Design , Analysis and Optimization of Intze Type Water Tank With Sloshing Effect

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Abstract - *Liquid storage tanks whether it be underground or overhead or on the surface are commonly used in industries for storing chemicals, petroleum products, many such fluids, etc. and for storing water in public water distribution systems. Indian seismic code IS 1893:1984 showed very limited provisions on seismic design of both elevated and underground tanks. Compared to present international practice, those provisions of IS 1893:1984 are highly inadequate. Moreover, the code failed to cover ground-supported tanks. In 2002, revised Part 1 of IS 1893 was established in the market by the Bureau of Indian Standards (BIS) in order to maintain safety issues for these tanks.*

The present study will deal with the whole design analysis and parametric study of structural analysis of circular and rectangular water tank to avoid stresses and cracking. Modal analysis of tank will be done to define the mode shapes of tank under self-weight. After modal analysis seismic loading of tank will be done to check for deformations. The simulation of tank will be done using ANSYS work bench considering both thermal and structural analysis of tank. Based on structural and thermal analysis after setting up the parameters in tank for minimal stresses seismic loading is done and deformation of tank will be analysed to see further improvements.

***Key Words*: IS code, ANSYS, Parametric, Structural, Modal, Seismic loading**

1.INTRODUCTION

Reservoirs and Tanks are used to ensure the safety from the liquid it is storing, unwanted spillage and in majority cases to store products like liquid petroleum, water, petroleum products and different types of fluids. The structural analysis mainly the forces involved with these reservoirs or tanks is about the same importance when compared to the chemical degradation of the products. All tanks are designed in order to have a crack free structures so as to eliminate any leakage from it. . To achieve high resistivity of concrete, very higher density of concrete should be achieved during the structure building process of the tank or reservoir. Permeability of concrete in solid form is directly proportional to the volume of water cement ratio being prepared for the mix. One of the most common way to achieve this kind of compactness is to use vibrators. To keep the shrinkage low, cement content having a density range of 330 to 530 kg per cubic metre is preferred. By observation, it has been found that when the water or liquid head stored in the tank is increased, the tank or reservoir becomes more prone to leakage and normally a head upto 15 metres is preferred for any tank. Bars of grade Fe415 or mils steel are used for constructing these liquid retaining structures. Normally for a liquid retaining structure, crack width of 0.1 mm is very much acceptable .

1.1 General Design Requirements (I.S.I.)

A.Plain Concrete Structures:

The design of plain concrete structure with reinforcement can be considered against structural failure by adopting tension limits to be well under the permissible limits for bending in the concrete structure along with the reinforcement .

B.Permissible Stresses in Concrete:

1. For resistance to cracking: .For structures having a thickness of 225 mm and in contact with liquid on one side, the permissible limits are even applicable for the structure part that is remotely away from the liquid.

2. For strength calculations: For strength calculations, the permissible limits to be considered are the bending stresses that the concrete along with the reinforcement can endure.

Concrete Grade	Permissible limits in KN / m2		Shear
	Direct	Bending	
M15	1.1	1.5	1.5
M20	1.2	1.7	1.7
M25	1.3	1.8	1.9
M30	1.5	2.0	2.2
M35	1.6	2.2	2.5
M40	1.7	2.4	2.7

C. Permissible Stresses in Steel:

1) **For resistance to cracking:**For concrete structures ,the tensile stress in steel shall be equal to product of modular

ratio of steel and concrete and the allowable tensile stress in concrete.

2) **For strength calculations:** In strength calculations, the permissible stresses can be as follows:
   - Tensile stress in structure for direct tension = 1000 kg/cm^2.
   - Tensile stress in structure for bending on liquid retaining face or for face away from liquid and of thickness less than 225mm = 1000 kg/cm^2.
   - Tensile stress in members for face away from liquid and of thickness more than 225mm = 1250 kg/cm^2.

D. Permissible Stresses due to Shrinkage or Temperature Change:

If Shrinkage is considered for any concrete structure designing process, than the permissible limits for the concrete (both direct and bending) is to be increased by 33.33 percent .

