

Wind and Seismic Analysis of Elevated Tank using Staad Pro

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Abstract- Any project of water tanks is subject to live load, dead load and wind load or seismic load according to IS codes of conduct. In this study the wind forces and the seismic force acting on the raised water tank are studied. The standard code of India IS 1893-2000 and IS 875 (part 3) 2003 for seismic and wind effects is used in this study. Most often, tanks are designed for wind forces and are not controlled to determine the seismic load, assuming that the tanks will be safe under seismic forces once designed for wind forces. Water tanks are an important public utility and an industrial structure. Reinforced concrete design and construction methods are influenced by prevailing construction practices, physical properties of the material and climatic conditions. The project involves the analysis of the entire structure by STAAD.Pro and the analysis of the response spectrum provides the displacement, the bending moment, the axial force, the torsion values and the cutting force. The Eigen solution thus obtained helps to determine the base shear.

Key Word: Elevated water tank, response spectrum analysis, STAAD.Pro, Time history analysis

I. INTRODUCTION

Water is a lifeline for every kind of creature in this world. All over the world, liquid storage tanks are widely used by municipalities and industries for water supply, firefighting systems, flammable liquids and other chemicals. Therefore, water tanks play a vital role for public utility, as well as the industrial structure which has the basic purpose of ensuring a constant supply of water from a greater distance with a sufficient static charge to the desired location under the effect of gravitational force.

The high water tanks are clearly visible to the public and are visible from close distances over long distances. The Intze type tank is commonly used as a water reservoir in India. Currently, a large number of water tanks are used at the top to distribute water for public use. They often become landmarks in the landscape. Therefore, it is important that the shape and shape of the container and the support structure receive due attention from an aesthetic point of view. The water storage tanks must remain operational in the post-earthquake period to ensure the supply of drinking water to the regions affected by the earthquake and to meet the demand for fire fighting. Industrial tanks containing liquids may contain highly toxic and flammable liquids and these tanks should not lose their contents during the earthquake. During the earthquakes, a series of large elevated water tanks suffered serious damage, while others survived without damage. An analysis of the dynamic behavior of these tanks must take into account the movement of water in relation to the tank, as well as the movement of the tank with respect to the ground. The current design of support structures for high water tanks is extremely vulnerable to lateral forces due to an earthquake as it is designed for the wind and seismic forces.

Two aspects came to the fore for the design of tanks:

- The effects of liquid spray and the flexibility of the container wall should be duly taken into consideration during the evaluation of the seismic forces in the tanks.
- It is recognized that the tanks are less ductile and have a low energy absorption capacity and redundancy compared to conventional construction systems.

The Intze water tanks are built to minimize the cost of the project because the lower dome in this construction resists horizontal thrust. This type of tank is the simplest way compared to the circular tank.

1.1 WIND LOAD

Wind pressures acting at any height in a structure are calculated using the methods recommended by the IS code. The basic wind speed (V_b) for any site will be obtained from the basic wind map shown in IS 875 (Part 3) 2003 and will be modified to include the following effects to obtain the design wind speed at any height (V_z) for the chosen structure:

- Risk Coefficient (k_1 factor)
- Terrain roughness (k_2 factor)

- Local Topography (k_3 factor)

According to the normal wind speed, there are 6 zones, zone I to zone VI. The normal wind speed should be modified to include the following effects to obtain the wind speed in height for the chosen structure. There are four categories of terrain based on the code based on wind obstruction. From the map of the Indian wind area shown. It has been discovered that, based entirely on the basic wind rhythm, India is divided into six wind zones, such as Zone I and Zone VI.

| Zone | Basic wind speed (m/sec) | K1 Factor |
|------|--------------------------|-----------|
| I | 33 | 1.05 |
| II | 39 | 1.06 |
| III | 44 | 1.07 |
| IV | 47 | 1.07 |
| V | 50 | 1.08 |
| VI | 55 | 1.08 |

Design wind speed (V_z) at any height can be calculated as follows:

$$V_z = V_b k_1 k_2 k_3$$

Where, V_z = Design wind speed at any height 'z' in m/s

V_b = Basic wind speed for any site

k_1 = Probability factor (Risk coefficient)

k_2 = Terrain, height and structure size factor

k_3 = Topography factor

k_1 , k_2 & k_3 are calculated by means of tables in IS 875 (Part-3) 2003.

