Study of Hydrodynamic Effects on RC Elevated Water Tank under Seismic Excitations

[1]Naveen V M,[2]Sanya Maria Gomez
[1]P. G. Student, Department of Civil Engineering, SSET, Kochi, Kerala
[2]Assistant Professor, Department of Civil Engineering, SSET, Kochi, Kerala

---

***Abstract* - Recent earthquakes caused severe damages to several elevated water tanks. During earthquakes, supports of an elevated water tank are subjected to time varying acceleration which is transferred to the infilled water through the container. Moving water imparts hydrodynamic pressure on the tank walls and thus the effects are in turn carried over to the supporting structure and this alters the response of the staging which is already vibrating due to seismic shaking. Most of the studies where done by taking the fluid as two mass system and the hydrodynamic effect and design was considered according to the GSDMA guidelines. This implies that the behaviour of partially infilled elevated water tanks can be properly captured only by proper modelling of the structure as well as the moving fluid. The objective of the present work is to evaluate the applicability of the general purpose with analysis program ANSYS14.5 in the modeling and seismic analysis of elevated water tanks.**

***Index Terms* - GSDMA guidelines, seismic analysis, hydrodynamic pressure**

I. INTRODUCTION

Liquid storage tanks are used in industries for storing chemicals, petroleum products, and for storing water in public water distribution systems. Elevated liquid tanks and especially the elevated water tanks are considered as important city services in many cities. Their safety performance during strong earthquakes is of critical concern. They should not fail after earthquake, so that they can be used in meeting essential needs like preparing drinking water and putting out fires. The failure of these structures and the subsiding of water may cause some hazards for the health of city due to the shortage of water or difficulty in putting out fire during critical conditions.

II. SCOPE OF STUDY

During recent earthquakes, several elevated water tanks suffered severe damages which shows the inefficiency of current seismic codal provisions to prevent damage. Water tanks being considered as lifeline structures need to be functional for preventing post-earthquake fires and for other domestic purposes. Elevated tanks holds a huge mass of water over a staging which is most critical condition during earthquake. Damages to this structure will effect the supply of water of domestic, public utilities and industrial purposes. During the design of water tanks effect of sloshing and the hydrodynamic pressure on the walls of the tank should be considered for different levels of filling liquid. The filling liquid inside the tank vibrates due ground motion which in turn exert pressure on the wall and to the supporting structure beneath it. Most damages in the liquid storage tank during earthquake occur due to sloshing. sloshing is a long period and long duration ground motion.

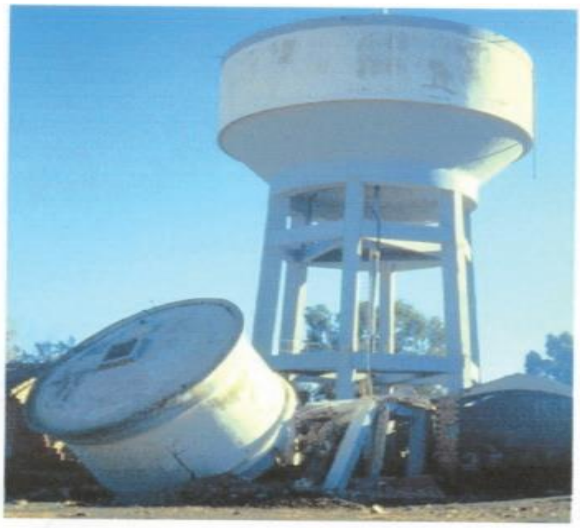

Fig. 1 Failure of the reinforced concrete supporting tower of an elevated reinforced concrete water tank during the 1980 El-Asnam Earthquake, Algeria.

As GSDM guide lines for the seismic design of liquid storage tanks there is fluid structure interaction and the hydrodynamic forces are evaluated by spring mass model. The hydrodynamic pressure has two components the impulsive mode and the convective mode. The convective parts the upper portion of the tank which has free surface liquid causing sloshing effect. The lower portion of the tank is rigid part which exert impulsive pressure. the convective liquid mass has different sloshing effect as the depth varies. Study of sloshing involves the computation of hydrodynamic pressure, forces, moments and the natural period of free liquid surface. The previous studies indicate that during earthquakes the collapse of water tank occurs mainly due to the failure of staging. When the tank is partially filled with water, sloshing occurs at the top portion of water during base excitation. And this causes an additional pressure on tank walls and may causes damages to the tank. But these factors are not considered by the Water Authority Department while designing the tank. So there are more chances of failures of tank during earthquakes.

