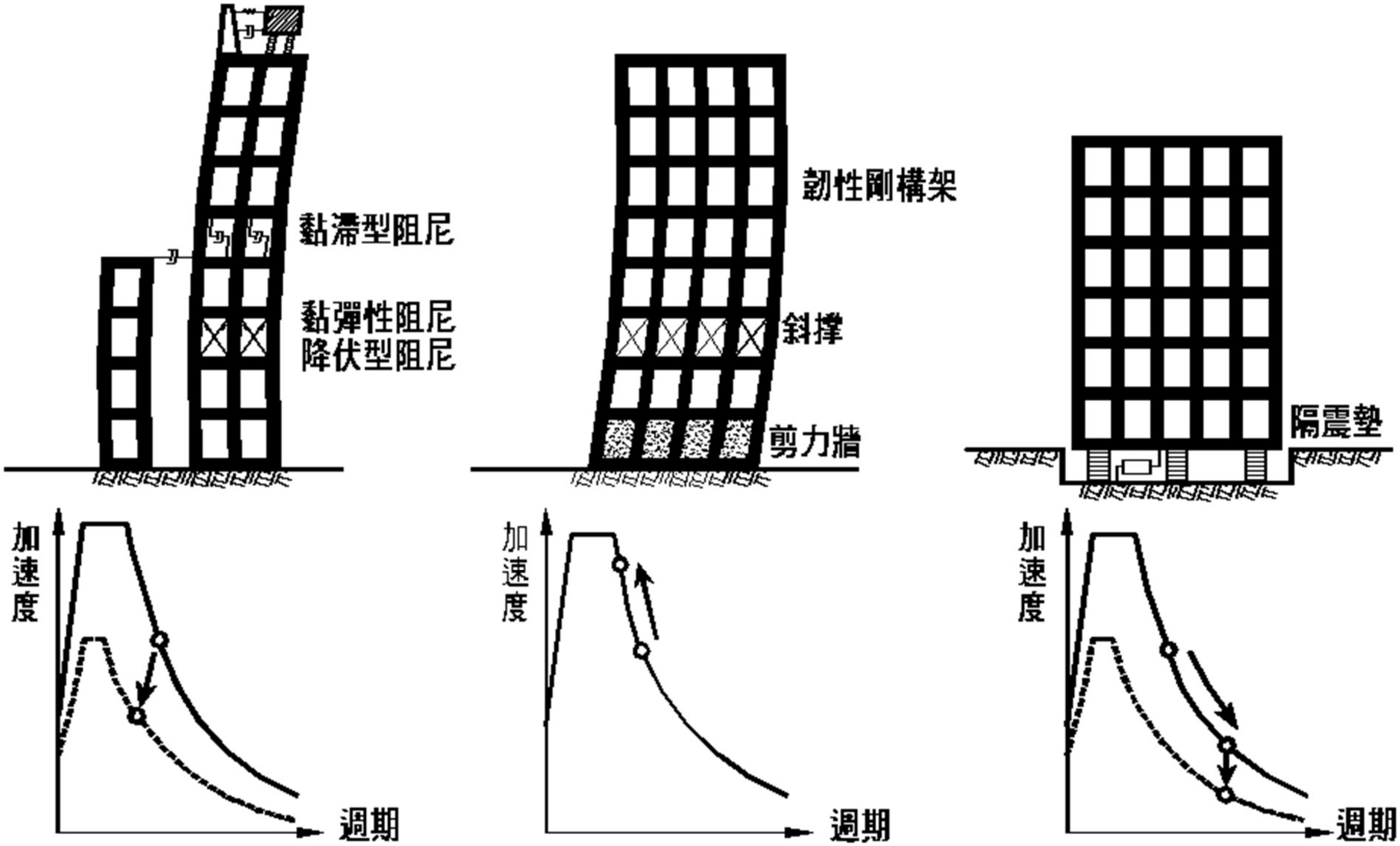
Recent Progress on Seismic Isolation and Energy Dissipation of Structures at NCREE

Kuo-Chun Chang

Seismic Design Strategies

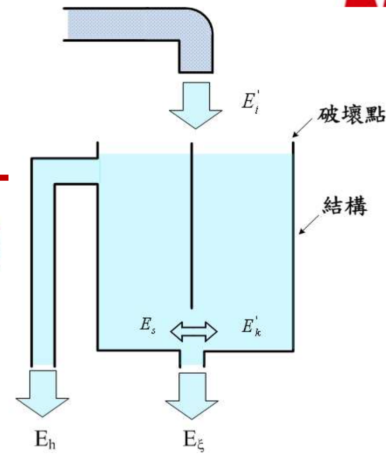
Increasing Damping | **Conventional** | **Seismic Isolation**



