

ANALYSIS AND DESIGN OF STEEL WATER TANK USING STAAD.PRO

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ABSTRACT

Elevated water tanks are an essential part of water supply systems in towns, villages, industrial campuses, and residential complexes. They store treated water at a height so that it can be distributed by gravity with adequate pressure. Steel is an attractive material for such tanks because it is strong, light, quick to fabricate and erect, and can be dismantled or relocated if required. Unlike reinforced concrete tanks, steel tanks do not suffer from cracking and leakage due to shrinkage, although they require protection against corrosion. The present study deals with the analysis and design of an elevated rectangular steel water tank and its supporting staging using STAAD.Pro. A rectangular pressed steel tank of 100 cubic metre capacity, with plan dimensions of 6 m by 5 m and a water depth of 3.4 m, supported on a four-legged braced steel staging of 12 m height, is considered. The tank plates, stiffeners, bottom beams, columns, and bracing are modelled together in STAAD.Pro, with plate elements for the tank walls and floor and beam elements for the staging members. The loads considered are self-weight, hydrostatic pressure of water, wind load according to IS 875 (Part 3):2015, and seismic load according to IS 1893 (Part 1):2016 and IS 1893 (Part 2):2014 for liquid retaining tanks.

The tank is analysed for both the full and empty conditions, since the full condition gives the largest seismic mass and the empty condition may govern for wind uplift and overturning. Load combinations are formed according to IS 800:2007, and the staging members are designed by the limit state method of IS 800:2007 for combined axial force and bending. The tank plates are checked for stress and deflection under hydrostatic pressure, and stiffener spacing is fixed so that the plate stresses remain within permissible limits.

The analysis shows that the maximum plate stresses occur near the bottom of the side walls and at the junction of the walls and floor, where hydrostatic pressure is greatest. Seismic load in the tank full condition governs the design of the staging columns and bracing, while wind load in the tank empty condition governs the uplift check on the foundation. Hollow circular and angle sections selected for columns and bracing satisfy the strength and slenderness requirements with adequate reserve.

The study demonstrates that finite element modelling in STAAD.Pro allows the tank container and supporting staging to be analysed as one structure, giving realistic force distribution and allowing the design to be checked directly against IS 800:2007. The design procedure presented can serve as a guide for students and practising engineers engaged in the design of small and medium capacity elevated steel tanks.

I. INTRODUCTION

A reliable water supply system requires storage at a height that provides sufficient pressure to deliver water to consumers throughout the distribution network. Elevated service reservoirs perform this function by storing water pumped during off-peak hours and releasing it by gravity during periods of high demand. They also act as a

buffer that maintains supply during pump failures or power interruptions. Small and medium elevated tanks are common in rural water supply schemes, housing colonies, schools, hospitals, and industrial plants.

Elevated tanks may be built in reinforced concrete or in steel. Reinforced concrete tanks are durable and require little maintenance, but they need formwork at height, take a long time to construct, and must be designed carefully to avoid cracking and leakage according to IS 3370. Steel tanks can be fabricated from standard pressed panels or plates in a workshop, transported to site, and erected quickly on a steel staging. They are lighter, which reduces seismic forces and foundation size, and they can be expanded or relocated. Their main disadvantage is the need for periodic painting to prevent corrosion.

The design of an elevated steel tank involves the container, consisting of plates and stiffeners that resist hydrostatic pressure, and the staging, consisting of columns and bracing that carry the gravity load of the water and tank and resist lateral loads from wind and earthquake. Elevated tanks are particularly vulnerable to earthquakes because a large mass is concentrated at the top of a relatively flexible support, and several elevated tanks have failed or been damaged in past Indian earthquakes. IS 1893 (Part 2):2014 provides specific guidance on the seismic analysis of liquid storage tanks, including the impulsive and convective components of the liquid mass.

The present work carries out the analysis and design of a 100 cubic metre elevated rectangular steel tank on a braced steel staging using STAAD.Pro. The tank and staging are modelled together, loads are applied according to the relevant Indian Standards, and the members are designed according to IS 800:2007. The objective is to understand the behaviour of the tank under different loading conditions and to prepare a safe and economical design.

