Wind Force Analysis of Intze Type Water Tank In Various Wind Zones Using Staad-Pro

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Abstract- *Elevated water tanks play a vital role in municipal water supply systems, and their structural integrity is crucial to ensure public safety and health. However, these structures are susceptible to various environmental loads, including wind, which can cause significant stress and damage. This study presents a comprehensive wind force analysis of Intze-type elevated water tanks in India, considering the country's diverse wind zones and terrain categories. The primary objective of this research is to investigate the structural behavior of two commonly used tank configurations: straight-leg and inclined-leg designs.*

Using advanced structural analysis software, STAAD-Pro, this study evaluates the lateral displacements, wind forces, and overall performance of both tank configurations under various wind loads. The analysis takes into account the complex interactions between wind, terrain, and structural components, providing a detailed understanding of the tank's behavior.

The results of this study reveal that lateral displacements increase with height and wind zone intensity, with inclined-leg tanks exhibiting larger displacements than straight-leg tanks. This finding highlights the importance of minimizing lateral displacement to prevent sloshing and structural failure, which can have catastrophic consequences. Furthermore, the study shows that design wind forces increase with height due to increased exposure and terrain factors, emphasizing the need for careful consideration of these factors in tank design.

The findings of this research have significant implications for the design and construction of elevated water tanks in high-wind areas. The study suggests that straight-leg configurations are a better option for stability, providing greater resistance to wind-induced displacements. Additionally, the research highlights the need for further studies on seismic analysis, dynamic load considerations, and alternative structural materials to ensure the safety and durability of water tanks.

By providing valuable insights into the structural behavior of elevated water tanks under wind loads, this research contributes to the development of safer and more effective water tank designs. The study's outcomes can be used by engineers, designers, and policymakers to improve the design and construction of water tanks, ensuring the reliability and sustainability of municipal water supply systems.

I. INTRODUCTION

Overhead and underground tanks are critical for storing water for irrigation, drinking, firefighting, and industrial use. The design prioritizes economy, strength, durability, and resistance to environmental factors like wind and earthquakes. Reinforced concrete or steel tanks are designed per IS codes, with variations for above-ground, underground, or ground-level positioning. Overhead tanks, supported by columns, enable gravity-based distribution, while underground tanks are embedded below ground level.

II. WIND EFFECTS ON DESIGN

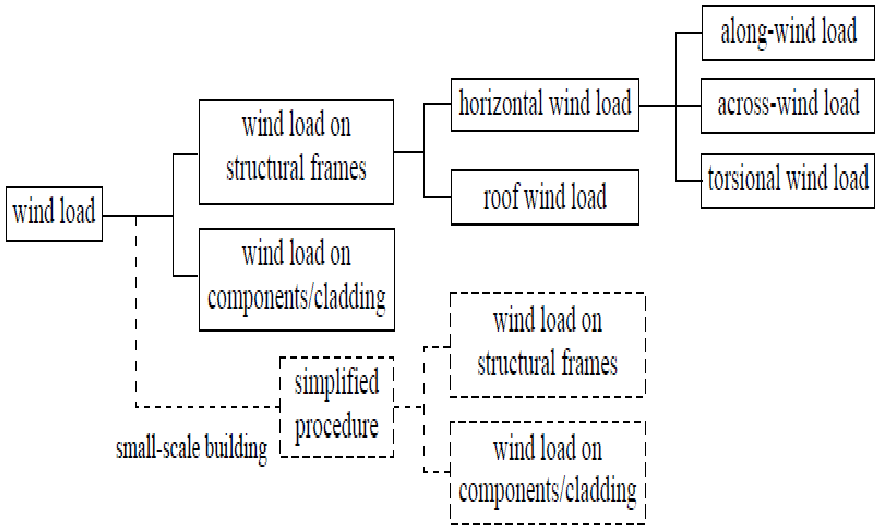


Figure 3.2 Classification of wind loads

The wind analysis of elevated water tanks is conducted in accordance with the Indian Standard IS 875 (Part III): 1987. The methodology involves the following key aspects:

