# Analysis of Circular Elevated Water Tank with Slant Columns Considering Hydrostatic Load: A Review

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*Abstract*— the research presents literature review on analysis 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. 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. These events showed that importance of supporting system is uncompromising for elevated tank as compared to any other type of tank. Damages caused are the results of unsuitable design of supporting system; wrong selection of supporting system, etc. These structures have heavy mass concentrated at the top of slender supporting system hence these structures are especially vulnerable to horizontal forces due to earthquakes. Comparison of elevated tanks with different supporting system, capacities and seismic zones states that these parameters may considerably change the seismic behaviour of tanks.

***Keywords:*** Elevated Water Tank, Sloping Columns, Hydraulic Pressure, Lateral Forces and STAAD.Pro

## I. INTRODUCTION

An elevated water tank is a large water storage container constructed for the purpose of holding water supply at certain height to provide sufficient pressure in the water distribution system. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Industrial liquid tanks may contain highly toxic and inflammable liquids and these tanks should not lose their contents during the earthquake. These tanks have various types of support structures like RC braced frame, steel frame, RC shaft, and even masonry pedestal. The frame type is the most commonly used staging in practice. The main components of the frame type of staging are columns and braces. The staging acts like a bridge between container and foundation for the transfer of loads acting on the tank. Thus Water tanks are very important for public utility and for industrial structure.

Elevated water tanks consist of huge water mass at the top of a slender staging which are most critical consideration for the failure of the tank during earthquakes. Elevated water tanks are critical and strategic structures and the damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economical loss. Since, the elevated tanks are frequently used in seismic active regions hence; seismic behaviour of them has to be investigated in detail. Due to the lack of knowledge of supporting system some of the water tanks were collapsed or heavily damaged. So there is need to focus on seismic safety of lifeline structure with respect to alternate supporting system which are safe during earthquake and also to withstand more design forces.

In this study we are presenting review of publications, journals, citations and researches related to research on elevated water tanks.

MareddyArun Kumar et. al (2018) the primary objective of the research paper was to plan, analysis and design a Circular Overhead Tank of 15 lakh litres capacity at N.B.K.R. Institute of Science and Technology, Vidyanagar using structural application STAAD.Pro. The overhead circular water tank with 1500 KL capacity was modelled.

Conclusion stated that the proposed tank in NBKRIST College campus designed in STAAD Pro software. Design of tank is safe from the software design with respect to loads applied. For small capacities we go for rectangular water tanks while for bigger capacities we provide circular water tanks. Since proposed tank is of 12lakh capacity the Planned analyzed and designed the circular over head tank in STAAD Pro software. Design of water tank is a very tedious method.

Hemishkumar Patel et. al (2014) the research paper was an application of optimization method to the structural Analysis and design of circular elevated water tanks, considering the total economy of the tank as an objective function with the properties of the tank that are tank capacity, width and length of tank in rectangular, water depth in circular, unit weight of water and tank floor slab thickness, as design variables. A computer program was developed to solve numerical examples.

The results stated that the tank capacity taken up the minimum economy of the rectangular tank and taken down for circular tank. The tank floor slab thickness taken up the minimum economy for tanks. The unit weight of water in tank taken up the minimum economy of the circular tank and taken down for rectangular tank.

Conclusion stated that entire water load in Rectangular tank is slightly higher than water load in circular tank. A hoop tension force for Circular tank is lower compare to Rectangular tank for higher capacity. An axial force in column due to total water load in Circular tank is lower compare to Rectangular tank for higher capacity. Software results compare to IS code calculation is higher.

Tiruveedhula Chandana and S.V. Surendhar (2019) the research paper dealt with the performance of elevated reinforced concrete overhead water tanks to seismic and wind forces. Tanks of various shapes were considered in the present study. Circular, Rectangular and Intze Elevated water tanks and modelled in STAAD.PRO software. Gravity

 

analysis, Seismic analysis and wind analysis are performed on the modelled structure. The seismic parameters such as displacements, base shear and over turning moments were examined and compared and cost analysis was performed for all the three water tanks and compared.

The conclusion derived from the results stated that considering the shape and geometry, over-turning moment was found to be greater in rectangular water tank when compared to the other two water tanks (Circular and Intze). Under seismic loading, Circular water tank was recommended. Under wind loading, Intze water tank was recommended. Circular water tank experiences greater displacement when compared to other two water tanks due to its support conditions. Circular water tank experiences greater base shear when compared to Rectangular and Intze water tanks. Comparing seismic analysis and wind analysis results, Intze water tank was recommended and as per cost analysis, Circular water tank was found to be economical when compared to the other two tanks extensions.

