Retrofitting and Rehabilitation of Existing Elevated Storage Water Tank

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R. K. Ingle at el (2015) presented at providing governing load case for ESR i.e. whether wind or earthquake force is governing. Earthquake analysis is done according to IS 1893 Part I & II. Wind analysis is done according to IS 875-1987 (Part III) & IS 875 draft (Part III). In this paper ESR of staging height 12m is considered with capacity varying from 20 m3 to 100 m3. Analysis has been done using SAP-2000. Three types of soil conditions, namely soft, medium, hard and seismic zones, Zone-II, Zone-III, Zone-IV and Zone V are considered.

Keyur Y. Prajapati at el (2014) presented the main aim of this study is to compare cost for conceptualize innovative hybrid staging systems of ESR, considering seismic loading and analyzed with SAP2000. Economic aspects are studied for different innovative water tanks staging systems with reference to conventional frame type and shaft type staging of ESR.

Prof. Dr. Kamila Kotrasová at el (2013) presented theoretical background for analytical calculating of elevated tanks during an earthquake and deals with comparing of simplified seismic design procedures for elevated tanks, and the applicability for subsoil classes. The analysis has been carried out considering four different subsoil classes A, B, C, D, given EC8. The design by simplified seismic procedures given EC8 and Housner model was compared.

Inel and Ozmen at el (2006): This paper discusses the effects of plastic hinge properties on nonlinear response of reinforced concrete buildings. The paper discusses the results of pushover analysis with default and user defined hinge properties. The paper gives details of reinforcement as well as other structural features of the building under consideration. It has been observed that plastic hinge length and spacing of transverse reinforcement does not affect the base shear capacity of the structure but they have considerable effects on displacement demands.

Applied Technology Council1 (1996): The document provides analytical procedures for evaluating the seismic performance of existing buildings. Simplified nonlinear analysis methods are provided. Use of nonlinear procedures in general has been discussed and capacity spectrum method is introduced. Although the methods mentioned in the document are not intended for new buildings, the analytical procedures are applicable to new structures as well. The analytical procedures incorporated in the methodology accounts for post elastic deformations of the structure by using simplified nonlinear static analysis methods.

P. Muthu Vijay at el (2014): presents analysis to study the effects of sloshing in overhead liquid storage tank. In such structure a large mass concentrated at the top of slender supporting structure makes the structure vulnerable to horizontal forces e.g. due to earthquakes. This study focuses mainly on the response of the elevated Intze type water tank to dynamic forces by both equivalents static method and finite element analysis using commercial software.

Abstract— Elevated water tanks are one of the most important lifeline structures in earthquake prone regions. In major cities and also in rural areas elevated water tanks forms an integral part of water supply scheme. These structures has large mass concentrated at the top of slender supporting structure hence these structures are especially vulnerable to horizontal forces due to earthquake. Analysis is done according to IS 1893 Part I & II, Wind analysis is done according to IS 875-1987 (Part III) & IS 875 draft (Part III). In this paper ESR of staging height 12m is considered with capacity varying from 20 m3 to 100 m3. Analysis has been done using SAP-2000. The Rehabilitation of the existing damaged Elevated storage reservoir with pile foundation is used in this work to evaluate the effectiveness of retrofitting techniques, called Concrete Jacketing. Economic aspects are studied for different innovative water tanks staging systems with reference to conventional frame type and shaft type staging of ESR. Reinforced concrete elevated water tanks are critical structures that are expected to remain functional after severe earthquake in order to serve water system network. During earthquake activity the liquid exerts impulsive and convective pressures (sloshing) on the walls and bottom of tank.

Key words: Impulse Mass, Convective Mass, SAP-2000

I. INTRODUCTION

Water is source of every creation.” In day to day life one cannot live without water. Therefore water needs to be stored for daily used. Depending upon the location of the tank the tanks can be name as overhead, on ground and underground. Elevated water tank is a large elevated water storage container constructed for the purpose of holding a water supply at a height sufficient to pressurize a water distribution system. Elevated concrete water tanks are mainly used for water supply and fire protection. One of the major problems that may lead to failure of these structures is earthquakes. Therefore the analysis of elevated tank must be carefully performed, so that safety can be assured when earthquake occurs and the tanks remain functional even after earthquake. The irregular shape of an elevated water tank, for which most of the mass of water, confluent in the upper part of the tank makes it more sensitive for staging of tank to fail especially due to an earthquake.

