

## **ANALYSIS OF CONICAL WATER TANK WITH WIND LOAD**

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### **ABSTRACT**

Elevated water tanks are essential components of urban and rural water supply systems, since they provide the pressure needed to distribute water by gravity to consumers. Among the different shapes used for elevated containers, the conical or Intze-type container with a conical bottom is widely adopted because the inclined wall transfers a large part of the water load efficiently to the supporting ring beam. This study presents the analysis of an elevated reinforced concrete conical water tank subjected to wind load, with the aim of understanding how wind forces combine with hydrostatic and gravity loads in the container and the supporting staging.

The tank considered has a capacity of 500 cubic metres and is supported on a frame staging of eight columns with bracing at regular intervals, giving a total height of 18 m from the foundation to the bottom of the container. The container consists of a top dome, top ring beam, cylindrical wall, bottom ring beam, conical wall and bottom dome, proportioned according to common practice for Intze tanks. The tank is assumed to be located at Visakhapatnam, a coastal city with a basic wind speed of 50 m/s, where wind is expected to be a significant design action.

The structure is modelled in STAAD.Pro using plate elements for the shells and domes and beam elements for the ring beams, columns and braces. Dead load, hydrostatic pressure for the tank-full condition, and wind load according to IS 875 (Part 3):2015 are applied. Wind pressure on the container is calculated using force coefficients for circular sections and is distributed around the circumference, while the wind on the staging is applied to the columns and braces. Both the tank-full and tank-empty conditions are considered, since the empty tank is more vulnerable to overturning and the full tank produces the largest axial forces in the columns.

The analysis provides the hoop tension and meridional forces in the conical and cylindrical walls, the moments in the ring beams, the axial forces and moments in the staging columns, the forces in the braces, and the lateral displacement at the top of the tank. The results are compared with the forces obtained by the conventional membrane analysis of the container and by the approximate portal analysis of the staging. The design of the container walls is checked for the limit state of cracking in accordance with IS 3370 (Parts 1 and 2):2009 so that the structure remains watertight.

The study shows that wind load has only a small effect on the stresses in the container walls but produces significant bending moments in the staging columns and braces, particularly at the lowest panel. The maximum lateral displacement at the top of the container is found to be within acceptable limits. The combination of dead load, tank-empty condition and wind load governs the check against uplift at the foundation. The work demonstrates the value of finite element modelling for elevated tanks and can be extended to seismic analysis using the impulsive and convective mass model of IS 1893 (Part 2).

## **I. INTRODUCTION**

The supply of safe drinking water is one of the most important responsibilities of local bodies, and elevated storage reservoirs play a central role in this service. Water pumped from treatment plants is stored at a height so that it can be supplied to homes by gravity with adequate pressure, and the stored volume also balances the difference between the pumping rate and the fluctuating demand of consumers. Elevated tanks are therefore found in almost every town and village, and their failure can interrupt water supply to large populations and cause damage to nearby property.

Elevated tanks are tall structures with a large mass concentrated at the top, supported on a relatively slender staging. This arrangement makes them sensitive to lateral loads such as wind and earthquake. The container presents a large area to the wind at a considerable height, where wind speeds are higher than near the ground, and the resulting horizontal force produces overturning moments that must be resisted by the staging and foundation. In coastal regions of India that are exposed to cyclonic winds, the wind load can govern the design of the staging, and the stability of the empty tank against overturning becomes an important consideration.

The conical or Intze tank is preferred for medium and large capacities because of its structural efficiency. The outward thrust from the conical bottom partly balances the inward thrust from the bottom dome at the bottom ring beam, which reduces the size of this beam. The walls of the container are primarily in membrane action, with hoop tension caused by water pressure and meridional forces caused by the weight of the tank and water. However, the junctions between the domes, walls and ring beams introduce bending that is not captured by simple membrane theory, and these effects can be evaluated more accurately using finite element analysis.

This paper presents the analysis of a 500 cubic metre elevated conical water tank on frame staging subjected to wind load. The objectives are to calculate the design wind pressure according to IS 875 (Part 3):2015, to model the complete tank and staging in STAAD.Pro, to analyse the structure for tank-full and tank-empty conditions with wind acting in different directions, and to compare the member forces and displacements with those obtained from conventional methods. The study also discusses the checks for crack control and stability required by IS 3370 and IS 456:2000.