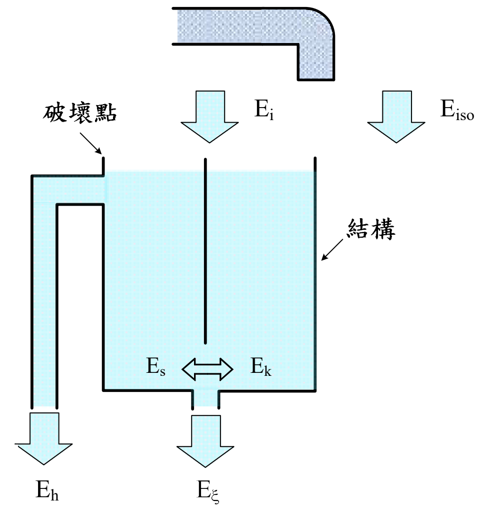
Energy Principal

$$E_K + E_D + E_S = E_I$$

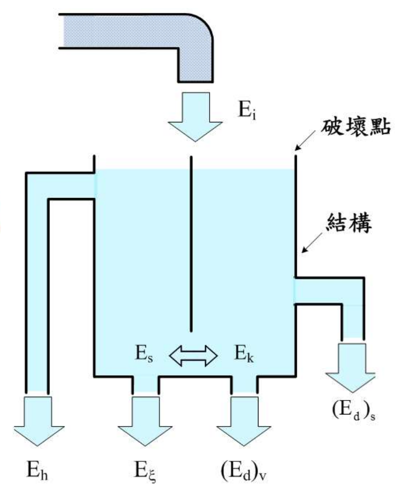
- 傳統結構耐震設計以建築本身強度(Strength)及延展性(Ductility)合稱韌性(Toughness)抵抗地震



