QuakeCoRE
NZ Centre for Earthquake Resilience

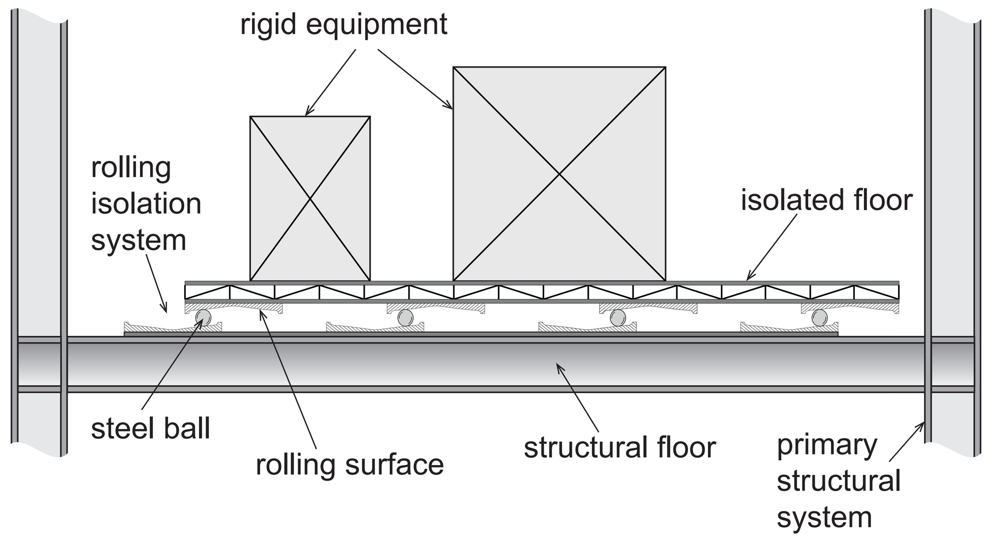
Application of Floor Isolation Systems for Multi-functional Seismic Mitigation: Computational Results

P. Scott Harvey Jr., Nisal Halaba Arachchige Senarathna, and Skylar J. Calhoun

The UNIVERSITY of OKLAHOMA
Gallogly College of Engineering
School of Civil Engineering and Environmental Science

Equipment/Floor Isolation System

- The functionality of critical facilities is not solely dictated by the primary building structure's integrity, but instead must also consider damages to the building contents [1]
- Seismic isolation is widely used for individual pieces of equipment and entire floors within buildings



- Isolation involves *detuning* from the fundamental period of the primary structure (PS)
- Isolation systems have limited displacement capacities [2]

