6. Chapter 6: Comparative analysis of cost-effectiveness and structural integrity of hybrid vs. conventional water tanks in 16 Indian urban centers

6.1. Introduction

This study compares the cost-effectiveness and structural performance of HWTs and CWT in 16 major cities across India, considering diverse seismic zones and wind speeds. The chosen cities represent a range of seismic zones: Bhopal, Hyderabad, Jaipur, Puducherry (Zone II); Ahmedabad, Vadodara, Lucknow, Chennai (Zone III); Shimla, Alibag, Delhi, Dwaraka (Zone IV); and Mandi, Kohima, Imphal, Guwahati (Zone V). Encompassing all seismic zones and considering wind speeds from 39 m/s to 50 m/s, the study designs 600 kL Intze water tanks and 200 kL Circular water tanks using in-house developed C++ software programs. Key parameters, including the cost of tanks, tank body, staging, ferrocement lining in HWTs, material consumption, seismic base shear, wind force, crack width, deflection, maximum bending moment in columns, and the influence of coastal regions compared to non-coastal areas, are examined.

The primary objective of this study is to assess the feasibility of HWTs compared to Conventional RCC tanks across 16 major cities and State Capitals in India. This evaluation will encompass various factors such as cost-effectiveness, durability, and sustainability. By conducting a comparative analysis, the study aims to provide valuable insights into the potential advantages and challenges of implementing HWTs in different geographical and urban settings across the country.

This study aims to evaluate and compare the structural performance and cost-effectiveness of CWT, designed according to criteria II of IS 3370:2021, with HWTs, to determine the optimal choice for tank design and construction across 16 major cities/ State capitals of India.

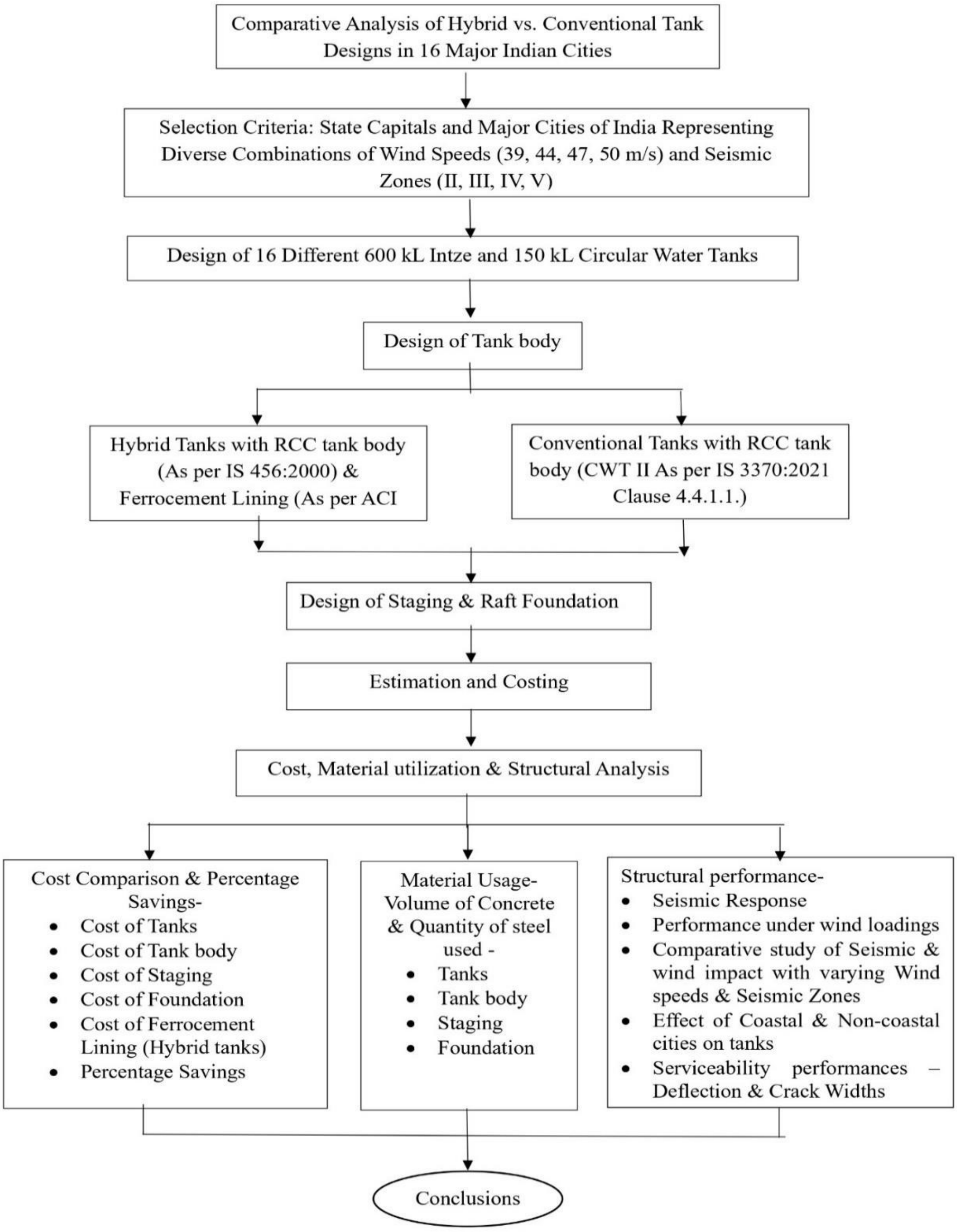

Fig. 6.1 :Methodological Framework for comparative study

The research specifically focuses on validating the hybrid design across various seismic zones and wind speeds, assessing both structural performance and costs. tanks are designed for 16 major Indian cities/state capitals, each situated in different seismic zones (ranging from Zone II to V) and experiencing varying wind speeds (39-50 m/s). Additionally, the study examines the impact of coastal regions on water tank structures, focusing on four coastal cities: Alibag, Puducherry, Dwaraka, and Chennai. Figure 6.1 represents the methodological framework of the comparative study.

6.2. Application & comparison criteria

6.2.1. Application criteria

- For this study, a 600 kL Intze water tank was specifically chosen as it represents a medium capacity tank commonly constructed across India to meet the water needs of larger populations. Depth of the foundation is also increased here in this case.
- A 200 kL Circular tank is also chosen to see the validity of HWTs over CWT. In Rural area mostly 150 kL Circular tanks are constructed to fed the village or community populations.
- Conventional tank type II has been found to be more cost-effective than Conventional tank type I, and therefore, it has been selected for the comparative study.
- Specifications of the Intze water tanks used in the study are detailed in Table 6.1. The cities chosen for the study are listed in Table 6.2.
- The study focuses on specific evaluation criteria, including structural integrity metrics, cost breakdowns, and leakage resistance, to ensure a rigorous and systematic comparison.

