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Vertical Rocking Isolation System using simply supported devices with uplift allowed for low-mass industrial structures

Sergio I. Reyes & José L. Almazán

Department of Structural Engineering, Pontificia Universidad Católica de Chile.

Introduction

The rocking with uplift behavior of some slender structures and his natural association with a possible collapse by overturning make it have a negative connotation so that measures are used to restrain uplift and avoid this failure (e.g. large foundations on buildings, anchorages on steel structures, etc). However, restraining this behavior might lead to an increase of the internal forces on the elements. As a matter of fact, it has been seen that in many strong seismic events tall and slender steel anchored structures survived to the ground movement whereas more robust and stable structures were severely damaged, being Housner one of the first to investigated this phenomenon on inverted pendulum structures determining that the yielding and stretching of anchors leaves a gap that allows the structure to rock forth and back on their foundations [1].

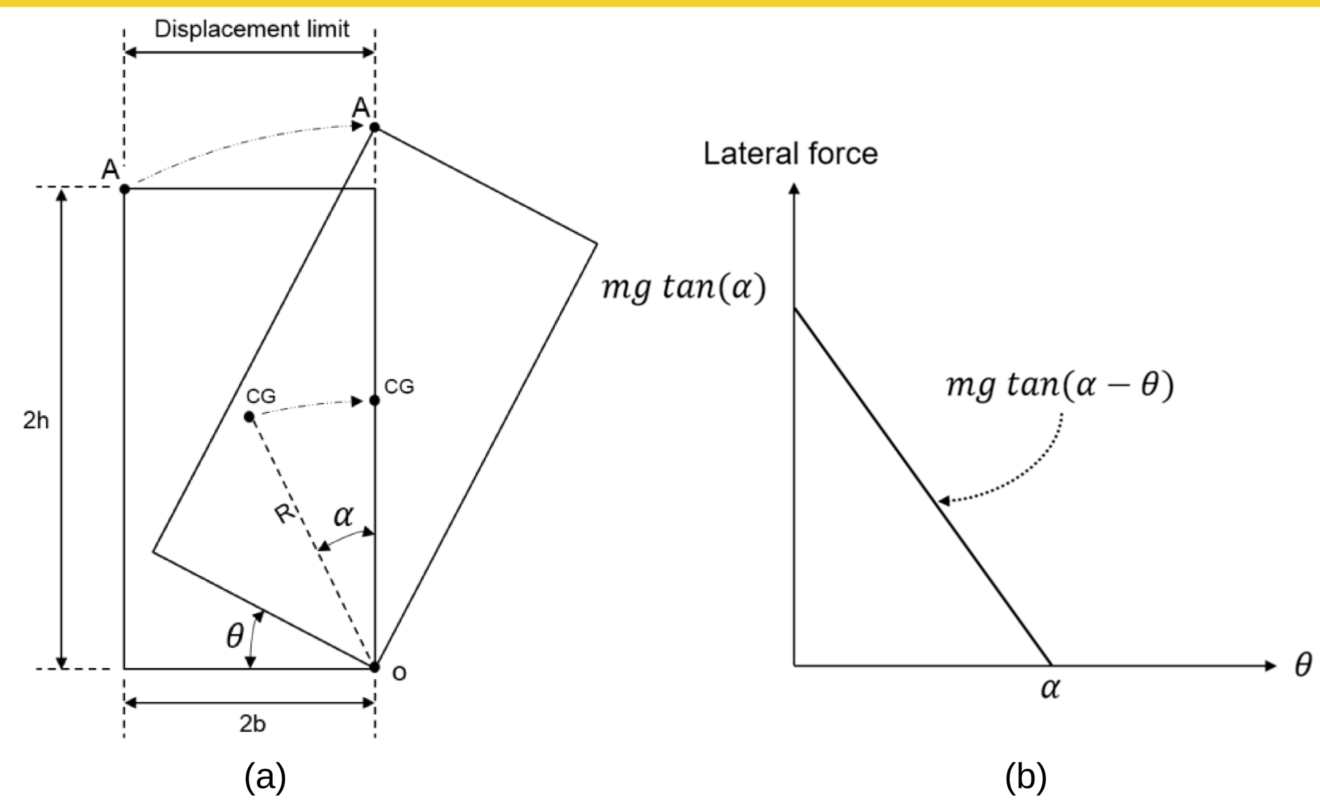

Fig. 1. (a) Simply supported rigid body and, (b) his lateral force-rotation relationship.