III. LITERATURE REVIEW

M. Moslemi, M.R. Kianoush 2012[1] Parametric study on dynamic behavior of cylindrical ground-supported tanks. the dynamic behavior of cylindrical open top ground-supported water tanks is investigated. Both time history and free vibration analyses are carried out on concrete tank models with different aspect ratios. Time history response of both rigid and flexible tanks having different conditions at the base; fixed and hinged under both horizontal and vertical components of earthquake is obtained using the direct integration method. Based on the computed results, recommendations on seismic design of cylindrical liquid containers are made. It is concluded that the current design procedure in estimating the hydrodynamic pressure is too conservative. This journal is referred for the validation purpose and convective modes of vibration of tall ground supported tank is found.

M.V.Waghmare, Prof. B.G.Birajdar and Prof. R.C.Pathak (2008) [2], studied the seismic response of the cylindrical storage tanks. Finite elements are used for the liquid and tank wall. They considered elevated water tanks of capacity 120 m^3. The staging height is varied from 25 m. to 5m. The sloshing phenomenon is studied for various depths of water in container, i.e., full, ¾, ½ and ¼. Modal analysis and response spectrum analysis were performed using ANSYS. On increasing the height of the staging the displacement of water goes on decreasing, but at certain stage the response again increases. It is interesting to note that for tank filled up-to 70% of its capacity the behaviour is totally different i.e. as the height of the staging is increased, the displacement of water also increases up-to certain stage and then the response dies out.It is also very important to note that for the tanks are filled up-to 50% and 70% of their capacity the amount of displacement is more than the tanks are filled up-to 30% and 100% of their capacity.

According to Uma Chaduvula, Deepam Patel and N Gopalakrishnan (2013)[7], soil-Structure interaction causes rocking motion and Fluid Structure interaction causes the hydrodynamic behaviour of water tank. 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. Test program on elevated steel water tank consisted of combined horizontal, vertical and rocking motions, for a synthetic earthquake excitation for 0.1 g and 0.2 g accelerations, with increasing angle of rocking motion. The impulsive base shear and impulsive base moment values increase with increase in earthquake acceleration. Whereas, the convective base shear and base moment values increase for increase in earthquake acceleration, but decrease with increasing angular motion. Hence, there is no considerable effect of rocking motion on sloshing of water. The non-linearity in structure is observed, when the impulsive pressure of tank decreases with increase in tank acceleration. The pressure variation along tank height due to vertical excitation increased with increasing acceleration, and increased furthermore with added rocking. Using various codes available on water tanks, the recorded experimental results were used to calculate and compare the base shear, base moment, pressure variation in the tank.

Praveen K Malhothra, Thomas Wenk and Martin Wieand (2000)[3] proposed the theoretical background of a simplified seismic design procedure for cylindrical ground-supported tanks. The procedure takes into account impulsive and convective (sloshing) actions of the liquid in flexible steel or concrete tanks fixed to rigid foundations. Seismic responses – base shear, overturning moment, and sloshing wave height – are calculated by using the site response spectra and performing a few simple calculations. The simplified procedure has been adopted in Eurocode 8.

K. C. Biswal, S. K. Bhattacharyya and P. K. Sinha (2006)[4], used a finite element method for computing the non-linear sloshing response of liquid in a two dimensional rigid rectangular tank with rigid baffles. The potential formulation is considered for the liquid domain and a mixed Eulerian–Langrangian scheme is adopted. The solution is obtained by the Galerkin method. The fourth-order Runge–Kutta method is employed to advance the solution in the time domain. A re-gridding technique is applied to the free surface of the liquid, which effectively eliminates the numerical instabilities without the use of artificial smoothing. Through the comparison with the available results for the rectangular tank without baffle, the validity of the formulation is checked and then extended to the solution of tanks with rigid baffles. The effects of baffle parameters such as position, dimension and numbers on the non-linear sloshing response are examined. The numerical solution procedure is also applied to the non-linear sloshing problems in a circular cylindrical container with annular baffle.

