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Performance of Overhead Water Tank with Staging under Seismic Conditions– A Review.

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Abstract – *Water is an important source hence water tank storage tanks also play a vital role. Earthquake is a major natural calamity all over the world, during earthquakes there are effects on water tank so designing and analyzing them plays a vital role nowadays. In this paper seismic analysis of a water tank is done considering many parameters such as base shear, base moment, displacement, overturning moment, axial force, story drift with capacity of tank, types of tank and IS code, different staging patterns for various soil condition and various bracing patterns studied. The water tank analysis can be done with three conditions such as partial, empty, and filled condition.*

Key Words: water tank, IS codes, response spectrum parameters, STAAD.Pro, SAP2000.

1. INTRODUCTION

Water tanks are one kind of storage device which can handle both the weight of the water they and any external forces or pressures acting on them, these tanks are frequently constructed from reinforced materials like concrete or steel. For various uses, including residential, commercial, and industrial ones water tanks are a popular option. These tanks are often used to hold water for irrigation, firefighting, and other uses. They may be constructed in a range of sizes or capacities and forms to fit individual demands. Water tanks that have been reinforced are made to endure extreme weather, water pressure, and other environmental elements. To keep the tank in excellent condition and functioning as intended, proper maintenance and periodic inspections are necessary. Liquid storage structures can be divided into many bases on their shape, location, and capacity of the water tank. Based on their shape they are classified into rectangular, circular, conical, square, Inez, and polygonal. Based on their location they are divided into elevated water tanks resting above the ground and underground water tanks. Water tank resting on the ground is most commonly used in clear water reservoirs and setting tanks. The water is built on the ground surface and the distribution of water is done either through pumps or freely due to gravity from one location to another. The underground water tank is resting below the ground surface. Water pumps are used to withdraw water for use since it is present below the ground surface. An elevated water tank is built above the ground level and this type of water tank consists of a frame structure which includes the column, bracing, or staging. The water is distributed under gravitational force. Circular water tank are having specified radius or diameter of the tank model, and plate elements i.e. slab elements are made in circular condition. Rectangular and square water tanks are similar but vary in dimension accordingly. Inez type of water tanks are those structures resting on a circular beam. The following are the Mode of Failure:

1.1 Modes of failure

1. Shear failure of beam:

Shear cracks occur at an angle of 45 degrees in the plastic joints and lead to failure at the end beam due to high shear force. An example of this failure is the Bhuj earthquake in 20001 in India with a magnitude of 7.7. The elevated water tank having a capacity of 100 cubic meters of volume collapsed due to improper design and connection of beam and column. Beam connecting the column suffered from the failure.

2. Bending shear failure in beams:

Bending shear failure occurs in a beam when shear resistance is lesser than that of flexural strength. While conducting a junction with the plastic end of beams to the middle of beams to create this sort of provide failure, bending shear fractures in a beam appear in the middle of the beam with gradual growth towards middle support. It has been proven that joint damage in plastic beams forming a strut has been documented; Chile (South America), which had an earthquake with a magnitude of M=8.5 in 1960, is an example of this sort of seismic failure. The raised water tank volume was 700 cubic meters. There have been reports of stirrups in the water tank that were around 600 cubic meters in size and shape during the earthquake. Additionally, it was stated that a pipe underneath the tank ruptured and separated by one meter when the water came out. Additionally, it was stated that a pipe underneath the tank ruptured and split by one meter as the water leaked out from the tank with concrete many years ago, after the earthquake they had some fine cracks in Beam-Column connections, vertical cracks in Columns and also shear cracks in beams. Due to the high compressive forces on columns, some columns had several vertical cracks which

they occurred between the borders of old concrete and sprayed concrete (C Rai 2003).

3. Torsion failure:

Torsion failure, the other type of failure, is more frequent in concrete elevated tanks with frame staging. In general, the geometry of elevated tanks should be designed so that the centroid and center of rigidity are at the same location, as well as the symmetry axis is at the geometric center. However, unintentional eccentricity between the centroid and the center of rigidity is brought on by the usage of ladders, stairs, installation pipes, and managerial errors. In previous seismic events, many elevated water tanks collapsed vertically without any lateral sway, but by observing the destroyed tanks, it is apparent that many of them had additional torsion deflection. The impact of improper connections and an expanded treatment plan caused by the 1980 El-Asnam earthquake, which had an Algeria M=7.2 magnitude, resulted in the collapse of an elevated water tank. Frame members are positioned such that enlargement of the deflection characteristic does not happen when they are standing in the raised tank. The failure occurred as a result of inadequate reinforcing details at the beam-column connections.