Table 6.1: Cities with wind speeds and seismic zones.

Seismic zone	Wind speed			
	39 m/s	44 m/s	47 m/s	50 m/s
II	Bhopal	Hyderabad	Jaipur	Puducherry
III	Ahmedabad	Vadodara	Lucknow	Chennai
IV	Shimla	Alibag	Delhi	Dwaraka
V	Mandi	Kohima	Imphal	Guwahati

Table 6.2: Specifications of Intze water tanks used for the study.

Parameters	Specifications	
Quantity (in kilo liters)	600	150
Staging height (m)	16	14
Concrete grade & steel	M 30 & Fe 500	
Soil bearing capacity & foundation depth	80 kN/m^2 and 2 m	80 kN/m^2 and 2 m
Wind & seismic parameters	Seismic Zone II, III, IV & V Wind speed 39, 44, 49, 50 m/sec	
Conventional tank type	Conventional tank type II is used in this study as it is cost effective than Conventional type I	
Lining only for HWT	The lining is also optimized in this 12 mm thick ferrocement lining with of 1:2 cement sand mortar. Cement- OPC 43 Grade. Mesh- 3 layers HB wires 1mm diameter square steel welded mesh	

Table 6.3: Member cross sections/ thicknesses for hybrid & conventional tanks.

Member dimensions/ Thickness (mm)		Intze tank		Circular tank	
		HWT	CWT	HWT	CWT
Top dome		80	120	80	120
Top ring beam		200 x 200	200 x 200	200 x 200	200 x 200
Cylindrical wall	Top	100	100	100	200
	Bottom	100	100	100	200
Middle ring beam		1000 x 120	1000 x 150	1000 x 120	1000 x 120
Conical dome	Top	150	330	-	-
	Bottom	150	200	-	-
Bottom dome		120	160	120	120
Middle ring beam		400 x 600	400 x 600	400 x 500	400 x 600
Column	Nos	10	6	6	6
	Dia	400	400	400	400
Braces size		200 x 500	200 x 500	200 x 500	200 x 500
Foundation beam & raft dimensions		Different for all 16 tanks		Different for all 16 tanks	

6.2.2. Comparison criteria

The comparative study evaluates the following parameters:

Cost efficiency assessment parameters in 16 state capitals-

- Cost of CWT vs Cost of HWT (including ferrocement lining).
- Comparative evaluation of tank body, staging plus foundation, 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 savings in steel and concrete in HWTs.

Structural efficiency assessment parameters-

- Seismic and wind analysis of Hybrid and Conventional designs to assess the performance of both tanks under the impact of wind & seismic forces and to ascertain the maximum lateral forces in both full & empty tank conditions.
- Effect of coastal regions in the design of water tanks.
- Serviceability check for crack width for deflection in both the tanks in both full & empty tank conditions.

6.3. Results and discussion: Comparing 600 kL hybrid and conventional Intze water tanks

A comprehensive comparative study was undertaken to evaluate the economic and structural aspects of a HWT design in comparison with conventional methods. 16 Hybrid and conventional Intze tanks of 600 kL capacity are meticulously designed using specialized software programs. 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 evaluations, including the total water tank, tank body, lining, staging, and foundation.

6.3.1. Cost comparison of hybrid and 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. Cost comparison of HWT and CWT. is shown in Figure 6.2.

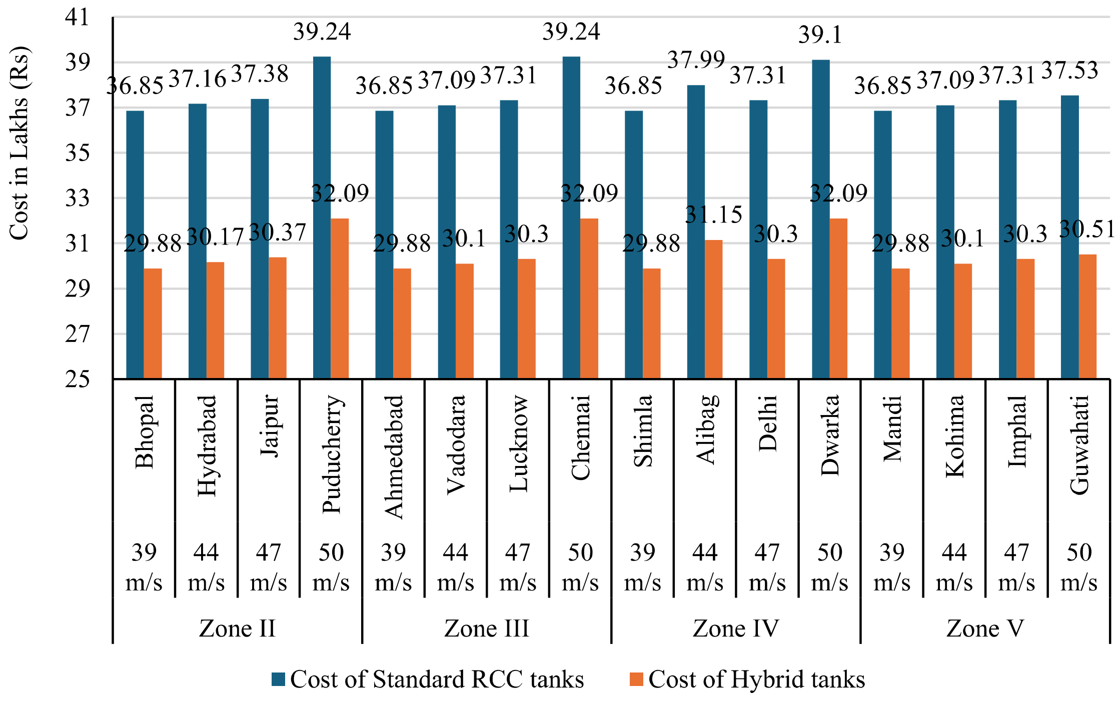

Fig. 6.2: Cost comparison of 600 kL Hybrid & Conventional Intze tanks

The outcomes are summarized as follows:

- Figure 6.2 clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs for all 16 cities.
- The cost of the tanks increases with the increase in the seismic zones & wind speeds.
- The cost of the tanks in Coastal cities is highest in their Zones because of the increase in wind shear forces.
- The percentage difference in cost savings falls within the range of 16-21% in non-coastal cities and increases with an increase in Seismic zones. Coastal cities show a substantial savings of about 16%.
- The cost of the HWT includes the lining cost. On average, there is a savings of about 18 %, which is about one-fifth of the total cost, specifically in material expenses which is huge.

