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A Review on Seismic Analysis of Elevated Water Tank

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Abstract

An elevated water tank is a water storage container constructed for the purpose of holding water at a certain height to pressurize the water distribution system. Water tanks are very important components of lifeline. They are critical elements in municipal water supply, fire-fighting systems and in many industrial facilities for storage of water. Elevated water tanks are critical and strategic structures and damage of these structures during earthquakes may endanger drinking water supply, cause to fail in preventing large fires and substantial economic loss. A large number of overhead water tanks were damaged during the past earthquakes. Hence seismic behaviour of these structures during the earthquakes has to be investigated in detail in order to meet the safety objectives while containing construction and maintenance costs. So, there is need to focus on seismic safety of lifeline structure using with respect to alternate supporting system which are safe during earthquake and also take more design forces.

Keywords: *Elevated Water Tank, Earthquake, Modal Analysis, Seismic Analysis..*

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1. Introduction

There are a large number of storage tanks around the world most of which are used as water storage facilities. These structures play an imperative role in municipal water supply and firefighting systems. Elevated water tanks are water storage facilities, which are installed on a supporting staging to provide necessary pressure for the water distribution system obtained by gravity instead of the implementation of a heavy pumping facility. There are numerous elevated water tanks that are considered as indispensable facilities and are expected to be functional after the occurrence of a severe earthquake. Elevated water tanks rely on hydrostatic pressure produced by the elevation of water, hence are able to supply water even during power outages. This feature of elevated water tanks becomes more critical when a power outage occurs after a severe earthquake; therefore, pumping systems are inoperable due to the dependency on electrical power. Overall, the supporting structure of the elevated water tanks can be classified as reinforced concrete frame, steel frame, masonry shaft or a reinforced concrete shaft. In this thesis, the term "Elevated Water Tank" only refers to the last group, which is the tank, mounted on the reinforced concrete shaft and will be the subject of this research.

The elevated water tank, supported by the reinforced concrete (RC) shaft, commonly has two main configurations. The first type being the "Elevated Concrete Tank" (Figure 1.1.), where both the shaft and tank are constructed from reinforced concrete. However, the second type "Elevated Composite Steel-Concrete Tank" or simply a "composite elevated tank", consists of a RC shaft and welded steel tank. The welded steel tank is mounted on top of the RC shaft. The lower section of the tank is cone shaped, whereas the upper part is cylindrical.

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2. Literature Review

In this chapter an extensive literature review on dynamic response of liquid containing structures is presented. There are a number of reports that show inefficient and occasionally catastrophic seismic performance of elevated water tanks due to previous earthquakes in the literature. The damages were reported from minor cracks in RC shafts to severe damages and complete failure of elevated water tanks.

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 Housner'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.

3. Conclusion

The papers reviewed above have dedicatedly worked on the related topics. This work has brought forward the critical analysis of various extreme scenarios to overcome the economy. A number of load combinations are discussed to reach an outcome with parameters of safety as well. It is very much necessary to practically improve the modern-day technology with intense research in the field of construction for the safety of mankind. In this world of advanced research and technology, heavy structures are necessarily required to be designed with techno economical solutions. RC curved beams can be analyzed using a software approach, although this is dependent on the formation of plastic hinges, and the conditions of the sections in which they are formed. The ultimate load, internal forces and mode of failure for a curved beam can be predicted using the first criterion.

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