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Overhead Intze Water Tank with Sloshing Effects: A Seismic Analysis

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ABSTRACT: *For earthquake analysis of R.C.C. water tank, the code IS: 1893-1984 was published in 1984. In 2002, though the revised code is published, but in this code the criteria for earthquake analysis of water tank has not been included. This project work is an attempt has been made to analyze and design large R.C.C. water tank subjected to seismic as well as wind forces. Therefore, programs of the seismic and wind analysis and design of water tank with single container and twin containers are developed.*

The simulation of tank is done using STAAD Pro. Based on the entire design, analysis, structural limitations are verified using a hydrostatic loading for the full capacity of the tank. The designed tank is also being studied to understand the sloshing effect of water stored under it under seismic loads so as to understand the chance of water spillage from the tank and also to observe the complete integrity of the tank under such loads. Thus, overall this project gives in brief, the theory behind the design of overhead liquid retaining structure, the structural limits of the designed tank and ensuring the safety of the structure under seismic forces.

Key Words: earthquake analysis, RCC water tank, loads, sloshing, structures.

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I. INTRODUCTION

A roundabout chamber when exposed to an outspread power will foster a loop force in the shell. On the off chance that the power is applied from inside, there is loop strain and whenever applied from outside, there is circle pushed in the shell. The twisting minutes in the shell are created either because of limit impacts or because of unsymmetrical burdens. A legitimate choice of the limit associations can limit the bowing minutes. Barrel shaped water tanks are usually utilized in above water tanks[1].

For huge limit of the tank by and large intze kind of tank is favored contrasted with some other shape. Intze tank can be named as a superior adaptation of round and hollow tanks. In the event of barrel shaped tank when the arch with little ascent is utilized just compressive anxieties are created which helps in making the water holding structure water tight[2]. Be that as it may, in the event of tube shaped tank when the heap on the base vault is weighty and its breadth is huge, the ring shaft turns out to be exceptionally weighty and needs a lot of support. In such circumstances the more practical choice could be to decrease its breadth by presenting one extra part as a conelike vault. Such tank with extra part in type of funnel shaped shell is known as intze tank[3].

II. ACTION PLAN & PROBLEM FORMULATION

The literature review shows that significant exploration has been performed to figure out, model and further develop the plan measures for seismic execution of tanks. Be that as it may, a large portion of the work was centered around seismic execution of the Intze type water tank[4]. Raised water tanks are especially powerless against tremor powers because of the huge mass upheld on a slim supporting construction, called organizing. The breakdown of raised water tanks during past tremor have been principally ascribed to disappointment of the organizing[5]. The round, built up concrete R.C.C shaft-type support for raised tanks needs overt repetitiveness, damping and extra strength regularly present in building outlining frameworks and, hence, ought to be intended for bigger seismic obstruction.

Here certain information has been gathered from different counseling engineers. By alluding every one of the literary works, Intze tank is planned. Additionally arranging framework is taken as shaft type and it is intended for quake obstruction. In the event of the Intze type water tank assuming holder would help out, water couldn't be provided around. Thus, two-compartment framework has been utilized. On the off chance that one compartment would help out, the other holder is utilized to supply water around. This sort of framework is planned here[6]. The limits of these compartments are kept same as the Intze type holder. There are two holders upheld on arranging. So model of this kind of tank is two mass framework. The limit of one holder is half than Intze tank.

III. GENERAL DESIGN REQUIREMENTS (I.S.I.) [IS 456:2000]

Concrete's Permissible Stresses

For cracking resistance: Direct, bending, and shear stresses must be taken into account when designing the structure's concrete for crack resistance. The values for these three kinds of permissible limits of stresses for different grades of concrete are specifically mentioned in the table below[7]. For structures having a thickness of 225 milimeter and in one side contact with liquid, these permissible limits are even applicable for the structure part that is remotely away from the liquid. Compressive Strength: The strength of the concrete, typically specified as a compressive strength value (e.g., 20 MPa or 3000 psi), affects the permissible stress. Higher-strength concrete can generally withstand higher stresses[8]. Reinforcement: The presence of reinforcement, such as steel bars or mesh embedded in the concrete, can significantly increase the permissible stresses. Reinforcement helps to resist tensile forces and improves the overall strength and ductility of the structure[9]. Loading Conditions: Different types of loads, such as dead loads (permanent loads like the weight of the structure itself) and live loads (variable loads like occupancy or furniture), have specific load factors applied to determine the permissible stress levels[10]. Durability: Environmental factors like exposure to moisture, chemicals, and temperature variations can affect the permissible stress values[11]. For aggressive environments, lower permissible stress values may be required to ensure long-term durability.