The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$P_z = 0.6 V_z^2$$

Where, P_z = Design Wind pressure in N/m^2 at height z,

V_z = Design wind velocity in m/s height z

1.2 EARTHQUAKE LOAD

An earthquake is a phenomenon that derives and is driven by the sudden release of energy stored in the crust that propagates through seismic waves. On the surface of the Earth, earthquakes can occur with shocks or earth shifts and sometimes tsunamis, which can lead to loss of life and destruction of property. The word Earthquake is used to describe any seismic event or a natural phenomenon or an event caused by a human being that generates seismic waves. Most earthquakes of natural origin are related to the earth's tectonic nature. These earthquakes are called tectonic earthquakes. The Earth's lithosphere is a mosaic of slow moving but constant plates caused by the heat in the mantle and in the core of the Earth. The borders of the plates join together, creating frictional stress. When the friction tension exceeds a critical value, called local resistance, a sudden failure occurs. The limit of the tectonic plates along which the error occurs is called fault plane. When the fault in the

fault plane causes a violent movement of the earth's crust, elastic deformation energy is released and seismic waves are emitted, causing an earthquake.

As per IS 1893:1984 Code India is divided from Zone 1 to Zone 5. But as per IS 1893:2002 Code it has been divided from Zone 2 to Zone 5. Zone 1 has been discarded.

| Seismic Zone | Basic horizontal seismic coefficient | Zone Factor Z |
|--------------|--------------------------------------|---------------|
| I | 0.01 | 0.05 |
| II | 0.02 | 0.10 |
| III | 0.04 | 0.20 |
| IV | 0.05 | 0.25 |
| V | 0.08 | 0.40 |

II. LITERATURE REVIEW

Several literatures were presented in the form of technical documents to date on wind and seismic analysis of elevated water tanks. This analysis deals with various topics and points: the wind speed of different cities based on seismic zones, hydrodynamic pressure and the dynamic response of framed staging, etc. Some of them are analyzed below:

1. **Livaoglu. R. and Dogangun A.** (2006) studied the effects of the incorporation of the bottom on the seismic behavior of the raised system of a fluid tank with a structural structure that supports the reservoir containing the fluid. Six different soil types defined in the seismic codes were considered.
2. **Durgesh C. Rai and Bhumika Singh (2004)**, studied reinforced concrete pedestal (hollow shaft type circular supports) is a popular choice for elevated tanks because of the ease of construction and the more solid form it provides compared to the framed construction. In the recent Indian earthquakes, Gujarat (2001) and Jabalpur (1997), the thin shells (150 to 200 mm) of concrete pedestals have had an unsatisfactory performance when many developed circumferential cracks due to tension in the pedestal near the base and some they collapsed.
3. **IITK-GSDMA Guidelines (For Seismic Design of Liquid Storage Tanks)** says that, most elevated tanks are never filled completely with liquid. Hence a two mass idealization of the tank is more appropriate as compared to a one-mass idealization, which was used in IS 1893: 1984. Two mass models for elevated tank were proposed by Housner (1963) and are being commonly used in most of the international codes.
4. **Pavan S. Ekbote and Dr. Jagdish G. Kori:** During the earthquake, the elevated water tanks suffered severe damage or collapsed. This could be due to the lack of knowledge of the behavior of the water tank support system, once again, to the dynamic action and also to the inadequate geometric selection of tank staging models. Because of the interactions of the fluid structure, the seismic behavior of elevated water tanks has the characteristics of complex phenomena. The main objective of this study is to understand the behavior of the support system (or staging) that is more effective with different methods of response spectrum with the software SAP 2000. In this work several support systems such as radial reinforcement have been studied and transversal.

