University of Thessaly, Department of Mechanical Engineering
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Reliability-Based Analysis and Design of Isolation Systems for Large Scale Building Models

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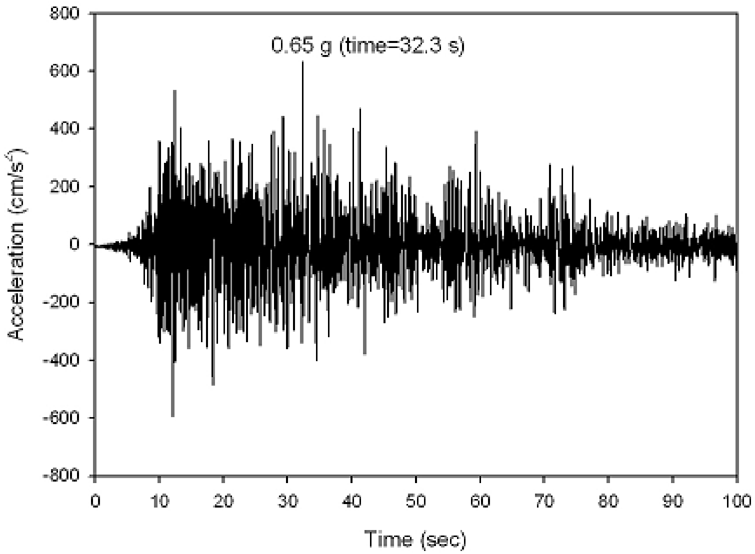
Motivation



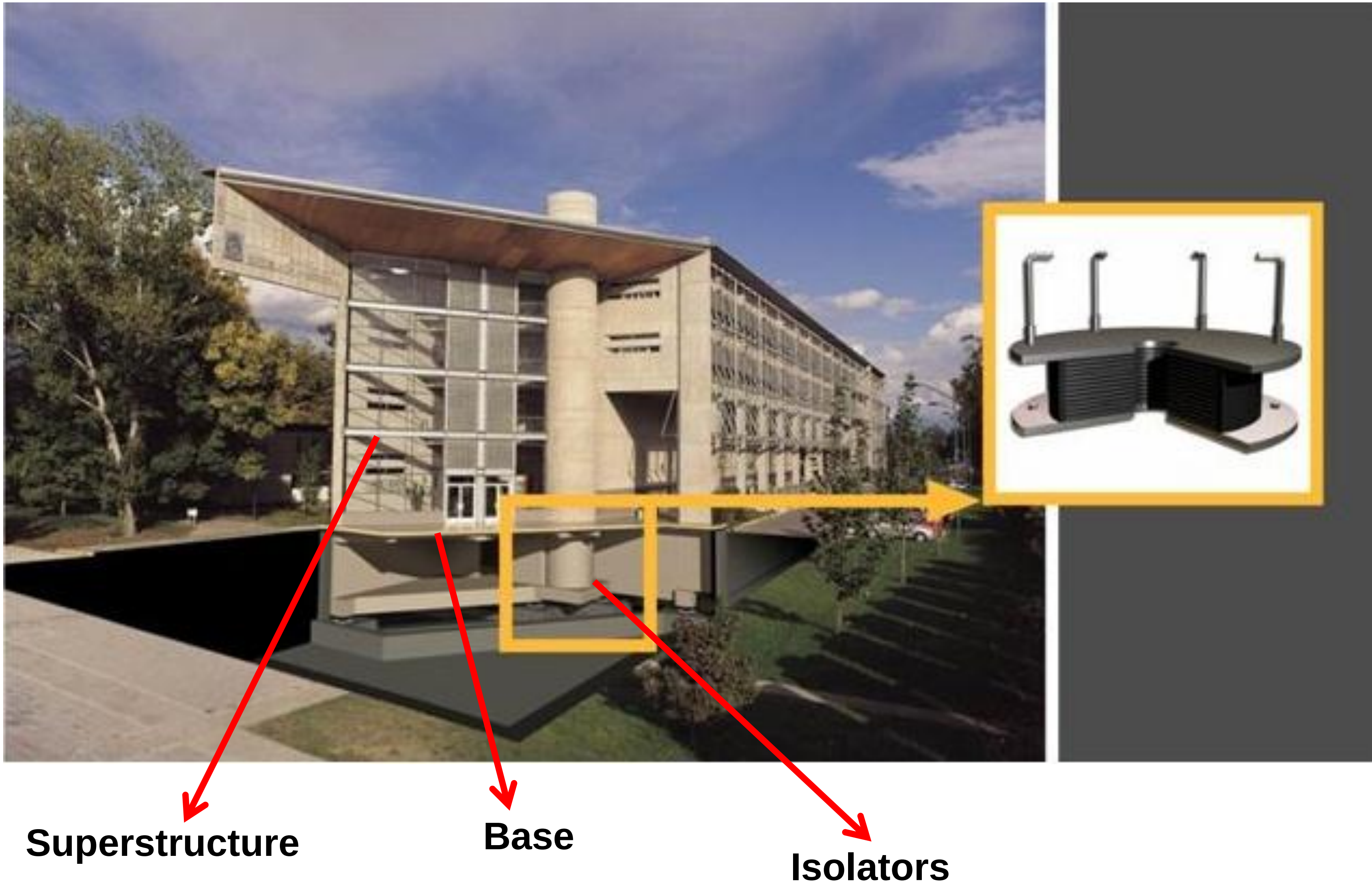
Chilean earthquake, February 27, 2010
(Magnitude 8.8)