1.2 Sloshing Effect on the Water Tank

The movement of liquid inside another object is known as Sloshing. The liquid sloshing may cause various engineering problems, for example instability of ships, in aerospace engineering and ocean engineering, failures on structural system of the liquid container. The motion of liquid with a free surface is of great concern in many engineering disciplines such as propellant slosh in spacecraft tanks and rockets (especially upper stages), cargo slosh in ship and trucks transporting liquid (for example oil and gasoline), oil oscillation in large storage tanks, water oscillation in a reservoir due to earthquake, sloshing of water in pressure-suppression pools of boiling water reactors and several others. The basic problem of liquid sloshing involves the estimation of hydrodynamic pressure distribution, moments, forces and natural frequencies of the free surfaces of the liquid. These parameters have a direct effect on the dynamic stability and performance of moving containers.

1. Linear Wave Theory:

Sloshing is often analyzed in a simpler form where no overturn takes place, that is to say when the free surface strays intact. Assumptions like incompressibility, irrotational flow, inviscid (viscous/drag/friction terms are negligible), no ambient velocity (no current), two dimensional and small amplitudes allow for a simplified analysis via linear wave theory.

2. Sloshing in Moving Vehicles:

The problem of liquid sloshing in moving or stationary containers is of great concern to aerospace, nuclear and civil engineers, designers of road tankers, physicists, and ship tankers and mathematicians. Seismologists and civil engineers have been studying liquid sloshing effects on oil tanks, large dams, and elevated water towers underground motion. They also mounted liquid tanks on the roofs of multistory buildings as a means to control building oscillations due to earthquakes.

2. DESIGN REQUIREMENTS OF INTZE TYPE WATER TANK

1 Dome at the top of the reservoir is almost 100 to 150 mm thick and reinforcements are provided along the latitudes and meridians of the reservoir.
2. Ring beam in the dome is to be provided so as to accommodate the horizontal component of the thrust force and resist the hoop stress induced on the surface.
3. Cylindrical walls are to be made to resist the hoop stress caused by the water pressure in horizontal direction.
4. Ring beam at the junction of the conical and cylindrical walls are to be provided so as to resist the hoop stress generated as a reaction of conical and cylindrical interface.
5. Conical Slab is to be considered in the reservoir in order to accommodate hoop stress due to water pressure.
6. Floor of the tanks may be circular or domed in nature.
7. The columns are designed in order to accommodate the total load acting on the reservoir. These are placed at fixed intervals and are to be designed in such a way that it resist the wind pressures or the seismic loads that the reservoir experiences.
8. Foundation is the base of any reservoir and is so designed that it bears all the load acting on the reservoir and also consists of a ring girder and a circular slab.

For calculating the different dimensions of the Intz tank we follow few assumptions to attain a volume accordingly:

- Total Volume, V = 0.585D^3 as per Reynolds' assumption
- Total Volume, V = 0.3927D^3 as per Greys' assumption and H=D/2

3. DESIGN SPECIFICATION

- Capacity of Intze Tank = 300000 litres
- Height of Tank Above ground level = 12 m (assumed)
- Number of column = 8
- Safe Bearing Capacity of Soil = 200 kN/m^2
- Wind Pressure = 1.5kN/m^2 (assumed as per IS 875 code)
- Concrete grade = M20

4.METHODOLOGY

The methodology involved in this study involves designing Intz reservoir completely and then simulating the model of the reservoir in a virtual environment so as to study the effect of hydrostatic forces on the surface of the reservoir and also avoiding crack formation and propagation at the same time by optimizing the designed model characteristics. The entire methodology is broken down into two stages primarily – Design Phase and Simulation Work which is supported by analytical calculations so as to get the standard dimensions of the Intz reservoir to be modelled.

