

# Analysis of Dynamic Behaviour of RCC Elevated Water Tank

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**Abstract:** As known from the very past experiences, elevated water tanks were collapsed or heavily damaged during earth quakes all over the world. These unusual events showed that the supporting system of the elevated tanks has more critical importance than the other structural types of tanks. The main aim of this project is to understand the seismic behaviour of the elevated water tank and comparison of various seismic analysis parameters of the elevated reinforced concrete water tank with consideration and modelling of impulsive and convective water masses inside the container in Two Mass Model as per IS: 1893(part 2)-2002. The behaviour of elevated water tanks with frame staging pattern is analysed using from the codes IS 1893 (part 1): 2002 and IS 1893 (part 2): 2002. It can be observed from the analysis that elevated water tank with frame type of staging can perform better by following IS: 1893 (part 2): 2002 because, IS 1893 (part 1): 2002 is only for buildings and is not suitable for liquid retaining structures. The Base Shear and Overturning moments obtained from the code IS 1893 (part 1):2002 are greater than the values obtained from the code IS 1893 (part 2): 2002, this is due to the consideration of single degree of freedom in earlier code. Then finally concluded that in the earlier code the reinforcement is heavy, this will leads to uneconomical and it is considered as one of the disadvantage. From the recent code the base shear and overturning moment is less from that the reinforcement is reduced. It is very necessary to design and analyze the water tank as economical as possible. Finally, the results have been presented in the form of graphs and tables.

**Keywords:** Elevated water tank, Design, Analysis, Comparative study

## 1. Introduction

Water is human basic needs for daily routine. Actual water distribution depends on design and type of a water tank in certain area. An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to Pressurization the water distribution system. Many new ideas and innovations have been made for the storage of water and other liquid materials in different forms. There are many different ways for the storage of liquid such as underground, ground supported, elevated etc. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus Water tanks are very important for public utility and for industrial structures.

## A. Sloshing

Liquid sloshing is a kind of wave motion inside a partially filled tank. The sloshing phenomenon is of great theoretical and practical importance in coastal and offshore engineering with regard to the safety of sea transport of oil and liquefied natural gas (LNG). Under external excitations that are of large amplitude or near the natural frequency of sloshing, the liquid inside a partially filled tank is prone to violent oscillations and large impact pressure on the tank.

The cycle time for one floor with the use of conventional formwork is minimum 3-4 weeks. Also, the block or Brick work and plastering is needed in order to get the finished surface. This takes more time and skilled labours too. This ultimately increases the time required for the completion of the project.

## B. Seismic analysis of overhead water tank

Analytical studies dealt with the hydrodynamics of liquids in rigid tanks resting on rigid foundations. It was shown that a part of the liquid moves in long-period sloshing motion, while the rest moves rigidly with the tank wall.

Tanks supported on flexible foundations, through rigid base mats, experience base translation and rocking, resulting in longer impulsive periods and generally greater effective damping. These changes may affect the impulsive response significantly. The convective (or sloshing) response is practically insensitive to both the tank wall and the foundation flexibility due to its long period of oscillation. Failure of tanks during Chilean earthquake of 1960 and Alaska earthquake of 1964 led to beginning of many investigations on seismic analysis of liquid storage tanks. Following two aspects came to forefront.

- Due consideration should be given to sloshing effect of liquid and flexibility of container wall while evaluating the seismic force of tank.
- It is recognized that tanks are less ductile and have low energy absorbing capacity and redundancy compared to the conventional building systems.

## C. Lumped mass modal method (IS 1893:2002)

For the purpose of this analysis, elevated tanks shall be

regarded as systems with a single degree of freedom with their mass concentrated at their centre of gravity. The damping in the system may be assumed as 5 percent of the critical for concrete. The Time period  $T$ , in seconds, of such structure shall be calculated from the following formula.

$$T = 2\pi \sqrt{\frac{m}{k_s}} \quad (1)$$

Where,

$m$  = mass of the tank container + 1/3<sup>rd</sup> weight of staging.

$k_s$  = lateral stiffness of the staging.

