International Journal of Civil
Engineering (IJCE)
ISSN(P): 2278-9987; ISSN(E): 2278-9995
Vol. 4, Issue 6, Oct - Nov 2015, 81-90

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

DYNAMIC BUCKLING OF STEEL WATER TANK UNDER SEISMIC LOADING

SUNITHA K R[1] & BOBY JACOB[2]

[1]PG Scholar, Computer Aided Structural Engineering, Department of Civil Engineering,
Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

[2]Assistant Professor, Department of Civil Engineering, Mar Athanasius College of Engineering,
Kothamangalam, Kerala, India

ABSTRACT

Many above-ground steel liquid storage tanks have suffered significant damages during past earthquakes. Such failures are due to several causes. The most common one is dynamic buckling. Several theoretical and experimental research studies were performed without solving this complex problem completely. The damages caused to these structures made them generally out of service. The emergency operations after an earthquake will be then particularly handicapped. These damages can also cause uncontrolled fires or environmental contamination in the case of flammable or toxic contents. Several analytical, experimental and numerical studies have been carried out to highlight the complexities associated with the behavior of liquid storage tanks against the dynamic buckling. This paper attempt to create a three dimensional finite element model of the steel tank to predict the performance under lateral loading.

KEYWORDS: Dynamic Analysis, Frequency, Water Tank

INTRODUCTION

Steel storage tanks are fairly common strategic constructions, as they represent the basic components in several industrial constructions especially in nuclear power plants. Unlike most structures, the storage tank weight varies with time due to the variable level of the stored fluid. These vessels may contain substances at low temperatures or corrosive products. Recently the storage tanks have suffered from the occurrence of catastrophic failures due to seismic shocks. The damages caused to these structures made them generally out of service. The emergency operations after an earthquake will be then particularly handicapped. These damages can also cause uncontrolled fires or environmental contamination in the case of flammable or toxic contents.

Cylindrical metal tanks are thin shell structures subject to internal pressure from stored liquid together with axial compression that can arise from roof loads, horizontal loads such as earthquake and the frictional drag of stored materials on the walls. Under earthquake loading, overturning is resisted by axial compressive stresses in the wall. The governing failure mode is usually buckling under axial compression. The internal pressure exerted by hydrostatic and hydrodynamic pressures can significantly enhance the buckling strength, but high internal pressures lead to severe local bending near the base. The failures of these structures are manifested by diamond or elephant's foot buckling, by uplift of their bases, by pipe damage, etc. Amongst these negative phenomena, dynamic buckling of tank walls remains the most common and the most dangerous one. This instability appears usually in two forms: the elephant foot buckling, which is an outward bulge located just above the tank base, results from the combined action of vertical compressive stresses, exceeding the critical stress, and hoop tension close to the yield limit. The elephant foot buckling bulge usually extends completely around the bottom of tanks due to the reverse in the direction of the seismic excitation. The second form, called diamond buckling, is an elastic instability phenomenon due to the presence of high axial compressive stresses.

Several investigators have attempted to study the behavior of steel tanks under lateral loads. Several analytical, experimental and numerical studies have been carried out to highlight the complexities associated with the behavior of liquid storage tanks against the dynamic buckling.

J.C. Virella and L.A. Godoy investigated dynamic buckling of aboveground steel tanks with conical roofs and anchored to the foundation, subjected to horizontal components of real earthquake records. [1]

