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A Review on Seismic Analysis of Elevated Water Tank with Different Seismic Zones

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ABSTRACT

As known from very upsetting experiences, liquid storage tanks were collapsed or heavily damaged during the earthquakes all over the word. The economic lifetime of concrete or steel tanks is usually in the range of 40 to 75 years (ALA 2001). Damage or collapse of the tanks causes some unwanted events such as shortage of drinking and utilizing water, uncontrolled fires and spillage of dangerous fluids. Due to this reason numerous studies done for dynamic behavior of fluid containers; most of them are concerned with cylindrical tanks. In this study, Seismic forces acting on an Elevated water tank e.g., circular Tank and rectangular tank are studied with constant stagging height. Seismic forces acting on the tank are also calculated changing the Seismic Response Reduction Factor(R). IS: 1893-1984/2002 for seismic design and then checked the Design of Tanks by using the software STAAD PRO.

Keywords: Water Tank, Stagging System, Staad Pro, Earthquake

1. Introduction

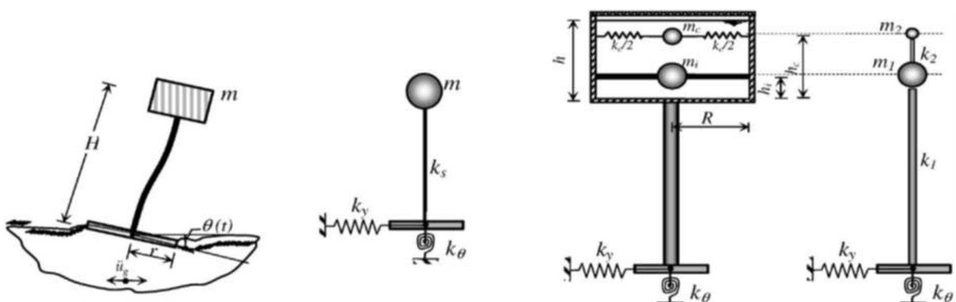
Water is life line for every kind of creature in this world. All around the world liquid storage tanks are used extensively by municipalities and industries for water supply, firefighting systems, inflammable liquids and other chemicals. Thus Water tanks plays a vital role for public utility as well as industrial structure having basic purpose to secure constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force. Storage reservoirs and overhead tank are used to store water, liquid petroleum, petroleum products and similar liquids. The force analysis of the reservoirs or tanks is about the same irrespective of the chemical nature of the product. All tanks are designed as crack free structures to eliminate any leakage. Water or raw petroleum retaining slab and walls can be of reinforced concrete with adequate cover to the reinforcement. Water and petroleum and react with concrete and, therefore, no special treatment to the surface is required. Industrial wastes can also be collected and processed in concrete tanks with few exceptions. The petroleum product such as petrol, diesel oil, etc. are likely to leak through the concrete walls, therefore such tanks need special membranes to prevent leakage. Reservoir is a common term applied to liquid storage structure and it can be below or above the ground level. Reservoirs below the ground level are normally built to store large quantities of water whereas those of overhead type are built for direct distribution by gravity flow and are usually of smaller capacity. Elevated tanks should remain functional in the post-earthquake period to ensure water supply is available in earthquake-affected regions. Never the less, several elevated tanks were damaged or collapsed during past earthquakes Due to the fluid–structure–soil/foundation interactions, the seismic behavior of elevated tanks has the characteristics of complex phenomena. Therefore, the seismic behavior of elevated tanks should be known and understood, and they should be designed to be earthquake-resistant. Some general programs have been carried out, which cover large amounts of data; these programs include STAAD PRO etc. However, a general-purpose structural analysis program generally exists in every engineering office. So, the evaluation of the applicability of these structural analysis programs in the design of elevated tanks is important from an engineering point of view and it will be helpful to present the application and results to designers. There is a second important reason that should be considered. That is, simplified models are used for a straightforward estimate of the seismic hazard of existing elevated tanks. Only if the estimated risk is high, it is convenient to measure all the data (e.g. geometry of the tank, material properties) that are required by the general finite element codes and to spend time and money to prepare a reliable general model.

