REVIEW ON STRUCTURAL PERFORMANCE OF WATER TANKS UNDER DYNAMIC LOADING

Shilja Sureshkumar[1], Asha Joseph[2]

[1]PG Student, Department of Civil Engineering, FISAT, Angamaly, India
[2]Assistant Professor, Department of Civil Engineering, FISAT, Angamaly, India

---

Abstract - *Liquid storage tanks are used to store different type of materials such as water, oil and gas etc. Damaged tanks containing any hazardous material causes environmental pollution. Failure of water tanks results very destructive hazards on life and property. Seismic study of water tanks are essential for strengthening the tank's performance and thereby damages can be reduced. Seismic analysis of water tanks are much complicated due the fluid structure interaction of the system. Fluid inside the tank are divided as impulsive and convective liquid mass, and both are induced hydrodynamic pressure on tank wall and base. Seismic energy is transferred to the fluid from ground due to movement of tanks. Soil structure interaction is another parameter which significantly effect on tank's performance. Interaction of tank with surrounding soil structure will be different, based on soil properties such as elastic properties, cohesion, angle of friction etc. Response of elevated tanks and ground supported tanks are different, based on their support conditions provided. Container height, geometry, soil denseness, types of foundation, damping parameters are some of the factors influencing tank response under different types of loadings. Variations in the structural performance of water tanks due to these factors are discussed in this paper based on various literatures studies.*

Key Words: Fluid structure interaction, Soil structure interaction, Sloshing, Seismic response, Impulsive and Convective liquid mass,

1. INTRODUCTION

The forces due to earthquakes and sloshing of fluid inside the tanks are important considerations in the design of civil engineering structures. Seismic safety of liquid-filled container is of great concern because of the potential adverse of economic and environmental impacts associated with failure of the containers and liquid spillage on the surrounding area. As a result, a considerable amount of research effort has been devoted for a better determination of the seismic behavior of liquid tanks and the improvement of associated design codes.

In a liquid storage tanks, liquid in the lower region of the tank behaves as a liquid mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induced impulsive hydrodynamic pressure on tank wall and tank base. Liquid mass in upper region of the tank undergo sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure. Housner developed a spring mass model system for representing tank and fluid interaction. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented and parameters of this model depends on geometry of the tank and its flexibility.

In early studies of tanks on its seismic response liquid and the tank together is considered as rigid body and attention was focused only on dynamic response of tank's liquid content. After some earthquakes such as Niigata, (1964); Alaska, 1964: and Park field, (1966); which caused severe damage to liquid storage tanks; it was observed that rigid tank concept for modelling of tank could not be adopted for analysis of the tanks. Interaction between the tank wall and the liquid inside the tank has to be taken in the seismic analysis of liquid storage tanks since the tanks itself deform under earthquake loads. Seismic analysis of liquid storage tank is complicated due to the complicated fluid structure interaction (FSI) of the system. From engineer's point of view storage tanks should maintain sufficient strength and resist all the forces acting on the tank with much safety. The past earthquakes studies shows that it is very necessary to study seismic response of water tanks.

Liquid storage tanks involve various types of failure mechanisms. Some of them are shell buckling, sloshing damages, support failure, base sliding etc. Past observations of the seismic performances of the liquid storage tanks have revealed that storage tanks failures are manifested in a wide variety of ways. Different failure mechanisms are possible, depending upon the configuration of tank geometry, possible fluid-structure-soil interaction, and a lot of other factors such as the tank material, type of support structure, etc. On the other hand, characteristics of earthquakes are also significantly influence the dynamic response of liquid storage tanks. Failure modes of rectangular tank are significantly different from those of cylindrical, spherical, and conical tanks. Similarly, the failure patterns for rigid tanks considerably differ from those for flexible tanks. Different combinations of above possible parameters make the failure mechanism more complex.

