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Seismic reliability of legged wine storage tanks retrofitted by means of a seismic isolation device

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ABSTRACT

Due to the booming of the winery industry in some seismic countries such as, the U.S, Italy, New Zealand, Chile and Argentina, the seismic protection of wine storage tanks may be of a practical importance. Wine storage tanks are classified in two major groups: continuously supported tanks and legged tanks. Previous research has described the seismic reliability of continuously-supported tanks, with and without seismic protection devices. Conversely, the seismic reliability of legged wine tanks has not been reported. Therefore, in this study, the seismic reliabilities of two typical stainless steel legged wine storage tanks (one of 3000 L capacity and one of 17,100 L capacity), used for fermentation and wine storage, in original and updated states are assessed by means of simulation. For the updated state, a non-linear isolation system for seismic isolation of legged wine tanks is used. The effect of the isolation system was numerically estimated by performing a group of non-linear time history analyses for each tank. Each non-linear time history analysis was obtained by means of a mathematical model. A set of different seismic ground motions was used for the purpose of obtaining robust results in the reliability analysis. Finally, the seismic reliability analysis shows that, for steel legged wine storage tanks, the effect of the isolation system would reduce the limit state probability in the order of 90%.

1. Introduction

Liquid storage tanks are used in many different civil engineering applications and industrial facilities. Some of these applications are the storage of liquids such as water, wine, oil, nitrogen, high-pressure gas, petroleum, etc. Almost every major earthquake around the world has affected many of these tanks. For instance, several reports provide evidence of failure and extensive damage in liquid storage tanks such as during the 1960 earthquake in Chile [1], the 1964 earthquake in Alaska [2], the 1977 earthquake in San Juan, Argentina [3], the 1979 Imperial County earthquake [4], the 1980 Livermore earthquake [5], the 1983 Coalinga earthquake [6], and the 1994 Northridge earthquake (all in California) [7], the 2001 Bhuj earthquake in India [8], and the 2010 earthquake again in Chile [9]. Therefore, the poor seismic reliability of these structures is evident.

Considerable economic losses and environmental hazards have been caused by the loss of contents of these tanks [10,11]. The most common types of damage observed in liquid storage tanks are: damage to the piping connections caused by large base uplifts, damage to the roof caused by the sloshing of the free liquid surface, buckling of the tank walls caused by the high compressive stress, 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 base, penetration of the tank wall with anchor bolts caused by the previous failure of the anchorage system and damage to the shell-base connection caused by the plastic rotation of the base plate. Among these causes, the failures that are responsible for a large or total loss of the liquids contained in storage tanks are buckling of the tank legs and rupture of the shell-base connection (see Fig. 1).

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. However, as stainless steel wine tanks were not in use when the 1985 earthquake occurred in Chile [10], local evidence of seismic behaviour of these kinds of structures is limited to the recent earthquake in central Chile in 2010. Consequently, there is little information available on seismic hazards in metallic wine storage tanks. It is important to note that at present steel tanks represent 80% of the country's wine storage capacity [11].

Steel wine storage tanks are classified in two major groups: continuously supported tanks and legged tanks (see Fig. 2). Several

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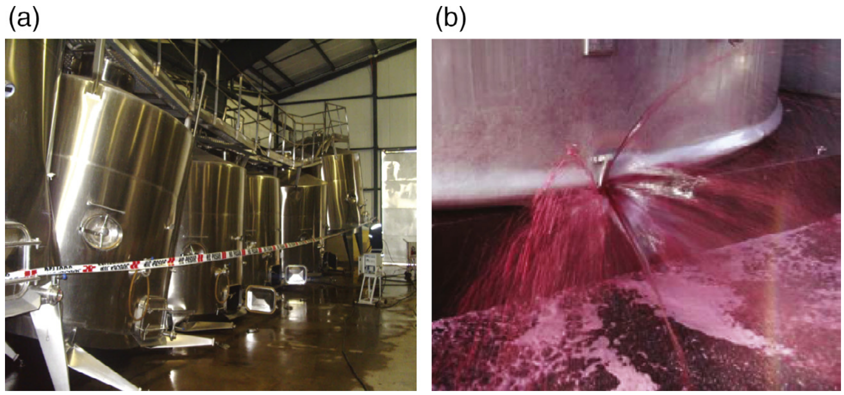

Fig. 1. Common failures in steel wine storage tanks that imply loss of the liquid content: (a) buckling of the tank legs and (b) rupture of the shell-base connection.