II. LITERATURE REVIEW

R. Ghateh at el (2015) presented a systematic approach is employed to establish the seismic response factors for a wide range of elevate water tank sizes and RC pedestal dimensions commonly built in industry. In total, forty-eight model configurations (prototypes) are selected and designed based on current codes and standards. The finite element (FE) method is then used for nonlinear static (pushover) analysis of the prototypes. The pushover curve of each prototype is developed and the seismic response factors are determined accordingly.
Gareane A. I. Algreane at el (2011): presented the soil and water behavior of elevated concrete water tank under seismic load. An artificial seismic excitation has been generated according to Gaspirin and Vanmarcke approach, at the bedrock, and then consideration of the seismic excitation based on one dimension nonlinear local site has been carried out.

Dr. Suchita Hirde at el (2011): This paper presents the study of seismic performance of the elevated water tanks 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 in this paper with the help of analysis of 240 models for various parameters.

III. METHODOLOGY

Two mass models for elevated tank were proposed by Housner [Housner, 1963] which is more appropriate and is being commonly used in most of the international codes. The pressure generated within the fluid due to the dynamic motion of the tank can be separated into impulsive and convective parts.

A. Impulsive Liquid Mass

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.

B. Convective Liquid Mass

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 of elevated water tank shown in Figure 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 as shown in Figure Structural mass, includes mass of container and one-third mass of staging. Mass of container comprises of mass of roof slab, container wall, gallery, floor slab, and floor beams. Staging acts like a lateral spring and one-third mass of staging is considered based on classical result on effect of mass on natural frequency of single degree of freedom system. Most elevated tanks are never completely filled with liquid. Hence a two-mass idealization of the tank shown in Figure is more appropriate as compared to a one mass idealization, which was used in IS 1893: 1984.

The response of the two-degree of freedom system will have to be solved using elementary structural dynamics. There are two cases for seismic analysis namely tank empty condition and tank full condition. For tank empty condition, tank will be considered as single degree of freedom system and empty tank will not have convective mode of vibration whereas tank full condition is considered as two degree of freedom system.

1) Seismic zone factor, Z

India has been divided into four seismic zones as per IS 1893 (Part 1): 2002 for the Maximum Considered Earthquake (MCE) and service life of the structure in a zone. Different zone have different zone factor. India is divided into four seismic zones. There are three types of soil considered by IS 1893 (Part 1): 2002 i.e. soft, medium and hard soil.

2) Importance factor, I

Importance factor depends upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance. Elevated water tanks are used for storing potable water and intended for emergency services such as firefighting services and are of post-earthquake importance. So importance factor is 1.5 for elevated water tank.

3) Response reduction factor, R

Response reduction factor depends on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. R values of tanks are less than building since tanks are generally less ductile and have low redundancy as compared to building. For frame confirming to ductile detailing i.e. special moment resisting frame (SMRF), R value is 2.5.

4) Structural response factor, (Sa/g)

It is a factor denoting acceleration response spectrum of the structure subjected to earthquake ground vibrations, and depends on natural period of vibration and damping of the structure.

C. Elevated Concrete Water Tank Subjected to Artificial Ground Motion

1) Seismic Excitation

The whole main steps to generate artificial earthquake and account the local site effects can be described as in Figure 1. It is started from artificial earthquake generation at the
bedrock which is compatible with local response spectrum. The generated earthquake has to be used to accounting the local site effects to predict the ground motion and ground response spectrum.

