Research Paper

SUPPORTING SYSTEMS FOR REINFORCED CONCRETE ELEVATED WATER TANKS: A STATE-OF-THE-ART LITERATURE REVIEW

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ABSTRACT

This paper provides a literature review on behavior and suitability of supporting system of reinforced concrete elevated/overhead tanks during vulnerable force events like earthquake with some unusual alteration. As from very offensive past records, many reinforced concrete elevated water tanks were collapsed or highly damaged during the earthquakes all over the world. General observations are pointing out the reasons towards the failure of supporting system which reveals that the supporting system of the elevated tanks has more critical importance than the other structural types of tanks. Most of the damages observed during the seismic events arise due to the causes like improper/unsuitable design of supporting system, mistakes during selection of supporting system, improper arrangement of supporting elements and/or underestimated demand or overestimated strength etc. Consequently the aim of this study is to know the effectiveness of supporting systems of elevated tanks with different alteration. A reviewed literature demonstrates the considerable change in seismic behavior of elevated tanks with consideration of responses like displacement, base shear, base moment, sloshing, torsional vulnerability etc. Finally study discloses the importance of suitable supporting configuration to remain withstands against heavy damage/failure of elevated water tanks during seismic events.

KEYWORDS—Elevated water tanks, Reinforced concrete, Seismic response, Tank Staging.

I. INTRODUCTION

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. Also, it is inevitable part of water supply system, and extensively used for storage and processing of variety of liquid like material such as water, petroleum product, liquefied natural gas, chemical fluid and wastage of different forms. Elevated water storage tanks (Fig. 1) features to look for are strength and durability, and of course leakages can be avoided by identifying good construction practices. But in reality these structures do not often last as long as they are designed for. In general, water retaining structure distress has been observed very early even in 9 to 10 years of service life due to some problems related to structural aspects and over emphasis of seismic analysis in earthquake prone zones. During the past earthquakes, tanks have suffered with varying degree of damages, which include: Buckling of ground supported slender tanks (Malhotra, 1997), rupture of steel tank shell at the location of joints with pipes, collapse of supporting tower of elevated tanks (Manos and clough, 1983, Rai, 2002), cracks in the ground supported RC tanks, etc.

Water tanks can experience distress in different components due to several reasons such as improper structural configuration design, inferior materials and workmanship, corrosion of reinforcement, wind forces, earthquake forces etc. From the past failure observations, as presented by Chirag and H. S. Patel [1] and percentage deterioration of components of overhead tanks (Fig. 2), most of the distress occur in the part of supporting system and also failure due to that as well.

Because of large mass, especially when the tank is full, earthquake forces are more or less govern the lateral force design criteria in the zone of high seismic activity. In the extreme case, total collapse of tank shall be avoided. However, some damage (repairable) may be acceptable during severe shaking not affecting the functionality of tank. Whatever may be the cause of distress but water tanks should fulfill the purpose for which it has been designed and constructed with minimum maintenance throughout its intended life.

Table 1 Summary of studies conducted on performance of supporting systems for RC elevated water tanks

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Authors</th>
<th>Year</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>M. Kalani and A. Salpedar</td>
<td>1997</td>
<td>Different method of analysis for staging of elevated tank</td>
</tr>
<tr>
<td>B.</td>
<td>R. K. Ingle</td>
<td>1996</td>
<td>Propostrion of columns for tank supporting structures</td>
</tr>
<tr>
<td>D.</td>
<td>S. C. Dieta, S.K. Jain and C. V. R. Mary</td>
<td>2000</td>
<td>Alternate staging with reduced torsional vulnerability</td>
</tr>
<tr>
<td>E.</td>
<td>R. Livigngha and A. Degaram</td>
<td>2007</td>
<td>Effect of supporting systems on fluid-tanks interaction</td>
</tr>
</tbody>
</table>

Figure 1. Elevated/Overhead water tanks

This necessitates the overhead tanks to be designed safe to the required degree against all possible forces expected to be encountered during its life time cost-effectively. Also, the poor performance of such critical facilities during recent seismic events in the country required careful scrutiny of their designs, construction quality and their post-earthquake performance. Hence, to overcome the above
discussed situations, attempt is been made to study and review the different past research literature as shown in Table 1.

