Design and Analysis Issues for Base Isolated Structures

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A Brief Introductory Remark

The sophistication of the analytical procedures presented here are not unique to base isolated structures. A conventional system designed to the implicit performance objectives of an isolated structure would ideally be subjected to the same level of rigor.

In the future, the effort required for structural analysis and design of a facility should be a function of the owner-specified performance objectives and not of the selected lateral system.

Outline of Presentation

• Summary of this Outline	1 min
• Available Methods of Analysis	4 min
• Useful Models for Isolation Devices	3 min
• Isolator Uplift: Modeling and Consequences	2 min
• Estimation of Peak Isolator Demands	3 min
• Dampers in the Basement	3 min
• Development of Floor Spectra	4 min
	± 20 min

Linear Static Analysis

Inputs: The Code spectra are the necessary inputs for this procedure

Is useful for:

- Preliminary design of isolation system
- Estimation of maximum total displacement (i.e. moat size)
- Strength-based preliminary design of superstructure
- Assessment of potential uplift
- Creating a benchmark for later analysis results

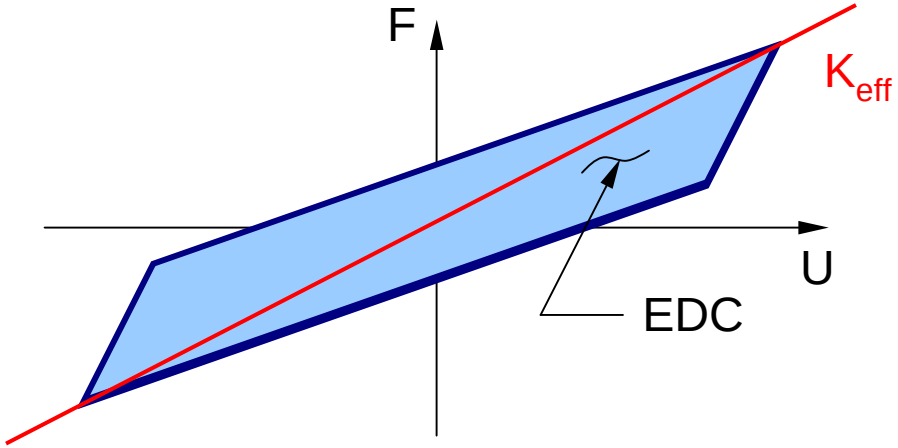
Is *not* useful for:

- Direct creation of floor spectra
- Assessment of magnitude of isolator uplift
- Design of flexible superstructure
- Design of inelastic superstructure

Note:

1. Linearization of isolator properties is necessary

Linearization of Isolator Properties



Linear Dynamic Analysis

Inputs: The Code spectra or site-specific response spectra are the necessary input for this procedure. This spectrum must be modified to account for the expected damping present in the isolation system

Is useful for:

- Design of flexible superstructure
- Generating more realistic story forces (and hence estimates of inter-story drift)

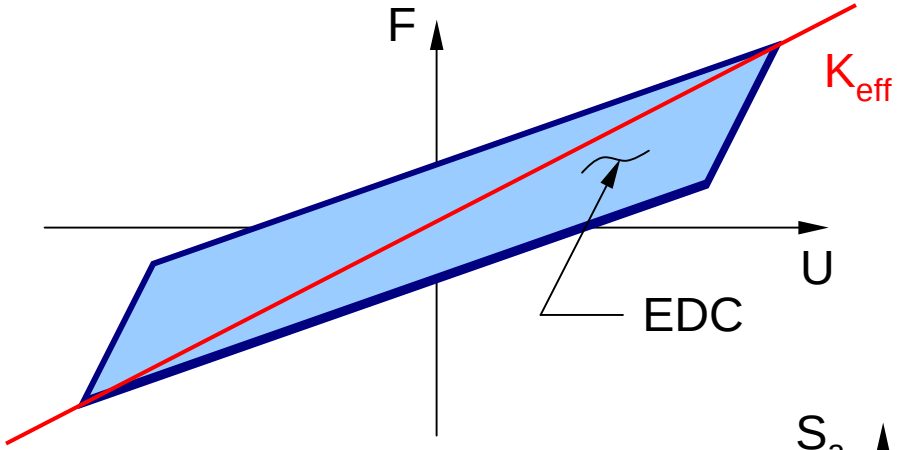
Is *not* useful for:

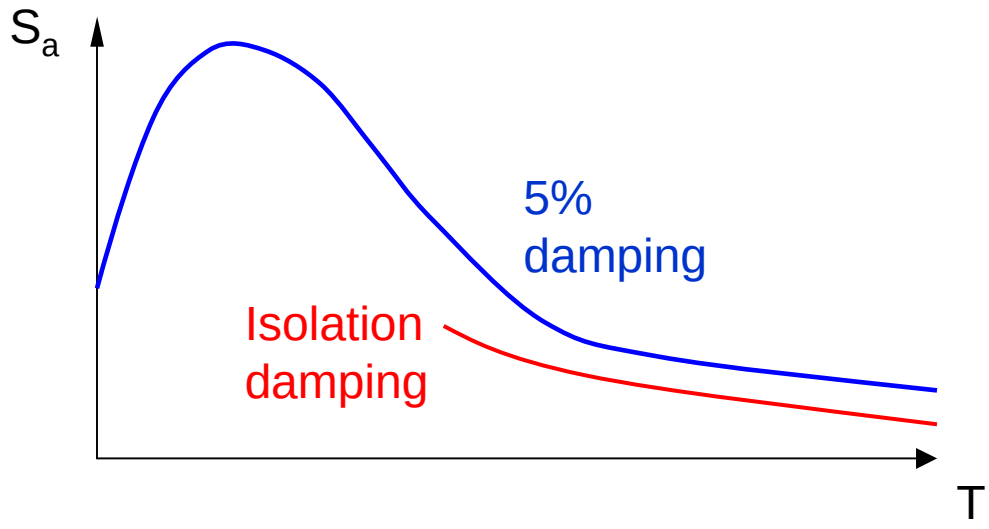
- Direct creation of floor spectra
- Assessment of magnitude of isolator uplift
- Design of inelastic superstructure

Notes:

1. Linearization of isolator properties is necessary
2. For typical period separation, isolator displacement will match LSP

Linearization of Isolator Properties





Non-Linear Dynamic Analysis

Inputs: A suite of acceleration records is the necessary input for this procedure. These records have been processed by a geotechnical consultant such that they are compatible with the site-specific spectra.

Features:

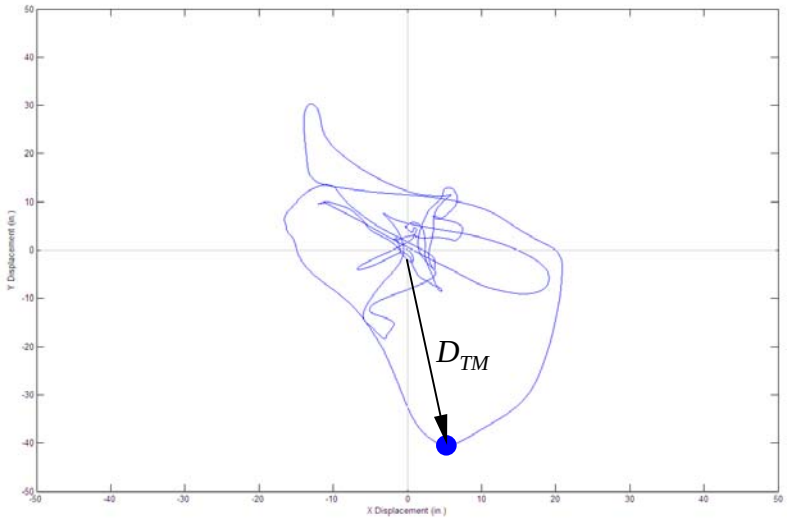
- Will *not* generally lead to significant improvements in the estimation of isolator displacement or inter-story drift compared to those from the LDP.
- Will lead to significant improvements in the estimation of peak floor acceleration.
- Allows the creation of floor spectra for use in the specification of nonstructural anchorage requirements.
- Leads to a meaningful comparison of multiple structural systems by considering drift *and* floor acceleration.
- Allows the estimation of isolator uplift magnitude.

Notes:

1. Modeling of isolators is important
2. The nature of the input gives rise to more subjectivity (and hence lack of robustness) in the characterization of seismic demand

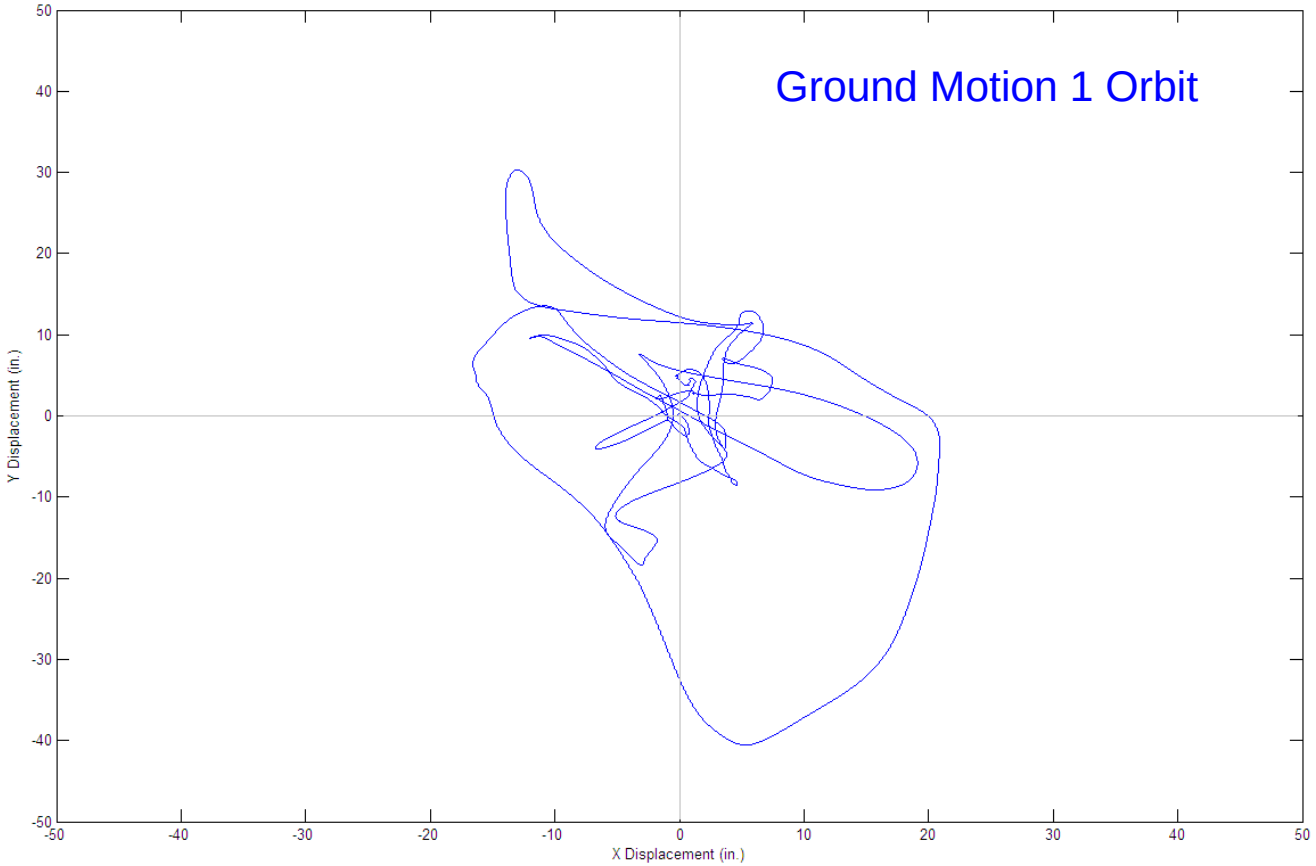
Peak Isolator Displacements

- The estimation of the peak bi-directional displacement of an isolator for a *particular* ground motion pair is straight-forward



- The averaging of a vector displacement over a suite of analyses requires further attention, and motivates the following…

Peak Isolator Displacements



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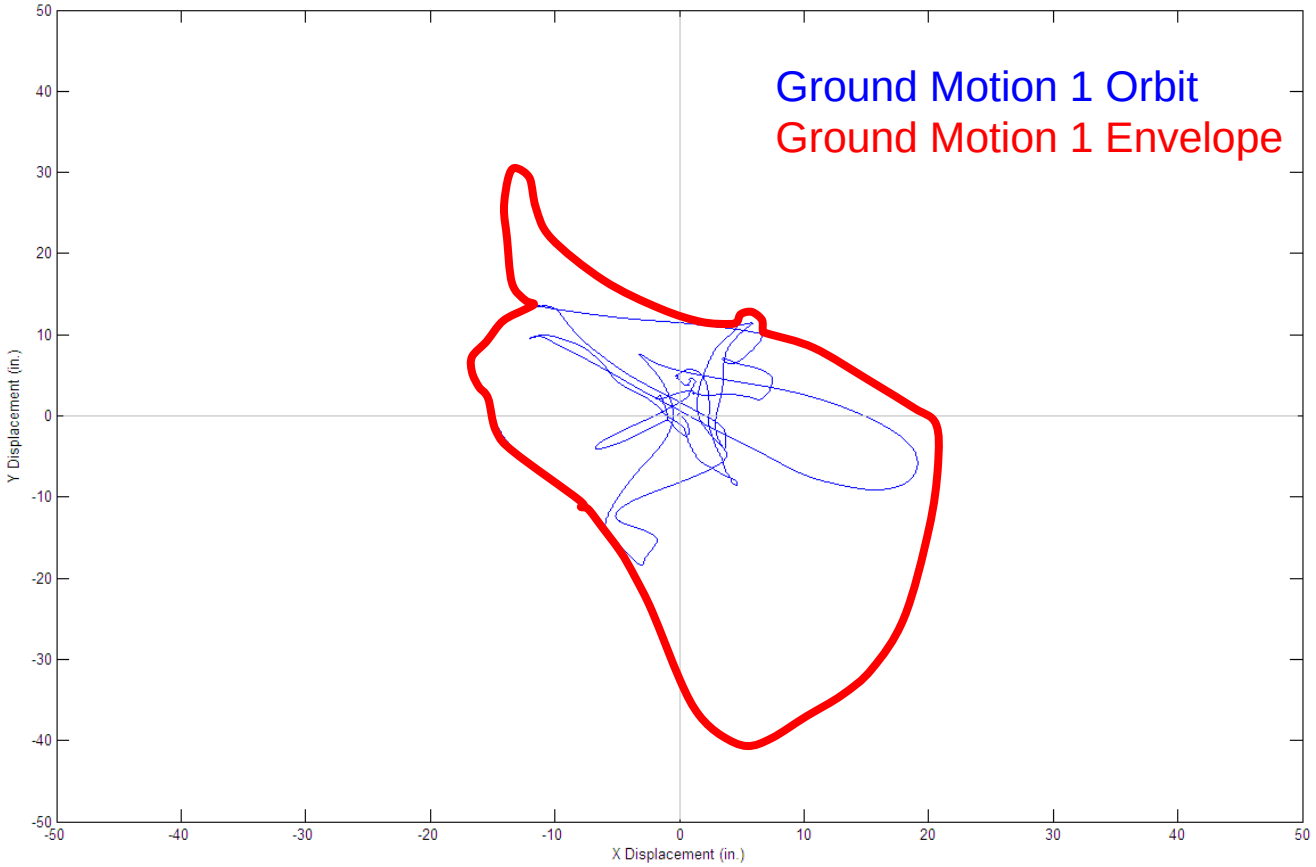