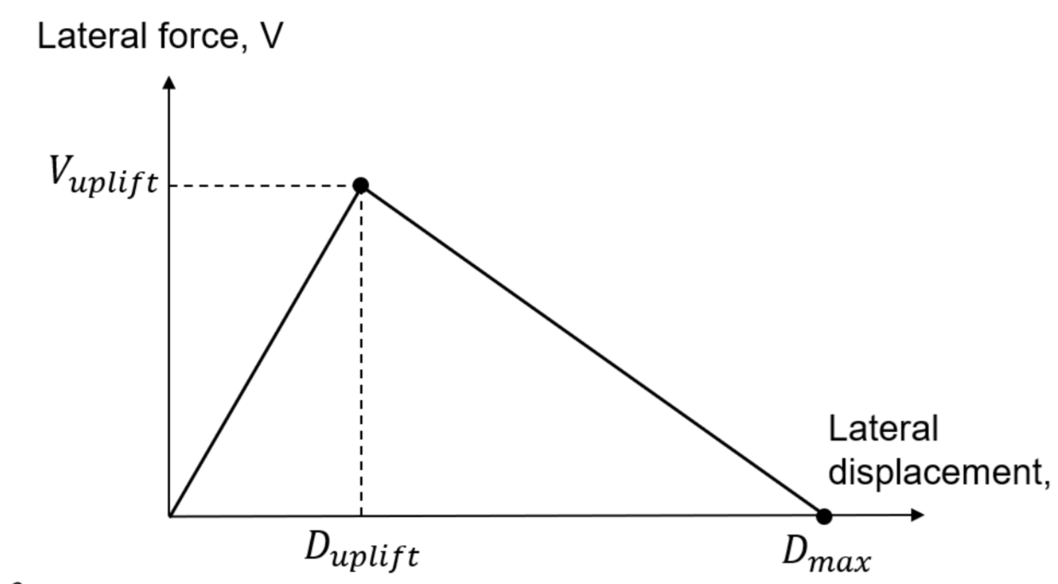

Fig. 2. Idealized lateral force-deformation relationship (pushover curve) for a simply supported structure on a flexible foundation

Simply supported devices: ISO3D-2G

The ISO3D-2G device uses elastomeric filled-rubber at uniaxial compression and tension as restoring force, providing a high amount of energy dissipation. Filled rubbers under cyclic uniaxial deformation are strongly characterized by a stress-softening behavior called "Mullins effect" [2], but although different dynamic models for rubber have been widely studied in elastomeric isolator devices [3,4], they only consider shear deformation and there is not a preferred model to represent the hysteretic uniaxial behavior. To represent the vertical constitutive of the device a numerical model was developed to fit experimental data using an Ogden hyperelastic model [5] to represent de elastic component, and a Bouc-Wen model [6] to represent the hysteretic component. This procedure was used for both compression and tensile rubbers.

As this device works simply supported, the contact between the device and the ground is modeled with friction. Eq. 1. present the equations of the Bouc-Wen model used for biaxial interaction to represent the friction between the devices and the ground.

$$\begin{pmatrix}\dot z_1\\ \dot z_2\end{pmatrix} = \begin{bmatrix} A-a_1z_1^2 & -a_2z_1z_2\\ -a_1z_1z_2 & A-a_2z_2^2\end{bmatrix}\begin{pmatrix}\dot u_1\\ \dot u_2\end{pmatrix} \qquad (1)$$

