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Seismic reliability of spherical containers retrofitted by means of energy dissipation devices

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ABSTRACT

For the purpose of enhancing the seismic reliability of structures, external energy dissipation systems may be advantageously used. In this paper, the reliabilities of a spherical storage tank in original and updated states are assessed by means of simulation. The effect of the energy dissipation system is numerically evaluated by performing a set of nonlinear dynamic analyses on a spherical tank based on a detailed model that takes the fluid–structure interaction into account. To obtain robust estimators of the reliability, an ensemble including acceleration records with markedly different characteristics is used in the simulation study. The full reliability analysis shows that, for a typical spherical container widely used in the petrochemical industries, a reduction of the limit state probability in the order of 85% may be expected by introducing additional energy dissipation systems.

1. Introduction

Spherical storage tanks are very important components, principally in refineries and petrochemical facilities, because they contain pressurized and refrigerated low density hazardous liquids, such as sulphur dioxide, carbon dioxide, anhydrous ammonia, propylene, etc. The importance goes beyond its economic cost because the effects of a failure are not limited to the risk to the lives of humans and to equipment in the vicinity, but can also lead to serious consequences for the environment. Containers of this type have been severely damaged and some have failed with disastrous consequences, revealing their vulnerability, in almost every major earthquake (e.g., experiences from Chile [1], Kocaeli, Turkey [2], San Fernando and Whittier earthquakes [3]). Therefore, it is of critical interest to ensure operational reliability, since many of them are located in areas of high seismicity worldwide.

In order to enhance the seismic-worthiness and reduce the risk of damage or failure, numerous experimental and theoretical studies have been carried out in recent years [4,5]. From this research, two major alternatives resulted: seismic isolation and external energy dissipation.

Especially as regards seismic retrofitting of liquid storage tanks, several contributions have been published, for example those of Shrimali and Jangid [6], Cho et al. [7], and Almazan et al. [8] who were concerned with isolation systems. Taking an alternative approach, Maleki and Ziyaeifar [9,10], Pirner and Urushadze [11], Liu and Lin [12] and Swaran et al. [13] investigated the effects of baffles in reducing the structural response to earthquakes. However, only a few works have been found in the technical literature concerned with the seismic performance of elevated spherical tanks. In order to quantify the reduction of the response to seismic loading, Bergamo et al. [14] have carried out parametric nonlinear time history analyses on a simplified Housner model of a typical sphere equipped with two different types of isolation systems (lead rubber bearings, LRB, and high damping rubber bearings, HDRB). Drosos et al. [15] investigated numerically the seismic response in terms of top displacement and base shear of a typical spherical liquid tank equipped with a nonlinear viscous bracing system. Similarly, Castellano et al. [16] evaluated the benefits of two seismic retrofit schemes with viscous fluid dampers and buckling-restrained braces by estimating the acceleration reduction of the center of mass. In both studies a set of artificial seismic ground motions in accordance with the EC8 [17] spectrum was assumed.

On the other hand, in the presence of uncertainties associated with the structural performance (capacity) and principally with the excitation (demand), one of the best tools for assessing the performance of new and existing structural systems is probabilistic seismic risk analysis, which has received increasing attention in the last two decades [18–23]. On this premise, in contrast to the case for previous works, the most appropriate approach for assessing the effectiveness of energy dissipation systems in structures under seismic excitation is a seismic risk analysis or reliability analysis [24].

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