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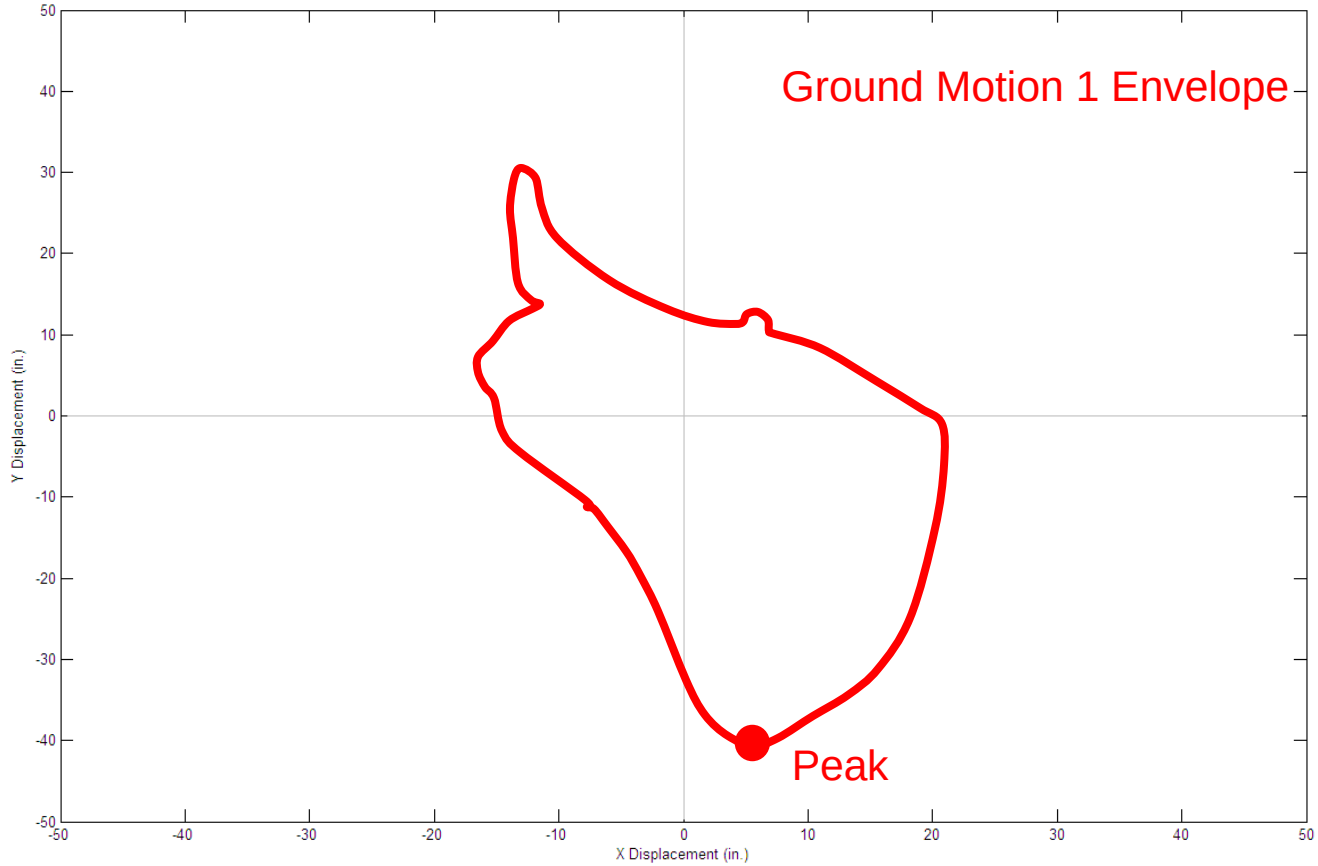

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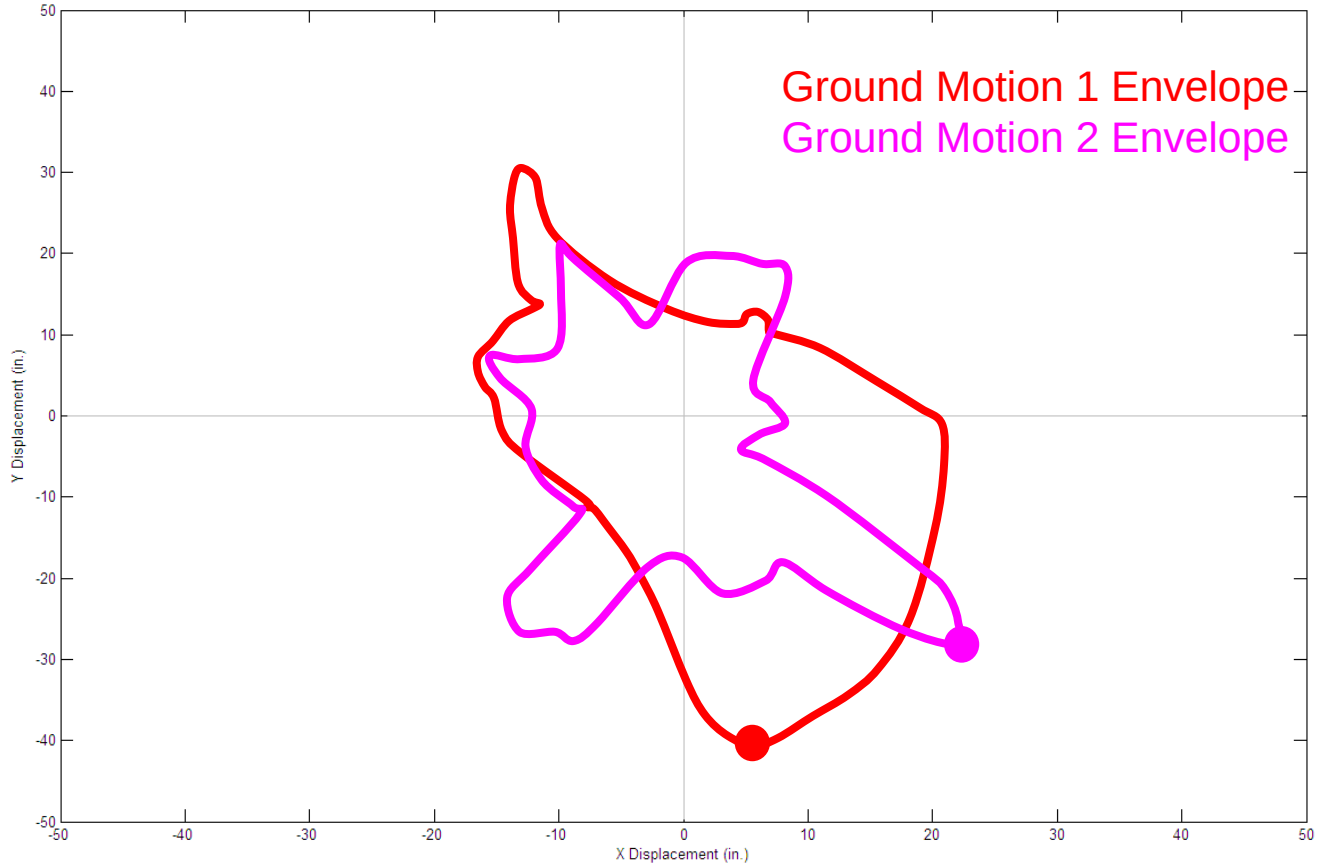

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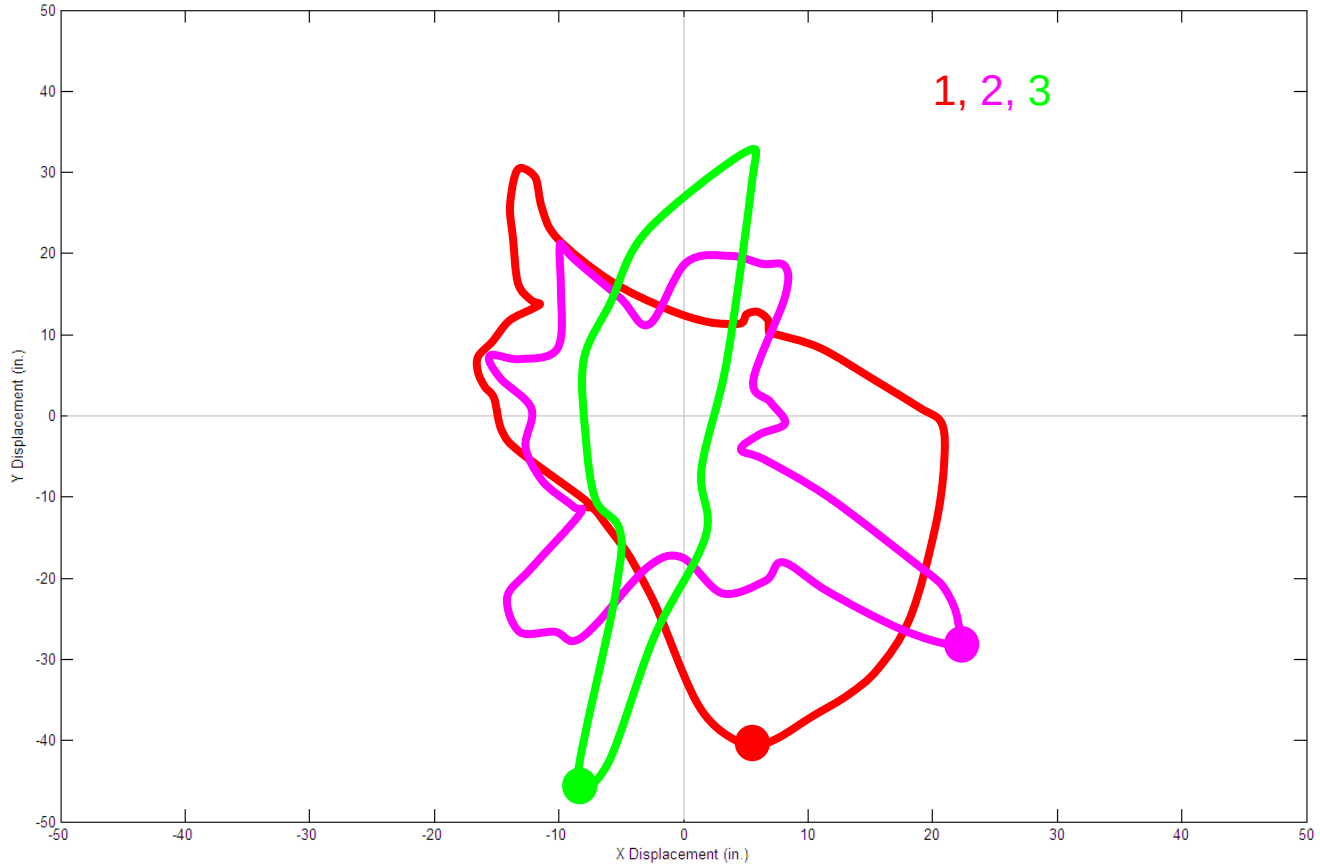

