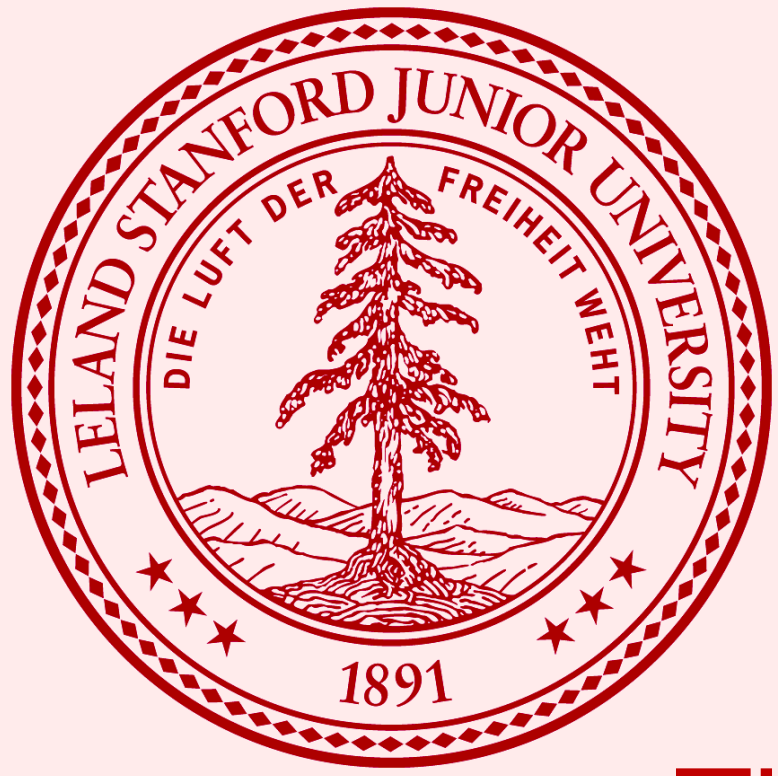


EFFECTS OF TORSION IN SLIDING-ISOLATED LIGHT FRAME STRUCTURES



PEER Internship Program – Summer 2013
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SACRAMENTO STATE

The John A. Blume Earthquake Engineering Center, Stanford University

1. Motivation & Background

The 1994 Northridge Earthquake displaced 60,000 people and caused over \$20 billion in total economic losses as a result of damages to residential structures. It therefore stands evident that given events like the 1994 Northridge Earthquake, the seismic resilience of conventional light-frame buildings needs to be improved on the large-scale in order to prevent such severe yet avoidable consequences from occurring. To do so, Stanford University and Sacramento State University are working together to develop an effective and, most importantly, affordable earthquake resistant system for mass-market implementation in order to create truly damage free housing. This system consists of two approaches: (1) combining structural and non-structural components together so that the building responds as a “unibody” to increase lateral stiffness; (2) developing a cheap sliding base isolation system to reduce base shear. This particular project investigates the possible consequences that can arise in the second approach, sliding base isolation.

In order to keep the system affordable, the size of the sliding interfaces themselves need to be kept minimal and the materials being used affordable. Therefore, the frictional properties of the material-steel interface become paramount in reducing cost. Considering different polymers for the material face due to their low cost, versatility and availability, polymers in general exhibit viscoelastic behavior to a pronounced degree. This in turn gives rise to various factors such as time, pressure, velocity and temperature each of which can influence the frictional properties of the sliding interface.

Pressure dependence in particular can be an important factor since it creates a non-uniform distribution of friction coefficients across the base isolators. This then causes an eccentricity between the center of mass and center of stiffness which provides the necessary conditions for torsion. Not only can torsion cause severe structural damage, but it can also lead to additional sliding displacement, which increases the necessary size of the sliding interfaces at each isolator. Cost-wise, that is not desirable. Cases for torsion therefore require investigation especially in this untouched context: low-pressure sliding isolators for housing.