- 隔震結構以隔震系統延長週期及增加阻尼減少結構受震反應



- 制震結構以消能系統增加阻尼減少結構受震反應



Isolation System

Equipment Isolation

Periodic Foundation

Steel Damper

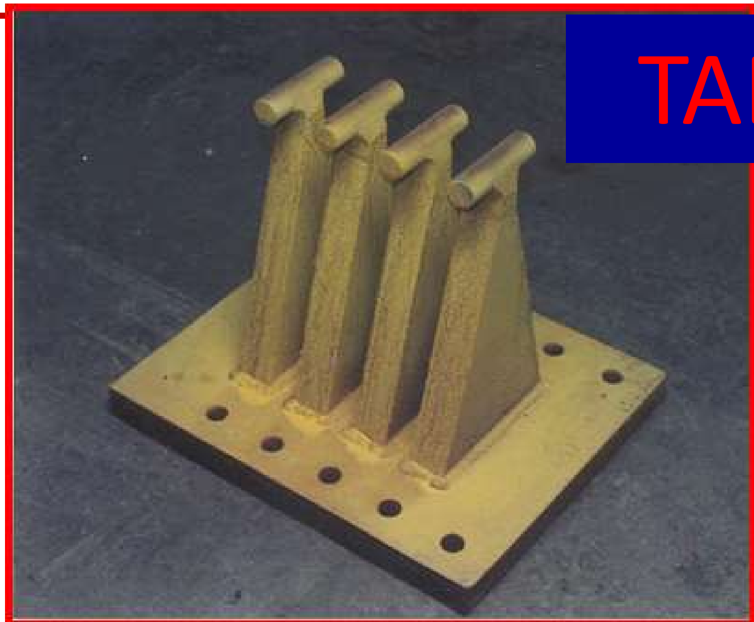
Viscoelastic Damper

Viscous Damper

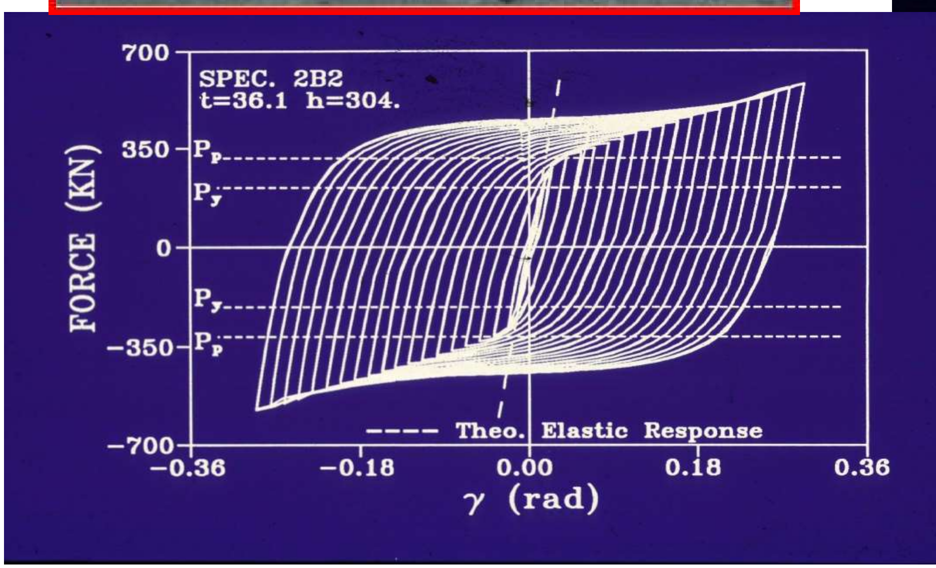
Research Overview

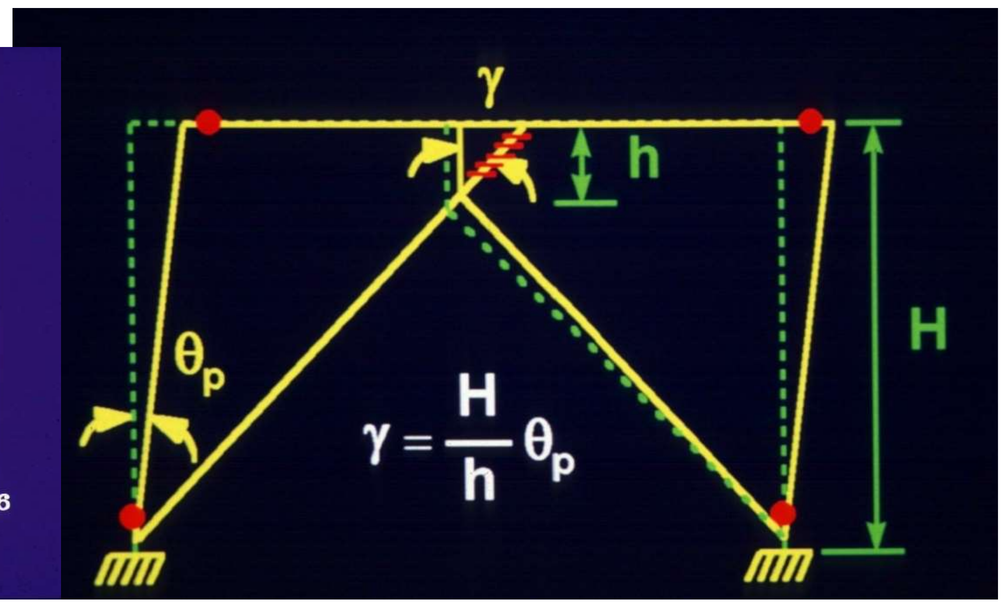
on passive structural control at NCREE

Triangular Added Damping and Stiffness (TADAS) Devices (Prof. K.C. Tsai since 1990's)



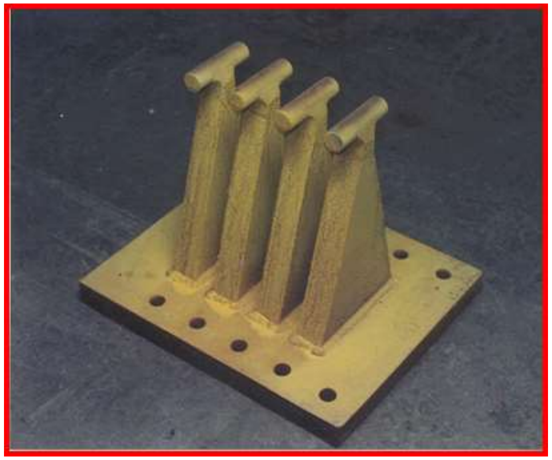
TADAS





Fubong Building in Nanjing East Road

富邦南京東路辦公大樓 (2002)

