63.93	6.84
	CWT I	86.76	8.54
	CWT II	86.78	7.63
600 kL	HWT	140.8	15.93
	CWT I	182.71	23.03
	CWT II	188.86	17.38
1000 kL	HWT	223.86	25.8
	CWT I	310.07	38.35
	CWT II	321.5	26.6

Outcomes are summarized as follows-

- The Hybrid design consistently demonstrates lower concrete and steel requirements compared to the conventional design for all tanks.
- In the case of HWTs as compared to CWT II Concrete savings range from 35-43%, while steel savings vary between 3-11%
- In the case of HWTs as compared to CWT I Concrete savings range from 34-38%, while steel savings vary between 24-48%, showcasing a substantial and consistent reduction across low to high-capacity tanks.
- Concrete savings in CWT I compared to CWT II are 7%, while steel savings in CWT II range from 11.9% to 44% compared to CWT I, indicating substantial reductions across tanks of varying capacities.
- This highlights the robust effectiveness of the Hybrid design approach in achieving significant material savings across various tank capacities.

4.5.6. Deflection

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. 4.22.

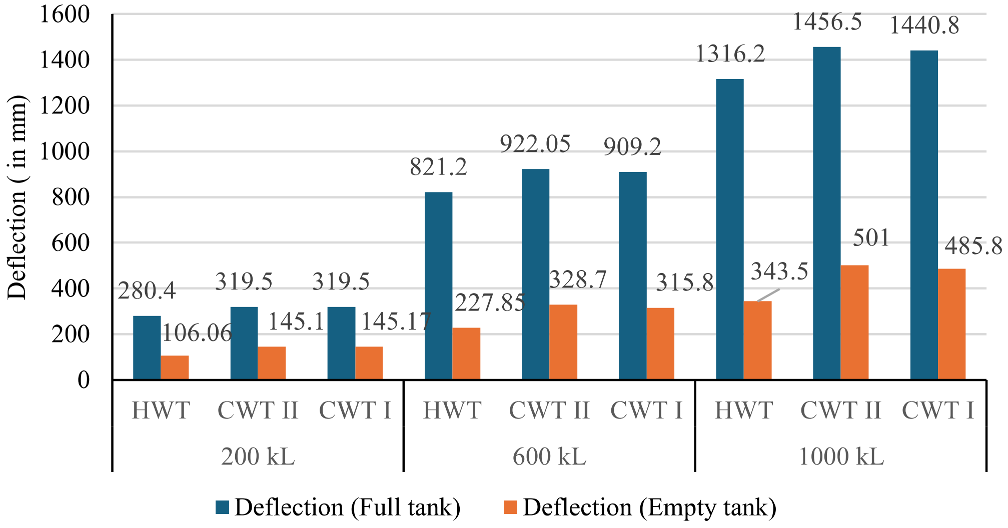


Fig. 4.22: Deflection in both Full & empty tank conditions for Hybrid, CWT I & CWT II tanks

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.
- Compared to CWT II, HWTs exhibit a 10%-14% lower deflection in full tank condition and a significantly reduced deflection of 36%-46% in empty tank condition.
- In comparison to CWT I, HWTs show a 9%-14% lower deflection in full tank condition and a considerably reduced deflection of 36%-41% in empty tank condition.
- CWT I tanks show less deflection in both Full & empty tank conditions as compared to CWT II.

4.5.7. Seismic and wind analysis of HWT, CWT I and CWT II

A comparison of seismic and wind forces acting on tanks Hybrid and Conventional is shown in Figure 4.23.

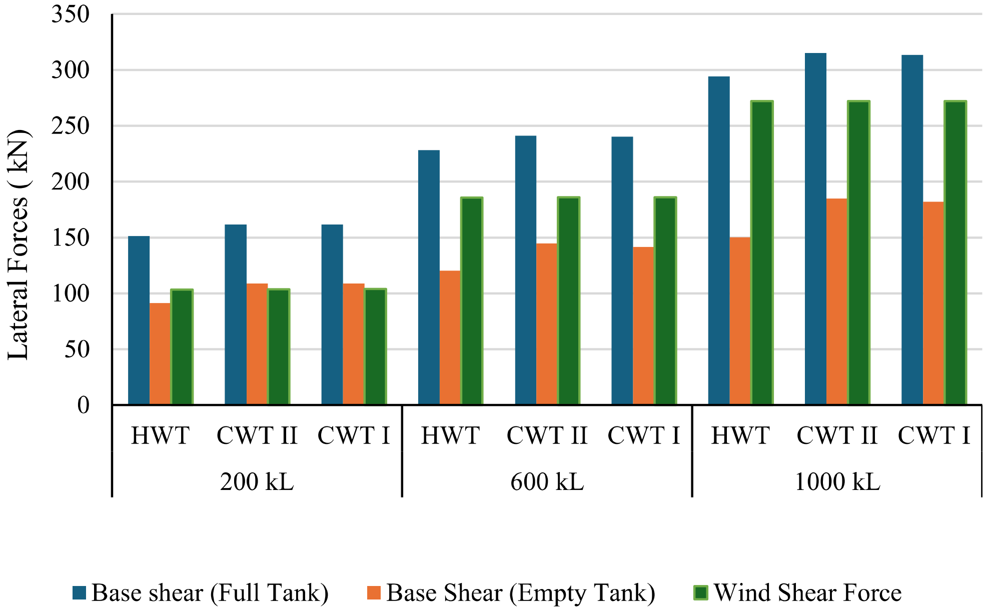


Fig. 4.23: Comparative analysis of seismic and wind forces acting on hybrid & conventional tanks.