Outline

- Introduction
- Structural Model
- Isolation System Modeling
- Stochastic Excitation Model
- Reliability Measures
- Example Problem
- Conclusions

Introduction

Base-isolated structural system



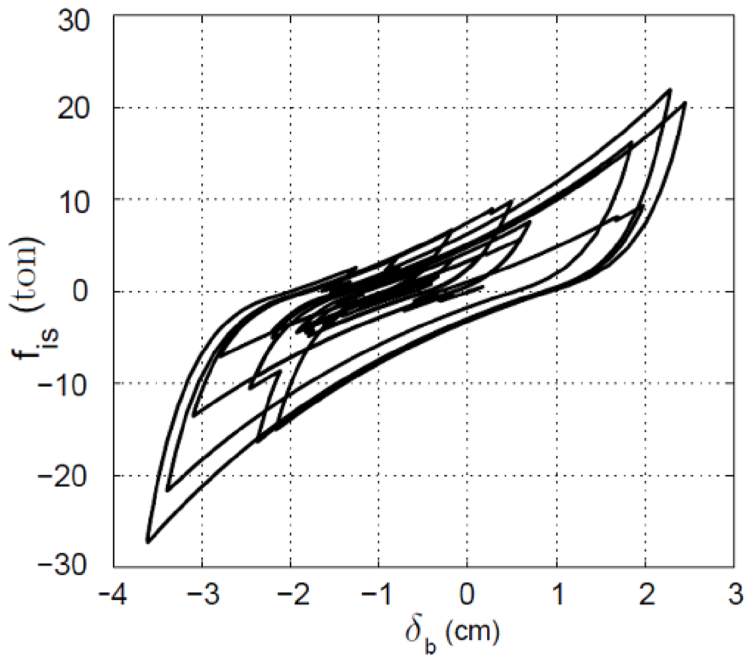
Isolation systems

Isolation elements

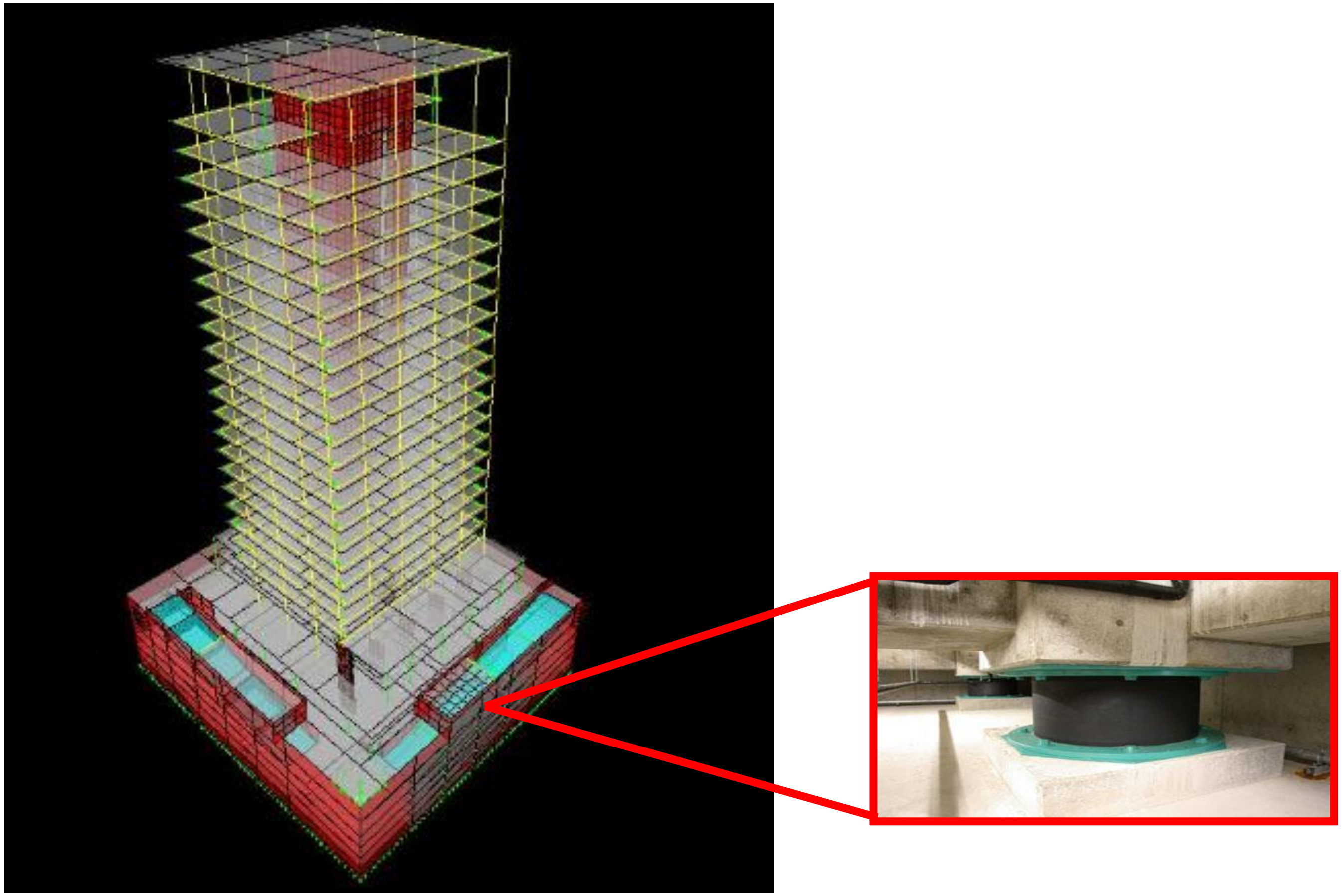
· **Lead rubber bearings or high-damping rubber bearings**
· **Nonlinear fluid dampers**
· **Sliding friction bearings**
· **Friction pendulums**

