SEISMIC BEHAVIOUR OF CIRCULAR WATER TANKS UNDER COMBINED FLUID-STRUCTURE AND SOIL- STRUCTURE INTERACTION EFFECTS

Asha Joseph
Research Scholar, Cochin University of Science and Technology, Kochi, Kerala, India
Glory Joseph
Professor, Cochin University of Science and Technology, Kochi, Kerala, India

ABSTRACT- In this paper, the seismic behavior of ground-supported cylindrical water tanks resting is investigated. The focus of the study is to identify the effect of soil structure interaction on the behavior of the water tank in response to seismic loading. For this purpose, circular tank resting on very dense soil is considered and the seismic response of tank under Northridge earthquake, 1994 was observed by performing the time history analysis. The response parameters are compared with idealized condition of tank with fixed base slab. The study infers that soil structure interaction significantly magnifies the response parameters such as radial displacement, hoop force, bending moment and base shear. The effect of water fill condition on the seismic response of the tank is examined by analyzing two water fill conditions; full fill and half fill.

***Keywords*-fluid – structure interaction, soil- structure interaction, water storage tank, time history analysis, finite element analysis**

INTRODUCTION

By observing the available field reports on the structural performance of tanks during past earthquakes, it can be seen that liquid storage structures are susceptible to damage and eventual collapse. The failure of these structures during earthquakes can lead to substantial economical losses and hence the reliability of these structures against failure under seismic loads is of critical concern.

There are various national and international codes for seismic design of cylindrical liquid storage tanks. ACI 350.3, API 650, NZSEE and Eurocode 8 are most commonly referred ones. All codes and standards suggest mechanical analogs for modelling tank-liquid system, wherein liquid mass is divided into impulsive and convective masses. The impulsive liquid mass vibrate along with the tank wall and convective liquid mass undergoes sloshing motion. Liquid in lower portion mostly contributes to impulsive mass and liquid in upper portion undergoes sloshing motion [Housner, 1963]. Two types of mechanical analogs are available: first one is for tank with rigid walls , that represent tank – liquid system as two mass model [Housner 1963, Veletsos and Yang 1977] and the second one for tank with flexible wall , that represent tank – liquid system as three mass model, in which the effect of wall flexibility is included [Haroun and Housner, 1981 and Veletsos1974]. The properties of the mechanical analogue are corresponding to the tank dimensions and fluid properties. A common feature to all these codes is the clear distinction between the treatment of anchored and unanchored tanks.

Hydrodynamic pressure on tanks under earthquake forces plays an important role in the seismic design of water tanks. In order to make sure that the water tank is capable to withstand any earthquake loads, detailed investigation of fluid structure interaction must be taken into account [Housner, 1963; Kianoush and Chen, 2006; Gareane et al., 2009]. During earthquake the behaviour of any structure is influenced not only by the response of the superstructure, but also by the response of the soil beneath. Structural failures in past have shown the significance of soil-structure interaction (SSI) effects on water tanks [Livaoglu and Dogangun , 2007; ChinmayiandJayalekshmi,2013].

FLUID STRUCTURE INTERACTION

Fluid-structure interaction problems can be investigated by using different techniques such as added mass, Lagrangian, Eulerian, and Lagrangian–Eulerian approaches in the finite element method (FEM) or by the analytical methods like Housner's two-mass representation or multi-mass representations of Bauer [Livaoglu and Dogangun, 2007]. There are two types of FSI simulation: one way, when information from flow simulation is transferred into structure and two way simulation, where data are exchanged between both: fluid and structure.

For fluid structure interaction problems the acoustic and the structural matrices are coupled. In liquid domain, the pressure wave equation governs the hydrodynamic pressure distribution. The velocity of pressure wave is assumed to be infinity as the volume of container is small. The boundary conditions of the Laplace's equation are defined by the dynamic response of the tank structure, which is the combination of the vibration in response to the ground excitation and the deformation in response to the hydrodynamic load. Thus the motion of the liquid content and the dynamic response of the tank structure are coupled together [Feng, 1997].

SOIL STRUCTRUE INTERACTION

The deformations of a structure during earthquake is affected by interactions between three linked systems: the structure, the foundation, and the geologic media underlying and surrounding the foundation. A seismic Soil-Structure Interaction (SSI) analysis evaluates the collective response of these systems to a specified free-field ground motion [Domagala and Lisowski, 2011]. SSI effects can be classified into two: kinematic and inertial interactions. Inertial interaction effects are due to the mass of the foundation-superstructure system, which imparts inertial forces onto the surrounding soil and causes the foundation to experience a response different from the foundation input motion. An analysis with the omission of mass of the structure results in kinematic interaction[Wolf,1985; Wolf and Song,1996; Uma etal.,2013].

