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Seismic response of liquid-filled elevated tanks

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ABSTRACT

The main focus of the current study is to evaluate the performance of elevated tanks under seismic loading. In this study, the finite element (FE) technique is used to investigate the seismic response of liquid-filled tanks. The fluid domain is modeled using displacement-based fluid elements. Both time history and modal analyses are performed on an elevated tank. Using the FE technique, impulsive and convective response components are obtained separately. Furthermore, the effect of tank wall flexibility and sloshing of the water free surface are accounted for in the FE analysis. In this study complexities associated with modeling of the conical shaped tanks are discussed. This study shows that the proposed finite element technique is capable of accounting for the fluid-structure interaction in liquid containing structures. Using this method, the study of liquid sloshing effects in tanks with complex geometries such as conical tanks is made possible. The results of this study show that the current practice predicts the response of elevated tanks with reasonable accuracy.

1. Introduction

There are a large number of storage tanks around the world most of which are used as water and oil storage facilities. They also play an important role in municipal water supply and fire fighting systems. In order to provide the head of water required for a water supply process, water tanks are usually installed on a supporting tower, thereby instead of requiring heavy pumping facilities, the necessary pressure can be obtained by gravity. The supporting structure could be an axisymmetrical concrete shaft or a framed assembly. Elevated tanks normally consist of a thin-walled steel vessel welded at its base to a circular steel plate which in turn is anchored to the underlying concrete slab.

Many storage tanks are considered essential facilities and are expected to be functional after severe earthquakes. This is partly due to the need for water to extinguish fires that usually occur during such earthquakes. Severe damage suffered during the 1964 Alaska earthquake [1] revealed a complicated behavior of liquid storage tanks during seismic motions. Since then, many research studies have been conducted on the seismic behavior of ground-supported storage tanks. However, little effort has been made to better identify the dynamic behavior of elevated tanks. Poor performance of some elevated water tanks having reinforced concrete shaft-type supports during the 2001 Bhuj [2,3] and the 1997 Jabalpur [4] earthquakes in India is an indication of lack of knowledge regarding the seismic behavior of such structures. In the Bhuj earthquake, three elevated water tanks collapsed completely, and many more were damaged severely. Similar damage was also observed in the Jabalpur earthquake.

In the early 1960s, Housner [5] proposed a useful idealization for obtaining the liquid response of rigid rectangular and cylindrical water tanks fully anchored to the rigid foundation and subjected to horizontal ground motion. He separated the tank's hydrodynamic response into "impulsive" motion, in which the liquid is assumed to be rigidly attached to the tank and moves in unison with the tank's shell, and "convective" motion, which is characterized by long-period oscillations and involves vertical displacement of the fluid's free surface.

Many current standards and guides such as ACI 350.3-06 [6] and ACI 371R-08 [7] have adapted Housner's method with some modifications which were the results of subsequent studies by other researchers for seismic design of liquid storage tanks. Later, Veletsos [8] showed that the flexibility of the tank's shell could have a significant effect on dynamic forces induced by horizontal ground motion in liquid-filled cylindrical containers. It was concluded that the flexibility of the walls of such tanks has a substantial effect on the impulsive component of the response. Veletsos and Yang [9] modified this method by using Flugge's shell theory in combination with the Rayleigh–Ritz procedure to calculate the natural frequencies of the liquid-shell system. Both shell analysis and the simpler beam-type analysis were carried out. Several other numerical and analytical studies taking into account the interaction between flexible shell and the containing liquid

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