Net effect
reduce the energy dissipation demand of the superstructure

Typical displacement-restoring force curve (rubber bearing)



In general the design of isolation systems is performed (at the design stage) using deterministic analyses (code based)



Objective

Propose a general framework for the analysis and design of isolation systems from a reliability point of view

Structural Model

Equation of motion (superstructure FEM model)

$$[M_s]\{\ddot{u}_s(t)\} + [C_s]\{\dot{u}_s(t)\} + [K_s]\{u_s(t)\} = -[M_s][G_s](\{\ddot{u}_b(t)\} + \{\ddot{u}_g(t)\})$$

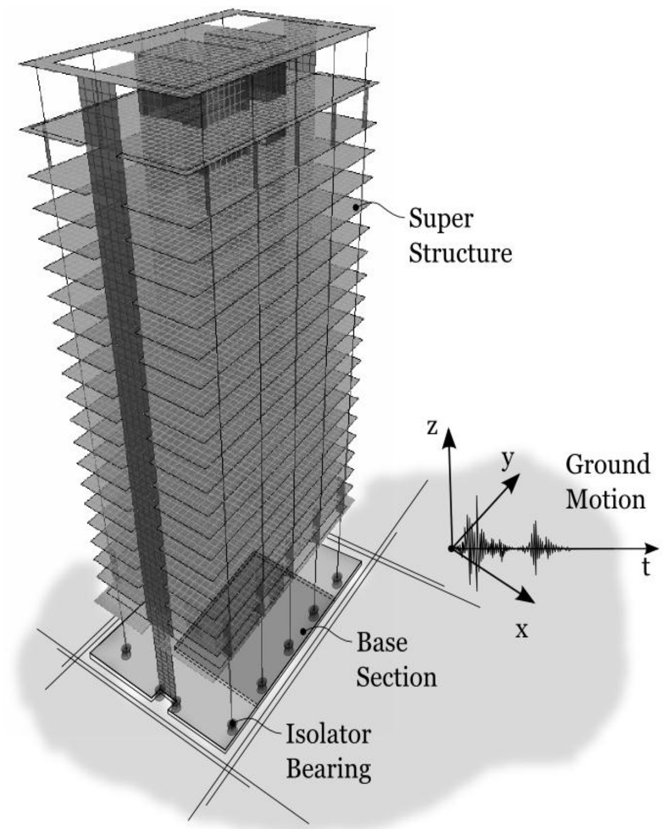
$\{u_s(t)\}$: vector of absolute displacements

$[M_s]$, $[C_s]$, $[K_s]$: mass, damping, stiffness matrices

$\{u_b(t)\}$: vector of base displacements

$[G_s]$: matrix of earthquake influence coefficients

$\{\ddot{u}_g(t)\}$: vector of excitation components



Equation of motion (base)