Using time period  $T$  calculated in above and 5 percent damping, the spectral acceleration shall be read off from the average acceleration spectra given in Figure.3.2 The design horizontal seismic coefficient.

The lateral force shall be taken equal to:

$$\alpha_h * W \quad (2)$$

Where,

$\alpha_h$  = Design horizontal seismic coefficient

$W$  = Seismic Weight.

The design shall be worked out both when the tank is full and when empty. When empty, the weight  $W$  used in the design shall consist of the dead load of the tank and one-third the weight of the staging. When full, the weight of liquid is to be added to the weight under empty condition.

Design horizontal seismic coefficient shall be calculated  $W$  by response spectra method

$$\alpha_h = \beta . I . F_0 (S_a/g) \quad (3)$$

Here:

$\beta$  = a coefficient depending upon the soil foundation

$I$  = a factor depend upon the importance of the structure

$F_0$  = seismic zone factor for average acceleration spectra

$S_a/g$  = average acceleration coefficient as read from the Fig. 2 for above time period and 5% damping.

#### D. Two Mass Modal Method (Is 1893: 2002) (Part 2 Draft)

Most elevated tanks are never completely filled with liquid. Hence a two-mass idealization of the tank is more appropriate as compared to a one mass idealization. Failure of tanks during Chilean earthquake of 1960 and Alaska earthquake of 1964 led to beginning of many investigations on seismic analysis of liquid storage tanks and this aspect came to forefront that consideration should be given to sloshing (convective) effect of liquid and flexibility of container wall while evaluating the seismic force of tank.

##### 1) Impulsive mode

Time period of impulsive mode, in seconds, is given by

$$T_i = 2\pi \sqrt{\frac{m_i + m_s}{k_s}} \quad (4)$$

Where,

$m_i$  = impulsive mass,

$m_s$  = mass of container one-third mass of staging, and

$k_s$  = lateral stiffness of the staging.

##### 2) Convective mode

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

$$T_c = 2\pi \sqrt{\frac{m_c}{k_c}} \quad (5)$$

Parameters of circular tank i.e. Impulsive mass ( $m_i$ ), convective mass ( $m_c$ ), height at which impulsive mass is acting ( $h_i$ ), height at which convective mass is acting ( $h_c$ ), height at which impulsive mass is acting considering base pressure ( $h_i^*$ ), height at which convective mass is acting considering base pressure ( $h_c^*$ ) and convective stiffness ( $k_c$ ) based on  $h/D$  ratio

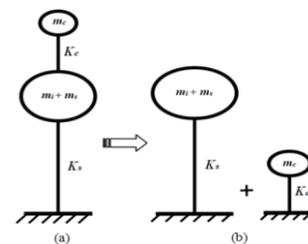


Fig. 1. Base Shear in lumped mass model

## 2. Objective

To study behaviour of elevated circular R.C. water tanks supported on shaft staging under earthquakes.

Seismic analysis of elevated circular R.C. water tanks supported on shaft staging considering lumped mass model as per IS 1893-Part 1.

Seismic analysis of elevated circular R.C. water tanks supported on shaft staging considering two mass model as per draft code 1893-Part 2, (2005).

Analysis of elevated circular R.C. water tanks supported on frame staging using commercial F.E.A package SAP 2000 V14

Considering lumped mass model Considering two mass model.

## 3. Literature review

Here various methods for Seismic analysis of elevated water tanks parameters such as spring mass model parameters, time period, base shear, base moment, hydrodynamic pressure, sloshing height of liquid was presented by various eminent persons from different parts of the world were discussed.

A. M. Kalani and S. A. Salpekar: They have observed that for different staging configuration, results gives a comparative study between conventional and matrix methods of analysis for staging of overhead water tanks. In this report design have been carried out using computer program economic dimensions. The geometrical dimensions of the system remains the same except that the number of columns considered as 6, 8 and 10 with

inclination of column varies with 0°, 30° and 60°. Here, straight bracings are provided at three levels, which divide the staging in four panels.