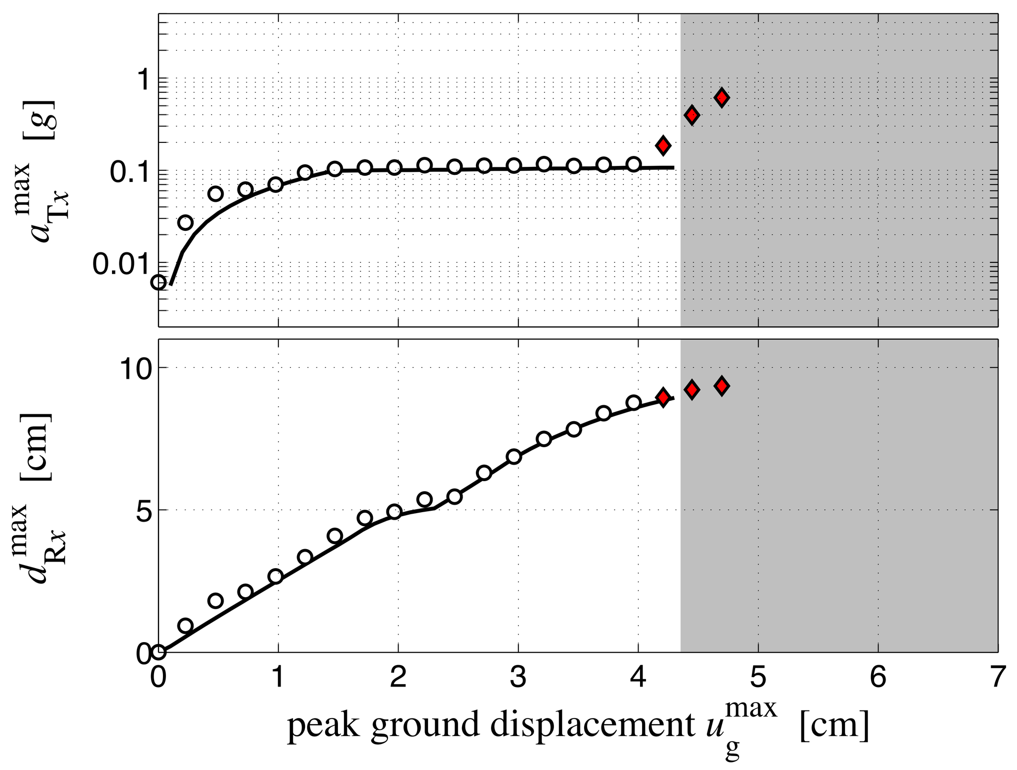


Figure 1: Measured (markers) and predicted (line) peak acceleration a_{Tx}^{max} and displacement responses d_{Rx}^{max} versus peak ground displacement for f_g = 1.25 Hz. Responses exhibit regions of (I) good isolation performance, $a_{Tz}^{max} \le 0.1g$ (∘); (II) impacts $a_{Tz}^{max} \gg 0.1g$ (⋄). [3]

Dynamic Vibration Absorber

- Floor isolation systems (FISs) can be designed to behave as dynamic vibration absorbers (or tuned mass dampers) to reduce the response (drift) of the primary structure [4]
- The FIS is *tuned* to the primary structure's natural period [5], **negating the isolation performance of the system**
- *Nonlinear energy sinks* transfer energy from lower modes to higher modes of the system
- The seismic mitigation performance of *vibro-impact dampers* may be be superior to their linear counterparts [6]

Abstract

Vibration-sensitive equipment within buildings may be susceptible to damage from harsh floor motions transmitted from the primary structure due to strong ground motions. Isolation devices are capable protecting fragile equipment from seismic hazards by decoupling individual pieces of equipment or entire floor slabs. A practical limitation associated with equipment isolation is that these systems have limited displacement capacity, which if exceeded lead to impacts degrading performance. However, even the most effective isolation systems are incapable of protecting equipment from building collapse. This study investigates the use of floor isolation systems (FISs) as multi-functional structural units to mitigate both equipment accelerations and structure responses to achieve desired building-system performance. These multi-functional FISs not only serve their traditional purpose (equipment isolation), but they are also engaged to protect the primary structure under extreme earthquake loads by passively adapting to function as nonlinear dynamic vibration absorbers. In so doing, this concept bridges the gap between equipment isolation and vibration absorption, yielding a novel adaptive passive seismic protective technique. Simulation results indicate that multi-functional FIS can reduce equipment accelerations for small to moderate earthquakes, as well as deflections (drifts) of the primary building over a range of disturbance intensities. Overall, multi-functional FISs are shown to enhance building-system resilience over a broad range of seismic hazard levels.

Multi-functional Floor Isolation System

Primary Structure (PS)

- Primary structures considered in this study (right) are steel moment-resisting frame buildings [7]
- Natural frequencies for frames considered are

Structure		Natural frequencies [Hz] f_1	f_2	f_3	f_4
4-story	flexible	0.81	2.59	4.54	5.80
	rigid	1.37	4.50	7.82	9.93
8-story	flexible	0.52	1.45	2.42	3.40
	rigid	0.85	2.25	3.89	5.40

Floor Isolation System (FIS)

- An FIS is to be installed on the j^{th} floor, isolating a portion of the floor mass m
- The FIS has displacement capacity d_c
- *Critical peak ground acceleration* PGA_c is the GM intensity capable of producing an impact
- Non-dimensional parameters:

$$\mu = m_{FIS} \div m \qquad (\textit{mass ratio})$$
$$\eta = f_{FIS} \div f_1 \qquad (\textit{freqeuency ratio})$$

Model of Impacts

Coefficient of restitution: $r = \dfrac{\dot{u}_{FIS}^{+} - \dot{u}_j^{+}}{\dot{u}_j^{-} - \dot{u}_{FIS}^{-}}$