2. Objectives

- Investigate the effects of torsion in light-frame construction using pressure dependent friction-based sliding isolators operating at low pressures around 500 psi.
- Compare the results to non-pressure dependent friction-based isolators to reveal the additional amount of sliding displacement induced by torsion when using a pressure dependent material
- Research the benefits of using dish sliding isolators as opposed to flat sliding isolators in terms of peak displacement during shaking, residual displacement after shaking, and additional torsional displacement caused by pressure dependent friction.

3. Methods

Testing will be done in OpenSees using (1) the VelDependent friction model and high torsional stiffness flatSliderBearing parameter value to simulate non-pressure dependent sliding friction and (2) the VelPressureDep friction model and low torsional stiffness parameter value to simulate highly pressure dependent sliding friction at low pressures ($\mu=0.25$ at 250 psi and $\mu=0.20$ at 500 psi). Comparing these two models over 80 GMs scaled to MCE, various studies to investigate whether pressure dependent friction induces additional torsional displacement in the structure:

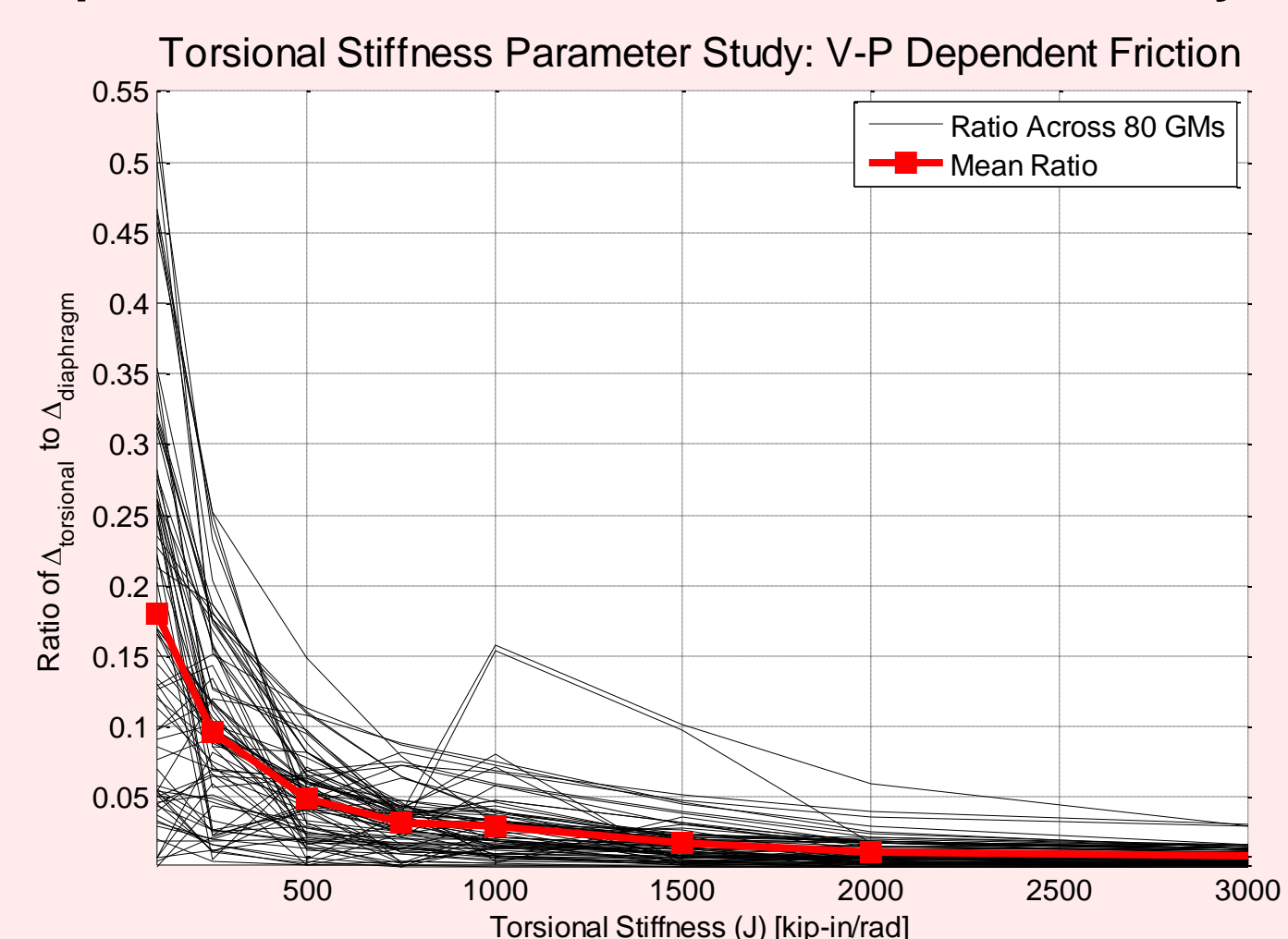
- OpenSees torsional stiffness parameter study
- Case for torsion under a real load distribution
- Case for torsion under an exaggerated COS-COM separation
- Case for torsion when a sliding isolator locks or sticks
- Flat vs. Dish sliding isolator study