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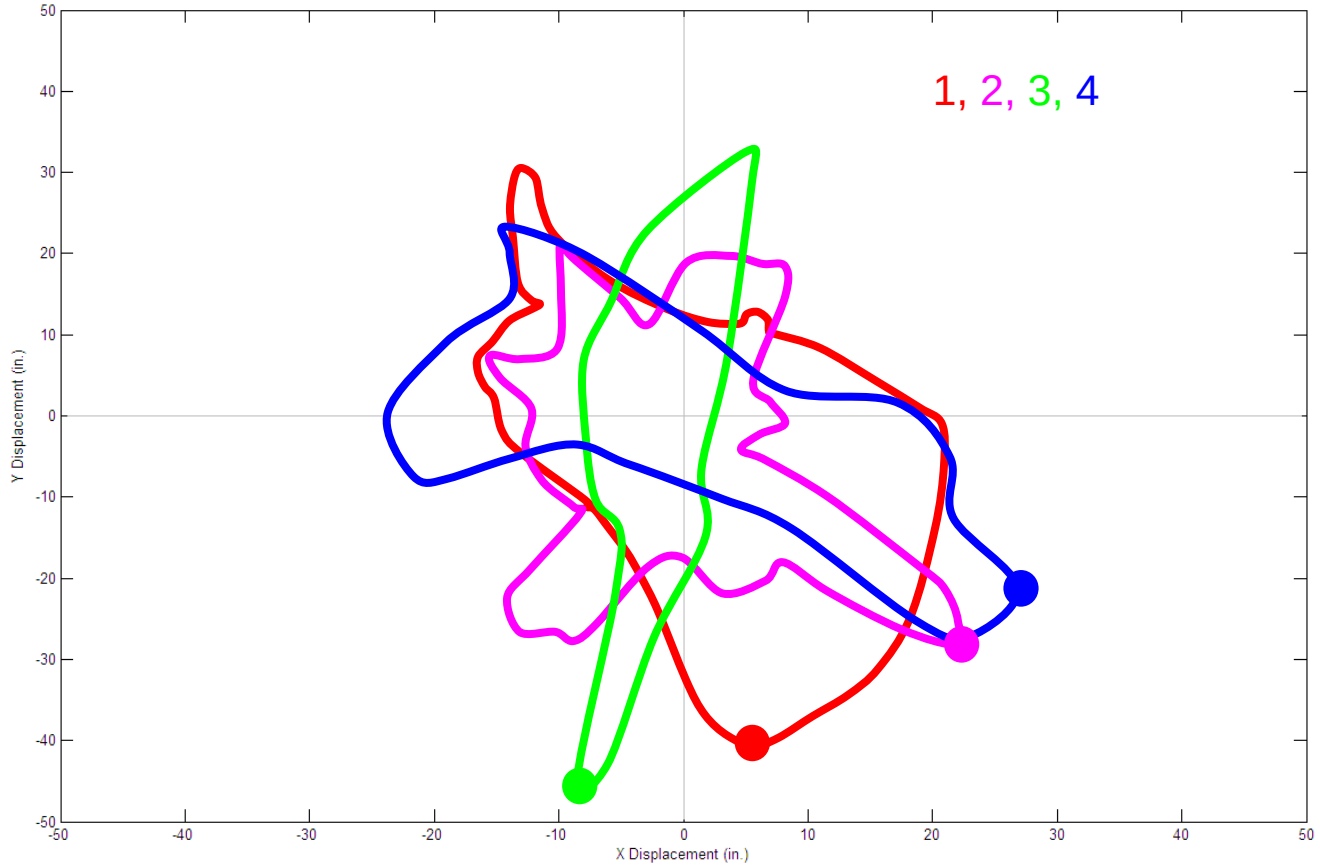

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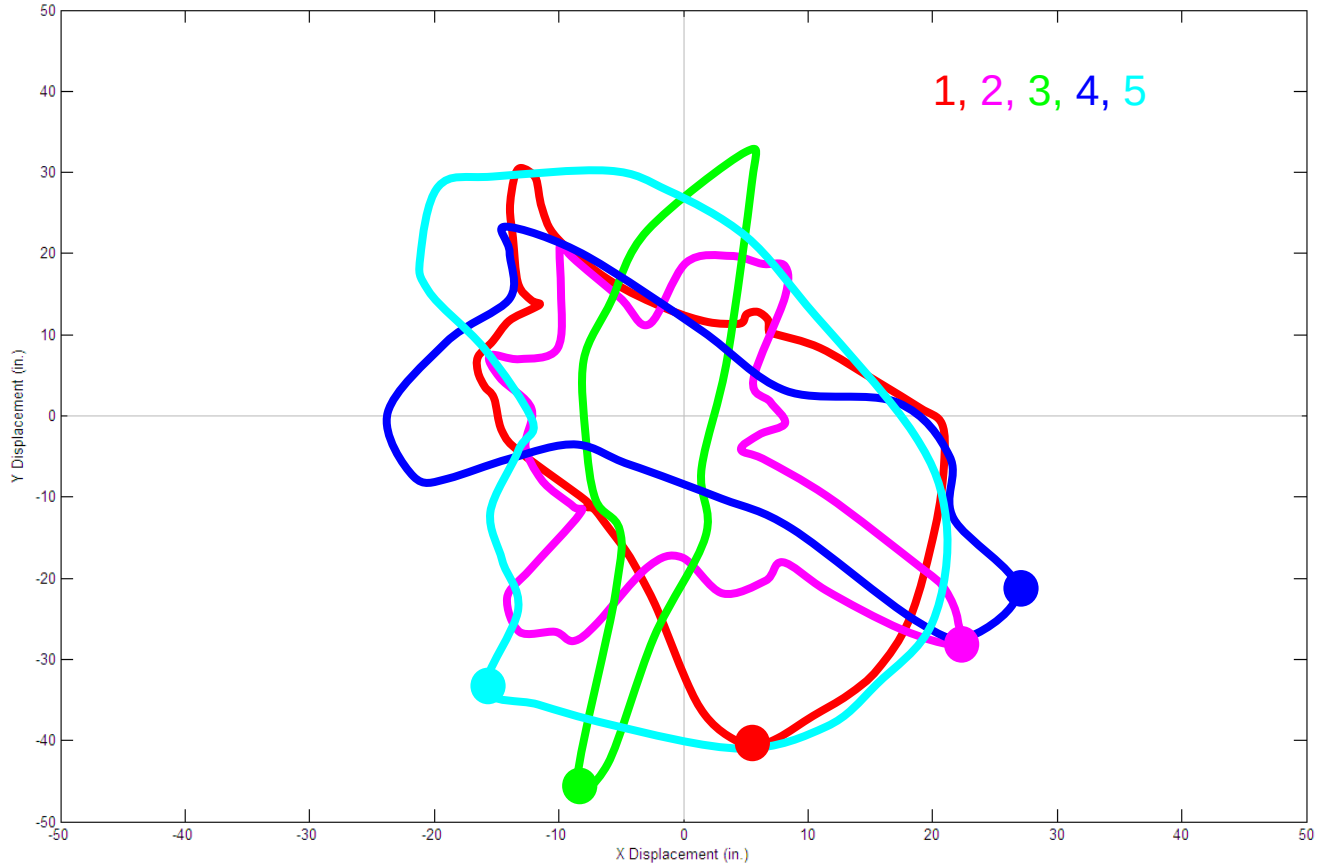

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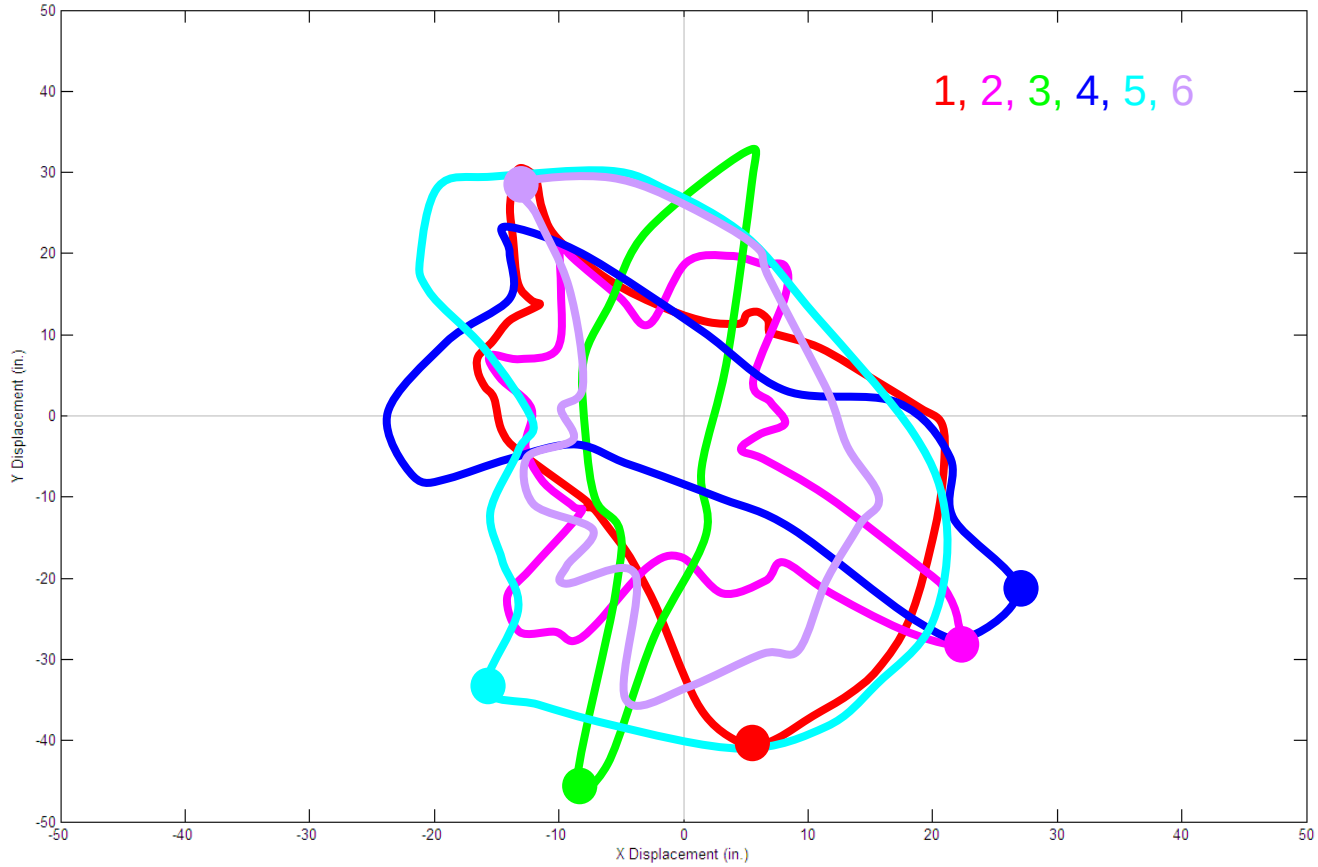

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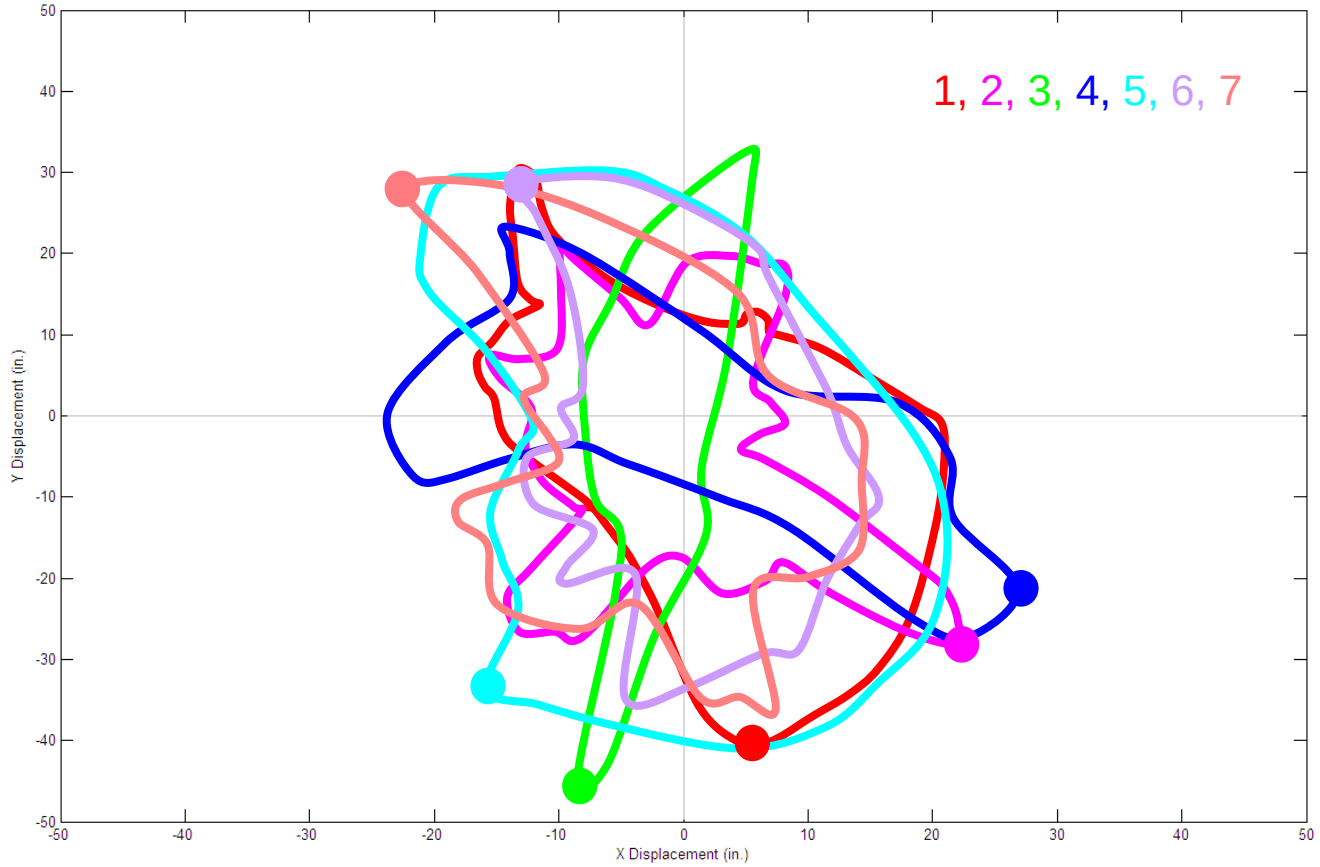

