On the Suitability of Rolling Isolation for the Seismic Hazard Mitigation of Wine Barrel Stacks

P. Scott Harvey Jr., Ph.D.
Assistant Professor
School of Civil Engineering & Environmental Science
University of Oklahoma, Norman, OK 73019

Henri P. Gavin, Ph.D., P.E.
Associate Professor
Department of Civil & Environmental Engineering
Duke University, Durham, NC 27708

INTRODUCTION

On August 24, 2014 Napa County, California was struck by a magnitude 6.0 earthquake, injuring two-hundred people, killing one, and causing as much as $1 billion in damage. Earthquakes, like the 2014 South Napa quake, have the potential to disrupt the California viticulture industry. The economic value of the California Wine Industry is $61.8 billion and it creates 330,000 jobs within California [1]. Steps need to be taken to protect this billion dollar industry from similar devastating earthquakes in the future.

The typical wine barrel stacking system is susceptible to sliding, rocking, overturning, and collapse [2]. Seismic isolation, in particular rolling isolation, is a proven technology to protect the wine barrel inventory from damaging earthquakes by reducing the base shear demand on the racks [3]. Chadwell *et al.* [4] proposed and developed an isolation system prototype for use with wine barrel stacks. The isolation system decouples the racks from the ground motion by reducing the base shear through rolling rigid steel balls in recessed surfaces. For three representative ground motions, the isolation system effectively protected stacks consisting of one level and two levels. The SiesmaRack [5] and ISO-Base [6] systems by WorkSafe Technologies, Inc. function via a similar mechanism to the prototype by Chadwell *et al.*, making them viable solutions to protecting valuable property, such as wine storage racks.

MODELING AND TESTING ROLLING ISOLATION SYSTEMS

The authors have extensive experience modeling and testing rolling isolation systems (RISs) [7, 8]. We developed and validated numerical models for both lightly- and heavily-damped RISs. A schematic drawing of the lightly-damped RIS is shown in Fig. 1(a). The system is able to isolate motion in two orthogonal directions (x, y), as well as rotation (θ). With an equivalent damping ratio of 1–2% minimal base shear is transmitted to the isolated object. Further, the system allows for large relative displacements — 20 cm capacity.

For cases in which the displacement demand needs to be decreased, additional damping (or energy dissipation)

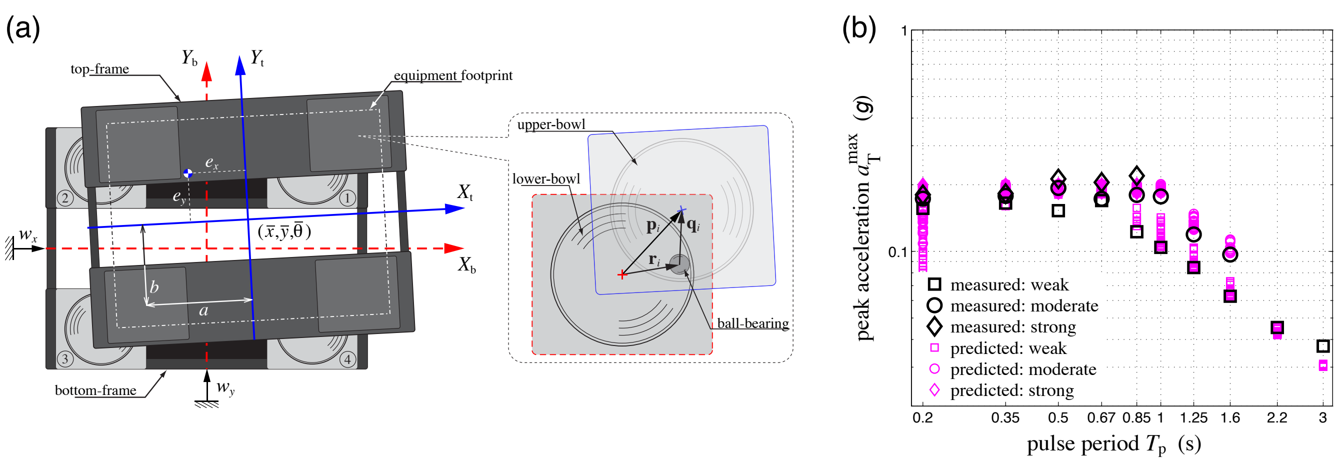

Figure 1: (a) Rolling isolation system geometry and notation [7]. (b) Measured and predicted response of a heavily-damped rolling isolation system [8].

is ideal. By simply adhering rubber sheets to the steel rolling surfaces, additional rolling resistance (damping) is readily introduced in the RIS. For the same disturbance strength, the heavily-damped RIS will exhibit smaller relative displacements than the lightly-damped RIS, reducing the possibility of exceeding the system's displacement capacity.

The recessed dishes in both systems were designed to have constant slopes with a spherical portion in the vicinity of their centers. A constant slope limits the total acceleration felt by the isolated object. The ISO-Base system has a slope of 1:10. Therefore, the peak total acceleration for the lightly-damped system is constrained to be less than $0.1g$. Whereas, the heavily-damped RIS exhibits slightly higher accelerations ($\sim 0.2g$) due to the additional damping. Figure 2(b) shows the results of experimental tests on a heavily-damped RIS subjected to pulse-like disturbances. In the absence of impacts, the accelerations are $\leq 0.2g$; the theoretical models successfully predict the response of the RIS.

We are qualified and prepared to carry out detailed high-fidelity computational simulations and supporting experiments for the development of RISs specifically for protecting fluid-filled barrels. To this end, we can couple the sloshing dynamics of fluid in barrels to the flexible behavior of stacked racks, and the nonholonomic dynamics of RISs. Ultimately these dynamics can be driven by site-specific ground motion records that are representative of the Napa area, possibly including some of the records from the 2014 Napa Valley earthquake.

REFERENCES

[1] Wine Institute (2013), "California Wine Industry Statistical Highlights." http://www.wineinstitute.org/files/CA%20Wines%20Stat%20Profile%202013.pdf (accessed 03/01/2015).

[2] Brown, D. T. (2007), *Investigation Into the Slide-rock Seismic Response of Wine Barrel Stacks and an Alternate Stacking Method to Mitigating the Rocking Response: A Thesis*, California Polytechnic State University.

[3] Chadwell, C. B., Brennan, K. R., Porter, M. W. (2008), "Seismic isolation of wine barrel stacks on portable steel racks" *Proc. of the 14th World Conference on Earthquake Engineering*, Beijing, China.

[4] Chadwell, C. B., Brennan, K. R., Porter, M. W. (2009), "Seismic hazard mitigation of wine barrel stacks," *Structures Congress 2009*: 1–10.

[5] WorkSafe Technologies, Inc. (2015), "SeismaRack System." http://www.seismarack.com/ (accessed 02/28/2015).

[6] WorkSafe Technologies, Inc. (2009), "ISO-Base." http://www.iso-base.com/ (accessed 02/28/2015).

[7] Harvey, P. S., Jr., Gavin, H. P. (2013), "The nonholonomic and chaotic nature of a rolling isolation system," *Journal of Sound and Vibration* 332: 3535–3551.

[8] Harvey, P. S., Jr., Zéhil, Z.-P., Gavin, H. P. (2014), "Experimental validation of a simplified model for rolling isolation systems," *Earthquake Engineering & Structural Dynamics* 43: 1067–1088.