2. SEISMIC ANALYSIS OF ELEVATED WATER TANK

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

1. Equivalent Static analysis of elevated water tanks.
2. Dynamic analysis of elevated water tanks

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 has provided the method of analysis of elevated water tank for seismic loading. Historically, seismic loads were taken as equivalent static accelerations which were modified by various factors, depending on the location's seismicity, its soil properties, the natural frequency of the structure, and its intended use. Elevated water tank can be analyzed 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. For equivalent static analysis, water-structure interaction shows, both water and structure achieve a pick at the same time due to the assumption that water is stuck to the container and acts as a structure itself and both water and structure has same stiffness. The response of elevated water tanks obtained from static analysis shows the high scale value. That's why for large capacities of tanks, static response are not precise. If we analyzed the elevated water tank by static method and design by the same, we get over stabilized or say over reinforced section but it will be uneconomical. That's why static systems of designing of elevated water tanks is not useful in seismic zones. And hence, IS code provision for static analysis is restricted for small capacities of tanks only.



(a) A simple structure supports on deformable soil (b) Simple idealized model for soil-structure interaction (c) Springs-masses model for considering the effects of the fluid-structure-soil interaction model for the soil-structure interaction

Fig. 1. Mechanical model for the fluid–structure–soil interaction of the elevated tank

3. LITERATURE REVIEW

Joshi (2000) proposed an equivalent mechanical model for seismic analysis of rigid intze type tanks under horizontal seismic load by replacing with equivalent cylindrical tank model. Model parameters were evaluated for a wide spectrum of tank shapes and compared with those of the equivalent cylindrical tanks. Fluid pressure was calculated using linearized potential flow theory. The fluid was assumed inviscid and incompressible and the sloshing height was assumed to be small. Furthermore, in developing the mechanical model only first sloshing mode was taken into account. It was concluded that the associated errors due to the use of equivalent cylindrical tank model instead of the original intze tanks were negligible. As a result, for design applications, the intze tank models could be replaced by the equivalent cylindrical models without loss of accuracy.

Rai (2002) studied the performance of elevated tanks damaged and collapsed in 2001 Bhuj earthquake. It was concluded that RC shaft type supporting structures extremely vulnerable to severe earthquake forces. Moreover, results showed that India codes underestimated design forces compare to the international building code (IBC) requirements. The main accent was made on the luck of redundancy in RC shafts. It was concluded that thin shaft was not able to dissipate the seismic energy due to lack of redundancy.

Rai, et al. (2004) carried out an analytical investigation and case study of RC shaft supported tanks. The study showed that shear demand was more for empty tank rather than when it was full. For studied tanks it was concluded that for all shaft aspect ratios of empty tank flexure strength governed the failure mode. However, for full tanks, shear mode was found to be governing in stiffer shafts and tension-flexure mode in more flexural shafts, having long fundamental period and large aspect ratio. Moreover, the damage patterns during previous earthquakes showed that for tanks with large aspect ratio which have long fundamental periods, flexural behaviour was more critical than shear under seismic loads.

Livaoglu and Dogangun (2004; 2005) proposed a method for seismic analysis of fluid-elevated tank-soil system considering interaction effects. The new method can be used for the frequency domain analysis. The method provided an estimation of the base shear and overturning moment, top lateral displacement of supporting system as well as wave height on the vessel. Results showed that sloshing response was not affected by soil properties. Moreover, it was concluded that softer soils increased roof displacement and reduced the base shear and overturning moment of the supporting system. The new method could lead to the economic design of the elevated water tanks.

A review of simplified seismic design procedures for elevated tanks carried out by Livaoglu and Dogangun (2006). 10 models were evaluated by using mechanical and finite-element approaches including approach for the fluid–structure models, the massless foundation and soil–structure interaction. Soil types for this analysis were taken from Eurocode 8. It was concluded that single lumped-mass models could lead to underestimation of the base shear and the overturning moment. Other approaches showed acceptable assessment however the added mass approach had an advantage of not using any fluid finite element. It was recommended that the distributed mass approach for seismic analysis of elevated tanks was used in general-purpose structural analyses programs. Additionally results showed that periods for convective modes were not remarkably different for any approach and soil type.

Dutta, et al. (2009) conducted FE analytical and small-scale experimental studies on the dynamic behaviour of RC elevated tanks. The soil structure interaction effect was included in the study. This study concluded that empty-tank condition governed by axil tension in the tank staging, white base shear was the major matter in full tank condition. Also, it was concluded that fundamental period could be changed by soil-structure interaction. Moreover, the effect of soil-structure interaction considerably increased tension and compression forces in comparison to fixed support condition.

