Kalpa Publications in Civil Engineering
Volume 1, 2017, Pages 1–6
ICRISET2017. International Conference on Research and Innovations in Science, Engineering &Technology. Selected papers in Civil Engineering

Design and Seismic Analysis of Ground Supported Water Tank

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Abstract

The ground supported tanks are firmly attached with ground and tank walls are subjected to hydrostatic as well as hydrodynamic pressure due to seismic forces. Base of the tank is subjected to weight of water and pressure of soil. Top of the tanks may be covered and is designed by using IS 3370:2009 Part (I, II) [4] and IS 1893:2007 (part-2) draft code[3] is used for the seismic analysis of the tank. This paper gives idea behind the design of liquid retaining structure (rectangular ground supported water tank) using working stress method. This paper includes the seismic analysis and design of the tank. The values are obtained with the help of spreadsheet program. Analysis of ground supported water tank has been carried out and relationship between tank capacity with moment capacity and reinforcement area, base shear with impulsive height and overturning moment with convective height is derived.

1. Introduction

Water tank is designed to store water. As water is basic need for all living organisms it is necessary to keep water tank safe and functional during earthquake. Seismic design and analysis of water tank is very important aspect for structure engineers. Elements of ground water tank include base slab and tank walls. Tank should be resting on ground firmly, here base slab will not be a critical element and hence only nominal reinforcement should be required. When a tank containing liquid is subjected to earthquake ground motion tank walls and liquid is subjected to horizontal acceleration. Due to this tank walls will subjected to hydrodynamic pressure. To understand hydrodynamic pressure spring mass model from IS: 1893:2007 (part-2) draft code[3] can be considered. The liquid in the lower portion of tank behaves like a mass rigidly attached with tank wall. This liquid mass is termed as impulsive mass which moves along with the wall. Impulsive hydrodynamic pressure acts on tank walls due to Impulsive liquid mass. Liquid mass in upper region of tank experience sloshing motion. This mass is termed as convective liquid. Thus total liquid mass gets divided into two parts i.e. impulsive mass and convective mass. This study derives the relationship between tank capacity with moment capacity and reinforcement area, base shear with impulsive height, overturning moment with convective height using computer subroutines and design of ground supported water tank by working stress method.

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Spring Mass Model

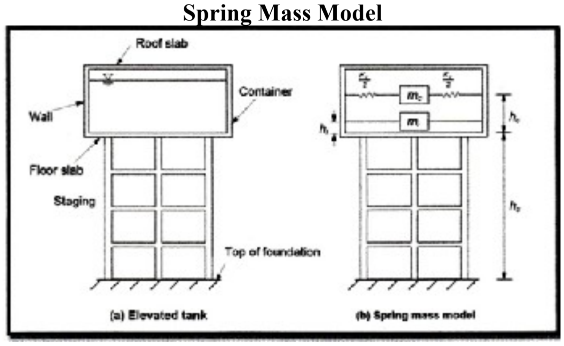

Figure 1: Spring Mass Model For Water Tank As Per Is:1893-2007[3] Draft Code

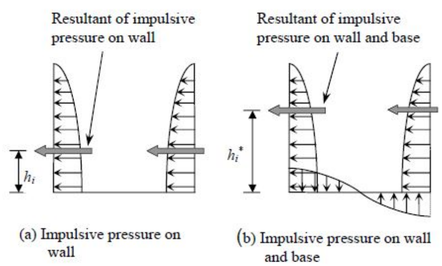

Figure 2: Hydrodynamic Pressure On Water Tank

h_i = the height at which impulsive hydrodynamic pressure acts on tank walls from bottom of the tank.
h_i* = the height at which the of impulsive pressure on wall and base is located from the bottom of tank wall.
The mass of liquid in upper region of the container of tank will undergoes sloshing motion. This mass termed as convective mass.