Alemdar Bayraktar et. al studied the effect of the finite element model updating on the earthquake behavior of steel storage tanks considering fluid_structure interaction. For this purpose, a cylindrical steel storage tank filled some liquid fuel oil located in Trabzon, Turkey is selected as an example. Initial finite element model of the storage tank is developed by ANSYS software and dynamic characteristics (natural frequencies, and mode shapes) are determined analytically. Ambient vibration tests are conducted on the storage tank under natural excitations to obtain dynamic characteristics (natural frequencies, mode shapes and damping ratios), experimentally.[2] Amr M.I. Sweedan investigated the dynamic response of liquid-filled combined vessels to the vertical component of earthquake excitation . An equivalent mechanical model is proposed to predict the seismically induced forces due to vertical excitation. An extensive parametric study is conducted to identify the basic characteristics of the equivalent model. [3] F.H. Hamdan presents a review on the behaviour and design guidelines of cylindrical steel liquid storage tanks subjected to earthquake motion. Field observations during past earthquakes are presented and then used together with finite element analyses and published experimental results to assess the accuracy of current design guidelines. [4] M. K. Shrimali et. al. (2012) is investigated the seismic response of the liquid storage tanks isolated by lead-rubber bearings for bi-directional earthquake excitation. The biaxial force-deformation behaviour of the bearings is considered as bi-linear modelled by coupled non-linear differential equations.[5] Ayman A. Seleemah et. al. investigated the seismic responses of base-isolated broad and slender cylindrical liquid storage ground tanks. Three types of isolation systems are considered. The seismic responses are compared with the corresponding responses of non-isolated tanks. [6] Naghdali Hosseinzadeh and Hamid Kazem (2013) conducted a comprehensive study to highlight the shortcomings of the API650-2008 code. For this purpose 161 existing tanks in an oil complex were classified into 24 groups for seismic assessments. The numerical finite element models of tanks were constructed using ANSYS software (2007). Modal periods, base shear, elephant-foot buckling, sloshing and uplift predicted using the code and from analytical approaches were compared. The results demonstrate that, in some cases, there are some imperfections in the code requirements that require further investigation.[7] Minas K. Minoglou and George D. Hatzigeorgiou done this work . The aim of this work is the simplified, fast and direct optimum seismic design of these special structures, avoiding complicated computational methods such as the finite element or the boundary element methods. This objective is achieved using software developed in-house, where the optimum seismic design is achieved satisfying the stability of these structures under extreme seismic design loads according to the Eurocode 8 or the Greek seismic regulation provisions.[8]

NEED FOR DYNAMIC ANALYSIS

The dynamic behavior of water tank during seismic events can be studied by the detailed seismic analysis using any finite element software package. The seismic analysis can be performed using static and dynamic analysis. Static methods specified in codes are based on single mode response with simple corrections for including higher mode effects. While this is appropriate for simple regular structures, the simplified procedures do not take into account the full range of seismic behavior of complex structures. Therefore dynamic analysis s the preferred method. All real physical structures structures behave dynamically when subjected to loads or displacements. The additional inertial force, from Newton's second law are equal to mass times the acceleration. If the loads or displacements are applied very slowly, the inertia force can be neglected and a static load analysis can be justified. Hence dynamic analysis is a simple extension of static analysis.

Methods of dynamic analysis are

- Elastic response spectrum analysis
- Elastic or inelastic time history analysis

NUMERICAL INVESTIGATION OF WATER TANK MODEL

This tank has been treated by several authors, using different loads. Sosa [9] studied the behavior of the same structure under wind loads. Virella et al. [10] used this tank (among others) to evaluate its resistance under seismic excitations. This tank characterized by the ratio H/R = 0.8 and with mechanical properties R = 15m, H = 12m, HL = 10m, q_s = 7850 kg/m3, m = 0.3, E = $2x10^{11}$ Pa, q_w=100kg/m3. Where D is the diameter of tank, H is the height, HL is the water level, q_s is the density of steel, E is the Youngs Modulus of steel and q_w is density of water. Figure 1 shows the tank details

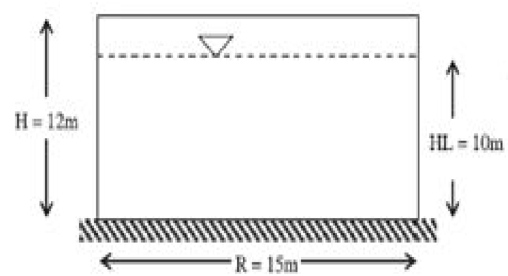

Figure 1: Water Tank

MODAL ANALYSIS

Modal analysis is used to determine the vibration modes of a structure. These modes are useful to understand the behavior of the structure. Modal analysis is used for calculating linear response of multi degree of freedom system. It is based on the idea that the response of the structure is the superposition of the individual modes of vibration, each mode responding with its own particular deformed shape, its own frequency, and with its own modal damping, The response of the structure is therefore determined from the response of a number of single – degree of freedom systems with properties chosen to be representative of the modes and the degree to which the modes are excited by the earthquake motion. The modal analysis was conducted to obtain the frequencies and mode shapes of the tank under study. It was conducted using the software ANSYS.