2. LITERATURE REVIEW

Pooja Anchal, et.al presented a study on "A Survey on Dynamic Analysis of RCC Elevated Water Tank". This study is carried out to review the various techniques for water tank analysis and design. To develop a study on the standards for the dynamic analysis and design of liquid-retaining structures by IS Code and comprehend the design philosophy for a safe and cost-effective water tank. To examine if the computer software is appropriate and applicable for the dynamic analysis of RCC liquid storage tanks. Determine whether the displacement coefficient method is appropriate for the dynamic analysis of RCC liquid storage tanks.

Yogendar Borkar, et.al. Presented a study on "Seismic Analysis of Water Tank Based on Location with Different Soil Types". This study has carried out a seismic analysis of all water tanks by defining the Response Spectrum Analysis method using ETABS software under guidelines of IS 1893 2016considering story displacement of water tank due to soil and earthquake at the top in X and Y directions with hard, medium and soft soil. Compared the Base Shear and Base Moment for all water tanks model with hard, medium, and soft soil and examine the facts of soil stiffness by seismic forces for underground, above the ground, and elevated water tank and bare frame using parameters. The capacity of all types of water tanks is 400cm3. After designing of water tank according to code provision, modeled using software and analyzed. Plotted graph of base shear, base moment, and displacement V/S different of soil i.e. soft, medium, and hard soil. They conclude that Base Shear increases by 26 % from hard soil to medium soil, and Base shear increases by 18% from medium soil to soft soil. , Base Moment was increased by 26.5% from hard soil to medium soil, and the base moment was increased by 19% from medium soil to soft soil. displacement at the top increases by 29% from hard to soft soil for the underground water tank, displacement due to earthquakes is the same in the case of ground level water tank for medium and soft soil and increased by 40% from hard to soft soil in case of elevated water tank due to earthquake actions.

Prasad D Konde, et.al presented a study on "Comparative structural analysis of overhead water tank for different heights". This study has been carried out for 10 different heights of overhead water tanks using different codes of provisions. The codes used here were IS code, ACI, and BS code. The model was made by STAAD Pro software with varying heights of 6m, 9m, and 12m height using 6 water tank-6m height by ACI code • Model-V: Rectangular water tank-9m height by ACI code • Model-VI: Rectangular water tank-12m height by ACI code • Model-VII: Rectangular water tank-6m height by British code • Model-VIII: Rectangular water tank-9m height by British code • Model-IX: Rectangular water tank-12m height by British code • Model-X: Rectangular water tank-15m height by IS code. The parameter here is displacement, reaction, moment plate stress, story drift, and average displacement. They concluded that t model-3 has the highest moment (kNm) as compared to the other models and has the maximum value and model-7 has the minimum. Model 10 has the maximum membrane stress (N/mm2) and model 7 has a minimum value as compared to the other models. Model-10 has the drift (mm) as compared to the maximum value and the minimum value for model-7. Model-10 has the maximum Average Displacement (cm) of 3.6 cm and a minimum value of 1.0 cm for model-7. From the above results, it is observed that model-7 has the highest frequency as compared to the other models and has a maximum value of 60 Hz.

Bhakthi B Jani, et.al presented a study on "Effects of Soil Condition on Elevated Water Tank Using Time History Analysis with Different Staging System". Intze elevated water tank was considered here of capacity 250cm3 and modeled using the software. The tank has a fixed base and frame type with the different bracing systems considered here. Bracing types are radial bracing system, normal bracing system, and cross bracing system. A total of four earthquake records of Uttarkashi, Kachchh, Dharamsala, and Chamba are taken here for analysis. Base shear, displacement, and overturning moment for soft, medium, and hard soil of varying heights of 16m, 20m, and 24m for partially and filled water tanks are taken for analysis. They conclude that critical response depends on earthquake characteristics especially on the frequency of earthquakes and in the case of full tank condition due to the presence of higher hydrodynamics pressure when compared to other conditions of the water tank. Soil interaction is mostly observed in medium and rocky soil conditions than in soft soil.

Tejaswini, et.al presented a study on "Design and Analysis of Elevated Water Tank". The model considered was a rectangular water tank with a capacity of water 250m3 on an RC frame with a staging of 10m height and consisting of four columns only. The limit state method and working stress method are used as per IS 3370 2019 code and compared. The tank is analyzed for various soil conditions i.e. soft soil, medium soil, and hard soil with various zone of an earthquake using both linear and nonlinear analysis in Etabs considering fully and half-filled water content. The parameters were base shear, base moment and displacement at the top, and axial force. On comparing different codes they concluded that are of steel required for the limit state method using IS 3370 1965 is higher than that of the working stress method using IS 3370 2009. The displacement is high in hard soil in full tank condition than in empty tank due to the lateral force which is acting more. They also said that the base moment and base shear for an empty tank is more than full tank because of no pressure is acting and there may induce some outer pressure during an earthquake in an empty tank condition. Whereas moment is acting inversely and they summarize that, these parameters may vary depending on earthquake characteristics.