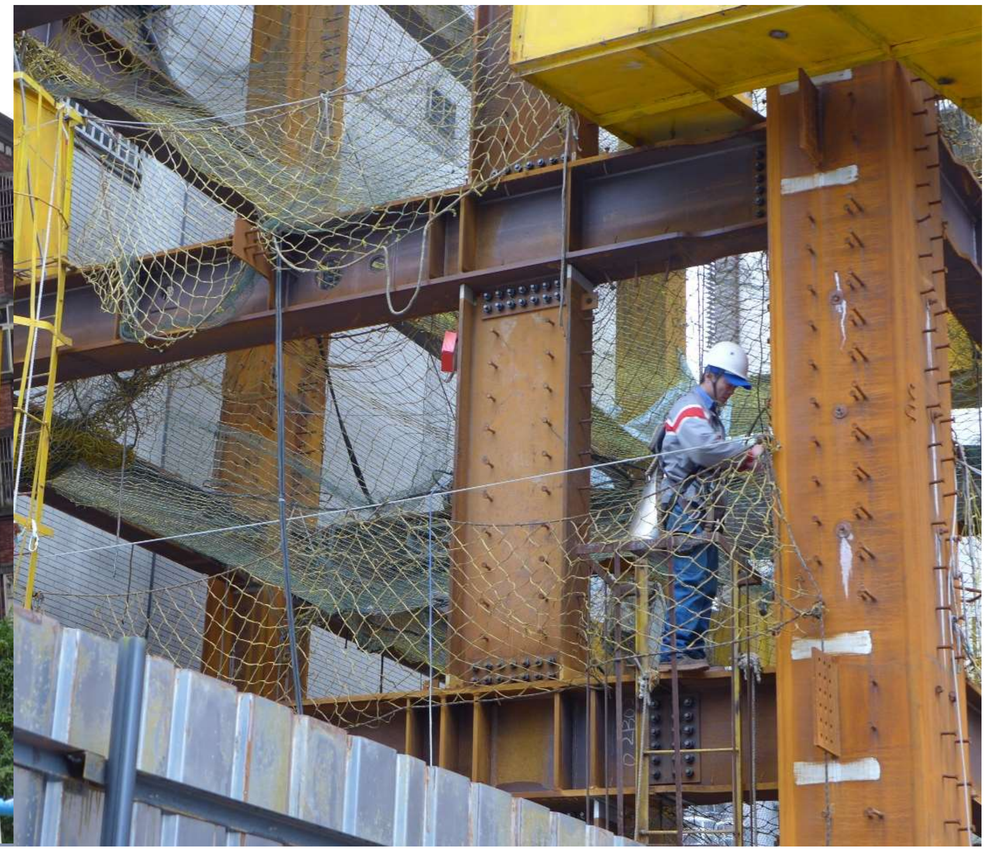


採用三角形鋼板消能裝置

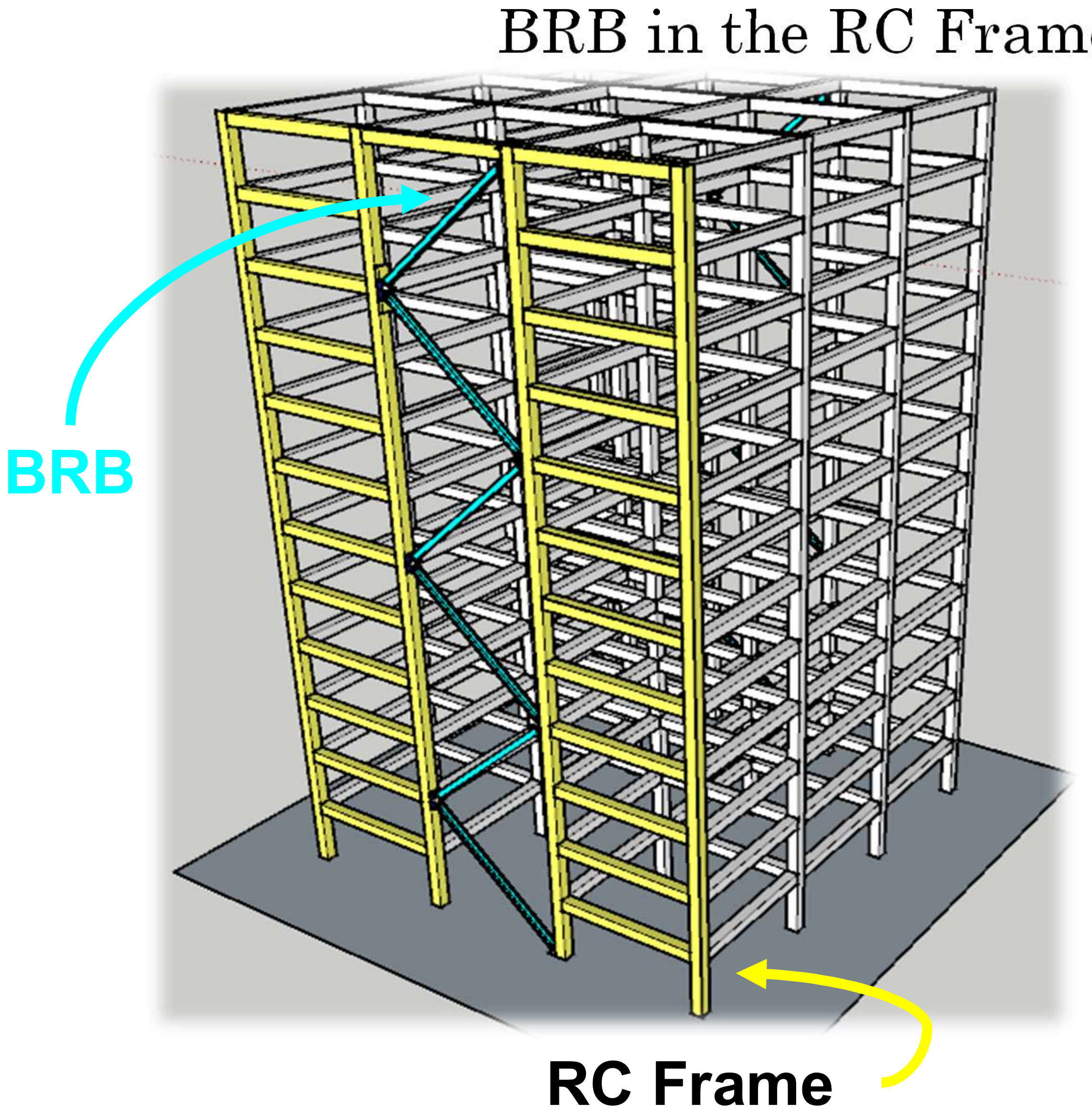
Using Steel
Damping and Stiffness (TADAS)