2. Design of Ground Supported Tank

The tanks may be circular or rectangular in shape. For rectangular shape tank it is preferable that longer side should not be greater than twice the smaller side. Moments are caused in two directions of the wall i.e. both in horizontal as well as in vertical direction. If the length of the wall is more than its height, the maximum moments will be in the vertical direction, i.e., the wall bends as vertical cantilever. When the height is larger than to its length, the moments will be in the horizontal direction and wall bends as a thin slab supported on edges. The walls are designed both for direct tension and bending moment.
For design of tank walls as continuous frame subjected to Hydrostatic pressure varying from zero at top to maximum at H/4 or 1m from base slab, whichever is more. The bottom portion of H/4 or 1m is designed as cantilever.
For bending, walls are subjected to direct tension caused by hydrostatic pressure on the walls.
It is necessary to design it for both direct tension and bending moment. The bending moment in the walls are calculated by moment distribution method.

Design steps for ground supported water tank

1. Determination of dimension of the tank
2. Design of long walls
3. Design of short walls
4. Base slab is checked against uplift.
5. Design of base slab

Data: capacity-80000 lit, depth of tank container- 3.35 m, free board- 0.15 m, diameter of bars- 8, 10, 12, 16 mm, compressive strength of concrete- 25 MPa

Design	Description	Program value
Design of Section	Grade of steel	Fe-415
	$d_{provided}$	225 mm
	$D_{provided}$	260 mm
	Direct tension in long wall	50 kN
	Direct tension in short wall	75 kN
	A_{st}	3254 mm^2
	Reinforcement	20mm # @ 90mm c/c [3489 mm^2]
	Steel at center of span	2453 mm^2
Cantilever portion	A_{st}	300.36 mm^2
	Moment	5.82 kNm
	Diameter of bar	8 mm
	Reinforcement	8mm # @160mm c/c
Distribution Steel	A_{st}	780 mm^2
	Steel on each face	390 mm^2
	Reinforcement	8mm # @120 mm c/c
Roof slab	d	214 mm
	D	240 mm
	A_{st}	317 mm^2
	Reinforcement	8mm # @ 150 mm c/c
Base Slab	A_{st}	2415 mm^2
	D	240 mm
	Reinforcement	8mm # @ 170 c/c

Table 1 : Design Results Of Ground Supported Water Tank

3. Seismic Analysis of Ground Supported Water Tank

	Description	Program value
Time period	Impulsive mode (T_i)	0.16 sec
	convective mode (T_c)	2.85 sec
Base shear	At bottom of wall in implusive mode (V_i)	496 kN
	At the bottom of wall in convective mode (V_c)	115 kN
	Total base shear at the bottom of wall (V)	509 kN
	Bending moment in impulsive mode (M_i)	656 kNm

Moment at bottom of tank wall	Bending moment in convective mode (M_c)	200 kNm
	Total bendingmoment	686 kNm
Over turning moment	At the bottom of the base slab in impulsive mode (M_i*)	2526.65 kNm
	At the bottom of the base slab in convective mode (M_c*)	792.63 kNm
	Total overturning moment at the bottom of base (M*)	2648 kNm
Hydrodynamic pressure	Impulsive pressure at the base of wall (Y=0) (P_{iw})	3.9 kN/m^2
	Impulsive pressure on top of base slab (Y=0) (P_{ib})	3.37 kN/m^2
	Convective pressure at the base of wall (Y=0) (P_{cw})	0.14 kN/m^2
	Convective pressure at Y=h (P_{cw})	0.41 kN/m^2
	Convective pressure on top of base slab (Y=0) (P_{cb})	0.137 kN/m^2
Pressure due to wall intensity	P_{ww}	0.94 kN/m^2
Pressure due to vertical excitation	P_v	3.28 kN/m^2
Max. hydrodynamic pressure	P	5.84 kN/m^2
Equivalent linear pressure distribution	q_i	52.97 kN/m
	a_i	27.76 kN/m^2
	b_i	14.32 kN/m^2
	q_c	14.32 kN/m
	a_c	3.67 kN/m^2
	b_c	4.90 kN/m^2
Sloshing wave height	d_{max}	0.1008

Table 2: Seismic Analysis Results For Ground Supported Tank

4. Results and Discussion

The result values are computed to determine the graph of reinforced area v/s capacity of tank and the moment v/s capacity of tank. With increase in the capacity of tank the reinforced area and moment increases. The graph of base shear v/s impulsive height and overturning moment v/s convective height is also determined which shows that as the height increases the time period also changes and as a consequence base shear and overturning moment also changes.

