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Resonant frequencies in a rectangular liquid storage tanks: Experiments and finite element methods

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Abstract

In this paper, an experimental-numerical study of the overall dynamic response of concrete rectangular tanks is presented. In order to identify the natural frequencies of the modes that mainly contribute to the response, modal tests on a 2D rectangular tank model for different liquid level were carried out. Next, a numerical model that takes into account the coupling between experimental and numerical result was obtained. The simulation model was validated with experimental results and good agreement was achieved. The results obtained show the influence of liquid levels on natural frequencies and indicate that the wall flexibility has a significant effect on the dynamical characteristic of the analyzed system.
Keywords: modal test, rectangular tank, fluid-structure interaction, finite element method.

1. INTRODUCTION

For several decades, the fluid-structure interaction problem has been a continuous challenging research subject in various scientific and engineering applications, such as stationary liquid storage tanks, dam-reservoir systems, nuclear reactors in fluid and tower-like structures [1]. The dynamic interaction between an elastic structure and a compressible fluid has been the subject of intensive investigations in recent years. At present, the most common approach being adopted is that the fluid and structure are coupled and solved as one system. This system can be solved by numerous numerical methods, such as finite element (FEM) [2], boundary element (BEM) [3] and coupled boundary element-finite element method (BEM/FEM) [4]. These methods have provided many useful and satisfactory results.

Studies on the seismic response of rectangular tanks are not adequate, while those concerning cylindrical tanks are numerous. Moreover, in most existing studies on the rectangular tanks, the tank structures are assumed to be rigid. Kim et al. [3] studied the dynamic behavior of 3-D rectangular flexible fluid containers using the Rayleigh-Ritz method. Park et al. [5] studied the dynamic behavior of rectangular concrete tanks using boundary element modeling for the fluid motion and finite element modeling for the solid walls. The time-history analytical method was used to obtain the dynamic response of fluid storage tank subjected to earthquakes. Both impulsive and convective effects were considered. Later, they presented an analytical method using three-dimensional hydrodynamic pressure calculations. Chen and Kianoush [6] proposed a sequential method to determine the hydrodynamic pressures of rectangular tanks by considering the effect of wall flexibility on impulsive pressure.

Including the wall deformability in a dynamic analysis requires a systematic knowledge and understanding of the fluid–structure free-vibrational characteristics. Generally, research has been focused on the natural frequencies, while vibration mode shapes and modal damping has been overlooked [7]. Over the last decade, a number of new studies on the dynamics of partial filled cylindrical shells have been published [8].
One form of non–destructive testing that may be used to obtain information on the dynamic behavior of actual structures is the experimental modal analysis. The experimental study of structural vibration is often performed to determine the modal parameters of a structure (i.e. natural frequencies, damping and mode shapes), or to verify the theoretical models and predictions. This technique has the advantage of determining the real structural properties without using any assumption and taking into account the actual boundary condition.