6.3.2. Cost of ferrocement lining

The thickness of the ferrocement lining & number of steel mesh requirements depend on the strain occurring at the interface of the RCC tank body and lining. The cost of lining includes the cost of mortar and steel required.

- Uniform 15 mm lining with steel mesh square welded mesh in three layers is provided in all the water-facing elements of the tank body with 66 bars used per mesh.
- The cost of ferrocement lining for the tank amounts to around Rs 1.1 lakhs. For this study, it is assumed that the lining will be done using guniting or shotcreting methods. Including the cost of machinery, the total expense for lining increases to approximately 1.2 to 1.5 times the combined material and labor costs. This additional expenditure due to machinery usage raises the actual cost to approximately Rs 1.2 to 1.5 lakhs, depending on the location. This cost represents about 4-5% of the overall structure's total cost.

6.3.3. Material utilization

Quantity of material (Concrete & Steel) used in the hybrid & ferrocement tanks are calculated for all the cities and are shown in Fig. 6.3.

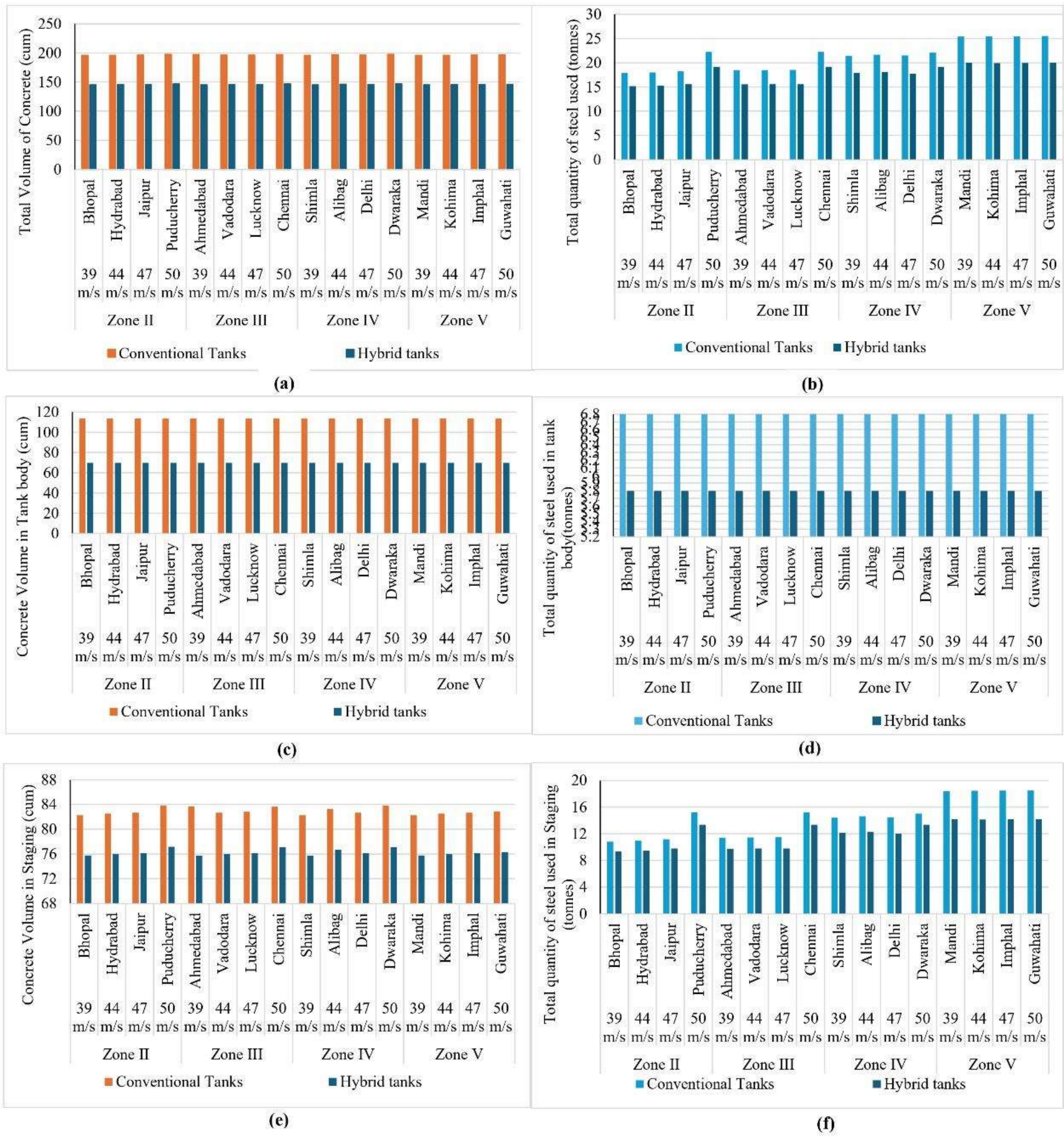

Fig. 6.3: (a)Total volume of concrete used in tanks; (b) Total volume of concrete used in tank body; (c) Total volume of concrete used in staging; (d)Total quantity of steel used in tanks; (e) Quantity of steel used in tank body; (f) Quantity of steel used in staging;

Results shows that-

- Concrete usage in the body of a HWT is approximately 38% less compared to CWT.
- The staging of HWTs requires about 7-8% less concrete than in CWT.
- HWTs, in total, use about 25% less Concrete compared to CWT.
- Steel usage in the body of HWTs is approximately 17% less than in CWT.
- The staging of HWTs requires only about 13% of the steel quantity compared to CWT.
- HWTs, in total, use about 15% less steel compared to CWT.
- The volume of steel & concrete in the tank body is uniform, whether it's a Hybrid or Conventional tank, across all 16 cities.
- The volume of concrete utilized in staging increases in seismic zones and is higher in coastal cities.
- Similarly steel usage in tanks increases with an increase in seismic zones & also higher in coastal cities as compared to non-coastal cities of the same Seismic zone.
- 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.
- 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 increase with the increase in the capacity of water tanks.

6.3.4. Deflection and crack widths

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. 6.4.