1. PLANNING A DOME MADE OF RC

Least of 80mm is to be given in order to oblige the two layers of steel with sufficient front of steel over them.

Least measure of steel that will be given should be around 0.15 percent of the sectional region toward every path along the meridians as well as along the scopes. It is exceptionally fundamental to give the support in the thickness of the shell and to be more exact close to the edges of the shell as the need might arise to guarantee the shell from the bowing anxieties that get created close to the edges. Further, fortifications are additionally to be given at the top as well as the lower part of the arch[12]. Size of the ring pillar is acquired from circle pressure created in the ring because of level part of the meridian pressure. The substantial region is not entirely set in stone and ought not be more than 1.1 to 1.7 N/mm2 for direct strain and 1.5 to 2.4 N/mm2 for pressure because of bowing in the fluid opposing construction relying upon the level of substantial that is utilized for the reason[13].

Support against the band pressure can be given permissible pressure of 115 or 150 N/mm2 in the event of fluid holding structures and 140 or 190 N/mm2 for outstanding circumstances. From reasonable applications, the support is to be given so that the centroid of the support matches with the centroid of the ring pillar and to keep away from blockage of the support to be given close to the crown region, two separate lattice structures are made. For lantern based opening vaults, ring bar are to be given at this opening to give strength against the assembled load at the highest point of the arch[14].

The table below gives us the permissible limits for forming the mesh of RC structure in order to retain liquid and also for different grades of concrete:

Table 1: Permissible Limits for bars used to make reinforcements in Domes made of RC

Grades of Concrete	Direct Tension Limit (in N/mm^2)	Tension due to Bending (in N/mm^2)
M15	1.1	1.5
M20	1.2	1.7
M25	1.3	1.8
M30	1.5	2.0
M35	1.6	2.2
M40	1.7	2.4

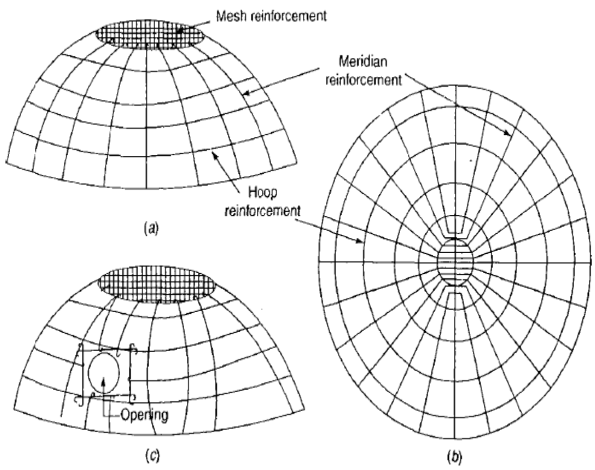

Fig 1: Mesh orientation for dome made of RC

At the point when cement and steel are to be utilized to guarantee the supply be protected from direct pressure and furthermore strain because of bowing, as far as possible is drawn to be the tractable line of the pressure in the steel which is thought to be a duplication result of secluded proportion and reasonable pressure of cement. To oblige shrinkage and development stresses in the vault, a shrinkage kind of 300×10-06 might be expected or probably the shrinkage or extension stresses are not considered for the arch under ostensible circumstances. Assuming the vault is to be intended to oblige shrinkage focuses on, the restricting states of stresses can be expanded by 33%[15].

Least support of every one of two bearings at right points will have a thickness of 100 mm concrete for 0.3 % of region to 450 mm thick cement for 0.2 % of region. In floor sections, least support to be given is 0.15 %.