$$a_i=\gamma+\beta sign(z_i\dot u_i) \quad i=1,2$$

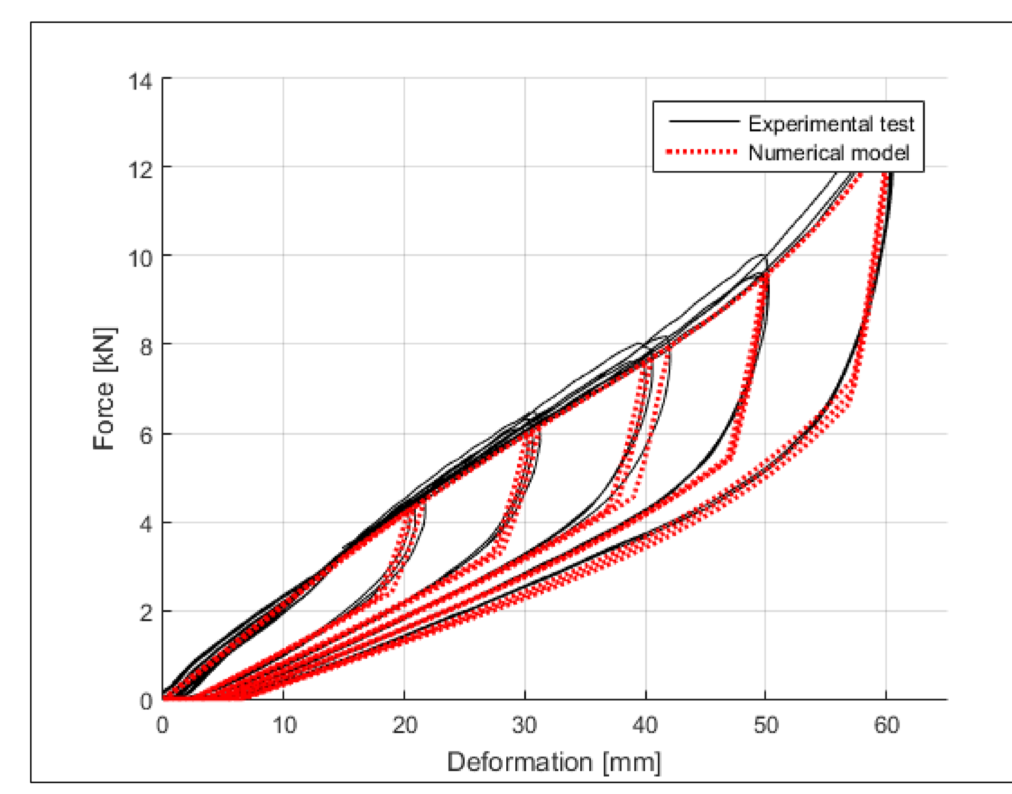

Fig. 3. Numerical model fitting for compression rubber.

Case Study

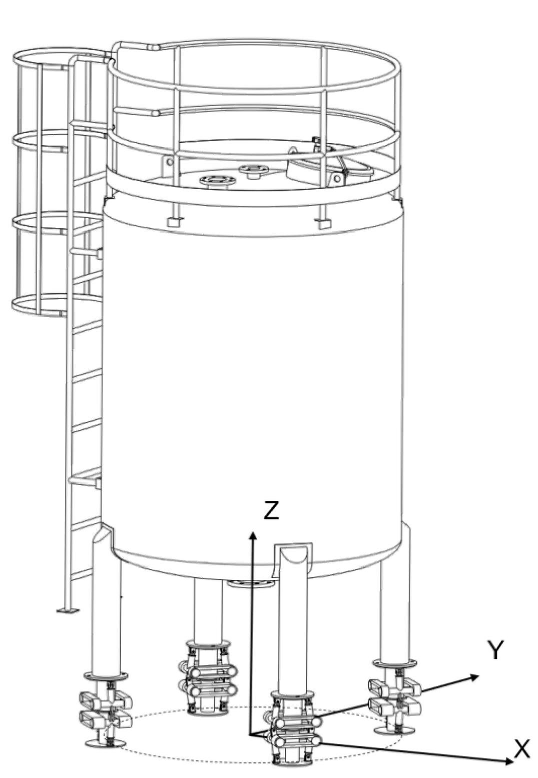

Fig. 4. Isolated storage tank.