M Sai Ramya, et.al presented a study on "Seismic Analysis of RC Elevated Rectangular Water Tank Using Various Staging Patters". This deals with the seismic response of elevated water tanks with different staging patterns considered for the study of partially and filled water tanks. The parameters are base shear, roof displacement, and base moment. There are four different bracing systems they are, diagonal, radial, normal, and v bracing system. This rectangular tank with a 108000-liter capacity water tank supporting an RC column with horizontal bracing at their levels of 200X200 mm. The software used here is SAP 200 V20 for modeling. They conclude that diagonal bracing will provide minimum lateral displacement for all tank conditions and is more effective. The value of base shear and base moment also shows the minimum value for the diagonal bracing system. Base shear increase with an increase in the capacity of water.

Prashant A Basonde et.al presented a paper on "Seismic Analysis of Elevated Water Tank with Different Staging Configuration". The objective is the study hydrodynamic effects of water tanks with staging patterns with different tank conditions. The circular water tank is having capacity of 900m3, 16m diameter with a height of 4m, consists of 9 columns located on soft soil in II seismic zones and analyzed by STAAD.pro v8i. The tank was analyzed with bracing and without bracing (diagonal and x bracing) with parameters such as base shear, base moment, lateral displacement, and time period of vibration. It observed that base shear, base moment, and lateral displacement were found to increase from 3.33% to 6.67%, 5.1% to 6.67%, and 72.425mm to 6.477mm respectively from diagonal bracing to x bracing type, and base moment, base shear increase with an increase in the level of bracing. Lateral displacement and time period of vibration decrease with an increase in the level of bracing due to an increase in the stiffness of the structure.

Jindal Bharth, et.al presented a study on "Compressive Study of Design of Water Tank Concerning Is Code 3370". This deals with the type of water tank designed as per the working stress method and limits state according to code provision of IS code 3370 (1965) and IS code 3370 (2009). The objective of this study is to analyze the above-stated design methods so that a conclusion can be made before a designer which method is more reliable and economical. To do the comparative study of provisions in IS 3370 (1965) and IS 3370 (2009), the Intze type of water tank was chosen since it is widely used for large capacity and the comparison of provisions can thus be better highlighted through the Intze type of water tank. The size of members remained the same for the working stress method by IS: 3370 (1965) and IS 3370 (2009). However, the requirement of an area of steel increased in IS: 3370 (2009) as the allowable stresses in steel were lower. The change in the clause of the requirement of minimum steel decreased the steel required in the bottom spherical dome. The size of members remained the same for limit state design methods by IS: 3370 (2009) in limit state of collapse as well is deemed to satisfy criteria. However, the requirement of an area of steel increased in IS: 3370 (2009) is deemed to satisfy criteria in comparison to serviceability as the allowable stresses in steel were lower. The size of members as well as the requirement of steel decreased for the limit state design method by IS: 3370 (2009) in comparison to working stress design methods of both IS: 3370 (1965) and IS 3370 (2009) provisions. It was found that the provisions of reinforcement through the surface zones in IS: 3370 (2009) provide economical and more effective reinforcement.

Abb Masid Aflanda, et.al presented a study on "Comparative Analysis of Circular and Rectangular Reinforced Concrete Tank Based on Economical Design Perspective". It deals with a detailed study of rectangular water tanks considering the BS 8007 code. This study is to compare the economical design and cost estimation of circular and rectangular water tanks. The capacity of the water tank is 40000L. After designing and cost estimation process compared and plotted the graph of formwork distribution volume, reinforced required and concrete volume V/S types of water tank considered. From the plots of the graph, it's concluded that even though both shapes of the tank have the same capacity of water, the material required for circular tank shows better resistance towards seismic but required a higher quantity of material than rectangular and it is same in the terms of formwork distribution also. But in the case of formwork rectangular required higher than that of circular tank. Finally cost estimation for the circular tank was found to be higher than circular. The circular required 703287K whereas the rectangular required only 400564K only.

