

Dynamic Analysis of RCC Water Tanks with Varying Height of Water Level

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ABSTRACT: Water tanks are one of the most important lifeline structures. In most of the cities and rural areas, water tanks forms an integral part of water supply scheme. The liquid storage tanks possess low ductility and energy absorbing capacity as compared to the conventional buildings. So seismic safety of liquid storage tanks is of considerable importance. The water tanks get heavily damaged or collapsed during earthquake due to the fluid-structure interactions, hence the seismic behaviour of tanks has the characteristics of complex phenomena. Water storage tanks should remain functional in the post earthquake period to ensure potable water supply to earthquake affected regions. The main aim of this study is dynamic analysis of different types of RCC water tanks. Ground supported rectangular and circular water tanks, over head circular and rectangular water tanks are considered. Housner's two mass model for water tank is selected for dynamic analysis where the whole mass of water is divided in to two, impulsive liquid mass and convective liquid mass. Analysis is carried out to find the base shear and base moment. The manual dynamic analysis is done with varying height of water level in the tank using IS 1893 (Part 2) guide lines and study the effects due to change in height of water level. The manual dynamic analysis is compared with dynamic analysis performed in FEM software ETABS for varying height of water level.

KEYWORDS: Water Tanks, Dynamic Analysis, Height of Water Level, Spring Mass Model, Base Shear, Base Moment

I. INTRODUCTION

Water tanks are the life line structures to store water for the purpose of water supply. They may be elevated or ground supported tanks with different geometries depending on the nature and topography of land. Here elevated and ground supported water tanks of RCC with circular and rectangular geometry are taken into consideration.

Badly constructed structures may fail during earthquakes. There are many examples of failure of liquid storage tanks in past years. They take many life and property. The properties can be recreated to some extent but life loss cannot. So the water storage tanks should remain functional during and after earthquake to ensure potable water supply to earthquake affected regions. It should not damage during earthquake. According to seismic code IS 1893:2002, more than 60% of India is prone to earthquakes. Hence it is important to analyse the structure for effects of earthquake force.

The water level in the tank effects the seismic performance of water tank. The parameters like base shear and base moment helps to understand the seismic performances of a structure. The seismic design should be based on these parameters. Water level in the tank has a important role in contributing base shear and base moment in case of water tank. During earthquake, the water inside the tank also undergoes sloshing motion. That sloshing motion depends the seismic performance of tank. Here manual dynamic analysis and software dynamic analysis were conducted to find out variation of base shear and base moment of different types of RCC water tanks of 500 m³ capacity at Calicut for medium soil condition with varying height of water level in the tank. Dynamic analysis performed using the well-known software ETABS 2016.

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II. RELATED WORK

A number of studies have been performed on dynamic analysis of water tank. Dona Rose et al.[1] studied the response of the elevated circular type water tanks to dynamic forces. Tanks of various capacities with different staging height was modelled. RCC frame staging is chosen. The time history analysis of the water tank is carried out by using earthquake acceleration records of El Centro Earthquake. The peak displacements and base shear were obtained from the analysis. The peak displacement from the time history analysis increases with staging heights. The displacement for half filled tanks is lesser than the displacement for tanks with full capacity. The base shear values from time history analysis were increasing as staging height increased. Also, the base shears decreases and then increases with capacity. Base shear for half capacity tanks are lesser than that for full capacity tanks under same staging condition. Suchita Hirde et al.[2] presented the 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. The effect of height of water tank, earthquake zones and soil conditions on earthquake forces have been presented with the help of analysis of models of various parameters. It has been concluded that, the seismic forces are directly proportional to the Seismic Zones and capacity of water tank and inversely proportional to the height of supporting system. Also the seismic forces are higher in soft soil than medium soil and higher in medium soil than hard soil. Earthquake forces for soft soil is about 40-41% greater than that of hard soil for all earthquake zones at tank full and tank empty condition.

Urmila Ronad et al.[3] presented seismic behaviour of cylindrical liquid storage tanks by performing dynamic response spectrum analysis as per IS 1893:2002. Analysis was carried out for elevated circular RC tank for empty and full tank condition under different soil conditions and different zones. The responses include base shear and base moments in all soil conditions had been compared. It is concluded that, If the water tank is located in higher seismic zone corresponding base shear and base moments would also increase. It is observed that the base shear and base moment changes with soil conditions. Latesh Patil et al.[4] performed analysis of rectangular water tank resting on staging by different analysis techniques viz Equivalent static analysis, response spectra analysis and linear time history analysis. It is concluded that response spectrum analysis is on conservative side as compared to other two methods of analysis. The seismic responses namely base shear, story displacements, lateral forces in both the directions are found to vary in similar pattern for all the time histories. The study gives an idea of seismic performance of column under different analysis techniques.