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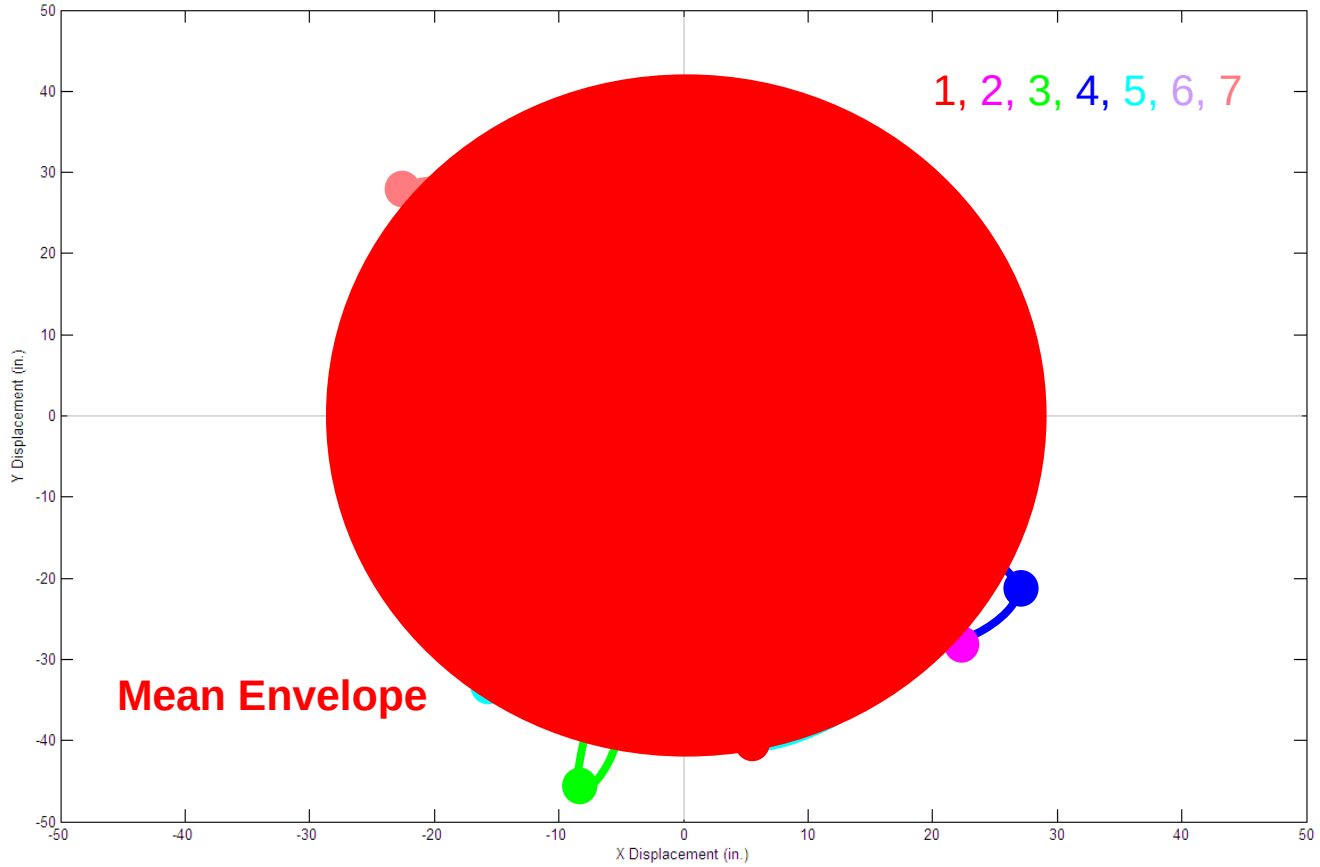

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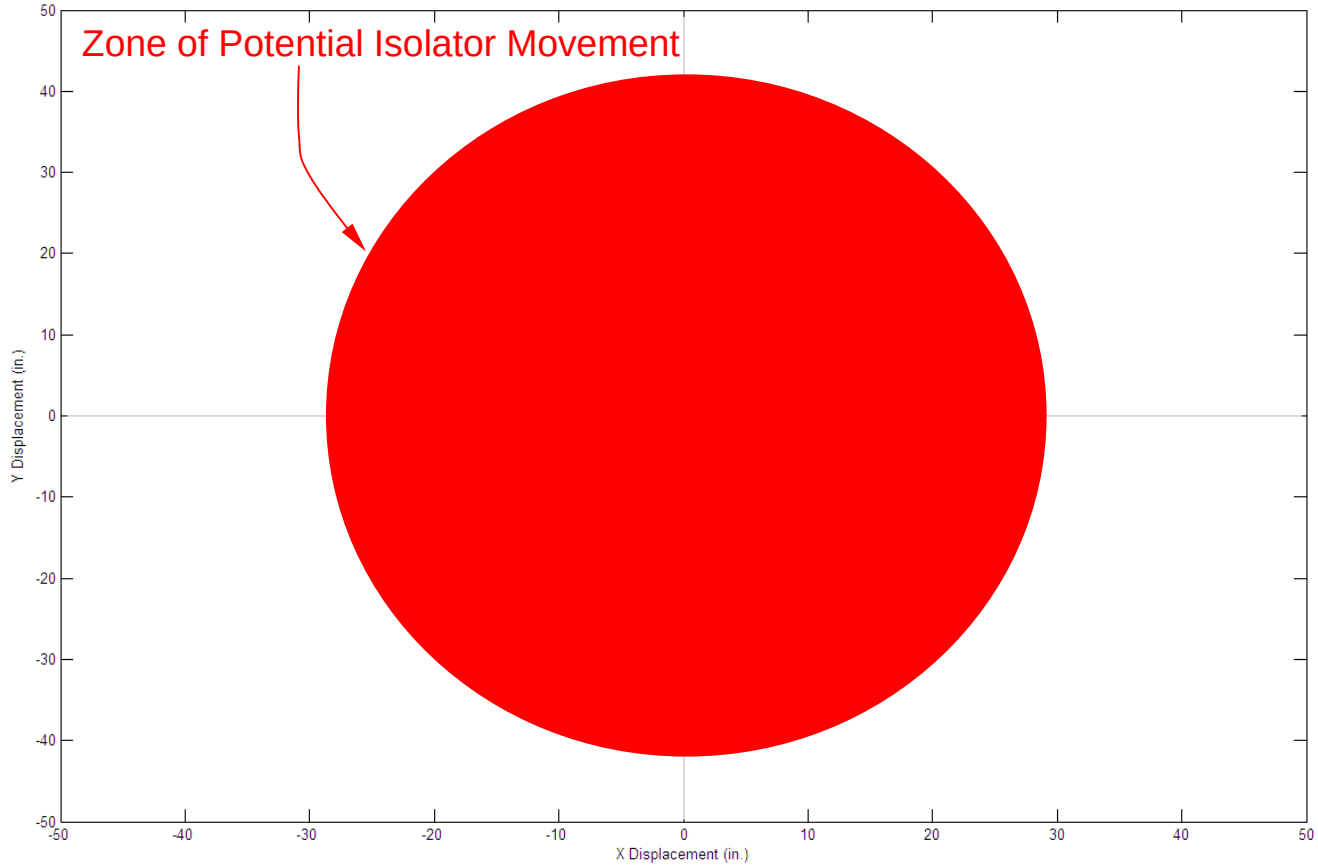
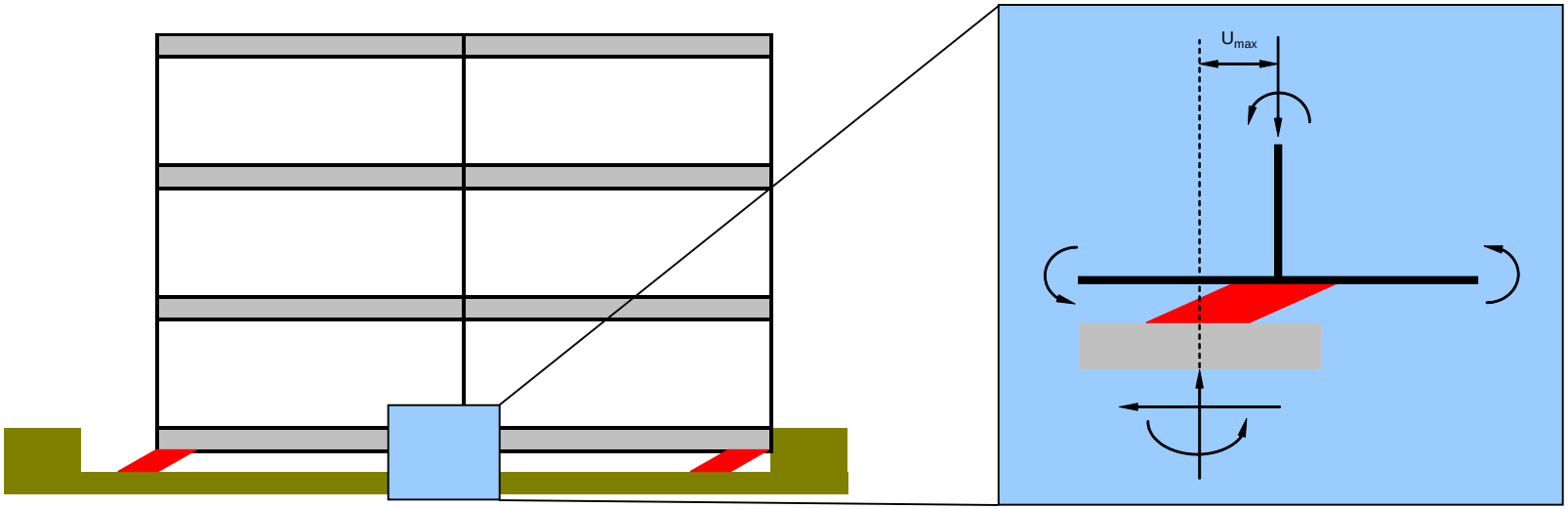


Peak Isolator Displacements

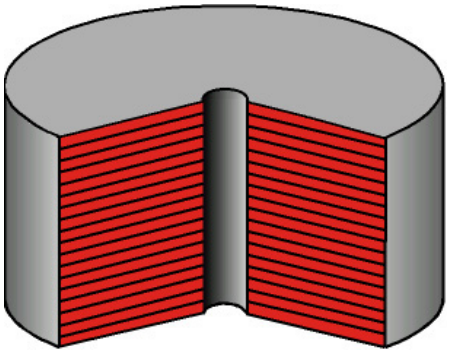
What is this estimate of *peak isolator displacement* used for?

1. For the DBE, D_D defines displacement at which isolator cyclic behavior (stiffness and energy dissipation) must be as specified on contract documents

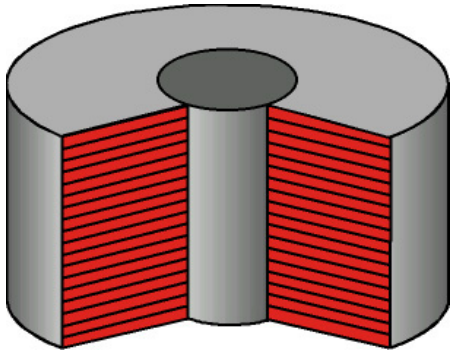
2. For the MCE, D_{TM} defines displacement at which isolation system must be stable.



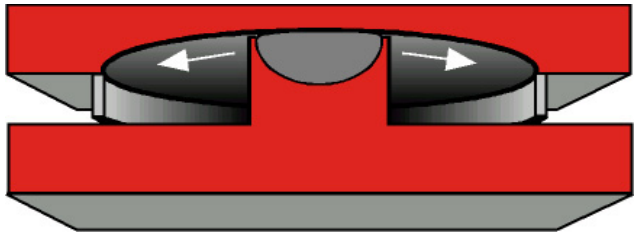
Models of Isolation Devices



High-Damping Rubber



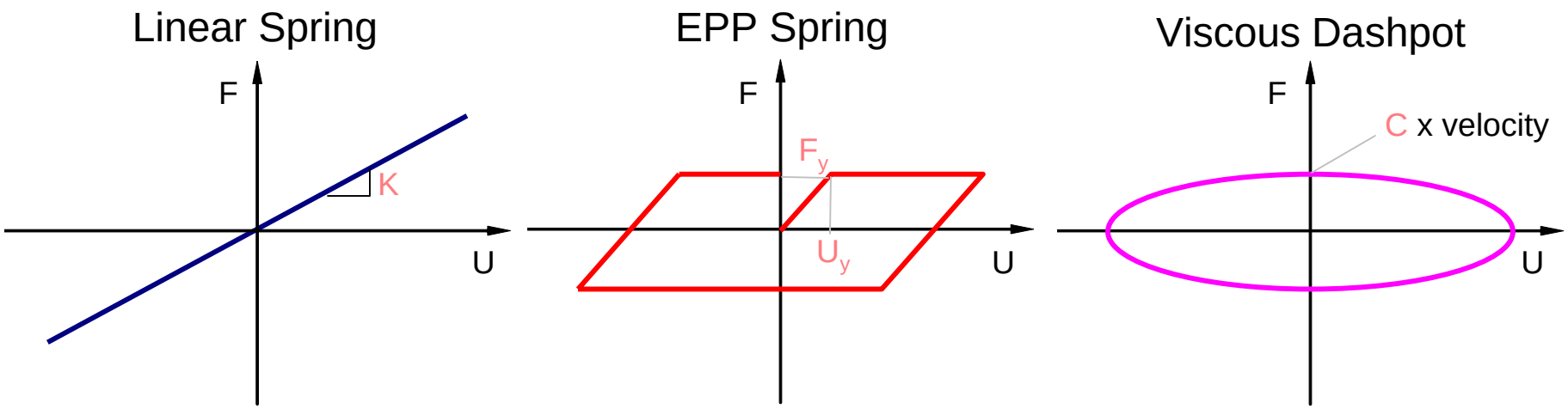
Lead Rubber



Friction Pendulum

Models of Isolation Devices

Each type of device can be effectively modeled as some parallel combination of 3 basic elements

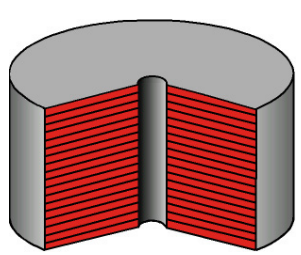


Lead Rubber Bearings

Natural Rubber Bearing

Press-Fit Lead Core

Lead Rubber Bearing



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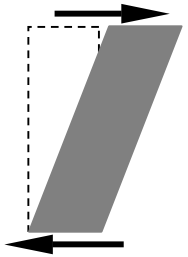

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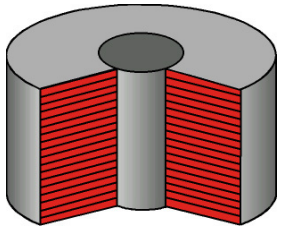