1. Computational Modeling: Utilizing STAAD.Pro analysis software to evaluate the structural response of elevated water tanks to wind loads, considering various wind zones and terrain categories.
2. Structural Classification: Structures are categorized into three classes based on their maximum dimensions:
   Class A: Structures ≤ 20m
   Class B: Structures between 20m and 50m
   Class C: Structures > 50m
3. Terrain Categorization: Four terrain categories are considered:
   - Category 1: Exposed open terrain with minimal obstructions (height ≤ 1.5m)
   - Category 2: Open terrain with scattered obstructions (height = 1.5m to 10m)
   - Category 3: Terrain with numerous obstructions (height ≤ 10m)
   - Category 4: Terrain with large, closely spaced obstructions
4. Wind Speed and Zone: India is divided into six wind zones (I-VI) based on basic wind speed (Vb). The design wind velocity (Vz) is calculated using the following factors:
   - Risk Coefficient (K1): accounts for the probability of extreme wind speeds
   - Terrain and Height Factor (K2): considers the effect of terrain roughness and structure height
   - Topography Factor (K3): accounts for local topographic features

Design Wind Load Calculations

The design wind pressure (Pz) is calculated using the formula:
$Pz = 0.6\ Vz^2$
Where $Vz = Vb * K1 * K2 * K3$

Wind Load Evaluation
Wind loads are evaluated for:
- The water tank as a whole
- Individual structural elements (e.g., roofs, walls)
- Cladding units (e.g., glazing, sheeting)

Pressure Coefficients

Pressure coefficients (Cp) are used to calculate wind loads on surfaces, taking into account local effects and suction. The coefficients are applied to the design wind pressure to determine the wind load on individual surfaces. Wind pressure is calculated per IS 875 (Part 3) 2015. The design wind speed (Vz) at height *z* is:
Vz=Vb×k1×k2×k3$Vz=Vb\times k1\times k2\times k3$
where:

- VbVb = Basic wind speed (location-dependent)
- k1$k1$ = Risk coefficient
- k2$k2$ = Terrain/height factor
- k3$k3$ = Topography factor

Design wind pressure (PzPz):
Pz=0.6×Vz2$Pz=0.6\times Vz2$
3. Intze Tank Design
Named after German engineer Otto Intze, this tank features a brick/masonry shaft with an iron/metal hoop anchor to transfer only vertical forces. Components include:

- **Top Dome**: 100–150 mm thick, reinforced.
- **Top Ring Beam**: Resists meridional thrust and hoop tension.
- **Cylindrical Wall**: Designed for hoop tension from water pressure.
- **Bottom Ring Beam**: Resists horizontal thrust from the conical slab.
- **Conical Slab**: Handles meridional thrust and hoop tension.
- **Bottom Dome**: Transfers loads to the circular girder.
- **Circular Girder & Columns**: Supports the tank, designed for bending and torsion.
- **Foundation**: Combined footing for columns.

III.METHODOLOGY

Member	Thickness (mm)
Top dome	200 mm
Cylindrical wall	1000
Conical wall	500
Bottom dome	300

Member	Size (mm)
Column rectangular type	1000x500 mm
Bracings	400x400mm
Bottom ring Beam	500x500 mm

