International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | May-2018 www.irjet.net p-ISSN: 2395-0072

Behaviour of Elevated Water Tank under Seismic Load - Review

Dhanya Johnson[1], Dr. M. Sirajuddin[2]

[1]M. Tech student, Dept. of Civil Engineering, T.K.M College of Engineering, Kollam, India
[2]Professor, Dept. of Civil Engineering, T.K.M College of Engineering, Kollam, India

---

Abstract - *Water tanks are used as storage containers for storing water. For the social and industrial development of the country, water supply projects are essential. Earthquakes are one of the major natural calamities which have a potential to stop the normal going life of human by causing damage to infrastructure and lifeline facilities. Elevated water tanks should not collapse even after the earthquake since they are essential for supplying drinking water and quenching fires. From the past experience of few earthquakes occurred, like Bhuj earthquake (2001) in India, RCC elevated water tanks were heavily damaged and a few were collapsed. The main objective of this paper is to study the performance of reinforced concrete elevated water tank under dynamic load. In addition, the variation of dynamic responses such as base shear, overturning moment, displacement with change in height of staging, capacity of water tank, seismic zone, soil conditions etc. were also studied*

Key Words: Elevated water tank, Earthquake,

1. INTRODUCTION

Water tank is used to store water for daily requirement of the human being. Water is the life line for every kind of creatures in this world. To secure constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force, the elevated water tanks are necessary. Demand for drinking water has increased by with the rapid increase of human population. The height of the elevated tank depends on the area to be covered for the water supply. Height of the tank will be higher if the area to be covered is wider.

India is highly vulnerable to natural disasters like earthquake, droughts, floods, cyclones etc. Among these earthquake is the worst natural calamity. Many causalities and huge property loss occurs every year due the natural calamities. It is said that natural calamities itself never kills people; it is badly constructed structure that kills []. Elevated water tank consists of a slender supporting system with a large mass on the top, which makes the water tank more critical and are more vulnerable during an earthquake. Hence it is important to analyse the structure properly for earthquake. Water tanks are classified on the basis of shape and head.

1.1 Classification of Water Tank

Water tanks are classified on the basis of shape and head.

On the basis of head water tanks are classified as:

- Circular tanks
- Rectangular tanks
- Spherical tanks
- Conical tanks
- Intze tanks

On the basis of head water tanks are classified as:

- Tanks resting on ground
- Elevated tanks supported on staging
- Underground tanks

Elevated water tanks are further classified based on their supporting system or staging. The staging can be of frame type or shaft type.

1.2 Types of Staging of Elevated Water Tank

The frame type is the most commonly used staging in practice. The main components of frame type 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, the head requirement for distribution of water is satisfied by adjusting the height of the staging portion. Frame type staging is 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. Fig - 1 shows an elevated circular water tank supported on frame staging.

Fig -1: Elevated circular water tank with frame staging [1]

Shaft staging has thin shell section which supports the container on the top. Lateral resistance of shaft type staging is less compared to frame type staging, hence not very common in practice. Shaft type staging contains poor ductility of thin shell section and in addition to that, it has lack of redundancy of load path and toughness. The shaft can be of masonry or RCC. Fig - 2 shows an elevated conical water tank supported on shaft staging.

Fig -2: Elevated conical water tank with shaft staging [2]

2. MODES OF FAILURE

[3] Conducted a study on the losses occurred in reservoirs during past earthquakes and the reasons for these occurred damages. Examining the reports of the earthquakes and investigation on existent elevated water tanks in the region, the failure modes were classified as shear failure modes in beams, bending - shear failure in beams, axial failure in columns, cracks in connection and torsion failure.

2.1 Shear Failure Modes in Beams

Shear failure modes in beams occurs due to high shear force in the end of beams. Because of this high shear force, 45 degree angle shear cracks appears in the plastic joints thus creating the end of the beams to fail.

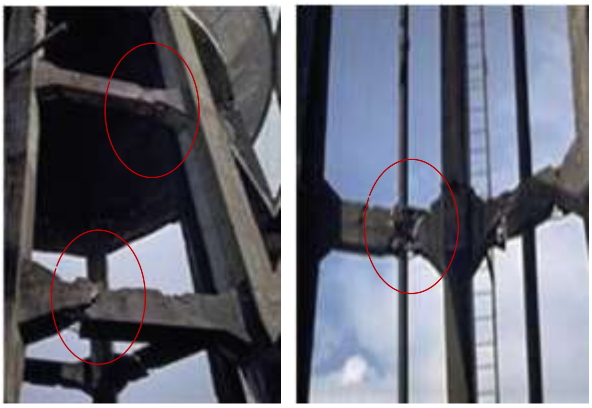

Fig -3: Elevated water tank of Puetro varas hotel after the occurrence of Chile earthquake, May 22nd, 1960 [3]