To investigate the effects of soil-foundation-structure interaction, the effect of soil can be included implicitly or explicitly. In implicit methods, the effects of the soil are added to the analysis using springs and dampers without modeling the soil itself. Different implicit analysis techniques use different assumptions and are suitable for specific problems. In an explicit analysis method, however, the soil itself is modeled with finite elements. The soil body should be large enough to be accurate and, therefore, it is more time consuming compared to the implicit method[Austin, 2017]

The simulation of the infinite medium in the numerical method is very important in the dynamic soil- structure interaction problems. The near field is modeled using finite elements and the soil in most cases is a semi- infinite medium which can be treated by adding some special artificial boundaries or some special connection elements. A sufficiently large soil model is considered to be adequate to include the effect of soil structure interaction [Wolf,1985; Livaoglu and Dogangun,2007; Domagala and Lisowski, 2011; Clough and Penzin, 2015].

In the present study the effect of soil structure interaction on the seismic response of ground supported circular water tanks is examined by performing time history analysis of circular water tank of 12m diameter and aspect ratio 1.0. Tanks resting on very dense soil is considered and comparison of the results with idealized condition of tank with fixed base slab is also performed. Effect of water fill condition on the seismic behavior is obtained by studying the results of the transient analysis of the tank at full fill and half fill conditions. As it is observed from the previous study that the convective response are very small in comparison to impulsive response, the study focus on the impulsive response parameters alone [Moslemi and Kianoush 2012, Rawat et al. 2015].

GEOMETRIC MODELLING OF WATER – TANK – SOIL SYSTEM

Cylindrical ground supported water tank of 12m inner diameter and 12 high tank is considered for the evaluation of combined SSI – FSI effects on dynamic behavior of concrete water tank. The thickness of tank wall considered is 0.5m and the seismic response of the tank in two water fill conditions are studied; full fill condition and half fill conditions corresponding to the water height of 11m and 6m respectively. The tank is provided with a base slab of 1m thick having 1 m projection around the tank wall. The material properties of tank and water considered are given in Table 1.

Table 1. Material Properties of concrete and water

Concrete			Water	
Density (kg/m^3)	Modulus of Elasticity (GPa)	Poisson's ratio	Density (kg/m^3)	Sonic Velocity (m/s)
2500	27.39	0.16	1000	1483

Time history analyses of the tank resting soil is performed and the results are compared with that of fixed base slab. The properties of soil under consideration for investigation of effect of soil structure interaction on tank response, are given in Table 2 [Livaoglu, and Dogangun, 2007; Kianoush and Ghaemmaghami, 2011].The width and the thickness of the soil medium are taken as five times and three times the diameter of the base slab respectively so that sufficiently large soil mass is available to include the SSI effects [Chinmayi and Jayalekshmi, 2013].

Table 2. Properties of soil

Description	Very Dense soil
Density (kg/m^3)	1900
Modulus of Elasticity (MPa)	500
Poisson's ratio	0.35
Bulk Modulus (MPa)	673.08
Shear wave velocity (m/s)	309.22
Dilatational wave velocity (m/s)	643.68

FE MODELLING OF WATER – TANK – SOIL SYSTEM

The walls of the tank are considered as thin plates made of linearly elastic, homogenous and isotropic material and are assumed to perform transverse bending deflection but no inplane deformation[Hashemi,2013]. For modelling of tank wall in ANSYS, SHELL181 element which is a four-node element with six degrees of freedom at each node is used. FLUID 30 elements with FSI having four degrees of freedom (three translational and pressure) is used for layers of fluid elements in touch with structural elements whereas uncoupled acoustic FLUID 30 is employed for other layers of fluid elements, The fluid flow inside the tank is described by the Navier–Stokes equations, but various assumptions are introduced, such as inviscid and incompressible fluid, irrotational motion. For one-way load transfer coupling, only the structural effect on the acoustic fluid is taken into account, and the structural results are used as the excitation source during the sequential acoustic solution. The base slab and soil medium beneath it are modelled using solid 185 element with 8 nodes having three degrees of freedom at each node. All translations were restricted at the bottom of soil block.Fig.1 gives the finite element model of the tank and water generated in FE software ANSYS. Tank resting on soil is modelled and is shown in Fig.2.

