

Study of Seismic Analysis of Water Tank at Ground Level

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ABSTRACT: Liquid tank and especially the tanks are structures of high importance which are considered as the main lifeline elements that should be capable of keeping the expected performance that is operation during and after earthquakes. Thus, researchers, in recent years, have focused on studying the seismic behaviour analysis and design of water tank. The paper consists of study of guidelines for seismic analysis of water tank at ground level. In this paper, Hydrodynamic forces exerted by the liquid on the wall of water tank and base slab will be considered in the analysis. These hydrodynamic forces will be evaluated with the help of spring mass model of water tanks. And also comparison of various parameters like seismic coefficient and hydrodynamic pressure of circular tank for various capacity and different heights of water level and water tank will be done by calculating seismic weight of tank and horizontal & vertical acceleration coefficient.

KEYWORDS: seismic behaviour, Hydrodynamic forces, spring mass model, seismic coefficient, etc.

I. INTRODUCTION

Water supply is a life line facility that must remain functional in natural disaster, ground level water tank are used for clear water reservoirs, settling tanks, aeration tanks etc. these tanks directly rest on the ground. The walls of these tanks are subjected to water pressure from inside and the base is subjected to weight of water from inside and soil reaction from underneath the base. The tank may be open at top or roofed. Ground water tank is made of lined carbon steel, it may receive water from water well or from surface water allowing a large volume of water to be placed in inventory and used during peak demand cycles. However, in many cases, water is stored in reservoirs located at ground level due to lower initial cost of construction, a lower maintenance cost, the ease with which water quality can be tested, greater safety, and a greater aesthetic value. In primary tank is a lack of water pressure. The water in ground tanks is not put under a significant amount of pressure unless the tank is located at a high elevation, such as on top of a hill. Any pressure in a ground tank must be maintained through directly pumping can be costly and also means that water pressure in the distribution system will to be shut down. A water tank or reservoir on the ground will have its contents excited into sloshing by an earthquake and the amplitude of the sloshing is indicative of intensity of ground motion. Sloshing means any motion of the free liquid surface inside its container. It is caused by any disturbance to partially filled liquid containers. In particular, liquid sloshing on the free surface may have significant influence on the response of the container. The basic problem of liquid sloshing involves the estimation of hydrodynamic pressure distribution, forces moments and natural frequencies of the free-liquid surface. These parameters have a direct effect on the dynamic stability rigid containers has two distinct components. One component is directly proportional to the acceleration of the tank. This component is caused by the part of fluid moving with the same tank velocity. The second is known as "convective" pressure and represents the free-surface-liquid motion. Mechanical models such as mass-spring-dashpot or pendulum systems are usually used to model the sloshing part. Sloshing waves have been studied numerically, theoretically and experimentally in the past several decades and many significant phenomena have been considered in those studied, especially the linear and nonlinear effects of sloshing for both in viscous and viscous liquids.

II. RELATED WORK

Much of a literature has presented in the form of technical papers till date on the dynamic analysis of Elevated Water Tanks. Different issues and the points are covered in that analysis i.e. dynamic response to ground motion, sloshing effect on tank, dynamic response of framed staging etc. Some of those are analyzed below.