2.1 Bending- Shear Failure in Beams

Bending shear failure occurs in the middle section of beams with a gradual increase towards the middle of support. This type of earthquake failure was reported for an elevated water tank (volume of 700 cubic meters), when Chile earthquake (South America) in 1960 with a magnitude M=8.5 was occurred. And has reported joint damage in plastic beams creating a strut. Open stirrups with W shape was also reported and it shows that the shear failure of beams are in the middle. Fig. 2.2 shows bending-shear failure modes in beams of elevated water tank of volume 700 m^3, after the occurrence of Chile earthquake in South America (May 22nd, 1960).

Fig -4: Elevated Water Tank with 700 m^3 Capacity after the Occurrence of Chile Earthquake, May 22nd, 1960 [3]

2.3 Axial Failure in Columns

Axial failure in columns occurs due to the compressive forces on column. This type of failure was reported for an elevated water tank with 20 cubic meters capacity located in Gujarat near Anjar, built in 1958, when Bhuj earthquake in India occurred 2001 with a magnitude M=7.7. Columns were severely damaged and deep cracks in column were observed. The cracks occurred along of longitudinal reinforcement of column. Also, in the column connection to the container holder system were developed cracks vertically that lowered the performance of columns. The elevated tank was heavily damaged, however it did not collapsed. Fig. 2.3 shows the axial failure in columns in an elevated water tank of Gujarat, located in India after the occurrence of Bhuj Earthquake in 2001.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 05 | May-2018 www.irjet.net p-ISSN: 2395-0072

Fig -5: Elevated Water Tank of Gujarat, Located in India after the Occurrence of Bhuj Earthquake in 2001 [3]

2.4 Cracks in Connection

Elevated water tank (which its legs sprayed many years ago) with a capacity of 680 m3 suffered small cracks in the joints and vertical cracks in some columns after the occurrence of Bhuj earthquake in India (2001). Some columns had numbers of vertical cracks which they occurred between the borders of old concrete and sprayed concrete due to the high compressive forces on columns.

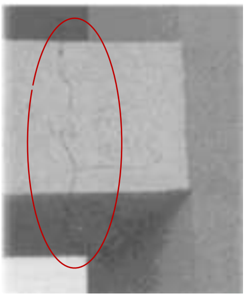

Fig -6: Elevated Water Tank with a Capacity of 680 m3, Bhuj Earthquake in India (2001), Suffered Small Cracks in the Joints [3]

2.4 Torsion Failure

Torsion failure is a common type of failure in elevated concrete tanks with frame staging. Design of elevated water tanks should be in such a way that the geometry is symmetrical about the centroid axis. The geometric centre, centroid and centre of rigidity should lie at the same point. However, using ladder, stairs, installation pipes and executive errors cause incidental eccentricity between centroid and centre of rigidity. Many elevated water tanks collapsed on vertical direction without any lateral sway in past earthquakes, however by perceiving collapsed tanks, it understands which a large number of them had extra torsion deflection. Fig. 2.5 shows the torsion failure the reinforced concrete supporting tower of an elevated reinforced concrete water tank during the 1980 El- Asnam Earthquake, Algeria (M=7.2). Failure was due to poor detailing of the reinforcement at the beam-column connections.

Fig -7: Failure of the reinforced concrete supporting tower of an elevated water tank during the 1980 El- Asnam earthquake, Algeria [3]

3. TYPES OF SEISMIC ANALYSIS OF ELEVATED WATER TANK

Seismic analysis of elevated water tank involved two type of analysis,

- Equivalent Static analysis of elevated water tank.
- Dynamic analysis of elevated water tank.

3.1 Equivalent Static Analysis of Elevated Water Tank

Equivalent static analysis of elevated water tanks is the conventional analysis based on the conversion of seismic load in equivalent static load. IS: 1893- 2002 (part 1) has provided the method of analysis of elevated water tank for seismic loading. For the purpose of the analysis, elevated tanks shall be regarded as systems with a single degree of freedom with their mass concentrated at their centre of gravity (lumped mass method). Elevated water tank can be analysed for both the condition i.e. tank full condition and tank empty condition. For both the condition, the tank can be idealized by one- mass structure. The damping in the system may be assumed as 2 percent of the critical for steel structures and 5 percent of the critical for concrete (including masonry) structures.

