VIBRATION CONTROL OF RECTANGULAR LIQUID STORAGE TANK

[1]M. Subita Deeneshwari, [2]M. Gayathri

[1]Assistant Professor, [2]Assistant Professor
[1]Department of Civil Engineering,
[1]E.G.S Pillay Engineering College, Nagapattinam, Tamil Nadu, India

***Abstract*—Vibration control of liquid storage tanks for chemicals, water etc. is of great importance during earthquake seismic response considering safety factor. During earthquake, seismic excitations are generated, which can cause damage to the tank as well as loss of life and property. In chemical storage tanks, release of toxic chemicals or liquefied gases from the damaged tanks can lead to disastrous effects. Thus estimation of sloshing frequency of liquid in tank, hydrodynamic pressure on wall and proper analysis of fluid-tank interaction under seismic excitations is required for efficient design of storage tanks. In this present study, the behaviour of 3-D rectangular tank is investigated using ANSYS (Version 12.0) software, subjected to various seismic excitation frequencies, different fill levels in tanks.**

***Index Terms*— fluid-tank interaction; vibration; sloshing; Seismic response; ANSYS.**

I. INTRODUCTION

Liquid storage tanks (LST) are important role in human societies. The main component of LST services in human life through the fire-fighting systems and cooling systems in many industries like nuclear power plants, chemical plants. They are used in many industrial facilities for storage of water, oil, chemicals, and liquefied natural gas. The failure of many LST during an earthquake has implications far beyond the mere economic value of the tanks and their contents. Unlike other structures liquid storage tank structures are in contact with liquid and their response under seismic load is quite different. Apart from the hydrostatic pressure the seismic force imparts hydrodynamic pressure. This liquid structure interaction is of interest for the design of rectangular tanks and due consideration should be given during design of the structure.

The dynamic behaviour of a free liquid surface depends on the excitation type and its frequency, container shape, liquid motion. The excitation to the tank can be periodic, impulsive, sinusoidal and random. It can create lateral, planar, non-planar, rotational, irregular beating, parametric, symmetric, asymmetric, pitching/yaw or combinational effects. The aim of this study is to develop a finite element model that includes the effect of the liquid inside the tanks and large deformation of shell using existing finite element software and to study the dynamic buckling behavior of the tanks.

II. SLOSHING OF LIQUID STORAGE TANK

Sloshing can be defined as any movement of the free liquid surface inside other object. This motion can be caused by disturbance to partially filled liquid containers. For sloshing, the liquid must have a free surface to constitute a slosh dynamic problem, where the dynamics of liquid can interact with container to alter the system dynamic significantly. Sloshing behaviour of liquids within containers represents thus one of the most fundamental fluid-structure interactions.

Liquid sloshing and free surface motion is a common problem affecting not only the dynamics of flow inside the container, but also the container itself. The containers carrying the liquids, tanks used to store liquids have to withstand the complex dynamics of the transportation system, different ground motions which they are serving. This unavoidable motion of the container and the forces associated on the liquid inside it results in mostly violent and disordered movement of the liquid/gas (mostly air or vapour) interface or free surface. Containers having liquid with a free surface should be moved with proper attention to avoid spilling and other damages.

III. FLUID STRUCTURE INTERACTION

Fluid-Structure Interaction refers to the coupling of unsteady fluid flow and structural deformation. It is a two-way coupling of pressure and deflection. Its application includes airbag modeling, fuel tank sloshing, heart valve modeling, helicopter crash landings, etc. Purpose of studying FSI is that fluid mechanics may affect and be affected by the structural mechanics, and vice-versa. Hence in this case the coupling of the fluid's pressure and the motion of the structure is essential.

IV. NUMERICAL ANALYSIS OF LIQUID STORAGE TANK USING LUMPED MASS MODEL

When tank is excited by gravity force, a part of liquid moves independent of the tank, called the convective mass or sloshing mass (m_c). This mass lies towards the upper part of the tank. The second mass which also does not move in coordination with tank called as impulsive mass (m_i). This mass comes into picture when the flexibility of the tank wall is considered. This mass lies around the central portion of the tank. The third mass which moves in coordination with the tank called as rigid mass (m_r). This mass lies just below the central portion of the tank. The corresponding stiffness constants have been worked out according to the properties of the tank wall and liquid mass.These masses when applied to blast load, induces substantial hydrodynamic forces on the tank wall which in turn generates design forces such as base shear and overturning moments. The base shear is used for designing of the isolation system. The overturning moment develops high stress on one side of the tank and may cause uplift of anchor on the other side. Due to overturning moment buckling stress also develops on the tank wall. The designing becomes more complex when the liquid-structure interaction is taken into consideration.

V. STRUCTURAL MODEL OF LIQUID STORAGE TANK

A structural model of ground supported liquid storage rectangular tank with fixed base is shown in Figure 1 and the stick model is shown in the Figure 2. The liquid masses sloshing mass, impulsive mass and rigid mass are referred as m_c, m_i, m_r respectively. The stiffness constants of the springs which are associated with convective mass and impulsive mass are k_c and k_i respectively. The damping constants which are associated with convective mass and impulsive mass are c_c, c_i respectively.