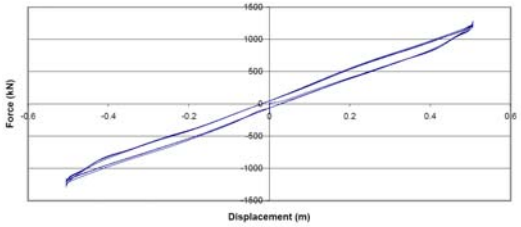

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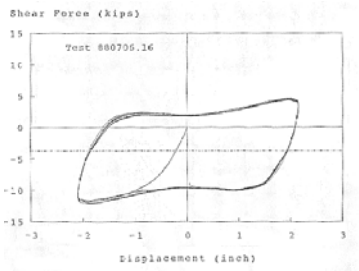

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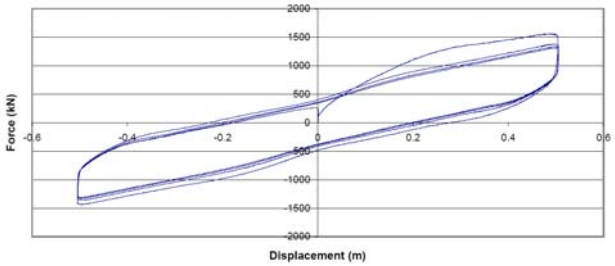

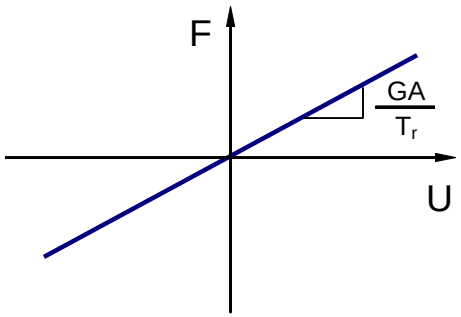

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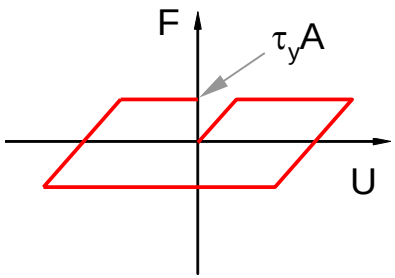

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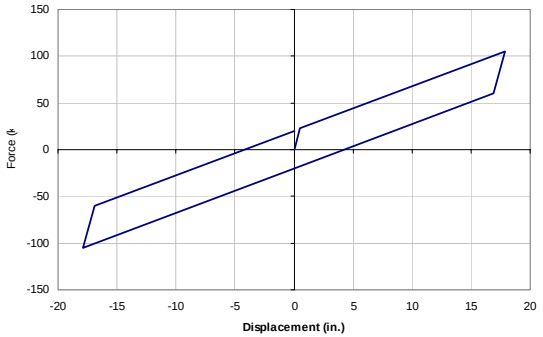
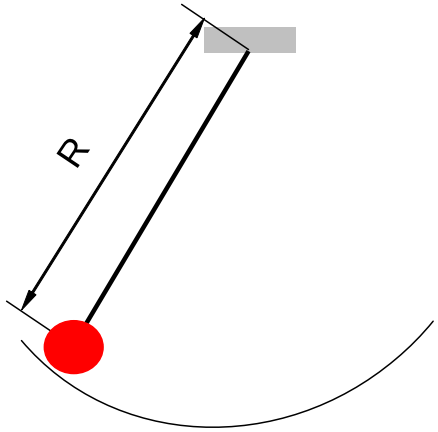


Friction Pendulum System Bearings

Simple Pendulum

PTFE Slider

FPS Bearing



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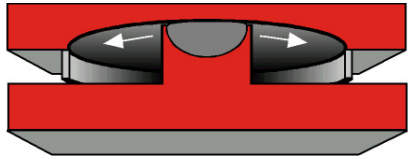

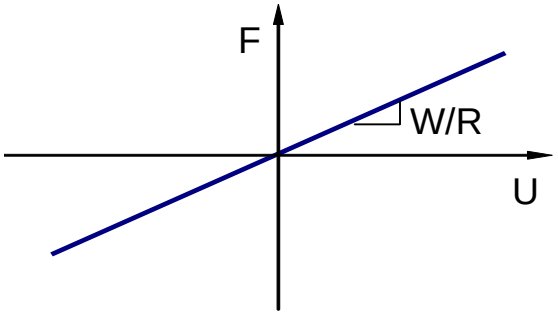

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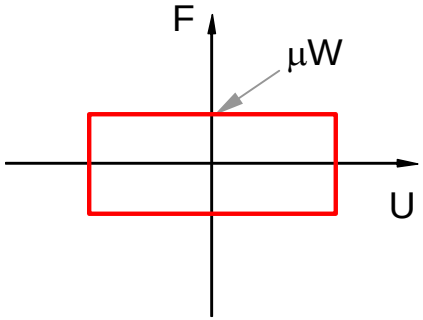

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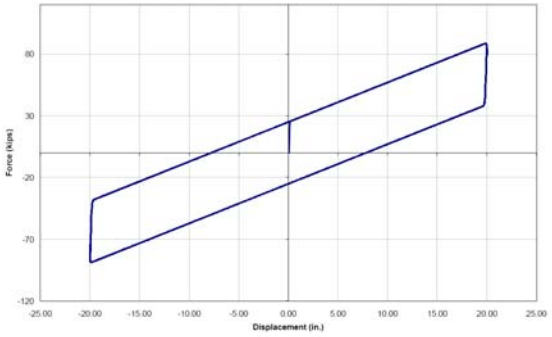
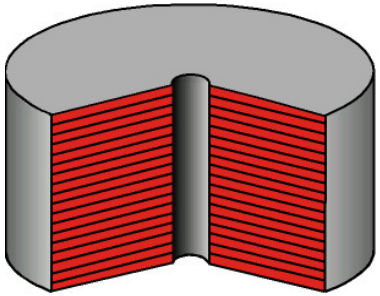
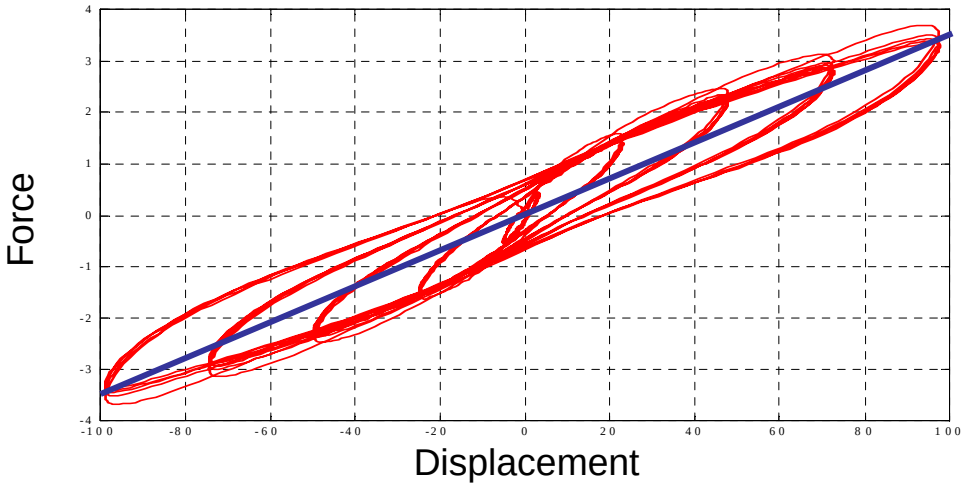
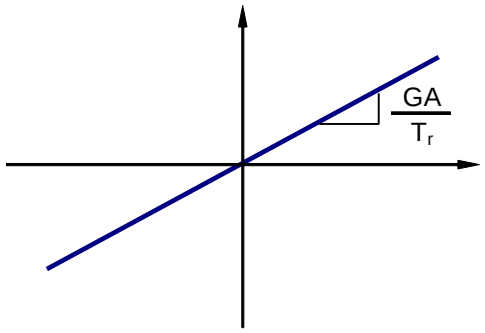


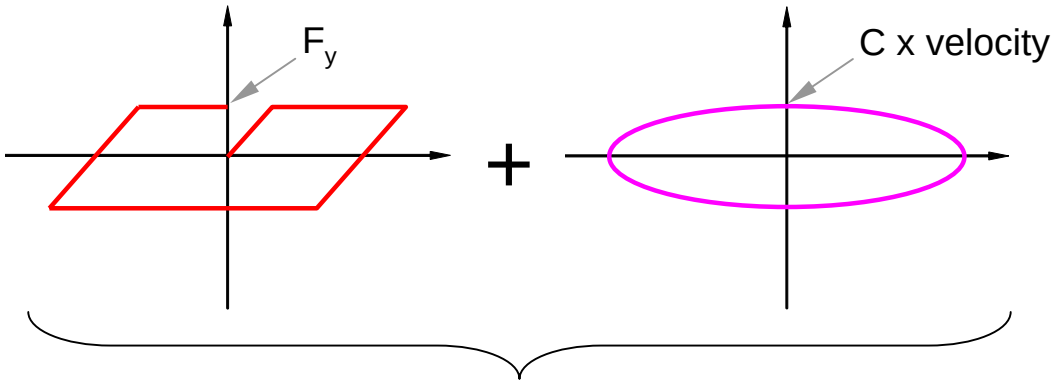
High-Damping Rubber Bearings





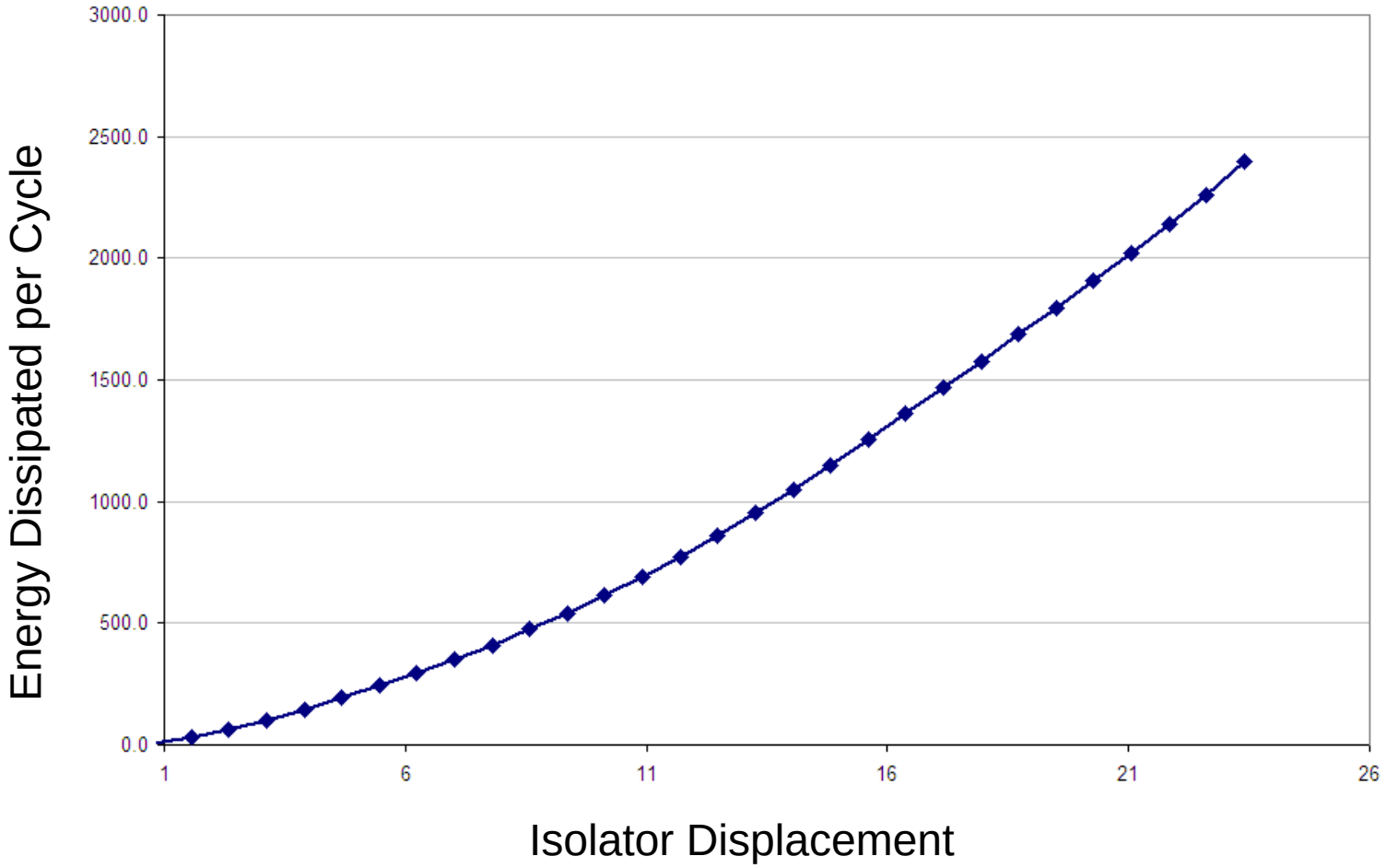


Spring



Energy Dissipated Per Cycle (EDC)