A structure interacts with its surrounding soil and this causes changes in effect of seismic waves. In seismic analysis, interaction of structure and soil should be considered. Dynamic response of soil-structure system is a function of two factors, dynamic parameters of site and forces. Dynamic parameters of the site include soil modulus of elasticity, soil Poisson's coefficient, and damping in soil. Damping is also divided into two, internal and radiation damping. Internal damping is caused by passage of vibration waves through soil and can be considered as factor of energy loss due to residue in soil but radiation damping causes energy loss due to emission of waves from foundation of the structure to half-space. Proper analysis of dynamic response of soil-structure interaction system requires recognition of different components of the system and excitations which include determination of free field motion i.e. earth motion without presence of structure and calculation of scattering of earthquake waves due to soil and structure interaction.

Type of soil has considerable effect on behavior of soil and structure interaction. Fine-grained or softer soils have higher interaction with structure. When the surrounding soil is softened i.e., shear modulus of the surrounding soil decreases, displacements and the term of damping motion of tank is elongated. Therefore, one should be careful that type of the surrounding soil is one of the important parameters in design and should be considered as important. With decrease of shear modulus of the surrounding soil, vertical stresses in different parts of tank also increases. But because the tanks used in the practical projects have been designed uneconomically, stresses don't increase to such extent that they crack wall of tank and consequently leakage of water from wall of the storage tank. Earthquake forces for soft soil is about 18-19% greater than that of medium soil, earthquake forces for medium soil is about 26-27% greater than that of 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.

2. LITERATURE REVIEW

George W. Housner [1963] discussed the relation between the motion of water with respect to tank & motion of whole structure with respect to ground. He had considered three basic conditions of tank for the analysis.ie fully filled, empty & partially filled. He said that if water tank is fully filled condition i.e. without free board then the sloshing effect of water is neglected and if the tank is empty then there is no sloshing effect. In the above two cases water body in the tank will behave as one-mass structure. But in third case i.e. water tank is partially filled, the effect of sloshing should be considered. In that case the water body will behave as two-mass structure. Finally he concluded 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.

Sudhir Jain K. and U. S. Sameer [1991] revised IS code for seismic design of elevated water tank. They derived simple expressions, which allow calculations of staging stiffness, and hence the time period, while incorporating beam flexibility. They give the value of performance factor 3 for the calculation of seismic design forces. The earthquake design criteria will be incomplete, unless clear specifications are include about how to calculate the time period. A method for calculating the staging stiffness which including beam flexibility and without having to consider finite element type analysis has been presented. This method is based on well-known portal method which has been suitably developed to incorporate the beam flexibility and the three dimensional behaviour of the staging.

Anestis S. and Veletsos et al. [1992] focussed on dynamic response of flexibility supported liquid storage tanks. Also critical responses are evaluated for harmonic and seismic excitations over wide ranges of tank proportions and soil stiffness, and the results are used to elucidate the effects of soil-structure interaction. It is shown that soil-structure interaction may reduce significantly the critical responses of broad tanks, but may increase those of tall, stiff tanks that have high fundamental natural frequencies. It is further shown that for tanks with height-to-radius ratios of the order of 1.5 or less, the higher modes of vibration are insignificant contributors to the overall response.

Medhat A. and Haroun et al. [1992] were studied dynamic soil-tank interaction under horizontal seismic excitations. It has a profound effect on the amplification of hydrodynamic forces and moments exerted on tank structure. Computer programs are implemented to evaluate the system response to ground earthquake motions. The results shows that interaction of the tank and foundation soil magnifies the tank response, and it is a factor of both the shear-wave velocity of soil (higher magnifications for soft soils) as well as the geometric properties of tank (higher magnification for tall tanks). In addition, the results indicate that shell flexibility has a pronounced influence on the dynamic behaviour of tanks; it contributes to the magnification of pressures developed in liquid and exerted on tank, thereby increasing the base shear and overturning moment, especially for stiff soils.