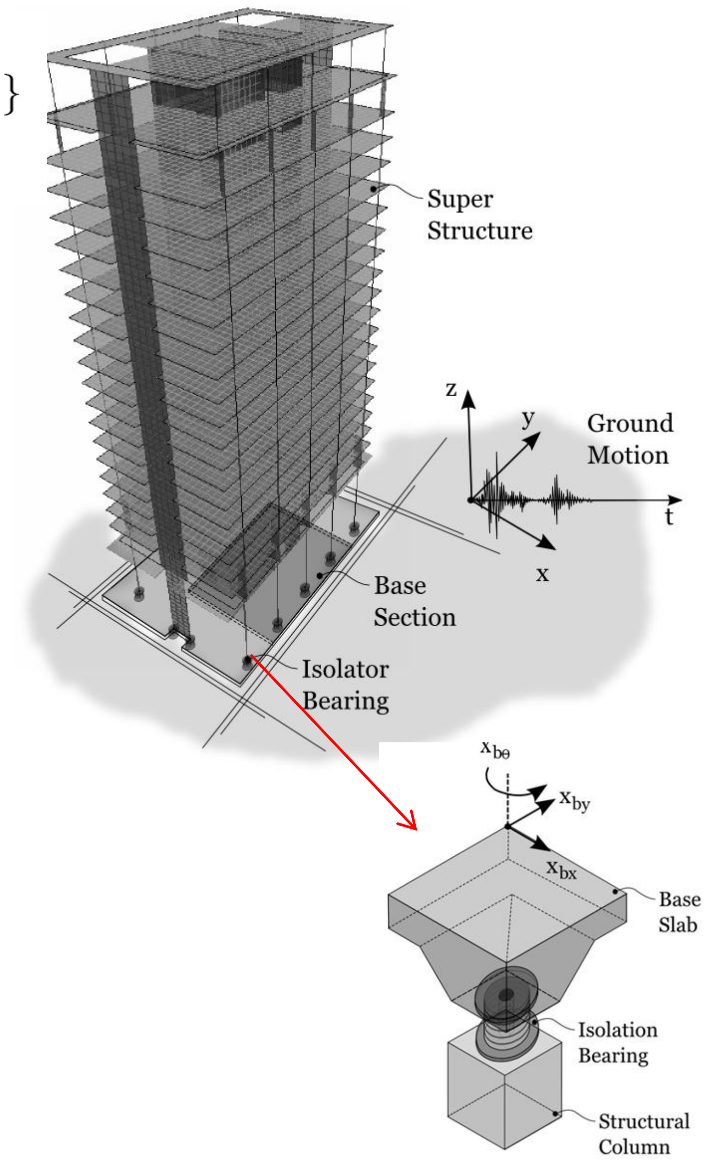
$$([G_s]^T[M_s][G_s] + [M_b])(\{\ddot{u}_b(t)\} + \{\ddot{u}_g(t)\}) + [G_s]^T[M_s]\{\ddot{u}_s(t)\}$$
$$+[C_b]\{\dot{u}_b(t)\} + [K_b]\{u_b(t)\} + \{f_{is}(t)\} = \{0\}$$

$[M_b]$: mass matrix of the rigid base

$[C_b]$: damping matrix of the viscous isolation components

$[K_b]$: stiffness matrix of the elastic isolation components

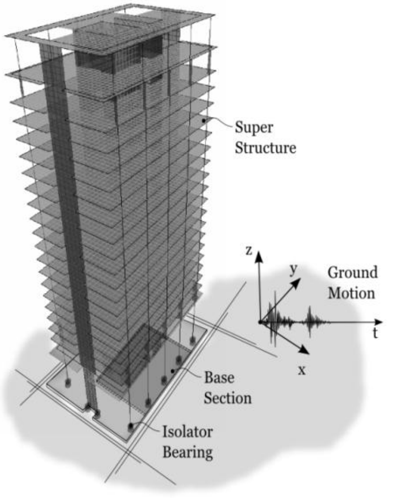
$\{f_{is}(t)\}$: vector of non-linear isolation forces



Combined equation of motion

$$\begin{bmatrix} [M_s] & [M_s][G_s] \\ [G_s]^T[M_s] & [M_b]+[G_s]^T[M_s][G_s] \end{bmatrix} \left\{ \begin{matrix} \{\ddot{u}_s(t)\} \\ \{\ddot{u}_b(t)\} \end{matrix} \right\} + \begin{bmatrix} [C_s] & [0] \\ [0] & [C_b] \end{bmatrix} \left\{ \begin{matrix} \{\dot{u}_s(t)\} \\ \{\dot{u}_b(t)\} \end{matrix} \right\} +$$

$$\begin{bmatrix} [K_s] & [0] \\ [0] & [K_b] \end{bmatrix} \left\{ \begin{matrix} \{u_s(t)\} \\ \{u_b(t)\} \end{matrix} \right\} = - \begin{bmatrix} [M_s][G_s] \\ [M_b]+[G_s]^T[M_s][G_s] \end{bmatrix} \{\ddot{u}_g(t)\} - \left\{ \begin{matrix} \{0\} \\ \{f_{is}(t)\} \end{matrix} \right\}$$



