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Seismic Behavior of RCC Circular Elevated Water Tank

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Abstract: This study focuses mainly on the response of elevated circular tank under seismic loading. Such overhead water tanks consists huge mass of water at top of slender staging which is a major concern of failure of tanks under horizontal vibration eg, earthquake loading. Tanks of different diameter and heights with constant staging are modeled using Staad.pro. The analysis is carried out for four cases viz., 100%, 75%, 50%, 25% fill condition. Sloshing effect along with hydrostatic effect is considered during analysis. A parametric study for max displacement and base shear is conducted.
Keywords: Elevated water tank, sloshing, hydrostatic load, impulsive mass, convective mass, Staad.pro modeling, Max displacement, base shear.

I. INTRODUCTION

Elevated water tanks form an integral part of water supply schemes in both urban and rural areas. These tanks must remain functional to meet the demand in any extreme situation like earthquake, fire outbreaks etc. (Moslemi et al. 2011).

Seismic safety of liquid storage tanks is of considerable importance. Water storage tanks should remain functional in the post earthquake period to ensure potable water supply to earthquake-affected regions and to cater the need for fire-fighting. Industrial liquid containing tanks may contain highly toxic and inflammable liquids and these tanks should not lose their contents during earthquake (Kianoush et al. 2015).

Sloshing is a classic and important problem of fluid dynamics. It has wide range of applications in engineering, such as moving vehicle and structure containing a liquid with free surface, ships etc (Zhen et al. 2016). The violent behavior of fluid inside a container/tank with free surface is known as sloshing. The presence of a free surface in partially filled liquid containers allows for a fluid motion relative to the containers, this is referred as 'liquid sloshing'. If the liquid is allowed to slosh freely it can produce forces that cause additional hydrodynamic pressure in case of storage tank and additional vehicle acceleration in case of moving tanks and space vehicles (Choudhary and Bhora 2017). Indian subcontinent is highly vulnerable to natural disasters like earthquakes, floods, cyclones etc., and according to IS: 1893-2002 (Part-1) more than 60% of India is prone to earthquakes. Since the elevated tanks are frequently used in seismically active regions also, their seismic behavior has to be investigated in detail.

During earthquake a number of large elevated water tanks were severely damaged whereas others survived without damage. An analysis of the dynamic behavior of such tanks must take into account the motion of water relative to the tank as well as the motion of the tank relative to the ground (Housner 1963). Most of the codes put emphasis on ground supported tank and very limited information is available on elevated tanks, (IITK-GSDMA). This study is concentrated mainly on Sloshing Effect that is happening in the water tank at different levels of water during Earthquake.

II. LITERATURE REVIEW

Significant literature is available on seismic design of water tanks both ground supported and elevated tank. Few researches published work on analysis of elevated tank under dynamic loading are reviewed in this section.

George W. Housner (1957, 1963) gave a simplified dynamic analysis for the response of elevated water tanks which are subjected to seismic forces. According to author the analysis of such tanks must take into account the motion of water relative to tank and also the motion of tank relative to the ground. If the tank is entirely filled with water or is empty, then it will behave as a one-mass structure. But if the tank has a free surface, as in many cases, there will be sloshing of water during earthquake, and at this stage the tank will be essentially a two-mass structure. Seismic force acting on the tank having free water surface are of two kinds, 1-When the walls of tank set into vibration and moves back and forth, a certain fraction of water is forced to participate in it, that exerts a reactive force on tank which is similar to the force exerted by mass Mi that is rigidly attached at a suitable height h_i. 2- The motion of the tank stimulates the water into oscillation which in turn exerts an oscillating force on the tank. This force is same as that would