Capacity	**B.M at support (kNm)**	**A_{st} at centre of span (mm^2)**
25000	12.98	602
30000	18.21	845
35000	23.59	1055
40000	28.82	1337
45000	34.04	1580

Table 3: Comparison Table For Bending Moment V/S A_{st}

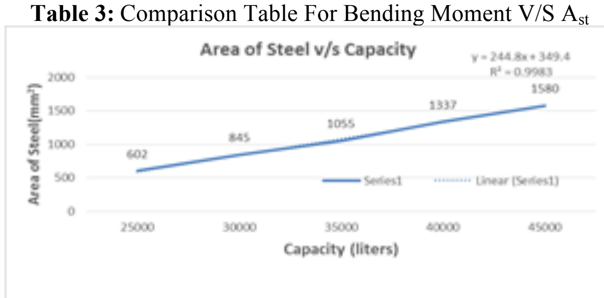

Figure 3: Comparison Graph For Capacity Of Tank V/S A_{st}

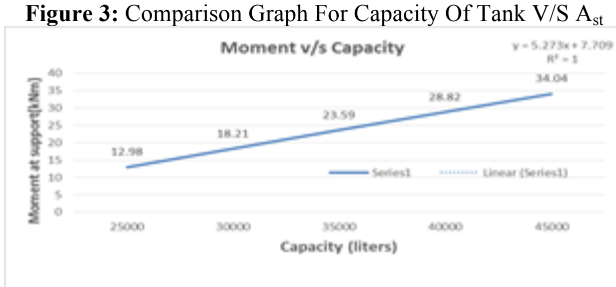

Figure 4: Comparison Graph For Capacity Of Tank V/S Bending Moment

Capacity (liters)	**Impulsive height (h_i) (m)**	**Base shear in impulsive mode (V_i) (kN)**	**Convective height (h_c) (m)**	**Moment (M_c^*) (kNm)**
25000	0.63	455	3.34	404.33
30000	0.75	460	4	479.93
35000	0.88	466	4.68	557.82
40000	1	471	5.34	633.41
45000	1.13	477	6	709.01

Table 4: Comparison Table For Seismic Analysis Results

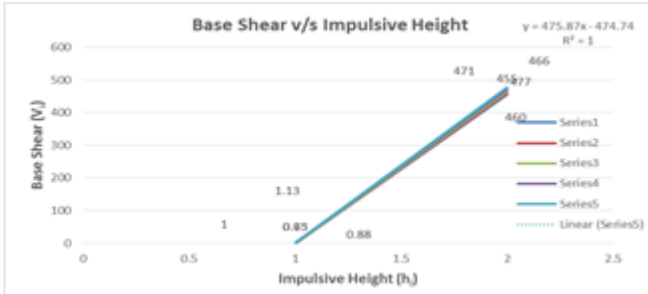

Figure 5: Comparison Graph For Base Shear V/S Impulsive Height Of Tank

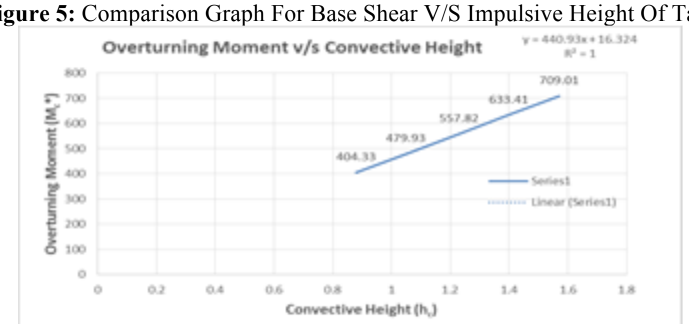

Figure 6: Comparison Graph For Overturning Moment V/S Convective Height

5. Conclusion

Design of underground water tank involves tedious mathematical formulae and calculation. It is also time consuming, hence the relationship is derived which can be helpful in deriving the base moment and wall reinforcement as well as the base shear and overturning moment. The relationship gives values of reinforcement area and moment capacity which increases with increase in the tank capacity. On the other hand as the convective and impulsive height increases, overturning moment and base shear increase respectively. These relationships are useful for easy analysis and design for tank. Also understands the seismic behavior of ground supported tank.

6. References

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[6] Dr. H.J. Shah(2012),"Reinforced Concrete Volume 2", 9th Edition