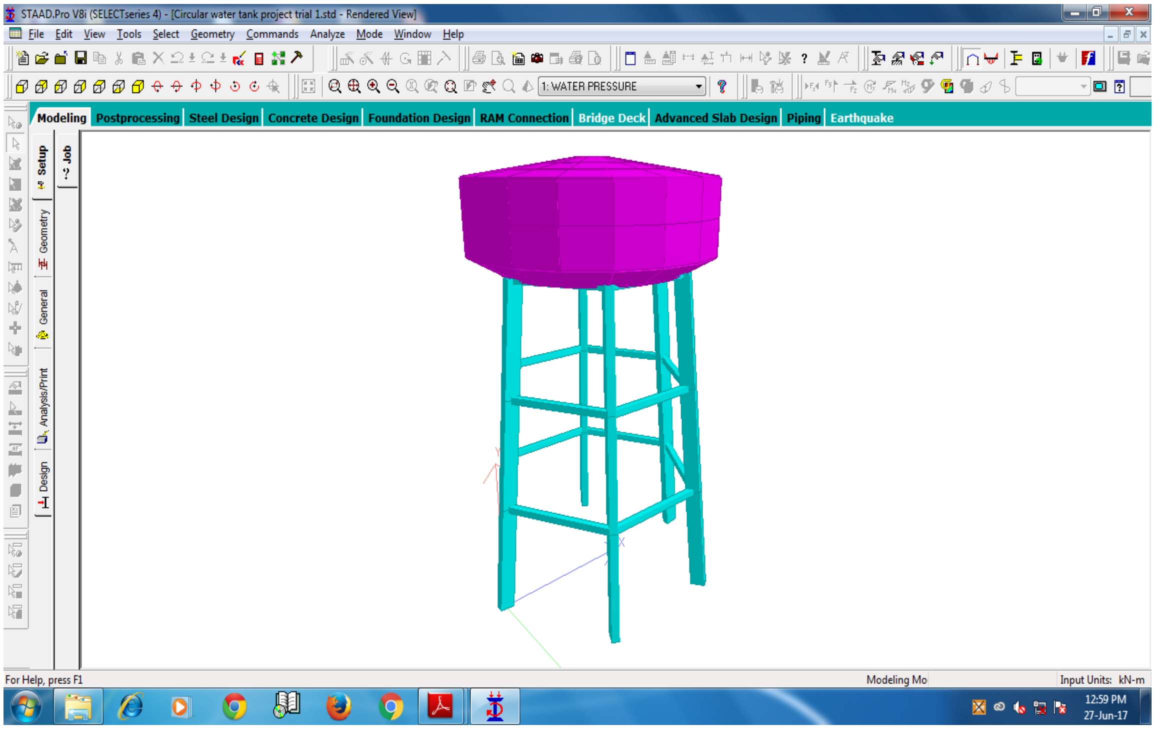
Manual Design

- **Capacity**: 300,000 liters.
- **Materials**: M30 concrete (σ_cbc = 10 N/mm², σ_ct = 8 N/mm²).
- **Loads**: Dead, live, wind, and seismic.

Key Calculations:

1. **Top Dome**:
    - Thickness = 100 mm, radius = 6.08 m.
    - Meridional stress = 0.17 N/mm², hoop stress = 0.15 N/mm².
    - Reinforcement: 300 mm²/m.
2. **Top Ring Beam**:
    - Size: 230 × 200 mm.
    - Hoop tension = 51.81 kN, steel = 452.39 mm² (4×12 mm bars).
3. **Cylindrical Wall**:
    - Thickness = 230 mm, hoop tension = 196.2 kN.
    - Steel: 1130.97 mm² (10×12 mm bars @ 200 mm c/c).
4. **Bottom Ring Beam**:
    - Size: 250 × 500 mm, hoop tension = 262.96 kN.
    - Steel: 1526.81 mm² (6×18 mm bars).
5. **Conical Slab**:
    - Thickness = 200 mm, hoop tension = 579.36 kN.
    - Steel: 2814.86 mm² (14×16 mm bars).
6. **Circular Girder**:
    - Size: 400 × 600 mm, load = 4385.4 kN.
    - Steel: 949.02 mm² (4×16 mm bars).

STAAD Pro Verification



- Modeled with 8 columns, M30 concrete, and wind/seismic loads.
- Results confirmed safe stresses and displacements, with minor reinforcement adjustments.

IV. RESULTS

- Manual and STAAD Pro designs aligned, with STAAD showing slightly lower reinforcement requirements.
- Critical stresses:
    - Hoop tension (cylindrical wall) = 0.18 N/mm².

Maximum wind moment (columns) = 8.86 N/mm².

Table 5.1: Wind Forces (KN) for different wind Zones of terrain category 1

Staging height (m)	Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
10m	35.69	42.58	48.492	51.799	55.62	61.182
20m	38.115	45.474	51.788	55.319	59.4	65.34
21m	38.219	45.598	51.929	55.47	59.562	65.519
25m	38.635	46.094	52.494	56.073	60.21	66.231
26m	38.739	46.218	52.635	56.224	60.372	66.409

Table 5.2: Wind Forces (KN) for different wind Zones of terrain category 2

Staging height (m)	Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
10m	33.957	40.513	46.138	49.284	52.92	58.212
20m	36.382	43.407	49.434	52.805	56.7	62.37
21m	36.556	43.614	49.669	53.056	56.97	62.667
25m	37.249	44.441	50.611	54.062	58.05	63.855
26m	37.422	44.647	50.864	54.313	58.32	64.152