Sudhir K. Jain and Sajjad Sameer U [1993] modify and give suggestions in IS: 1893-1984. They considered all the suggestion given by Sudhir Jain & Medhekar and added some extra suggestion – (1) in the seismic analysis, the effect of accidental torsion must be included. (2) An expression for calculating sloshing height of water may be introduced in the code. (3) The effect of hydrodynamic pressure for tanks with rigid wall and the tanks with flexible wall should be considered separately, as force in the tanks with flexible wall is higher than those tanks with rigid wall. (4)The stresses due to hydrodynamic pressure in the tank wall and base should be given in the form of table.

Praveen K. Malhotra [1998] conducted research on seismic strengthening of tanks using energy dissipating anchors. Numerical results are presented for two steel tanks supported on soil bed and anchored to the surrounding ring foundation by steel hysteretic dampers. During low-level shaking, the tanks behave as fully anchored systems; during strong shaking, the base of the tanks uplifts, and causing dissipation of seismic energy by inelastic action of the steel dampers. Energy-dissipating anchors can increase the effective damping in liquid-storage tanks to more than 20%.

M. K. Shrimali and R. S. Jangid [2003] conducted research on seismic response of elevated liquid storage steel tanks. These tanks are isolated by the linear elastomeric bearings under real earthquake ground motion. Two different isolated tank models are considered in which the bearings are placed at the base and top of the steel tower structure. The continuous liquid mass of the tank is modelled as lumped mass, it is known as sloshing mass and impulsive mass modelled as rigid mass. Depending upon the properties of the tank wall and liquid mass the corresponding stiffness constant associated with these lumped masses have been worked out. In this model the mass of steel tower structure is lumped equally at top and bottom. Since for the isolated tank system damping matrix is non-classical in nature, Newmark's step-by step method is used to obtain the seismic response. The response of two types of tanks, namely slender and broad tanks, is obtained and a parametric study is carried out to study the effects of important system parameters on the effectiveness of seismic isolation. The various parameters considered are the tank aspect ratio, the time period of tower structure, damping and time period of isolation system. It has been shown that the earthquake response of the isolated tank is significantly reduced. Further, it is also concluded that as compared to flexible tower structure, the isolation is more effective for the tank with a stiff tower structure.

J. Z. Chen and M. R. Kianoush [2004] studied the influence of different seismic zones on response of concrete tanks. The response of three different tanks subjected to three different time history ground motions located in different seismic zones are studied. They proposed a new procedure based on sequential analysis to determine hydrodynamic pressures for rectangular tanks. The effect of wall flexibility on impulsive pressures is considered in this method. The behaviour of three types of open top tanks is studied under seismic ground motions are studied. The tanks for this study are classified as shallow, medium and tall tanks. Three suites of time history representing low, moderate and high earthquake zones are used for dynamic time history analysis. It is concluded that a lumped mass approach cannot realistically represent the true behaviour of concrete liquid storage tanks. The dynamic response of liquid storage tanks determined based on the current design approach in terms of base shear is too conservative. This is mainly due to the inaccuracy in the determination of equivalent height for the impulsive mass of the liquid. It is also concluded that the hydrodynamic load is highly dependent on the input of ground motion.

O. R. Jaiswal and S. K. Jain [2005] recognizing the limitations in the provision of IS: 1893-1984 and give some suggestions. 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. Expressions for convective hydrodynamic pressure are corrected. Simple expression for sloshing wave height is used. New provisions are suggested for considering the effect of vertical excitation and to describe critical direction of earthquake loading for elevated water tanks with frame type staging.

R. Livaoglu [2007] evaluate the dynamic behaviour of fluid-rectangular tank- soil/foundation system with a simple and fast seismic analysis procedure. Housner's two mass approximations are used for fluid and cone model is used for soil/foundation system. This approach can determine; displacement at the height of the impulsive mass, the sloshing displacement and base forces for the soil/foundation system conditions including embedment and incompressible soil cases. In addition to this, some comparisons are made on base forces and sloshing responses for the cases of embedment and without embedment conditions by changing soil/foundation conditions. The results shows that displacements and base shear forces are generally decreases with decreasing soil stiffness. However, embedment, wall flexibility and SSI did not affect the sloshing displacements.