Sameer U. Sajjad and Sudhir K. Jain: This paper Presents an improved procedure for lateral-load analysis of polygonal braced staging with columns fixed at foundation level. The axial force in the columns is obtained assuming that it is proportional to the distance of the column from the bending axis of the staging. The shear in bracing is then obtained by considering vertical equilibrium of structural units isolated from the staging. Finally, the shear in columns is obtained from moment equilibrium in the plane of bending. The point of inflection is assumed at mid spans of columns in the intermediate panels and bracing girders.

Veletsos A.S and Shivakumar P: studied the response to horizontal ground shaking of a rigid cylindrical tank containing an in viscid liquid with a continuous vertical variation in density is presented. In addition to the free vibrational sloshing characteristics of the liquid, the responses examined include the vertical displacements at the free surface, and the impulsive and convective components of the hydrodynamic wall pressures and associated tank forces. The equations of motion for the system are formulated for an arbitrary variation in liquid density but the solutions presented are for a density that increases exponentially from top to bottom.

Aliakbar Qutubuddin and Ali Deepa P. Telang: They have Effects of hydrodynamic forces on tank walls are calculated. History of earthquake reveals that it have caused numerous losses to the life of people in its active time, and also post-earthquake time have let people suffer due to damages caused to the public utility services. Either in urban or rural areas elevated water tanks forms integral part of water supply scheme, so its functionality pre and post-earthquake remains equally important.

Sekhar Chandra Dutta: has review of past earthquakes reveals damage/failure of important lifeline facilities like elevated water tanks in recurrence, leading to serious hazards even after the event. In the context of such hazards indicating deficiencies in the existing seismic design strategy of such structures, dynamic characteristics of elevated tanks supported by cylindrical shaft (shaft staging) are comprehensively studied in their first part of investigation. The same is made through analytical formulations developed and validated by rigorous

finite element analysis and small-scale experimentation. Subsequent examination on seismic response of representative tanks indicates that the columns of the frame-supported tanks (tanks with frame staging) and the wall of the shaft-staging of such reinforced concrete (R.C.) tanks are susceptible to tension, particularly at tank empty condition.

#### 4. Methodology

*Problem Statement:* The elevated tank has a capacity of 300 m<sup>3</sup> is considered to be supported on 15 m high hollow RC shaft with reinforcement in two curtains. Grade of concrete and steel are M20 and Fe415, respectively. Site of the tank has taken in different soil condition in seismic zone both II & V. Density of concrete is 25 kN/m<sup>3</sup>.

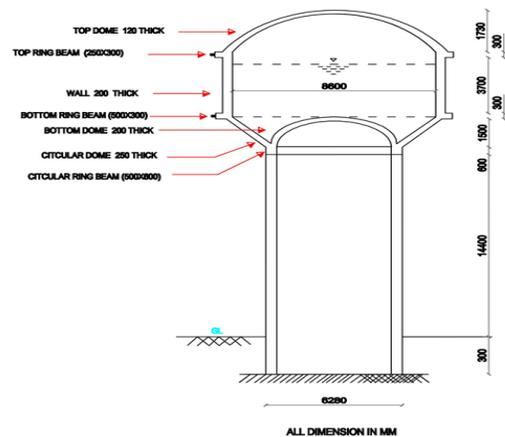


Fig. 2. Elevated water tank

#### 5. Result

Results of base shear and overturning moments of lumped mass model and two mass model are shown below, and those results are compared with SAP result.