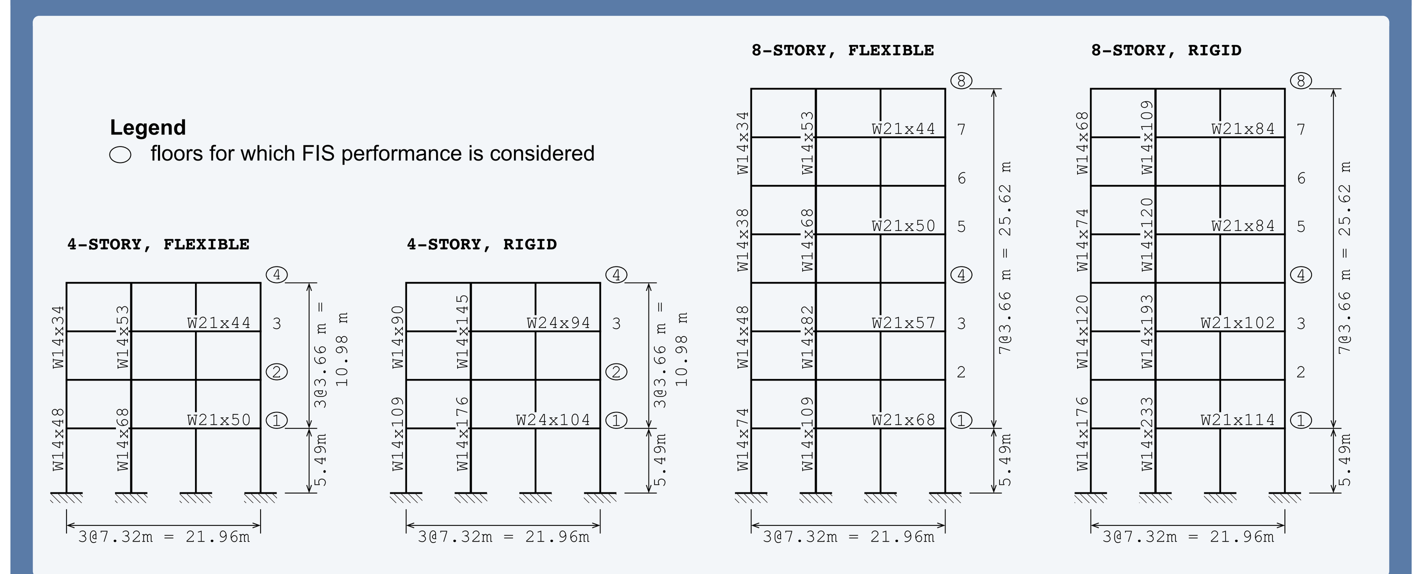
Conservation of momentum:

$$(1-\mu)\,\dot{u}_j^{-} + \mu\,\dot{u}_{FIS}^{-} = (1-\mu)\,\dot{u}_j^{+} + \mu\,\dot{u}_{FIS}^{+}$$

Performance Objective

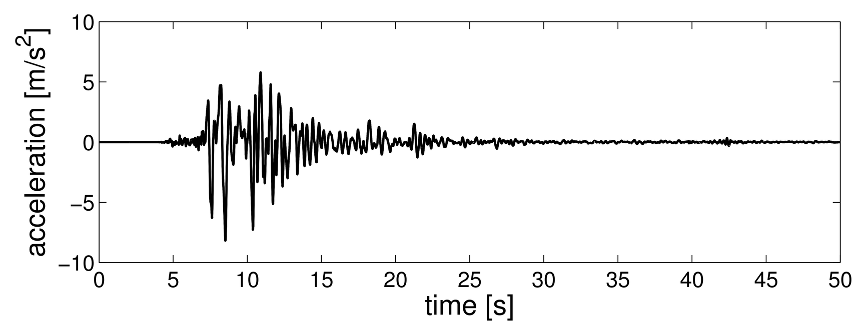
Protect the building contents (vital equipment) from harsh floor accelerations at low intensity events ($PGA \div PGA_c < 1$) and to protect the PS from collapse (reduce story drifts) at high intensity events ($PGA \div PGA_c > 1$), constituting an *adaptive passive seismic protective technique*.