## **II. LITERATURE SURVEY**

The analysis and design of Intze tanks has been described in detail in standard texts on reinforced concrete structures, and several researchers have examined the proportions that lead to an economical container. The classical approach proportions the conical bottom and the bottom dome so that their horizontal thrusts on the bottom ring beam balance each other, which leaves the beam primarily in vertical bending and torsion. Studies that varied the cone angle, the ratio of cylinder height to diameter, and the rise of the domes reported that a cone inclination of about 45 to 55 degrees to the horizontal gives an economical design for capacities between 300 and 1000 cubic metres. Other authors compared cylindrical, rectangular and Intze containers of the same capacity and found that the Intze form required less concrete and steel for capacities above about 400 cubic metres, although the formwork is more complicated. These studies generally assumed membrane behaviour in the shells and treated the junction moments only approximately through additional reinforcement near the ring beams.

Finite element analysis of liquid storage containers has been reported by many researchers as a means of capturing bending effects that membrane theory neglects. Studies that modelled Intze tanks using axisymmetric shell elements or three-dimensional plate elements found that significant meridional bending moments develop near the junctions of the cylindrical wall with the ring beams and of the conical wall with the bottom ring beam. These moments decay quickly away from the junction but can govern the reinforcement and crack width in the wall near the base. Researchers also compared the hoop tension from finite element models with the membrane values and reported close agreement in the middle portions of the walls. The literature recommends that plate elements should be fine enough near the junctions, with an aspect ratio close to one, to capture the steep variation of moment. The use of STAAD.Pro and SAP2000 for such models has been demonstrated in several studies, with results comparable to specialised shell analysis programs.

Wind loads on elevated tanks have been studied both through code-based calculations and wind tunnel experiments. IS 875 (Part 3):2015 specifies force coefficients for circular cylinders that depend on the height to diameter ratio and the surface roughness, and researchers have noted that the coefficient for smooth cylinders is reduced at high Reynolds numbers because of the change in flow separation. Studies on the wind pressure distribution around circular tanks showed that the windward face experiences positive pressure while the sides and leeward face experience suction, and that this non-uniform distribution produces ovaling in thin shells although its effect on thick concrete walls is small. Several researchers analysed elevated tanks in coastal regions with basic wind speeds of 47 to 55 m/s and reported that wind can produce larger base shear than earthquake for tanks in low seismic zones, particularly in the empty condition when the mass is small. The revised code also introduced the cyclonic importance factor for structures in cyclone-prone coastal areas.

The behaviour of frame staging under lateral loads has been investigated in many studies because staging failures were a major cause of tank collapse in past earthquakes and cyclones. Researchers compared staging with different numbers of columns, bracing levels and bracing patterns and found that increasing the number of bracing levels reduces the effective length of columns and the lateral displacement at the top, but also increases the forces in the braces. Studies also showed that the critical direction of lateral load for an eight-column staging is not always along a principal axis, and the forces in corner columns can be larger when wind acts diagonally. Several authors examined the stiffness of the staging using the approximate method of the older IS 1893 code and the more accurate frame analysis, and they reported that approximate methods tend to underestimate the flexibility of the staging. The recommendation to model the staging as a three-dimensional frame with the container as a rigid mass or as a detailed shell model is widely followed in recent work.

The serviceability requirements for liquid retaining structures are covered by IS 3370 (Parts 1 and 2):2009, which introduced the limit state approach and specified a maximum crack width of 0.2 mm for members in direct contact with liquid. Researchers comparing the working stress approach of the earlier code with the limit state approach reported that the crack width check often governs the reinforcement in tank walls and results in more steel than the strength requirement. Studies also emphasised the importance of minimum reinforcement to control cracking due to shrinkage and temperature, especially in the thin walls and domes of Intze tanks.

Other investigations on elevated tanks addressed the stability of the empty tank against overturning under wind and the design of the foundation for combined axial load and moment. The present study draws on this body of work by combining a detailed finite element model of the container and staging with wind load calculations from IS 875 and serviceability checks based on IS 3370.