Table 2  
Calculation

Components	Calculations	Weight (kN)
Top Dome	Radius of dome, $r_1 = [(8.8/2)^2 / 1.69 + 1.69] / 2 = 6.57$ $2 \times \pi \times 6.57 \times 1.69 \times (0.12 \times 25)$	209.3
Top Ring Beam	$\pi \times (8.6 + 0.25) \times 0.25 \times 0.30 \times 25$	52.1
Cylindrical Wall	$\pi \times 8.8 \times 0.20 \times 4.0 \times 25$	552.9
Bottom Ring Beam	$\pi \times (8.6 + 0.5) \times 0.5 \times 0.30 \times 25$	107.2
Circular Ring Beam	$\pi \times 6.28 \times 0.50 \times 0.60 \times 25$	148
Bottom Dome	Radius of dome, $r_2 = [(6.28/2)^2 / 1.40 + 1.40] / 2 = 4.22$ $2 \times \pi \times 4.22 \times 1.40 \times 0.20 \times 25$	185.6
Conical Dome	Length of Cone, $L_c = (1.65^2 + 1.41^2)^{1/2} = 2.17$ $\pi \times ((8.80 + 6.28) / 2.0) \times 2.17 \times 0.25 \times 25$	321.3
Water	$[(\pi \times 8.62 \times 3.7 / 4) + (\pi \times 1.5(8.62 + 5.632 + (8.6 \times 5.63)) / 12 - (\pi \times 1.32 \times (3 \times 4.22 - 1.5) / 3)] \times 9.81$	2,508