Table 5.3: Wind Forces (KN) for different wind Zones of terrain category 3

Staging height (m)	Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
10m	30.492	36.379	41.43	44.26	47.52	52.272
20m	33.957	40.513	46.138	49.29	52.92	58.212
21m	34.13	40.72	46.374	49.54	53.19	58.509
25m	34.823	41.547	47.325	50.54	54.27	59.697
26m	34.997	41.753	47.55	50.8	54.54	59.994

Table 5.4: Wind Forces (KN) for different wind Zones of terrain category 4

Staging height (m)	Zone I	Zone II	Zone III	Zone IV	Zone V	Zone VI
10m	26.334	31.418	35.781	38.22	41.04	45.144
20m	26.334	31.418	35.781	38.22	41.04	45.144
21m	26.923	32.121	36.581	39.075	41.958	46.154
25m	29.279	34.932	39.783	42.495	45.63	50.193
26m	29.868	35.635	40.583	43.35	46.548	51.201

Table 5.6: Lateral displacements at various heights of staging in various zone of India of terrain category 2

Staging Height	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
6.67 m	7.087	10.029	12.961	14.772	17.015	20.564
13.33 m	15.796	22.416	29.008	33.081	38.122	46.1
20 m	18.801	26.571	34.311	39.095	45.016	34.386
21 m	18.531	26.13	33.743	38.46	44.303	53.56
25 m	17.679	24.79	31.92	36.339	41.815	50.491
26 m	18.326	24.956	31.736	35.972	41.242	49.623

Table 5.7: Lateral displacements at various heights of staging in various zone of India of terrain category 3

Height	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Staging height (m) 6.67 m	6.058	8.553	11.051	10.571	14.496	17.514
Staging height (m) 13.33 m	13.585	19.248	24.908	25.863	32.715	39.554
Staging height (m) 20 m	16.256	22.92	29.586	33.597	38.78	46.84
Staging height (m) 21 m	16.063	22.551	29.092	33.011	38.149	46.106
Staging height (m) 25 m	15.372	21.44	27.564	31.174	36.049	43.505
Staging height (m) 26 m	16.23	21.802	27.584	31.189	35.693	42.873

Table 5.8: Lateral displacements at various heights of staging in various zone of India of terrain category 4

Staging Height	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
6.67 m	3.97	5.564	7.167	8.153	9.387	11.327
13.33 m	8.648	12.189	15.745	17.93	20.665	24.962
20 m	10.369	14.491	18.636	21.185	24.376	29.392
21 m	10.451	14.361	18.371	20.855	23.976	28.9
25 m	10.133	13.781	17.528	19.852	22.773	27.383
26 m	11.687	14.811	18.187	20.329	23.056	27.41

V.CONCLUSION

This study assesses the structural performance of Intze-type overhead water tanks with inclined and straight leg configurations under various wind loading conditions. The analysis focuses on design wind forces and lateral displacements across different wind zones (I-VI) and terrain categories (1-4).

Design Wind Forces Analysis

The results show significant variations in wind forces across different zones, with Zone I experiencing lower wind forces compared to higher zones. The wind forces intensify with height, consistent with IS Code 875 Part III, due to increased exposure area and the height/size factor (K_2). Category 1 terrain (open terrain with minimal obstructions) demonstrates the most critical wind loading conditions.

Lateral Displacement Analysis

- Inclined Leg Configuration: The inclined leg design exhibits increasing lateral displacement with higher wind zones and greater staging heights, with Zone I displacements being 29% to 65% lower than Zones II to VI.

– Straight Leg Configuration: The straight leg configuration shows comparable but slightly improved performance, with displacements increasing progressively with wind zone intensity and structural height. Zone I displacements are 30% to 66% lower than Zones II to VI.

Comparative Performance Evaluation

A direct comparison between the two configurations reveals that straight legs exhibit significantly less displacement than inclined legs across all terrain categories, with reductions ranging from 35% to 46%. The straight leg configuration offers superior resistance to wind-induced lateral displacements, enhancing stability and minimizing structural vibrations. The findings suggest that straight leg configurations are a more structurally resilient option, providing valuable insights for optimizing water tank designs in wind-prone regions.

- The 300,000-liter Intze tank with 12 m staging, designed per IS 3370, is structurally safe.
- STAAD Pro validated manual calculations, though reinforcement was slightly reduced in software results.

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