The fixed base tank has two-degrees-of-freedom which are associated with sloshing mass and impulsive mass where as in isolated tank there are three-degrees-of-freedom, the new degree of freedom is associated with the rigid mass or tank base. u_c, u_i, u_r are referred to as the absolute displacement of these masses. The liquid lumped masses can be evaluated by using the chart given by Haroun.

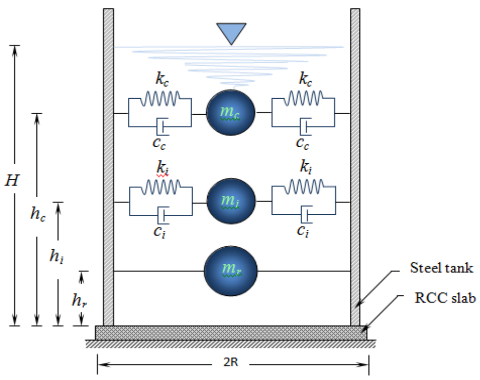


Fig. 1. Non-isolated liquid lumped mass model

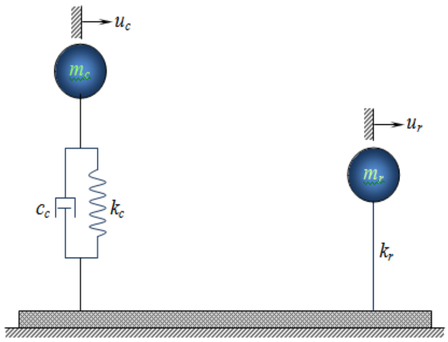


Fig. 2. Stick model of non-isolated tank

The chart values corresponds to the aspect ratio of tank, S , $H/R$and t_h/R. (where H is the height of liquid level and B is the breadth of the tank).

The natural frequencies of sloshing mass, impulsive mass are expressed as

$$\omega_c = \sqrt{1.84\left(\frac{g}{R}\right)\tanh(1.85S)} \qquad (5.1)$$

$$\omega_i = \frac{P}{H}\sqrt{\frac{E}{\rho_S}} \qquad (5.2)$$

Where, E and ρ_s are modulus of elasticity and density of tank wall respectively and g is the acceleration due to gravity.

The equivalent stiffness constants and damping coefficients of the convective and impulsive mass are expressed as

$$k_c = m_c\omega_c^{\ 2}, \qquad (5.3)$$

$$k_i = m_i\omega_i^{\ 2} \qquad (5.4)$$

$$c_c = 2\xi_c m_c \omega_c, \qquad (5.5)$$

$$c_i = 2\xi_i m_i \omega_i \qquad (5.6)$$

Where ξ_c and ξ_i are damping ratio of convective mass and impulsive mass respectively

VI. FINITE ELEMENT MODELING

The basis of the finite element method is the representation of a body or a structure by an assembler of subdivisions called finite elements. For many engineering problems analytical solution are not suitable because of the complexity of the material properties, the boundary conditions and the structure itself. Finite element analysis program occupy a major computational activity. A large number of general purpose program packages developed in university environments and commercial software houses are now available for stress analysis of complex shapes, material properties and of complicated boundary condition in several areas of engineering design. ANSYS is being used for analysis in this thesis work. Model the rectangular tank by using shell element. And fill the liquid into the tank by using the fluid element in ANSYS. The model fluid with tank would be developed by ANSYS software for predicting characteristics of the fluid tank system. A key step of the finite element method for numerical computation is mesh generation one is given a domain (such as a polygon or polyhedron; more realistic versions of the problem allow curved domain boundaries) and must partition it into simple "elements" meeting in well-defined ways. There should be few elements, but some portions of 77the domain may need small elements so that the computation is more accurate there. All elements should be well shaped. ANSYS modeling is generally performed by mapped meshing or free meshing. In this thesis work free mesh modeling is adopted.

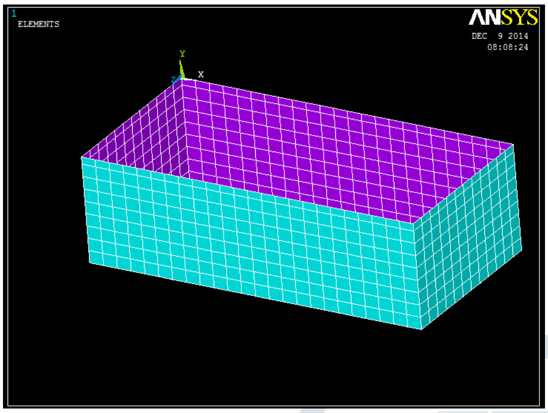
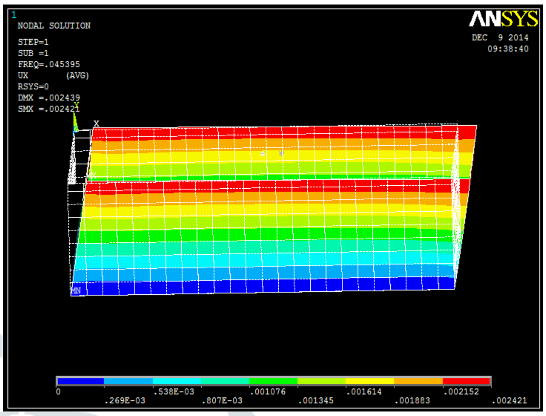


