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Fuzzy Methods for Modelling Earthquake Induced Sloshing in Rigid Reservoirs

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***Abstract*—This paper is devoted to analysis of liquid vibrations in rigid containers at seismic loads. An effective numerical method is developed involving boundary elements and fuzzy logics. The novelty of the proposed method consists in using fuzzy concepts to analyzing uncertainties in earthquake parameters. First, deterministic methods are used for estimation of dynamic characteristics of structures with compartments partially filled with liquids. Sloshing problems are solved both in linear and nonlinear formulations. Then randomness of some earthquake parameters is adding to mathematical model. The fuzzy stochastic differential equations are received and solved numerically. Numerical results are obtained that demonstrate influence of uncertainties. These results provide a more adequate estimate of the free surface level during earthquakes and allow us to draw a conclusion about the possibility of hazardous contents spilling.**

***Keywords*—liquid storage tanks, earthquake, stochastic differential equations, boundary element method, fuzzy approach**

I. Introduction

Shells and shell structures, partially filled with liquids, are widely used in various areas of modern technologies such as energy engineering [1], aerospace [2], oil and gas productions, chemical industry, and transportation [3]. Usually, fuel tanks and reservoirs are functioned at high operating loads and contain aggressive or flammable fillers. Liquid storage tanks are important components of rescue and industrial facilities. At intensive force influences or suddenly applied loading at these reservoirs, the sloshing phenomenon is observed [4, 5]. Breakdown of oil storage after devastating earthquakes can lead to environmental hazards, loss of valuable contents, fires [6]. Inadequately designed reservoirs have suffered great damage in past earthquakes, which has led to catastrophic consequences. In the first stages, the risks associated with earthquakes were estimated using deterministic seismic hazard analysis (DSHA) [7], [8]. But DSHA provides no information about likelihood of the controlling earthquake and effects of uncertainties. In the past 20 years the use of probabilistic concepts has allowed to estimate uncertainties in sizes, locations, frequencies, ground motion characteristics in seismic hazards [9], [10].

Deeper understanding of seismic hazard uncertainties is associated with using the concepts of interval-valued probability [11]. In this approach, possibility distributions are applied to define lower and higher probabilities (necessity and possibility measures). This approach was used in seismic hazard analysis for a long time. A natural extension to interval-valued probability is the notion of fuzzy probability. The concepts of fuzzy parameter and fuzzy logic were at first proposed by Zadeh in [12], and since then, they became a powerful tool for modelling uncertainties in a variety of practical engineering problems [13]. It should be noted that for such mathematical modelling, the usage of fuzzy differential equations is necessary.

Many authors devoted their research to numerical implementation of the fuzzy differential equations [14].

An increasing interest has been shown in treating the uncertainties involved in modelling structure vibrations under seismic loadings [15]. Recently researchers and engineers put forward their efforts to analyzing seismic loads and structure resistance by fuzzy analysis methods, using concepts of fuzzy earthquake intensities, fuzzy earthquake periods, fuzzy damping, fuzzy epicentral distances between a local sites and potential seismic sources and other basic notions [16]. At first stages, the deterministic methods to estimate strength dynamic characteristics of structures under seismic and impact loads are usually involved [17]. One of the ways to deal with uncertainties, is in adding randomness to some model parameters with using fuzzy stochastic differential equations [18].

The goal of this paper is to explore dynamic characteristics of liquid storage tanks under seismic loads, involving fuzzy vibration analysis. The topical issue here is describing the disturbance in an unrestrained free surface of liquid in a container at earthquake induced sloshing.

II. Metodology

Liquid vibrations are considered in rigid storage tanks containing liquids under horizontal and vertical excitations. The storage tanks are described as shells of revolution. The liquid is assumed to be an ideal and incompressible one, and its motion caused by applied loads is irrotational. Free vibrations are studied at first, and then the obtained own modes are used as basic functions to analyze the forced vibrations.

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It should be noted that the crisp values of the liquid free surface elevations are located between upper and lower bounds of the fuzzy peak ground accelerations.

IV. Conclusion and Further Research

The novelty of this study lies in proposing the approach based on the boundary element method to explore the liquid free surface elevation in rigid reservoirs under fuzzified seismic excitations both in linear and non-linear formulations. The earthquake is characterized by longitudinal and lateral loads with fuzzified accelerograms. The systems of ordinary differential equations are received to describe the crisp free surface elevation in rigid tanks. The results reveal that using the nonlinear approach leads to the process decreasing in time, while the linear formulation describes the vibration process with small amplitudes that is close to periodic. The synthetic accelerogram is used for deterministic earthquake induced sloshing analysis. At this, the maximum amplitudes of vibrations are reached in the first 30 seconds from the earthquake beginning, when the difference between the results in the linear and nonlinear formulations is small. It allows us to consider the linear formulation during this period. The peak ground accelerations in horizontal and vertical directions are fuzzified using triangular symmetric membership functions. The obtained systems of fuzzy differential equations are solved numerically with the MATLAB Simulink approach.

At the next stage, the developed methodology will be generalized for studying earthquake excitations with more else fuzzy parameters, such as earthquake magnitudes, frequencies and seismic intensity. The tanks with baffles for slosh damping also will be considered.

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