Impact of Sloshing Motion of water on Ground Supported Circular Liquid Storage Tank

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Abstract – *The seismic analysis of the ground supported circular steel tank resting on hard 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 very important to note that maximum hydrodynamic pressure on wall of tank in area located in Zone-V will have 3 to 3.5 times the maximum hydrodynamic pressure of an identical tank in Zone-II.*

Keywords : Impulsive and convective mass of water, Time period, Base shear, Overturning moment, Hydrodynamic pressure.

1. Introduction

Indian seismic code IS 1893:1984 had some very limited provisions on seismic design of elevated tanks. Compared to present international practice, those provisions of IS 1893:1984 are highly inadequate. Moreover, the code did not cover ground-supported tanks. In 2002, revised Part 1 of IS 1893 has been brought out by the Bureau of Indian Standards (BIS). The other parts, one of which will contain provisions for liquid storage tanks, are yet to be brought out by the BIS. In view of non availability of a proper IS code/standard on seismic design of tanks , IIT Kanpur prepared GSDMA Guidelines for seismic design of liquid storage tanks and this paper is implemented on this guidelines. Here in this paper case study had been performed on ground supported circular liquid storage steel tank on the basis of GSDMA guidelines.

2. Methodology

2.1. Parameter of Spring mass model

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 (mi) 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 (mc) 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. (IITK-GSDMA provision 4.2)

2.2 Time period

2.2.1 Time period in Impulsive mode (Ti)

When a tank subjected to horizontal earthquake ground motion, tank wall and liquid in lower region of tank will accelerates with same horizontal acceleration and it will possesses fundamental natural time period i.e. Time period in Impulsive mode (Ti) in seconds. (IITK-GSDMA 4.3.1.1)

2.2.2 Time period in convective mode (Tc)

When a tank subjected to horizontal earthquake ground motion , liquid mass in upper region of tank undergoes sloshing motion some horizontal acceleration that differ from above case and in this case fundamental natural period of time i.e Time period in Convective mode (Tc) in seconds (IITK-GSDMA 4.3.2.2)

2.3. Design Horizontal seismic coefficient

Design Horizontal seismic coefficient ,Ah obtained by the following expression ,

$$(Ah) = \frac{Z}{2}\frac{I}{R}\frac{Sa}{g}$$

Where , Z= Zone factor (Table 2 ,IS 1893(Part-I) :2002)

I= Importance factor factor (=1.75 **,**for hazardous liquid, =1.5 ,for water storage tank)

R= Response reduction factor (Ground supported steel tank base fixed ,=2.5)

2.4 Total base shear

The total base shear at the bottom of shear wall can be obtained by combining the base shear in impulsive and convective mode through square root sum of base shear due to impulsive mass and base shear due to convective mass of liquid and is given by (IITK-GSDMA 4.6.3)

Total base shear can be obtained by ,

$$V=\sqrt{Vi^2 + Vc^2}$$

Where ,

Vi= Base Shear due to Impulsive mass

Vc= Base Shear due to Convective mass

2.5 Base moment

2.5.1 Total bending moment

Total bending moment at bottom of wall shall be obtained by combining the moment in impulsive and convective modes through square of sum of squares (SRSS) and is given as follows (GSDMA 4.7)

$$M= \sqrt{Mi^2 + Mc^2}$$

2.5.2 Total overturning moment

The total overturning moment at the bottom of base slab shall be obtained by combining the moment in impulsive and convective modes through square of sum of squares (SRSS) and is given as follows

$$M^* = \sqrt{Mi *^2 + Mc *^2}$$

2.6 Maximum Hydrodynamic pressure

The maximum value of hydrodynamic pressure acting on bottom of tank wall should be obtained by combining pressure due to horizontal and vertical excitation through square root of sum of squares (SRSS) rule, which can be given as (IITK-GSDMA 4.10.2),

$$p_{max} = \sqrt{((\text{piw} + \text{pww})^2 + \text{pcw}^2 + \text{pv}^2)}$$

Where ,

piw = Pressure on wall due to impulsive mass of water

pww= Pressure on tank wall due to its inertia

pcw = Pressure on wall due to convective mass of water

pv = Hydrodynamic pressure on tank wall due to vertical ground acceleration

3. Case study

A Ground supported steel tank with Details of sizes of various components and geometry are shown in Table 1 and Figure 1

Table No. 1 Geometrical Description of Tank

Inside diameter of tank,D =	12 m
Wall thickness ,tw=	5 mm
Base plate thickness ,tb=	10 mm
Specific gravity of liquid =	1
Roof cover thickness tr=	5 mm
Density of steel ρs =	78.53 KN/ m^3
Supported on	Soft soil
Seismic Zone no.	V
Damping for impulsive mass,	2 %
Damping for convective mass	0.5 %