Fig. 4. Tank model with meshing



a. Deformation contour at first mode

Fig. 5. Natural frequency and mode shape of tank

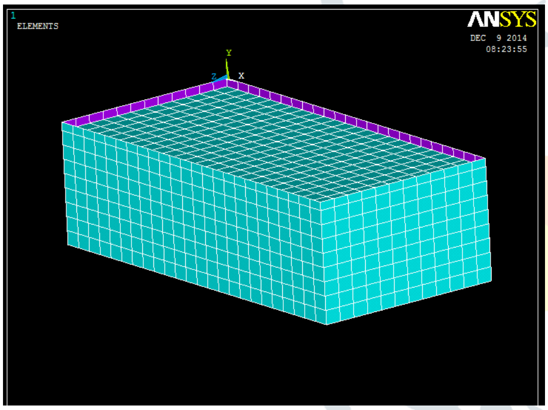
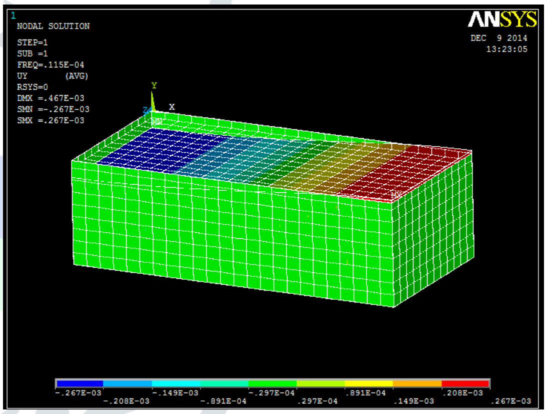


Fig. 6. Fluid tank model with meshing



a. Deformation contour at first mode

Fig. 7. Natural frequency and mode shape of tank with fluid

VII. RESULT AND DISCUSSION

Table 7.1: General information of studied tank parameters

SL NO	**Tank model parameters**			
	Geometrical parameters	*Value*	*Material Parameters*	*Value*
1	Height of tank (H) in meter	14.6	Fluid density (γ), kg/m^3	1000
2	Length of tank (L) in meter	48.8	Fluid bulk modulus(K), Mpa	2.15
3	Breadth of tank(B) in meter	37.6	Steel density, kg/m^3	7860
4	Height of water (h) in mm	1000	Poisson ratio of steel	0.3
5	Thickness of wall (t_w) in mm	3	Modulus of steel, Mpa	2

Table .7.2: Tank system natural periods of the four modes

SL NO	*Volume of fluid m^3*	**Modal results**			
		Natural period (Hz)			
		Sloshing modes			
		First	*Second*	*Third*	*Fourth*
1	$24.95X10^3$	0.04531	$0.153x10^{-3}$	$0.411x10^{-3}$	$0.593x10^{-3}$

Table 7.3: Fluid /tank system natural periods of the modes

SL NO	*Thickness of wall m*	**Modal results**			
		Natural period (Hz)			
		Sloshing modes			
		First	*Second*	*Third*	*Fourth*
1	0.03	$0.115x10^{-4}$	-	-	-

VIII. CONCLUSION

The finite element micro models provide increased possibilities for a more detailed study of the stress, strain and available strength. In this way better understanding of their mechanical behaviour is possible, by detecting their critical areas and contributing to the improvement of their design. ANSYS is being used for analysis in this thesis work. The test results were used to calibrate the initial finite element model. Another finite element model was developed test the performance of a similar sub assemblage with improves design detailing to overcome deficiencies identified in the first test.

REFERENCES

[1] Amiri, H. Saeed Reza Sabbagh-Yazdi (2012) “Influence of roof on dynamic characteristics of dome roof partially filled with liquid”, journal of thin-walled structures.

[2] Yung, H.C, et al. (2007), “Sloshing behaviour of rectangular and cylindrical liquid storage tank subjected to harmonic and seismic excitation”, Journal of earthquake engineering and structural dynamics.

[3] Mirzabozorg, H. et al. (2012),“Free surface sloshing effect on dynamic response of rectangular storage tank”American journal of fluid dynamics,

[4] Mahmood hosseini et al. (2003) “simplified dynamic analysis of sloshing in rectangular tanks with multiple vertical baffles”. Journal of water sciences research.

[5] Birhan U. Guzel et al. (2004), “Control of liquid sloshing in flexible containers: part 1. Added mass”, 15 Australasians fluid mechanics conference