![Main steps to generate and evaluate the ground motion](image)

Selection of appropriate seismic excitations that compatible with design response spectrum in particular region could affect the results significantly (Azlan et al., 2005). In this paper the procedure of artificial earthquake generation developed by Gasparini and Vanmarcke (Gasparini and Vanmarcke, 1976) is adopted. The procedure is based on the fact that any periodic function

\[
x(t) = \sum_{i=1}^{n} A_i \sin(\omega_i t + \varphi_i) \hspace{1cm} (1)
\]

Where \(A_i\) is the amplitude and \(\varphi_i\) is the phase angle of the \(i^{th}\) contributing sinusoidal, the amplitudes \(A_i\) are related to power spectral density function \((\omega)\) in the following way:

\[
A_i = \sqrt{2 \int_{0}^{\omega_i} G(\omega) \, d\omega} \hspace{1cm} (2)
\]

The relationship between \((\omega)\) of seismic excitation and response spectrum can be expressed as following

\[
G(\omega) = \frac{1}{\omega_1^2} \left( \frac{\omega^4}{\omega_1^4} - 1 \right) \left( \frac{s_p^2}{\omega_1^2} \right)^2 \left[ \int_{0}^{\omega_i} G(\omega) \, d\omega \right]^{1/2} \hspace{1cm} (3)
\]

Where \(r_p\) is the peak factor; \(s_p\) is the target velocity of the response spectrum; \(\omega_1\) is the circular frequency of the \(i^{th}\) contributing sinusoid; \(\varphi_1\) is the fictitious time-dependent damping factor for duration \(t\). The definitions of these parameters can be found in Gasparini and Vanmarcke (1976). To simulates the transient character of real earthquakes, the steady-state motions are multiplied by deterministic envelope function \((t)\). The artificial motion \((t)\) becomes:

\[
x(t) = x(t) = \int_{0}^{t} A_i - \sin(\omega_i t + \varphi_i) \hspace{1cm} (4)
\]

![Simplified models for inertial interactions analysis](image)

**D. Numerical Analysis**

Two methods of seismic analysis are employed for elevated tank. The first method is the Eigen value natural frequency analysis solves using spectral response methods. For the analysis, the response spectrum for 5% of critical damping gives a ZPA of 0.231g Figure 6. The analyses are solved using the complete quadratic combination (CQC) method in all cases except SDOF to take account of the correlation between modes of similar frequencies.

The second method is a full time stepping implicit dynamics solution of elevated tank using acceleration time histories as input to the base supports of the model. The acceleration time history was taken from Figure it has a zero period acceleration (ZPA) of 0.149g.

Several linear integration dynamic analyses are made to investigate the performance of an elevated tank through the implicit time stepping FEM dynamic analysis with assumption that the soils do not liquefy. The investigation focuses upon how the responses vary with: (1) the size of time step \((\Delta t)\); (2) the density of the soil mesh \((\Delta L)\). In this study Parameters obtained from direct integration linear analysis \((\Delta t = 0.02)\) and appropriate mesh size is used also for nonlinear analysis.

**Table 1: Results obtained from SDOF**

<table>
<thead>
<tr>
<th>Analysis</th>
<th>(F_s) (KMN)</th>
<th>(M_s) (KMN.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Case-7</td>
<td>70.77</td>
<td>1364.44</td>
</tr>
<tr>
<td>Nonlinear Case-8</td>
<td>67.45</td>
<td>1315.70</td>
</tr>
</tbody>
</table>

**Table 2: Results of direct integration**

**E. Finite Element Modeling**

FEM of the Intze tank is rendered for the following dimensions, The Intze Tank is to be designed for the capacity of 10,00,000 liters with staging height of 20 m above ground on a hard strata in Seismic zone IV by using concrete of grade M20 and Steel of grade Fe415.
Retrofitting and Rehabilitation of Existing Elevated Storage Water Tank

- Top dome plate thickness: 150mm
- Tank wall plate thickness: 300mm
- Bottom conical dome plate thickness: 500mm
- Top ring beam dimension: 350*500mm
- Bottom ring beam dimension: 1000*730mm
- Circular ring beam dimension: 600*1200mm
- Top ring dimension: 350*500mm
- 8 columns of diameter: 750mm
- And of height (including 1m inside GL): 2160mm
- Bracings: 300*600mm
- Raft circular foundation: 450mm (Depth) 13.65m (dia.)

