Abstract— Water is human basic needs for daily life. The term ‘Water Tank’ generally refers to distinctive liquid retaining structure. It has been developed about 80 years ago and recognized as well-designed, efficient and economical unit for commercial as well as residential use. Elevated water tanks should be competent of keeping the expected performance during and after earthquake. It has large mass concentrated at the top of slender supporting structure hence extremely vulnerable against horizontal forces due to earthquake. Staging is formed by a group of columns and horizontal braces provided at intermediate levels to reduce the effective length of the column. A dynamic analysis of such tanks must take into account the motion of the water relative to the tank as well as the motion of the tank relative to the ground. For certain proportions of the tank and the structure the displacement of the tank may be the dominant factor, whereas for other proportions the displacement of tank may have small effect.

The main aim of this study is to understand the seismic behaviour of the elevated water tank with consideration and modeling of impulsive and convective water masses inside the container as one mass model and two mass model as per IS:1893-2002 under different time history records using finite element software SAP 2000. The present work aims at checking the adequacy of water tank for the seismic excitations. The result shows that structure response is exceedingly influenced by different capacities of water tank and their one mass and two mass models and earthquake characteristics. The responses include displacement at top level and base shear of existing model and its one mass and two mass model under the four different time history have been compared.

Keywords— one mass model, two mass model, frame staging, base shear, displacement

I. INTRODUCTION

Seismic safety of liquid tanks is of considerable importance. Water storage tanks should remain functional in the post earthquake period to ensure potable water supply to earthquake-affected regions and to cater the need for fighting.

Industrial liquid containing tanks may contain highly toxic and inflammable liquids and these tanks should not loose their contents during the earthquake. Liquid storage tanks are mainly of two types: ground supported tanks and elevated tanks. Elevated tanks are mainly used for water supply schemes and they could be supported on RCC shaft, RCC or steel frame, or masonry pedestal.

1. Frame type staging:

The frame type is the most commonly used staging in practice. The main components of frame type of staging are columns and braces. In frame staging, columns are arranged on the periphery and it is connected internally by bracing at various levels. The staging is acting like a bridge between container and foundation for the transfer of loads acting on the tank. In elevated water tanks, head requirement for distribution of water is satisfied by adjusting the height of the staging portion. Frame type staging are generally regarded superior to shaft type staging for lateral resistance because of their large redundancy and greater capacity to absorb seismic energy through inelastic actions. Framed staging have many flexural members in the form of braces and columns to resist lateral loads. RC frameworks can be designed to perform in a ductile fashion under lateral loads with greater reliability and confidence as opposed to thin shell sections of the shaft type staging. The sections near the beam-ends can be designed and detailed to sustain inelastic deformation and dissipate seismic energy. Frame members and the brace column joints are to be designed and detailed for inelastic deformations, or else a collapse of the staging may occur under seismic overloads. The collapse of the members could have been prevented if the members of staging were detailed according to BIS.

The collapse of the structure could have been prevented if the frame members of staging were detailed according to provisions of IS: 13920-1993(BIS 1993a) and IS: 11682-1985 (BIS 1985) which refers to the ductility requirements of IS: 4326-1976(BIS 1976).
2.1 One mass model

Elevated tanks shall be regarded as systems with a single degree of freedom with their mass concentrated at their centre of gravity. The analysis shall be worked out both when the tank is full and when empty.

\[ T = 2\pi \sqrt{\frac{\Delta}{g}} \]

\( \Delta \) – is deflection of center of gravity of tank when a lateral force of magnitude equal to W is applied at the center of gravity of tank.

\( g \) – acceleration due to gravity.

For modeling of the one mass model the lateral stiffness \( K_e \) is calculated by applying the lateral force to the staging of the existing tank. And deflection (\( \Delta \)) is noted then by using following formula the stiffness is calculated.

\[ K = \frac{P}{\Delta} \quad \text{(1)} \]

This calculated stiffness is given by,

\[ K = \frac{3EI}{L^3} \quad \text{(2)} \]

Where,

\( EI \) – flexural rigidity of structure.

Equating eq\(^a\) (1) and (2):

The equivalent diameter (\( D_e \)) for one mass model is calculated.

The lumped mass for one mass model is calculated from existing model and it consists of mass of water, mass of container and one third mass of staging.

2.2 Two mass model

The two mass model of elevated tank was firstly proposed by Housner (1963) after the chilean earthquake of 1960, which is more appropriate and is being commonly used in most of the international codes including GSDMA guideline. The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts. 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, termed as impulsive liquid mass. Liquid mass in the upper region of tank undergoes sloshing motion, termed as convective liquid mass. For representing these two masses and in order to include the effect of their hydrodynamic pressure in analysis, two-mass model is adopted for elevated tanks. The response of the two-degree of freedom system can be obtained by elementary structural dynamics. In spring mass model convective mass (\( m_c \)) is attached to the tank wall by the spring having stiffness (\( K_c \)), whereas impulsive mass (\( m_i \)) is rigidly attached to tank wall. Spring mass model can also be applied on elevated tanks, but two-mass model idealization is closer to reality.