Dynamic analysis of liquid containing intze tank is worked out by Kulkarni Reshma et al.[5].The impulsive pressure and convective pressure are calculated using a modified equation. The impulsive pressure and convective pressure variation in different locations on both side wall and bottom slab of tank were plotted. Two mass modal for water tank is used to analyse the tank. Indian code was used. It is concluded that the impulsive pressure is always greater than convective pressure. The impulsive as well the convective hydrodynamic pressure on wall goes on increasing with y/d ratio. The value of pressure on base slab goes on increasing with increase in horizontal dimension in cylindrical portion.

III. DESIGN CODE PERSPECTIVE

Most of the available design codes for earthquake resistant building including IS 1893(Part 1):2002 [6], IS 1893(Part 2):2002 [7], recommend an empirical formula for the determination of time periods and base reactions of water tank.

1) Impulsive time period

- a) For ground supported rectangular tank

$$T_i = 2\pi \sqrt{\frac{d}{g}}$$

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Website: www.ijirset.com

Vol. 6, Issue 4, April 2017

where

d = deflection of the tank wall on the vertical center line at a height of \bar{h} , when loaded by uniformly distributed pressure of intensity q ,

$$q = \left[\frac{\frac{m_i}{2} + \bar{m}_w}{B h} \right] g$$

$$\bar{h} = \left[\frac{\frac{m_i}{2} \times h_i + \bar{m}_w \times \frac{h}{2}}{\frac{m_i}{2} + \bar{m}_w} \right]$$

\bar{m}_w = Mass of one tank wall perpendicular to the direction of seismic force, and
 B = Inside width of tank.

\bar{h} is the height of combined center of gravity of half impulsive mass of liquid ($m_i/2$), and mass of one wall (m_w). For tanks without roof, deflection, d can be obtained by assuming wall to be free at top and fixed at three edges.

Height \bar{h} which is subjected to concentrated load, $P = q h$

Thus, for a tank with wall of uniform thickness, one can obtain d as follows:

$$d = \frac{p \times (\bar{h})^3}{3 E I_w}$$

Where

$$I_w = \frac{1.0 \times t^3}{12}$$

b) For ground supported circular tank

$$T_i = \frac{C_i h \sqrt{\rho}}{\sqrt{\frac{t}{D}} \times \sqrt{E}}$$

Where

C_i - coefficient for impulsive time period

h - height of water

ρ - mass density of liquid in tank

t - thickness of side wall of tank

D - inner diameter of tank

E - modulus of elasticity of wall

c) For elevated tanks

$$T_i = 2\pi \sqrt{\frac{m_i + m_s}{K_s}}$$

Where

K_s - lateral stiffness of staging.

m_s - sum of mass of container and one-third mass of staging

2) Convective time period

Time period of convective mode of vibration, T_c in seconds, is given by

1) For rectangular tank

$$T_c = C_c \sqrt{\frac{L}{g}}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 4, April 2017

1) For circular tank

$$T_c = C_c \sqrt{\frac{D}{g}}$$

C_c = Coefficient of time period for convective mode. Value of C_c can be obtained from Fig. 7, IS 1893 part II,

L = Inside length of tank parallel to the direction of seismic force.

3) Base shear

Base shear in impulsive mode, at the bottom of tank wall is given by

$$V_i = (A_h)_i [m_i + m_w + m_t] \times g$$

Base shear in convective mode, at the bottom of tank wall is given by

$$V_c = (A_h)_c [m_c] \times g$$

The SRSS of base shear is given by

$$V = \sqrt{V_i^2 + V_c^2}$$

4) Base moment

Bending moment in impulsive mode, at the bottom of wall is given by

$$M_i = (A_h)_i [m_i h_i + m_w h_w + m_t h_t] \times g$$

and bending moment in convective mode is given by

$$M_c = (A_h)_c [m_c h_c] \times g$$

Where h_w = Height of center of gravity of wall mass, and

h_t = Height of center of gravity of roof mass.