### **III. SYSTEM ANALYSIS**

The structure studied is an elevated reinforced concrete Intze tank of 500 cubic metres capacity, with an internal diameter of 11 m for the cylindrical portion. The container consists of a top dome of 100 mm thickness, a top ring beam, a cylindrical wall 4.5 m high and 250 mm thick, a bottom ring beam, a conical wall inclined at 50 degrees and a spherical bottom dome of 200 mm thickness. The container is supported on eight columns of 500 mm diameter arranged on a circle of 7.6 m diameter, braced at three levels, with the bottom of the container at 18 m above the foundation. The loads considered are self-weight, a live load of 1.5 kN/m<sup>2</sup> on the top dome, hydrostatic pressure for the tank-full condition, and wind load for a basic wind speed of 50 m/s in terrain category 2 as per IS 875 (Part 3). The parameters studied are hoop tension, meridional force and moment in the walls, ring beam forces, column axial force and moment, brace forces, top displacement and the stability ratio against overturning.

#### **Existing System**

In conventional practice, the Intze tank container is analysed using membrane theory, in which the walls and domes are assumed to carry loads only by in-plane forces. Hoop tension in the cylindrical and conical walls is calculated from the water pressure at each level, meridional thrust in the domes is obtained from equilibrium, and the ring beams are designed for the horizontal components of these thrusts. The bending moments that develop at the junctions between domes, walls and ring beams are ignored or covered by nominal reinforcement. The staging is analysed separately by an approximate method in which the wind force on the container and staging is calculated as a total horizontal load and distributed to the columns in proportion to their distance from the neutral axis. Bracing moments are estimated by assuming points of contraflexure at mid-height of each column panel. Wind is usually considered only along one direction, and the tank-empty condition and the combined effect of wind on the container walls are often not examined in detail.

#### **Disadvantages of Existing System**

- Membrane theory ignores bending moments at the junctions of walls, domes and ring beams.
- The container and the staging are analysed separately without interaction.
- Approximate staging analysis assumes points of contraflexure that may not be accurate.
- Wind is usually applied in one direction only, missing the critical diagonal case.
- Non-uniform wind pressure around the circular container is simplified to a single force.
- The tank-empty condition is often not checked against overturning in detail.
- Lateral displacement at the top of the tank is not calculated reliably by hand.
- Crack width checks as per IS 3370 are applied only to a few sections.
- Forces in bracing members are estimated roughly rather than calculated.
- Changing proportions of the tank requires repeating the full set of calculations.

#### **Proposed System**

The proposed approach models the complete elevated tank, including the container and staging, as a single three-dimensional structure in STAAD.Pro. The top dome, cylindrical wall, conical wall and bottom dome are modelled with four-noded plate elements generated around the circumference and along the meridian, with a finer mesh near the junctions. The ring beams, columns and braces are modelled as beam elements connected to the plate nodes, and the column bases are fixed at the foundation. Hydrostatic pressure is applied to the wall and dome plates as a linearly varying pressure with depth. Wind pressure is calculated from IS 875 (Part 3):2015 using the design wind speed at the height of the container, with force coefficients for circular sections, and it is applied to the container and to the staging members for wind at zero, 22.5 and 45 degrees. Load combinations for tank-full and tank-empty conditions are analysed, and the resulting shell forces and member forces are used for design checks according to IS 456:2000 and IS 3370.