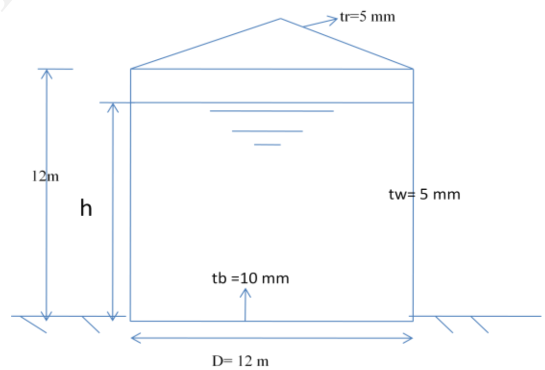

Fig.1 Details of component of Ground supported tank

4. Results and Interpretation

The maximum depth of water (h) is kept as variable for checking the effect of variation of maximum depth of water (h) to diameter (h/D) ratio on different parameters considered.

4.1 Variation of Impulsive mass and convective mass with respect to (h/D) ratio

The variation of Impulsive mass participation factor (mi/m) i.e. ratio of Impulsive mass of water to Total mass of water and Convective mass participation factor (mc/m) with respect to (h/D) ratio is plotted in .2 ,for instant if we take (h/D)=0.5 then (mi/m)=0.542 and (mc/m)= 0.437

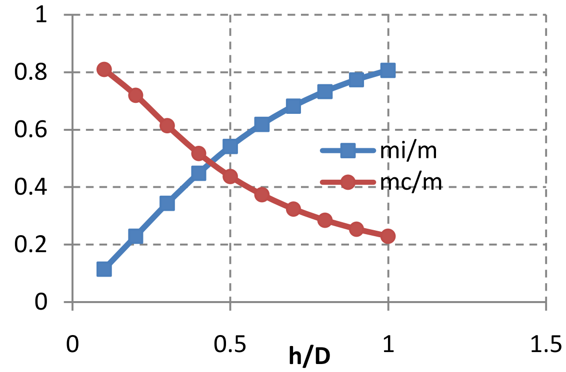

Fig.2 Variation of mi/m & mc/m Vs h/D ratio

4.2 Variation of Time perod of impulsive mode(Ti) and Time period of convective mode (Tc) with respect to (h/D) ratio

The variation of Time period of Convective mode (Tc) with respect to (h/D) ratio is plotted in Figure 3. The variation of Time period of impulsive mode with respect to (h/D) ratio is plotted in figure 4.

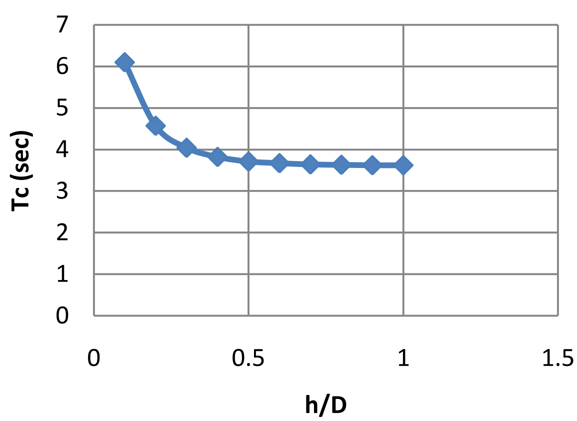

Fig .3 Variation of Time period (Tc) Vs h/D ratio

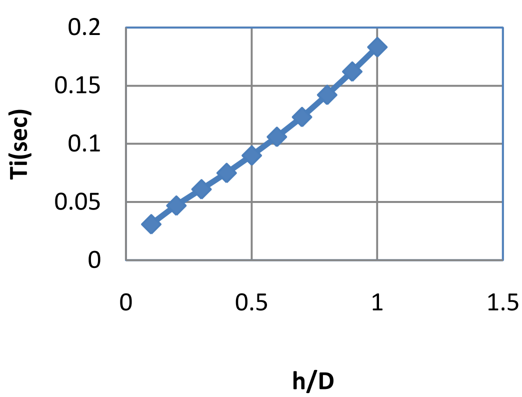

Fig 4 Variation of Time period(Ti) Vs h/D ratio

4.3 Variation of lateral base shear in percentage of seismic weight of tank with respect to (h/D) ratio

The variation of lateral base shear in terms of percentage of seismic weight of tank is plotted on Y-axis is shown in fig.5