Mor Vyankatesh K. and More Varsha T. (2017) the research paper presented 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. The dynamic analysis of elevated water tanks was conducted with respect to the latest IS code published for liquid retaining structures by Bureau of Indian Standards i.e. IS 1893 (Part 2) : 2014. Comparison of elevated tanks with different supporting system, capacities and seismic zones states that these parameters may considerably change the seismic behaviour of tanks. The hydrodynamic effect on elevated water tank, with different supporting system i.e. framed staging and concrete shaft placed in different seismic zones was further valuated.

Results stated that base shear for elevated tanks, supported on concrete shaft is greater than that of elevated tanks supported on frame staging. Base moment being important parameter while designing the structure is considerably greater for tanks with concrete shaft supported. Hence the areas with high seismic intensity, threat to tank with shaft supporting are more than that of staging support. Time period in impulsive mode for shaft supported tanks and frame supported tanks differ subsequently. But for convective mode the difference is less comparatively. The deflection of staging is found to be decreasing with increase of capacity and change in staging pattern, further causing increase in its stiffness. Sloshing wave height is approximately same for the tanks with different supporting system, but it differs for tanks as the capacity increases.

Manish N. Gandhi and Ancy Rajan (2016) the primary objective of the research paper was to understand the behavior of different staging pattern in bracing to strengthening the conventional type of staging, to give better performance during earthquake. Equivalent static analysis for staging with different types of bracing system applied to the staging of elevated circular water tank in zone V was carried out using STAAD Pro. Comparison of base shear and maximum displacement in X, Y &Z direction of circular water tank is done.

Different model were used for calculating base shear and maximum displacement for staging with cross bracing, staging with diagonal bracing, staging with K-type bracing, staging with V- type bracing staging with chevron bracing and alternate cross bracing in staging, alternate K-type bracing in staging, alternate V-type bracing in staging alternate diagonal bracing in staging and alternate chevron bracing in staging. While carrying out parametric study carried out by using different patterns of bracings in staging of an elevated water tank. base shear for different bracing pattern it was clear that the base shear value, reduces for alternate bracing pattern in staging. This is apparent because of the reduction of overall stiffness of the structure.

Conclusion stated that Cross Bracing in staging most effective in reducing Displacement due to lateral loading reducing displacement effectively by 81.09 % in X direction and 92.98 % in Z direction from that of structure without bracings. From the comparision between displacement for different bracing system and displacement for different alternate bracing it was conclude that cross bracing pattern gives the minimum value of displacement.

Ayazhussain M. Jabar and H. S. Patel (2012) the primary objective of the research was to understand the behaviour of supporting system which is more effective under different earthquake time history records with SAP 2000 software. Two different supporting systems such as radial bracing and cross bracing are compared with basic supporting system for various fluid level conditions. For later conditions water mass has been considered in two parts as impulsive and convective suggested by GSDMA guidelines. In addition to that impulsive mass of water has been added to the container wall using Westergaard's added mass approach. Tank responses including base shear, overturning moment and roof displacement have been observed, and then the results have been compared and contrasted.

The result stated that the structure responses are exceedingly influenced by the presence of water and the earthquake characteristics. For basic staging overturning moment is highest in half-full condition for Loma Prieta having high PGA value. In case of Full condition, highest base shear is obtained for radial bracing in Imperial Valley having low PGA value. Roof displacement is considerably decreases with increase in PGA value of earthquake time history and also noted higher value in Imperial Valley. Higher Roof displacement values are obtained in full fill up condition for all patterns.

Ayub Patel and Sourabh Dashore (2017) the research paper presented the comparison of the seismic behaviour of elevated square and circular RCC water tanks having different capacities of storage. For this purpose square and circular elevated water tanks of capacities 1 lakhs and 2 lakhs was considered to analyse under seismic forces. Heights of staging considered were 12m, 18m and 24m for square and circular tanks for both the capacities. All the models were analysed for zone III, zone IV and zone V using Staad.Pro v8i software to study the seismic behavior of both the tanks the response parameters selected are lateral displacement and base shear.

For all the zones considered in both square and circular water tank deflection values follow around similar gradually increasing straight path along staging heights. For all the models deflection values and base shear are less for

 

lower zones and it goes on increases for higher zones. It is experienced in all the models for all zones that values of deflection and base shear are increasing largely almost double as the capacity increases from 1 lakh litre to 2 lakhs litre. From staging point of view it is observed that as the height increases from 12m to 18m and 24m, deflection slightly decreases at 3m, 6m and 9m but above that it increases. By increasing staging height the value of base shear decreases for both square and circular tanks for all the earthquake zones. In comparison to square and circular water tanks value of deflection and base shear are observed more in circular tank and less in square tank.

