ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad

SEISMIC ANALYSIS OF LIQUID STORAGE TANKS

SYED SAIF UDDIN

M.Tech (Structural Engineering II YR)
Department of Civil Engineering
Lords Institute of Engineering & Technology
Himayath Sagar, Hyderabad – 500008.
E-mail:saifuddinsyed8@gmail.com

Abstract— **Liquid storage tanks are used in industries for storing chemicals, petroleum products, and for storing water in public water distribution systems. Behavior of liquid storage tanks under earthquake loads has been studied as per Draft code Part II of IS 1893:2002. A FEM based computer software used (SAP 2000) for seismic analysis of tanks which gives the earthquake induced forces on tank systems.**

Indian seismic code IS 1893:1984 had some very limited provisions on seismic design of elevated tanks. This code did not cover ground-supported tanks. Draft code Part II of IS 1893:2002 which will contain provisions for all types of liquid storage tanks. Dynamic analysis of liquid containing tank is a complex problem involving fluid-structure interaction. Under earthquake loads, a complicated pattern of stresses is generated in the tanks. Poorly designed tanks have leaked, buckled or even collapsed during earthquakes. Common modes of failure are wall buckling, sloshing damage to roof, inlet/outlet pipe breaks and implosion due to rapid loss of contents.

An example intz shape tank is analyzed as per the Draft code Part II of IS 1893:2002. This thesis consists of two different parts. In a first part, a theoretical point of view & formulations for analysis. The second part focuses on the model example to determine the seismic forces on tank.

Index Terms— **Analysis, Damages, Earth Quake, Intz Tank, Liquid Storage Tank, Sloshing, Structures.**

I. INTRODUCTION

Structures located in seismically active areas have to withstand lateral forces generated due to earthquake in addition to their primary purpose of carrying gravity loads. Every year hundreds of all kinds of water tanks and other liquid retaining structures are being built in different parts of the country. These liquid retaining structures have faced many storms and earthquakes. Housner(1963) studied the behavior of small steel tanks with open roof under dynamic forces. He has given expressions for impulsive and convective modes of vibrations were provided for few cases. However, no significant research was carried out during the past four decades. The performance of a liquid tank structure during earthquake depends on the intensity of the earthquake and the properties of the structure. Reliability and accuracy of design of a structure largely depends on the well defined structural properties like configuration of the structural system, analysis and design procedure, the detailing of the structural elements and skilful construction. IS:1893 draft code on the design of liquid storage tanks has given expressions for time periods in impulsive and convective modes of vibrations and hydro-dynamic forces for both elevated tanks and ground supported tanks. According to draft code a water tank should be modeled as a two degree of freedom system based on the work of Housner(1963): mass one consists tank container and staging and impulsive water, mass two consists convective water.

II. DAMAGES TO STORAGE TANKS DURING EARTHQUAKES

Research on seismic response and behavior of liquid storage tanks is a matter of special importance, not only because of the economic factors, but also because of the consequences that result from failing tanks. Without an assured water supply, uncontrolled fires may cause enormously more damage than the earthquake itself, as it happened 1906 in the great San Francisco (USA) or 1995 in the earthquake of Kobe (Japan).

Spillage of toxic chemicals or liquefied gases from the damaged tanks can lead to disastrous effects in populated areas. The seeping of oil into the ground can ruin the ground water, so happened 1978 in Japan. Failure of tanks containing high inflammable products can lead to extensive fires, as occurred following the Nigata and Alaska of 1964, or the earthquake in Turkey on 17.8.1999 when over 17100 people died.

It becomes very important to study the liquid storage tank, when these liquid storage tanks are subjected to earthquakes, they suffer significant damage It becomes important to study and understand the behavior of tank under these conditions and various failures modes.

ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad

Figure 2.1: Damaged Liquid Storage tank (A) due to sloshing

The major damages observed in the liquid storage tanks are “Elephant foot” and “Diamond shape” buckling,. “Uplifting of tank, “Damage and collapse of tank roofs”. The seismic design standards have been revised several times to improve the performance. Because of cost, ground supported liquid storage tanks are often not fixed to their foundation, even in seismic areas. In this work we will study and understand the effect of sloshing on the tank. Tanks that are not provided with sufficient freeboard can be damaged by the sloshing waves.