1. George W. Housner (1963) had studied about the relation between the motion of water in the tank with respect to tank and motion of whole structure with respect to ground. He has considered three basic conditions for this analysis. He studied that if water tank is fully filled i.e. without free board then the sloshing effect of water is neglected, if the tank is empty then no sloshing as water is absent. In above two cases water tower will behave as one-mass structure. But in case if there is free board, the water tower will behave as two-mass structure. Finally, he concluded that the tank fully filled is compared with the partially filled tank then it is seen that the maximum force to which the half-full tank is subjected may be significantly less than half the force to which the full tank is subjected. The actual forces may be as little as 1/3 of the forces anticipated on the basis of a completely full tank.
2. Sudhir K. Jain & Sameer U. S. (1991) Revised the IS code provision for seismic design of elevated water tanks. It is seen that, due to absence of a suitable value of performance factor for tanks, the code provision for rather low seismic design force for these structure. Simple expressions are derived, which allow calculations of staging stiffness, and hence the time period, while incorporating beam flexibility. The code must include an appropriate value of performance factor, say 3.0 for calculation of seismic design force for water tanks. An earthquake design criterion is incomplete, unless clear specifications are include on how to calculate the time period. A method for calculating the staging stiffness including beam flexibility and without having to resort to finite element type analysis has been presented. This method is based on well-known portal method which has been suitably developed to incorporate the beam flexibility and the three dimensional behaviour of the staging.
3. O. R. Jaiswal (2008) had done experimental and numerical study to obtain the sloshing frequency of liquid contained in tanks of different shapes and tanks with internal obstructions. The experimental study is done on laboratory models of tanks, which are excited using an Electro-Magnetic Shake Table. The numerical study is done with the help of finite element model of tank-fluid system using ANSYS software. A comparison of experimental and numerical results is carried out.
4. Gaikwad M. V. & Prof. Mangulkar M. N. (2013) had detail study and analysis it was found that, for same capacity, same geometry, same height, with same staging system, with same Importance factor & Response reduction factor, in the same Zone; response by equivalent static method to dynamic method differ considerably. Even if we consider two cases for same capacity of tank, change in geometric features of a container can shows the considerable change in the response of tank. As the capacity increases, difference between the response increases. Increase in the capacity shows that difference between static and dynamic response is in increasing order. It is also found that, for small capacity of tank the impulsive pressure is always greater than the convective pressure, but it is vice-versa for tanks with large capacity. Magnitude of both the pressure is different.

III. THE METHODOLOGY

The theoretical formulae's and methodology used for the analysis of water tank at ground level. These theoretical formulae's and methodology used for the analysis are based on the "IITK-GSDMA Guidelines on Seismic Design of Liquid Storage Tanks" (Provisions with commentary) given by Sudhir K. Jain and O R Jaiswal, in October 2007. When earthquake occurs water inside the tank is in motion due ground motion. Due to this ground motion hydrodynamic forces are acting on wall and slab. Hydrodynamic forces exerted by liquid on tank wall shall be considered in the analysis in addition to hydrostatic forces. The basis of these guidelines is to evaluate the Hydrodynamic forces exerted by sloshing liquid on tank wall and tank base slab in addition to hydrostatic forces. When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank

wall and the tank base in addition to the hydrostatic pressure. Thus in order to include the effect of hydrodynamic pressure in the analysis, the tank is idealized as an equivalent spring mass model as stated by Housner, which includes the effect of tank wall – liquid interaction. The parameters of this model depend on geometry of the tank and its flexibility. The approach followed for the analysis of different water tank problems is same, only the formulation and parameters used in each case vary according to the Geometry and support conditions