Halil Sezen and Livaoglu et al. [2007] evaluate the seismic performance of tanks and investigate the parameters influencing the dynamic behaviour. Simplified and finite element dynamic analyses of the tanks are carried out including the effect of liquefied gas–structure interaction using a ground motion recorded at a nearby site. The dynamic analysis are carried out by a simplified three-mass model and a finite element model. From the study it is confirmed that the axial and lateral strength of the columns supporting the two nearly full tanks were not sufficient to resist the demand imposed during the earthquake. Also based on observed results an elastic response is predicted for the columns which supporting the undamaged 25% full identical tank.

R. Livaoglu and A. Dogangun [2007] investigates the influence of foundation embedment on the seismic behaviour of fluid-elevated tank-foundation–soil system with a structural frame supporting the fluid containing tank. The sloshing effects of the fluid inside the tanks and soil-structure interaction of the elevated tanks located on six different soils were included in the analyses. The models were analysed for the foundations with and without embedment. It was observed that the tank roof displacements were affected significantly by the embedment in soft soil, however, this effect was smaller for stiff soil types. Except for soft soil, embedment did not have any effect on the other response parameters, such as sloshing displacement.

Gareane A. I. and Algreane et al. [2008] studied soil & water behaviour of elevated concrete water tank under seismic load. They have chosen seven cases to make comparisons with direct nonlinear dynamic analysis, mechanical models with and without soil structure interaction (SSI) for single degree of freedom (SDOF), two degree of freedom (2DOF), and finite element method (FEM) models. Soil structure interaction (SSI) and fluid structure interaction (FSI) have been analysed using direct approach and added mass approach respectively. The result shows that soil structure interaction has significant effect in shear force, overturning moment and axial force at the base of elevated tank.

A.R Ghanemmaghami and M.R Kianoush [2010] investigates on effect of wall flexibility on dynamic response of rectangular tank under horizontal and vertical ground motions. Two different finite-element models corresponding with shallow and tall tank configurations are studied using the scaled earthquake components of the 1940 El-Centro earthquake record. The containers bottom face are assumed fixed to the rigid ground. Fluid-structure interaction effects on the dynamic response of liquid storage inversely proportional to the height of supporting system and directly proportional to the capacity of water tank. Seismic forces are higher in soft soil than medium soil, higher in medium soil than hard soil.

M. Moslemi and M.R. Kianoush [2012] investigates the dynamic response of cylindrical open top ground-supported water tanks. The main focus of this study is to identify the major parameters affecting the dynamic response of such structures and to address the interaction between these parameters. Parameters considered for the study are sloshing of liquid free surface, tank wall flexibility, vertical ground acceleration, tank aspect ratio, and base fixity. Dynamic results obtained from rigorous FE method are compared with those obtained based on ACI code provisions. Both time history and free vibration analyses are carried out on concrete tank models with different aspect ratios. It is concluded that the current design procedure based on ACI code provisions in estimating the hydrodynamic pressure is too conservative. Finite element method can be accurately employed in both free vibration and transient analysis

of ground supported cylindrical tanks.

M. V. Waghmare and S.N.Madhekar [2013] studied behaviour of tank under sloshing effect. Different parameters have been considered such as height of container, depth of water in tank (30%, 50%, 70% and full) and height of staging etc. It is observed that Sloshing of water in tank depends not only on the volume of water in tank but also on staging height and aspect ratio (h/D).

Uma Chaduvulaa and Deepam Patela et al. [2013] investigates Fluid-Structure-Soil Interaction Effects on Seismic Behaviour of Elevated Water Tanks. An experimental investigation for a 1:4 scale model of cylindrical steel elevated water tank has been carried out on shake table facility at CSIR-SERC, Chennai. Experimental study on water tank consist of combined vertical, horizontal and rocking motions. For this study a synthetic seismic excitation for 0.1g and 0.2g accelerations, with increasing angle of rocking motion are considered. When earthquake acceleration increases, convective base shear and base moment values are increases, but decreases with increasing angular motion.