Solution equation of motion

Newmark method (second-order)

Crank-Nicolson method (second-order)

Runge-Kutta method (fourth-order)

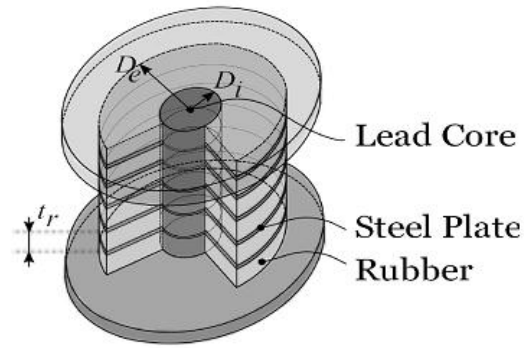
Model reduction techniques:

Static condensation-Guyan reduction

Component mode synthesis techniques

Isolation System Modeling

Standard approach
(mathematical model)



Schematic representation of a rubber bearing

(Buoc-Wen model)

$$U^y \, \dot{z}(t) = \dot{x}_b(t)[\alpha - z^n(t)(\gamma \, \mathrm{sgn}(\dot{x}_b(t)) + \beta \, \mathrm{sgn}(z(t)))]$$

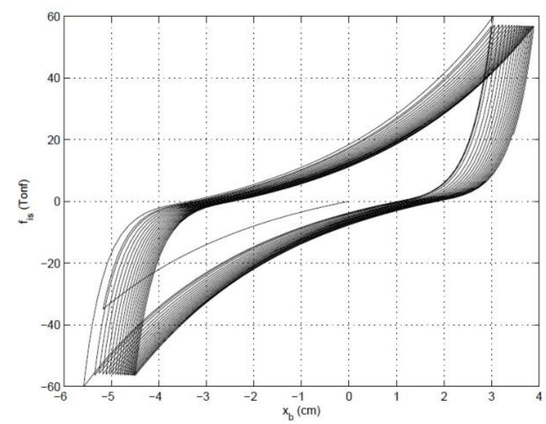
$z(t)$: dimensionless hysteretic variable

α, β, γ: dimensionless quantities

U^y: yield displacement

$x_b(t)$, $\dot{x}_b(t)$: base displacement and velocity

$\mathrm{sgn}(\cdot)$: sign function



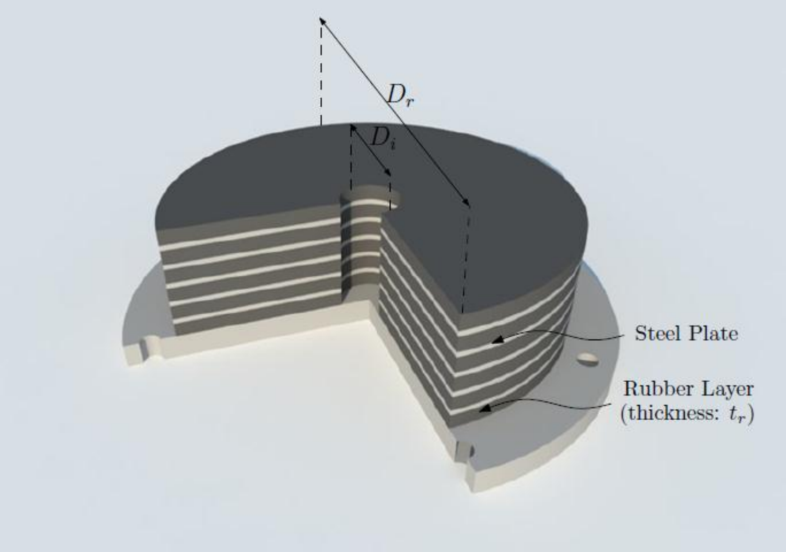
Displacement-restoring force curve

Force activated

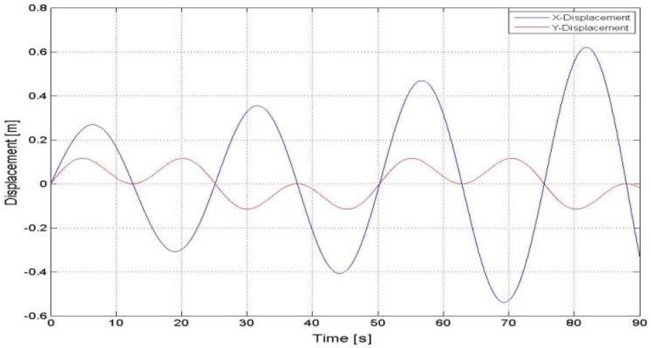
$$f_{is}(t) = k_p \, x_b(t) \; + \; c_v \, \dot{x}_b(t) \; + \; (k_e - k_p) \, U^y \, z(t)$$