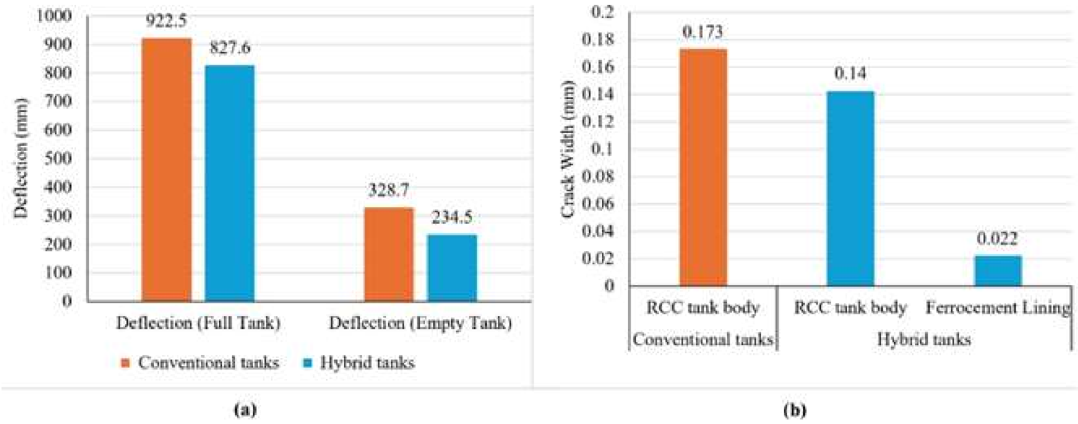

Fig. 6.4 (a) Deflection in both F.T and E.T. (b) Crack width for Hybrid and CWT.

The outcomes are summarized as follows:

a). Deflection-

- The deflection in CWT typically ranges around 922.5 mm when full and 328.7 mm when empty, showing consistent patterns across various tanks with a variation of approximately 2-3%.
- In HWTs, the values differ, with deflection measuring around 827.6 mm when full and 234.5 mm when empty.
- 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 - 11% lower in the full tank condition.
- Deflection is significantly reduced, ranging from 27% to 28%, in the empty tank condition in comparison to the conventional approach.
- This decrease is attributed to the reduced dead weight of the tank body in the hybrid design.

b). Crack width-

- The conventional tank body exhibits a crack width of 0.173 mm.
- Within the HWT, the RCC body displays a crack width of 0.14 mm.
- The ferrocement lining of the HWT showcases a crack width of 0.022 mm.

- The crack width of the HWT RCC body is approximately 19.08% less than that of the conventional tank body.
- The crack width of the HWT ferrocement lining is approximately 87.28% less than that of the conventional tank body.
- 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 the results are below the ACI standard of 0.05 mm.
- The crack width in RCC tank bodies is considerably reduced in HWTs compared to CWT, remaining well below the allowable limit for CWT and significantly under the limit specified for RCC structures as per IS 456:2000.
- HWTs exhibit significantly less crack width compared to CWT.
- 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.
- HWTs offer enhanced structural integrity, ensuring better long-term serviceability compared to CWT, thanks to their superior control over crack width and Deflections.

6.3.5. Structural performance under wind and seismic loadings

Structural performance, encompassing response to wind and seismic forces, assessment of bending moment at the base of columns, and evaluation of the impact of major lateral forces, is thoroughly examined for all 16 cities in both Full and Empty tank conditions. Additionally, the performance of tanks under wind loads is meticulously studied in coastal and non-coastal cities. Results are shown in Fig. 6.5.

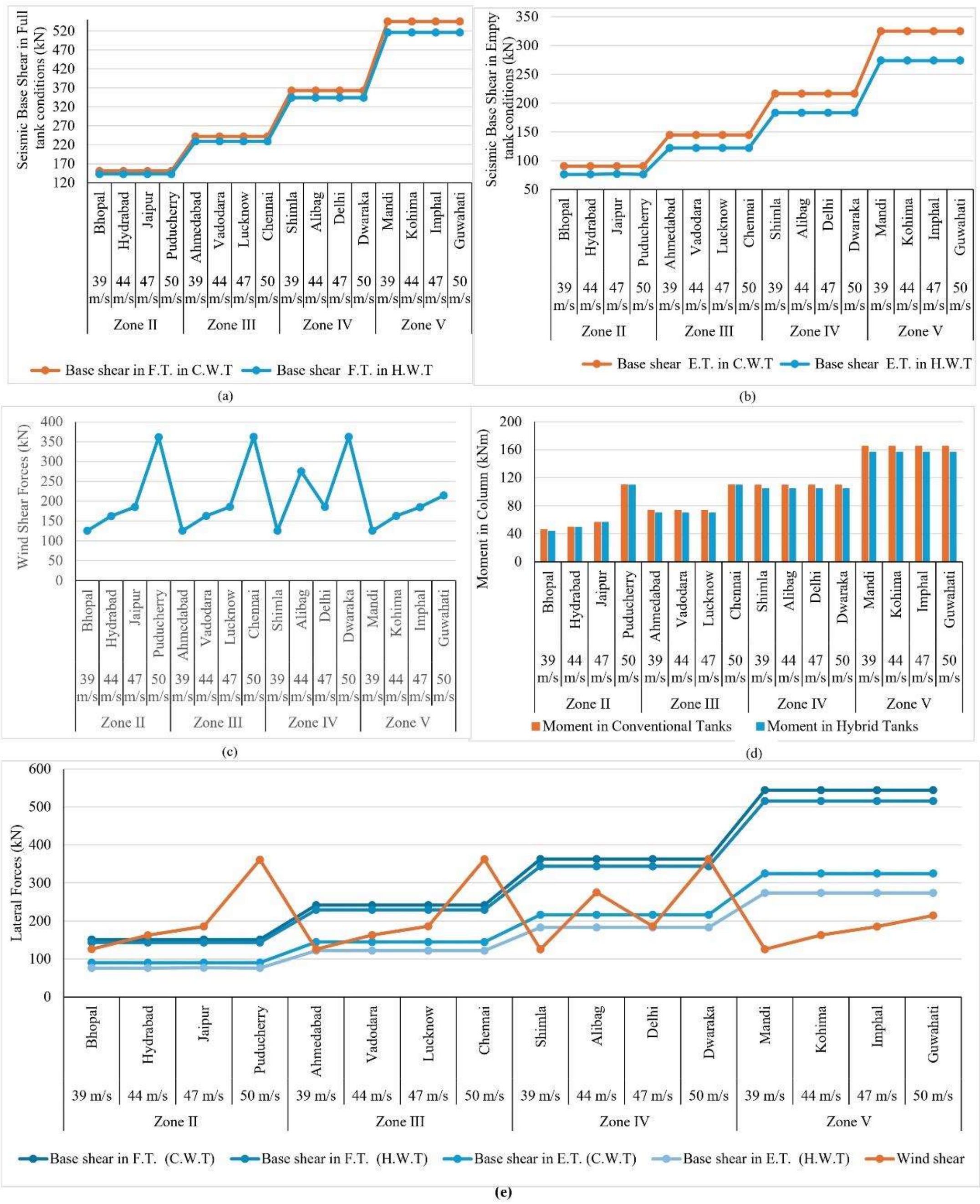

Fig. 6.5 (a)Seismic base shear in Full tank conditions; (b) Seismic base shear in Empty tank conditions; (c) Wind shear forces acting on tanks in 16 cities; (d) Bending moment in columns; (e) Comparative analysis of Base shear forces & wind shear forces in Full & Empty tank conditions across 16 cities.

