Study of Seismic Analysis of Water Tank at Ground Level

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Abstract - *The seismic analysis of the ground supported water tank resting on soft soil consisting of mass of roof, mass of tank wall, mass of water and mass of base slab is carried out. In this paper a parametric study on spring mass model, Time period in impulsive and convective mode, Design horizontal seismic coefficient, Base shear and Hydrodynamic pressure due to impulsive and convective mass of water is considered. It has been found that under influence of seismic forces with increasing ratio of maximum depth of water to the diameter of tank (h/D) the more mass of water will excite in impulsive mode while decreasing ratio of (h/D) more the mass of water will excite in convective mode. The Time period of Impulsive mode increase with increase in (h/D) ratio and Time period in convective mode decrease with increase in (h/D) ratio. It is assumed that tank is located in seismic zone IV.*

Key Words: Sloshing; Impulsive Mass; Convective Mass; Hydrodynamic Pressure; Spring Mass Model

1. INTRODUCTION

Liquid tanks especially water 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. Many researchers have been done on the behavior, analysis and design of ground tanks. Indian subcontinent is highly vulnerable to natural disaster like earthquake, draughts, floods, cyclones etc. Majority of states or union territories are prone to one or multiple disasters. These natural calamities are causing many casualties and innumerable property loss every year, According to seismic code IS: 1893 (Part 1): 2000, more than 60% of India is prone to earthquakes. The main reason for life loss is collapse of structure. It is said that earthquake itself never kills people; it is badly constructed structures that kill. Hence it is important to analysis the structure properly for earthquake effects. 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.

For storage of large quantities of liquids like water, oil, petroleum, acid and sometime gases also, containers or tanks are required. These structures are made of masonry, steel, reinforced concrete and pre stressed concrete. Out of these, masonry and steel tanks are used for smaller capacities. The cost of steel tanks is high and hence they are rarely used for water storage. Reinforced concrete tanks are very popular because , besides the construction and design being simple , they are cheap , monolithic in nature and can made leak proof .Generally no crakes are allowed to take place in any part of the structure of Liquid Retaining RCC tanks and they are made water tight by using richer mix of concrete . In some times water proofing materials also are used to make tanks water tight.

1.1 Sloshing

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[6].

2. LITERATURE REVIEW

George W. Housner [1963][1] 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 basic of a completely full tank. Jaiswal O. R & Jain S. K. [2005][2] studied limitations and shot comings in the provision of IS:1893-1984, given by Jain and Medhekar, Jain and Sameer on a seismic design of liquid storage tanks, the author has given some further recommendations, 1) Design horizontal seismic coefficient given in revised IS: 1893(Part-1)-2002 is used and values of response reduction factor for different types of tanks are proposed. 2) Different spring-mass model for tanks with rigid & flexible wall are done away with; instead, a single spring-mass model for both types of tank is proposed. 3) Expressions for convective hydrodynamic pressure are corrected. O. R. Jaiswal & et al. [2008][3] The author 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. Dr. Suchita Hirde & et al. [2011][4] Studied the performance of the elevated water tank for various seismic zones of India for various heights and capacity of elevated water tanks for different soil conditions. The effect of height of water tank, earthquake zones and soil, on earthquake forces have been presented in this paper with the help of analysis of 240 models of various parameters. In this paper, the study is carried out on RCC circular elevated water tank with M-20 grade of concrete and Fe-415 grade of steel & SMRF are considered for analysis. Elevated water tank having 50,000 liters and 100,000 liters capacity with staging height 12 m. 16 m, 20 m, 24 m, 28 m considering 4 m height of each panels are considered for the study. Author has given following conclusions from his analysis 1) Seismic forces are directly proportional to the Seismic Zones. 2) Seismic forces are directly proportional to the capacity of water tank. 3) Seismic forces are higher in soft soil than medium soil, higher in medium soil than hard soil. Earthquake forces for soft soil is about 40-41% greater than that of hard soil for all earthquake zones and tank full and tank empty condition. Gaikwad M. V. & Prof. Mangulkar M. N. (2013)[5] From 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.