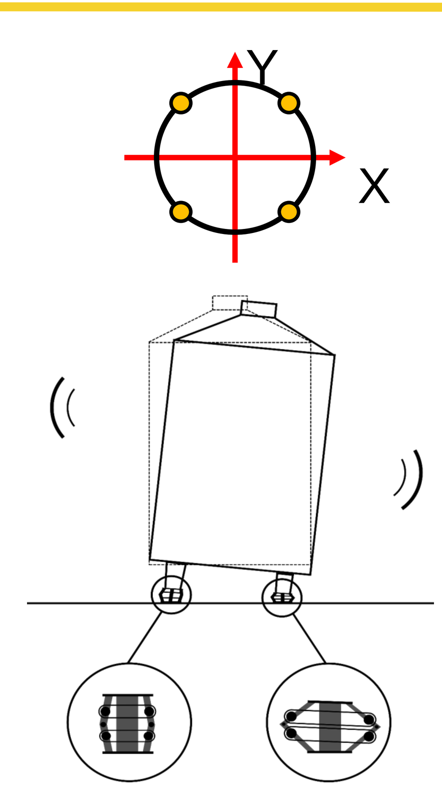

Fig. 5. schematic view of the isolation system.

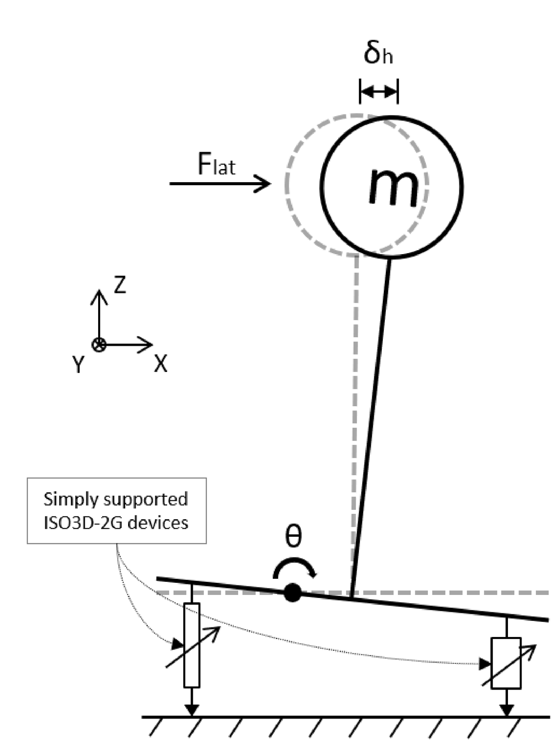

Fig. 6. Idealized lumped-mass model.

Three tanks are analyzed considering different dimensions for the radius and mantle height (change the slenderness of the tank). Each tank weight of 3,200 kgf and has four legs of 90 cm height. Table 1 presents the properties of the models and the idealized pushover curve. Two conditions were applied to each model:

- An Initial condition of velocity to force the uplifting of the system and the subsequent dropback impact.
- Seismic records: the three components of some ground motions of the Maule Earthquake, Chile, 2010.

Table 1. Tanks properties.

Tank Model	Tank radius (cm)	Mantle height (cm)	CG height (cm)	D_{uplift}(cm)	V_{uplift} (kgf)	V_{uplift}/W
M1	75	210	195	11.76	666	0.208
M2	67.4	260	220	14.77	471	0.147
M3	61.7	310	245	17.97	330	0.103

Results

Fig. 7 shows the results obtained for the initial condition of velocity. Time-history analysis showed the effectiveness of the isolation system for the 2010 Maule Earthquake, obtaining basal shears lower than 0.14 times the weight of the structure, consistent with the seismic isolated structures performance.