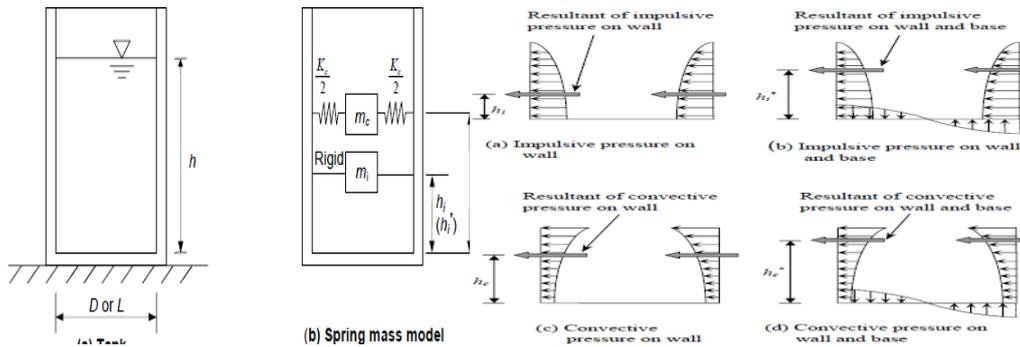


Fig 1: Spring Mass Model

Fig 2: Pressure distribution diagram

Circular tank	Rectangular tank
$\frac{m_i}{m} = \frac{\tanh\left(0.866 \frac{D}{h}\right)}{0.866 \frac{D}{h}}$	$\frac{m_i}{m} = \frac{\tanh\left(0.866 \frac{L}{h}\right)}{0.866 \frac{L}{h}}$
$\frac{h_i}{h} = 0.375$ for $h/D \leq 0.75$ $= 0.5 - \frac{0.09375}{h/D}$ for $h/D > 0.75$	$\frac{h_i}{h} = 0.375$ for $h/L \leq 0.75$ $= 0.5 - \frac{0.09375}{h/L}$ for $h/L > 0.75$
$\frac{h_i^*}{h} = \frac{0.866 \frac{D}{h}}{2 \tanh\left(0.866 \frac{D}{h}\right)} - 0.125$ for $h/D \leq 1.33$ $= 0.45$ for $h/D > 1.33$	$\frac{h_i^*}{h} = \frac{0.866 \frac{L}{h}}{2 \tanh\left(0.866 \frac{L}{h}\right)} - 0.125$ for $h/L \leq 1.33$ $= 0.45$ for $h/L > 1.33$
$\frac{m_c}{m} = 0.23 \frac{\tanh\left(3.68 \frac{h}{D}\right)}{\frac{h}{D}}$	$\frac{m_c}{m} = 0.264 \frac{\tanh\left(3.16 \frac{h}{L}\right)}{\frac{h}{L}}$
$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.68 \frac{h}{D}\right) - 1.0}{3.68 \frac{h}{D} \sinh\left(3.68 \frac{h}{D}\right)}$	$\frac{h_c}{h} = 1 - \frac{\cosh\left(3.16 \frac{h}{L}\right) - 1.0}{3.16 \frac{h}{L} \sinh\left(3.16 \frac{h}{L}\right)}$
$\frac{h_c^*}{h} = 1 - \frac{\cosh\left(3.68 \frac{h}{D}\right) - 2.01}{3.68 \frac{h}{D} \sinh\left(3.68 \frac{h}{D}\right)}$	$\frac{h_c^*}{h} = 1 - \frac{\cosh\left(3.16 \frac{h}{L}\right) - 2.01}{3.16 \frac{h}{L} \sinh\left(3.16 \frac{h}{L}\right)}$
$K_c = 0.836 \frac{mg}{h} \tanh^2\left(3.68 \frac{h}{D}\right)$	$K_c = 0.833 \frac{mg}{h} \tanh^2\left(3.16 \frac{h}{L}\right)$

Table 1: Expression for parameters of spring mass model

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In this number of problems of various capacities ranging from 400 m³ to 1200 m³ for circular tank by keeping its diameter constant by varying its height. By using IITK-GSDMA guideline solve the different problem and find out the different parameters as shown below:

Table 2: Problems having different capacity

Capacity (cub.m)	Diameter (m)	Height of tank up to Free board (m)
400	12	3.54
600	12	5.31
800	12	7.1
1000	12	8.84
1200	12	10.61

Table 3: Parameters of Spring –Mass Model

Capacity (cub. m)	mi (kg)	mc (kg)	hi (m)	hc (m)	hi* (m)	hc* (m)
400	135492	248015	1.33	1.93	4.78	4.43
600	294000	288000	1.99	3.08	4.74	4.46
800	491021	303097	2.67	4.5	4.90	5.3
1000	702681	309470	3.31	5.99	5.19	6.42
1200	924000	311228	4.24	7.64	5.58	7.85

Capacity (m ³)	Ti (sec)	Tc (sec)	(Ah) _i	(Ah) _c	V _i (KN)	V _c (KN)	V (KN)	M _i (KN-m)	M _c (KN-m)	M (KN-m)	M _i * (KN-m)	M _c * (KN-m)
400	0.02	4.2	0.225	0.065	518	158	542	840	305	894	2104	764
600	0.03	3.87	0.225	0.068	936	192	955	2125	592	2206	4346	934
800	0.04	3.76	0.225	0.07	1495	208	1509	4457	937	4554	7559	1186
1000	0.05	3.59	0.225	0.073	2057	222	2069	7503	1328	7620	11363	1511
1200	0.06	3.53	0.225	0.075	2641	229	2651	11984	1747	12111	15956	1889

Table 4: Seismic Parameters

Capacity (m ³)	Sloshing wave height (m)	Piw (y=0) (KN/s qm)	Pib (y=0) (KN/s qm)	Pcw (y=0) (KN/sqm)	Pcw (y=h) (KN/s qm)	Pcb (y=0) (KN/s qm)	Pressure due to wall inertia (KN/sqm)	Pres. Due to ver. Exc. (KN/sqm)	Max hydro. Pres. (KN/s qm)
400	0.78	6.71	6.08	1.74	2.89	1.76	1.41	7.29	11.05
600	0.82	9.72	7.64	1.33	3.02	1.12	1.41	10.94	15.64
800	0.84	2.22	8.47	0.72	3.1	0.66	1.41	14.63	20
1000	0.87	14.05	8.93	0.4	3.24	0.43	1.41	18.21	23.88
1200	0.9	15	9.22	0.04	3.33	0.26	1.41	21.86	27.35