The SRSS of base moment is given by

$$M = \sqrt{M_i^2 + M_c^2}$$

IV. METHODOLOGY & OBJECTIVES

- Objectives:** The salient objectives chosen for the present study are: (a) To perform manual dynamic analysis of different types of RCC water tanks with varying water level to find out base reactions at every 10% of maximum water level. (b) To compare the base reactions of each water tanks obtained using manual dynamic analysis with software dynamic analysis by using ETABS 2016 [12] software.
- Methodology:** The steps undertaken in the present study to achieve the objectives are as follows: (a) Models of ground supported rectangular water tank, ground supported circular water tank, elevated rectangular water tank and elevated circular water tank each of RCC with capacity $500 m^3$ were selected. (b) Manual dynamic analysis were performed in each water tank at every 10% rise in water level upto tank full condition. (c) The selected water tanks were modelled in ETABS 2016 as per required specifications in the software and dynamic analysis were conducted at every 10% rise in water level upto tank full condition. (d) The base reaction obtained in manual and software dynamic analysis were compared.

V. MODEL PROVISION

Two mass models for elevated tank was proposed by G.W. Housner (1963) was used, which is used in most of the International codes. In two mass model, the water mass in the tank is divided into two. Impulsive mass and convective mass. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall.

International Journal of Innovative Research in Science, Engineering and Technology

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Website: www.ijirset.com

Vol. 6, Issue 4, April 2017

This mass is termed as impulsive liquid mass, which induces impulsive hydrodynamic pressure on tank wall and base. Liquid mass in the upper region of tank undergoes sloshing motion. This is termed as convective liquid mass. It exerts convective hydrodynamic pressure on tank wall and base.

VI. STRUCTURAL GEOMETRY AND MODELLING

The ground supported water tank consists of roof slab, walls and base slab. They are directly resting on ground but in case of elevated tanks suitable RCC framed staging were also provided to support the tank. Elevated rectangular tank were provided with RCC framed staging rectangular in plan where columns are rectangular in shape. Similarly for elevated circular tank were provided with RCC framed staging circular in plan here columns are circular in shape. Each water tank have capacity of 500 m^3 , located at Calicut with medium soil condition. The specifications of water tanks are given in table 1.

Table 1: Dimensions of water tanks

Specifications	Ground supported rectangular tank (GRT)	Ground supported circular tank (GCT)	Elevated rectangular tank (ERT)	Elevated circular tank (ECT)
Capacity, m^3	500	500	500	500
Internal dimension, m	10.5 x 10 x 5	11.52 dia, 5 ht	10.5 x 10 x 5	11.52 dia, 5 ht
Roof thickness, mm	120	120	120	120
Side wall thickness, mm	200	200	200	200
Floor slab tk, mm	150	150	150	150
Free board, mm	200	200	200	200
Zone	Zone III	Zone III	Zone III	Zone III
Soil type	Medium	Medium	Medium	Medium
Bottom ring beam, mm	-	-	300x 400	300 x 400
Column dia, mm	-	-	650	650
RCC Bracing, mm	-	-	300x400	300x400

In manual dynamic analysis, the analysis were performed using IS 1893 part (2):2002 guidelines. Base shear and base moments are calculated at every water levels. In software dynamic analysis two mass model of water tank were modelled in ETABS 2016 software. The convective mass were connected to tank wall by two springs having stiffness $kc / 2$. Similarly impulsive masses were connected by two rigid beams. In software modeling walls and slabs of tanks were modeled as shell elements, columns, beams and bracings were modeled as frame element. The springs were modeled as links having properties of spring. The FEM models of water tanks are shown in figure 1.

