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Seismic fragility curves for legged wine storage tanks with a novel isolation device

J.I. Colombo[a,]*, J.L. Almazán[a]

[a] *Department of Structural and Geotechnical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile*

Abstract

Seismic protection of wine storage tanks has become a very important issue due to the boom of the winery industry in some seismic countries such as, the U.S, Italy, New Zealand, Chile and Argentina. Wine storage tanks are classified in two major groups: continuously supported tanks and legged tanks. Previous research has developed fragility curves for continuously supported tanks, with and without seismic protection devices, in order to establish the seismic reliability of this kind of tanks. However, fragility curves of legged wine tanks have not been reported. Therefore, in this study, the fragility curves of a typical stainless steel legged wine storage tank (one of 3,000 litres capacity), used for fermentation and wine storage, are assessed by means of numerical simulation. The fragility curves were developed by the results obtained from a mathematical model capable to perform the nonlinear time history analysis of the tank subjected to several artificial ground motions. The artificial ground motions are based on ground motion prediction from earthquakes recorded in Chile. Finally, the seismic fragility for a typical legged wine storage located in Chile was presented. Furthermore, the seismic fragility of a same damage state for a typical legged wine storage tank with and without a novel isolation device were compared.

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Keywords: Seismic isolation; fragility curves; wine storage tanks.

1. Introduction

Legged stainless steel tanks are used in the winery industry for fermentation and storage of high quality wine since the 1950s in USA [1], and since the 1980s, approximately, in Chile and Argentina [2]. However, several earthquakes have affected many of these tanks. For instance, many reports of damage provide evidence of failure

* Corresponding author. Tel.: +56 2 354 4204.
E-mail address: jicolombo@uc.cl

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and extensive damage in wine storage tanks such as during the 1977 Caucete earthquake in Argentina [3], the 1980 Livermore earthquake [4], the 1983 Coalinga earthquake [5] and the 1989 Loma Prieta earthquake [6] (all in California, USA), and the 2010 Maule earthquake in Chile [2]. Therefore, the seismic vulnerability of these structures is evident.

Considerable economic losses and environmental hazards have been caused by the loss of contents of these tanks [2]. The most common types of damage observed in legged storage tanks are: damage to the piping connections caused by large tank displacements, buckling of the tank legs caused by large axial loads coupled with lateral loads, failure of the anchorage system caused by the high overturning moment transmitted to the tank legs. Among these causes, the failures that are responsible for a large or total loss of the liquids contained in legged storage tanks are buckling of the tank legs (see Fig. 1(a)).

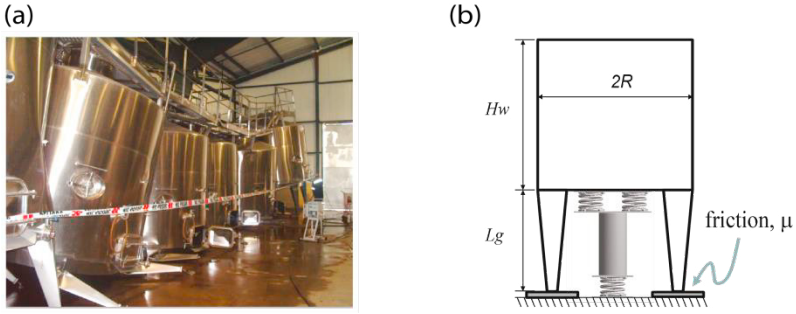

Fig. 1. (a) Buckling failure of the tank legs; (b) Legged storage tank with the seismic isolation system.

Due to the booming wine industry in some seismic countries such as the US, Italy, New Zealand, Chile and Argentina among others, seismic protection of wine storage tanks in the face of earthquake hazards is of paramount economic importance. For instance, in the past 2010 earthquake in Chile the losses reached approximately 125 million litres of wine (250 million U.S. dollars) representing 12.5% of production in 2009 [2]. The earthquake struck a week before the start of the harvest, when only 50% of storage capacity was in use. This indicates that more than 25% of tanks with wine lost all or part of their content.

Recently investigations have been performed in this field in order to improve seismic behaviour and to reduce the risk of damage or failure of liquid storage tanks [7]. In these studies two major alternatives are presented: seismic isolation and external energy dissipation. Additionally, seismic fragility analysis is one of the best tools for measuring the seismic performance of a structural system due to uncertainties related to structural performance and, predominantly, to excitation, [8]. However, previous work on seismic fragility analysis for liquid storage tanks is scarce.

Consequently, with the premise that the most appropriate approach for measuring the effect of any seismic protection system in structures under seismic excitation is a seismic fragility analysis, in this work the seismic fragility curves of a typical legged steel wine storage tank with and without a seismic isolation system was evaluated numerically. The seismic behaviour of the structure is examined by performing a set of non-linear dynamic analyses based on a mathematical model that takes the fluid-structure interaction and the non-linear behaviour of the isolation system into account [9]. The behaviour of the isolation system due to restitutive element, i.e. the force-displacement relationship, was established by means of an ANSYS model and the respective non-linear pushover analysis. The behaviour of the isolation system due to the frictional effect in the tank legs was taken account with a frictional model proposed by Constantinou et al. [10]. Several artificial ground motions were considered in the simulation study in order to obtain robust results. The artificial ground motions were based on ground motion from subduction earthquakes recorded in Chile. The structure with the novel seismic isolation system showed a significant increase in structural performance, measured by means of the peak ground acceleration (PGA) required for the median fragility.