4. Results

Shown in this section will be the results of the OpenSees flatSliderBearing element Torsional Stiffness Parameter Study and the results of the Real Load Distribution Torsion Case Study.

OpenSees Torsional Stiffness Parameter Study:

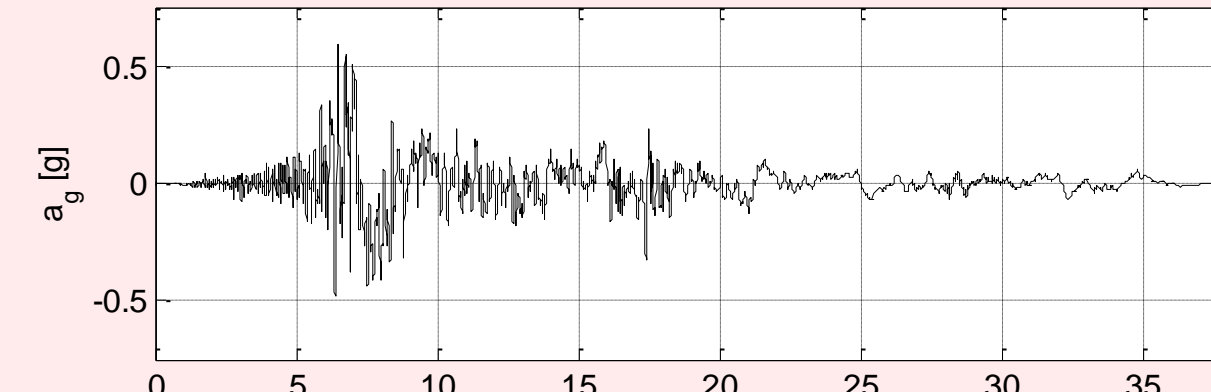


Mean Ratio of $\Delta_{torsional}$ to $\Delta_{diaphragm}$ at $J = 100$ kip-in/rad is 0.1800.