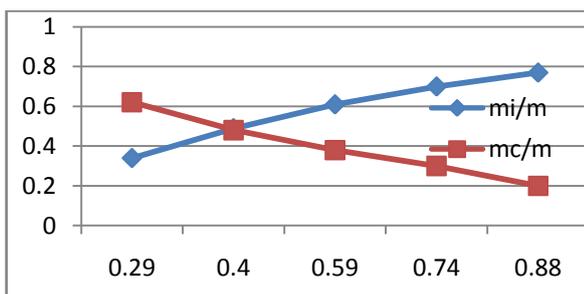
Table 5: Hydrodynamic Parameters

IV.RESULTS

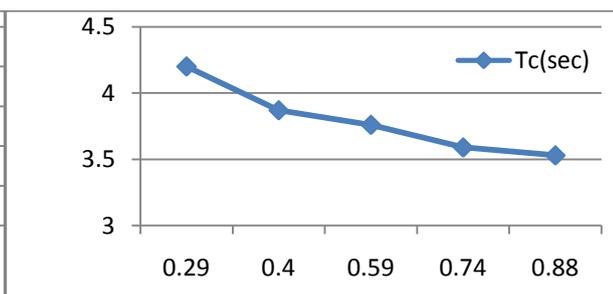
The following results are obtained by solving the different problem and compare water tank at ground level for various parameters like base shear hydrodynamic pressure impulsive and convective mass, bending moment at base, sloshing wave height for same and different capacity.

h/D (m)	0.29	0.4	0.59	0.74	0.88
mi/m	0.34	0.49	0.61	0.70	0.77
mc/m	0.62	0.48	0.38	0.3	0.2

h/D (m)	0.29	0.4	0.59	0.74	0.88
Tc (sec.)	4.2	3.87	3.76	3.59	3.53



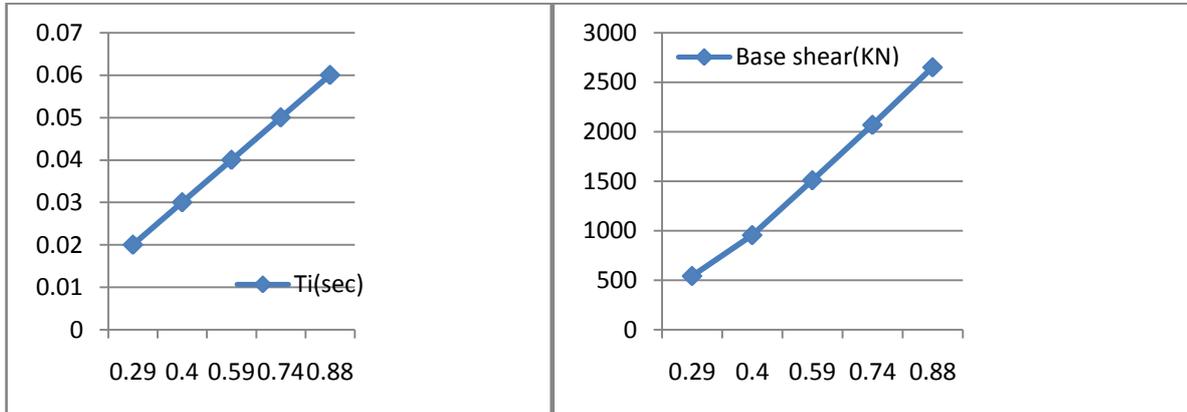
Variation of mi/m & mc/m Vs h/D ratio



Variation of Convective Time period(Tc) Vs h/D ratio

h/D (m)	0.29	0.4	0.59	0.74	0.88
Ti (sec.)	0.02	0.03	0.04	0.05	0.06

h/D (m)	0.29	0.4	0.59	0.74	0.88
Base Shear (KN)	542	955	1509	2069	2651



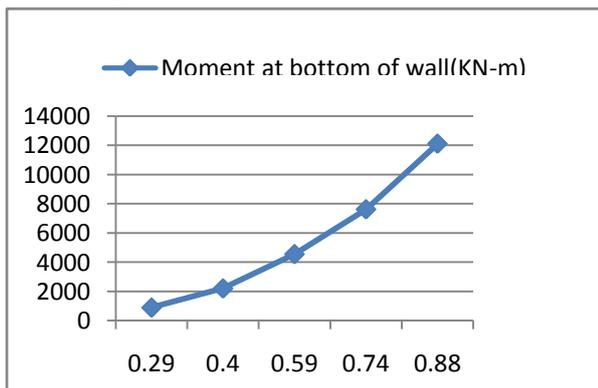
Variation of impulse Time period (Ti) Vs h/D ratio

