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Experimental investigation on the seismic isolation for a legged wine storage tank

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ABSTRACT

Because of the booming of the winery industry in some seismic countries such as, the U.S, Italy, Chile and Argentina, the seismic protection of wine storage tanks may be of a practical importance. Previous numerical and theoretical investigations have shown that seismic isolation can reduce the seismic demand on liquid storage tanks compared to the fixed base case. However, there are not experimental works about the seismic performance and protection of legged wine storage tanks, nor practical applications, reported in the technical literature. Therefore, in this paper, the effectiveness of a novel seismic isolation system has been investigated by shaking table tests on a full-scale legged tank, typically used in the wine industry. A comparison of the seismic behaviour of fixed base and isolated base configurations is presented. Two alternative base isolation systems have been studied: flat sliding bearings with a central leg acting as restoring element, and flat sliding bearings without any restoring element. The restoring force of the central leg was performed by means of five compression springs. The experiments were carried out using 3 natural and 3 artificial records. Measurements were made of the shear and axial forces in one leg of the tank, and the horizontal displacement of the tank. The experiments showed the beneficial effects of using the proposed isolation system in legged wine storage tanks, reducing the shear and axial forces in comparison with the fixed base configuration and reducing the horizontal displacement compared to the flat sliding bearing configuration without any restoring element.

1. Introduction

Stainless steel tanks are used in the winery industry for fermentation and storage since the 1950s in USA [1], and since the 1980s, approximately, in Chile and Argentina [2]. The use of this material, i.e. stainless steel, over other material for fermentation and wine storage tanks is due to its: (i) ease cleaning; (ii) noble chemical inertness; (iii) better control of the fermentation process; and (iv) aesthetically attractive appearance. However, several earthquakes have affected many of these tanks. For instance, many reports of damage provide evidence of failure 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], the 1989 Loma Prieta earthquake [6] and the 2003 San Simeon earthquake [7] (all in California, USA), the 2007 Pisco earthquake in Peru [2], the 2010 Maule earthquake in Chile [2], and the 2014 South Napa earthquake again in California, USA [8]. Therefore, the seismic vulnerability of these structures is evident.

The poor seismic reliability of wine storage tanks has caused considerable economic losses and environmental hazards by the loss of contents of these tanks [2]. 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).

Stainless steel wine storage tanks are classified in two major groups: continuously supported tanks and legged tanks (see Fig. 2). Several damages have been reported for both types of tanks. For instance, in the past 2010 earthquake in Chile the losses reached approximately 125 million l 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.

On the basis of the above-mentioned observations, and due to the successful of the wine industry in some seismic countries such as the

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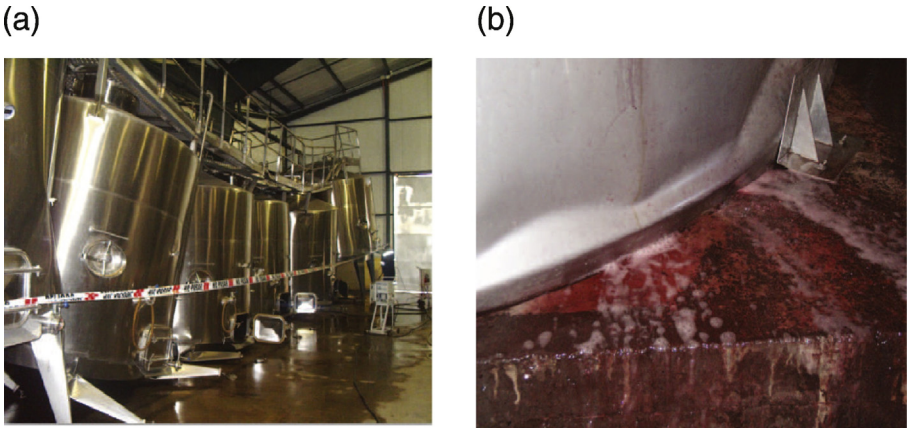

Fig. 1. Typical failures in steel wine storage tanks that imply loss of the liquid content: (a) buckling of the tank legs and (b) rupture of the shell-base connection.