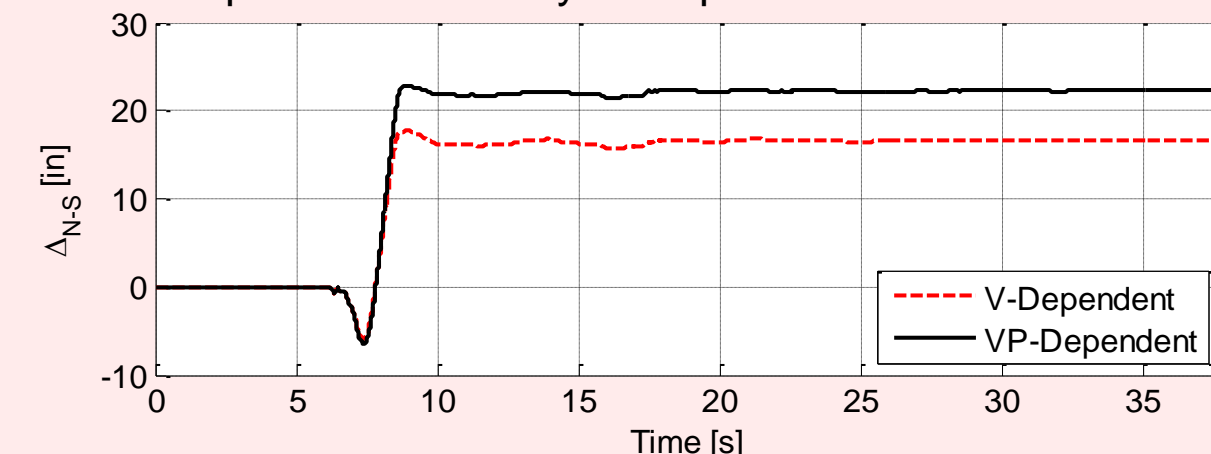
Median Ratio of $\Delta_{torsional}$ to $\Delta_{diaphragm}$ at $J = 100$ kip-in/rad is 0.1659.

Low J will be used for the Velocity and Pressure Dependent Model and High J will be used for the Velocity (non-pressure) Dependent Model

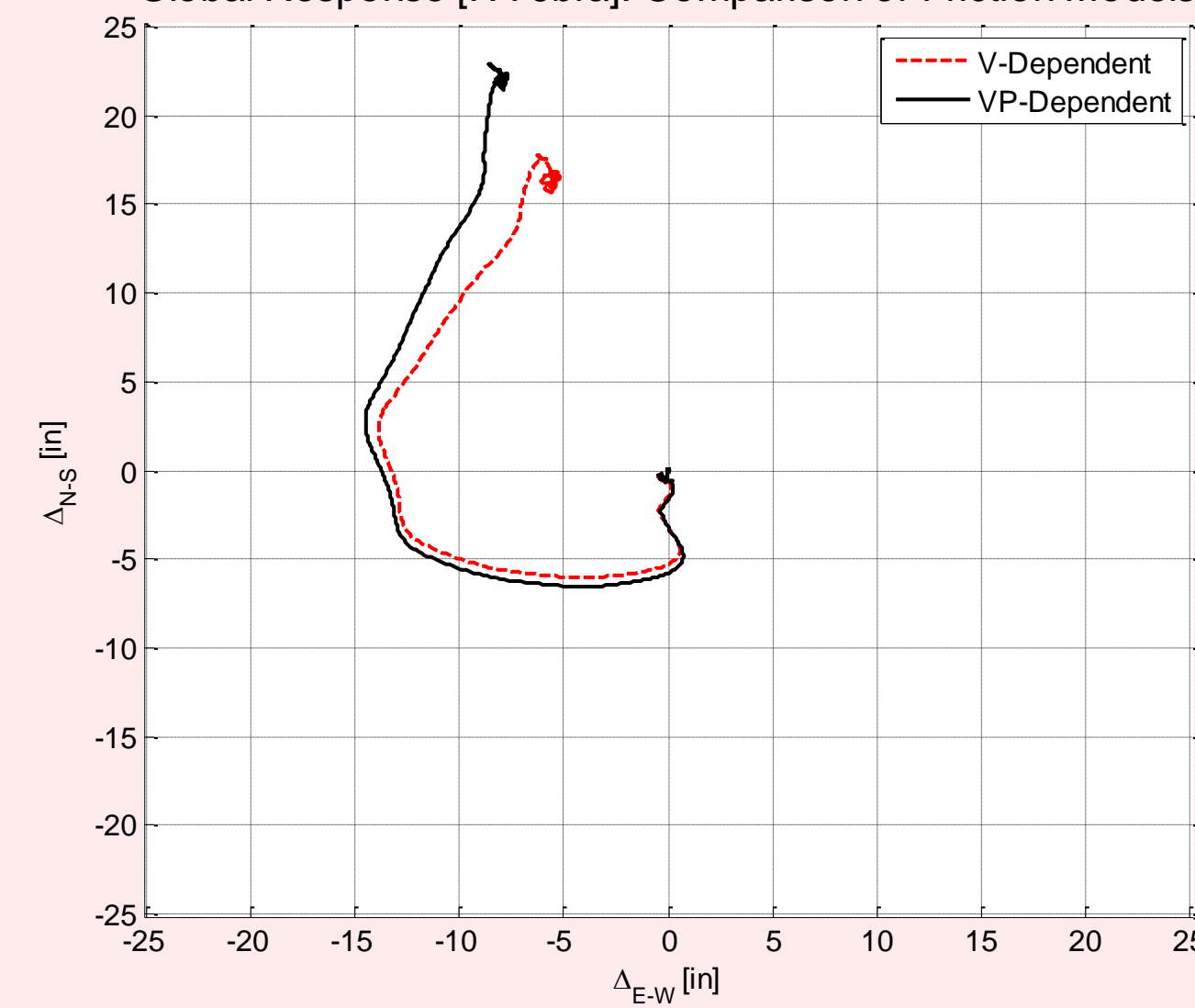
Acceleration Series for GM [IV79bra]: N-S Direction