III. MODELLING AND ANALYSIS

For the analysis of the type of Intze type high water tank, the following dimensions are considered as described below. From the study of the Intze high water tank, the main objective is to know the deviated form, the tensions and the B.M. for the same.

| | |
|---------------------------|--------------|
| Height of the tank - | 25m |
| Staging height (linear) - | 18m |
| Base diameter of tank- | 10 m |
| Diameter of Sphere - | 15 m |
| Number of columns - | 4 |
| Grade of Concrete - | M30 |
| Grade of Steel - | Fe415 |
| Size of column - | 600mm |
| Size of Beam - | 350 X 400 mm |
| Plate Thickness - | 200 mm |

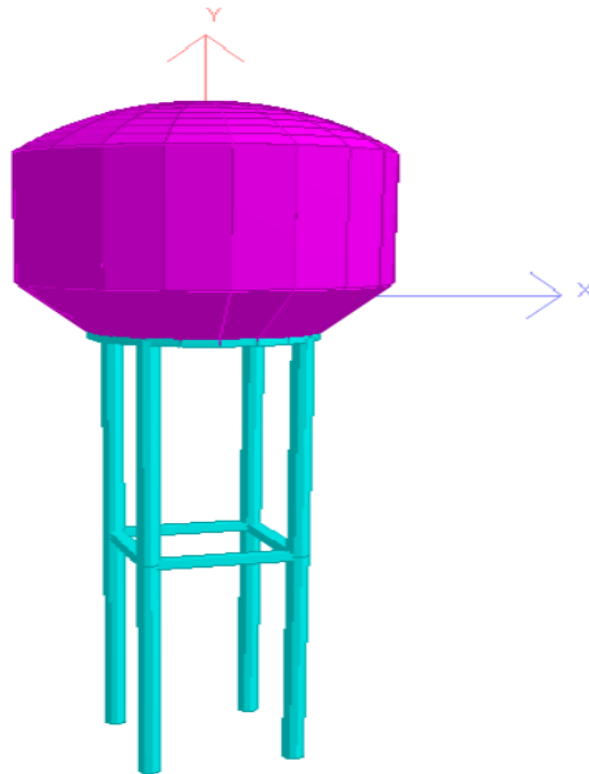


Fig 1: 3D Model of Intze Tank

Load Applied

- Dead load
 - Self Weight - 1 kN/m^2
 - Plate load - 20 kN/m^2
- Live Load
 - UVL - 20 kN/m^2
- Wind Load
 - Basic Wind Speed - 39 m/s