Figure 2.2: Damaged Liquid Storage tank (B) due to sloshing

Figure 2.3: Elephant-foot buckling of a tank wall

The buildings are vulnerable to earthquake forces in most of the cases where heavy roof top water storage tanks are placed. Dead load is taken care of by the structural columns of the RC frame buildings or load bearing walls of masonry structures, but the dynamic behavior of these tanks remains unattended. This wrong practice has its own obvious implications.

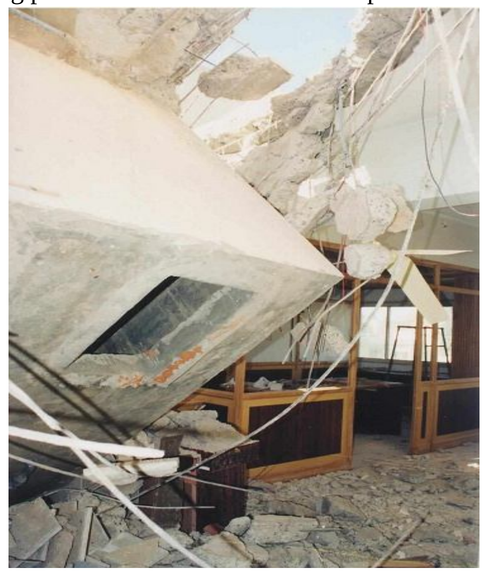


Figure 2.4 : The water tank pierced through the roof and fell on the first floor, damaging the structural members of the building beyond repair.

Figure 2.5 : The beams of ground floor roofs were heavily damaged due to fall of filled water tank from the roof of the adjacent building.

III. Seismic Analysis

This chapter presents the analysis procedure employed to determine the hydrodynamic pressures on various parts of container. Liquid retaining structure was analyzed for self-weight and seismic loads. Details of analysis are as follows: This code describes procedure for analysis of liquid containing ground supported and elevated tanks subjected to seismic base

ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad

excitation. The procedure considers forces induced due to acceleration of tank structure and hydrodynamic forces due to acceleration of liquid. When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base in addition to the hydrostatic pressure. In order to include the effect of hydrodynamic pressure in the analysis, tank can be idealized by an equivalent spring mass model, which includes the effect of tank wall – liquid interaction. The parameters of this model depend on geometry of the tank and its flexibility.

When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass. In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented.

Sometimes, vertical columns and shaft are present inside the tank. These elements cause obstruction to sloshing motion of liquid. In the presence of such obstructions, impulsive and convective pressure distributions are likely to change. At present, no study is available to quantify effect of such obstructions on impulsive and convective pressures. However, it is reasonable to expect that due to presence of such obstructions, impulsive pressure will increase and connective pressure will decrease.

Complete analysis of tanks consists following steps

1) Weight calculations
2) Modeling of liquid
3) Lateral stiffness of staging
4) Time period calculations
5) Design horizontal Seismic coefficient
6) Base shear and Base moment
7) Hydrodynamic pressure & Sloshing wave height
8) Analysis for tank empty condition

3.0 Weight Calculations:

Mass of container comprises of mass of roof slab, container wall, gallery, floor slab and floor beams. In the figure ms is the structural mass, which comprises of mass of container and one third mass of staging.

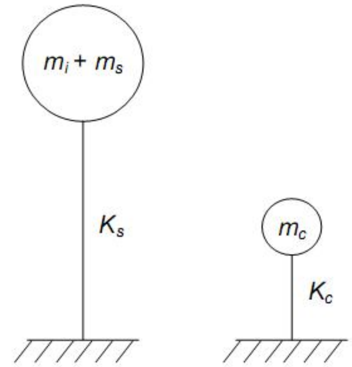


Figure 3.1 Equivalent uncoupled system

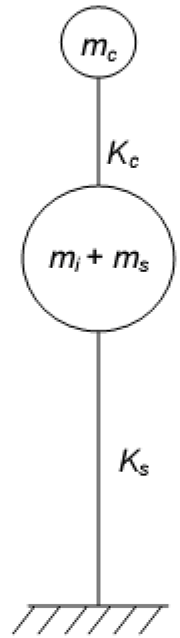


Figure 3.2 Two mass idealization of elevated tank

3.1 Modeling of Liquid:

Under static condition, liquid applies pressure on container. This is called hydrostatic pressure. But during base excitation liquid applies additional pressure on wall and base this is hydrodynamic pressure. This is in additional to the hydrostatic pressure. Total liquid mass gets divided into two parts

- Impulsive liquid mass
- Convective liquid mass

In static design we are considering hydrostatic pressure only but in seismic design considering hydrodynamic pressure also. Net hydrostatic force is zero on container wall and net hydrodynamic force on the container is not zero. Hydrostatic pressure affects container design only and not the staging or the foundation but hydrodynamic pressure affects design of container, staging and foundation.

ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad

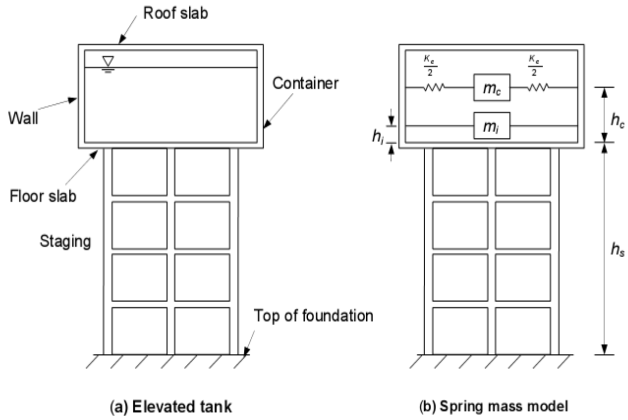


Figure 3.3 Mechanical analogue or Spring mass model of tank

Hydrodynamic forces exerted by liquid on tank wall shall be considered in the analysis in addition to hydrostatic forces. These hydrodynamic forces are evaluated with the help of spring mass model of tanks. The masses mi and mc and their points of application depends on aspect ratio of tanks and the all parameters of mechanical analogue are obtained from mathematical expressions given in the code.

IV. CONCLUSION

This project critically reviews earthquake induced forces on container systems and it is observed that there is a maximum increase of 15% to 25% in hydrodynamic pressures in elevated tanks and ground supported tanks, respectively.

An example intz shape tank is designed as per the Indian codes IS : 3370-1965/1967(parts I to IV), IS:456-2000, IS 1893 (Part 1):2002, draft code Part II of IS 1893:2002.

In the given example problem the maximum hydrodynamic pressure is about 15% of hydrostatic pressure at base (ρgh = 1000X 9.81X 4.0= 39.24 KN/m^2).There is a need to specify increase in permissible stresses when earthquake forces are included in the design forces in the draft code while designing the liquid container using the working stress method

APPENDIX

An intz shape water container of 250 m^3 capacity is supported on RC staging of 6 columns with horizontal bracings of 300 x 600 mm at three levels. Details of staging configuration are shown in figure below. Grade of concrete and steel are M20 and Fe415, respectively. Tank is located on hard soil in seismic zone IV. Density of concrete is $25KN/m^3$. Analyze the tank for seismic loads.

