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The effect of earthquake frequency content on the seismic behavior of concrete rectangular liquid tanks using the finite element method incorporating soil–structure interaction

M.R. Kianoush*, A.R. Ghaemmaghami

Civil Engineering Department, Ryerson University, Toronto, ON, Canada

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ABSTRACT

A three-dimensional soil–structure–liquid interaction is numerically simulated using the finite element method in order to analyze the seismic behavior of partially filled concrete rectangular tanks subjected to different ground motions. In this paper, the effect of earthquake frequency content on the seismic behavior of fluid rectangular tank system is investigated using four different seismic motions. A simple model with viscous boundary is used to include deformable foundation effects as a linear elastic medium. This method is capable of considering both impulsive and convective responses of liquid-tank system. Six different soil types defined in the well-recognized seismic codes are considered. The sloshing behavior is simulated using linear free surface boundary condition. Two different finite element models corresponding with flexible shallow and tall tank configurations are studied under the effects of longitudinal, transversal and vertical ground motions. By means of changing the soil properties, comparisons are made on base shear, base moment and sloshing responses under different ground motions. It is concluded that the dynamic behavior of the fluid–tank–soil system is highly sensitive to frequency characteristics of the earthquake record.

1. Introduction

The dynamic interaction between fluid, structure and soil is a significant concern in many engineering problems. These problems include systems as diverse as off-shore and submerged structures, biomechanical systems, suspension bridges and storage tanks. The interaction can drastically change the dynamic characteristics of the structure and consequently its response to transient and cyclic excitation. Therefore, it is desired to accurately model these diverse systems with the inclusion of fluid–structure interaction (FSI).

One of the critical lifeline structures which has become widespread during the recent decades is liquid storage tank. These structures are extensively used in water supply facilities, oil and gas industries and nuclear plants for storage of a variety of liquid or liquid-like materials such as oil, liquefied natural gas (LNG), chemical fluids and wastes of different forms.

Problems associated with liquid tanks involve many fundamental parameters. In fact, the dynamic behavior of liquid tanks is governed by earthquake characteristics, the interaction between fluid and structure as well as soil and structure along their boundaries. For example, it has been found that hydrodynamic pressure in a flexible tank can be significantly higher than the corresponding rigid container due to the interaction effects between flexible structure and contained liquid.

Even though there have been numerous studies done on the fluid–structure interaction effects in liquid containers, most of them are concerned with cylindrical tanks and the studies on seismic response of rectangular tanks are quite rare. Housner [1] developed the most commonly used analytical model for rigid tanks in which hydrodynamic pressure is separated into impulsive and convective components using lumped mass approximation. This model has been adopted with some modifications in most of the current codes and standards.

Later, Yang [2], Veletos and Yang [3] studied the effects of wall flexibility on the pressure distribution in liquid and corresponding forces in the tank structure through an analytical model. Minowa [4,5] investigated the effect of flexibility of tank walls and hydrodynamic pressure acting on the wall using both analytical and experimental methods.

Studies on the three-dimensional fluid–structure interaction in a domain of a more general geometry, other than the cylindrical shape, can be found in the literature on the seismic design of concrete dams.

Chopra and Gupta [6] investigated the effects of fluid–structure and soil–structure interaction on the frequency function responses of water–dam–foundation system. They concluded that

* Corresponding author. Tel.: +416 979 5000x6455.
E-mail addresses: kianoush@ryerson.ca (M.R. Kianoush), aghaemma@ryerson.ca (A.R. Ghaemmaghami).

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