The paper consists of study of guidelines for seismic analysis of water tank at ground level. The project was based on analysis of ground water tank subjected to seismic excitation considering the forces induced due to acceleration of ground. In this Study, Hydrodynamic forces exerted by the liquid on the wall of water tank and base slab were considered in the analysis. These hydrodynamic forces were evaluated with the help of spring mass model of water tanks. Also in this paper comparison of various parameters like base shear and hydrodynamic pressure of circular and rectangular tank for various capacity and different heights of water level and water tank was done by calculating seismic weight of tank and horizontal & vertical acceleration coefficient.

3. METHODOLOGY

The theoretical formulae and methodology used for the analysis of Ground supported water tanks. These theoretical formulae and methodology used for the analysis are based on the "IITK-GSDMA Guidelines on Seismic Design of Liquid Storage Tanks" (Provisions with commentary)[6] and Sudhir K. Jain and O R Jaiswal, in October 2007[2].

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 as shown in figure -1. The parameters of this model depend on geometry of the tank and its flexibility. When a tank containing liquid with a free surface Is subjected to horizontal earthquake ground Motion, tank wall and liquid are subjected to Horizontal acceleration. The liquid in the lower Region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as Impulsive liquid mass which accelerates along With the wall and induces impulsive Hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank Undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective Hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two Parts, i.e., impulsive mass and convective mass as shown in figure -2.

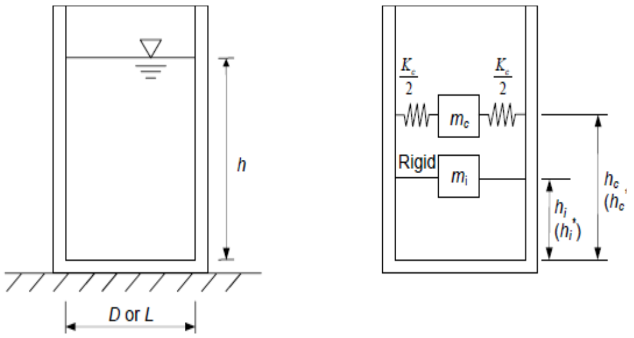

Fig -1: Tank and spring mass model[1][2][6]

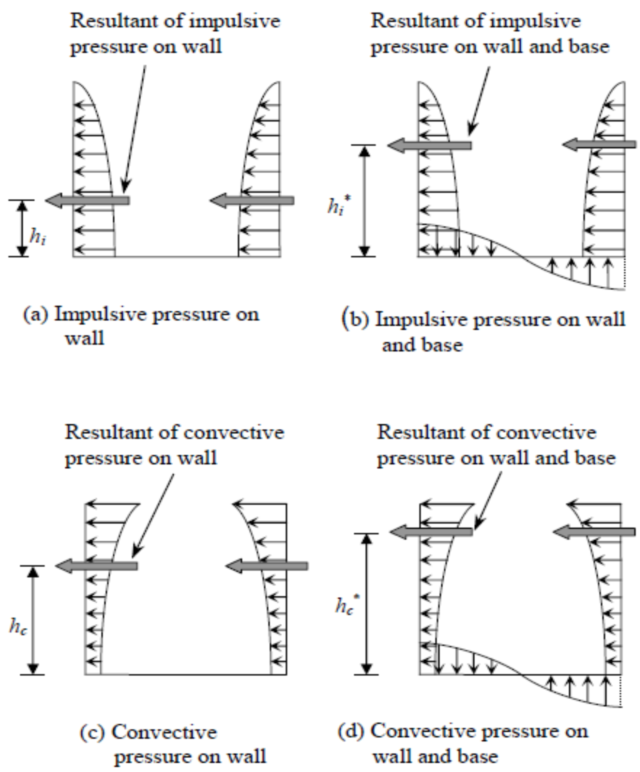

Fig -2: Pressure distribution diagrams[1][2][6]

Here,
h = Height of liquid in tank;
D = Internal diameter of tank.
L = Length of the tank wall along which the direction of the Earthquake force is considered.

4. RESULTS AND DISCUSSION

In this project number of problems of various capacities ranging from 400 m³ to 1200 m³ for circular and rectangular tank by keeping its diameter and length and width constant by varying its height has been solved[7][8][9][10]. The results obtained are as follows.