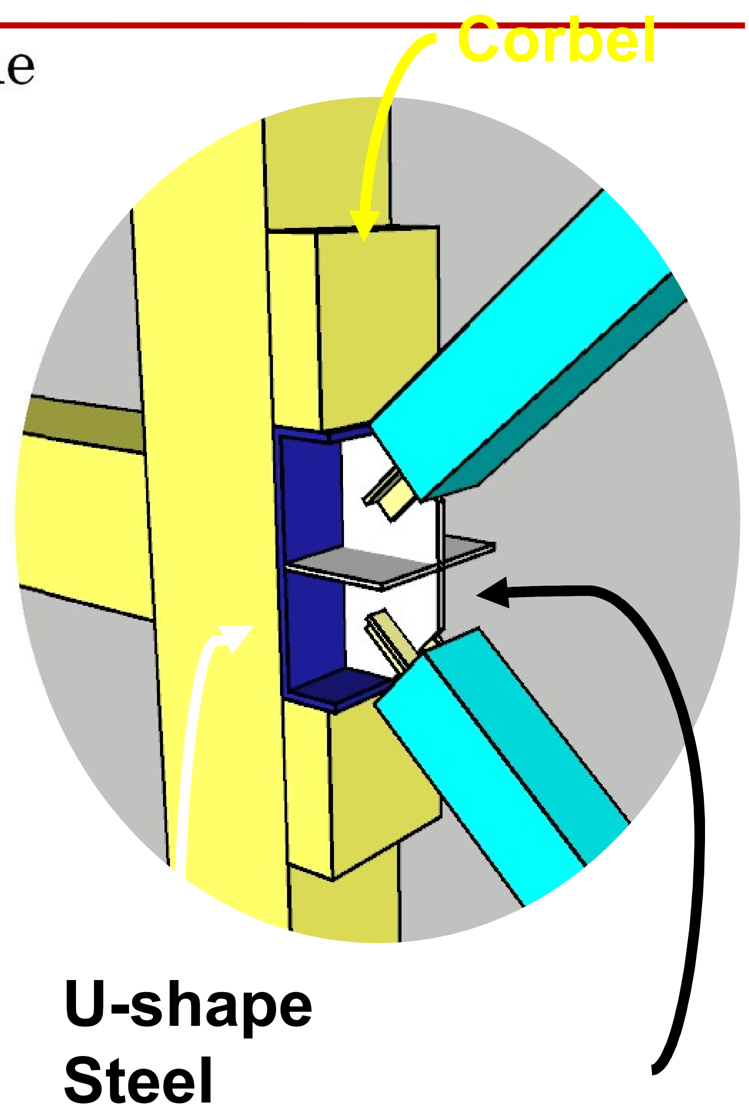
Buildings with Steel Panel Dampers

Buildings with Steel Panel Dampers



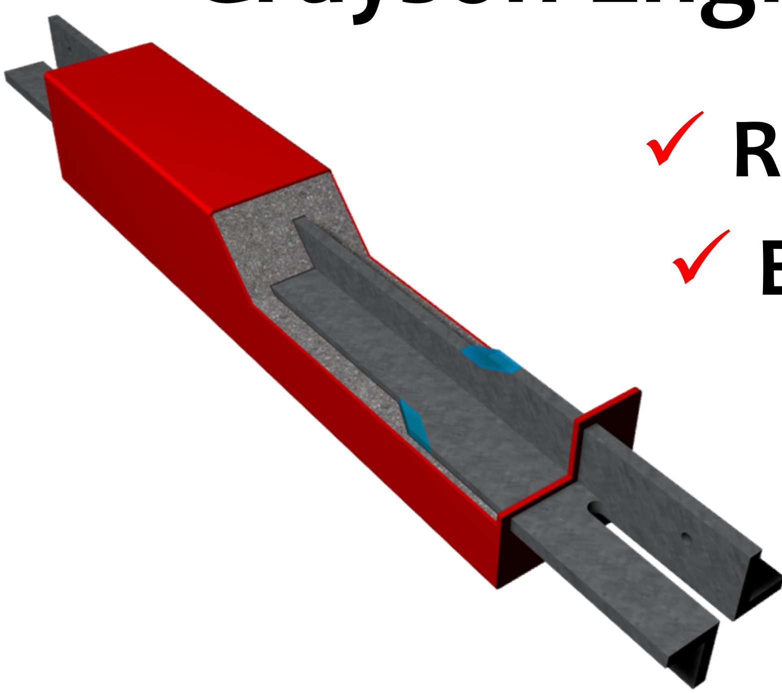
Seismic Design and Tests of Joint in the Buckling Restrained K-Braced RC Frame