Shakib, et al. (2010) carried out investigation on the seismic nonlinear response of concrete elevated water tanks supported by moment resisting frame by using FE analysis. Three RC elevated water tanks were subjected to horizontal seismic excitations. It was concluded that the maximum response did not always occur in the full tanks for frame support elevated water tanks. The results also showed that the reduction of stiffness of the reinforced concrete frame staging resulted in the fundamental period increase. On the other hand, the increase of mass resulted in increase of the fundamental period.

Moslemi, et al. (2011) evaluated the performance of conical elevated tanks under seismic motions. Both free vibration and transient analysis were conducted to study fluid-structure interaction in elevated water tanks. The effects of liquid sloshing and tank wall flexibility were considered and fundamental modes were divided to impulsive and convective. The obtained results were also compared with those recommended by current practice. The objective of the study was responses were shear and overturning moment at the base of the shaft. It was concluded that modal FE analyses results were very close to those obtained from Horner's method.

Nallanathel, et al. (2018) had study of Design of water tank both overhead and underground tank of shapes rectangular, square and circular shapes the paper includes the study of shape deflections and the actions produced when the tank is empty or full using STAAD.PRO is discussed. From these designs it is showed that corner stresses and maximum shear and bending stresses are found to be less in case of circular tanks than remaining other designs and the shapes of water tanks plays vital role in the stress distribution and overall economy. By using Staad.Pro, the results obtained will be very accurate than conventional results. In Underground tank, Uplift pressure plays predominant role in design which is caused by surrounding soil on outside walls of tank. The shape of the tanks plays predominant role in the design of overhead and underground water tanks. Usage of Staad.Pro in design gives accurate results for shear force and bending moment than convenient method.

Vanjari et al. (2017) had given an overall designing procedure of an overhead circular tank using working state method from IS 3370:2009. Elevated water tanks provide head for supply of water. When water has to be pumped into the distribution system at high heads without any pumps for supply however pumps are necessary for pumping only till tank is filled. Once it is stored in tank the gravity creates the pressure for free, unlike pumps. We need pressurized water to fledge and make taps eject water at an appropriate rate. Elevated tanks do not require continuous operation of pump, as it will not affect the distribution system since the pressure is maintained by gravity. Strategic location of tank can equalize water pressure in the distribution system.

Dhage et al. (2017) study and analysis some of the conclusions can be made as follows for same capacity, same geometry, same height, with same staging system, in the same Zone, with same Importance Factor & response reduction factor; response by Equivalent Static Method to Dynamic method differ considerably. It also states that even if we consider two cases for same capacity of tank, change in geometric features of a container can show the considerable change in the response of elevated water tank. At the same time Static response shows high scale values that of the Dynamic response. It happens due to the different picks of time periods and hydrodynamic factors are ignored during the analysis they will affect vigorously and collapse of the structure can take place.

Housner (1963) discussed the relation between the motion of water with respect to tank and motion of whole structure with respect to ground. He had considered three basic conditions i.e., tank empty, tank partially filled and tank fully filled for the analysis, and finely concluded that the maximum force to which the partially fill tank subjected is less than the half the force to which the full tank is subjected. The actual forces may be little as 1/3 of the forces anticipated on the basis of a completely full tank. Sudhir Jain and U. S. Sameer [2] had given the value of performance factor K =3, which is not included in IS 1893:1984 for the calculation of seismic design force and also given some expressions for calculation of lateral stiffness of supporting system including the beam flexibility.

Jain and Medhekar (1990) had given some suggestions and modification in IS 1893: 1984. He had replaced the single degree of freedom system by two degree of freedom system for idealization of elevated water tank, the bracing beam flexibility is to be included in the calculation of lateral stiffness of supporting system of tank, the effect of convective hydrodynamic pressure is to be included in the analysis.

Jain & Sajjad Sameer (1993) added more suggestions other than above i.e. accidental torsion, expression for calculating the sloshing wave height of water, effect of hydrodynamic pressure for tanks with rigid wall and the tanks with flexible wall should be considered separately.

Shrimali and Jangid (2003) discussed the earthquake response of elevated steel structural failures result in release of hazardous material. Quantitative Risk Analysis (QRA) provides a guide for analysis of industrial risk; such an assessment may include the seismic threat if ground motion related malfunctioning (i.e. failure) rates are available for components.

Kalani and Salpekar, (1978) studied comparison between the conventional and matrix methods of analysis for staging of overhead water tanks. A number of parametric studies, such as the batter and number of columns have been carried out. The results obtained by the conventional strip and plate theory methods for annular raft are compared and observed that the conventional strip method may result in an unsafe design in critical sections.