4.1 Results for circular water tank of varying capacity

As shown in Chart-1, the h/D ratio increases, the value of mi/m also increase and the value of mc/m decreases. As the capacity of water tank increases, the impulsive hydrodynamic pressure increases and convective hydrodynamic pressure decreases. In chart -2, the value of Base Shear increases when the h/D ratio increases. Base Shear increase with increases in capacity of water tank. As the h/D ratio increases, the value of the Bending Moment also increases as shown in chart -3. The value of bending moment increases with increase in capacity of water tank.

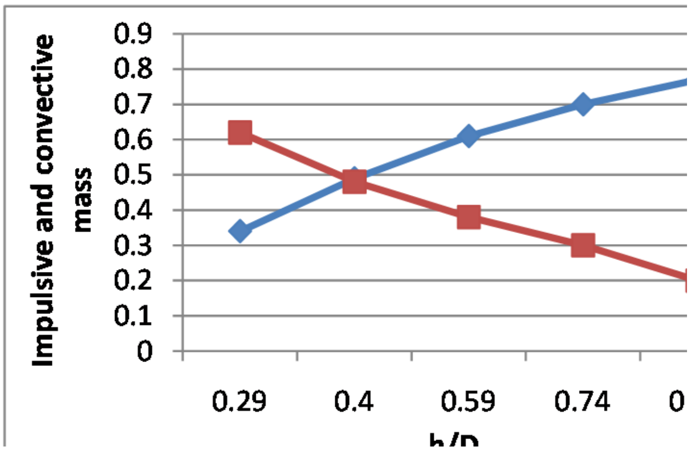

Chart -1: Impulsive mass (mi/m) and Convective Mass (mc/m) Vs h/D

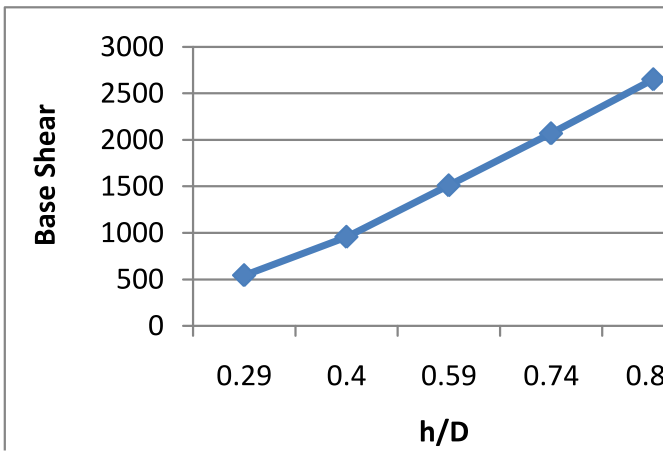

Chart -2: Base shear Vs h/D ratio

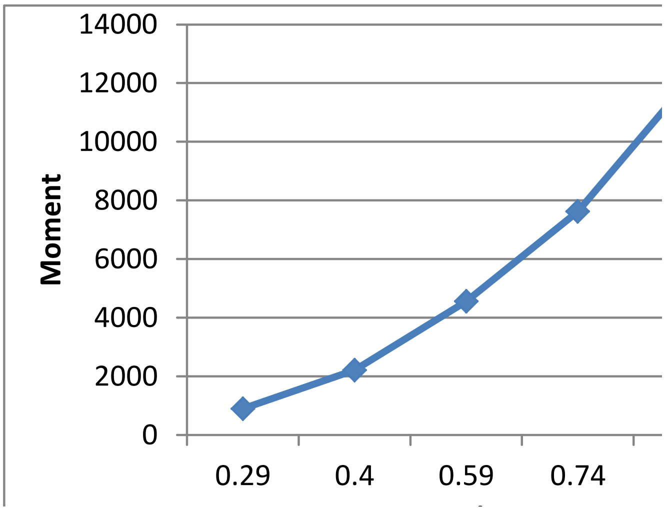

Chart -3: Bending Moment Vs h/D ratio.