be exerted by mass Mc attached at height h_c. Thus, the hydrodynamic pressure was divided into two parts; first, the impulsive component caused by the portion of the liquid at the bottom accelerating with the container and the convective component associated with the sloshing liquid. The liquid was assumed to be incompressible and undergo small displacement. Due to its implementation simplicity, it has been adopted in many codes and standards with certain modifications**.** Veletsos **(**1974) developed a simple procedure for evaluating the hydrodynamic forces induced in liquid filled flexible cylindrical tanks, giving due consideration to tank flexibility. Only the impulsive effects were investigated. He assumed single degree of freedom system for the tank such that the cross section of the tank remained circular, and the distribution of deflection along the height of the tank was of a prescribed form. Study concluded that the seismic effects in flexible tanks may be substantially greater than those induced in similarly excited rigid tanks. Malhotra et al. (2000) provided the theoretical background of a simplified seismic design procedure for cylindrical ground supported tanks. The procedure included both impulsive and convective (sloshing) actions of the liquid in flexible steel or concrete tanks fixed to rigid foundations. The dynamic analysis of a liquid filled tank was carried out using the concept of generalized SDOF system representing the impulsive and convective modes of vibration of tank-liquid system. Seismic responses were calculated using the site response spectra and few simple calculations. He presented an example to illustrate the procedure and compared with detailed modal analysis procedure.
Kianoush et al. (2002) studied the behavior of liquid containing structures subjected to seismic excitations. Major parameters affecting the response of concrete circular tanks were discussed. With the help of a design example, results of the various design standards were compared. The effects of earthquake load on the behavior of reinforced concrete tanks were also investigated through a detailed example. Moslemi et al. (2011) employed the finite element technique to investigate the seismic response of liquid filled tank. The liquid inside the tank was modeled using displacement–based fluid finite elements. Both impulsive and convective response components were obtained separately using FE technique. The free vibration analysis in addition to transient analysis using modal superposition technique was carried out to investigate fluid-structure interaction problem in elevated tank. Furthermore, the effect of tank wall flexibility and sloshing of water free surface are accounted for in FE analysis. The computed FE time history results were compared with current practice and very good agreement was observed.
Krishna Rao et al. (2015) analyzed 1000 Cu.m capacity elevated water tank for four seismic zones viz. Zone II, Zone III, Zone IV, Zone IV and three different soil types (Hard rock, Medium soil, and Soft soil). Theoretical procedures of IS: 1893-1984 and IS: 1893-2002 (part -2) were compared with the seismic responses of tank.
Dona Rose et al. (2015) studied the seismic analysis of tank for two cases namely, tank full and half level condition. This analysis included sloshing effect along with hydrostatic effect. The time history analysis was carried out using the earthquake acceleration record of El Centro. The peak displacements and base shear obtained were compared.
IITK-GSDMA, provided guidelines which describe procedure for analysis of ground supported and elevated water storage tanks subjected to seismic forces. The procedure considers forces induced due to acceleration of tank structures and hydrodynamic forces due to acceleration of liquid. Based on numerous analytical, numerical, and experimental studies, simple spring mass models of tank liquid system is developed to determine hydrodynamic forces.

III. SCOPE OF THE PROJECT

Aim of this paper was to study the effect of sloshing in tank with four water fill conditions. Response for different heights and diameter are also studied. Finite element modeling of tank was carried out using software Staad.pro and seismic analysis was carried out. Peak displacements, base shear obtained from analysis were compared.

IV. METHODOLOGY

The methodology includes fixing the dimension of selected type of water tank and performing linear dynamic analysis (response spectrum method) using IS 1893-2002 (part2) draft code and IIT-K guidelines. In this study $70m^3$ capacity tank is considered for analysis. It is analyzed for four different water levels viz., 100%, 75%, 50%, 25% full conditions considering the sloshing effect along with hydrostatic effects. Finite element model (FEM) is used to model the elevated tank using Staad.pro software. Peak displacements and base shear obtained from analysis are compared.

V. FEM ANALYSIS USING STAAD.PRO

The details of $70m^3$ circular overhead water tank considered for seismic analysis are listed below:
Internal diameter- 5m
Height -4m (Including FB-0.4m)

Wall thickness of tank - 0.2m
Top ring beam-0.25m x 0.3m
Bottom ring beam-0.25m x 0.6m
Floor slab-0.3m
Column diameter-0.45m
Bracing- 0.3m x 0.6m
Staging height-12m
Boundary conditions at base – Fixed
Tank is located on hard soil in seismic zone IV.

VI. MODELING

Line elements are used for modeling the ring beam, bracing, column and area elements (plate) for wall, top dome and bottom slab.

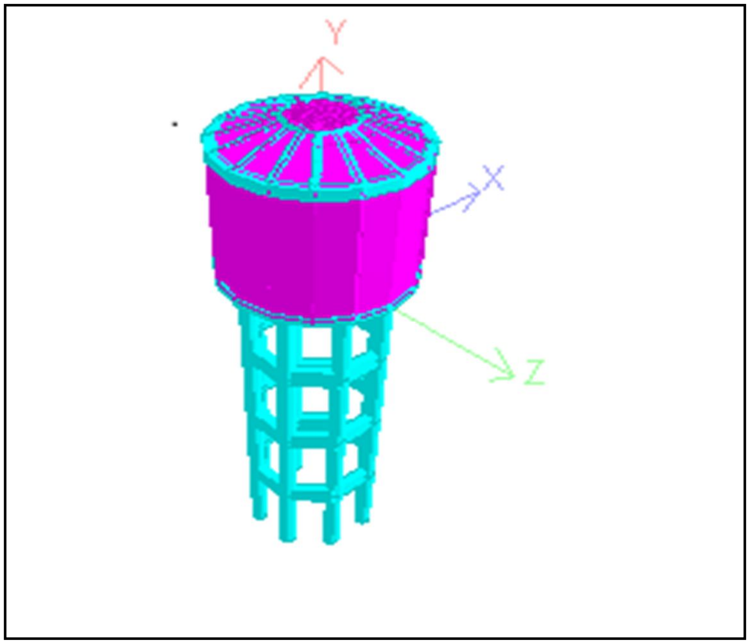

Figure. 1 3D model of water tank

VII. RESULTS

Max nodal displacement for four models is shown below in table-1 and the position of node where max displacement occurred is shown in fig 1.1.
Base shear obtained from analysis for four cases is shown in table-2.
Graphs obtained for peak displacements and base shear are shown in fig1 and fig 2 respectively.
Peak displacements were compared with permissible displacements as per IS: 1893-2002 and are found to be satisfied.