Alternative approach

(experimental data)



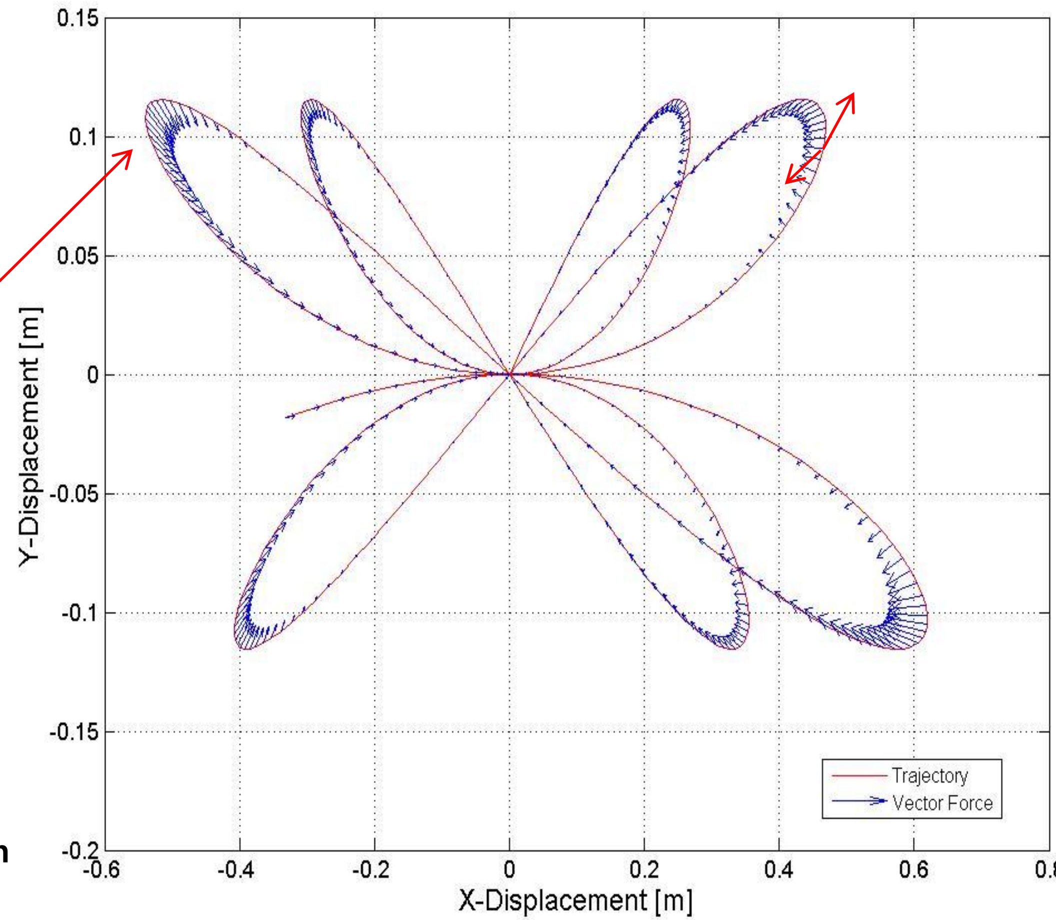
From observation of a series of test (using horizontal bidirectional loading) it has been proposed to compose the restoring force in terms of a force directed to the origin and another force approximately opposite to the direction of the movement (Yamamoto, 2012)