TIME HISTORY ANALYSIS

Time history analysis is a step by step analysis of the dynamical response of a structure to a specified loading that may vary with time. The analysis may be linear or non linear. Time history analysis is used to determine the dynamic response of a structure to arbitrary loading. If the load includes ground acceleration, the displacements, the velocities, and the accelerations are relative to the ground motion. Any number of time history analysis cases can be defined. Each time history case can differ in the load applied and in the type of analysis to be performed.

ANALYSIS PROCEDURE

The method consists of applying a specific earthquake motion directly to the base of a computer model of a structure. Instantaneous stresses throughout the structure are calculated at small intervals of time for the duration of the earthquake or a significant portion of it. T he maximum stresses that occur within the entire analysis period are found by scanning the computer results. The procedure includes the following steps.

- An earthquake record representing the design earthquake is selected
- The record is digitized as a series of small time intervals of about
- A model of water tank is set up.
- The digitized record is applied to the model as acceleration at the base of the tank.
- The computer integrates the equation of motions and gives a complete record of the acceleration, velocity, and displacement at each interval.

GROUND MOTION TIME HISTORIES ADOPTED FOR THE ANALYSIS

A suite of ground motion records were selected for range of acceleration levels and duration. The studies were conducted using these earthquake records. Two different earthquake data Korbe earthquake and EL CENTRO earthquake hich which happened in 1940 were used for the analysis. The acceleration time histories of the previous earthquakes were applied at the base of the model for time history analysis. The different earthquake data were selected in such a way that they posses different properties so that the effect of each one can be studied.

RESULTS OF MODAL ANALYSIS

Usually for most of the structures which are exposed to vibration, running the Modal analysis is essential, because the structure should be designed to be far from the resonant frequency domain. Also this analysis is used to determine natural frequencies and seismic mode-shapes of the structure. The value of natural frequency of the structure depends on the shape, type and supports of the structure. For cylindrical tanks containing fluids, this is important that modes of the structure occur at high frequencies and modes of the fluid occur at low frequencies. Modes related to the fluid which are famous as oscillation modes, appear at pristine frequencies of Modal analysis. However all or some of the pristine modes may not be important, and is a result of internal rotational motion in the fluid. Figures 2 to 7 shows the mode shapes.