Applications of Weled End Slot BRBs

- 7 fabricators licensed in Taiwan
- More than 5,000 WES-BRBs installed in more than 50 buildings
- Grayson Engineering in NZ is licensed



✓ Reliable unbonding mechanism

✓ Excellent seismic performance

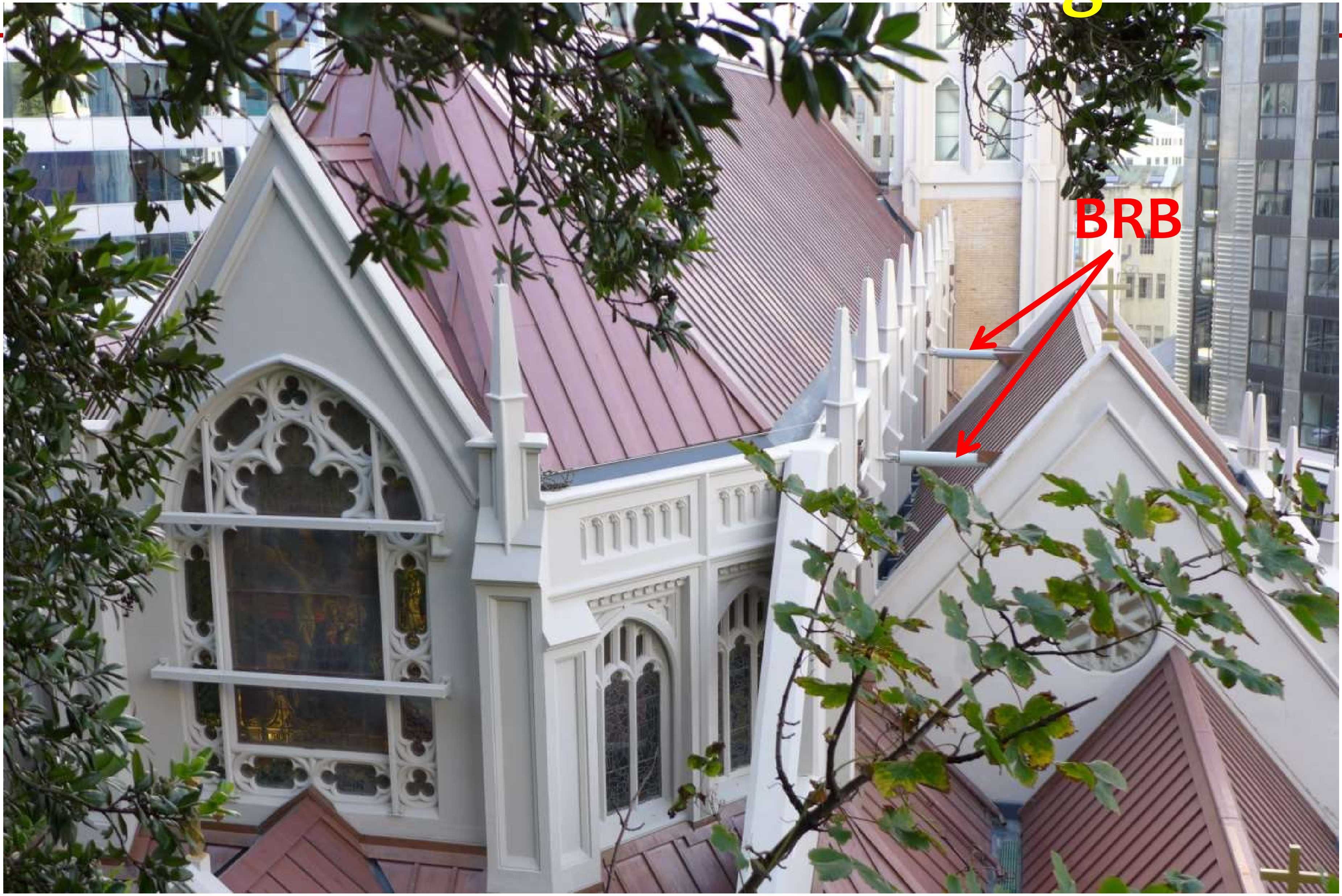
✓ Cost-effective fabrication

✓ Compact and stable end connection

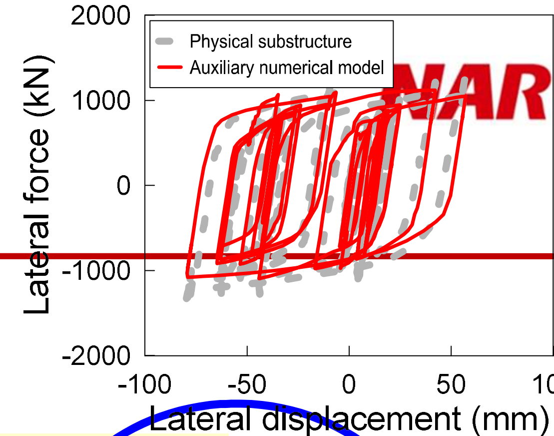
New Taipei City Stadium-1


New Zealand Society for Earthquake Engineering Conference,
Wellington, NZ; April, 2017.
Clendon Burns & Park Ltd
CONSULTING CIVIL & STRUCTURAL ENGINEERS
St Mary of the Angels Churc
2
Speaker/Engineer: Anthony Taylor

St. Mary of the Angels Church, Wellington



Hybrid simulation of steel panel damper substructures in NCREE (2017)

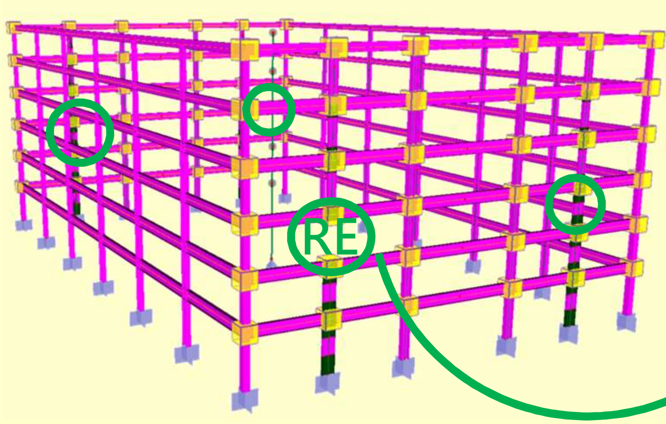


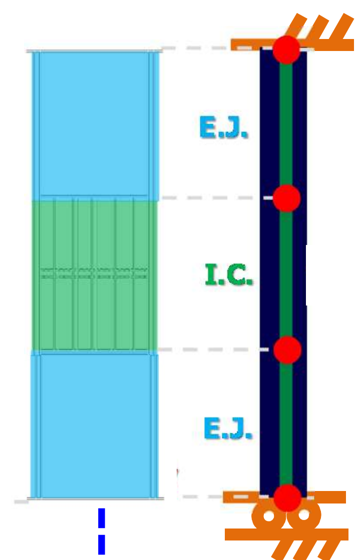