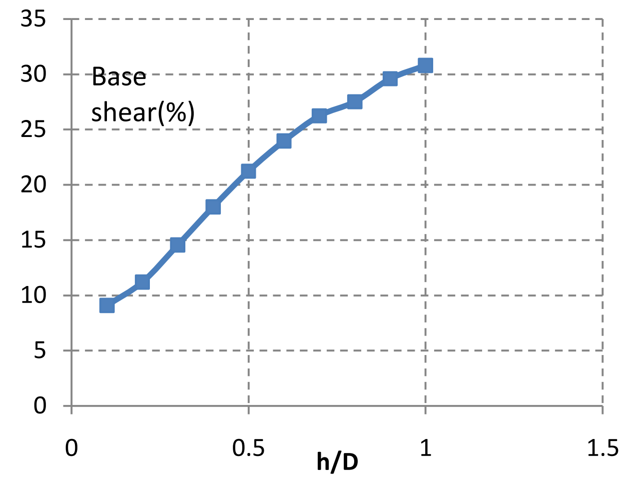

Fig. 5 Base shear versus h/D ratio

4.4 Variation of Moment at base and Overturning moment with respect to (h/D) ratio

Variation of Bending moment at the bottom of tank wall versus (h/D) ratio is shown in figure 6 whereas variation Overturning moment at the bottom of base slab versus (h/D) ratio is shown in figure 7.

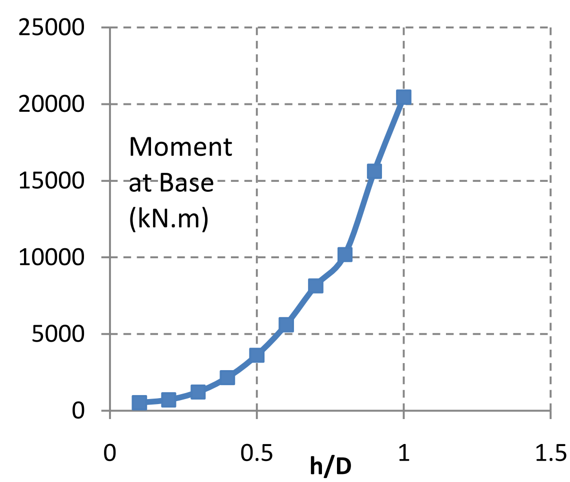

Fig 6 Bending Moment versus h/D ratio

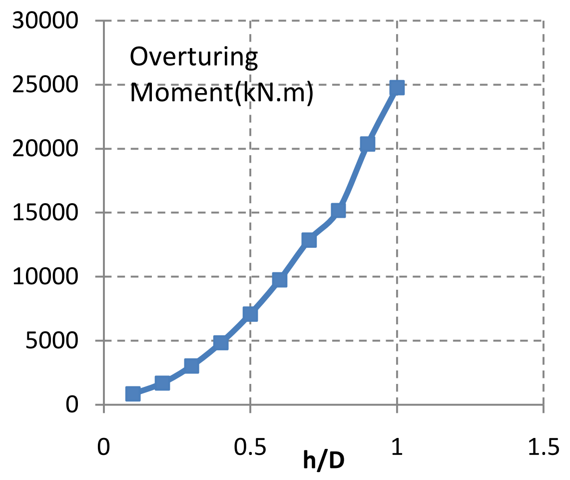

Fig 7 Overturning Moment versus h/D ratio

4.5 Variation of maximum hydrodynamic pressure acting on wall with respect of (h/D) ratio

Variation of maximum hydrodynamic pressure acting on wall with respect of (h/D) ratio is shown in figure 8, maximum pressure varies with (h/D) ratio almost linearly.

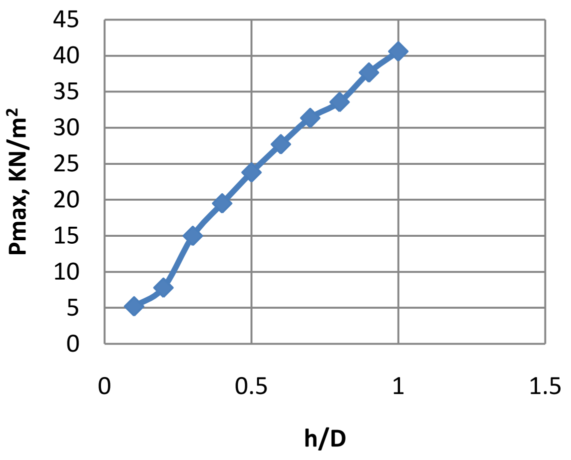

Fig 8 Max hydrodynamic pressure versus h/D ratio

Conclusion

1) The increase in 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 illustrate that the sum of mass participation factor (i.e. impulsive and convective) exhibit the unit value all along the horizontal axis. For h/D ratio 0.5, the mass participation factor for impulsive and convective are nearly equal.
2) Time period in Impulsive mode increase with increasing ratio of (h/D) .Time period in Convective mode decrease with increasing ratio of (h/D) ratio.
3) If two tank possesses same storage capacity but with different height of tank wall ,In such case tank with less h/D ratio hydro dyanamic pressure acting on wall due to Convective mass of water will be more.
4) After performing number of trail it is found that maximum hydrodynamic pressure acting on wall of tank located in seismic Zone-V will have approximately 3.5 times the maximum hydrodynamic pressure of an identical tank in Zone-II.

References

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