Results show that-

- Seismic forces increase with the increase in seismic zones.

- Across different seismic zones, the seismic base shear for CWT varies as follows: In Zone II, it is 151.28 kN for full tank condition and 90.31 kN for empty tank condition. In Zone III, it is 242 kN for full tank condition and 144.5 kN for empty tank condition. In Zone IV, it is 363 kN for full tank condition and 216.4 kN for empty tank condition. In Zone V, it is 544.6 kN for full tank condition and 325.1 kN for empty tank condition.
- For HWTs, across different seismic zones, the seismic base shear varies as follows: In Zone II, it is 143.3 kN for full tank condition and 76.29 kN for empty tank condition. In Zone III, it is 229.3 kN for full tank condition and 122 kN for empty tank condition. In Zone IV, it is 344 kN for full tank condition and 183 kN for empty tank condition. In Zone V, it is 516 kN for full tank condition and 274 kN for empty tank condition.
- Difference in Seismic base shear increases with an increase in the seismic zone between hybrid & CWT.
- In Zone III, seismic base shear increases by approximately 60% for both Conventional and HWTs compared to Zone II, while in Zone IV, there's a notable spike with seismic base shear surging by roughly 140% for both tank types. Moving to Zone V, the increase is even more significant, with seismic base shear soaring by approximately 260% for both Conventional and HWTs compared to Zone II.
- The percentage savings for HWTs compared to CWT across different seismic zones range approximately between 5.24% to 5.27% for full tank conditions and 15.46% to 15.70% for empty tank conditions.
- Wind forces acting on the tanks are similar in both HWT and CWT because height and dimensions are kept same in all the tanks.
- The magnitude of wind forces escalates as wind speeds increase, with values ranging from 125.68 kN in cities experiencing winds at 39 m/s, 162.5 kN at 44 m/s, 185.4 kN at 47 m/s, and 214.5 kN at 50 m/s in non-coastal cities.
- Wind shear forces peak in coastal regions. In cities such as Alibag, where the wind speed is 44 m/s, the wind shear forces reach 275 kN. In cities like Puducherry in Zone II, Chennai in Zone III, and Dwaraka in Zone IV, where the wind speed is 50 m/s, the highest wind forces are experienced, reaching 361.2 kN.

- The maximum moment in the column, as depicted in the figure, is contingent upon the highest lateral forces stemming from either wind shear forces or seismic forces. The moment tends to be nearly the same or lower in HWTs when compared to CWT.
- The bending moment in the column spans from 43.6 kN to 156.3 kN across different cities.
- The disparity in moments amplifies with the escalation of seismic zones.
- Fig shows a comparative study of seismic base shear & wind forces across all the cities.
- In Seismic Zone II, wind forces prevail over seismic base shear in empty tank conditions. However, in full tank conditions, cities such as Bhopal (wind speed 39 m/s) exhibit wind forces that are lower than seismic base shear, whereas cities like Hyderabad (44 m/s), Jaipur (47 m/s), and Puducherry (50 m/s), wind forces exceed seismic base shear.
- In Zone III, wind forces are generally lower than seismic base shear for full tank conditions, except for Chennai, a coastal city experiencing wind speeds of 50 m/s. However, in empty tank scenarios, wind forces are either comparable to or higher than seismic base shear for all cities in the zone.
- In Zone IV, wind forces are generally lower than seismic base shear for full tank conditions, except for Dwaraka, a coastal city experiencing wind speeds of 50 m/s. For Dwaraka, wind shear forces exceed seismic base shear in HWTs and are equivalent in CWT. In empty tank scenarios, wind forces are lower than seismic base shear for all cities in the zone, except for coastal cities like Alibag with a wind speed of 44 m/s, and Dwaraka with a wind speed of 50 m/s.
- In Zone V Seismic base shear is higher than wind forces in both Full and empty tank conditions.
- HWTs consistently exhibit lower seismic base shear across all seismic zones compared to CWT.
- Percentage savings range between approximately 5.24% to 5.27% for full tank conditions and 15.46% to 15.70% for empty tank conditions.
- HWTs maintain similar or lower moments in columns compared to CWT, ensuring structural integrity under seismic forces.

- Both HWT and CWT exhibit similar wind forces, ensuring structural stability.
- In coastal areas, HWTs demonstrate superior performance, with wind shear forces exceeding seismic base shear in CWT but remaining optimized in HWTs.

6.3.6. Concluding remarks

Based on the comprehensive comparative study of 600 kL Hybrid and Conventional (type II) Intze tanks across 16 major Indian cities, several key findings emerge. HWT designs consistently demonstrate significant cost savings ranging from 16% to 21% across non-coastal cities, with coastal cities showing savings of about 16%. These designs also exhibit superior performance in seismic and wind conditions, with lower seismic base shear and reduced deflection compared to CWT. Moreover, the integration of ferrocement linings in HWTs enhances impermeability and durability, contributing to their long-term structural integrity. Overall, these findings underscore the economic and structural advantages of HWT designs in diverse environmental and seismic conditions.

6.4. Results and discussions: Comparing 150 kL hybrid and conventional circular water tanks

A comprehensive comparative study was undertaken to evaluate the economic and structural aspects of a HWT design in comparison with conventional methods. 16 Hybrid and conventional Circular tanks of 150 kL capacity are meticulously designed using specialized software programs. Results encompass detailed cost evaluations, including the total water tank, tank body, lining, staging, and foundation.

6.4.1. Cost comparison of hybrid & conventional circular tanks

Cost comparison of 150 kL HWT and CWT. is shown in Figure 6.6.