II. LITERATURE SURVEY

The design of steel water tanks has a long history in structural engineering, and classical design methods based on plate theory and simple frame analysis are described in standard textbooks on steel structures. In these methods, the side plates of a rectangular tank are treated as plates supported on stiffeners or on adjacent plates and subjected to triangular hydrostatic pressure, and the bending stresses are computed using coefficients derived from plate theory. The bottom plate is designed as a plate supported on a grid of beams, and the staging is analysed as a space frame by approximate methods. Researchers have noted that these methods are reliable for routine designs but require a number of simplifying assumptions about edge conditions and load sharing. With the availability of finite element programs, several studies have modelled the complete tank with plate elements and compared the results with classical methods, generally finding good agreement for plate stresses but identifying higher local stresses at corners and at the junction of the walls and floor that the classical approach does not reveal.

Seismic behaviour of elevated liquid storage tanks has been studied extensively because of damage observed in past earthquakes. During ground shaking, part of the liquid moves rigidly with the tank wall, known as the impulsive mass, while the remaining liquid near the free surface sloshes with a much longer period, known as the convective mass. Researchers developed spring-mass models that represent these two components, and these models form the basis of IS 1893 (Part 2):2014 and other international codes. Studies have shown that for elevated tanks the impulsive mode, in which the tank and staging sway together, dominates the base shear, while the

convective mode governs the sloshing wave height and the freeboard required. Investigators have also examined the difference between the tank full and tank empty conditions and reported that the tank full condition generally governs the seismic design of the staging.

The staging of elevated tanks has been identified as the most vulnerable part of the structure. Studies of braced steel staging have examined the effect of the number of panels, bracing configuration, and column inclination on the lateral stiffness and strength of the support structure. Researchers have reported that cross bracing and K-bracing both provide adequate stiffness when properly designed, but that slender bracing members may buckle in compression and lose effectiveness under cyclic loading. Studies using STAAD.Pro and SAP2000 have compared staging with different numbers of panels and found that increasing the number of bracing levels reduces the effective length of the columns and the lateral displacement at the tank level. Authors have recommended that bracing members be designed with adequate slenderness limits as specified in IS 800:2007 and that connections be designed for the full capacity of the members.

Wind loading on elevated tanks has been examined in relation to the exposed area of the container and the staging. IS 875 (Part 3):2015 provides force coefficients for rectangular and circular containers and for lattice frames, and researchers have discussed the shielding effect of the windward frame on the leeward frame of the staging. Studies have shown that for small and medium tanks in regions of moderate wind speed, wind load may govern the design of the staging in the tank empty condition, when the gravity load that stabilises the structure is small and the risk of uplift at the column bases is greatest. The foundation must then be designed against overturning and uplift with an adequate factor of safety. These observations indicate that both the full and empty conditions must be analysed for wind as well as seismic loads.

Design of steel structures in India has moved from the working stress method of IS 800:1984 to the limit state method of IS 800:2007. Researchers comparing the two methods for tank staging and similar lattice structures have reported that the limit state method generally leads to lighter sections because it uses partial safety factors on loads and materials and accounts for the actual buckling behaviour of members through column curves. The limit state method also introduces section classification, which determines whether plastic, compact, or semi-compact capacity can be used, and interaction formulae for members under combined axial force and bending. Studies have shown that analysis programs such as STAAD.Pro, which implement IS 800:2007 code checks, greatly reduce the effort of checking every member for every load combination. The present study uses this approach, together with IS 1893 (Part 2):2014 for seismic load and IS 875 (Part 3):2015 for wind load, to analyse and design the tank.

III. SYSTEM ANALYSIS

The structural problem addressed is the analysis and design of an elevated rectangular steel water tank of 100 cubic metre capacity together with its braced steel staging. The tank has plan dimensions of 6 m by 5 m and a total height of 3.6 m with a freeboard of 0.2 m, giving a water depth of 3.4 m. The tank walls are made of 8 mm steel plates stiffened by vertical and horizontal angle stiffeners, and the floor is a 10 mm plate supported on a grid of ISMB beams. The staging is 12 m high with four columns of hollow circular section, horizontal braces at every 3 m, and diagonal cross bracing of

angle sections in each panel. Steel of grade E250 conforming to IS 2062 is used. The loads considered are self-weight, hydrostatic pressure, a live load of 1.5 kN/m² on the roof, wind load for a basic wind speed of 39 m/s according to IS 875 (Part 3):2015, and seismic load for Zone III according to IS 1893 (Part 2):2014. Both tank full and tank empty conditions are studied.