**A. Zone II**

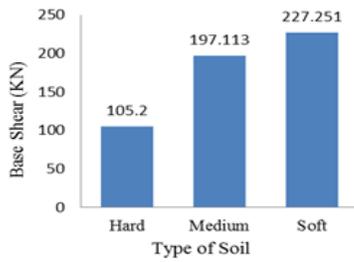


Fig. 3. Base Shear in lumped mass model

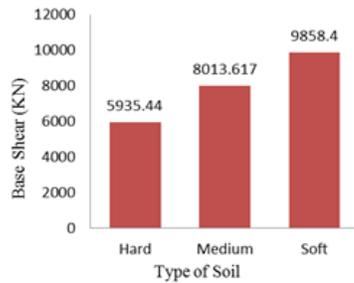


Fig. 4. Base Shear in two mass model

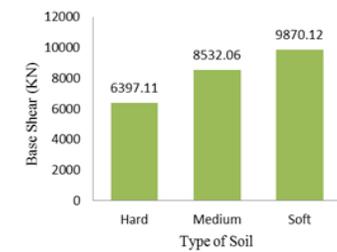


Fig. 5. Base Shear in SAP result

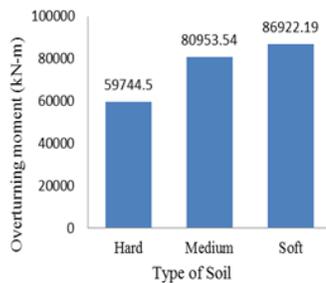


Fig. 6. Overturning Moment in lumped mass model

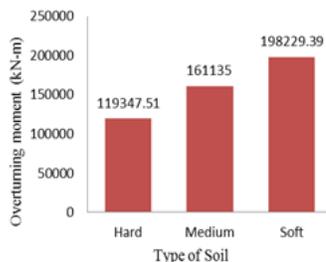


Fig. 7. Overturning Moment in two mass model

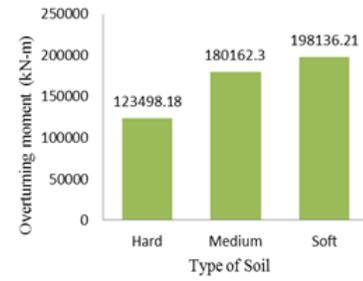


Fig. 8. Overturning Moment in SAP result

**B. Zone V**

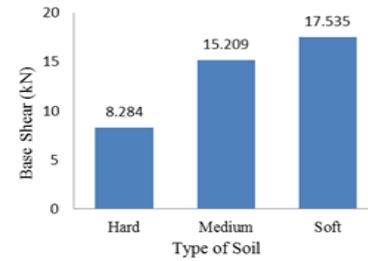


Fig. 9. Base Shear in lumped mass model

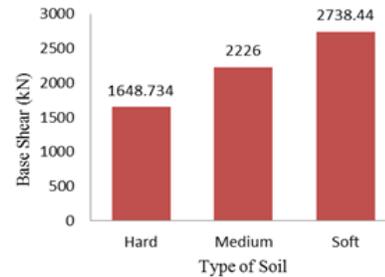


Fig. 10. Base Shear in two mass model

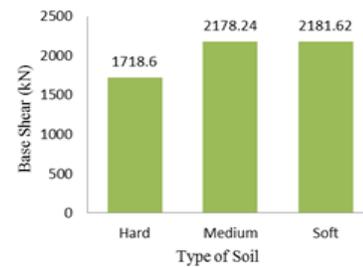


Fig. 11. Base Shear in SAP result

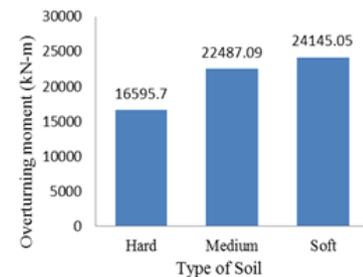


Fig. 12. Overturning Moment in lumped mass model

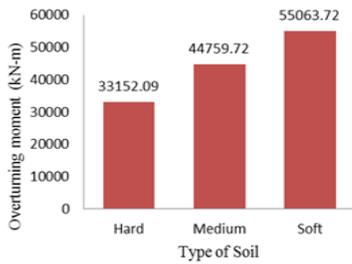


Fig. 13. Overturning Moment in two mass model

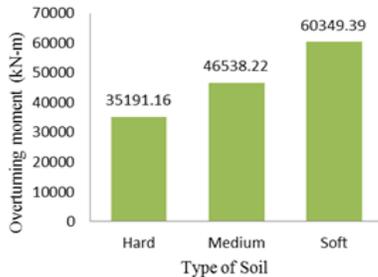


Fig. 14. Overturning Moment in SAP result

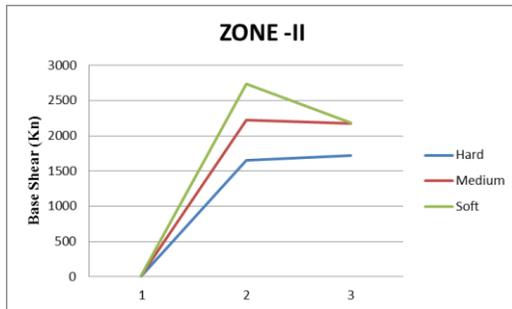


Fig. 15. Comparison of Base Shear in zone II

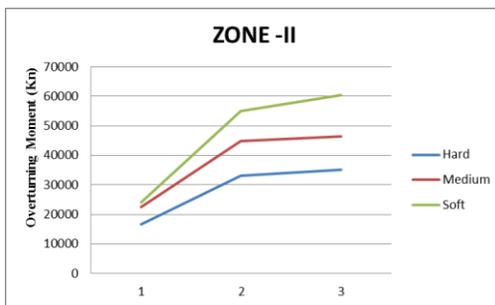


Fig. 16. Comparison of Overturning moment in zone II

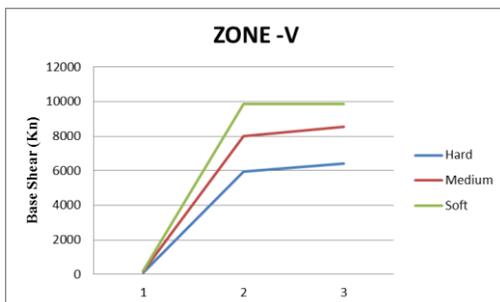


Fig. 17. Comparison of Base Shear in zone V

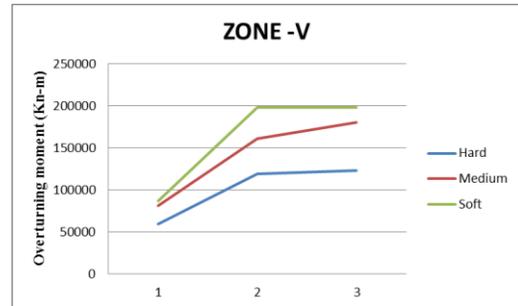


Fig. 18. Comparison of Overturning moment in zone V

## 6. Conclusion

From the present studies we can observe that, base shear & overturning moments in Two Mass model are comparatively less in lumped mass model. Idealization of water tank as single degree of freedom system is not appropriate for seismic analysis of water tanks with large capacity - two mass idealization should be used for dynamic analysis of water tanks.

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