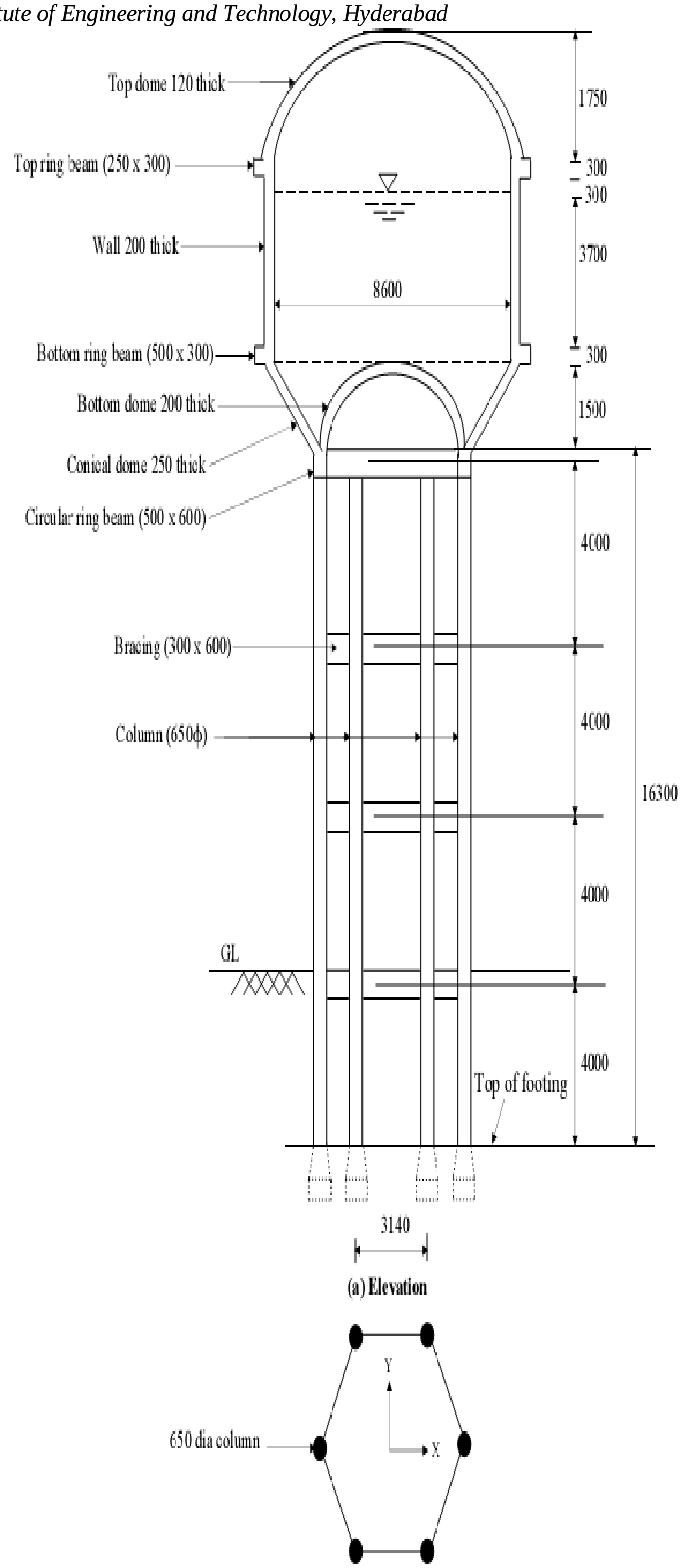


Figure 3.4: Plan,Dimensions of Intz Tank (all are in mm)

.

ISSN 2278-3091

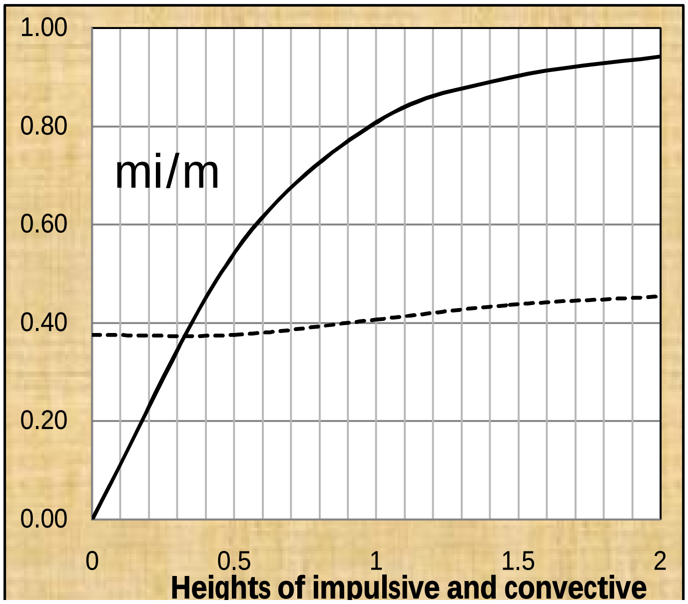
International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad

Component	**Size(mm)**
Top Dome	120 thick
Top Ring Beam	250 x 300
Cylindrical Wall	200 thick
Bottom Ring Beam	500 x 300
Circular Ring Beam	500 x 600
Bottom Dome	200 thick
Conical Dome	250 thick
Braces	300 x 600