The reinforcements to be provided for the entire tank are provided in the table given below:

Table- 4.1: Reinforcements Table

Distance from the top	Main Hoop Steel (each face)	Vertical Distribution Steel (each face)
0 to 2 m	10 mm – 320 mm c/c	10 mm – 350 mm c/c
2 m to 4 m	16 mm – 400 mm c/c	10 mm –260 mm c/c
4 m to 6.5 m	20 mm – 320 mm c/c	10 mm – 200 mm c/c

Table -4.2: Moment versus number of Columns

Number of Columns, n		Negative Bending Moment at support	Positive Bending Moment at centre of spans	Maximum Twisting Moment or Torque	Angular distance for maximum torsion
4	90°	0.0342	0.0176	0.0053	19 degree 12 secs
5	60°	0.0148	0.0075	0.0015	12 degree 44 secs
8	45°	0.0083	0.0041	0.0006	9 degree 33 secs
10	36°	0.0054	0.0023	0.0003	7 degree 30 secs
12	30°	0.0037	0.0014	0.0017	7 degree 15 secs

From the above table, it is seen that

Maximum negative BM at support section for 8 columns = 0.0083 WR = 0.0083×7164×3 = 178.38 kN-m

Maximum positive BM at the mid span section = 0.0041 WR = 0.0041×7164×3 = 88.12 kN-m

Torsional Moment = 0.0006 WR = 0.0006×7164×3 = 12.9 kN-m.

4.1 Simulation Procedure

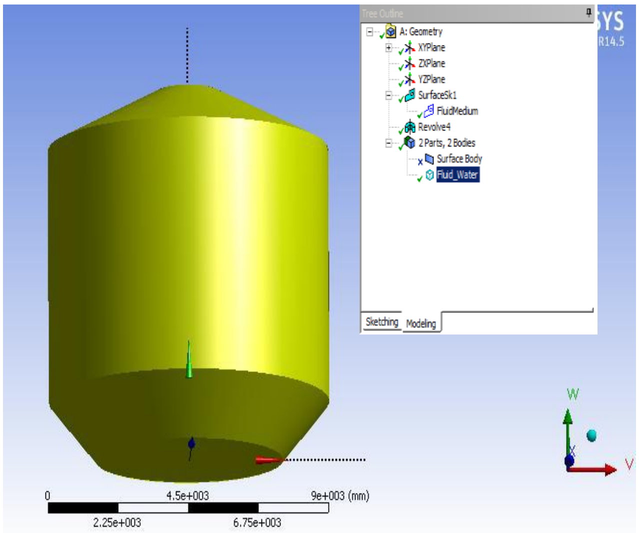

Fig -1: CAD model of the designed Intze tank

5.RESULT AND DISCUSSION

The results from the simulation showed positive ways in how to capture the hydrostatic loads acting on the walls of a water tank and how the modal analysis enhances better beam structure modelling so that the reinforcement could be optimised to a better one. The results that were seen was very well under considerable limits. These are segregated as such:

5.1 Modal Analysis of Reservoir

The data statistics of the reservoir model without the columns are as given below:

Geometry Statistics:

1. Total number of nodes = 144
2. Total number of elements = 22
3. Total number of plate members = 126

Material Used:

1.Concrete used for plates having Elastic Modulus E = 21.718 kN/mm^2, Poisson Ratio = 0.170 and Density = 2.4e03 kg/m^3
2. Steel Reinforcements used for supporting the concrete structure having Elastic Modulus E = 205 kN/mm^2, Poisson Ratio = 0.3 and Density = 7.83e03 kg/m^3

Loading Statistics:

1. Load Case 1 – Hydrostatic Loading = Minimum of 0 and Maximum of 78.48 kN/m^2
2. Load Case 2 – Self Weight of the tank = Mode Shape Calculations in all three directions i.e. x, y and z axis. Along with the self-weight criteria, we are also focussing on performing the mode shape calculations which will be performed based on mass model method.

The other types of loading that can be incorporated in this model are the live loads, wind loads, seismic loads and many other. However, in our study as we are more confined to designing an entire tank assembly so we will be indulging only to the basic and simple loading condition of hydrostatic and self-loads.