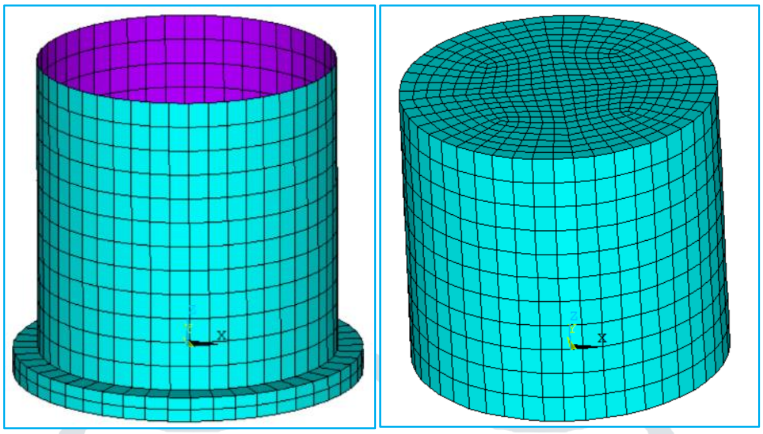


Fig 1: FE model of (a) tank with base slab (b) water

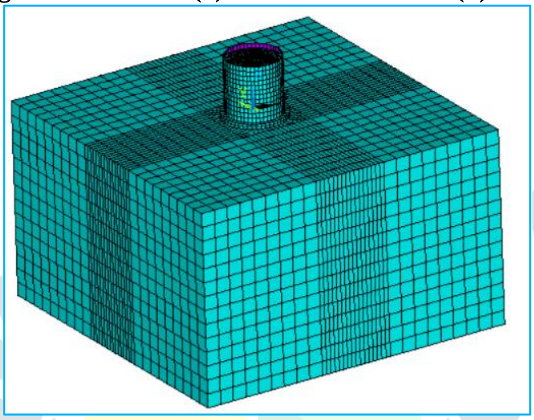


Fig.2 FE model of water filled tank resting on soil

SOIL STRUCTURE INTERACTION EFFECTS ON SEISMIC BEHAVIOUR OF WATER TANK

The tank is subjected to horizontal component Northridge earthquake 1994, having magnitude of 6.7 and peak ground acceleration of 0.583g. First 20s of the acceleration time history is given as the input motion. Since the ratio of peak ground acceleration (PGA) to peak ground velocity (PGV) of Northridge earthquake is less than 0.8, it is considered as low frequency earthquake. The effect soil properties and water fill condition on time history response of maximum radial displacement (control point on the top of tank wall), hoop force, bending moment and base shear developed in the tank wall are noted. Table 3 gives the maximum response parameters of the full fill tank and Table 4 the corresponding values of half fill tank.

Table 3 Response parameters of full fill tank to transient loading

Description	Fixed	Very dense soil
Maximum radial displacement (mm)	1.52	161.4
Ultimate Hoop stress (MPa)	0.95	12.9
Ultimate Normal stress (MPa)	2.26	30.1

Table 4 Response parameters of half fill tank to transient loading

Description	Fixed	Very dense soil
Maximum radial displacement (mm)	0.61	73.43
Ultimate Hoop stress (MPa)	0.72	7.52
Ultimate Normal stress (MPa)	1.19	11.6

From Table 3 and Table 4, it is evident that the response displacement, maximum hoop stress and maximum normal stress of the both full fill and half fill tanks increases when SSI effects are taken into consideration. The maximum radial displacement of the full fill tank in very dense soil is 106.2 times that of tank with fixed base, whereas the corresponding value for tank in half fill condition is 120.4. All the response parameters of tank resting on soil is higher than that of tank with fixed base, indicating the effect of soil structure interaction on the seismic behavior of the tanks. The Fig. 3, Fig.4 and Fig.5 gives the peak hoop force, bending moment and base shear of the full fill and half fill tanks with fixed base and on very dense soil.