Naveen V M and Sanya Maria Gomez [2015] studied on hydrodynamic effect on RC elevated tank. The ductility demand for beams are determined separately in order to determine the safety of sections. Seismic analysis of tank carried out in ANSYS 14.5 software. It is found that, due to the influence of hydrodynamic effects, ductility demand on staging increases.

Dona Rose K J and Sreekumar M et al. [2015] investigates the behaviour of overhead tanks under dynamic loading. Tanks of various capacities with different staging height is modelled using ANSYS software. The analysis is carried out for two cases i.e., tank full and half level condition. The sloshing effect along with hydrostatic effect are considered for the study. It is concluded that the peak displacement from the time history analysis increases with staging heights. But the displacement first decreases and then increases with tanks are taken into account incorporating wall flexibility. The results show that the wall flexibility and fluid damping properties have a major effect on seismic behaviour of liquid tanks and should be considered in design criteria of tanks.

Suchita Hirde and Manoj Hedaoo [2011] conducted research on seismic 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. They concluded that seismic forces are directly proportional to the Seismic Zones. The base shear values from time history analysis were increases as staging height increases. Also, the base shears decreases and then increases with capacity. It is also observed that, base shear for half capacity tanks are lesser as compared to full capacity tanks under same staging condition.

Neeraj Tiwari and M. S. Hora [2015] studied transient analysis of elevated intze water tank- fluid- soil system. To evaluate the principal stresses in different parts of the tank and supporting layered soil mass 3D interaction analysis of intze type water tank-fluid-layered soil system is carried out using ANSYS software. The resultant deflections, Von-mises stress, natural frequency of the tank are calculated and also evaluate acceleration by Transient analysis under different filling conditions of the intze tank. It is observed that the natural frequency of the interaction system decreases as the weight of water increases in the tank and hence failure criteria will be different for different filling condition.

Rupachandra J. Aware and Vageesha et al. [2015] conducted research on effect of container height on base shear of elevated water tank. Analysis is carried out by using STAAD-PRO software. It is observed that the base shear increases with increase in container height. And by varying zone, Base shear successively increases from zone II to V.

Yonghui Wang and J.Y. Richard Liew et al. [2015] studied structural performance of water tank under static & dynamic pressure loading. The loading was applied using hydraulic actuator/dropped projectile on an inflated high pressure airbag to assert static/dynamic pressure on the specimens. The failure modes and maximum resistance of the specimens were obtained from the test and compared to the numerical results. It was found from the static pressure test that, tank with full filled water level condition exhibited up to 31% increase in flexural resistance under static loading as compared to the empty water tank with the same material and geometry.

3. CONCLUSIONS

From the literatures it is find out that, structural performance of water tanks depends a lot of factors which includes, fluid structure interaction, soil structure interaction, type of supports, wall flexibility, presence of dampers, staging height, water fill conditions etc. Failure of water tanks are caused by various reasons. The main problem is water tanks are not much safe under different loading conditions due to lack of its strength and capacity to withstand the worst conditions. Hence design a water tank which provide much safety and strength is a challenging task for the engineers. For this, it is important to know the tank response under various loading, and its failure patterns.

REFERENCES

[1] George W. Housner, "The Dynamic Behaviour of Water Tank" *Bulletin of the Seismological Society of America,* (1963) Vol. 53(2), (381-387).

[2] K Sudhir Jain and U.S Sameer, "Seismic Design of Frame Staging For Elevated Water Tank" *Ninth Symposium on Earthquake Engineering,* (1990), Vol1 (12), (14-16).

[3] S. Anestis and Veletsos et al, "Dynamic response of flexibility supported liquid- storage tanks", *Journal of Structural Engineering-ASCE,* (1992), Vol. 118(1), (264-283).