Existing System

In conventional practice, elevated steel tanks are designed by hand using separate calculations for the container and the staging. The side plates are designed using plate bending coefficients for an assumed edge condition, with the hydrostatic pressure taken as triangular. Stiffener spacing is fixed by trial so that plate stresses remain within permissible values. The weight of the tank and water is then treated as a concentrated load at the top of the staging, and the staging is analysed as a simple braced frame, often by resolving forces at each joint or by assuming equal sharing of lateral load among the columns. Seismic load is frequently estimated using the entire water mass as a single lumped mass without separating the impulsive and convective components, and wind load on the container and staging is computed separately. Many designs still follow the working stress method of the older code rather than the limit state method of IS 800:2007. This approach is familiar but involves considerable approximation and does not capture the interaction between the container and the staging.

Disadvantages of Existing System

- Container and staging are designed separately without considering their interaction.
- Plate stresses depend on assumed edge conditions that may not match reality.
- Local stress concentrations at wall corners and wall-floor junctions are not captured.
- The entire water mass is often treated as a single rigid mass in seismic analysis.
- Lateral load sharing among columns and bracing is based on simple assumptions.
- Tank empty and tank full conditions are not always checked for every load.
- Working stress design gives heavier sections than the limit state method.
- Checking every member for every load combination by hand is very lengthy.
- Uplift and overturning of the foundation are sometimes checked only approximately.
- Revising plate thickness or bracing layout requires redoing all calculations.

Proposed System

The proposed approach models the complete elevated tank, including the container and the staging, in STAAD.Pro. The tank walls and floor are represented by plate elements with their actual thicknesses, the stiffeners and floor beams by beam elements connected to the plate nodes, and the columns and bracing of the staging by beam and truss members. The column bases are fixed. Self-weight is generated automatically, hydrostatic pressure is applied to the wall plates as a linearly varying pressure and to the floor as a uniform pressure, and roof live load is applied according to IS 875 (Part 2). Wind loads on the container and staging are computed according to IS 875 (Part 3):2015 using appropriate force coefficients. Seismic loads are calculated according to IS 1893 (Part 2):2014 by separating the liquid into impulsive and convective masses, computing their time periods and design coefficients, and applying the resulting base shear at the corresponding heights. Load combinations are

generated according to IS 800:2007 for both tank full and tank empty conditions. After analysis, plate stresses are checked and the staging members are designed by the limit state method of IS 800:2007.

Advantages of Proposed System

- Container and staging are analysed together as a single structure.
- Plate stresses are obtained at every point of the tank walls and floor.
- Stress concentrations at corners and wall-floor junctions are identified.
- Hydrostatic pressure is applied with its actual linear variation over depth.
- Impulsive and convective seismic effects are included according to IS 1893 (Part 2).
- Tank full and tank empty conditions are analysed with the same model.
- All staging members are checked to IS 800:2007 for every combination.
- Limit state design leads to lighter and more economical sections.
- Support reactions for foundation and uplift design are obtained directly.
- Plate thickness, stiffener spacing, or bracing layout can be revised quickly.

IV. METHODOLOGY

The methodology begins with the determination of tank capacity from the water demand and the selection of tank dimensions, freeboard, and staging height. The geometry of the container and staging is generated in STAAD.Pro, with nodes created at stiffener and bracing locations. Plate elements are assigned to the walls and floor, beam elements to the stiffeners, floor beams, columns, and horizontal braces, and truss elements to the diagonal braces. Section properties and E250 steel are assigned, and fixed supports are provided at the column bases. Self-weight and roof live load are applied, and hydrostatic pressure is applied to the plates for the tank full condition. Wind loads are computed from IS 875 (Part 3):2015 and applied to the container and staging members. The impulsive and convective masses, their heights, and their time periods are calculated according to IS 1893 (Part 2):2014, and the corresponding lateral forces are applied. Load combinations of IS 800:2007 are formed for both tank conditions. The model is analysed, plate stresses and member forces are extracted, staging members are designed, and support reactions are used to check foundation uplift.