Rai, (2002) discuss unfavorable features related to shaft supported elevated tanks in high seismic areas and suggest retrofitting technique to overcome with seismic deficiencies. Also, raised the issue related to the weaknesses of the current Indian code (IS 1893, 1984) of seismic design and analysis of structures against other international codes and ignorance of Housner’s two-mass idealization.

Rai, (2003) enclosed extreme vulnerability of current designs for staging of elevated water tanks under lateral forces considering illustration of the

Bhuj (2001) earthquake, it recorded the flexure cracks in shaft staging at various lift and collapse of frame type tank staging due to not meeting the ductility and toughness requirements by brace and column member joints. Also, concluded that, currently IS: 1893-1984 (IS 1893, 1984) underestimates the forces for water tanks and failures of framed staging was primarily due to non-compliance of ductility provisions of IS codes intended for earthquake resistance.

Dutta et al., (2000a) aims to estimate the range of variation of torsion to lateral natural period ratio for usually constructed reinforced concrete elevated water tanks with frame-type staging for assessing their torsional vulnerability. Closed-form expressions for torsional and lateral stiffness of tank staging are derived and verified by standard finite element software. It is also seen that the frame staging of these tanks normally designed for seismic lateral force, may yield through formation of plastic hinges simultaneously in all columns instead of in beams if they are subjected to large rotational response for having torsion to lateral natural period ratio possibly very close to 1.

Dutta et al., (2000b) presents a limited parametric study to evaluate the effectiveness of each of these configurations in changing ratio of torsional and lateral natural period. A systematic stepwise approach is proposed for checking torsional vulnerability of the tanks and choosing a suitable configuration. Since the magnitude and direction of eccentricity for elevated water tanks is often not known, configuration-based solution may be preferable to the conventional increased strength design.

Bhadauria and Gupta, (2007) conducted a study of deteriorated water tank structures based on durability parameters and observed that, failure of the water tanks has taken place mainly due to carbonation and chloride-initiated corrosion because of the less concrete cover. Due to corrosion, spalling of concrete had taken place which reduces the area of steel in bracing, columns and stairs, etc.

Masood et al., (2008) investigated a technological failure of project in rural areas of Agra and Mathura districts due to extreme damages in form of corrosion of reinforcement and spalling of concrete within a period of 10 to 15 years. Also, conclude that poor quality of concrete in terms of durability under the prevailing environmental conditions lead to the distress in water tanks. So, site selection of the project and location plays a very important role for the economy, safety and success of the project.

GSDMA Guideline, (2007) describes procedure for analysis of liquid containing elevated tanks subjected to seismic base excitation. The procedure considers forces induced due to acceleration of tank structure and hydrodynamic forces due to acceleration of liquid. Also, provide basics and calculating terms of fluid mass distribution within the container considering two uncoupled single degree of freedom systems.

IS 11682 Draft code, (2011) lays down criteria for analysis, design and construction of reinforced cement concrete staging of framed type with columns or shaft type, for achieving a desirable level of safety and durability of the supported liquid storage structure. The provisions of this standard refer to staging for the storage of liquids; the recommendations are applicable mainly to water storage or containment.

4. CONCLUSION

Water is life line for every kind of creature in this world. All around the world liquid storage tanks are used extensively by municipalities and industries for water supply, firefighting systems, inflammable liquids and other chemicals. Thus, Water tanks plays a vital role for public utility as well as industrial structure having basic purpose to secure constant water supply from longer distance with sufficient static head to the desired location under the effect of gravitational force. Storage reservoirs and overhead tank are used to store water, liquid petroleum, petroleum products and similar liquids. The force analysis of the reservoirs or tanks is about the same irrespective of the chemical nature of the product. All tanks are designed as crack free structures to eliminate any leakage. Water or raw petroleum retaining slab and walls can be of reinforced concrete with adequate cover to the reinforcement. Water and petroleum and react with concrete and, therefore, no special treatment to the surface is required. Industrial wastes can also be collected and processed in concrete tanks with few exceptions. The petroleum product such as petrol, diesel oil, etc. are likely to leak through the concrete walls, therefore such tanks need special membranes to prevent leakage. Reservoir is a common term applied to liquid storage structure and it can be below or above the ground level. Reservoirs below the ground level are normally built to store large quantities of water whereas those of overhead type are built for direct distribution by gravity flow and are usually of smaller capacity.

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