Table 1 Peak Nodal Displacements

Water level (%)	Max Nodal displacement (mm)	
	Hydrostatic	Hydrostatic +sloshing
100% full	0.018	0.026
75% full	0.016	0.022
50% full	0.012	0.019
25% full	0.009	0.014

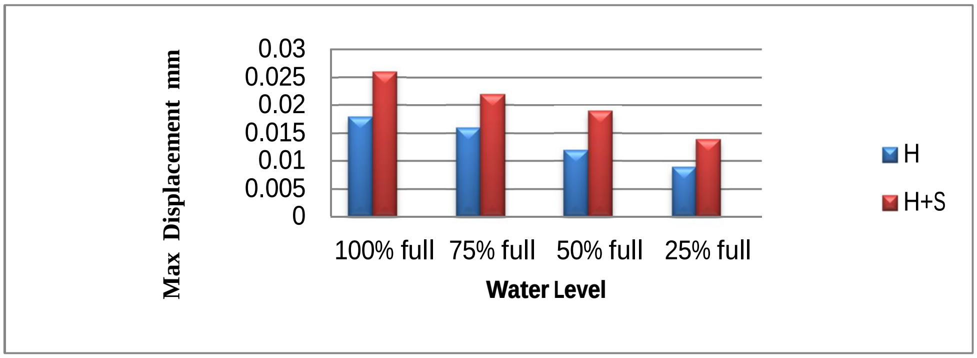

Figure. 2 Water level v/s max nodal displacement

Table 2 Base Shear In Kn

Water level	Base Shear KN
100%	220.49
75%	200.07
50%	168.64
25%	146.52

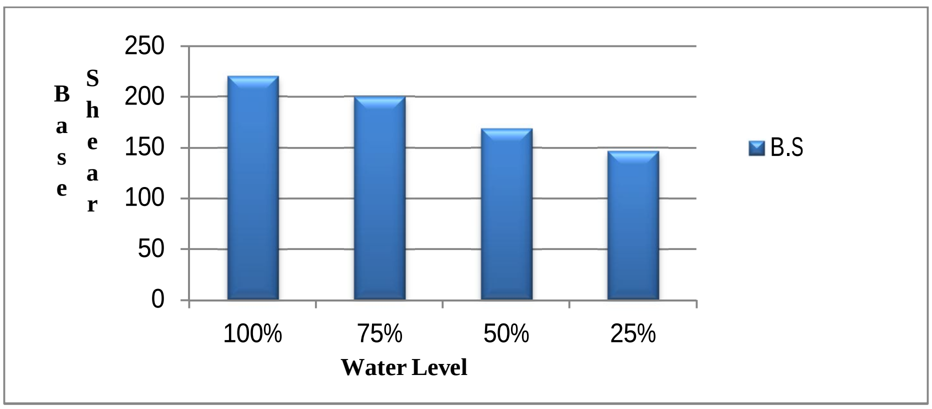

Figure. 3 Water level v/s Base Shear

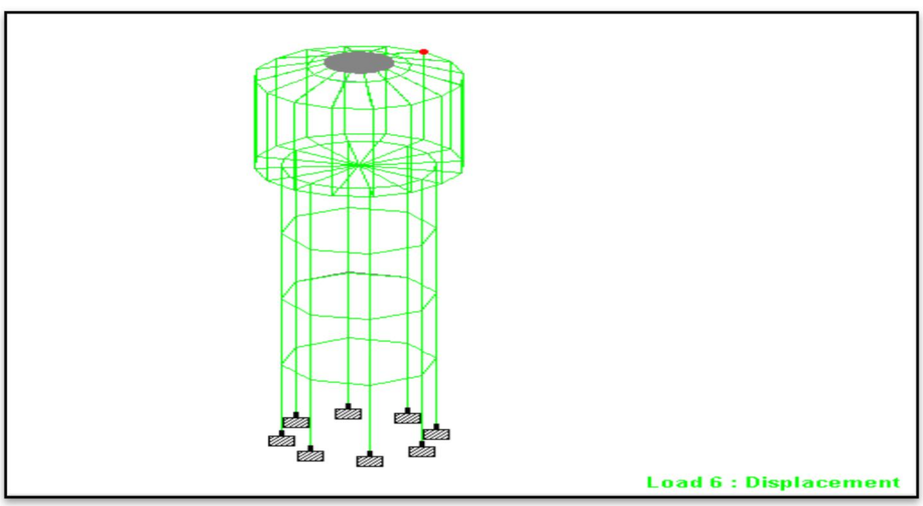

Figure 1.1 Position of node

VIII. CONCLUSIONS

On the basis of results obtained from analysis we can conclude that,