3.2 Dynamic Analysis of Elevated Water Tank

As the behaviour of elevated tank is unpredictable the dynamic response of elevated tanks is hard to define. During the earthquake, water contained in the tank exerts forces on tank wall as well as bottom of the tank. These hydrodynamic forces should consider in the analysis in addition to hydrostatic forces [4]. Based on numerous analytical, numerical and experimental studies, simple spring- mass models of tank- liquid system have been developed to calculate the hydrodynamic forces [4]. Two mass model for elevated tank was proposed by Housner (1963) is more appropriate and is being commonly used in all international codes. Most elevated tanks are never completely filled with liquid [4]. The pressure generated within the fluid due to dynamic motion of tank can be separated into impulsive and convective pressures [4]. When a tank containing liquid with free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration [4]. 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. Sloshing is the motion of the free liquid surface inside its container. The base shear, base moment and hydrodynamic pressure is calculated as per IS: 1893-2014 (Part 2) respectively.

4. PARAMETRIC STUDIES

Parametric studies were done by many researchers and studied the variation in responses (base shear, overturning moment, displacement) of the elevated tank with the change in staging height, seismic zone, soil conditions etc. And also studies on the comparison of frame staging and shaft staging were discussed in this section.

[5] Conducted a study to compare the static and dynamic analysis of elevated water tank. From the study it was found that, for same capacity, same geometry, same height, with same staging system, with same importance factor & response reduction factor, in the same zone; response by equivalent static method to dynamic method differ considerably. It was also found that as the capacity increases difference between the response increases and for small capacity of tank the impulsive pressure is always greater than the convective pressure, but it is vice- versa for tanks with large capacity.

[6] Carried out manual seismic analysis (response spectrum analysis) of elevated circular water tank of capacity 50 m3 in accordance with IS: 1893-1984 (i.e. lumped mass model) and IS: 1893-2002 (Part-2) draft code (i.e. two mass model). Four cases were considered in the study ((i) zone III and hard rock soil, (ii) zone III and soft soil, (iii) zone V and hard rock soil, (iv) zone V and soft soil) for both tank empty and tank full conditions. Further comparison between the framed type and shaft type staging was done as per manually calculated responses such as base shear and base moment. From the study it was found that dynamic responses such as base shear, base moment and hydrodynamic pressure increase with increasing zone factors. It was concluded from the study that shaft type staging should be avoided as far as possible in the near future to avoid damage to the water tanks and convective pressures play a major role in seismic analysis of the elevated water tank.

[7] Conducted a comparative study of elevated water tanks subjected to dynamic loading supported on RC framed structure and concrete shaft structure with different capacities and placed in different seismic zones. Manual dynamic analysis of elevated water tanks was done with respect to the latest IS code published for liquid retaining structures by Bureau of Indian Standards i.e. IS 1893 (Part 2) : 2014. From this paper they concluded that base shear and base moment for elevated tanks supported on concrete shaft is greater than that of elevated tanks supported on frame staging. Hence the areas with high seismic intensity, threat to tank with shaft supporting are more than that of frame staging support. They also observed that (1) time period in impulsive mode for shaft supported tanks and frame supported tanks differ subsequently. But for convective mode the difference is less comparatively (2) the deflection of staging decreases with increase of capacity and change in staging pattern (3) sloshing wave height is approximately same for the tanks with different supporting system, but it differs for tanks as the capacity increases.

[8] studied the influence of various parameters (Seismic intensity, soil conditions, etc.) on the seismic behaviour of elevated water tank and the influence of staging height on the base shear and ductility characteristics of elevated water tank by performing non-linear static analysis using SAP2000. They observed that the base shear increases until a critical staging height and then it start decreasing and the variation of base shear with respect to seismic intensity factor was found to be linearly varying. It was also found that grade of concrete has influence on the stiffness of the staging which effects the base shear of the structure.

[9] Conducted a study on the analysis and design (Response Spectrum Analysis, Frequency Analysis and Time History Analysis) of an elevated circular water tank using STAAD.Pro V8i. Response Spectrum Analysis gave displacement, bending moment, shear force, axial force, and torsion values. Eigen solution so obtained helps in determining the base shear and various peak story shear values of the structure. Frequency analysis gave the natural frequency of the structure and time history, which defines the behaviour of the structure in certain interval of time against various functions like velocity, displacement and acceleration. From the study they observed that the value of the peak story shear (kN) decreases as the number of stories increases with the height of the structure and Raleigh frequency for x, z directions is obtained with the joint number on which maximum deflection occurs. The value of frequency is found out to be almost same.

[10] Studied the seismic performance of the elevated water tanks for various heights and various seismic zones of India. They considered a circular cylindrical elevated water tank with 500 cubic meters capacity and the analysis was carried out using finite element software STAAD-PRO. They observed that the base Shear increases from zone II to Zone V and base shear is at its peak for 10m height and again goes down from 10-25 m.