R. Uma MaheshwaraRao et. al (2018) the primary objective of the research was to evaluate the effects of lateral forces namely seismic and wind forces on elevated water tanks. STAAD.pro was used for designing and analysis of the defined model. Structural aspects such as axial forces, shear forces and bending moments are compared for different structural components of tank.

In analysis that the bearing capacity increases for the same wind speed volume of concrete and quantity of steel both are decreased. For Columns maximum bending moment occurred in Z-direction for the member 306 is 511.864 KNm with a shear force of 252.673. Ring beams @ Bottom of the tank maximum bending moment occurred in Z-direction for the member 4022 is 382.35 KNm with a shear force of 355.039 KN. For Ring beams @ Top of the tank maximum bending moment occurred in Z-direction for the member 4138 is 29.086 KNm with a shear force of 28.579 KN. For Tie beams maximum bending moment occurred in Z-direction for the member 2008 is 471.68 KNm with a shear force of 350.95 KN.

Sagar Mhamunkar et. al (2018) the objective of the research paper was to design and analyze a safe Elevated Storage Reservoir (ESR) as per IS code and study the various forces acting of the structure.

Conclusion stated that Elevated circular water tank with large capacity and flat bottom needs large reinforcement at the ring beam, to overcome this in intze tank, by providing a conical bottom and another spherical bottom reduces the stresses in ring beams. intze tank is more economical for high capacity reducing the steel requirement. Per capita demand has been calculated which helped us, to know about the water consumption in residential area and further helped in design the tank. Limit state method was found to be most economical for design of water tank as the quantity of steel and concrete needed is less as compare to working stress method. After manual design and analysis in staad pro our structure is safe.

Dona Rose K J et. al (2015) the research paper focused on the response of the elevated circular type water tanks to dynamic forces. Tanks of various capacities with different staging height were modelled using ANSYS software and the analysis was carried out for two cases namely, tank full and half level condition considering the sloshing effect along with hydrostatic effect. The time history analysis of the water tank was carried out by using earthquake acceleration records of El Centro. The tanks withstood the acceleration with the displacements within the permissible limits. The peak displacements and base shear obtained from the analysis were also compared.

Conclusion drawn from the analysis stated that the peak displacements from the time history analysis under El Centro earthquake records was below the maximum permissible displacement for different water levels. The peak displacement from the time history analysis increases with staging heights. But the displacement first decreases and then increases with capacities. The displacement for half filled tanks is lesser than the displacement for tanks with full capacity. The base shear values from time history analysis were increases as staging height increases. Also, the base shears decreases and then increases with capacity. Base shear for half capacity tanks are lesser than that for full capacity tanks under same staging condition.

Dhotre Chandrakala and Jawalkar G.C.(2015) primary objective of the research was to study the effects of bearing capacity of soil on the quantity of concrete and steel required to construct circular tank. Variation of axial force, shear force and bending moment were compared for different components of tank like columns, base beam and bracing beam due to sloping ground. Comparison of different forces induced in various members of tank on leveled surface & with increasing slope for different heights was analyzed and axial force, shear force & bending moment was compared for different structural components of tank viz. base beams, columns & bracings.

Results stated that both shear force and bending moment increases steeply in the column resting on the higher side of the sloping ground. Increase in Shear force & Bending Moment becomes milder as one goes towards downward side of slope. It was also observed that as one moves towards upper stories, effect of increase in shear force & bending moment due to sloping ground becomes still milder. There is no significant change in axial force with respect to variation of slope of ground. For the increase in height of staging, the cross section of required area of column also increases. As the wind speed increases for the same bearing capacity volume of concrete and quantity of steel both are increased. As the bearing capacity increases for the same wind speed volume of concrete and quantity of steel both are decreased.

Urmila Ronad,Raghu K.S and Guruprasad T.N (2016) in the research, seismic behavior of cylindrical liquid storage tanks was carried out by performing dynamic response spectrum analysis using FEM base software (ETABS) as per IS 1893: 2002.Analysis was carried out for elevated circular RC tank for empty & full tank condition under different soil conditions & different zones. The responses include base shear & base moments in all soil conditions have been compared. The methodology includes fixing the dimensions of components for the selected water tank and performing nonlinear dynamic analysis by: 1893-2002 (Part 2) draft code. This work proposes to study Circular tanks of different zones with all type of soil condition. The analysis is carried out for tank with full tank and empty condition. Finite Element Model (FEM) is used to model the elevated water tank using ETAB software.

Results stated that for tank full condition the base shear is more. The base moments is higher for full tank condition as compare to empty tank condition. If the water tank is located in higher seismic zone corresponding base

 

shear and base moments would also increase. The base shear &Base moment changes with soil medium.