- Earthquake Load
 - Seismic zone II,III,IV,V

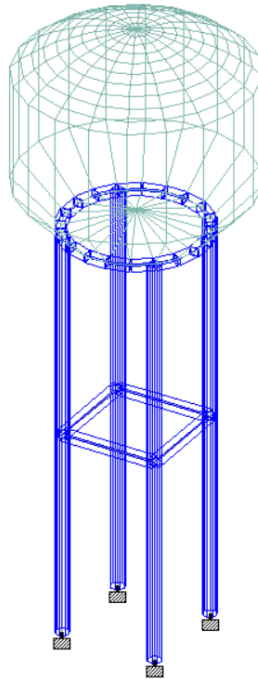


Fig 2: Section Outline

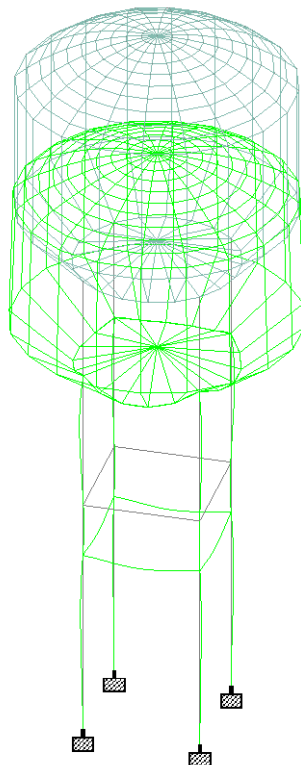


Fig 3: Deflection due to Dead Load

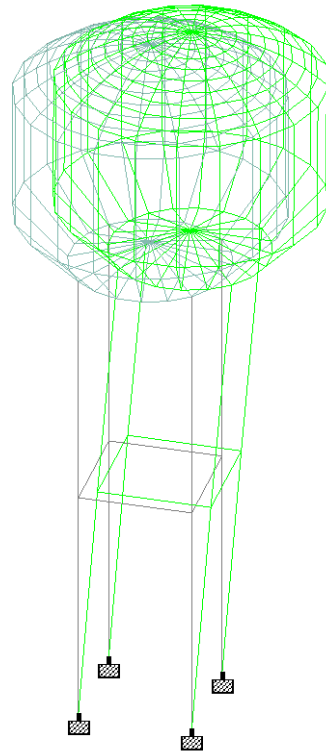


Fig 4: Deflection due to Earthquake Load

IV. RESULTS

Two different analyzes were discussed, namely Response Spectrum, Time History Analysis in pre-calculated load values. The analysis of the response spectrum provides the displacement, the bending moment, the shear force, the axial force and the torsion values. The Eigen solution thus obtained helps to determine the base shear and different peak shear values of the structure. Time history analysis defines the behavior of the structure in a certain time interval in the face of different functions such as speed, displacement and acceleration. Thus, the graphic solution was designed for each analysis.

Based on the previous discussion, the following results were obtained:

| Mode | Frequency (cycles/sec) | Period (sec) |
|------|---------------------------|-----------------|
| 1 | 0.482 | 2.07626 |
| 2 | 0.482 | 2.07626 |
| 3 | 0.579 | 1.72847 |
| 4 | 3.706 | 0.26980 |
| 5 | 3.706 | 0.26980 |
| 6 | 4.979 | 0.20848 |
| 7 | 6.087 | 0.16428 |

| | | |
|----|--------|---------|
| 8 | 6.087 | 0.16428 |
| 9 | 7.487 | 0.13356 |
| 10 | 12.040 | 0.08306 |
| 11 | 38.900 | 0.02571 |
| 12 | 48.776 | 0.02050 |
| 13 | 48.776 | 0.02050 |
| 14 | 49.816 | 0.02007 |
| 15 | 58.539 | 0.01708 |
| 16 | 59.700 | 0.01675 |
| 17 | 59.700 | 0.01675 |
| 18 | 60.296 | 0.01658 |
| 19 | 63.610 | 0.01572 |
| 20 | 63.610 | 0.01572 |

1. Response Spectrum Analysis

Response spectrum analysis (RSA) is a dynamic linear statistical analysis method that measures the contribution of each natural vibration mode to indicate the possible maximum seismic response of an essentially elastic structure. Analysis of the response spectrum provides information on dynamic behavior by measuring acceleration, velocity or pseudo-spectral displacement as a function of the structural period for a given chronology and damping level.

STAAD.Pro calculates by default the value of the first 6 modes in terms of modal weight or modal frequency. We have changed the default value to 20. The table below gives the value of frequency in accordance with the mode shapes.

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear (**V**) depend on:

- soil conditions at the site
- proximity to potential sources of seismic activity (such as geological faults)
- probability of significant seismic ground motion
- the level of ductility and overstrength associated with various structural configurations and the total weight of the structure
- the fundamental (natural) period of vibration of the structure when subjected to dynamic loading

The maximum **Base Shear** obtained is **406.3524 KN**.

2. Time History Analysis

STAAD is equipped with a facility to perform a response history analysis on a structure subjected to time varying forcing function loads at the joints and/or a ground motion at its base. This analysis is performed using the modal superposition method. Hence, all the active masses should be modeled as loads in order to facilitate determination of the mode shapes and

frequencies. In time history analyses the structural response is computed at a number of subsequent time instants. In other words, time histories of the structural response to a given input are obtained as a result. In response spectrum analyses the time evolution of response cannot be computed.