Variation of Base Shear Vs h/D ratio

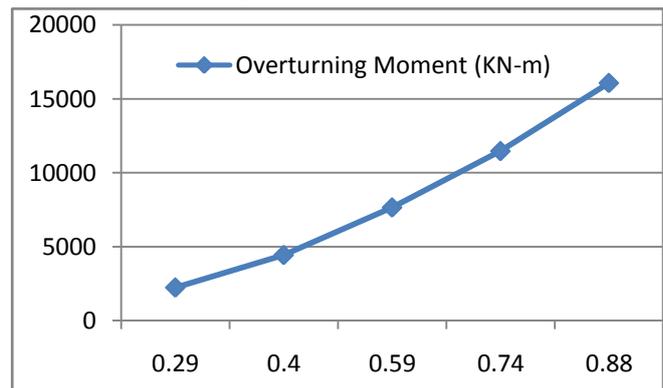
h/D(m)	0.29	0.4	0.59	0.74	0.88
Moment at bottom of wall (KN-m)	894	2206	4554	7620	12111

h/D (m)	0.29	0.4	0.59	0.74	0.88
Overturning Moment (KN-m)	2238	4435	7651	11463	16067

Variation of Bending Moment Vs h/D ratio:

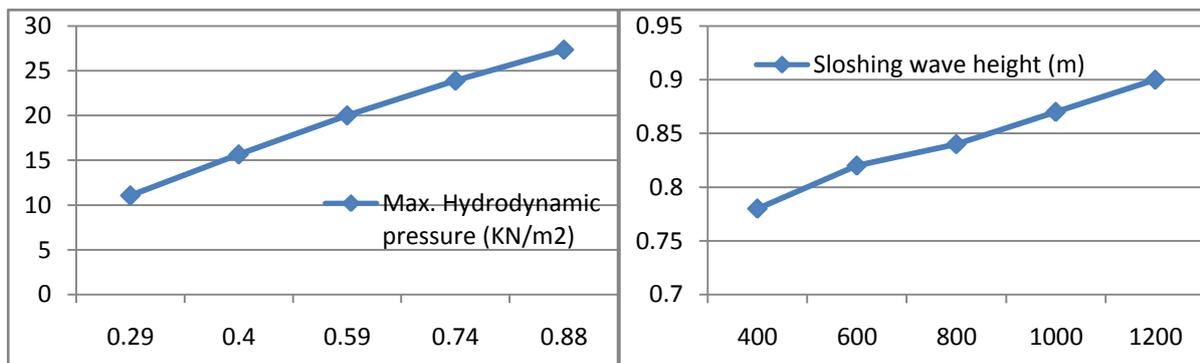


Variation of Overturning Moment Vs h/D ratio



h/D(m)	0.29	0.4	0.59	0.74	0.88
Max. Hydrodynamic pressure (KN/m ²)	11.05	12.64	20	23.88	27.35

Capacity(m ³)	400	600	800	1000	1200
Sloshing Wave height(m)	0.78	0.82	0.84	0.87	0.9



Variation of Max. Hydrodynamic pressure Vs h/D ratio

Sloshing wave height Vs Capacity

V. CONCLUSION

For circular water tank with same storage capacity and different height, the Base shear, Bending Moment & Max. Hydrodynamic pressure gradually increases with increase in h/D ratio.

For circular water tank with same storage capacity but different height of tank wall, in such case sloshing wave height increases up to certain limit & after that it gradually decreases.

The increase in the ratio of maximum depth of water to the diameter of tank i.e. (h/D) will lead to increase in impulsive mass participation factor and decrease in convective mass participation factor. The graph also illustrates that the sum of mass participation factor (impulsive & convective) exhibit the unit value all along the horizontal axis. For circular water tank the h/D ratio 0.4, the mass participation factor for impulsive & convective are nearly equal.

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