loading displacements

upper flange plate

displacement pattern

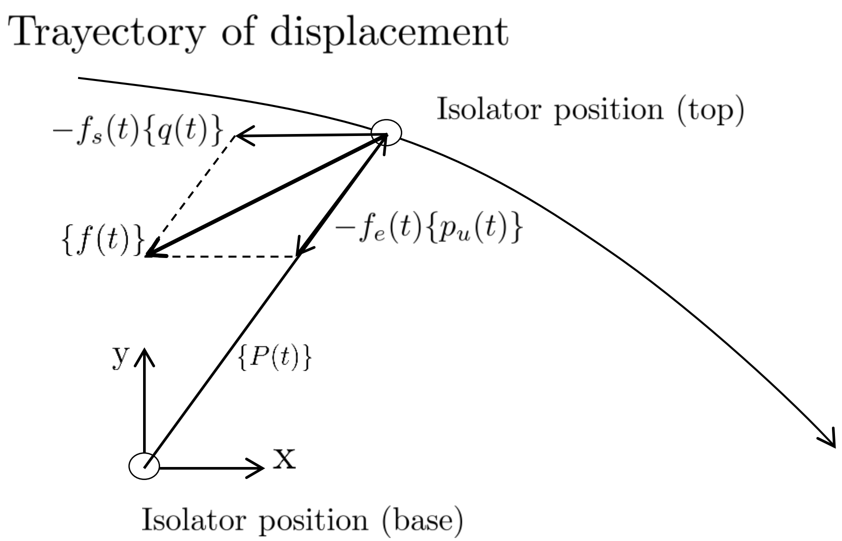


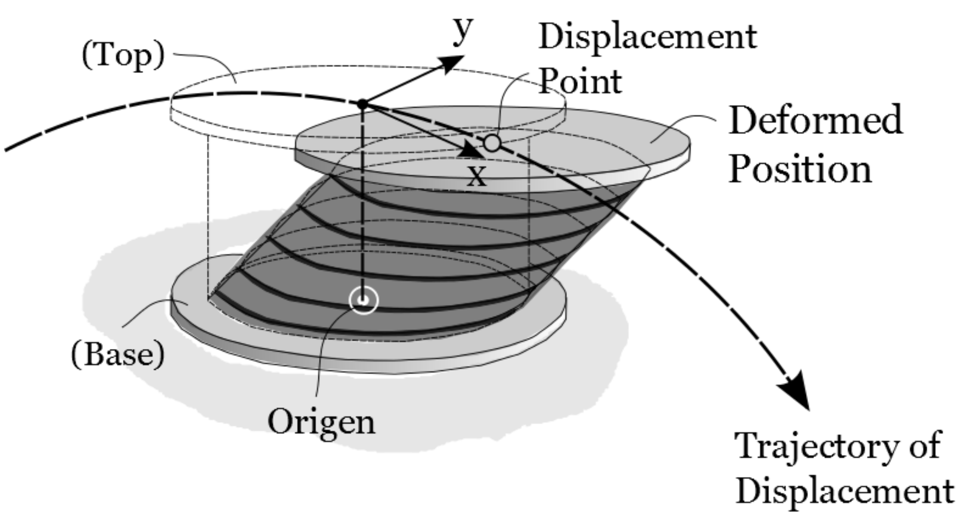
Restoring forces along the path of the loading

direction do not lead straight to the origin

internal twisting shear deformation occurs in the bearing

Analytical Model





$\{p(t)\}$: displacement vector (trajectory of the isolator)

$\{p_u(t)\}$: unit directional vector

$\{q(t)\}$: direction of the movement

$f_e(t)$: elastic component of the force

$f_s(t)$: elastoplastic component of the force

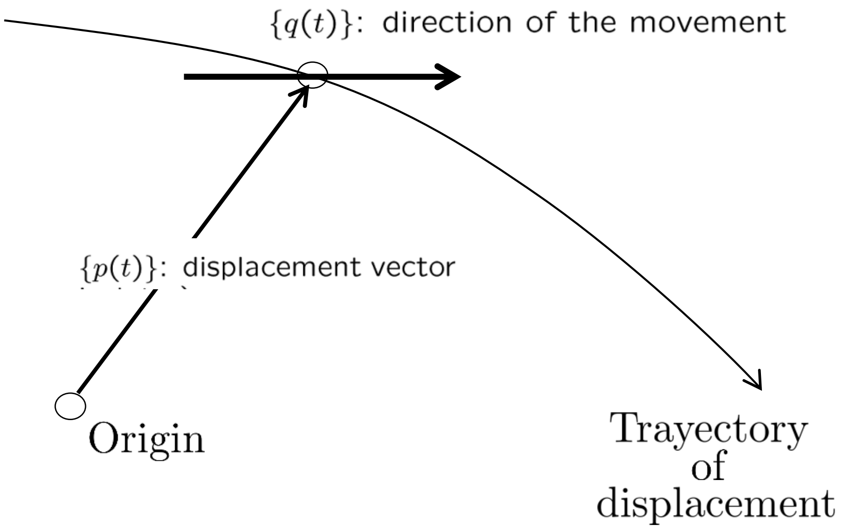
restoring force:

$$\{f(t)\} = -\{p_u(t)\}f_e(t) - \{q(t)\}f_s(t)$$

Direction of the movement

$$\{\dot{q}(t)\} = \frac{1}{\alpha} \parallel \{\dot{p}(t)\} \parallel [\{\dot{p}_u(t)\} - \parallel \{q(t)\} \parallel^n \{q_u(t)\}]$$

$$\{p(0)\} = \{0\}\ ,\ \{q(0)\} = \{0\}$$



$\{\dot{p}(t)\}$: velocity vector

$\{\dot{p}_u(t)\}$: unit directional vector of the velocity vector

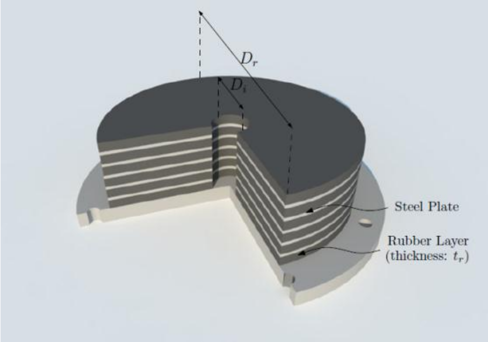
$\{q_u(t)\}$: unit directional vector of the movement