[11] Carried out a study on the hydrodynamic analysis of Intze water tank and comparison of the cost of water tank for different staging conditions like shaft and frame type. For this the container of the water tank was designed by prepared Excel worksheet. The hydrodynamic analysis was carried out in excel worksheet. The staging part was analysed in software STAAD Pro. V8i and the design was done in excel worksheet. For frame type supporting system

the horizontal parallel type bracing was considered at various levels. The various parameters considered were tank capacity, number of columns, height of staging, spacing of bracing, earthquake zone and soil type. After the complete design the quantity of material was found and then the costing of water tank was done using GWSSB- SOR. From the study it was found that the cost of water tank on frame type staging is more than shaft type staging and cost of water tank increase with change in soil type from hard to soft. It was also observed that the base shear and overturning moment increases with decrease in bracing spacing, change of seismic zone from 3 to 4 and change of soil type from hard to soft.

3. CONCLUSIONS

Following conclusions are drawn from the study

- The failure modes of reinforced concrete elevated tanks with frame staging - shear and bending modes in beams, axial mode in columns, cracks in connection and torsion failure
- Failure modes of shear forces in beams and the failure mode of axial force are dominant in the reservoir.
- Shaft type staging should be avoided as far as possible in the near future to avoid damage to the water tanks and thus prevent loss of lives.
- The base shears, base moments and hydrodynamic pressures increase with increasing zone factors.
- The base shear and overturning moment increases with decrease in bracing spacing and change of soil type from hard to soft.
- The cost of water tank on frame type staging is more than shaft type staging and cost of water tank increase with change in soil type from hard to soft.
- The deflection of staging decreases with increase of capacity and change in staging pattern and sloshing wave height is approximately same for the tanks with different supporting system, but it differs for tanks as the capacity increases.
- With the consideration of convective hydrodynamic pressures, bases shear and base moment values increases considerably which were quite small for lumped mass idealization of tank - convective pressures play a major role in seismic analysis of the elevated water tank
- 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.

REFERENCES

[1] Kapadia, I., Dholiya, N., Patel, P., and Patel, N., "Parametric Study of RCC Staging (Support Structure) for Overhead Water Tanks as per 1S 811682–1985 and IS-3370", International Journal of Advance Engineering and Research Development, Vol. 4, Jan. 2017, pp. 76-80.

[2] Musa, A. and Damatty, A. A., "Capacity of Liquid Steel Conical Tanks under Hydrodynamic Pressure due to Horizontal Ground Excitations", Thin Walled Structures, Vol. 6, Dec. 2016, pp. 157-170.

[3] Soroushnia, S., Tafreshi, S. T., Omidinasab, F. and Beheshtian, N., "Seismic Performance of RC Elevated Water tank Frame Staging and Exhibition Damage Pattern", the Twelfth East Asia-Pacific Conference on Structural Engineering and Construction, Vol. 14,2011, pp. 3076-3087, doi:10.1016/j.proeng.2011.07.387.

[4] IITK-GSDMA, "Guidelines for Seismic Design of Liquid Storage Tanks", Gujarat State Disaster Management Authority, Indian Institute of Technology Kanpur, 2007.

[5] Madhurar, V. G. and Madhuri, N. M. "Comparison between Static and Dynamic Analysis of Elevated Water Tank", International Journal of Scientific & Engineering Research, Vol. 4, June 2013, pp. 2043-2052.

[6] Sambary, P. V. and Joshi, D. M., "Seismic Analysis of RC Elevated Water Tanks", International Journal of Scientific & Engineering Research, Vol. 6, Dec. 2015, pp. 247-252.

[7] Vyankadesh, K. M. and Varsha, T. M., "Comparative Study on Dynamic Analysis of Elevated Water Tank Frame Staging and Concrete Shaft Supported", International Journal of Mechanical and Civil Engineering, Vol. 14, Jan. 2017, pp. 8-46.

[8] Devadanam, B., Ratnam, M. K., and Rangaraju, U., "Effect of Staging Height on the Seismic Performance of RC Elevated Water Tan"', International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Jan. 2015, pp. 18568-18575.

[9] Hariteja, N., Kaushik, Y., Varma, M. R., Sharma, S. and Pathania, S., "Seismic Assessment of Elevated Circular Water Tank", International Journal of Engineering Technology Science and Research, Vol. 3, May 2016, pp. 265-270

[10] Aware, R. J. and Mathada, V. S., "Seismic Analysis of Cylindrical Liquid Storage Tank", International Journal of Science and Research, Vol. 4, Dec. 2015, pp. 552-557.

[11] Lakhanakiya, J. and Shah, H. J., "A Parametric Study of an Intze Tank Supported on Different Stagings", International Journal for Scientific Research & Development, Vol. 3, Nov. 2015, pp. 1108-1112.