The base support as determined above might be diminished by

20 %, on the off chance that high strength twisted bars are utilized. Least cover to support on the essence of fluid is 25 mm or distance across of the bar, whichever is bigger and ought not to be diminished by 12 mm for tanks for ocean water or fluid of destructive person[16].

2. MODAL ANALYSIS OF RESERVOIR

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

Geometry Statistics:

Total number of nodes = 144

Total number of elements = 22

Total number of plate members = 126

Material Used:

Concrete used for plates having Elastic Modulus E = 21.718 kN/mm^2, Poisson Ratio = 0.170 and Density = 2.4e03 kg/m^3

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:

Load Case 1 – Hydrostatic Loading = Minimum of 0 and Maximum of 78.48 kN/m^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.

3. BOUNDARY AND LOADING CONDITIONS

In this section, the boundary and loading conditions are shown in details as to how the entire model is being setup to account for the hydrostatic loading and which members are to be fixed in order to create the desired environment.

The first step before applying the hydrostatic load is to fix the model node wise at the base. In STAAD Pro we can multiply the boundary and loading conditions by applying them to a singular element and after that performing a circular repeat on all the elements including the boundary and load conditions so as to complete the entire assembly.

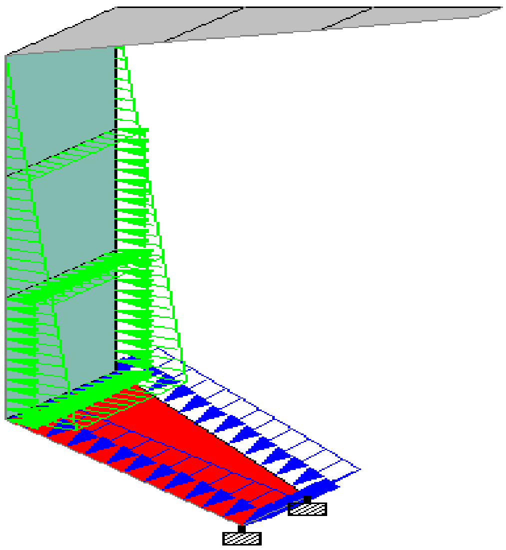

Fig 2: Hydrostatic Loading of The Plate Elements

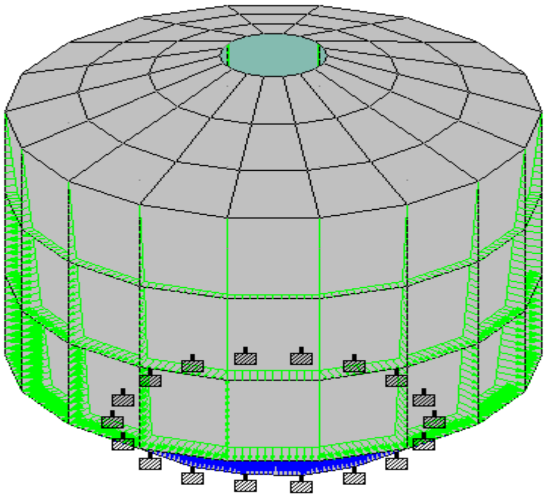

Fig 3: Loads and Supports on the Entire Circular Region of Tank

The second step is to circular rotate the entire visible plate parts along with the beams and all the Boundary and Loading condition along with them so as to form the entire circular wall and lower conical dome region for the tank

The third step is to incorporate the self-weight condition for the tank so as to get an idea of the mode shapes for the tank assembly. To do so perform similar steps and insert a load case for self-weights under load cases by selected new load case situation. Under self-weights, load self-weights in three directions namely x, y and z with a factor of 1. Along with this setups, a different setup is made so as to calculate the mode shapes for the tank assembly which is performed by incorporating a Eigen value extraction methodology under load items.