II. REVIEW OF LITERATURES

A. M. Kalani and A. Salpekar (1978)
Regarding different staging configuration, paper gives a comparative study between conventional and matrix methods of analysis for staging of overhead water tanks. Using computer program economic dimensions and design have been carried out. 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. The stiffness of ring beam connecting top end of columns is considered doubled and bottom ends of the columns are assumed to be clamped with base. These are approximations considered for the analysis. Structure is subjected to vertical loads due to self weight, live loads and the weight of water, which also, subjected to horizontal loads due to wind and earthquake.

The following observations are made from the analysis:

- The values of absolute maximum axial force, bending moment and shear force by conventional method are on conservative side by 10.4%, 39.6% and 17.1% respectively in the lowest panel. It is observed that the maximum bending moment and axial force in a column occur in the lower most panels whereas, the maximum shear force in a column occurs in panel above the lowest.

- The maximum bending moment and axial force in columns occur in the lowest panel. The combined stresses gives 27.2% higher value in conventional method. Same way values of bending moment, torsion moment and shear forces in braces are also higher by 62.1%, 2.7% and 54% respectively. A number of parametric studies, such as the effect in stresses, loading and design of number of braces, column and also the batter of columns, have been carried out and it is observed that Axial force in column is not much affected by the batter in the column while stress-resultants in braces decrease about 28.8% to 27.6% and horizontal displacement at various braces level decrease about 28% to 37% with increase in the batter of the column.

In this paper overhead water tank structure is designed using P-DELTA effect. As per IS: 456 the final design forces shall include the effect of deformation (P-DELTA effect), and it is silent about the calculating this additional forces. As per IS: 11682 evaluate the effective length of column and calculate these forces due to its slenderness ratio. According to the ATC code consideration of P-DELTA effect is necessary if the stability index is more than 0.1 which depend upon drift ratio, story height, vertical and horizontal forces. For the study different shape of the column and its arrangement that is tangentially or radially are considered. And these arrangements plays important role in reducing drift and the stability index. The static analysis of the tank is carried out by using Arya [3,4] or matrix method. Space frame structure is considered having six-degree of freedom at each node. Different configuration of tank supporting structures such as four, six and eight columns for 2, 3 and 4 panel are considered.

In this study the effect of shape and arrangement of column with various h/b ratios are considered. The area of column is 0.09 m² constant for all and braces sizes are 230 × 400 mm. the different h/b ratios 1.0, 1.732, 2.414 for four, six and eight columns supporting tanks respectively and the following results were obtained:

- Decrease in top deflection for tangential disposition of column when the longer side of rectangle c/s placed perpendicular to diameter of column. Maximum increase in stiffness for four, six and eight column structure is 13%, 65% and 88% respectively and there is decrease in stability index from 10 to 50%. No. of panels increase, percent increase in stiffness goes down in comparison with square column for tangential disposition. Percent increase in stiffness goes up as the No. of columns is increased. Radial arrangement of rectangle columns shows decrease in stiffness and decrease in stability index.

Elevated water tanks have failed during past earthquakes including 1952 Kern county and recent 1993 Killari earthquakes owing to large torsional response. So these earthquakes have highlighted the importance of this problem. It is established that these structures may have amplified torsional-induced rotation if their torsional to lateral natural period ratio is close to 1 and also displacement of structural elements due to the coupled lateral- torsional vibration if \( \tau \) is within the range 0.7 to 1.25. The aim of this paper is assessing their torsional vulnerability. In 1993 Killari, India earthquake one RC elevated water tank collapsed vertically downwards, burying the six supporting columns directly underneath the bottom slab of its container due to torsional vibration. Elevated water tanks, with their broadly axi-symmetric geometry and mass distribution, should have no considerable eccentricity between centre of mass and centre of stiffness. However, asymmetric placement of ladders and water pipelines, sloshing of the water mass during shaking, and non-uniformity in construction may introduce small accidental eccentricity between centre of mass and centre of stiffness may cause considerably amplified rotational response under horizontal ground shaking in any structure if it has torsional to lateral time period ratio very close to 1.