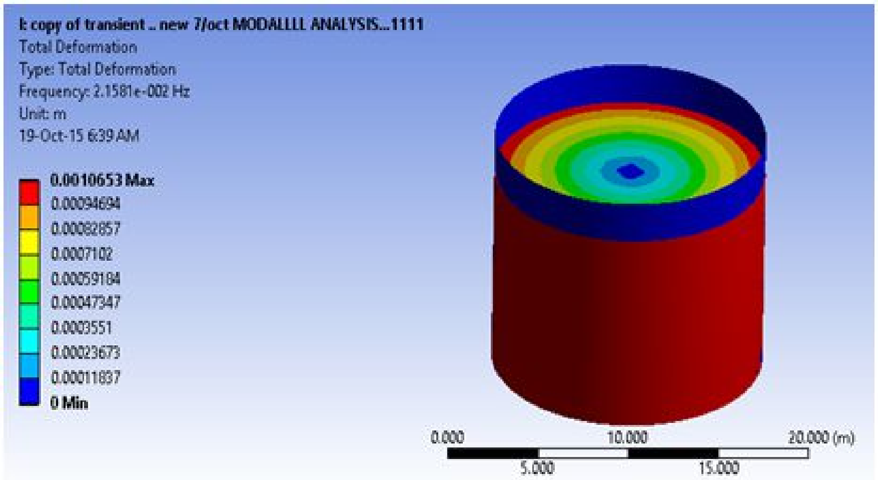

Figure 2: First Mode of Tank Resulting from Modal Analysis

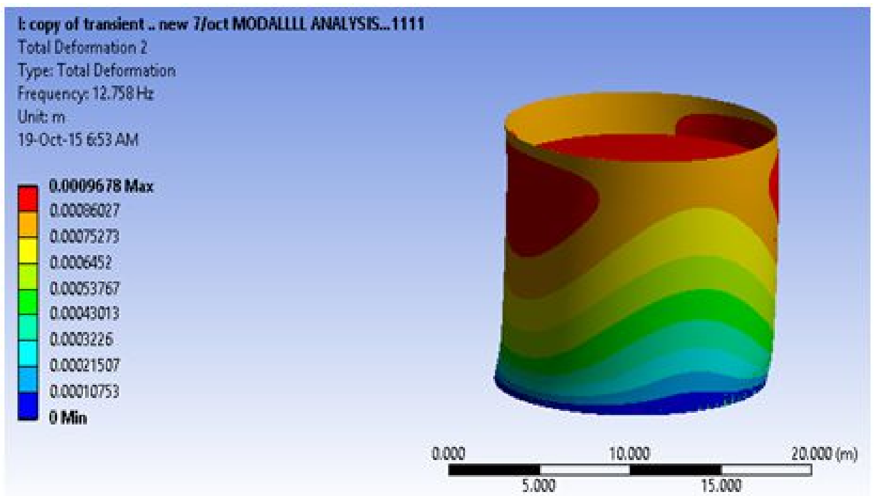

Figure 3: Second Mode of Tank Resulting from Modal Analysis

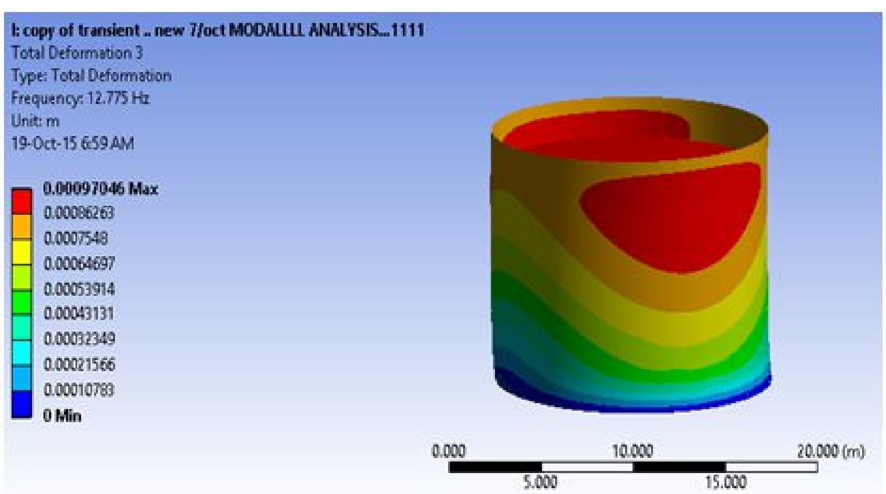

Figure 4: Third Mode of Tank Resulting from Modal Analysis

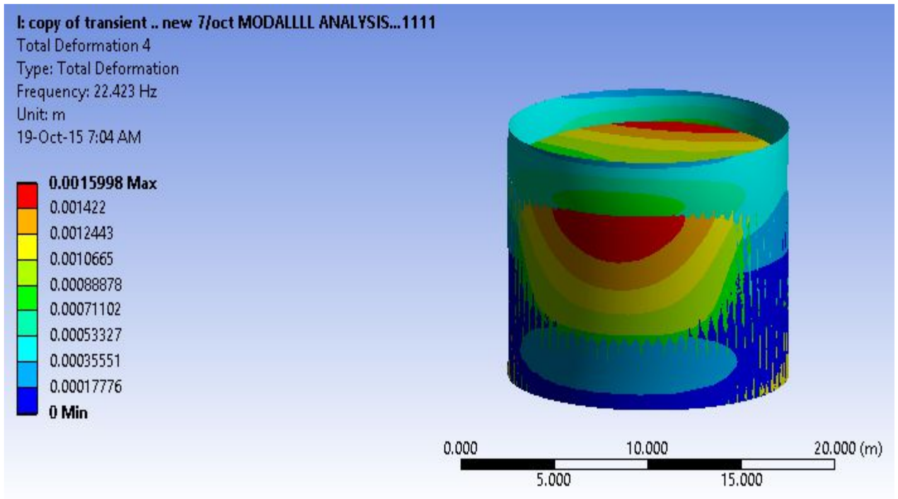

Figure 5: Fourth Mode of Tank Resulting from Modal Analysis

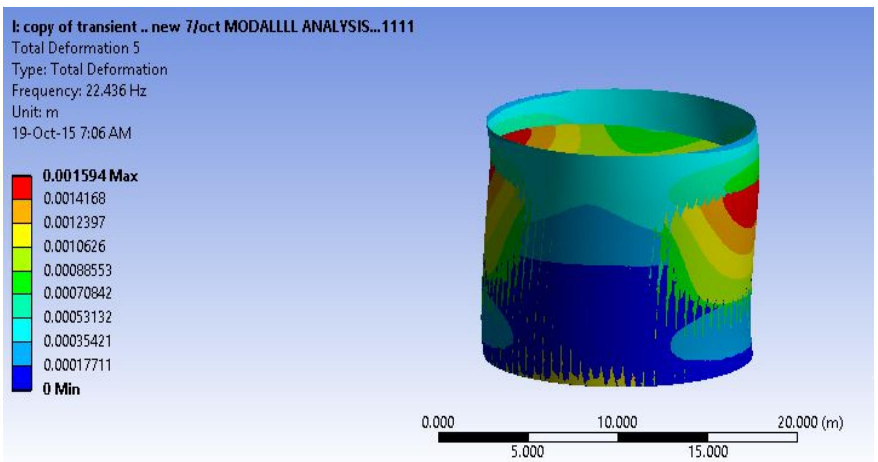

Figure 6: Fifth Mode of Tank Resulting from Modal Analysis