The variation of maximum Hydrodynamic pressure Vs h/D ratio is depicted from chart -4, as the h/D ratio increases, the value of the maximum hydrodynamic pressure also increases. Maximum hydrodynamic pressure of the Water Tank increases, with increases capacity of water tank. The chart -5 represents the variation in sloshing wave height Vs capacity of water tank. As the Capacity of water tank increases, the Sloshing wave height also increases. Sloshing Wave height increases with increases Capacity of Water tank. In all the problems free board height is kept as 0.5m. But, when sloshing wave height goes greater than 0.5m, there is need to increase the height of Free Board.

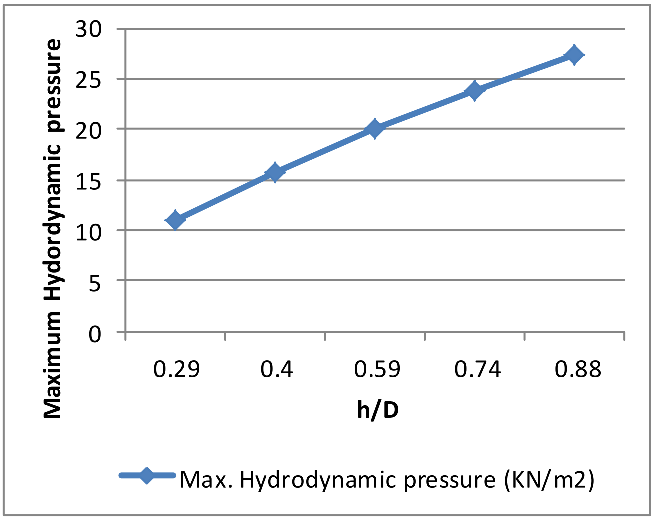

Chart -4: Max. Hydrodynamic pressure Vs h/D ratio

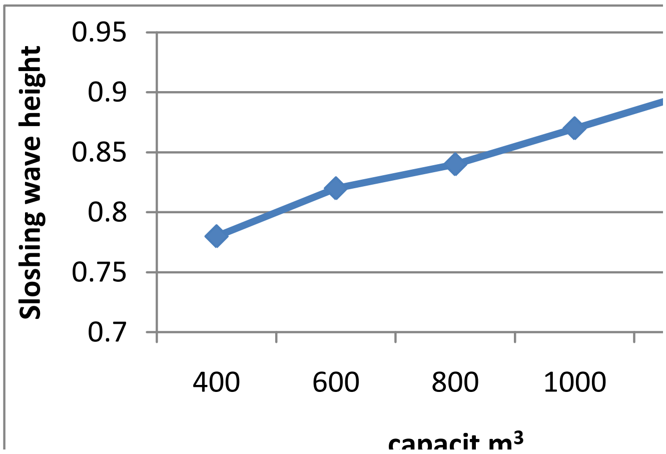