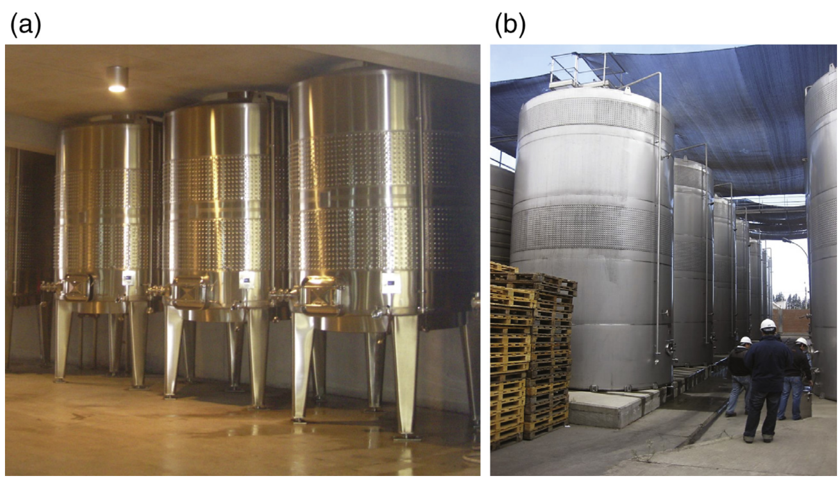

Fig. 2. Different foundation types for wine storage tanks: (a) legged tanks and (b) continuously supported tanks.

damages have been reported for both types of tanks. 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 [11]. 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 numerous studies have been carried out in this field in order to improve seismic behaviour and to reduce the risk of damage or failure of liquid storage tanks [12,13]. In these studies two major alternatives are presented: seismic isolation and external energy dissipation. Some examples of seismic protection in liquid storage tanks using isolation systems are given by Shrimali and Jangid [14], Cho et al. [15], and Almazán et al. [10]. Similarly, examples of seismic protection in liquid storage tanks using external energy dissipation devices are published by Maleki and Ziyaefar [16,17], Pirner and Urushadze [18], Liu and Lin [19], Malhotra [20], Curadelli [21], Ormeño et al. [22] and Colombo and Almazán [23]. However, only a few works have been found in the technical literature concerning the seismic performance and protection of legged tanks. For instance, Almazán et al. [10] investigated numerically, with a deterministic approach, the seismic response of a typical legged tank equipped with seismic isolation devices in the bottom of its legs.

Probabilistic seismic risk 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, [21,23–30]. Therefore, probabilistic seismic risk analysis has received increasing attention in the last two decades; however, previous work on probabilistic seismic risk analysis for liquid storage tanks is scarce. Only some recent investigations have presented a probabilistic seismic risk analysis for a few kinds of storage tanks; for instance, such risk analysis was published by Curadelli in order to assess the effectiveness of a specific retrofit on spherical storage tanks [21]. Similarly, a probabilistic seismic risk analysis was reported by Colombo and Almazán [23] in order to measure the effectiveness of a specific energy dissipation system on continuously supported wine storage tanks. It would appear earlier seismic reliability analyses for measuring the effect of any seismic improvement in legged cylindrical tanks have not been reported in the literature, i.e. only deterministic approaches have been shown in previous works. Additionally, it is important to remark that some recent studies have been carried out in order to evaluate the seismic reliability of structures isolated by friction pendulum devices [30,31].

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 risk analysis or reliability analysis [24], in this work the seismic reliability of two typical legged steel wine storage tanks – one of 3000 L capacity and one of 17,100 L capacity – with and without a seismic isolation system was evaluated numerically. More precisely, with the purpose of evaluating the effectiveness of using a novel seismic isolation system in this structure, the probability of reaching the limit state of two typical legged steel wine storage tanks with and without a seismic isolation system was calculated and compared. The