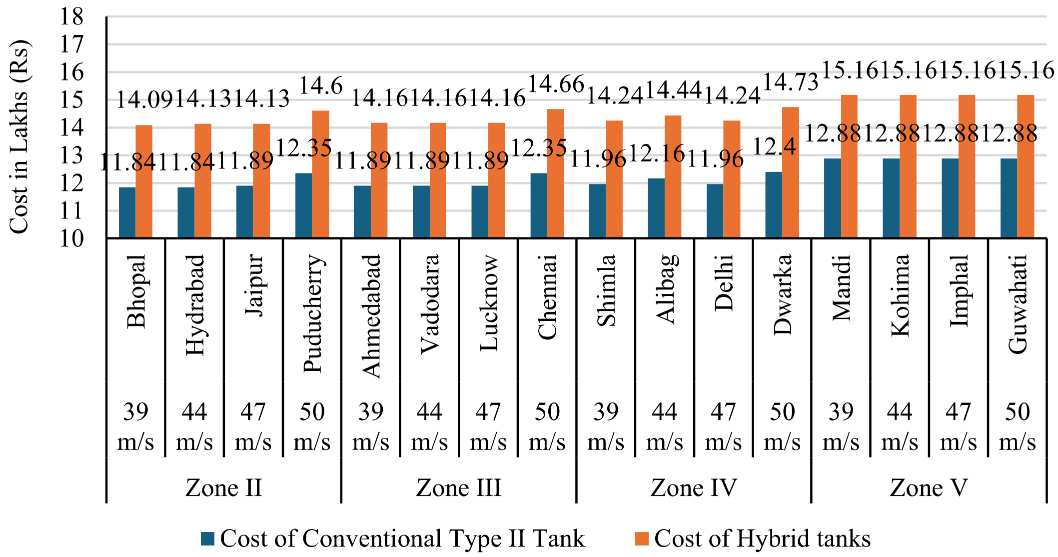

Fig. 6.6 Cost comparison of hybrid & conventional circular tanks

The outcomes are summarized as follows:

- Figure 6.6 clearly illustrates that Hybrid designs are considerably more cost-effective than conventional designs for all 16 cities.
- The cost of the tanks increases with the increase in the seismic zones & wind speeds.
- The cost of the tanks in Coastal cities is highest in their Zones because of the increase in wind shear forces.

- The percentage difference in cost savings falls within the range of 15-17% in non-coastal cities and coastal and increases with an increase in Seismic zones.
- The cost of the HWT includes the lining cost. On average, there is a savings of about 16 %, which is about one-fifth of the total cost, specifically in material expenses which is huge.

6.4.2. Cost of ferrocement lining

The thickness of the ferrocement lining & number of steel mesh requirements depend on the strain occurring at the interface of the RCC tank body and lining. The cost of lining includes the cost of mortar and steel required.

- Uniform 15 mm lining with three layer steel mesh square welded mesh in three layers is provided in all the water-facing elements of the tank body for additional safety.
- The cost of ferrocement lining is about 0.6 lakhs Rs which is about 4-5% of the overall cost of the structure.

6.4.3. Material utilization

Quantity of material (Concrete & Steel) used in the Hybrid & ferrocement tanks are calculated for all the cities and are shown in Fig. 6.7.

Results shows that-

- Concrete usage in the body of a HWT is approximately 39% less compared to CWT.
- The staging of HWTs requires about 6-8% less concrete than in CWT.
- HWTs, in total, use about 23% less Concrete compared to CWT.
- Steel usage in the body of HWTs is approximately 10-11% less than in CWT.
- The staging of HWTs requires only about 2-4 % of the steel quantity compared to CWT.
- HWTs, in total, use about 6-7% less steel compared to CWT.
- The volume of steel & concrete in the tank body is uniform, whether it's a Hybrid or Conventional tank, across all 16 cities.