Anand T Shrigandekar, et.al presented a study on "Performance of RC Elevated Water Tank for Different Bracing Patterns under the Effect of Earthquake". Intz type of water tank is considered here having a capacity of 400m3 under linear dynamic analysis. Seismic response factors such as base shear, tank displacement, and maximum bending moment at the base of the column at empty, partially, and filled conditions for different bearing arrangements have been calculated and compared. The bracing patterns considered here were octagonal, octagonal and, octagonal and square, octagonal and cross, octagonal and radial bracing. After the analysis, they conclude that the base shear for octagonal and radial bracing types is high and shows low story displacement compared to other bracing types. Base shear, story displacement, and maximum bending moment at the base increase with an increase in water level, and the maximum bending moment at the bottom of the column decreased with an increase in the level of water.

Anusha N Asati et.al presented a paper on "Seismic Analysis and Optimization of RC Elevated Water Tank for Various Staging Patterns". The paper deals with the seismic behavioral effect of circular water tanks with a specific capacity of water for staging patterns. The tank is having capacity of the tank is 500m3, 16m height located in medium soil condition soil at seismic zone 3. They included optimization which plays a vital role in reducing cost and making structure work effectively. They considered three types of bracing patterns such as normal, radial, and cross. Response spectrum parameters such as base shear, and roof displacement. The model is prepared using SAP2000. It observed that with an increase in the number of column in a tank base shear and moment also increase but displacement decrease. For the optimization water tank with filled with radial staging, patterns were considered. It observed that the cost of steel and concrete for six number columns is maximum and started to decrease at eight columns and then linearly increased with an increase in the number of columns. The roof displacement for models is within the permissible limit of IS code 1893 part 1.

S S Quadri et.al presented a study on "Seismic Analysis of RC Elevated Water Tank Using Different Staging Pattern". In this paper, they considered the RC elevated water tank of capacity 500m3 with a fixed base and analyzed it in STAAD.Pro structural software. The study of the behavior of the water tank was the main objective of the study considering response spectrum parameters such as base shear, base moment, axial force and displacement with constant height and water storage capacity, different h/d ratio, number of columns (eight, ten and twelve), different type of staging arrangement such as normal, cross, hexagonal and radial with a central column for empty, partial and filled water condition. It observed that base shear increase with an increase in h/d ratio and axial force decreases for 10 and 12 numbered column. Axial force seemed to be maximum for full tank conditions. The moment in x, y, and z direction with an h/d ratio of .5 and radial staging provide maximum value for 10 membered columns. An increase in columns decreases the displacement and the hexagonal staging type provides maximum displacement with 8, 10, and 12 number of columns. The water tank has a 0.7 h/d ratio with cross-staging types and gives the best results of displacement, axial force, and moment in the x, y, and z directions compared to others.

Bojja Devadanam, et.al presented a study on "Effects of Staging Height on the Seismic Performance of RC Elevated Water Tank". Water tank analysis was carried out under guidelines of IS 1893 part 2 code long with IITK GSDM. The capacity of the water tank is 100m3 with a diameter of 5.65m. The behavior of the water tank has been analyzed using various parameters like changes in the height of staging combined with the different zone of an earthquake. Using the SAP 2000, mode shapes and mass ratios are obtained for full and half-filled tank conditions of the water tank. From the results, they conclude that base shear increases until critical heights of staging and starts to decrease later. Base shear varies linearly with the seismic intensity factor. They plotted a graph for soil type V/S base shear which shows linear behavior from soft to hard soil type.

Soheil Soroushina, et.al presented a study on "Seismic Performance of RC Elevated Water Tank with Frame Staging and Exhibition Damage Pattern". In this paper, they discussed different failure patterns such as shear failure modes in beams, bending shear failure in beams, axial failures in columns, cracks in connection, and also torsion failure. A FEM model of an elevated water tank is considered for three cases i.e. empty, partial, and complete water filling conditions using DUZCE earthquake records on a scale of 0.1g to 1g. The water contained was modeled by using AC3D8 and frustum, and container cylindrical walls were modeled by S3R and S4R. The analysis said that the increase in acceleration of earthquake tensile damages due to the bending beam starts to increase gradually with an increase in acceleration in the initial and end of the beam and damages due to the axial forces in the initial time. It was found that concrete had a plastic strain of 0.0018 and a concrete strain was 0.003, whereas considering the relationship between the damage and strain can conclude that concrete may damage or may collapse if a concrete strain is 0.55.

3. CONCLUSIONS

In water tank design implementation of seismic factors and using code provisions is more important. IS: 3370 (2009) provides economical and more effective reinforcement. The factors like base shear, base moment, and story displacement increase with an increase in water capacity, and earthquake acceleration and reduce with the increase in the level of bracing patterns due to stiffness. Water tank characteristics vary from one soil type to another. Base shear linearly varies with seismic intensity as well as the capacity of the tank.

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