Displacement History: Comparison of Friction Models



Global Response [IV79bra]: Comparison of Friction Models



Real Load Distribution Study:

Load Distribution acquired from given line and area loads. The separation between the center of stiffness and center of mass in this scenario is 8.28” (a minimal distance relative to 456”x288” dimensions of the isolation diaphragm).

Across 80 GMs:

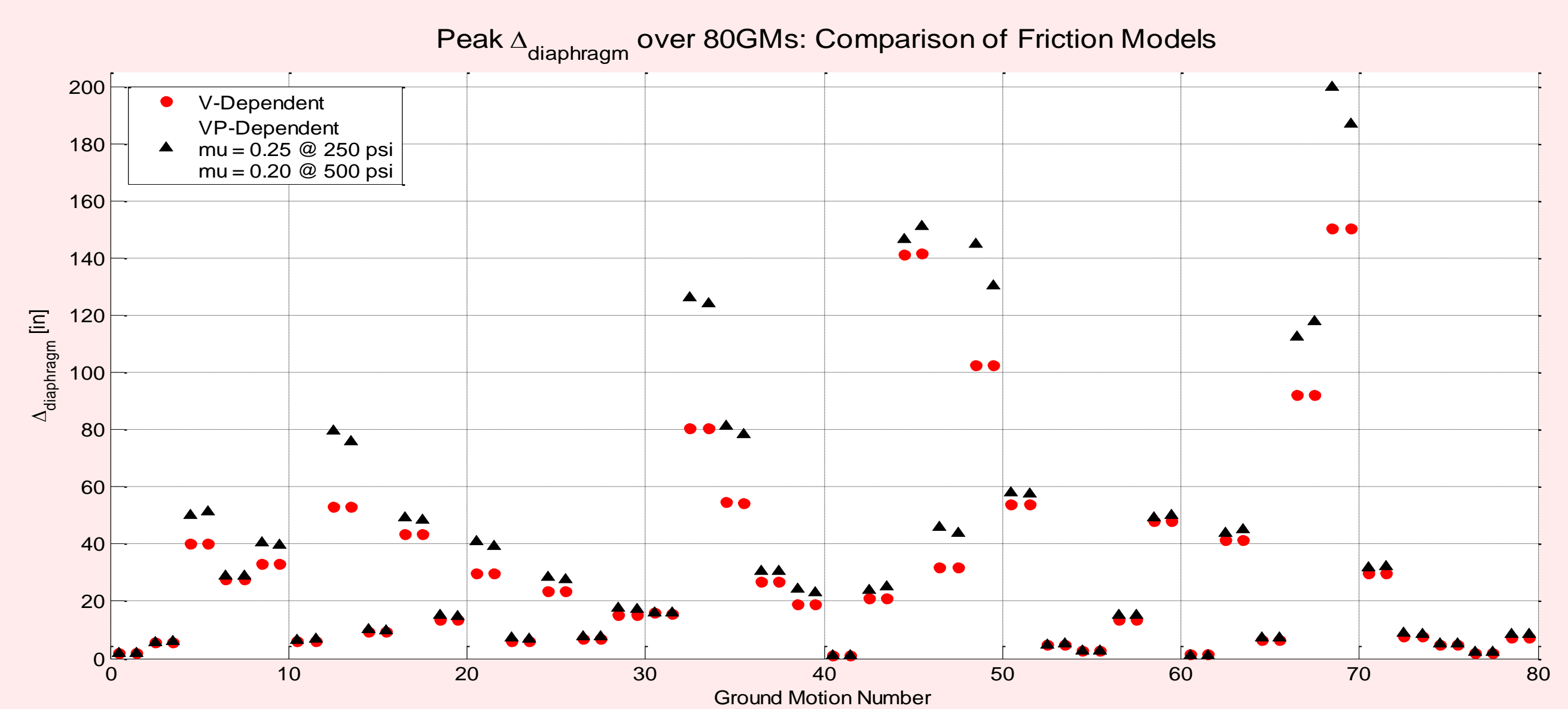
Mean and Median Peak $\Delta_{diaphragm}$ of V-Dependent Friction Model are 32.20” and 20.57” respectively.