This may cause progressively increasing localized damage in the yielded structural element due to strength deteriorating characteristics of concrete under cyclic loading during an earthquake. Hence to assess the torsional vulnerability of the elevated tanks, it needs to be investigated whether the ratio of torsional and lateral time periods, lie within the critical range of 0.7 to 1.25.

Elevated water tanks have filled during past earthquakes owing to large torsional response. Considerable torsional response may occur due to accidental eccentricity if the uncoupled torsional and lateral natural periods of the tanks are closely spaced.

In this paper, alternate staging configurations are studied with a view to move the natural time period ratio ($\tau$) away from critical range of 0.7 to 1.25. Hence the alternate structural configurations are needed for staging so that $\tau$ lies outside the critical region. The alternate configurations are made by adding to the basic configuration which are radial beams, radial beams and a central column, another concentric row of column connected through radial and circumferential beams, Diagonal braces and the dynamic characteristics of usually constructed elevated water tanks on a circular row of columns beams are studied.

**Figure 3. Staging with Radial Bracing**

**Figure 4. Staging with Radial Bracing and a central column**

**Figure 5. Staging with another concentric row of column connected through radial and circumferential beams**

**Figure 6. Staging with Diagonal Bracing**

Approximate closed form expressions are derived for lateral and torsional stiffness’s for such staging configuration. These expressions are used for studying the natural time period ratio for those alternate configurations. The closed form expression and result in this paper are limited to the staging with equal height, although the method of derivations presented are general enough to overcome these limitation. So the derivation of first three configurations are obtained from analytical methods are also checked against the ones obtained from FEM (exact method) for several elevated water tank examples. For conducting the analysis by FEM, standard finite element software, SAP 80 is used. This may prove useful in initial design if anyone of the alternate configurations is chosen either to avoid large torsional response and to retrofit existing staging.

**E. R. Livaoglu and A. Dogangun (2007)**

Here attempt is made to find out the effects of supporting systems on the seismic response of elevated tanks considering the fluid-structure interactions. Finite elements in the frame type support system are modeled as frame elements and truncated cone and container walls are modeled with shell elements. Also shaft supporting system is modeled shell elements. In order to characterize fluid-elevated model (FEM) considered for the elevated tank-fluid system in this study. Columns and beams tank model and to determine the seismic behavior of the system, transient dynamic analysis was carried out using the FEM analysis program. In the seismic analysis, it is assumed that tanks are subjected to North-South component of the ground motion recorded at the Turkey. The time history analyses were carried out by using Rayleigh damping. The result concludes, the maximum response obtained between 9 to 10 seconds for frame supported tank and 5 and 10 seconds for shaft supported tank. Also, it shows that, supporting system affect the sloshing displacement but not as much as roof displacement response by observing decrement of 83% and 12% in shaft type as compare to frame type staging respectively.

**III CONCLUSION**

Generally, when earthquake occur major failures of elevated water tank take place due to failure of supporting systems, as they are to take care for seismic forces. Therefore supporting structures of elevated water tanks are extremely vulnerable under lateral forces due to an earthquake. Looking to the above literature study only frame type staging with a single row of columns placed along the periphery of a circle, are not adequate to support container of elevated water tanks. Apart from that, it is required to identify suitable modified water tank staging system by determining what improvements or added features are necessary for staging part of water tank for better performance during earthquake. Also, alternate or innovative configurations are also required to put in practice.

A reviewed literature demonstrates the considerable change in seismic behavior of elevated tanks with consideration of responses like displacement, base shear, base moment, sloshing, torsional vulnerability etc. when supporting system is used with appropriate
modifications. Finally study disclose the importance of suitable supporting configuration to remain withstands against heavy damage/failure of elevated water tanks during seismic events.

REFERENCES