High-Damping Rubber Bearings



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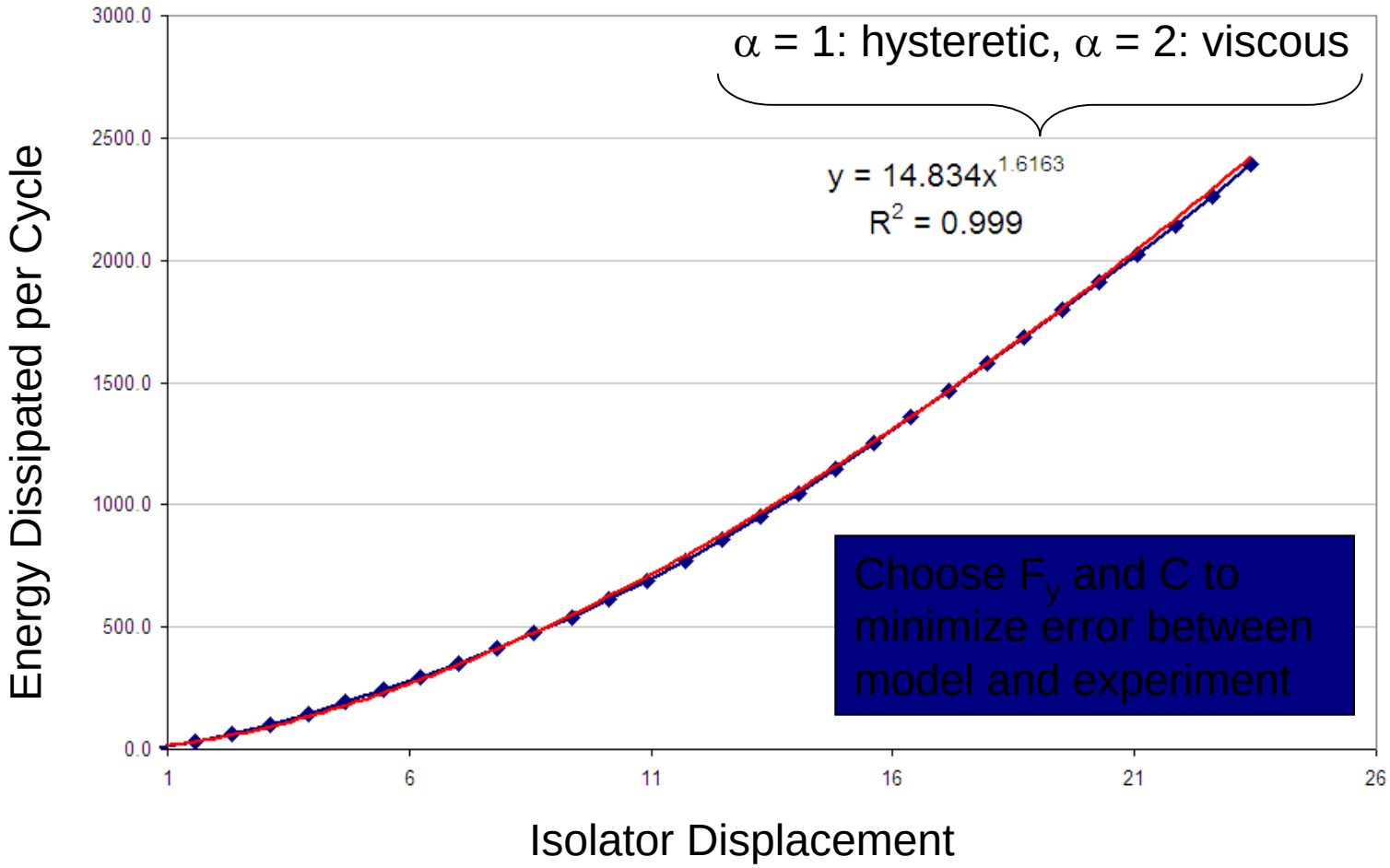
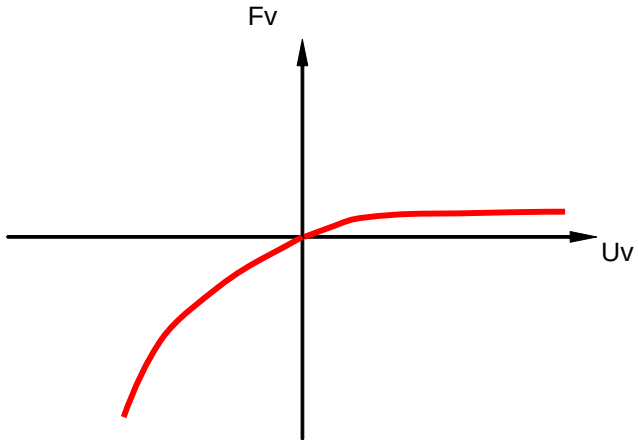


A Few Words About Isolator Uplift

- The most effective way to treat uplift is to avoid it.
- Elastomeric bearings resist a tensile stress of about 150 psi (1.0 MPa) prior to cavitation, after which the stiffness is nearly zero.



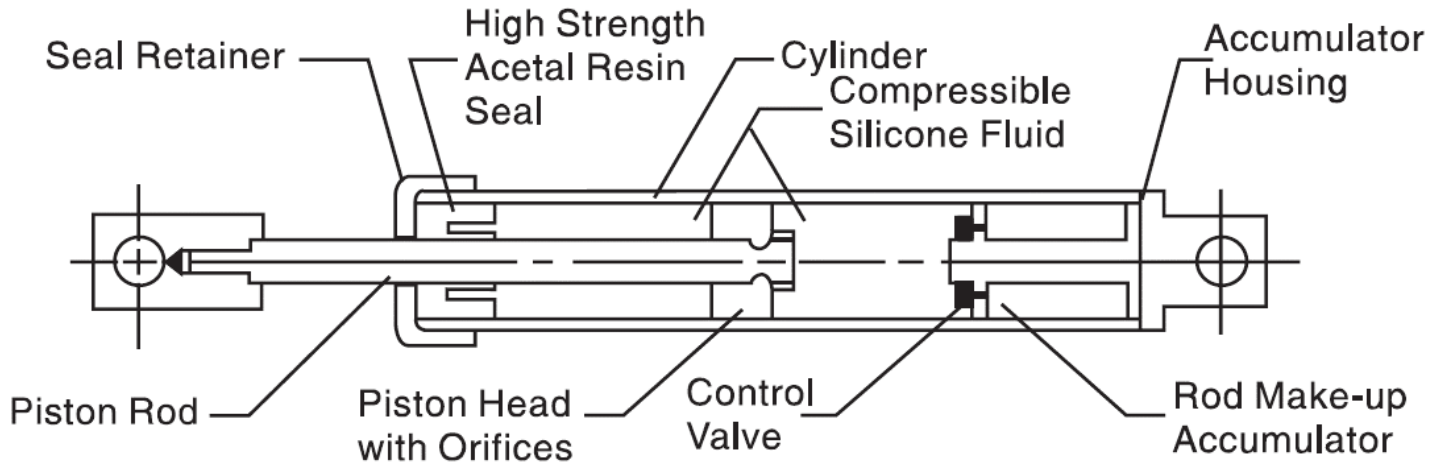
- Dish-based Friction Pendulum Bearings have zero tensile stiffness
- Using vertical gap elements, the vertical behavior of isolators can be characterized easily, and the anticipated uplift demands can be incorporated in prototype test programs.

How Do We Control Isolator Displacements?

- Shorten the isolated period to mitigate displacements.
- Add energy dissipation to the isolation bearings, either through a larger lead core or a higher friction coefficient.
- **Add supplemental viscous dampers at the isolation interface. These can be linear or nonlinear dampers**

A Damper Lurks in the Basement

The de Young Museum, San Francisco



Issues Related to Dampers at Isolation Interface

- A choice must be made: linear vs. nonlinear
- There is an increase in the floor accelerations and, in some cases, the base shear
- The dampers are large, up to 24” in diameter and 18’-0” in length (at mid-stroke)
- Dampers must be located in plan so as to not induce torsion
- Dampers add significant cost to a project

Development of Floor Spectra

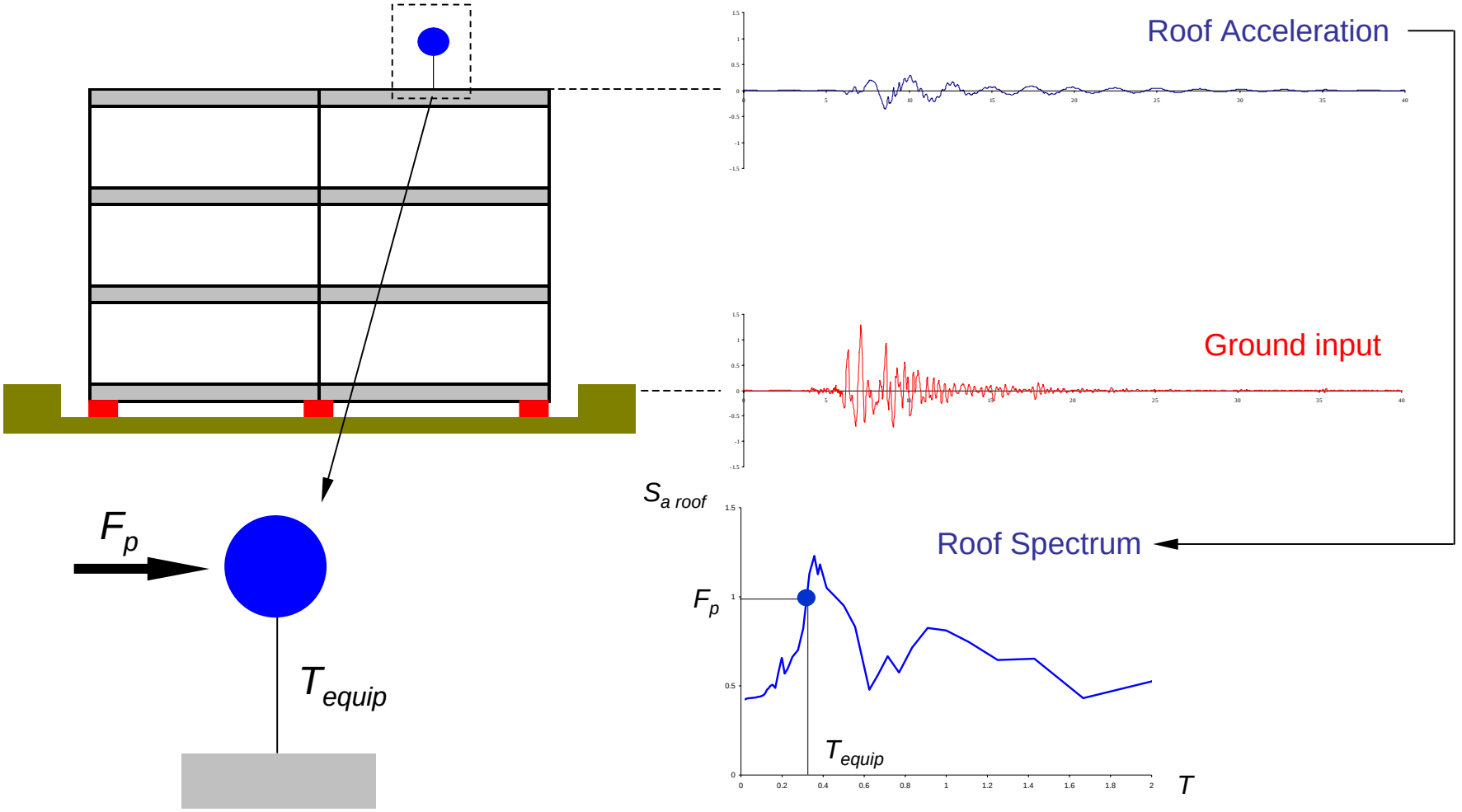
General procedure:

- Create linear model of superstructure including all quantifiable sources of stiffness
- Model isolators using the **most accurate nonlinear available**. Properties for the isolators should be based on the assumed *upper-bound* for the system
- Run the suite of response history analyses at the performance level of interest (DBE, MCE, etc.)

At the floor level of interest:

- Generate acceleration records for each input record.
- Transform these floor acceleration histories into a 5% damped spectrum.
- Reduce this spectrum by some appropriate means for design (divide by R_p, convert to constant ductility, average over some window, etc.)

Development of Floor Spectra

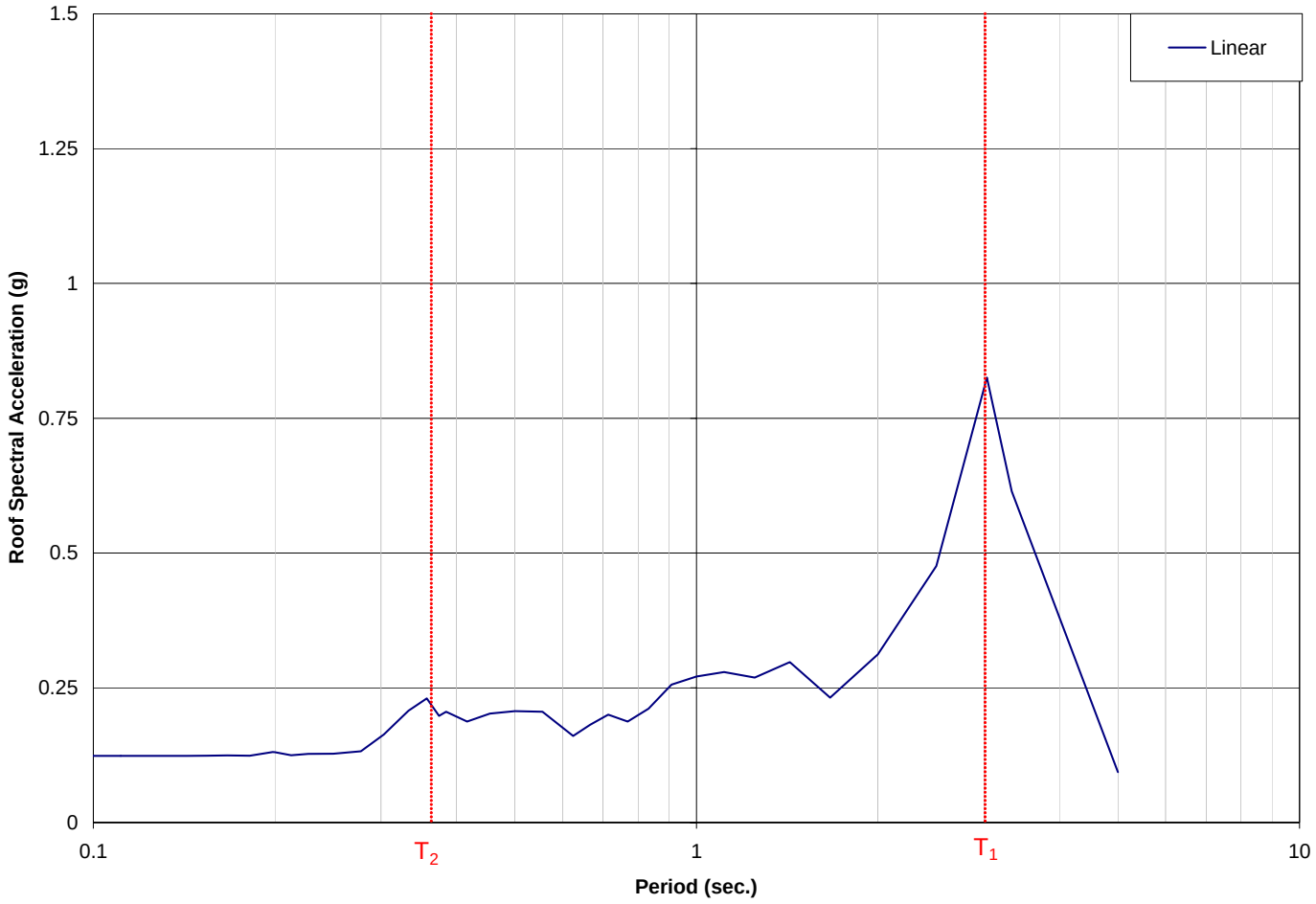


Development of Floor Spectra

For the following simple example:

- Consider a single acceleration record – 1994 Northridge, CDMG Station 24389 (Century City LACC)
- Base case: undamped linear isolation system, T = 3 sec.
- Hysteretic energy dissipation cases: F_y = 0.05 W and 0.10 W
- Supplemental damping cases: 10% and 30% critical

Dependence of Floor Spectra on Modeling



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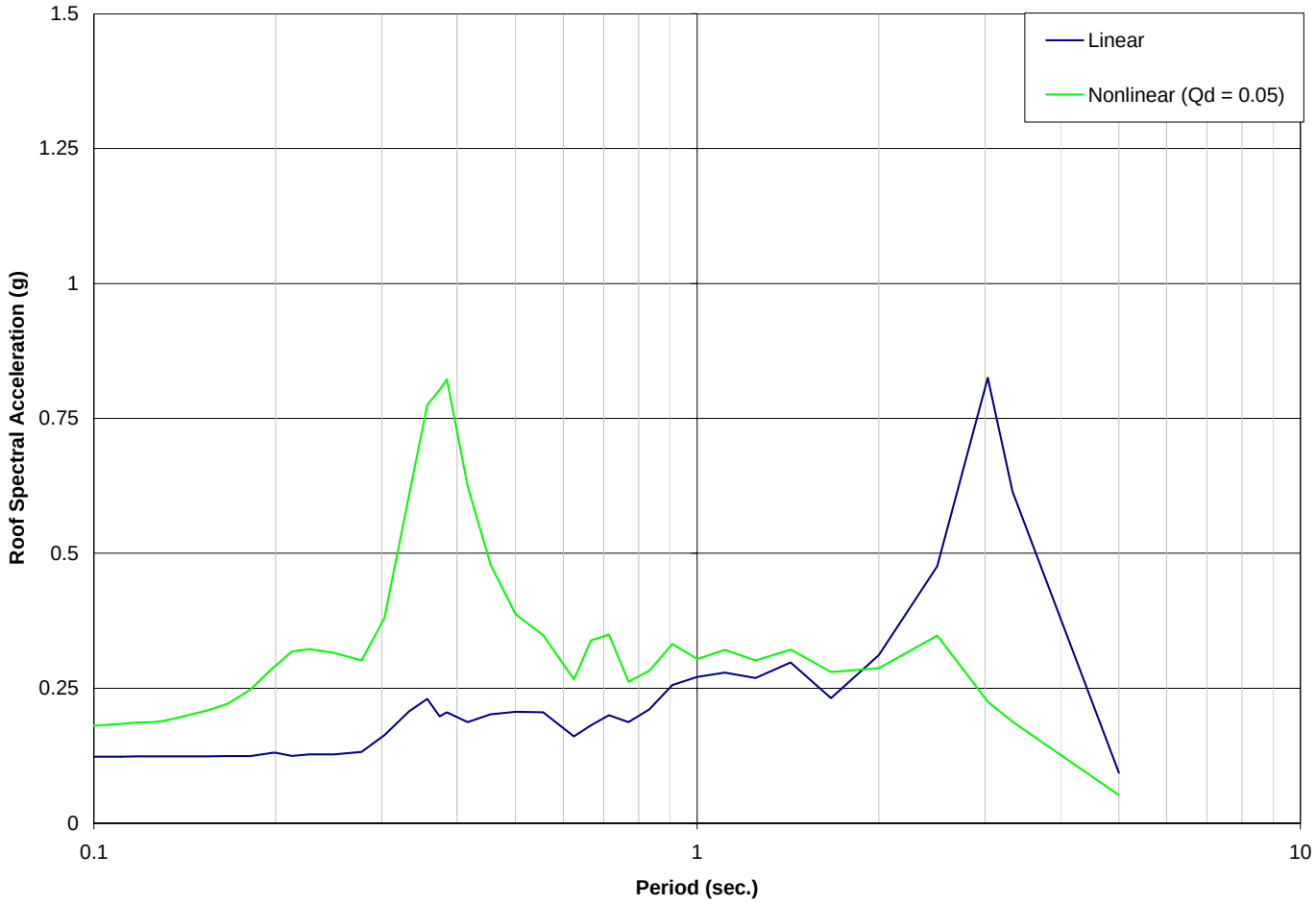

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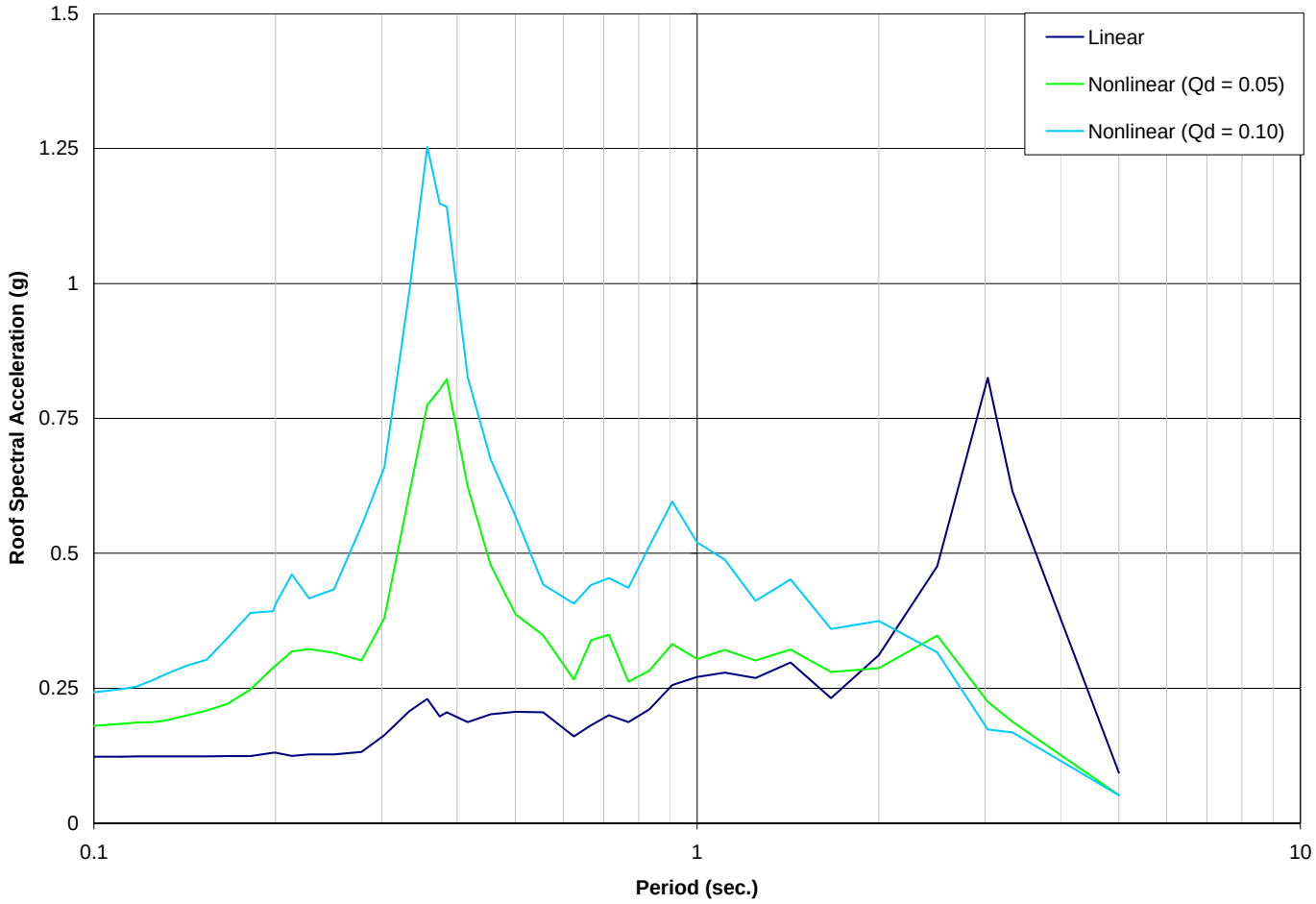
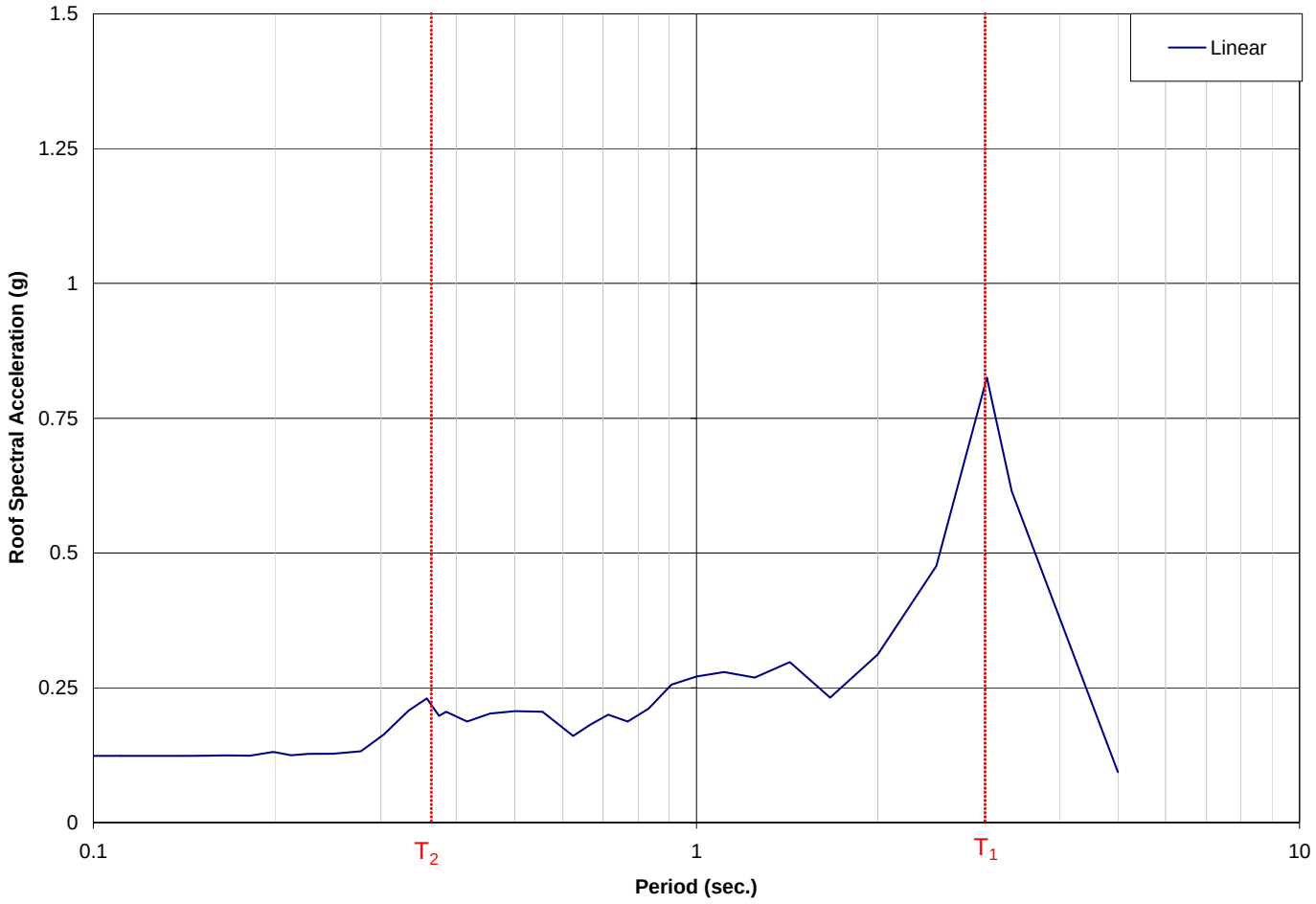