However, for most of elevated tanks it is observed that both the time periods are well separated. Hence, the two-mass idealization can be treated as two uncoupled single degree of freedom system as shown in Fig. 2 (b). The stiffness (\( K_e \)) is lateral stiffness of staging. The mass (\( m_s \)) is the structural mass and shall comprise of mass of tank container and one-third mass of staging as staging will acts like a lateral spring. Mass of container comprises of roof slab, container wall, gallery if any, floor slab, floor beams, ring beam, circular girder, and domes if provided. The two-mass model is shown in Fig. 2.
Lateral stiffness of the staging is the horizontal force required to be applied at the center of gravity of the tank to cause a corresponding unit horizontal displacement.

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

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

Where

- $C_c$ = Coefficient of time period for convective mode.
- $D$ = Inner diameter of tank.
- $g$ = acceleration due to gravity.

For modeling of the two mass model the lateral stiffness $K_s$ is calculated by applying the lateral force to the staging of the existing tank. And deflection ($\Delta$) is noted then by using following formula the stiffness is calculated.

$$K = \frac{P}{\Delta} \quad \ldots \ldots \ldots (1)$$

This calculated stiffness is given by,

$$K = \frac{3EI}{L^3} \quad \ldots \ldots \ldots (2)$$

Where,

- $EI$ = flexural rigidity of structure.

Equating eqn (1) and (2);

The equivalent diameter ($D_e$) for one mass model is calculated.

The lumped masses $m_i$ and $m_s$ for two mass model is calculated from the provisions of the IS 1893-2002 and it consists of mass of water, mass of container and one third mass of staging. The convective spring stiffness $K_c$ and the convective mass $m_c$ is calculated from the IS1893-2002 provisions which are based on the $h / D$ ratio of the tank container shown in fig.3.

### III. Problem Description

For the study, water tanks with five different capacities are considered, each water tank is modeled as Existing, One mass and Two mass models. The models which are used in this report are of 500m$^3$, 750m$^3$ and 1000m$^3$ capacities. The above models are analyzed for different time history data such as Kern city (1952), North ridge(1994) and Imperial Valley(1979). The comparison is made between the structural responses of existing, one mass and two mass models of above different capacities.
Table I: Description of a water tank model

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Type of Structure</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500 m3 capacity</td>
<td>ER5</td>
</tr>
<tr>
<td>2</td>
<td>750 m3 capacity</td>
<td>ER7</td>
</tr>
<tr>
<td>3</td>
<td>1000 m3 capacity</td>
<td>ER10</td>
</tr>
</tbody>
</table>

Above data and models are used for analysis of structures with respect to different parameters like time period, displacement, base shear of structure. The general characteristics of the structure are as per Table-II which is given below.

Table-II: General Characteristics of the Analyzed Structural Systems

<table>
<thead>
<tr>
<th>Member size</th>
<th>ER-5</th>
<th>ER-7</th>
<th>ER-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staging Ht(m)</td>
<td>14</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Container dia.(m)</td>
<td>11.7</td>
<td>14.1</td>
<td>16.775</td>
</tr>
<tr>
<td>Container Ht.(m)</td>
<td>5.2</td>
<td>5.3</td>
<td>5.25</td>
</tr>
<tr>
<td>Roof Slab (mm)</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Floor Slab (mm)</td>
<td>250</td>
<td>280</td>
<td>320</td>
</tr>
<tr>
<td>Wall(mm)</td>
<td>200</td>
<td>200</td>
<td>225</td>
</tr>
<tr>
<td>Gallery(mm)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Column (mm)</td>
<td>500 &amp; 450</td>
<td>500 &amp; 550</td>
<td>550</td>
</tr>
<tr>
<td>Braces(mm)</td>
<td>250 x 400</td>
<td>250 x 450</td>
<td>250 x 400</td>
</tr>
<tr>
<td>Material</td>
<td>Concrete M25, Steel Fe 415</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table-III

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td>EC meloland overpass</td>
<td>Koyana</td>
<td>Sylmar country hospital</td>
<td>Taft lincoln tunnel</td>
</tr>
<tr>
<td>PGA(g)</td>
<td>0.348</td>
<td>0.32</td>
<td>0.604</td>
<td>0.275</td>
</tr>
<tr>
<td>Magnitude</td>
<td>6.5</td>
<td>6.5</td>
<td>6.7</td>
<td>7.5</td>
</tr>
</tbody>
</table>

IV. RESULTS AND CONCLUSIONS

In this study, a reinforced elevated water tank with 1000m3, 750m3, 500m3 capacities and supported by fixed base frame type staging system has been considered. With considering one mass model as per IS:1893-1984 and two mass water model as per IS:1893-2002, seismic responses including displacements and base shear were assessed under four earthquake records.

The seismic responses of tanks have been determined using time history analysis in 1000m3, 750m3, 500m3 capacity tank with their one mass and two mass models. Displacement variation and base shear variation for 1000m3, 750m3, 500m3 capacity tank with one mass and two mass model and time history records are shown in figure below. The obtained results are summarized as follows:

1. The critical response depends on the earthquake characteristics and particularly frequency content of earthquake records.
2. It is observed that the displacements for two mass models are less than one mass and existing model. Base shear also shows a minimum value for two mass model for all the three capacities.
3. As per comparison the values of displacements and base shear are in order: One > Existing > Two.
4. The responses i.e. displacement and base shear are nearly same for one mass model and two mass model.
5. In some cases existing model shows maximum displacement than one mass than two mass model.

6. There is sudden change in displacement values for north ridge earthquake data. All the above modeled water tanks shows maximum displacement for north ridge earthquake data and minimum displacement for koyana earthquake data for all tank capacities.
REFERENCES