Primary Building Structures Considered



Seismic Response Analysis

- Response considered for N-S component recorded at the KJMA station during the Hyogo-ken Nanbu earthquake, 17 January 1995



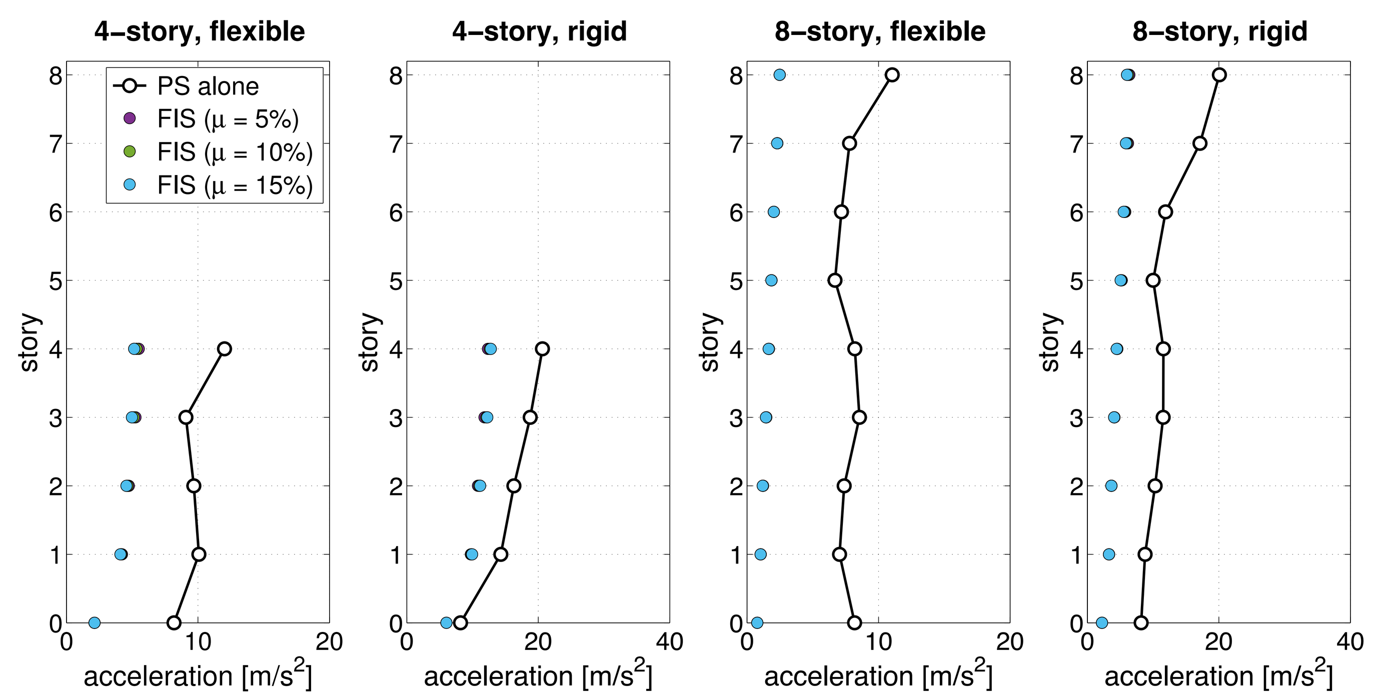


Figure 2: Peak accelerations sustained by equipment installed at various locations in the four structures without isolation ('PS alone') and on a floor isolation system (FIS) with varying mass ratio μ, without impacts.

Results and Discussion

Story drift evaluation criterion

$$\text{story drift measure} = \frac{\max_{i=1,2,\ldots,n} \|\delta_i(t)\|}{\Delta_{PS}^{max}}$$

where δ_i = inter-story drift ratio and Δ_{PS}^{max} = maximum L_2-normed inter-story drift ratio of the primary structure alone, i.e., *without* an FIS installed