SYSTEM ARCHITECTURE

The workflow of the study follows a series of stages from capacity estimation to final design. The Data Collection stage determines the required capacity, site wind speed, seismic zone, and soil conditions. The Tank Sizing stage fixes the plan dimensions, water depth, freeboard, and staging height. The Geometry Modelling stage creates the container and staging in STAAD.Pro with plate, beam, and truss elements. The Material and Section stage assigns E250 steel, plate thicknesses, and rolled sections. The Load Definition stage applies self-weight, hydrostatic pressure, and wind load according to IS 875 (Part 3). The Seismic Load stage computes impulsive and convective forces according to IS 1893 (Part 2):2014. The Load Combination stage forms the IS 800:2007 combinations for tank full and tank empty. The Analysis and Design stage checks plate stresses and designs staging members to IS 800:2007, and the Result Comparison stage compares governing cases, deflections, and support reactions.

Analysis and Design of Steel Water Tank Using STAAD.Pro

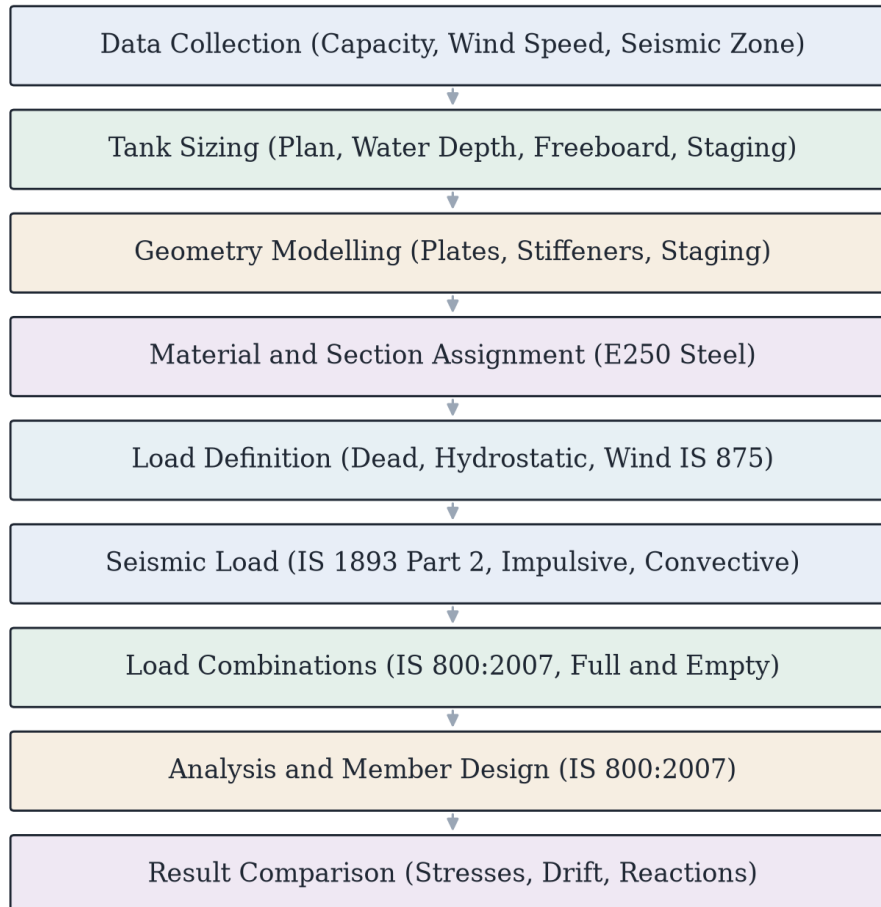
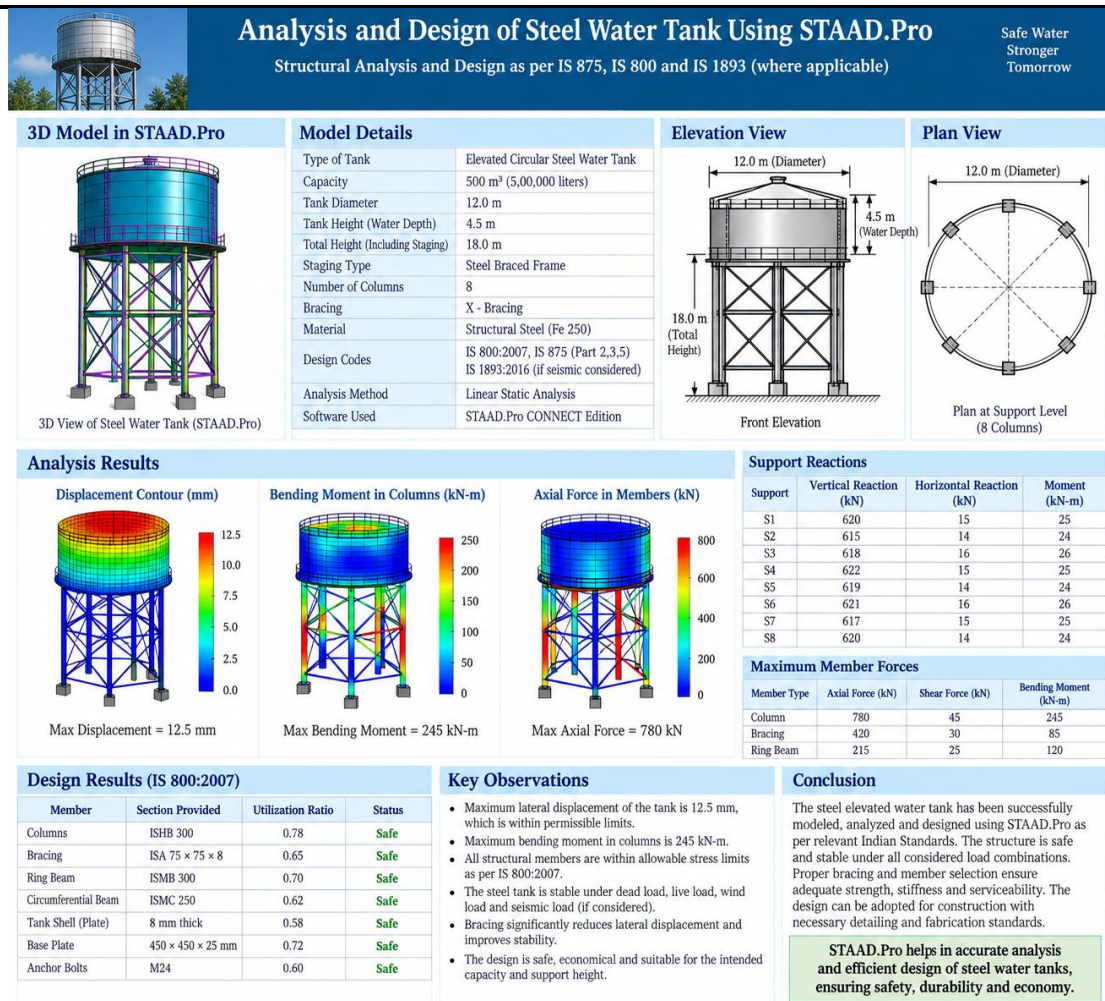