Outcomes are summarized as follows-

- Wind forces are similar due to consistent tank size and staging height.
- Notably, the seismic base shear is lower in the Hybrid approach for both empty and full tank conditions, with reductions of 5-7% for full tanks and 17-23% for empty tanks.
- This decrease is attributed to the reduced dead weight of the tank body in the hybrid design. CWT I shows better seismic performance as compared to CWT II.

4.5.8. Comparative analysis of annular raft footing

A comparative analysis of the area of annular raft footing designed for hybrid and conventional approaches has been conducted and is shown in Figure 4.24.

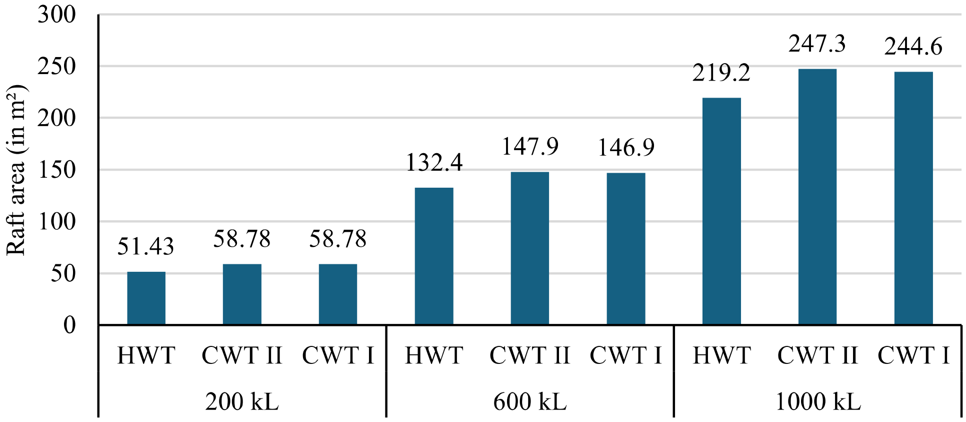


Fig. 4.24- Comparative analysis of the area of annular raft footing

- The findings reveal a substantial reduction in the raft area (in m²), ranging from 10% to 14% in the Hybrid design as compared to the Conventional design.
- Conventional tank type I requires lesser area as compared to Conventional type II.

4.5.9. Crack width calculations

In a comparative study of Hybrid and Conventional tank designs, crack widths were analyzed and are shown in Table 4.10.

Table 4.10: Crack width calculations for conventional & HWTs.

Quantity in kL	Crack width (in mm)		
	CWT II	CWT I	HWT
200	0.006866	0.00687	0.01384
600	0.047	0.04680	0.022
1000	0.042	0.03717	0.022

Outcomes are summarized as follows-

- The conventional tank's crack width is well below the IS 3370:2021 limit of 0.2 mm.
- Crack width calculations are not required for Conventional tank type I, yet they are computed for this study.
- For HWTs, crack width calculations for RCC and lining parts were performed, and the results are below the ACI standard of 0.05 mm.
- HWTs exhibit significantly less crack width compared to CWT, especially with larger capacities.
- In a 200 kL tank, the conventional design displays a lower crack width due to nearly double material consumption in the tank wall. The higher thickness, meeting minimum standards, results in increased use of steel and concrete, contributing to a substantial material volume. Due to the extensive use of materials in CWT, the crack width consistently remains within permissible limits, even for high-capacity tanks.
- In contrast, HWTs achieve low crack width with less material & reduced thickness, primarily attributed to the use of ferrocement lining. CWT I has a lesser crack width as compared to CWT II.

4.5.10. Conclusive remarks

The results highlight significant advantages of HWTs over CWT (CWT I and CWT II). HWTs achieve cost savings of 28-37% compared to CWT I and 17-24% compared to CWT II. Additionally, HWTs exhibit improved structural performance with reduced crack width, deflections ranging from 9-14% for full tanks to 36-46% for empty tanks, decreased base shear (5-7% for full tanks to 17-23% for empty tanks), enhanced seismic and wind response, and require a smaller raft area (approximately 10-14%).

Comparing the CWT I and CWT II Intze tanks CWT I requires more steel as compared to CWT II because of Steel limitations but this results in augmented concrete sections in CWT II as compared to CWT I. Hence lesser cost savings are observed in CWT I and CWT II as expected. HWTs outperform both the CWT for all the Capacities in variable wind speeds and Seismic zone.