The modal frequency for the water tank structure is stated in the table below:

Table -5.1: Mode Shape Calculation

Mode Shape	Frequency (cycles/sec)	Period (sec)
1	9.842	0.10161
2	10.047	0.09953
3	24.9	0.04016
4	33.726	0.02965
5	34.026	0.02939
6	34.07	0.02935
7	34.325	0.02913
8	36.269	0.02757
9	36.729	0.02723
10	37.247	0.02685
11	38.506	0.02597
12	38.643	0.02588

From the figure below, it is easily seen that the frequency levels remain low up to the 2nd mode shape, however after that there is sudden increase in the frequency level and up to 4th mode shape the frequency levels increases in a linear trend. After the 4th mode shape, the frequency levels become almost constant and varies less significantly. Thus, it is decided that for the range of mode shapes from 2nd to 4th, proper damping is necessary or considerable strength must be provided to the reservoir by making the supporting columns and foundation very much resilient to any kind of fluctuation falling under that frequency range

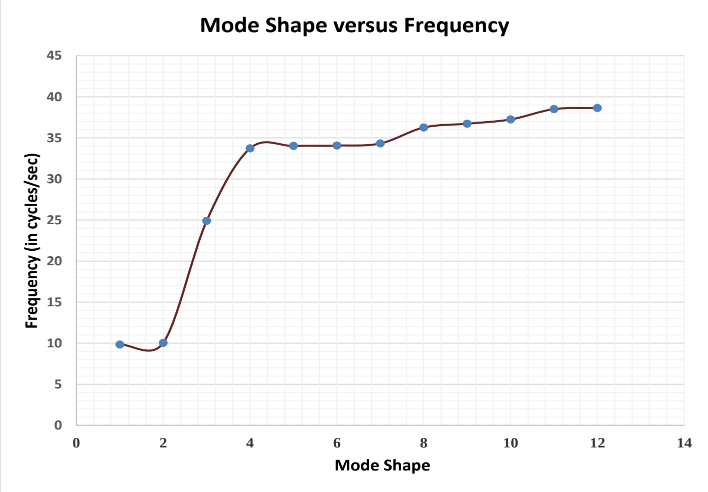

Fig -2: Variation of frequency along with mode shapes

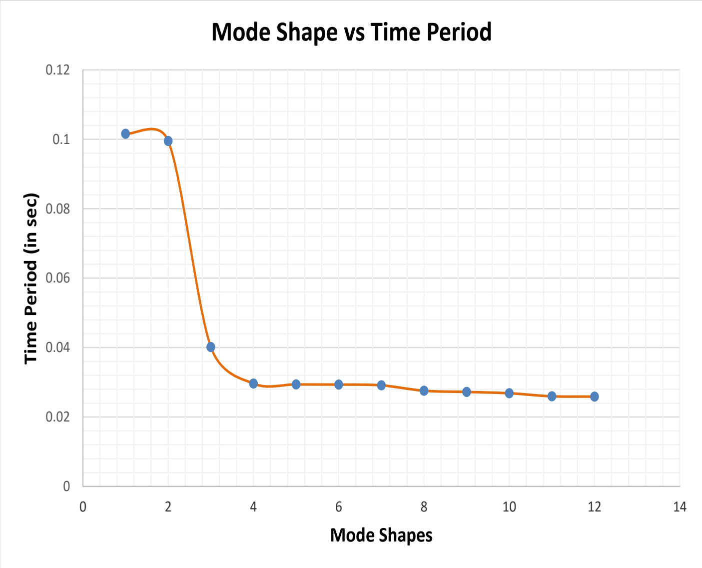

Fig-3: Variation of Time period along with mode shapes

5.2 Hydrostatic Results of Reservoir

In the figure shown below, it is seen that Maximum Von Mises Stress is found at the bottom conical dome part. The maximum value is found out to be equal to 1.61 N/mm^2. This value is well under the considerable limit for the concrete as well as that of steel.

For concrete, the average yield strength range is almost 2 to 10 MPa and for Steel its value is almost 200 MPa. So, with a value of 1.61 MPa, the water tank can be assumed to be considerably strong. The tank was designed for enduring a water capacity of 300000 litres however from the design optimization, it is clearly seen that the tank can endure almost 500000 litres of water inside it. Thus, a factor of safety of 1.7 (approx.) is considered for the water tank.