Mean and Median Peak $\Delta_{diaphragm}$ of VP-Dependent Model are 39.17” and 24.15” respectively.

Mean and Median Additional $\Delta_{torsional}$ [measured at $\Delta_{VP-Dep} - \Delta_{V-Dep}$] are 6.96” and 1.76” respectively.

Across GMs yielding $\Delta_{diaphragm}$ of 10”-20”:

Mean and Median Additional $\Delta_{torsional}$ are 1.88” and 1.38” respectively.



5. Conclusions

- The OpenSees torsional stiffness parameter for the flatSliderBearing element has significant influence over the amount of torsional displacement seen throughout the studies. How much realistic torsion occurs depends on the appropriate value for that parameter.
- Significant separation between the center of stiffness and center of mass did not correlate strongly with the extent of additional torsional displacement seen between the two OpenSees friction models.
- Pressure dependence may not have a large influence on torsion, so additional sources of torsion need to be investigated.
- Dish sliding isolators yield smaller peak, residual (near zero), and torsional displacements than the flat sliding isolators.
- Using a high friction material is still a higher priority than using a material that eliminates torsion regarding system affordability since larger amounts of displacement can be reduced via higher friction versus eliminating $\Delta_{torsional}$.

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Constantinou, M. C., John Caccese, and Harry G. Harris. "Frictional characteristics of Teflon-steel interfaces under dynamic conditions." *Earthquake engineering & structural dynamics* 15.6 (1987): 751-759.
Jampole, Ezra. "Damage Reduction in Light-Frame Structures through Seismic Isolation." Blume Seminar Series. Stanford University, Stanford, CA. 6 Sep. 2012.
Kircher, Charles A., et al. "Estimation of earthquake losses to buildings." *Earthquake spectra* 13.4 (1997): 703-720.
Takahashi, Yoshikazu, et al. "Shaking table test for frictional isolated bridges and tribological numerical model of frictional isolator." *Proceeding of thirteenth world conference on earthquake engineering, Vancouver, Canada*. 2004.



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