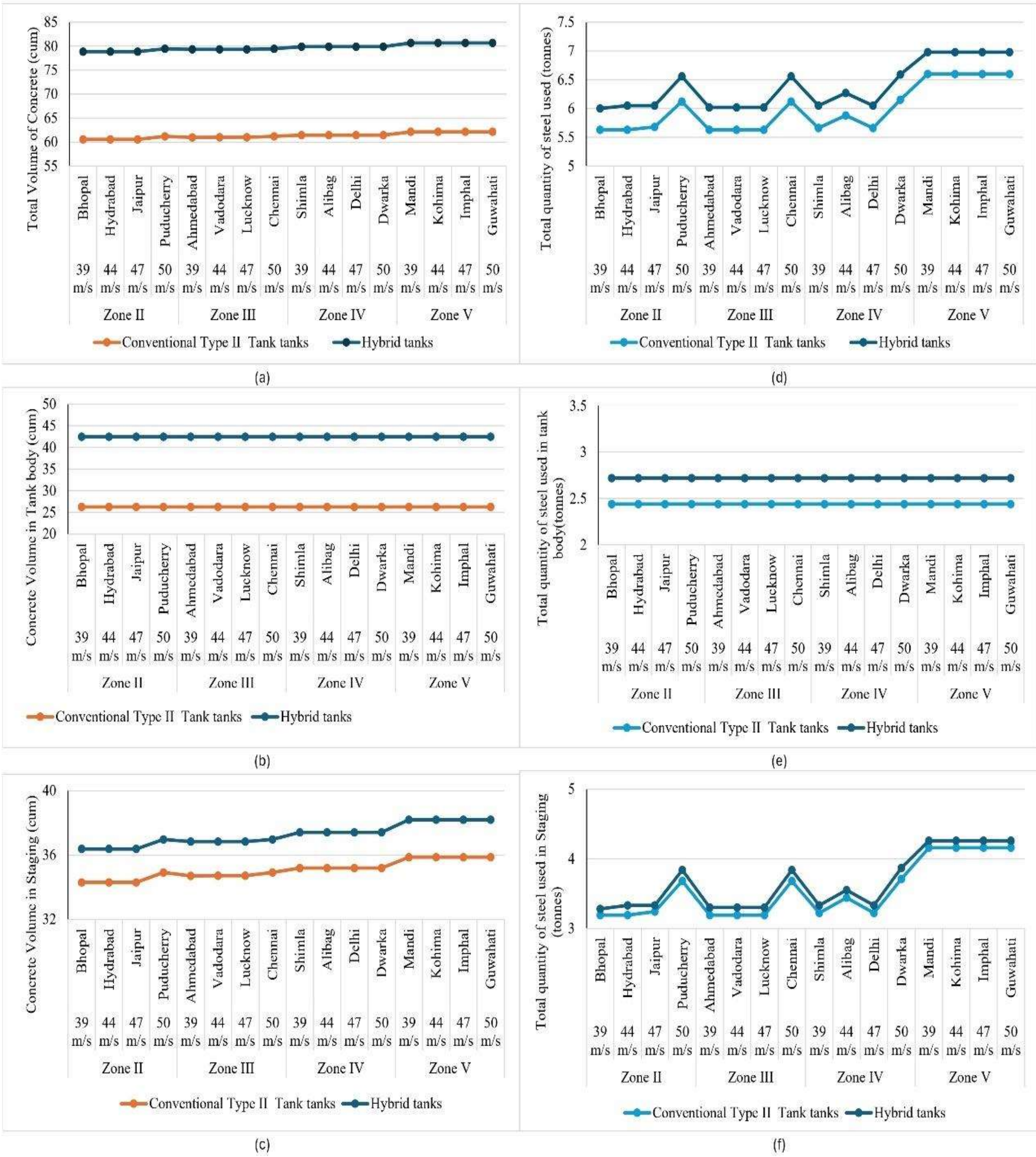

Fig. 6.7 (a)Total volume of concrete used in tanks; (b) Total volume of concrete used in tank body; (c) Total volume of concrete used in staging; (d)Total quantity of steel used in tanks; (e) Quantity of steel used in tank body; (f) Quantity of steel used in staging;

- The volume of concrete utilized in staging increases in seismic zones and is higher in coastal cities.
- Similarly steel usage in tanks increases with an increase in seismic zones & also higher in coastal cities as compared to non-coastal cities of the same Seismic zone.

- 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.
- 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 increase with the increase in the capacity of water tanks.

6.4.4. Deflection and crack widths

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. 6.8.

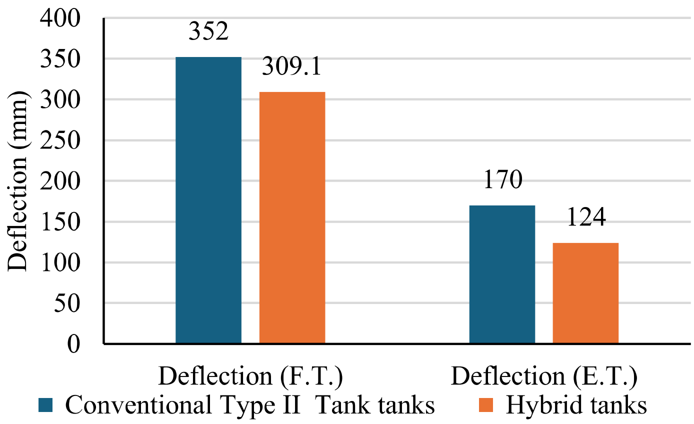

Fig. 6.8: Deflection in both Full & empty tank conditions

The outcomes are summarized as follows:

a) Deflection-

- The deflection in CWT typically ranges around 352 mm when full and 309 mm when empty, showing consistent patterns across various tanks with a variation of approximately 2-3%.
- In HWTs, the values differ, with deflection measuring around 170 mm when full and 124 mm when empty.

- 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 14 % lower in the full tank condition.
- Deflection is significantly reduced, ranging from 37% , in the empty tank condition in comparison to the conventional approach.
- 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.

b). Crack width-

- The conventional tank body and HWT body both exhibits a negative value of crack width which means the is no tension in the portion of tanks.
- The ferrocement lining of the HWT showcases a crack width of 0.022 mm.
- 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 the results are below the ACI standard of 0.05 mm.
- The crack width in RCC tank bodies is considerably reduced in HWTs compared to CWT, remaining well below the allowable limit for CWT and significantly under the limit specified for RCC structures as per IS 456:2000.
- HWTs exhibit significantly less crack width compared to CWT.
- 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.
- HWTs offer enhanced structural integrity, ensuring better long-term serviceability compared to CWT, thanks to their superior control over crack width and Deflections.

6.4.5. Structural performance under wind and seismic loadings

Results are shown in Fig 6.9.