IV. DETAILS OF TANK MODEL

A water tank has to be designed as per IS 1893:2002 and guidelines of IIT Kanpur and check whether it is safe during base excitation. The tank considered for the study is an elevated circular water tank, already designed by the Water Authority Department, which is commonly used in practice. The tank has a capacity of 2,00,000 litres with a staging height of 16.5m. The diameter of tank is 9m. Grade of concrete used for the tank M30 and grade of steel is Fe415. In the analysis special moment resisting frame (SMRF) are considered.

Table 1: Structural details of tank model

COMPONENT	SIZE (mm)
Roof Slab	100
Roof Beam	220 × 220
Floor Slab	200
Floor beam	300 × 500
Wall	150
Braces	250 × 350
Inner Column	300 × 300
Outer Column	300 ×300

V. SLOSHING IN WATER TANK

The motion of liquids in rigid containers has been the subject of many studies in the past few decades because of its frequent application in several engineering disciplines. This is important for problems relating to safety, including tank trucks on highways and liquid tank cars on railroads. In structural applications, the effects of earthquake induced loads on storage tanks need to be evaluated for design. Liquid motion in a container, phenomenon known as sloshing, is of great interest in many disciplines: naval, civil, chemical engineering etc. The motion of the fluid contained causes hydrodynamic forces on tank structure which might damage the tank. Fluid motion in partially filled tanks may cause large structural loads if the period of tank motion is close to the natural period of the fluid inside the tank. That is particularly dangerous when we are talking about container used to store fuel or toxic fluid.

VI. FINITE ELEMENT MODELLING

The modeling of RC water tank was done using the software ANSYS design modeler, in this the 3D model of the tank is made as per the structural details given above chapter. The model of the tank is created by sketching, extruding, boolean operations are done. The ANSYS Design Modeler application is designed to be used as a geometry editor of existing CAD models. The ANSYS Design Modeler application is a parametric feature-based solid modeler designed so that you can intuitively and quickly begin drawing 2D sketches, modeling 3D parts, or uploading 3D CAD models for engineering analysis preprocessing.

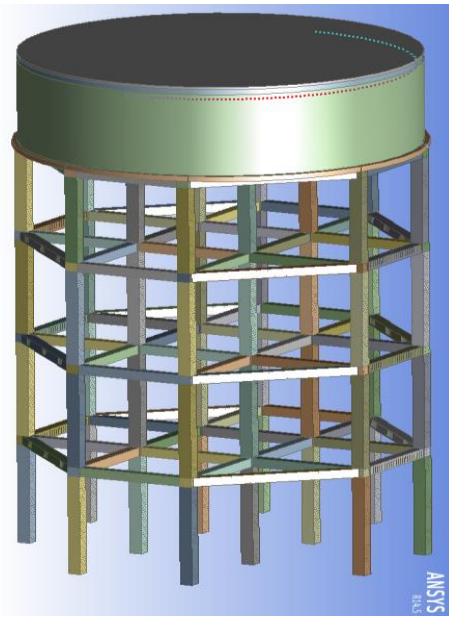

Fig. 2. Geometry of the tank

Dynamic Analysis of Elevated Water Tank

Dynamic response of elevated water tanks is hard to define, as the behaviour of tank is unpredictable. Dynamic analysis of liquid storage tank is a complex problem involving water-structure interaction. Based on numerous analytical, numerical and experimental studies, simple spring-mass models of tank-liquid system have been developed to calculate the hydrodynamic forces. During earthquake, water contained in the tank exerts forces on tank wall as well as bottom of the tank. These hydrodynamic forces should be considered in the analysis in addition to hydrostatic forces. The main objective of the present investigation is to evaluate the effect of moving water (hydrodynamic effect) on the response of staging during earthquake. Since the staging is composed of flexural elements, ductility demand is taken as the criterion for evaluation. Peak value of curvature obtained from time history analysis is taken as the ultimate curvature demand. Yield curvature is taken from the moment curvature characteristic of the cross-section. Moment-curvature relation is the basic tool in the non-linear analysis of the structure. It plays an important role in predicting the behaviour of the reinforced concrete members under flexure. In nonlinear analysis it is used to model plastic hinge behaviour. Curvature (f) is defined as the reciprocal of radius of curvature (R) at any point along a curved line. When an initial straight beam segment is subjected to a uniform bending moment throughout its length, it is expected to bend in a segment of circle with a curvature (f) that increases in some manner with increase in the applied moment (M).Curvature (f) may be alternatively defined as the angle change in slope of the elastic curve per unit length.