Fig. 1 System Architecture

V. RESULT AND OUTPUT



VI. CONCLUSION

This study presented the analysis and design of a 100 cubic metre elevated rectangular steel water tank supported on a 12 m braced steel staging, using STAAD.Pro. The container and staging were modelled together with plate, beam, and truss elements, and the structure was analysed for self-weight, hydrostatic pressure, wind load according to IS 875 (Part 3):2015, and seismic load according to IS 1893 (Part 2):2014. The members were designed by the limit state method of IS 800:2007.

The analysis of the container showed that the highest plate stresses occur near the bottom of the side walls and at the junction between the walls and the floor, where the hydrostatic pressure is greatest and the plates are restrained. With the adopted plate thickness and stiffener spacing, the maximum von Mises stress remained well below the yield stress of E250 steel divided by the partial safety factor, and plate deflections were small. The floor beams were governed by the combined load of the water and the floor plate.

The staging analysis showed that seismic load in the tank full condition governed the design of the columns and bracing, because the impulsive mass of water adds substantially to the lateral force at the top of the staging. The convective component contributed a smaller force but determined the sloshing wave height, which was found to be within the provided freeboard. Wind load in the tank empty condition produced

the largest uplift at the column bases, which governs the anchorage and foundation design. All staging members satisfied IS 800:2007 with utilisation ratios below unity. Future work may include time-history analysis to capture the dynamic response of the liquid more accurately, soil-structure interaction at the foundation, the use of cylindrical tanks or alternative staging configurations such as tapered or tubular towers, corrosion allowance and life-cycle cost assessment, and comparison with an equivalent reinforced concrete tank designed to IS 3370.

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