Salitha Elizabeth Ninan and Afia S Hameed (2018) the research paper conducted seismic analysis of rectangular and circular water tanks using SAP 2000. The structural elements of the supporting frame system were modelled as beam elements and area elements such as tank wall, roof slab and floor slab were modelled using shell elements. To incorporate the dynamic behaviour of the fluid mass in the FEM tank models, two masses were considered. The primary mass is the impulsive mass component of the fluid which is calculated as per IS 1893 (part 2).

Results concluded that the mode shape of circular water tank is torsion and that of rectangular is translation along Y axis. Time period decreases for water tank models with bracings. Shear and moment values increases for braced structures. This is due to the increase in mass due to bracings. The torsional mode shape of circular tank can be eliminated by rearranging the positions of column. Element size required for rectangular tank is more when compared to circular tank stating circular tank was more economical.

Patel Nikunjr and Jugal Mistry (2016) the research paper presented parametric study concerning behavior and design of overhead Rectangular concrete tank subjected to static loading conditions with special emphasis on IS:3370, PCA , and STAAD-Pro. The design involves load calculations manually and analyzing the whole structure by STAAD.Pro V8i. The design method used in STAAD. Pro analysis is Limit State Design and the water tank is subjected to dead load, self – weight and hydrostatic load due to water. The effect of the different tank aspect ratio, end condition for same capacity was reviewed and considered in the Analysis and Design.

Conclusion derived from the results stated that Deflection can be reduce by bracing system. Stability of water tank can be improved by providing heavy column at bottom level. At the mid span of top portion get maximum stresses. Fluid density must be considered in design and Slab thickness also effect on deflection.

Dixitkumar. B. Patel (2016) the main aim of research paper was to study behavior of EVT at under different type of soil-layered condition by Using FE-ANSYS Software to obtain result of different Stress pattern and Deformation and Von-Mises Stress and were further compared. Considering the Parameter of Staging System for EVT and different filling (Empty, Half, Full) condition and five Kinds of Soil. An RCC Overhead Intze water tank with Container capacity of 1000m3 resting on supporting layered soil mass and subjected to Earth gravity and water mass loading is analyzed. The elevated tank has a frame and shaft supporting on Rc Staging number of 8 columns are connected by the enclosing beam at usually, at 4m, 8m, 12m and 16m height level and also use Shaft supporting staging is 16 m height level is connected to below the foundation. The container is full filled with water. The container and the supporting structure are being used in most part of India located in earthquake prone zone. To investigate underneath the Soil Structure interaction conduct, the interaction.

Results stated that the interaction effect in Frame supporting tank causes increase in the stresses in the range of -13 to 59.52% in various components of the tank. The maximum principal stress occurs in the circular girder portion. The decrease of nearly 13% is found in the maximum principal stress in the conical dome. The interaction effect in shaft supporting tank causes increase in the stresses in the range of -12 to 64.22% in various components of the tank. The maximum principal stress occurs in the circular ring beam portion. The decrease of nearly 12% is found in the maximum principal stress in the ring beam. Principal stresses were same in both staging of the various component of the tank for different type of homogeneous soil mass below the foundation or layered soil mass below the foundation of the tank. The natural frequency of the interaction system in shaft supporting 0 to 44.49 Hz and In empty condition maximum natural frequency 32.116Hz and half condition 44.49Hz and Full filled condition 39.42Hz In Shaft supporting system.

Sagar T.Mane and Prashant M. Kulkarni (2019) time history analysis of rectangular and circular elevated water storage tank were analyzed using SAP 2000 software using the concrete baffle wall to reduce sloshing effect of the water tank. The tank responses such as maximum nodal displacement, base shear and result were compared for empty and full tank water fill condition. From IS 11682:1985provision when seismic loading is considered only two cases may be taken one is tank empty condition and other is tank full condition. The research discloses the importance of suitable supporting baffle wall to remain withstand against heavy damages of circular and rectangular elevated water tanks during earthquake. As per IITK-GSDMA guidelines for seismic design of liquid storage tanks, hydrodynamic pressure for impulsive and convective mode was calculated.

The baffle wall showcased less displacement and more base shear as compared to the without baffle wall simple water tank in rectangular and circular water tank for empty and full tank condition. The time period increases with baffle wall as compared to the without baffle wall in rectangular and circular water tank due to the increase in mass of the tank. The convective time period remains constant in both circular and rectangular water tank. This implies that the convective mode doesn't depend on staging and eventually depends on the size of the tank. The time period varies in tank empty condition and tank full condition, this is due to the sloshing effect and hydrodynamic pressure.

## II. CONCLUSION

The conclusion derived from the various research demonstrated analysis of elevated water tank using different software applications considering hydraulic loads, wind load and seismic loads. Different codes were used from different authors subjected to the geography of the author research case study.

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