DOI	https://doi.org/10.1061/(ASCE)ST.1943-541X.0001352
Title	Influence of Vertical Ground Shaking on Horizontal Response of Seismically Isolated Buildings with Friction Bearings
	Background
Why this paper? How'd you find it?	This paper revealed the Horizontal-Vertical coupling phenomenon in friction pendulum base-isolated buildings. I wanted to introduce this because it is one of the first full-scale experimental studies to prove this phenomenon. Considering the advancements in Performance-based Earthquake Engineering, this study showed that structural response not only in the vertical direction but also in the horizontal direction might be influenced by the 3D ground motions. It was the core concept of my previous research, so I'd like to share it with the Journal Club.
Study Objective	Improve the performance objectives for buildings isolated with friction bearings
Intended gaps to fill	Showing the coupling effects through experiment and these effects are predictable under certain modeling approaches
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Journal / Field	ASCE Journal of Structural Engineering
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Historical Context	Zayas et al. (1987) experimentally investigated vertical excitation in a single-story structure with single friction bearings. Mosqueda et al. (2004) studied the vertical component of ground motions in an experiment of a rigid frame model with single friction pendulum bearings. Fenz and Constantinou (2008) and Morgan and Mahin (2011) also conducted similar tests. In these experiments, the authors reported little/no significant influence.
Relationship to SEMM	CE 225, CE 223
	Methods
Given:	Experimental, analytical, and numerical structure equipped with friction-type bearings subjected to horizontal-only and 3D ground motions
Find:	Bearing displacements, total base shear (Fig. 4) and floor acceleration (Fig. 5)
Experimental Design	**1. Experimental:** Apply horizontal-only and 3D ground motions to a full-scale 5-story steel moment frame building (Fig.1) equipped with friction bearings and record the responses **2. Analytical: 3. Numerical:** To predict the coupling effect **i)** the isolation system model explicitly accounts for the influence of axial force on the isolator shear force **ii)** the structural system model accounts for composite stiffness of the beams and floor slabs (not a bare frame model) **iii)** damping to higher structural modes is assigned at appropriately low levels (2–3% for a steel frame building) reflecting response in the linear elastic range.
Test Subjects	Full-scale 5-story steel moment frame building with triple friction pendulum bearings
	Results
Baseline for comparison	Experimental data from the full scale building
Metric for comparison	Floor acceleration
Difference from baseline	Capturing the global behavior relatively well
	Conclusions
Authors'	Isolated buildings are frequently designed with the objective of keeping the building operational after the earthquake and/or protecting sensitive equipment. Because nonstructural components and equipment are sensitive to horizontal accelerations, the coupling phenomenon might, in some cases jeopardize the ability of the isolated building to meet its performance objectives
Yours	In this extensive experimental study, I find the influence of vertical excitations on the horizontal direction quite intriguing. Predicting this phenomenon for simple structures is easily achievable through fundamental physics knowledge. Under 3D ground motions, the vertical component produces high-frequency spikes in the base shear, leading to the excitation of higher modes in the superstructure. Nevertheless, as demonstrated by Huy in Kumar and Kumar's paper (2021) in the Journal Club, these higher modes are significantly affected by the damping model. To address this concern, the authors of this paper made adjustments to the damping models to accurately represent the test data. When all damping models were applied under horizontal-only excitation, the numerical structure produced relatively consistent results, matching the test outcomes. However, the story took a different turn under 3D excitations, as the numerical models with various damping methods deviated from the experimental data. Thus, once again, the proper choice of the damping model emerges as a critical factor in considering the effects of higher modes in base-isolated structures.
Applications	Modeling and analyzing structures with friction bearings for higher performance objectives

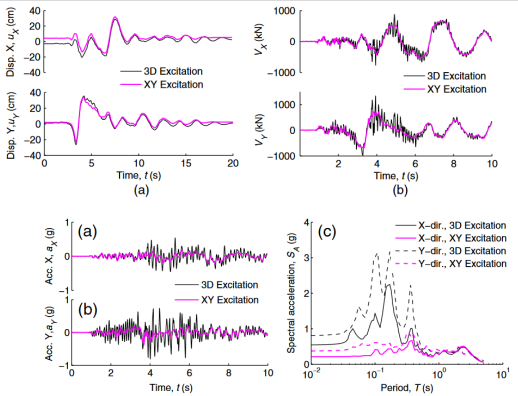

Fig. 5. (a and b) Acceleration histories; (c) response spectra of the accelerations in X and Y directions recorded at the roof due to 88 RRS: XY versus 3D excitation

Fig. 1. Five-story steel moment frame testbed set on triple pendulum bearings