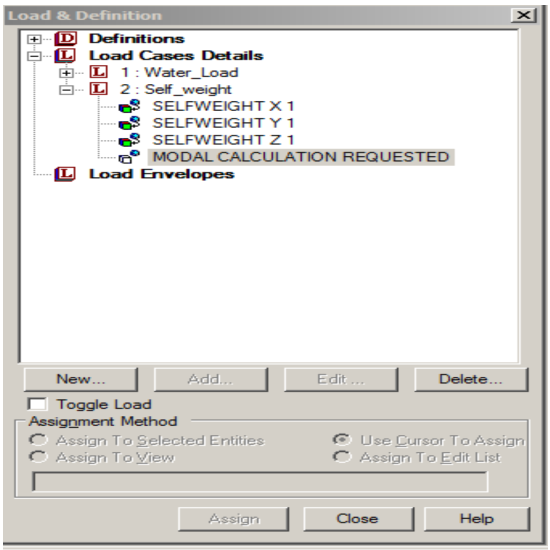

Fig 4: Applying Self Weight and Modal Calculation to the Model

When the entire loading is made for the tank, the analysis is run in STAAD Pro by selecting a no analysis print setting before starting the run. Thus, the above mentioned steps help us to get and overview of all the design considerations that are made while designing the water tank.

Similar steps are performed by adding the 8 columns for supporting this reservoir at a height of 12 m from the ground level. In this model also, emphasis is made on how the complete assembly of the water tank reacts against the hydrostatic forces acting on the wall and we perform modal analysis so as to get the modal frequencies of the tank along with the column on which they are being supported. The complete assembly is shown below where in the tank is supported by 8 columns.

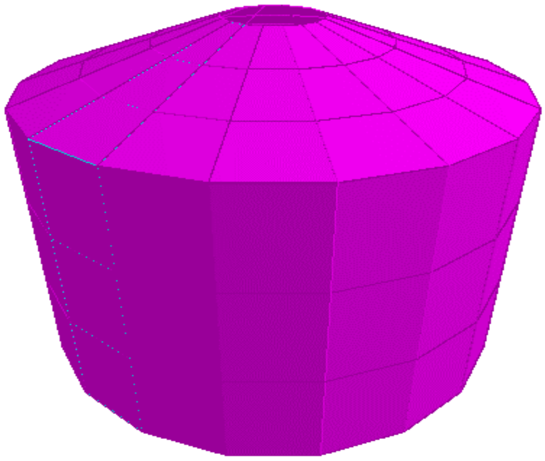

Fig 5: 3D Rendered Image of the Tank Region

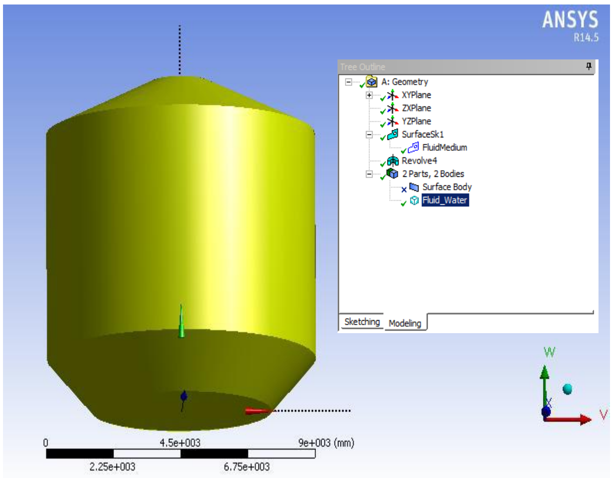

Fig 6: CAD Model of the Designed Intze Tank

CAD Model Generation

The CAD model generation in carried out in Design Modeler where the fluid medium is made first and then revolved around a common axis with 360 degrees of revolution around the common axis, in our case it's the z axis. The height of the upper dome is 1.5 m with bigger diameter being 8 m and smaller diameter being 1 m whereas the height of the lower dome is also 1.0 m with the bigger diameter being also 8 m but the smaller diameter is 5 m. The cylindrical middle part of the designed water tank is of 6.0 m in height and have a common circular diameter of 8 m.

Mesh Generation

The meshing process was done in Ansys Meshing tool and the following settings were used as shown below. The total count for nodes was found to be 345344 and that of elements is found to be 336550. The maximum skewness was found to be 0.74 with a minimum orthogonality of 0.36. The maximum Aspect ratio is found to be 12.567. The meshed generated is a three dimensional hex mesh.

The Named Selection for the entire tank included naming the entire fluid body as fluid and the surfaces of this fluid medium was named as tank top wall, tank wall and tank bottom wall in case if any energy loads are to be given to these specific surfaces.