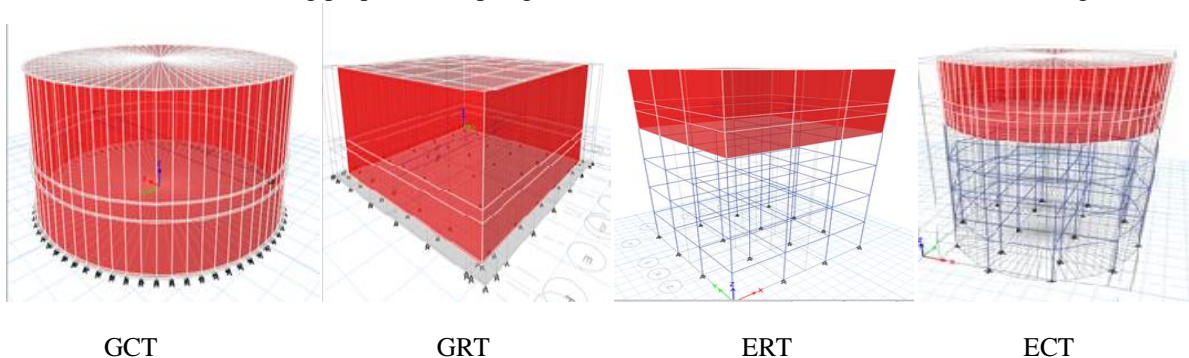


Fig. 1: FEM models of water tanks

International Journal of Innovative Research in Science, Engineering and Technology

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Website: www.ijirset.com

Vol. 6, Issue 4, April 2017

VII. RESULTS AND DISCUSSIONS

Manual and software dynamic analysis of four types of water tanks were carried out. Base shear and base moment of each tank for each cases are calculated. The variation of base shear and base moment of ground supported tanks are shown in figure 2 (a) and figure 2 (b) respectively. Similarly the variation of base shear and base moment of elevated tanks are shown in figure 3 (a) and figure 3 (b) respectively.

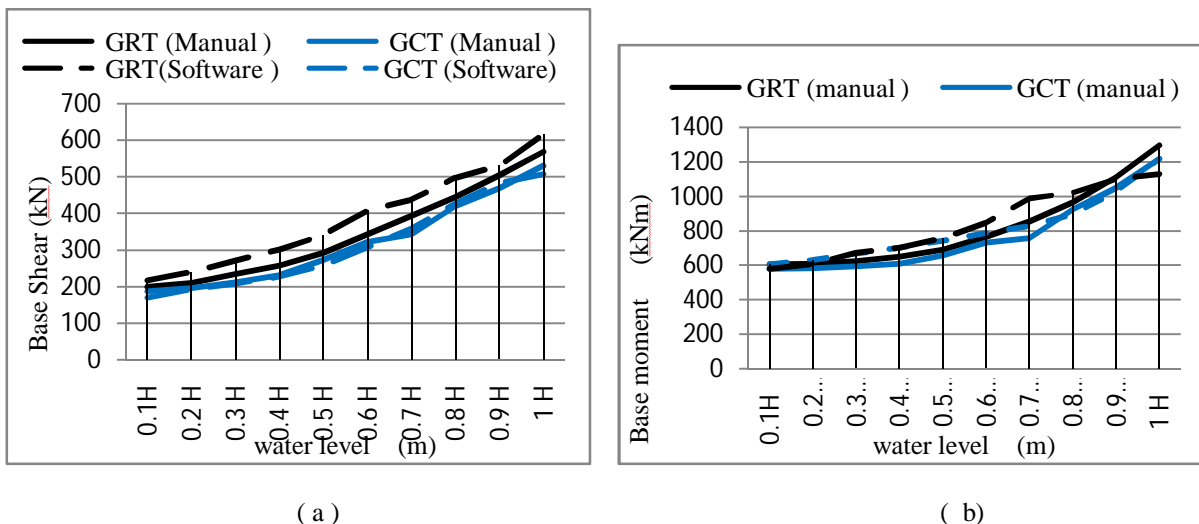


Fig. 2: Variation of (a) base shear and (b) base moment of ground supported water tanks.

Base shear and base moment are increasing with rise in water level. Ground supported rectangular water tank have higher base shear and base moment than ground supported circular tanks. The base shear and base moment of ground supported rectangular tank exceeds ground supported circular tank by 6.89% and 6% respectively at full tank condition.