Dependence of Floor Spectra on Modeling



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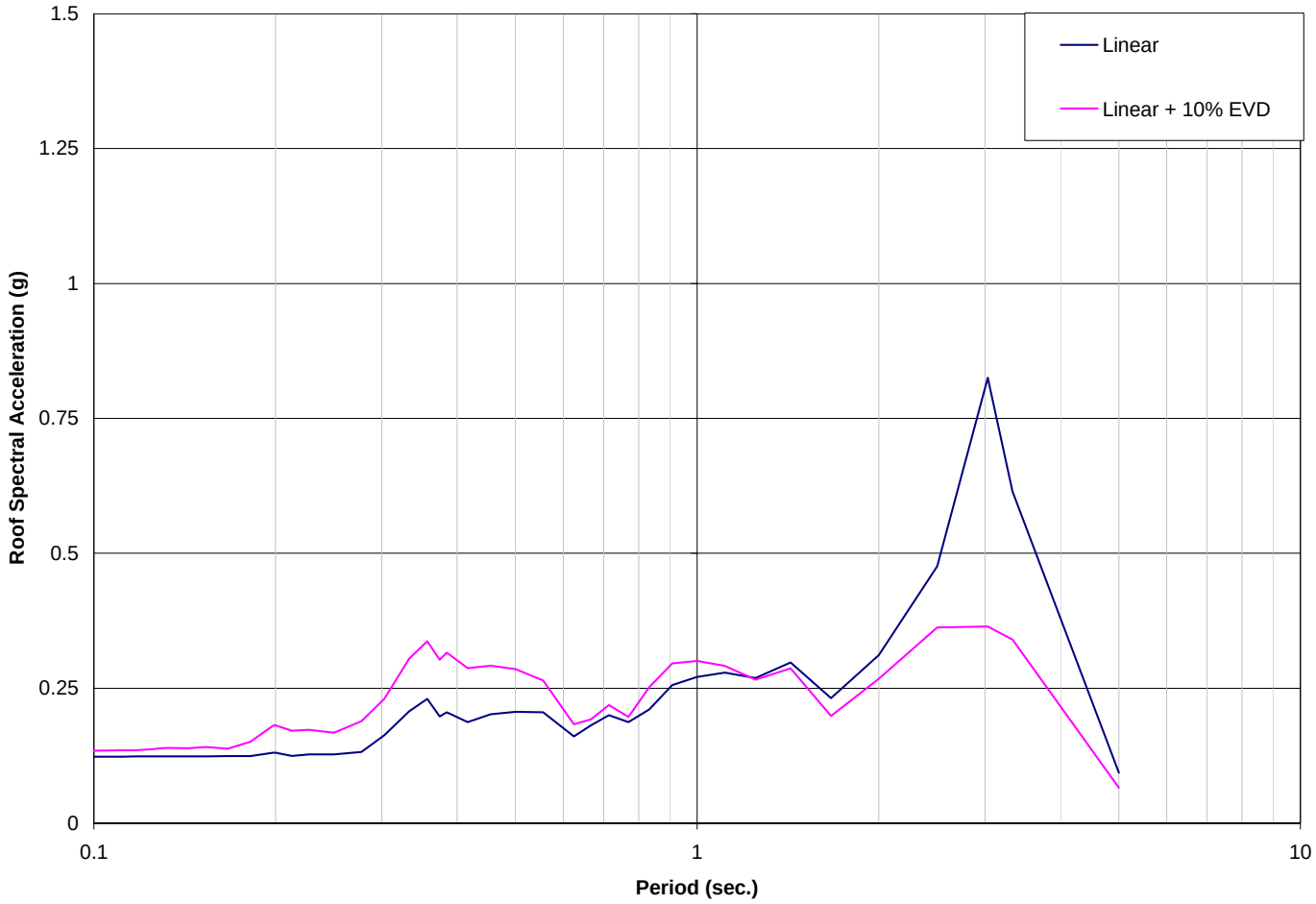

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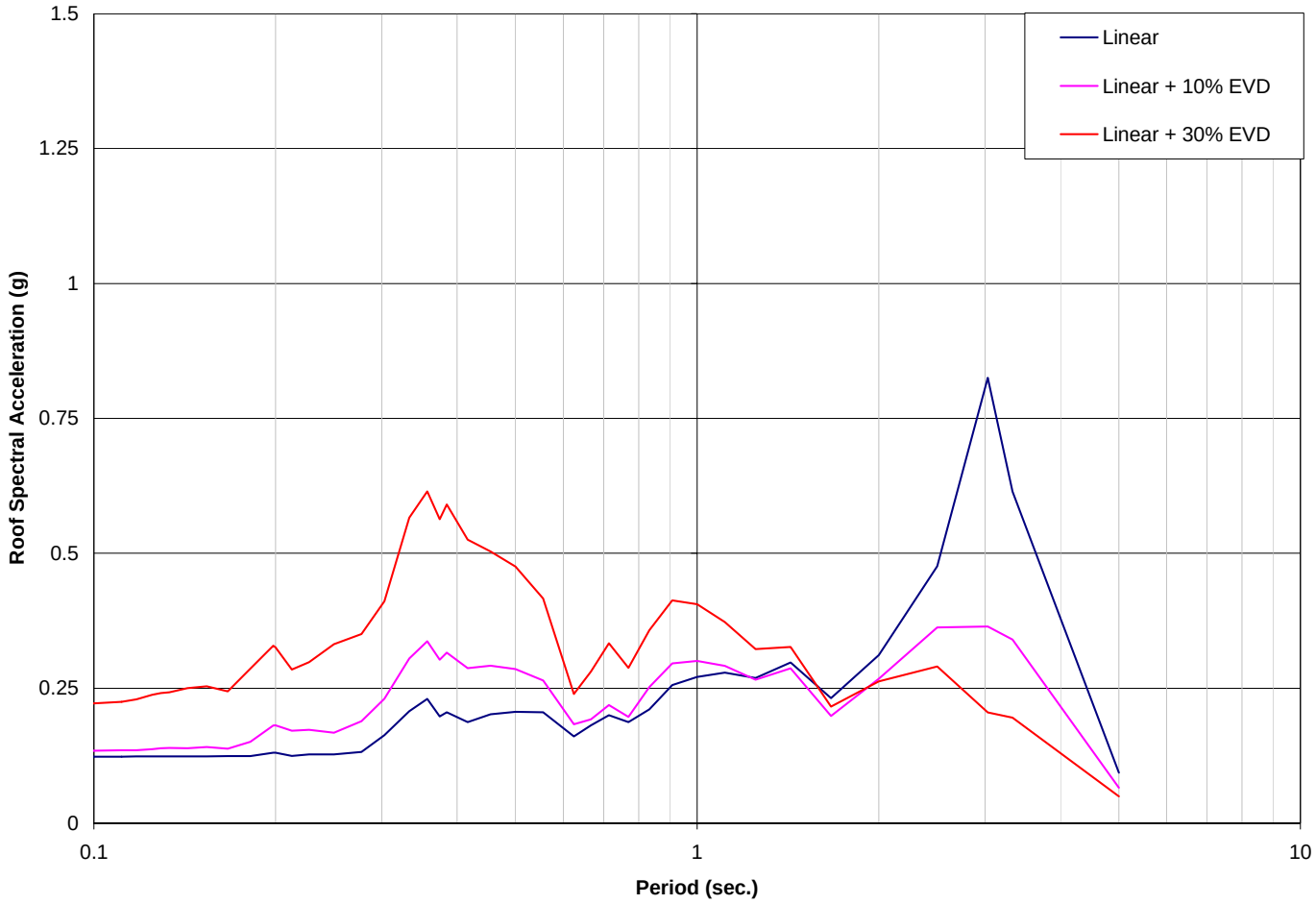
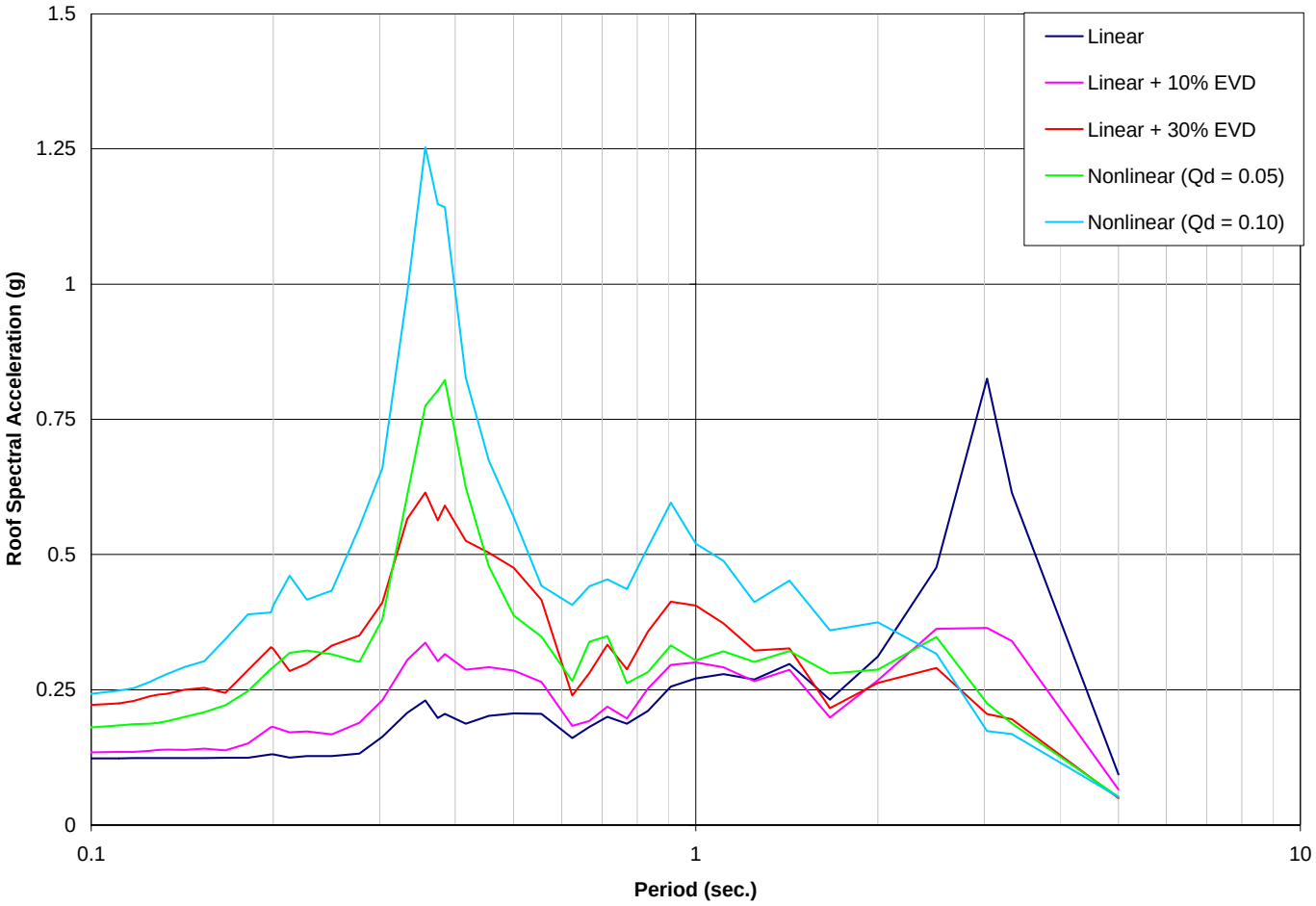
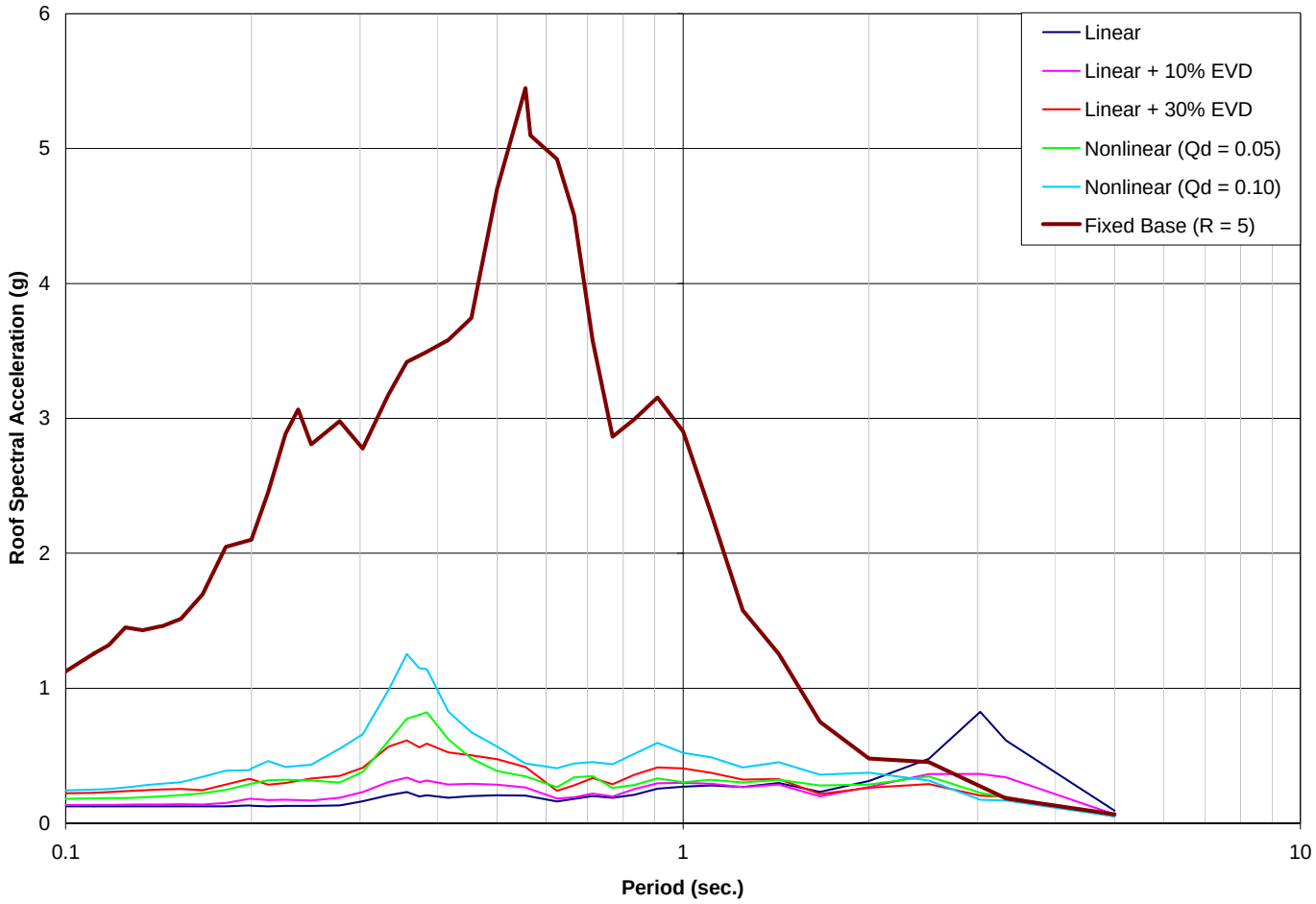


Dependence of Floor Spectra on Modeling



Comparison of Conventional and Isolated Floor Spectra



The End