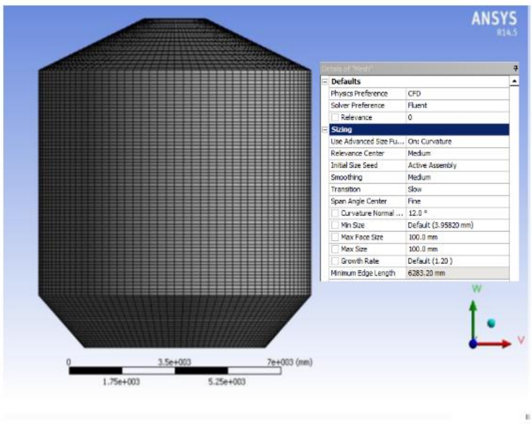

Fig 7: Meshed Water Tank Along With The Mesh Settings

IV. RESULTS

Table- 2: Comparison between Final Values of Conventional Method &Staad-Pro for Different Seismic Zone

Zone	Parameter	Methods	Base Shear	Base Moment
II	Design Parameter Given by	Software Method	303.18	4878
		Conventional Method	355.58	5566.12
III	Design Parameter Given by	Software Method	480	7223.58
		Conventional Method	568.61	8904
IV	Design Parameter Given by	Software Method	742.33	853.39
		Conventional Method	10501	13361
V	Design Parameter Given by	Software Method	1098.8	1280.32
		Conventional Method	17764	20046

Earthquake excitation causes fluid sloshing inside the container creating additional forces on its walls and roof. Free board to be provided in a tank should be based on maximum value of sloshing wave height. This is particularly important for tanks containing toxic liquids, where loss of liquid needs to be prevented. The roof structure should be designed to resist the uplift pressure caused by liquid sloshing if there is insufficient free board. Sloshing height for a circular tank is obtained as per IS 1983. The above graph shows the variation of sloshing height in different seismic zones. As the more sloshing wave height having more susceptible to damage due to earthquake[17].

Hydrodynamic Pressure Induced on Container Wall

The majority of elevated water tanks never have enough water in them. Consequently, a two-mass idealization of the water tank is preferable to a one-mass idealization. Numerous examinations on seismic investigation of fluid or water stockpiling tanks is finished and this angle came to very front that thought ought to be given to sloshing (convective) impact of fluid and adaptability of holder wall while assessing the seismic power of water tank[18].

Table- 3: Impulsive hydrodynamic on wall for different Zones (Kg/m^2)

Height	Zone			
	II	III	IV	V
Y=0	0	0	0	0
Y=0.2h	104.56	162.12	252.18	378.27
Y=0.4h	185.89	298.8	448.32	672.49
Y=0.6h	243.99	392.28	588.43	882.64
Y=0.8h	278.84	448.32	678.49	1008.73
Y=h	290.46	467.01	700.549	1050.77

Table- 4: Impulsive hydrodynamic in vertical direction on base slab for different Zones(Kg/m^2)

Height	Zone			
	II	III	IV	V
x=0	0	0	0	0
x=0.2R	63.53	101.65	152.49	228.74
x=0.4R	131.61	210.78	315.88	473.83
x=0.6R	209.09	334.56	501.83	752.76
x=0.8R	301.50	482.42	723.63	1085.45
=R	415.45	664.75	997.11	1495.58

Table-5: Convective hydrodynamic pressure on wall

Height	Zone			
	II	III	IV	V
Y = 0	500.34	815.20	1206.63	1824.66
Y = 0.2h	510.38	831.56	1230.84	1861.27
Y = 0.4h	540.90	881.30	1304.45	1972.5
Y = 0.6h	593.14	966.40	1430.458	2163.07
Y = 0.8h	669.17	1090	1613.1	2440.36
Y = h	772.07	1257.93	1861.93	2815.59

Table- 6: Convective hydrodynamic pressure on Base

Height	Zone			
	II	III	IV	V
x=0	0	0	0	0
x=0.2R	50.69	80.52	122.27	184.89
x=0.4R	85.38	135.67	205.93	311.41
x=0.6R	89.05	133.49	202.71	752.76
x=0.8R	32.01	50.85	77.22	1085.45
x=R	-90.72	-144.06	-218.80	1495.58