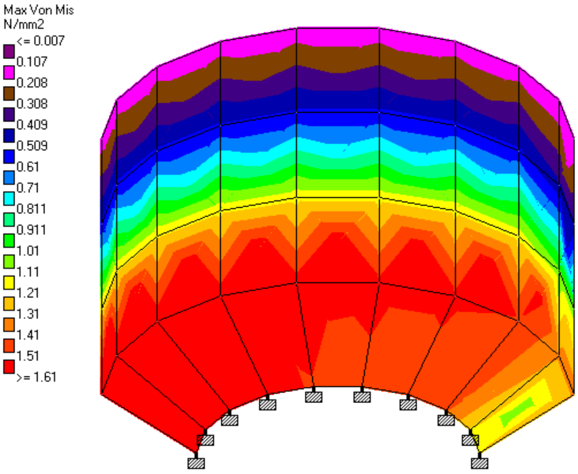

Fig-4: Maximum Von Mises Stress Distribution

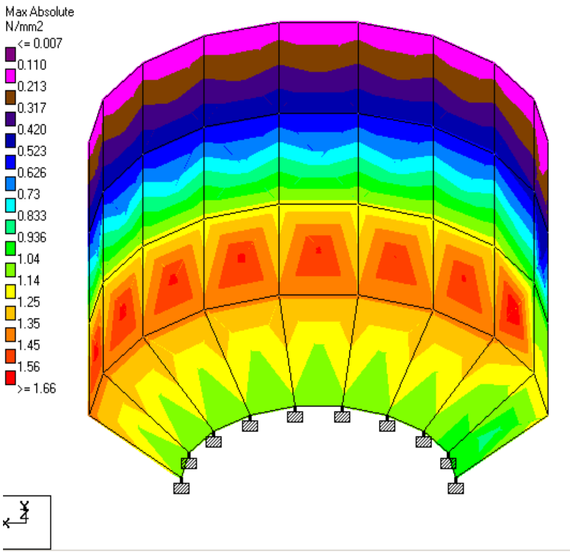

Fig-5: Maximum Absolute Stress Distribution

The above is the contour shape for absolute stress that is developed in the plate members of the tank. The maximum value obtained is 1.66 kN/mm^2 which is also very low with respect to different grades of concrete and also steel. Thus, we can consider that the tank can very efficiently withstand the hydrostatic loading on it