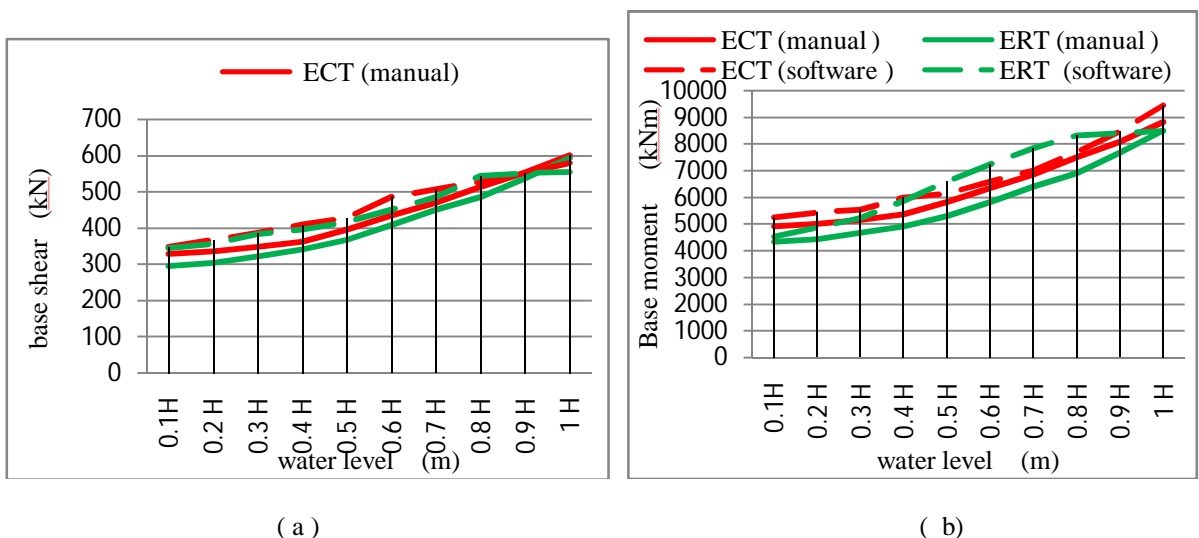


Fig. 3: Variation of (a) base shear and (b) base moment of elevated water tanks.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 4, April 2017

In case of elevated tanks the base shear and base moment of circular tank exceeds rectangular tank by 1.37% and 3.69% respectively. So the geometry of ground supported tank has importance in dynamic analysis. But in case of elevated water tank 12 m staging is provided which is much more than height of tank wall and the effect of geometry on base reactions are negligible. So Elevated circular water tank shows higher base shear and base moment than elevated rectangular water tanks. The elevated water tanks have higher base shear and base moment than ground supported tanks, which is due to presence of staging. While comparing staging height with height of tank wall, height of tank wall is too smaller than height of staging.

The results of manual and software dynamic analysis were comparable. For ground supported rectangular tanks the base shear obtained from software dynamic analysis at full tank condition exceeds 7% and base moment lags 13% from manual dynamic analysis but in the case of ground supported circular tanks the base shear and base moment obtained from manual dynamic analysis exceed software dynamic analysis by 4% and 0.08% respectively. For elevated rectangular tanks the base shear obtained from manual dynamic analysis at full tank condition exceeds 6.5 % and base moment exceeds 0.1 % from software dynamic analysis but in the case of ground supported circular tanks the base shear obtained from manual dynamic analysis exceed software dynamic analysis by 4% and and base moment lags 6 % .

VIII. CONCLUSION

Based on the work presented in this study, the conclusions can be summarized as follows:

1. Base shear and base moment are increases with increase in water level.
2. Elevated water tank shows higher base reactions than ground supported tanks. So base reactions increases with increase in staging height.
3. The base shear and base moment of ground supported rectangular tank exceeds ground supported circular tank by 6.89% and 6% respectively at full tank condition. So geometry of water tank can influence base shear. The ground supported circular tank have less base reactions . i.e it is better than ground supported rectangular tank.
4. In case of elevated tanks the base shear and base moment of circular tank exceeds rectangular tank by 1.37% and 3.69% respectively. The elevated rectangular tank is better than elevated circular tank..
5. In the case of elevated rectangular tanks the base shear obtained from manual dynamic analysis at full tank condition exceeds 6.5% and base moment exceeds 0.1% from software dynamic analysis but in the case of ground supported circular tanks the base shear obtained from manual dynamic analysis exceed software dynamic analysis by 4% and base moment lags 6 % .
6. The manual dynamic analysis and software dynamic analysis performed are found to be comparable.

1) SCOPE FOR FUTURE WORK

- 1 The present study is limited to reinforced concrete (RC) water tanks .Another study could be done on steel water tanks.
- 2 Soil-structure interaction effects are not considered in the present study. Further studies could be extended by considering Soil-structure interaction effect.
- 3 In this work staging pattern has been kept constant. One may go for the variation of staging pattern.
- 4 Column ends are assumed to be fixed at the foundation. Study may further be extended for different column supports like roller and pinned.

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Vol. 6, Issue 4, April 2017

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