Chart -5: Sloshing wave height Vs capacity

4.2 Results of circular water tank for constant capacity

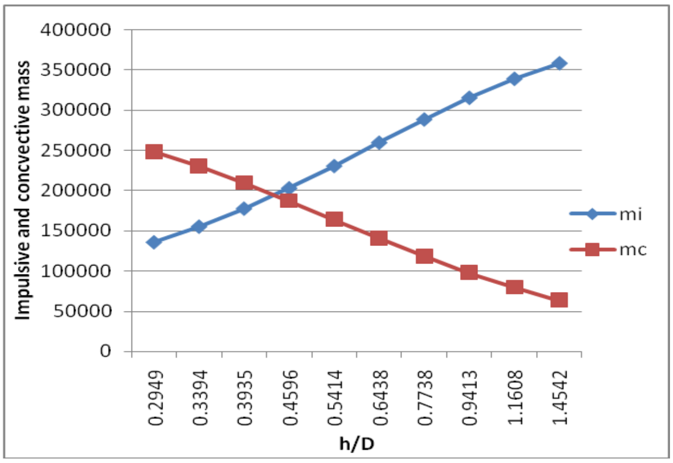

Chart -6: mi and mc Vs h/D

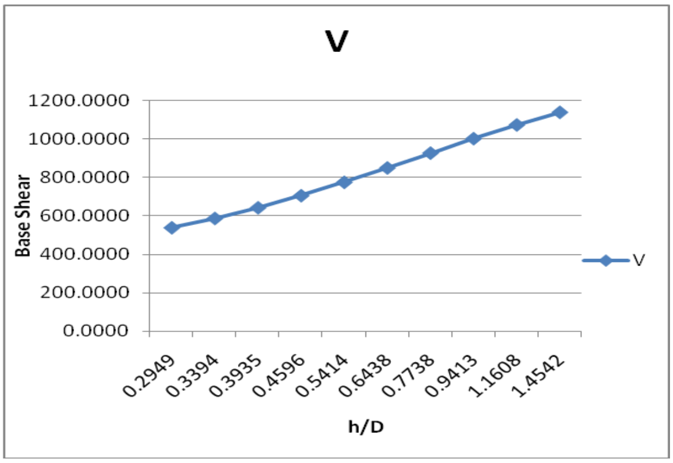

Chart -7: Base shear Vs h/D ratio

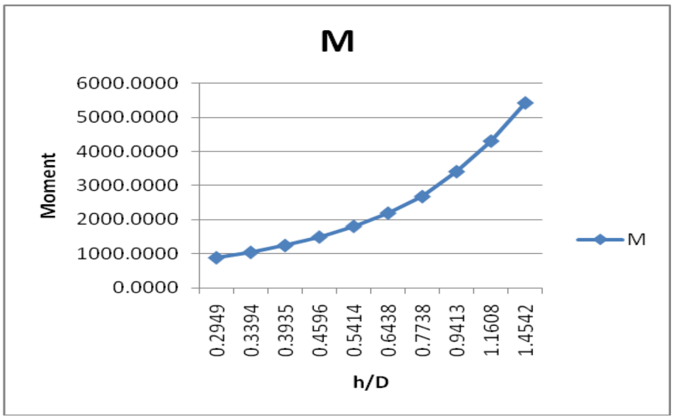

Chart -8: Bending Moment Vs h/D ratio.

Impulsive mass of water increases with increase in the h/D ratio and convective mass of water decreases with increase in h/D ratio as presented by Chart -6 . The chart -7, 8 and 9 shows Base shear, Moment at the bottom of wall and Hydrodynamic pressure increases with increases in h/D ratio respectively. Sloshing wave height increases with increase in h/D ratio gradually up to 0.3935 and it decreases with increase in h/D ratio for 400 m^3 capacity as shown in chart -10.