- Duration of Time History Analysis - 28.000 Sec
- Number of Time Steps in the Solution process = 1400
- Number of modes whose contribution is considered = 20

Parameters such as acceleration, velocity and displacement are also used, and whose value is imported through external text document. Hence the behavior of the structure in graphical form is obtained which is shown below:-

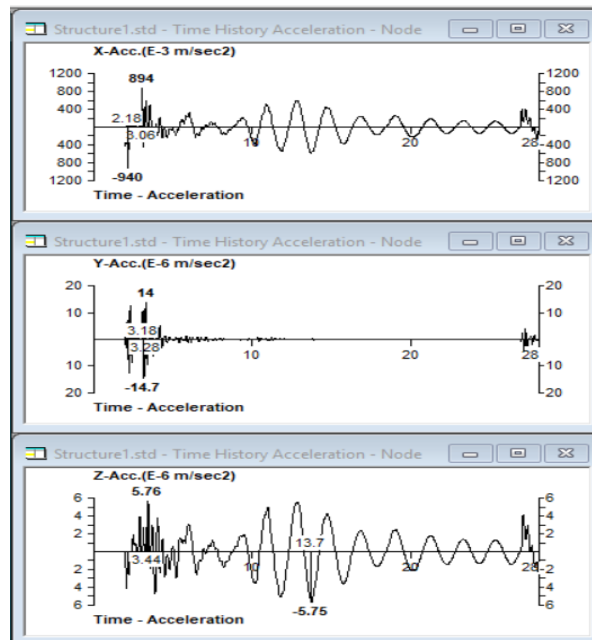


Fig 5: Time - Acceleration

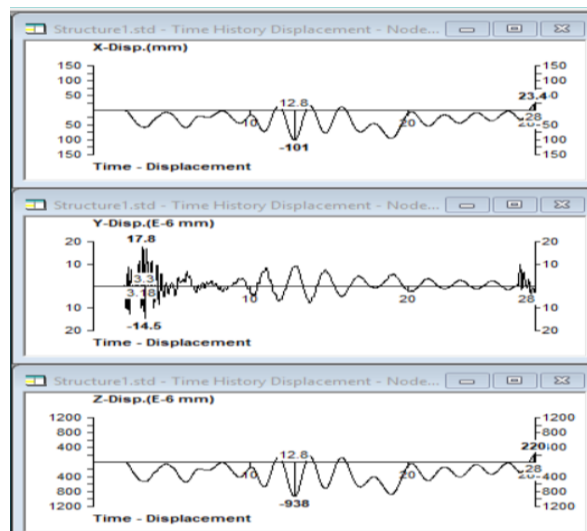


Fig 6: Time - Displacement

Displacement Summary

| | Node | L/C | Horizontal X mm | Vertical Y mm | Horizontal Z mm | Resultant mm |
|--------|------|------------|-----------------------|---------------------|-----------------------|-----------------|
| Max X | 201 | 1 EL +X | 23.110 | -0.000 | -0.001 | 23.110 |
| Min X | 201 | 11 DYNAMIC | -217.245 | -0.000 | 0.006 | 217.245 |
| Max Y | 6 | 11 DYNAMIC | -215.494 | 4.615 | 0.005 | 215.544 |
| Min Y | 16 | 11 DYNAMIC | -215.494 | -4.615 | 0.005 | 215.544 |
| Max Z | 201 | 3 EL +Z | 0.001 | 0.000 | 23.110 | 23.110 |
| Min Z | 201 | 4 EL -Z | -0.001 | -0.000 | -23.110 | 23.110 |
| Max rX | 243 | 3 EL +Z | -0.000 | 0.000 | 10.558 | 10.558 |
| Min rX | 243 | 4 EL -Z | 0.000 | -0.000 | -10.558 | 10.558 |
| Max rY | 216 | 11 DYNAMIC | -210.754 | 0.006 | -0.004 | 210.754 |
| Min rY | 206 | 11 DYNAMIC | -210.754 | -0.006 | -0.004 | 210.754 |
| Max rZ | 245 | 11 DYNAMIC | -101.495 | -0.000 | -0.001 | 101.495 |
| Min rZ | 245 | 1 EL +X | 10.558 | 0.000 | 0.000 | 10.558 |
| Max Rs | 201 | 11 DYNAMIC | -217.245 | -0.000 | 0.006 | 217.245 |