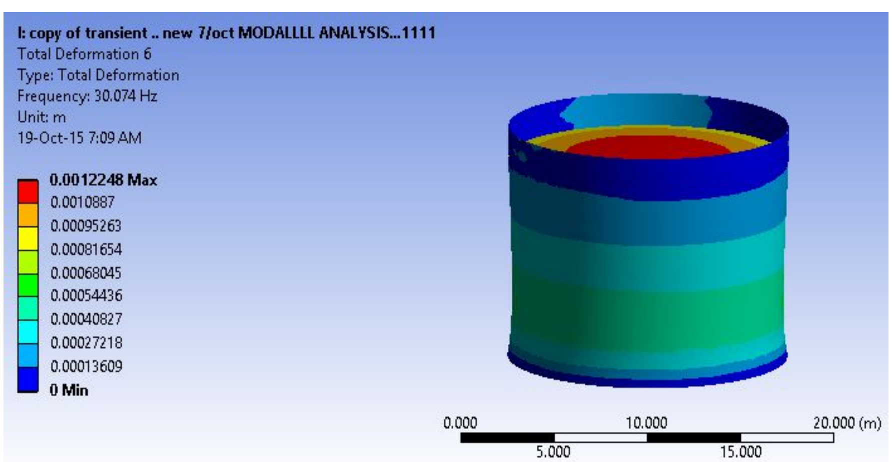

Figure 7: Sixth Mode of Tank Resulting from Modal Analysis

RESULTS OF TRANSIENT ANALYSIS

The performance of the structure when subjected to the two earthquakes i.e EL Centro earthquake and Korbe earthquake, ground motions were obtained from time history analysis. The results obtained from the time history analysis conducted on circular steel water tank subjected to both earthquake ground motion data is shown in fig