A. Displacement decreases with decrease in water level i.e., it is max for full fill condition and simultaneously goes on decreasing to quarterly fill condition.
B. Displacement considering sloshing effect is more as compared to only hydrostatic effect, thus more focus should be given for sloshing effect during design of elevated tanks.
C. Displacements obtained from the analysis are below maximum permissible displacements for different water levels.
D. Base shear value increases for increasing water level in tanks.

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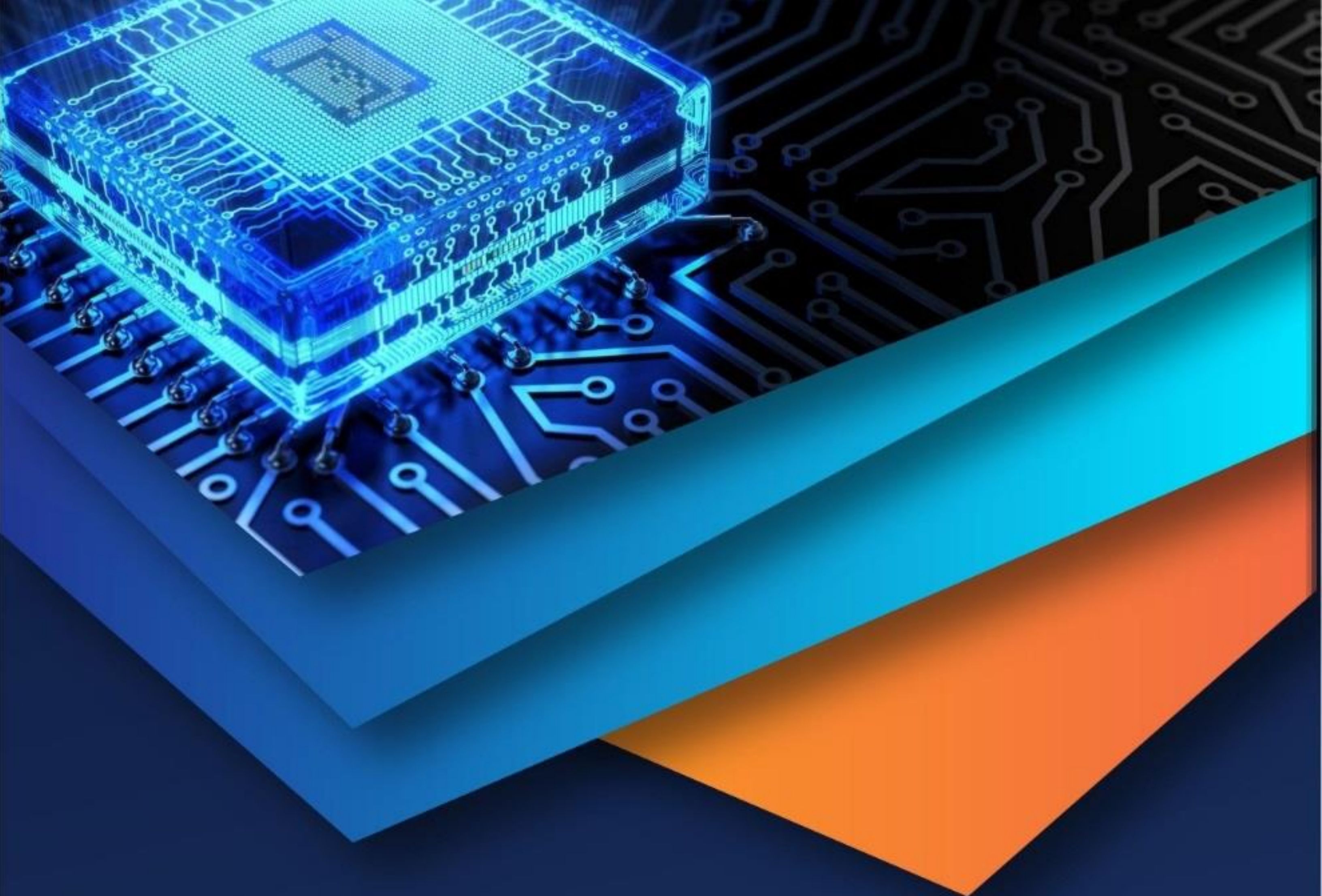

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