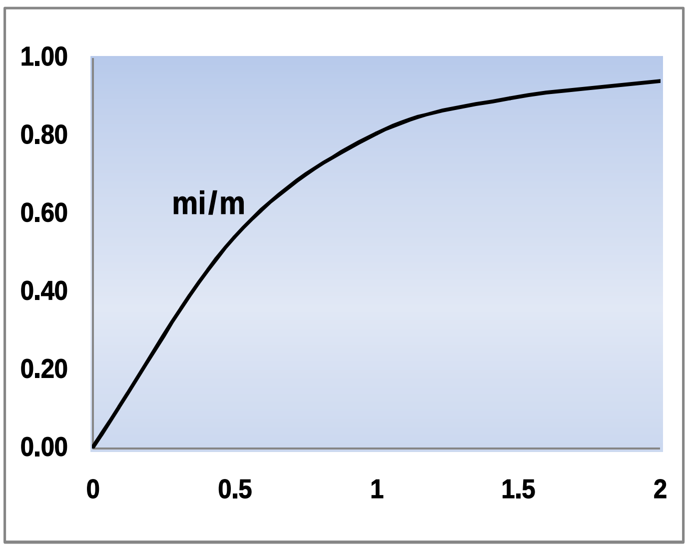
components	**calculations**	**Weight (KN)**
Top Dome	2 x π x 6.57 x 1.69 x (0.12 x 25)	209.3
Top Ring Beam	π x (8.6 + 0.25) x 0.25 x 0.30 x 25	52.1
Cylindrical Wall	π x 8.8 x 0.20 x 4.0 x 25	552.9
Bottom Ring Beam	π x (8.6 + 0.5) x 0.5 x 0.30 x 25	107.2
Circular Ring Beam	π x 6.28 x 0.50 x 0.60 x 25	148
Bottom Dome	2 x π x 4.22 x 1.40 x 0.20 x 25	185.6
Conical Dome	π x ((8.80 + 6.28) / 2.0) x 2.17 x 0.25 x 25	321.3
Water	$[(\pi \times 8.6^2 x3.7/4)+(\pi x1.5(8.6^2+5.63^2+(8.6x5.63))/12-(\pi x1.3^2 x(3x4.22-1.5)/3)] x9.81$	2,508
Columns	π x $(0.65)^2$ x 15.7 x 6 x 25 / 4	782
Braces	3.14 x 0.30 x 0.60 x 3 x 6 x 25	254

ISSN 2278-3091

International Journal of Advanced Trends in Computer Science and Engineering, Vol.2 , No.1, Pages : 357 – 362 (2013)
Special Issue of ICACSE 2013 - Held on 7-8 January, 2013 in Lords Institute of Engineering and Technology, Hyderabad



GRAPH 1.0 : **IMPULSIVE AND CONVECTIVE MASS AND CONVECTIVE SPRING STIFFNESS**



GRAPH 1.2 : **IMPULSIVE AND CONVECTIVE MASS AND CONVECTIVE SPRING STIFFNESS**

ACKNOWLEDGMENT

I am thankful to Dr. Giridhar Akula, Principal, Lords Institute Of Engineering And Technology, for providing the necessary facilities to carry out the investigations and Prof. D. Samuel John, (H.O.D.) Civil Engineering Department for allotting the project guide.

I am very much thankful to DR. MOHAMMED MASOOD (R&D) Director, Mechanical Engineering Department, Lords Institute Of Engineering And Technology, for encouraging me and helping out with new ideas during my project work

I wish to express my deep sense of gratitude and indebtedness to my learned and enlightened guide Syed Mohsin Associate Professor, Dept. of Civil Engineering, for his deep involvement, rational and expert guidance, constructive criticism, constant inspiration and moral encouragement throughout the period of the study. His proficiency in this project has been an asset to this work

REFERENCES

[1] IS : 3370 (part I to IV)-1965, Indian Standard Code Of Practice For Concrete Structures For The Storage Of Liquids, Bureau of Indian Standards, New Delhi.

[2] IS:1893:2002 (part II) IITK – GSDMA Guidelines for Seismic Design of Liquid Storage Tank.

[3] IS: 1893-2002 (part I), Indian Standard Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards, New Delhi.

[4] IS: 456-2000(2000), Indian Standard Code Of Practice For Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi.

[5] Reinforced concrete structures by Dr.B.C Punmia.

[6] Houner,G.W.1963a, "Dynamic analysis of fluids in containers subjected to acceleration", Nuclear reactors and earthquakes, Report No. TID 7024, U.S Atomic Energy Commission, Washington D.C