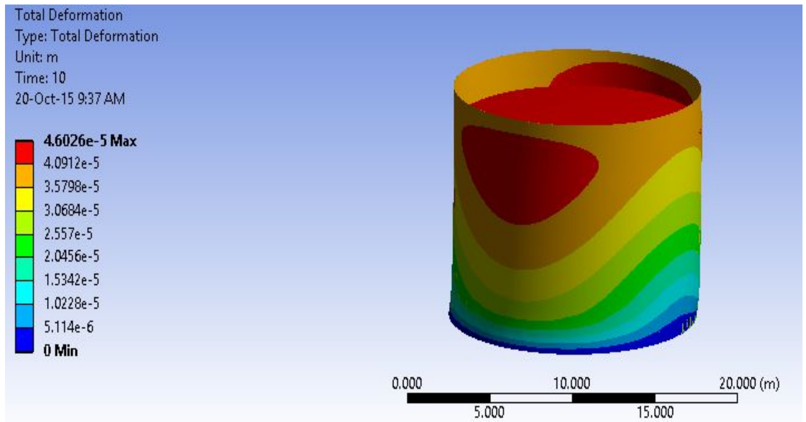

Figure 8: Deflection Diagram for Korbe Earthquake

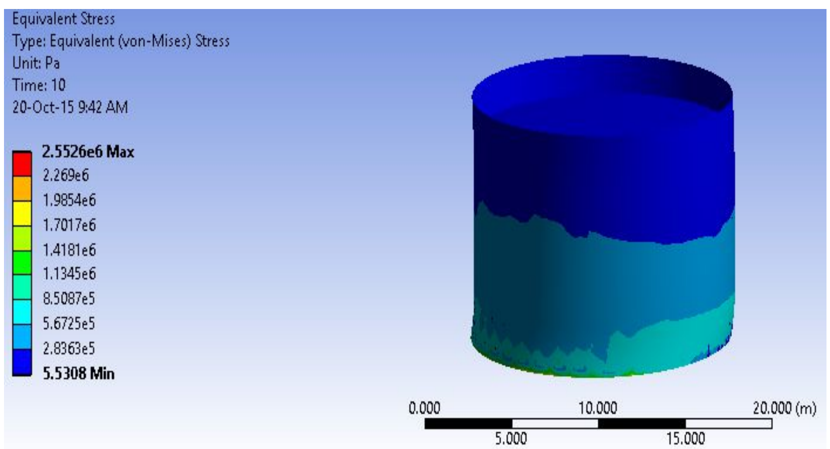

Figure 9: Stress Diagram for Korbe Earthquake

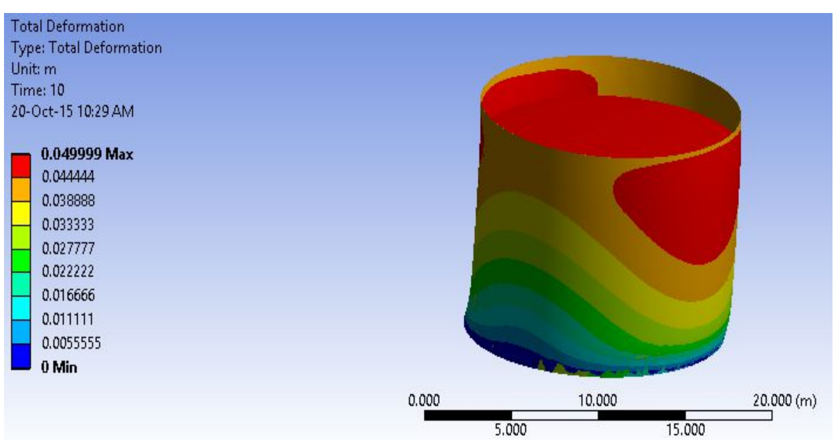

Figure 10: Deflection Diagram for El Centro Earthquake

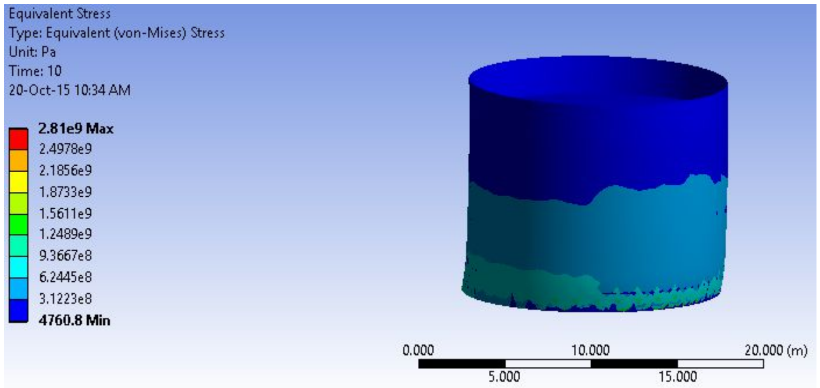

Figure 11: Stress Diagram for El Centro Earthquake

PARAMETRIC STUDY

The parametric study is carried by assuming a typical Steel tank. The influence of the parameter namely height of tank to diameter ratio on the frequency of has been studied. The parametric study is carried out using ANSYS 14.5 software.