5.3 Sloshing Results of Reservoir

5.3.1 Volume Fraction of Water

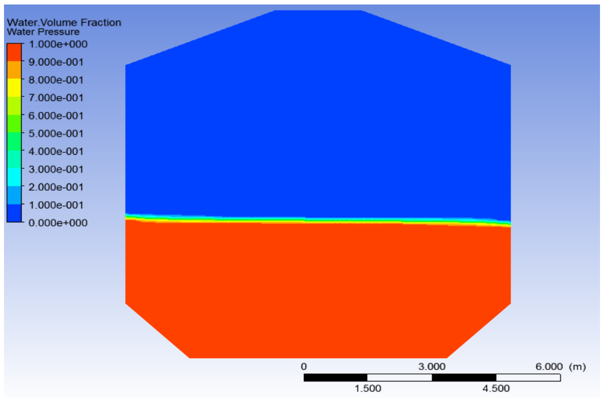

Fig-6: Volume Fraction of Water after 100 time steps

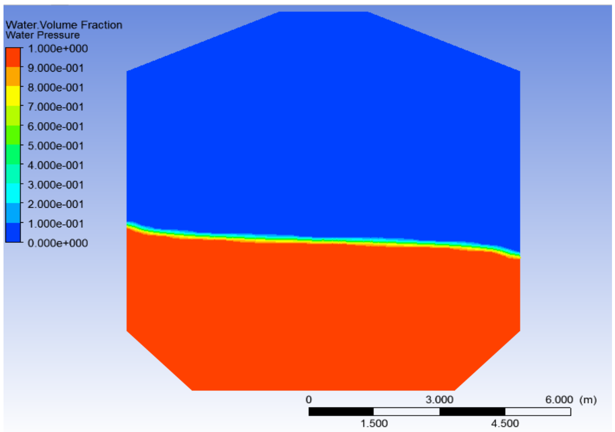

Fig-7: Volume Fraction of Water after 200 time steps

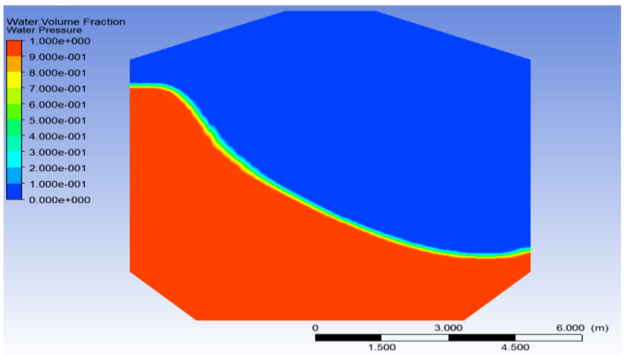

Fig-8: Volume Fraction of Water after 400 time steps

5.3.2 Peak Pressure Variation

The graph belowshows the pressures at the peak of the water levels that are seen at different time steps. All the values are negative which means that they are subjected to high velocities as a result of the momentum source term excitation however at 400th time step the value is found out to be positive which means the downfall of the source term in exciting the water content and that the water sloshing has reached its peak height (almost up to the conical part of the upper dome of the tank). Thus through Sloshing effect study we can visualize the water distribution inside the tank if it is being carried in a moving truck or when it is subjected to seismic excitation in the form of source term as we have used in our study.

Thus, the velocity at the water peaks with respect to the time steps can be visualized in the graphical data shown below. It is clearly seen that after 400th time step there is a steep rise in the velocity value which is caused by the down flow of the water that rose on the walls of the tank as a result of the momentum source term

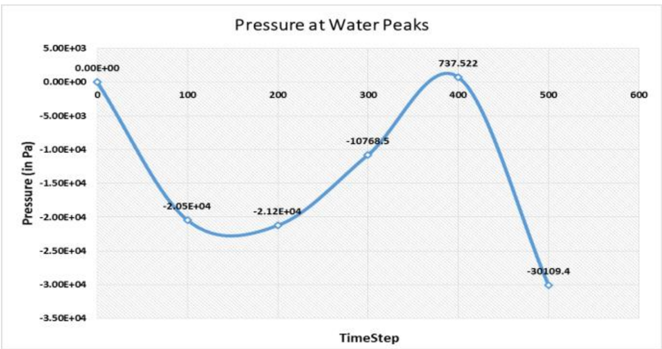

Fig-9: Variation of Pressures at Water Peaks

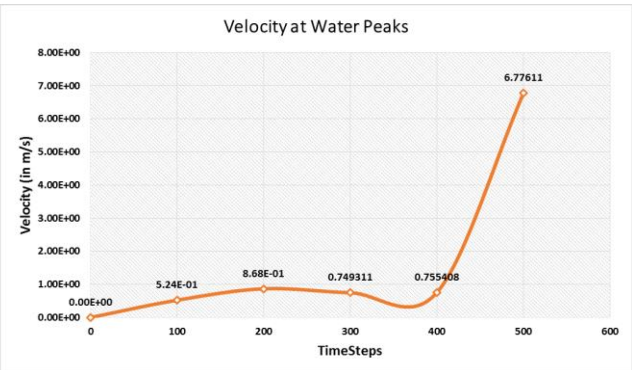

Fig-10: Variation of Velocities at Water Peaks

6.CONCLUSION

The storage of water and other liquids have become very much important for different day to day purposes, Water plays an important role in our life. We consume water starting from the moment we wake up from our bed till we sleep. For storing less quantity of water rectangular shaped tanks are used and for storing large quantity of water, the shape to be assumed is circular. In this study, we have considered a design strategy for Intze type water tank which is assumed to contain 300000 litres of water so that it can fulfil the water requirement of a society with at least 1500 people living.

The designed specifications that are found out to make a CAD model of the reservoir part of the tank and subjected to hydrostatic loading and self-weights. The results that were observed showed very positive aspects as all the forces that were calculated for the designed tank was all under considerable limit.

The sloshing effect of water inside the reservoir is a strange phenomenon but has been captured in this thesis work using Ansys Fluent and this study can become a strong base to avoid the spillage of water from any type of reservoir specially for reservoir trucks carrying liquids from one place to another.

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