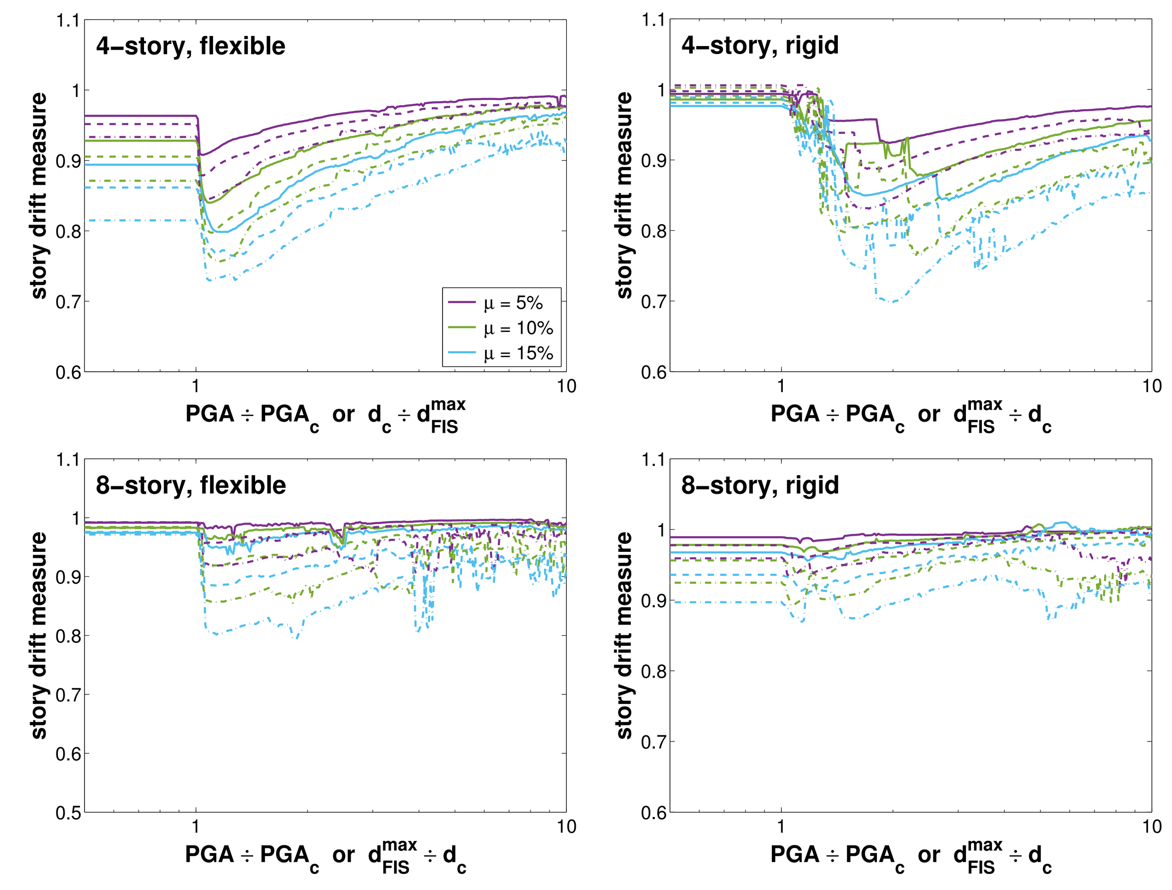


Figure 3: Story drift measure versus ground-motion intensity for FISs of varying mass ratio μ installed at the first story (—), mid-height (– – –), and roof (– · –).

- ✓ Reduced equipment accelerations for weak GMs: $PGA \div PGA_c < 1$ (Fig. 2)
- ✓ Reduced story drifts for strong GMs: $PGA \div PGA_c > 1$ (Fig. 3)
- ✗ Less effective for low mass ratios, taller structures

Acknowledgements

Partial support for travel and registration from the National Science Foundation (14-46424/14-46353) is gratefully acknowledged. The research was partially supported by the School of Civil Engineering and Environmental Science at the University of Oklahoma.

References

[1] D Konstantinidis and F Nikfar. Seismic response of sliding equipment and contents in base-isolated buildings subjected to broadband ground motions. *Earthq Eng Struct D*, 44(6):865–887, 2015.

[2] P S Harvey, Jr., G-P Zéhil, and H P Gavin. Experimental validation of simplified models for rolling isolation systems. *Earthq Eng Struct D*, 43:1067–1088, 2014.

[3] P S Harvey, Jr. Vertical accelerations in rolling isolation systems: Experiments and simulations. *J Eng Mech-ASCE*, page 04015091, 2015.

[4] E Matta and A De Stefano. Robust design of mass-uncertain rolling-pendulum TMDs for the seismic protection of buildings. *Mech Syst Signal Pr*, 23:127–147, 2009.

[5] J P Den Hartog. *Mechanical Vibration*. Dover, 1985.

[6] F Nucera et al. Targeted energy ttransfer in vibro-impact oscillator for seismic mitigation. *Nonlinear Dynamics*, 50, 651–677 2007.

[7] R P Santa-Ana and E Miranda. Strength reduction factors for multi-degree-of-freedom systems. In *Proc. 12th World Conf. on Earthquake Engineering*, Auckland, New Zealand, 2000.