Influence of height to diameter ratio on the frequency of steel tank

In this study a ground supported steel water tank is assumed. The height of water in tank and thickness of tank are made constant and is equal to 10m and 10mm. The ratio of height of tank to diameter(H/D) is varied from 0.8 to 0.6 varying the diameter. Table 1. shows the influence of H/D ratio on the frequency of structure.

Table 1: Shows the Influence of H/D Ratio on the Frequency of Structure

H/D Ratio	Mode 1 Frequency (Hz)	Mode 1 Frequency (Hz)	Mode 1 Frequency (Hz)	Mode 1 Frequency (Hz)	Mode 1 Frequency (Hz)	Mode 1 Frequency (Hz)
0.8	2.16E-02	12.758	12.775	22.423	22.436	30.074
0.75	2.08E-02	12.57	12.591	22.437	22.442	29.983
0.7	1.80E-02	12.191	12.207	22.457	22.468	29.465
0.65	1.67E-02	11.864	11.883	22.486	22.488	28.346
0.6	1.64E-02	11.189	11.392	22.51	22.518	27.342

CONCLUSIONS

The objective of the research was to study the dynamic properties of water tank during seismic loads .

From model analysis results of water tank under study , the dynamic properties were found out. Parametric study was done to find the influence of H/D ratio on the dynamic properties. The frequency of the structure changes with H/D ratio.

Non linear time history analysis of the water tank under study was conducted and the response of the structure for two different earthquakes were found out

REFERENCES

1. Alemdar Bayraktar ,Bar Sevim, Ahmet Can Altun, Temel Türker, *Effect of the model updating on the earthquake behavior of steel storage tanks ,* Journal of Constructional Steel Research, Vol 66, 2010, pp 462-468.
2. J.C.Virella, L.A.Godoy, L.E. Su´arez , *Dynamic buckling of anchored steel tanks subjected to horizontal earthquake excitation,* Journal of Constructional Steel Research, Vol 62, 2010, pp 521-531.
3. Amr M.I. Sweedan, *Equivalent mechanical model for seismic forces in combined tanks subjected to vertical earthquake excitation,* Thin Walled Structures, Vol. 47, 2011, pp 542-553.
4. F.H. Hamdan, *Seismic behaviour of cylindrical steel liquid storage tanks,* Journal of Constructional Steel Research Vol.53 ,2011. pp 307–333.
5. M.K. Shrimali, R.S. Jangid, *Non-linear seismic response of base-isolated liquid storage tanks to bi-directional excitation,* Nuclear Engineering and Design, Vol.217 ,2012, pp 1–20
6. Ayman A. Seleemah, Mohamed El-Sharkawy*, Seismic response of base isolated liquid storage ground tanks,* Ain Shams Engineering Journal , Vol.2,2012, pp 33–42.
7. Naghdali Hosseinzadel, Hamid Kazem , *Comparison of API650-2008 provisions with FEM analyses for seismic assessment of existing steel oil storage tanks,* Journal of Loss Prevention in the Process Industries, Vol. 26 ,2013, pp 666-675.
8. Minas K.Minoglou , George D.Hatzigeorgiou, *Heuristic optimization of cylindrical thin-walled steel tanks under seismic loads,* Thin Walled Structures, Vol 2. 2013, pp 345-354.
9. Sosa EM.*, Computational buckling analysis of cylindrical thin-walled above ground tanks.* PhD Thesis, University of Puerto Rico; 2005.
10. Virella JC, Godoy LA, Suarez LE. *Dynamic buckling of anchored steel tanks subjected to horizontal earthquake excitation*, J Constr Steel, Vol 62, 2006, pp 521-531.