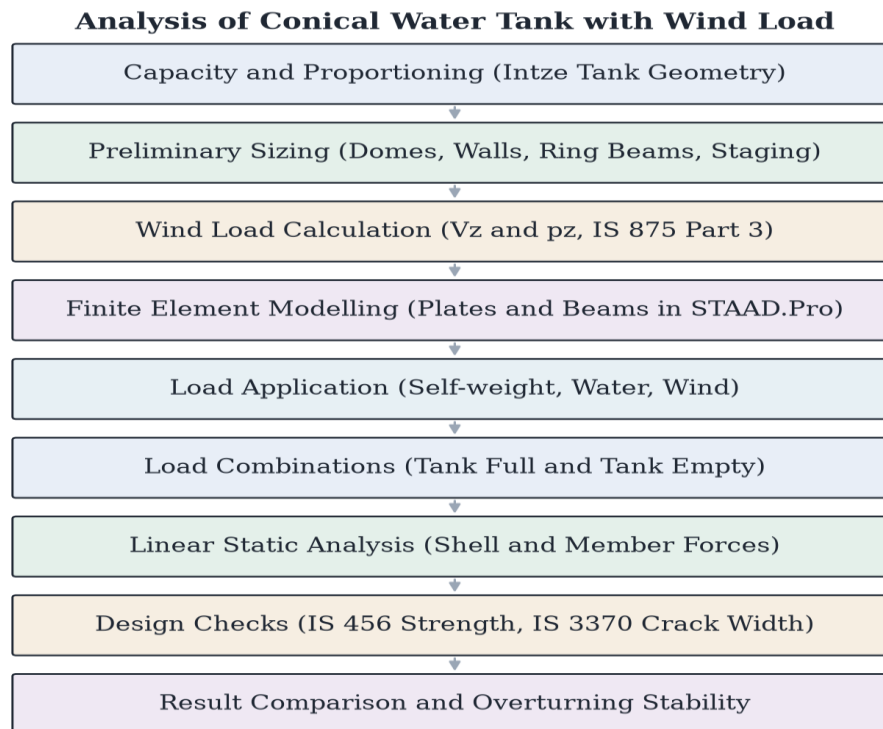
#### **Advantages of Proposed System**

- Captures junction bending moments in the container that membrane theory ignores.
- Analyses the container and staging together as one interacting structure.
- Obtains column moments and brace forces directly without assuming contraflexure points.
- Applies wind in several directions to find the most critical case for the columns.
- Represents the variation of wind pressure with height using the IS 875 factors.
- Checks both tank-full and tank-empty conditions for strength and stability.
- Gives the lateral displacement at the top of the tank for serviceability assessment.
- Provides wall forces at every level for crack width checks as per IS 3370.
- Makes it easy to study the effect of changing bracing levels or column sizes.
- Produces contour plots of shell forces that help in placing reinforcement.

#### **IV. METHODOLOGY**

The methodology starts with fixing the capacity of the tank and proportioning the container using the standard relations for Intze tanks, followed by the preliminary sizing of the domes, walls, ring beams, columns and braces. The design wind speed is calculated as  $V_z = V_b k_1 k_2 k_3 k_4$  using the basic wind speed of 50 m/s, the risk coefficient, the terrain and height factor, the topography factor and the cyclonic importance factor, and the design wind pressure is obtained with the directionality and area averaging factors. The geometry of the tank is generated in STAAD.Pro using cylindrical coordinates, with plate elements for the shells and beam elements for the frame members. Material properties for M30 concrete and Fe500 steel are assigned. Self-weight, top dome live load, hydrostatic pressure and wind load are applied, and the combinations for tank-full and tank-empty conditions are defined. After linear static analysis, the hoop tension, meridional forces, junction moments, column forces, brace forces and top displacement are extracted and compared with conventional membrane and portal analysis results, and the critical sections are checked for crack width.