Table 3: Support Reactions of Intze Tank by Considering Hydrostatic Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>Support Reactions (kN)</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FX</td>
<td>FZ</td>
<td>FY</td>
</tr>
<tr>
<td>1</td>
<td>3.086</td>
<td>49.609</td>
<td>9.715</td>
</tr>
<tr>
<td>9</td>
<td>-0.891</td>
<td>27.991</td>
<td>27.899</td>
</tr>
<tr>
<td>17</td>
<td>-5.889</td>
<td>36.043</td>
<td>9.903</td>
</tr>
<tr>
<td>25</td>
<td>3.075</td>
<td>45.883</td>
<td>-16.824</td>
</tr>
<tr>
<td>33</td>
<td>9.546</td>
<td>37.077</td>
<td>-25.002</td>
</tr>
<tr>
<td>41</td>
<td>4.068</td>
<td>27.914</td>
<td>-23.164</td>
</tr>
<tr>
<td>49</td>
<td>-7.549</td>
<td>37.757</td>
<td>-6.211</td>
</tr>
</tbody>
</table>

Table 4: Support Reactions of Intze Tank by Considering Sloshing Along with Hydrostatic Forces

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (Hz)</th>
<th>Period (Seconds)</th>
<th>Participation (X %)</th>
<th>Participation (Y %)</th>
<th>Participation (Z %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.103</td>
<td>9.725</td>
<td>80.691</td>
<td>0</td>
<td>1.955</td>
</tr>
<tr>
<td>2</td>
<td>0.103</td>
<td>9.768</td>
<td>80.691</td>
<td>0</td>
<td>1.955</td>
</tr>
<tr>
<td>3</td>
<td>0.933</td>
<td>1.685</td>
<td>98.836</td>
<td>1.057</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.836</td>
<td>1.182</td>
<td>98.836</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.343</td>
<td>0.427</td>
<td>16.482</td>
<td>0</td>
<td>0.068</td>
</tr>
<tr>
<td>6</td>
<td>2.728</td>
<td>0.567</td>
<td>14.045</td>
<td>0</td>
<td>0.145</td>
</tr>
</tbody>
</table>

Table 5: Mode Shapes for Hydrostatic Case

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (Hz)</th>
<th>Period (Seconds)</th>
<th>Participation (X %)</th>
<th>Participation (Y %)</th>
<th>Participation (Z %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.075</td>
<td>13.407</td>
<td>87.414</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.075</td>
<td>13.391</td>
<td>88.288</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.457</td>
<td>2.187</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.571</td>
<td>1.751</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.023</td>
<td>0.494</td>
<td>11.294</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2.169</td>
<td>0.461</td>
<td>10.217</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Mode Shapes for Sloshing Case

IV. CONCLUSION

1) There is almost 40% increase of time period for first and second mode on comparing hydrostatic case and sloshing case which indicates more consideration should be given to sloshing case rather than hydrostatic case.

2) On comparing the critical beam elements of tank, the maximum axial force in sloshing case increases nearly as thrice as in hydrostatic case, 47% in shear force and 16% increase of bending moment in x-direction, while 65% in y-direction and 47% in z-direction.

3) On examining the critical elements of staging, the maximum axial force in sloshing case increases 56% more than in hydrostatic case, 56% in shear force and 45% increase of BM in x-direction, while 40% in y-direction and 59% in z-direction.

4) Idealizing the tank based on SODF still inapplicable and may remain as overestimate analysis which economically inapplicable.

5) The simplified procedure that can utilized for evaluating the dynamic characteristics at dynamic response of elevated tank is more adequate by using 2DOF ,and economically may applicable .further more analysis with 2DOF procedure need less computational efforts than FEM.

6) The results of FEM based on first mode (impulsive mode) are reveals a very good estimation whilst in the case linear full dynamic analysis the result show excellent convergence but computationally more expensive.
REFERENCE

[4] Prof. Dr. KamilaKotrasova, Prof. Dr. Eva Kormanikova, Prof. Dr. IoanSorinLeoveanu“Seismic Analysis of Elevated Reservoirs” (2013).