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.

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 [9,10]. 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 [11], Cho et al. [12], and Almazán et al. [13]. Similarly, examples of seismic protection in liquid storage tanks using external energy dissipation devices are published by Maleki and Ziyaefar [14,15], Pirner and Urushadze [16], Liu and Lin [17], Malhotra [18], Curadelli [19], Ormeño et al. [20] and Colombo and Almazán [21]. 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. [13] investigated numerically the seismic response of a typical wine legged tank with seismic isolation in the bottom of its legs. Nevertheless, to the best of the author's knowledge, any experimental investigation about the seismic performance and protection of legged tanks has been reported in the technical literature.

Therefore, in this work the effectiveness of a novel isolation system on a legged wine storage tank has been investigated through shaking table test on full-scale of a real tank, typically used in the wine industry for fermenting and storing relatively small volumes of high quality wines. More precisely, with the purpose of evaluating the effectiveness of using a novel seismic isolation system in this structure, the seismic response of this tank with the isolation system was compared to that of fixed-base configuration. The isolation system was consisted of one multi-spring central leg, acting as a restoring element (i.e. the element responsible for the self-centring capacity), and one flat sliding bearing below each tank leg. Three tank anchorage configurations were evaluated: fixed base, isolated base without the restoring element (i.e. just with the flat sliding bearings) and isolated base with the restoring element. The force-displacement relationship of the multi-spring central leg was numerically established by means of an ANSYS model and the respective pushover analysis. The tests, which have been performed at the Laboratory of the Department of Structural and Geotechnical Engineering of the Pontificia Universidad Católica de Chile, demonstrated the effectiveness of the herein proposed seismic protection system.

2. Wine-tank considered

Experimental tests were carried out on a full-scale stainless steel legged tank which is typically used for fermentation and wine storage (see Fig. 3). When subjected to a strong seismic ground motion the structure may undergo several failure modes. The most significant failure modes are: buckling of the tank legs and failure of the anchorage bolts at the legs. Therefore, the purpose of this research is to avoid such failures modes using a new device for seismic isolation.

The dimensions of the tank are: radius $R = 0.8$ m, wall height $H_w = 1.70$ m, and length of the legs $L_g = 0.9$ m. The wall, base and legs are realized with stainless steel plates having a thickness of 2 mm. The tank is supported on four legs with upper width $w_u = 22$ cm, and lower width

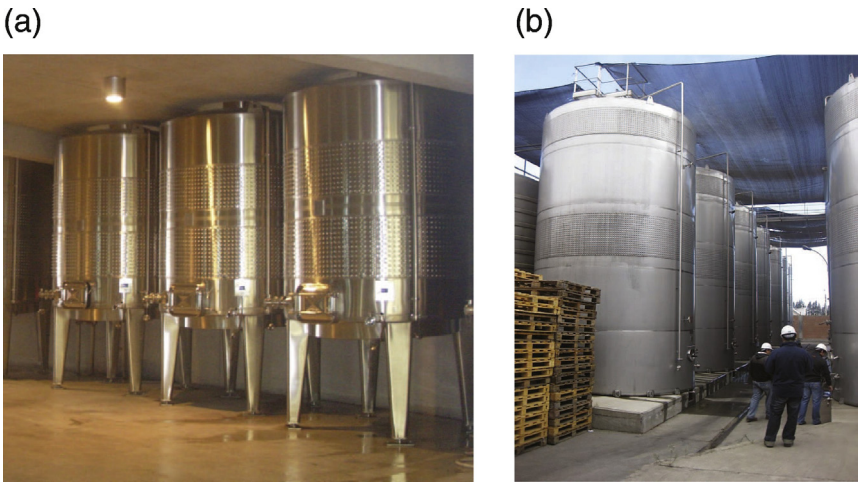

Fig. 2. Different foundation schemes for wine storage tanks: (a) legged tanks and (b) continuously supported tanks.