Parameter identification (PI) using the gradient-based method

Numerical Substructure (NS) + Recdex Elements (REs)

Physical Substructure (PS)

Auxiliary Numerical Model (ANM)





Conduct hybrid simulation

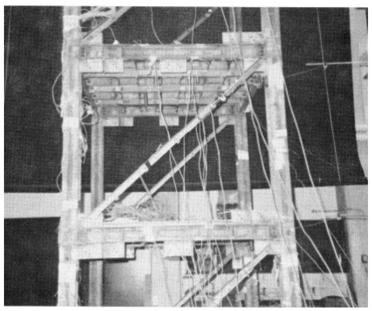
1. Update numerical models (8 SPD in 1F and 2F)
2. Update the 12 x12 stiffness matrix (Kt) via static condensation

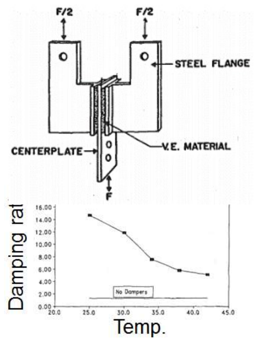
Viscoelastic Damper (Prof. KC Chyang since 1989)

1991

Effect of ambient temperature

Chang K.C, Soong TT, Oh ST, Lai ML

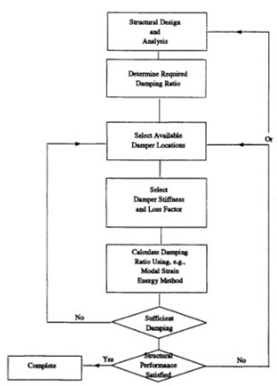




1993

Design procedure for damped structures

Chang KC, Soong TT, Lai ML, Nielsen E J



1998 懸吊式屋頂加裝黏彈性阻尼器之實例

張國鎮、許昌軍、賴明來

2001 Modal strain energy method

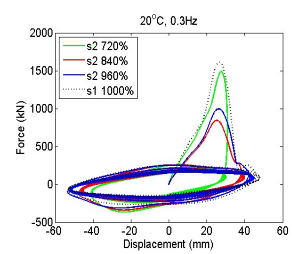
張國鎮、蔡孟豪、李森枏、陳長佑

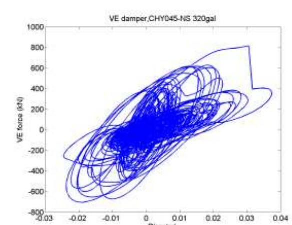
2003 High mode effect of buildings with viscoelastic dampers