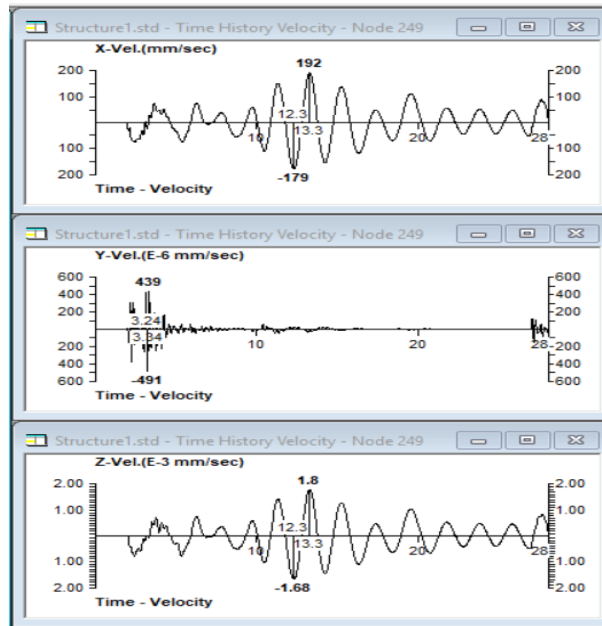


Fig 7: Time - Velocity

Reaction Summary

| | Node | L/C | Horizontal Fx kN | Vertical Fy kN | Horizontal Fz kN |
|--------|------|------------|------------------------|----------------------|------------------------|
| Max Fx | 244 | 11 DYNAMIC | 102.536 | 966.763 | 0.087 |
| Min Fx | 244 | 1 EL +X | -10.441 | -110.281 | -0.009 |
| Max Fy | 244 | 11 DYNAMIC | 102.536 | 966.763 | 0.087 |
| Min Fy | 248 | 11 DYNAMIC | 102.536 | -966.763 | 0.087 |
| Max Fz | 246 | 4 EL -Z | -0.009 | -110.281 | 10.441 |
| Min Fz | 246 | 3 EL +Z | 0.009 | 110.281 | -10.441 |
| Max Mx | 246 | 4 EL -Z | -0.009 | -110.281 | 10.441 |
| Min Mx | 246 | 3 EL +Z | 0.009 | 110.281 | -10.441 |
| Max My | 246 | 11 DYNAMIC | 100.640 | 0.012 | -0.087 |
| Min My | 250 | 11 DYNAMIC | 100.640 | -0.012 | -0.087 |
| Max Mz | 244 | 1 EL +X | -10.441 | -110.281 | -0.009 |
| Min Mz | 244 | 11 DYNAMIC | 102.536 | 966.763 | 0.087 |

V. CONCLUSIONS

In this work we tested the analysis and design (Response Spectrum Analysis and Time History Analysis) of a high water tank using STAAD.Pro V8i. The following conclusions (for Response Spectrum Analysis, Time History Analysis) are based on research and analysis performed by STAAD.Pro as described below:

1. Response Spectrum Analysis

- Because the shape of the model becomes complicated due to the higher modes, the modal frequency also increases and usually requires more energy to excite these modes than the simplest low-frequency modes.
- As the number of stories increases with the height of the structure, the maximum cutoff value of the story (kN) decreases.
- The base shear values and shear values is calculated.
- The total modal masses were obtained for different modal in different directions that represented more than 90% of the total seismic weight.

2. Time History Analysis

- Analysis was done by defining no. of modes (Eigen Values) as 20. The frequency and time period for each mode were obtained.
- Various parameters (acceleration, velocity, displacement) vs. time graph were obtained.

The various results obtained from the aforementioned analysis will help provide security against vulnerable earthquakes & wind force and determine the dynamic response of the water reservoir after a certain period of time.

Further studies can be performed to obtain more storage capacity of the tank and the structure response can be studied for longer periods. Design of water tank is a very tedious method. Particularly design of elevated cylindrical water tank involves lots of mathematical formulae and calculation. It is also time consuming. Hence Staad – pro gives a base shear value from the analysis immediately.

Present study will be useful to Civil Engineers to understand the behaviour of elevated water tank for various heights and also to get the feel of effect of earthquake zones and wind zones of India on earthquake forces.

VI. REFERENCES

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