Ductility demand for beams in fully filled condition

Table 1: Ductility demand for beams

STAGING LEVEL	ALTADINA 1	ALTADINA 2	HOLLISTER	AVERAGE
1	0.284	0.167	0.886	**0.445**
2	1.161	1.133	1.213	**1.169**
3	1.467	1.491	1.639	**1.532**
4	0.588	1.371	1.516	**1.158**

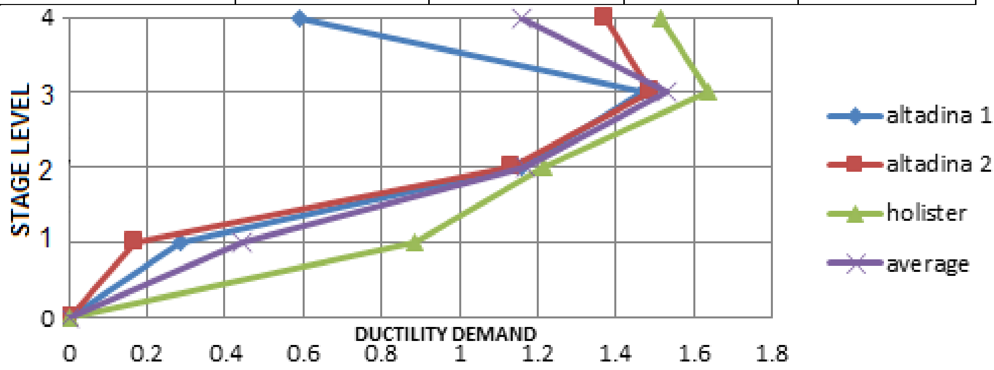

Fig. 2. Ductility demand for beams from the three time history analysis results

VII. CONCLUSIONS

The ductility demand for beams are found out separately in order to determine the safety of sections. It is found that ductility demand on staging increases due to hydrodynamic effects. From this analysis it can be conclude that the section provided by Water Authority Department is not sufficient to accommodate the hydrodynamic forces and sloshing effects of water during base excitation during fully filled conditions. And it was found that hydrodynamic forces have greater effects on water tanks during earthquakes, which were not taken into consideration by the Water Authority Department while designing.

VIII. ACKNOWLEDGMENT

I am very thankful to my project guide Ms. Sanya Maria Gomez, Assistant Prof. SCMS School of Engineering and Technology for her continuous support and encouragement in completing this work.

REFERENCES

[1] M. Moslemi, M.R. Kianoush , "Parametric study on dynamic behavior of cylindrical ground-supported tanks" , Engineering Structures 42 (2012) 214–230.
[2] Mrs. M V Waghmare, Prof. B.G.Birajadar (2008), “Behaviour of elevated water tank under sloshing”, The 14th World Conference on Earthquake Engineering October 12-17.
[3] Praveen K Malhotra, Thomas Wenk, Martin Weiland, (2000), “Simple procedure for Seismic Analysis of Liquid-Storage Tanks”, International Journal for Structural Engineering, Vol 3.
[4] K. C. Biswal1, S. K. Bhattacharyya and P. K. Sinha, (2006), “Non-linear sloshing in partially liquid filled containers with baffles”, International Journal for Numerical Methods in Engineering, pp:317–337
[5] G. W. Housner, “The dynamic behaviour of water tanks”, Bulletin of the Seismological Society of America, 1963, Vol. 53, No. 2,
[6] Sudhir K. Jain, O R Jaiswal (2007), IITKGSDMA Guidelines for Seismic Design of Liquid Storage Tanks.
[7] Uma Chaduvala, Deepam Patel, N Gopalakrishnan (2013), " Fluid - Structure Interaction Effects On Elevated Water Tanks", International Conference on Engineering.
[8] Soheil Soroushnia, Sh. Tavousi Tafreshi, F. Omidinasab, N. Beheshtian Sajad Soroushnia (2011), " Seismic Performance Of RC Elevated Water Tanks With Frame Staging And Exhibition Damage Pattern", Asia Pacific Conference ob Structural Engineering and Construction".
[9] A.Vakilaad Sarabi & M. Miyajima (2012), " Study of the Sloshing of Water Reservoirs and Tanks due to Long Period and Long Duration Seismic Motions",
[10] George W Housner (1963), Dynamic Analysis of Elevated Water Tanks, Bulletin of the Seismological Society of America, 53, pp. 381-387