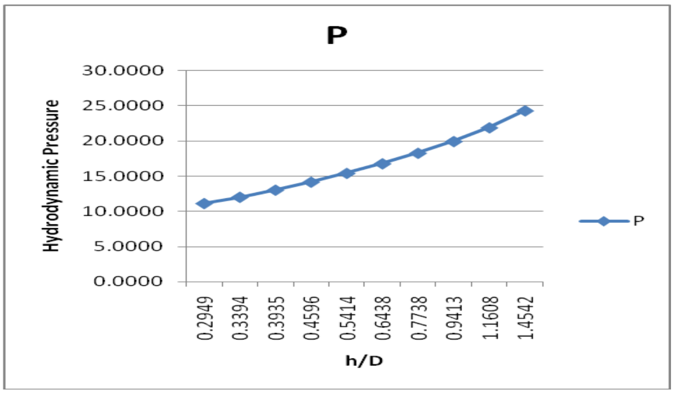

Chart -9: Hydrodynamic pressure Vs h/D ratio

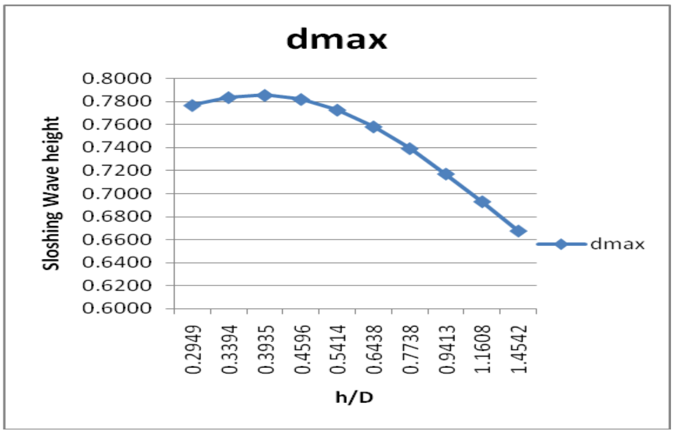

Chart -10: Sloshing wave height Vs h/D

4.3 Results for rectangular water tank of varying capacity and constant capacity

Similar graphs are of rectangular water tank. For rectangular water tank of varying capacity, both in X and Y direction, as the h/L ratio increases 1) the value of mi/m also increase, the value of mc/m decreases. The impulsive hydrodynamic mass increases and convective hydrodynamic mass decreases with increases capacity of water tank. 2) The value of Base Shear increases. As the capacity of water tank increases, then the Base Shear also increase. 3) The value of the Bending Moment increases. The Bending Moment of Water Tank increases, with increases capacity of water tank. 4) The value of the Max. Hydrodynamic pressures also increase. Max. Hydrodynamic pressure of the Water Tank increases, with increases capacity of water tank. 5) As the Capacity of water tank increases, the Sloshing wave height also increases.
For rectangular water tank of constant capacity, both in X and Y direction, as the h/L ratio increases 1) the Impulsive mass of water increases with increase in the h/L ratio and convective water mass decreases with increase in h/L ratio. 2) Base shear, Moment at bottom of wall, Maximum hydrodynamic pressure gradually increases with the h/L ratio up to 0.6 and then it suddenly increase between 0.6 to 0.8 after that it decreases gradually. Sloshing wave height increases with increase in h/L ratio gradually up to 0.52 it decreases with increase in h/L ratio for 400 m^3 capacity.

5. CONCLUSIONS

From above results and discussions it is concluded that,
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

In case of rectangular water tank with same storage capacity and different height of tank wall if the h/L ratio is up to 0.6 the base shear, Bending Moment& Max. Hydrodynamic pressure increases gradually and if the h/L ratio is in between 0.6 to 0.8; it suddenly increases & after that it decreases gradually. So for water tank at ground level the h/L ratio up to 0.6 is feasible.

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

The increase in the ratio of maximum depth of water to the diameter of tank i.e. (h/D) or (h/L) will lead to increase in impulsive mass participation factor and decrease in convective mass participation factor. The graph also illustrate that the sum of mass participation factor (impulsive & convective) exhibit the unit value all along the horizontal axis.

In case of circular water tank for h/D ratio 0.4, the mass participation factor for impulsive & convective are nearly equal.

In case of rectangular water tank for h/L ratio 0.5, the mass participation factor for impulsive & convective are nearly equal.

REFERENCES

[1] G. W. Housner, "The Dynamic Behaviour Of Water Tank" Bulletin Of The Seismological Society Of America, Vol. 53, No. 2, pp. 381-387, 1963.
[2] O. R. Jaiswal and S. K. Jain, "Modified Proposed Provisions For Aseismic Design Of Liquid Storage Tanks: Part II – Commentary And Examples", Journal of Structural Engineering Vol. 32, No.4, 2005.
[3] O. R. Jaiswal, S. Kulkarni, P. Pathak, "A Study on Sloshing Frequencies of Fluid-Tank System", in Proceedings of 14th World Conference on Earthquake Engineering, Beijing, China, 2008.
[4] S. Hirde, A. Bajare, M. Hedaoo, "Seismic Performance Of Elevated Water Tanks", International Journal of Advanced Engineering Research and Studies E-ISSN2249 – 8974, 2011
[5] M. V. Gaikwad, M. N. Mangulkar, "Seismic Performance of Circular Elevated Water Tank with Framed Staging System" International Journal of Advanced Research In Engineering And Technology (IJARET) Volume 4, Issue 4, May – June 2013, pp. 159-167, 2013
[6] IITK-GSDMA, "Guidelines For Seismic Design Of Liquid Storage Tanks", National Information Center Of Earthquake Engineering, 2007
[7] S. U. Pillai and D Menon, Reinforced Concrete Design, Pearson Education India, 2009.
[8] B. C. Punmia, A. K. Jain and A. K. Jain, Reinforced Concrete Structure, LaxmiOublications (P) Ltd., 2006.
[9] Indian Standard Code Of Practice For Concrete Structures For The Storage Of Liquids, Bureau Of Indian Standards, 2004.
[10] Indian Standard Code Of Practice Criteria for Earthquake Resistant Design of Structures, Bureau Of Indian Standards, 2002.