[4] A. Medhat and Haroun et al, "Parametric study of seismic soil- tank interaction I: horizontal excitation", *Journal of Structural Engineering-ASCE,* (1992), Vol. 118(3), (783-797).

[5] Sudhir K. Jain and M. S. Medhekar, "Proposed provisions for aseismic design of liquid storage tanks", *Journals of structural engineering*, (1993), Vol.-20(3).

[6] Praveen K. Malhotra, "Seismic strengthening of liquid storage tanks with energy dissipating anchors", *Journal of Structural Engineering-ASCE,* (1998), Vol. 124(4), (405-414).

[7] M.K. Shrimali and R.S. Jangid, "Earthquake Response of Isolated Elevated Liquid Storage Tank" (2003).

[8] J. Z. Chen and M. R. Kianoush, "Response of concrete liquid containing structures in different seismic zones",*13th world conference on earthquake engineering,* (2004), PN (1441)

[9] Sudhir K. Jain and O. R. Jaiswal, *Journal of Structural Engineering*, (2005) Vol-32 (9).

[10] R. Livaoglu, "Investigation of seismic behaviour of fluid-rectangular tank-soil/foundation systems in frequency domain ", *Soil dynamics and earthquake engineering- ELSEVIER,* (2008), (132-146)

[11] Halil Sezen and Livaoglu et al. "Dynamic analysis and seismic performance evaluation of above ground liquid- containing tanks", *Engineering structures- ELSEVIER,* (2008), (794-803).

[12] R. Livaoglu and A. Dogangun, "Effect of foundation embedment on seismic behaviour of elevated tanks considering fluid- structure –soil interaction", *Soil dynamics and earthquake engineering- ELSEVIER,* (2007), (855-863).

[13] A.I Gareane and Algreane et al, "Behavior of elevated concrete water tank subjected to artificial ground motion", *Electronic journal of geotechnical engineering,* (2008), Vol.16, (387-406).

[14] A.R Ghanemmaghami and M.R Kianoush, "Effect of wall flexibility on dynamic response of concrete rectangular liquid storage tanks under horizontal and vertical ground motions", *Journal of Structural Engineering-ASCE,* (2010), Vol. 136(4), (441-451).

[15] Suchita Hirde and Manoj Hedaoo, "Seismic performance of elevated water tanks", *International Journal of Advanced Engineering Research and Studies*, (2011), Vol.1 (1), (78-87).

[16] M. Moslemi and M.R. Kianoush, "Parametric study on dynamic behavior of cylindrical ground supported tanks", *Engineering structures- ELSEVIER,* (2012), (214-230).

[17] M.V Waghmare and S.N Madhekar, " Behavior of elevated water tank under sloshing effect", *International Journal of Advanced Technology in Civil Engineering,*(2013), Vol.2 (1), (51-54)

[18] Uma Chaduvulaa and Deepam Patela et al, "Fluid-structure- soil interaction effect on seismic behaviour of elevated water tanks", *Procedia engineering- ELSEVIER,* (2013), (84-91).

[19] V.M Naveen and Sanya Maria Gomez, "Study of hydrodynamic effect on RC elevated water tanks under seismic excitation", *International journal of engineering and research,* (2015)

[20] K.J Dona Rose and Sreekumar M et al, " A study of overhead water tanks subjected to dynamic loads", *International journal of engineering trends and technology,*(2015),(344-348).

[21] Neeraj Tiwari and M. S. Hora, "Transient analysis of elevated intze water tank- fluid- soil system", *ARPN Journal of Engineering and Applied Sciences,* (2015), Vol.10 (2), (869-882).

[22] Rupachandra J. Aware and Vageesha et al, "Effect of container height on base shear of elevated tank", *International Journal of Science and Research,* (2015), Vol.4 (12), (2123-2128).

[23] Yonghui Wang and J.Y. Richard Liew et al, "Structural performance of water tank under static and dynamic pressure loading", *International journal of impact engineering- ELSEVIER*, (2015), (110-123).