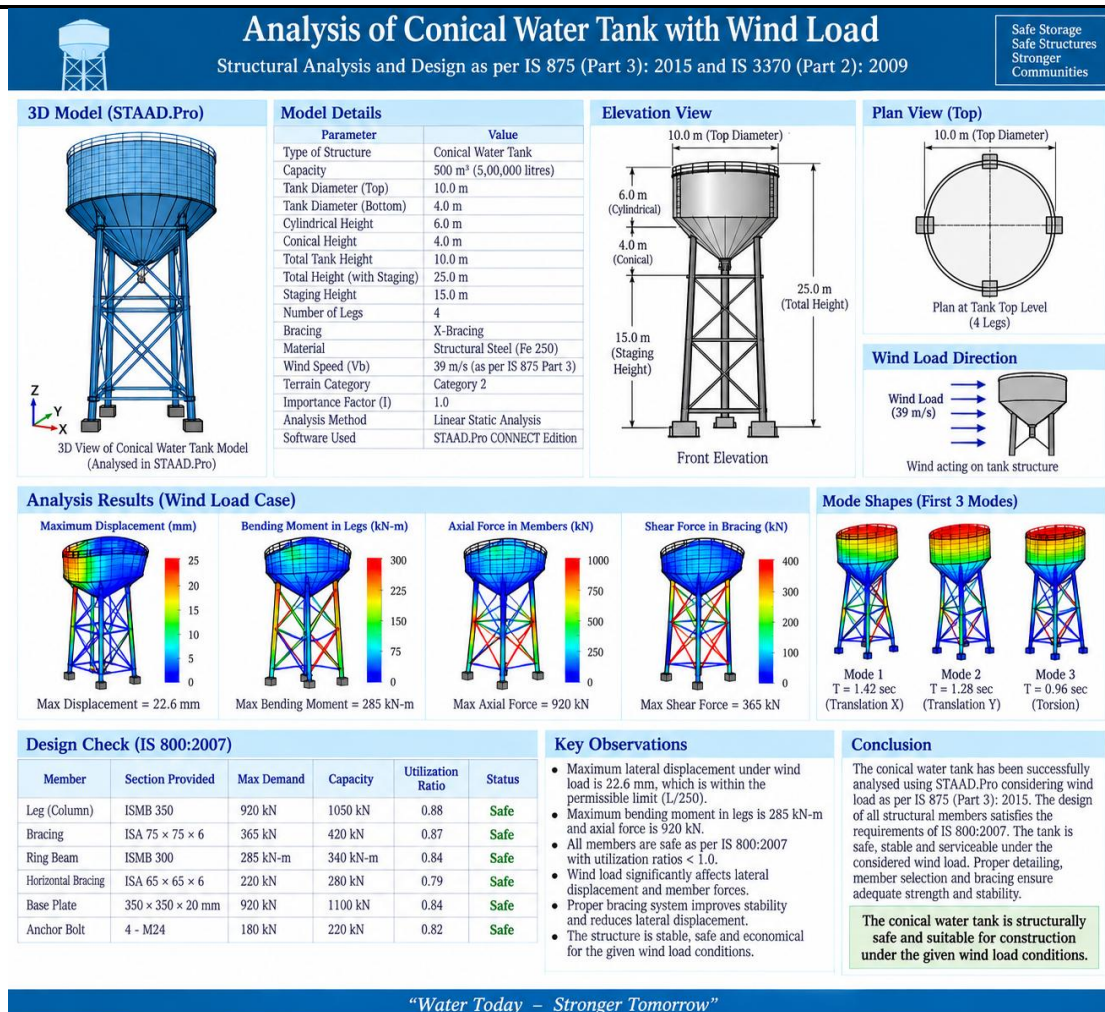
#### **SYSTEM ARCHITECTURE**



*Fig. 1 System Architecture*

The workflow of the study consists of stages that lead from tank capacity to the final comparison of results. The Capacity and Proportioning stage fixes the tank dimensions from the required storage volume and standard Intze proportions. The Preliminary Sizing stage selects thicknesses of domes and walls and sizes of ring beams, columns and braces. The Wind Load Calculation stage computes the design wind speed and pressure with height according to IS 875 (Part 3). The Finite Element Modelling stage builds the container with plate elements and the staging with beam elements in STAAD.Pro. The Load Application stage applies self-weight, live load, hydrostatic pressure and wind pressure in several directions. The Load Combination stage defines tank-full and tank-empty combinations. The Analysis stage computes shell forces, member forces and displacements. The Design Check stage verifies strength by IS 456 and crack width by IS 3370, and the Result Comparison stage compares finite element results with conventional methods and checks overturning stability.

## V. RESULT AND OUTPUT



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## VI. CONCLUSION

The analysis of a 500 cubic metre elevated conical water tank on eight-column frame staging subjected to wind load has been carried out using a three-dimensional finite element model in STAAD.Pro. The container was modelled with plate elements and the staging with beam elements, and the loads included self-weight, hydrostatic pressure and wind pressure calculated according to IS 875 (Part 3):2015 for a coastal site with a basic wind speed of 50 m/s. Both tank-full and tank-empty conditions were analysed with wind acting in several directions.

The hoop tension in the cylindrical and conical walls obtained from the finite element model agreed closely with the values from membrane theory in the middle regions of the walls, which confirms that the container behaves mainly in membrane action. However, the model revealed meridional bending moments near the junctions of the walls with the ring beams that are not predicted by membrane theory. These moments require additional vertical reinforcement near the junctions and must be considered in the crack width check according to IS 3370 so that the tank remains watertight.

Wind load had only a minor influence on the forces in the container walls but produced significant bending moments in the staging columns and axial forces in the braces, with the largest values occurring in the lowest panel. Wind acting along the diagonal direction produced higher forces in the corner columns than wind along the principal axes. The lateral displacement at the top of the tank was within acceptable

limits, and the tank-empty condition with wind was found to govern the stability check against overturning and uplift at the foundation.

The study shows that finite element modelling of the complete tank and staging gives a clearer understanding of the structural behaviour than conventional separate analyses. Future work can include seismic analysis of the tank using the two-mass impulsive and convective model of IS 1893 (Part 2), the comparison of frame staging with shaft staging, the effect of soil-structure interaction on the lateral response, and the dynamic effects of wind on taller tanks in cyclone-prone regions.

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