Sloshing Effect Due to Seismic Force

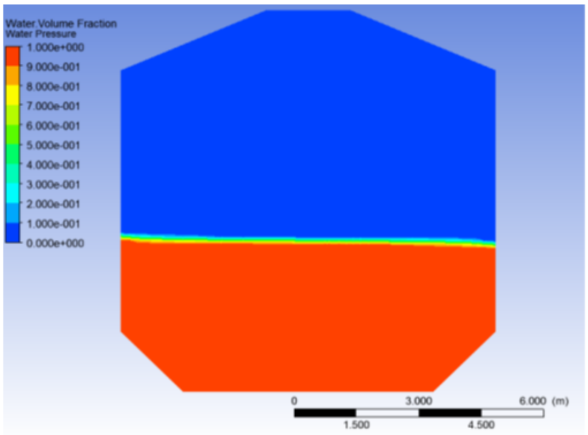

Fig 8: Volume Fraction of Water after 100 time steps

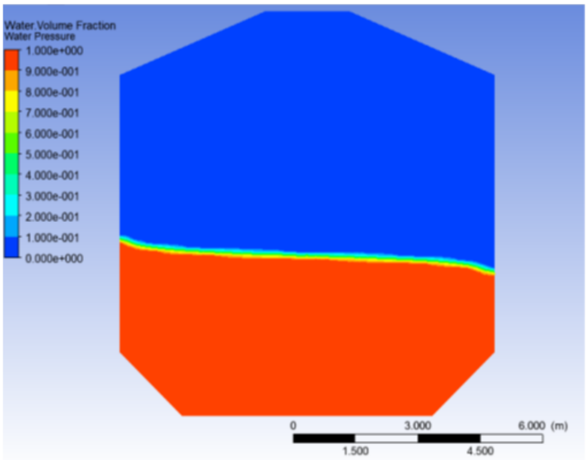

Fig 9: Volume Fraction of Water after 200 time steps

V. CONCLUSIONS

We reasoned that, based on the conventional method of planning and investigation:

The meridinal stresses and hoop stresses obtained are within considered limit Base shear and Moments are successively increases from seismic zone III to V Sloshing wave height also increases from seismic zone III to V successively The value of Base shear and moment for full tank is more then the empty condition. Hence design will be governed by tank full condition

Discussion Basis of Base Shear

For zone- II Total lateral base shear is about 6% of total seismic weight 5231.01 KN

For zone- III Total lateral base shear is 10% of total seismic weight 5231.01 KN

For zone- IV Total lateral base shear is 15% of total seismic weight 5231.01 KN

For zone -V Total lateral base shear is 28% of total seismic weight 5231.01 KN

As the Designed Base shear is less than the total seismic weight of the tank. Thus the tank will safe against lateral forces for each Zone.

Discussion Basis of Max Hydrodynamic Pressure

For zone- II Max Hydrodynamic Pressure is about 4.3% of total seismic weight 58.86 KN/m^2

For zone- III Max Hydrodynamic Pressure is 6.89% of total seismic weight 58.86 KN/m^2

For zone- IV Max Hydrodynamic Pressure is 10.56% of total seismic weight 58.86 KN/m^2

For zone -V Max Hydrodynamic Pressure is 15.85% of total seismic weight 58.86 KN/m^2

From the above study the following conclusion can be made:

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.

The tank's critical load is determined by the maximum values of the forces and moments obtained from STAAD Pro. The tank is stable for maximum forces and moments, as shown by the STAAD Pro check for critical members.

The Base shear and the Moments obtain from the STAAD Pro is lesser as compared to values obtain from IS 1893(part 1):2002. Thus STAAD Pro makes structure economical and stable.

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 Base shear and Base moment are increases from Zone III to Zone V

Base shear is increases 6 to 8% from Zone III to Zone IV.

Base shear increases 7 to 10% from Zone IV to Zone V

Base shear and Base moment values obtained in the tank full condition are greater than the values obtained in the tank empty condition, so the design will be governed by tank full condition.

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