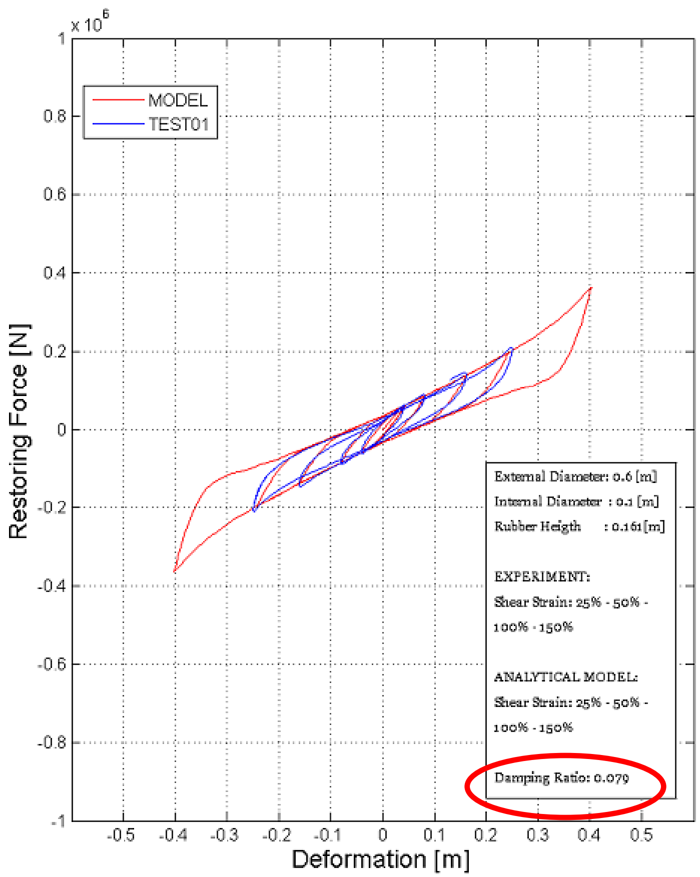
$\parallel \cdot \parallel$: Euclidean norm

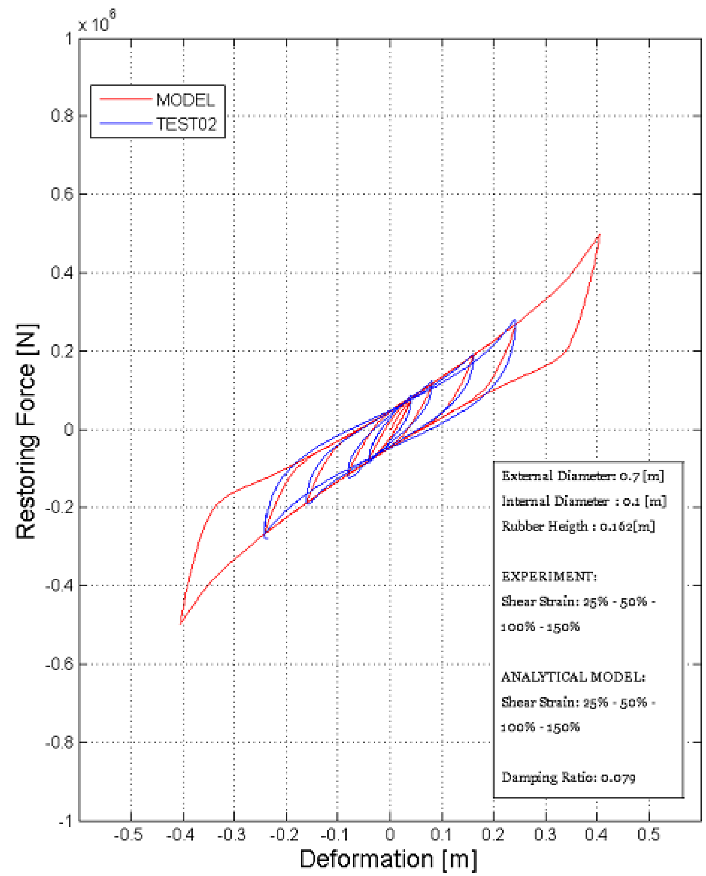
α, n: positive constants that relate to the yield displacement and smoothness of yielding

Validation

Small size rubber bearings







Equivalent viscous damping ratio

Medium size rubber bearings