Research Project Highlight

Geometrically Exact Nonlinear Modeling of Multi-stage Friction Pendulum Systems

Project # NCTRSG

Principal Investigator
Sanjay Govindjee, Professor of Civil Engineering, UC Berkeley

Research Team
- Paul Drazin, Graduate Student Researcher, UC Berkeley

Start-End Dates:
7/1/2016-6/30/2017

Abstract

The primary goal of this project is to improve the analytical and numerical modeling of multi-stage friction pendulum systems (MSFPs). Single, double, and triple friction pendulums have been proposed as seismic isolation devices for a wide range of structural and non-structural systems. However, no current model for MSFPs utilizes a rigorous setup for the kinematics of the internal sliders; they start directly with scalar equations. The rigorous use of vectors to describe the kinematics of the internal sliders will help to clarify the overall motion of MSFPs. This will also aid in the setup of the kinetics of the MSFPs, with no linearization assumption, as well as facilitating the modeling of multi-directional motion. The model to be developed will incorporate full vectorially-described motion with trajectories constrained to the configuration manifold as defined by mathematically precise constraints. Constructing the model in this way directly facilitates a number of modeling advances and can naturally lead to robust numerical approximations. The advantages of the proposed model will be (1) it will be a geometrically fully nonlinear model; (2) it will be able to naturally handle multi-directional motions, including complex rotary motions on the sliding surfaces, uplift, top and bottom plate rotations, etc.; (3) by construction, it will be fully dynamic and permit the modeling of multi-surface sliding during shock-like loading situations; and (4) it will be modular and permit the use of advanced friction models. The first stage of this project is to apply the vectorized motion to that of the friction triple pendulum (FTP) system, a type of MSFP, as a benchmark for the new model, as shown in the *Project Images.* The motion of each slider is described via a set of Euler angles with respect to the previous slider. This easily allows for expansion to other, more complicated MSFP systems.

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Deliverables

A PEER report and conference and journal papers describing the geometrically exact MSFP model, the testing of the model against existing experimental data, and explaining the importance of various modeling assumptions used previously for MSFP models, plus numerical source code.

Research Impact

California is at a constant risk of a major earthquake, and the proper usage of seismic isolators, such as MSFPs, can drastically reduce the damage sustained to buildings, bridges, etc. due to a seismic event. For this reason, well-functioning models of MSFPs are of importance to make sure that structures are properly isolated in the event of an earthquake. However, current models lack the ability to properly predict isolator response under seismic excitation, which can potentially lead to more physical damage to a structure than was predicted by the model. The proposed developments are designed to directly replace and enhance currently available models for performing design computations on MSFP isolated structural systems. Enhancements are envisaged with respect to both modeling fidelity as well as the robustness of the models within the context of time history analysis systems. These enhanced models are foreseen to help reduce the damage and downtime of structures during post-earthquake recovery. The proposed model will also lead to cost and time savings, since there will be less need to physically test either full-scale or scaled-down MSFPs in a laboratory setting to get accurate results. There is also potential impact for isolating systems other than standard civil structures. Certain machine tools and instruments need to be seismically isolated for proper use, and a more effective and efficient model will make it easier for MSFPs to be developed for these non-structural situations.

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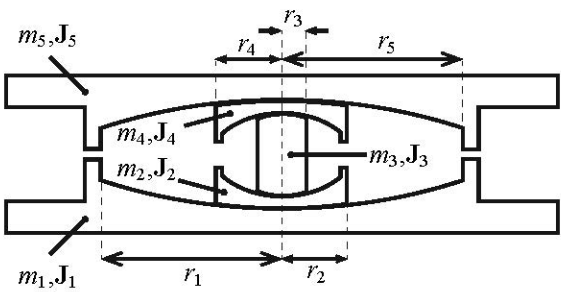
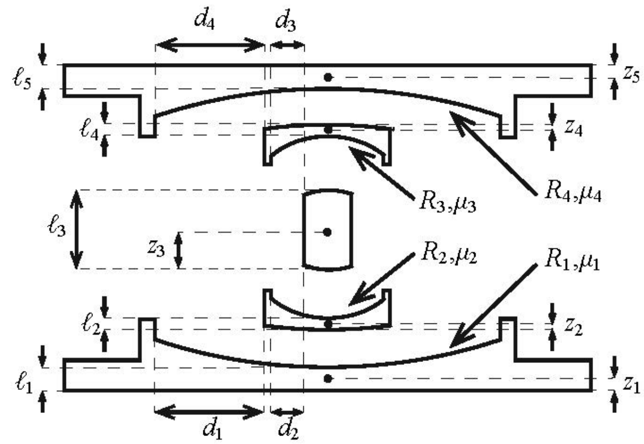
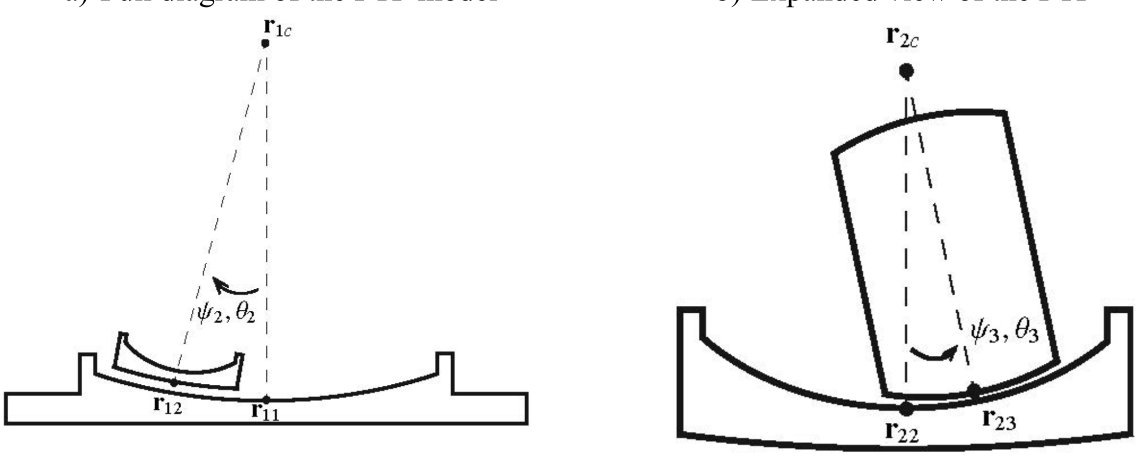
Project Images



a) Full diagram of the FTP model



b) Expanded view of the FTP



c) Views of the individual sliders showing the vectors and angles used to describe the kinematics

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