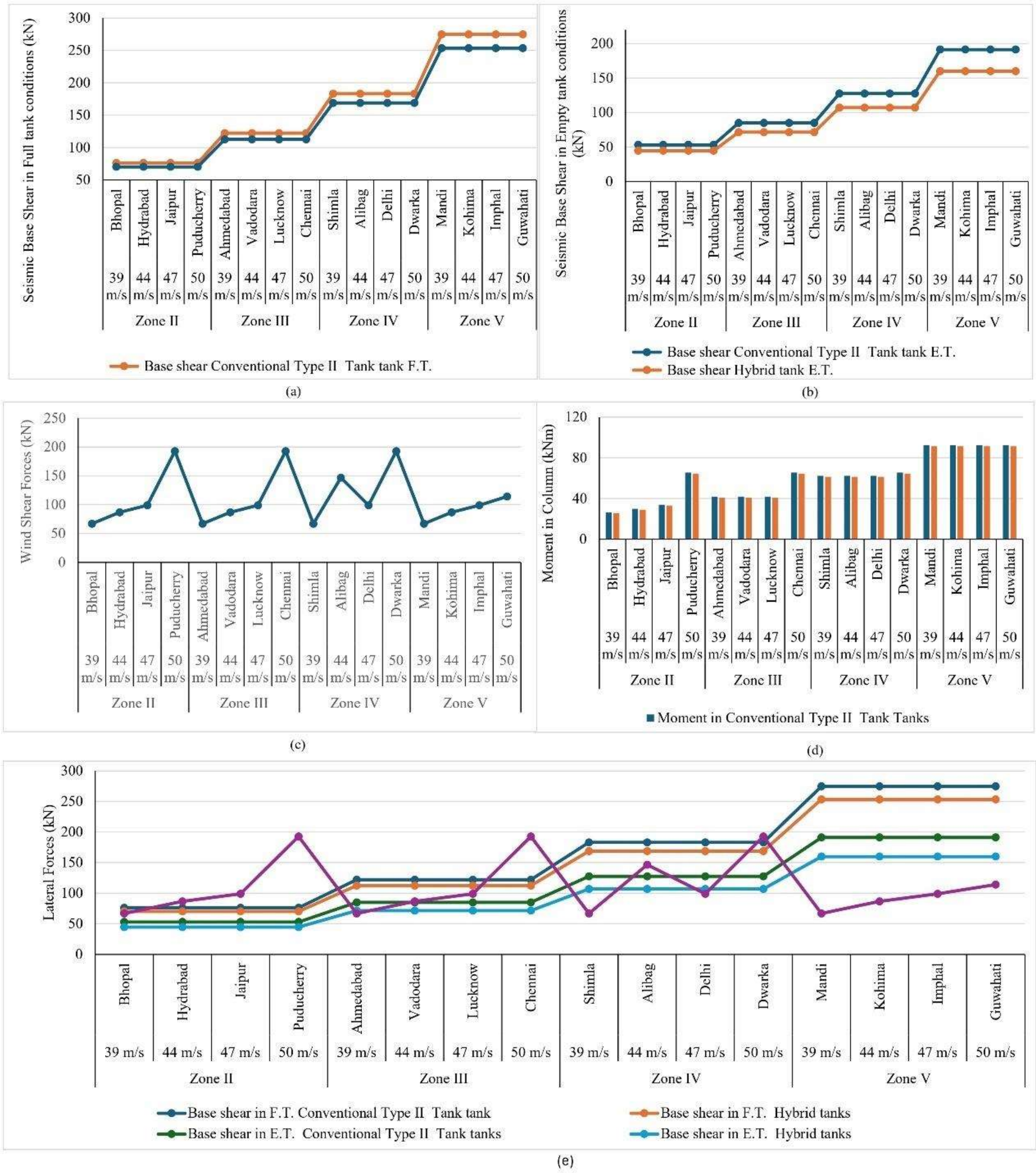

Fig. 6.9 (a)Seismic base shear in full tank conditions; (b) Seismic base shear in empty tank conditions; (c) Wind shear forces acting on tanks in 16 cities; (d) Bending moment in columns; (e) Comparative analysis of base shear forces & wind shear forces in full & empty tank conditions across 16 cities.

Structural performance, encompassing response to wind and seismic forces, assessment of bending moment at the base of columns, and evaluation of the impact of major lateral forces, is thoroughly examined for all 16 cities in both Full and Empty tank conditions. Additionally, the performance of tanks under wind loads is meticulously studied in coastal and non-coastal cities. Results show that-

- Seismic forces increase with the increase in seismic zones.
- Across different seismic zones, the seismic base shear for CWT varies as follows: In Zone II, it is 76.4 kN for full tank condition and 53.12 kN for empty tank condition. In Zone III, it is 122.1 kN for full tank condition and 85 kN for empty tank condition. In Zone IV, it is 183.2 kN for full tank condition and 127.5 kN for empty tank condition. In Zone V, it is 274.45 kN for full tank condition and 325.1 kN for empty tank condition.
- For HWTs, across different seismic zones, the seismic base shear varies as follows: In Zone II, it is 70.4 kN for full tank condition and 44.7 kN for empty tank condition. In Zone III, it is 112.6 kN for full tank condition and 71.5 kN for empty tank condition. In Zone IV, it is 168.9 kN for full tank condition and 107 kN for empty tank condition. In Zone V, it is 253.4 kN for full tank condition and 160 kN for empty tank condition.
- Difference in Seismic base shear increases with an increase in the seismic zone between hybrid & CWT.
- In Zone III, seismic base shear increases by approximately 60% for both Conventional and HWTs compared to Zone II, while in Zone IV, there's a notable spike with seismic base shear surging by roughly 140% for both tank types. Moving to Zone V, the increase is even more significant, with seismic base shear soaring by approximately 260% for both Conventional and HWTs compared to Zone II.
- The percentage savings for HWTs compared to CWT across different seismic zones range approximately between 7-8% for full tank conditions and 15.46% to 15.70% for empty tank conditions.
- Wind forces acting on the tanks are similar in both HWT and CWT because height and dimensions are kept same in all the tanks.

- The magnitude of wind forces escalates as wind speeds increase, with values ranging from 66.89 kN in cities experiencing winds at 39 m/s, 86.7 kN at 44 m/s, 98.99 kN at 47 m/s, and 114.3 kN at 50 m/s in non-coastal cities.
- Wind shear forces peak in coastal regions. In cities such as Alibag, where the wind speed is 44 m/s, the wind shear forces reach 146.6 kN. In cities like Puducherry in Zone II, Chennai in Zone III, and Dwaraka in Zone IV, where the wind speed is 50 m/s, the highest wind forces are experienced, reaching 192.4 kN.
- The maximum moment in the column, as depicted in the figure, is contingent upon the highest lateral forces stemming from either wind shear forces or seismic forces. The moment tends to be nearly the same or lower in HWTs when compared to CWT.
- The bending moment in the column spans from 23.3 kN to 91 kNm across different cities.
- The disparity in moments amplifies with the escalation of seismic zones.
- Fig shows a comparative study of seismic base shear & wind forces across all the cities.
- In Seismic Zone II, wind forces prevail over seismic base shear in empty tank conditions. However, in full tank conditions, cities such as Bhopal (wind speed 39 m/s) exhibit wind forces that are lower than seismic base shear, whereas cities like Hyderabad (44 m/s), Jaipur (47 m/s), and Puducherry (50 m/s), wind forces exceed seismic base shear.
- In Zone III, wind forces are generally lower than seismic base shear for full tank conditions, except for Chennai, a coastal city experiencing wind speeds of 50 m/s. However, in empty tank scenarios, wind forces are either comparable to or higher than seismic base shear for all cities in the zone.
- In Zone IV, wind forces are generally lower than seismic base shear for full tank conditions, except for Dwaraka, a coastal city experiencing wind speeds of 50 m/s. For Dwaraka, wind shear forces exceed seismic base shear in HWTs and are equivalent in CWT. In empty tank scenarios, wind forces are lower than seismic base shear for all cities in the zone, except for coastal cities like Alibag with a wind speed of 44 m/s, and Dwaraka with a wind speed of 50 m/s.

- In Zone V Seismic base shear is higher than wind forces in both Full and empty tank conditions.
- HWTs consistently exhibit lower seismic base shear across all seismic zones compared to CWT.
- HWTs maintain similar or lower moments in columns compared to CWT, ensuring structural integrity under seismic forces.
- Both HWT and CWT exhibit similar wind forces, ensuring structural stability.
- In coastal areas, HWTs demonstrate superior performance, with wind shear forces exceeding seismic base shear in CWT but remaining optimized in HWTs.

6.4.6. Concluding remarks

Based on the comparative study of 150 kL Hybrid and Conventional (type II) Intze tanks across 16 major Indian cities, several significant findings emerge. HWT designs consistently demonstrate substantial cost savings ranging from 15% to 17% in non-coastal cities, with further savings in coastal cities as seismic zones increase. These designs exhibit superior performance in deflection, seismic base shear, and wind forces compared to CWT, showcasing reductions of up to 14% in deflection and up to 260% in seismic base shear across different seismic zones. Additionally, HWTs require less concrete and steel, enhancing their cost-effectiveness and structural efficiency across diverse environmental conditions