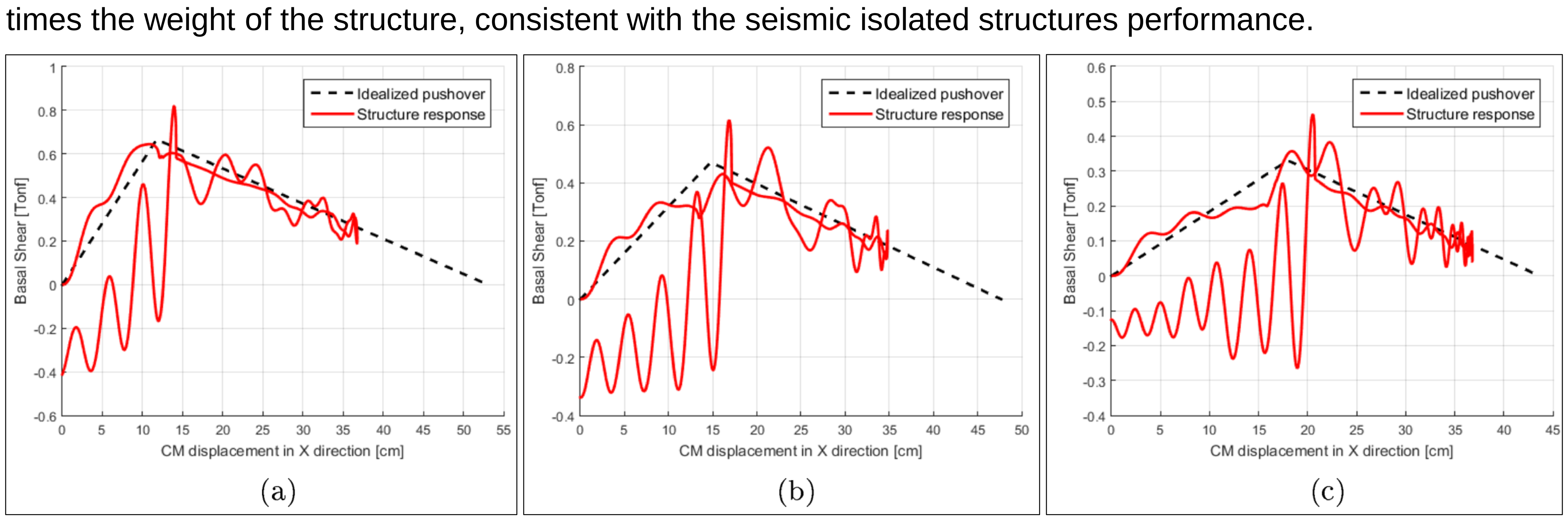

Fig. 7. Structure response to the initial condition of velocity and the idealized pushover curve for the three models: (a)M1, (b)M2, and(c)M3.

Conclusions

This research presents the Vertical Rocking Isolation System (VRIS) as a cost-effective alternative to the traditional horizontal isolation in the industrial sector. It is suitable to be applied to any low-mass industrial structures such as storage tanks, rotative machinery or any other industrial equipment.

A 3,000 kgf wine storage tank with three variations was analyzed and subject to two conditions, obtaining more than 80% of reduction in shear forces in the time-history analysis compared to traditional anchor systems to support the structure. Also is observed that the global dynamic behavior can be represented with simplified static procedures.

The VRIS besides reducing the shear forces on the structure, also limit the shear forces to a maximum possible value associated to the uplifting of some devices, freezing the internal forces and assuring the structure protection.

References :

[1] Housner, G. W. (1963). The behavior of inverted pendulum structures during earthquakes. Bulletin of the seismological society of America, 53(2), 403-417.. [3] Kelly, J. M., 1999. Analysis of rubber-reinforced elastomeric isolators. Journal of Seismology and Earthquake engineering 2 (1). [2] Diani, J., Fayolle, B., Gilormini, P., 2009. A review on the Mullins effect. European Polymer Journal 45 (3), 601-612. [4] De la Llera et. al. 2004. Analysis, testing, and implementation of seismic isolation of buildings in Chile. Earthquake engineering & structural dynamics 33 (5), 543-574. [5] Ogden, R. W., Saccomandi, G., & Sgura, I. (2004). Fitting hyperelastic models to experimental data. *Computational Mechanics*, *34*(6), 484-502. [6] Ismail, M., Ikhouane, F., & Rodellar, J. (2009). The hysteresis Bouc-Wen model, a survey. *Archives of Computational Methods in Engineering*, *16*(2), 161-188.