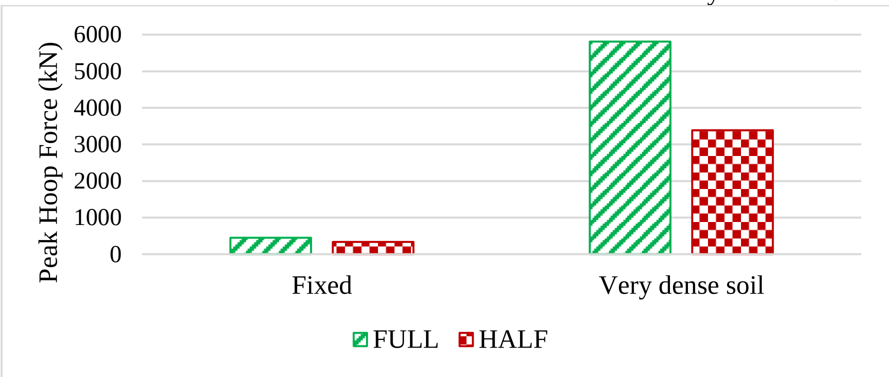


Fig.3 Peak Hoop force of the tank due to transient loading

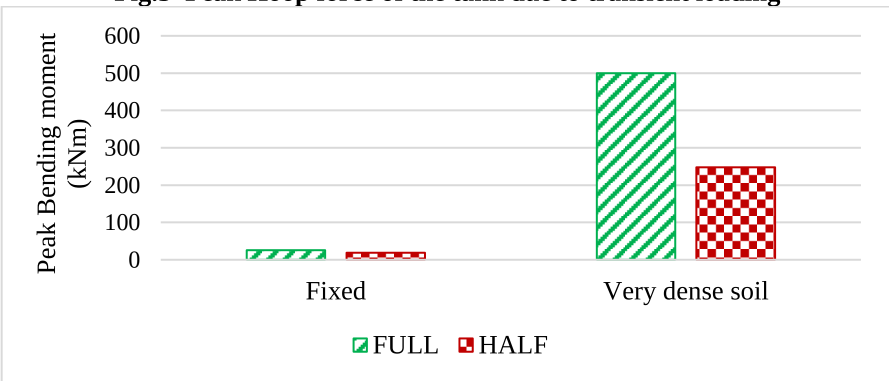


Fig.4 Peak Bending moment of the tank due to transient loading

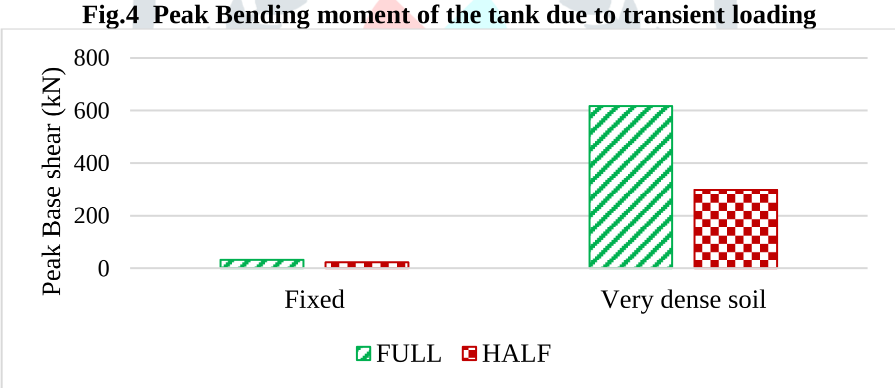
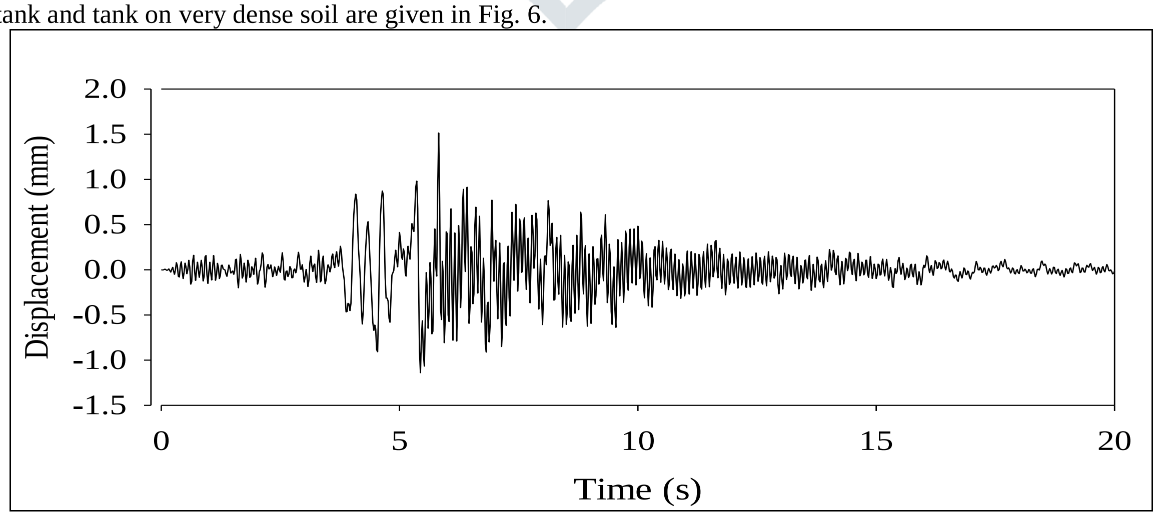
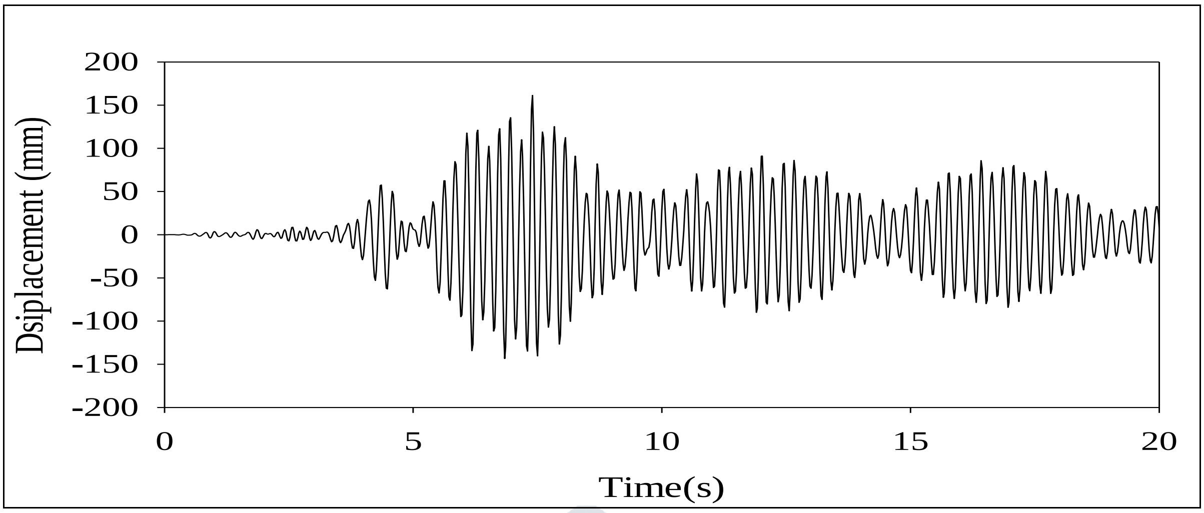


Fig.5 Peak Base Shear of the tank due to transient loading

The three figures, Fig 3- 5, also indicate that SSI effects leads to an increase in response parameters such as hoop force, bending moment and base shear. Peak hoop force and bending moment of full fill tank in very dense soil is 12.93 times of tank 19.35 times of tank with fixed base. Response of half fill tank is found to be less than the full fill tank. The time history plot of radial displacement of the fixed tank and tank on very dense soil are given in Fig. 6.



(a) Tank with fixed base in full fill level



(b) Tank on very dense soil in full fill level

Fig 6: Time history response of the tank on different resting conditions

It can be noticed that the amplitude of response displacement of tank on soil is more than the idealized fixed tank condition, leading to reduction in the frequency of vibration of the tank.

CONCLUSIONS

By performing time history analyses on circular water tank of diameter 12m and aspect ratio 1.0, resting on dense soil and comparing the result with that of idealized tank with fixed base, the following conclusions are made:

1. The maximum value of seismic response parameters such as radial displacement, hoop force, bending moment and base shear of the idealized fixed tank is less than the one resting on the soil considered.
2. The maximum radial displacement of the full fill tank in very dense soil is 106.2 times that of tank with fixed base, whereas the corresponding values for tank in half fill condition are 120.4 . This indicate that SSI significantly amplifies the response parameters.
3. Peak hoop force and bending moment of full fill tank in very dense soil is 12.9 and 19.4 times respectively of tank with fixed base slab.
4. The response of full fill tank to seismic excitation is more than half fill tank under Northridge earthquake
5. As SSI effects significantly magnifies all the response parameters compared to idealized fixed condition, soil structure interaction is to be considered for the accurate evaluation of seismic behavior of water filled tanks.

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