Chang, K.C, Lin YY, Tsai MH, Hwang, JS

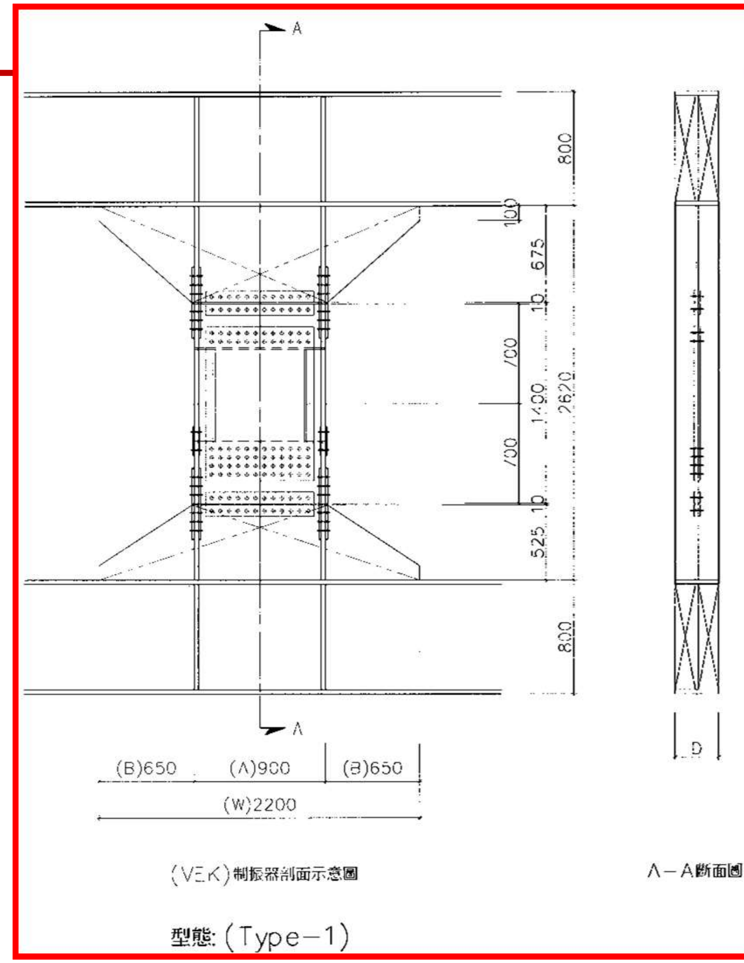
Present Full-scale viscoelastic dampers beyond design deformation

張國鎮、汪向榮、游忠翰、邱宜甄





Example of Application



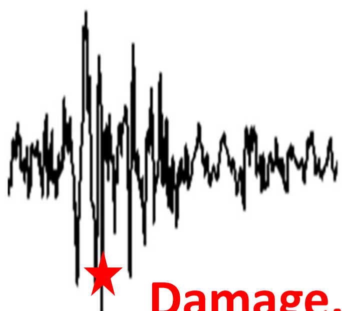
Panel-Type VE Damper

Motivation

VE dampers are often designed to remain intact (< 300% ~ 400% shear strain) under design basis shaking

What is actual performance, or any damage under…

Maximum considered or stronger ground shaking



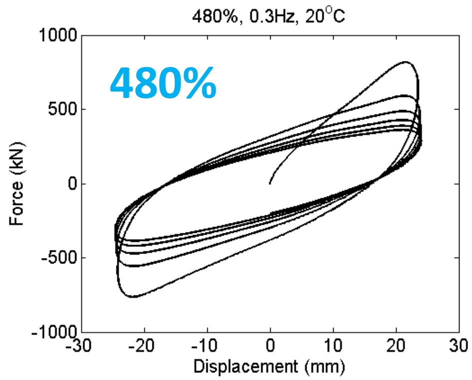
Damage, if any

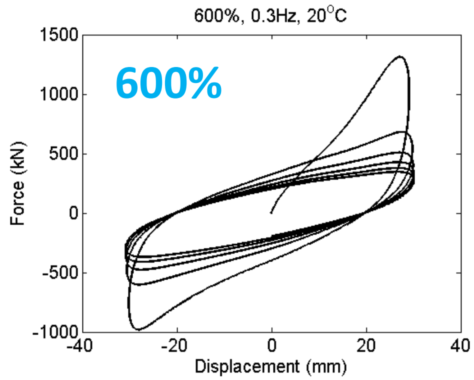
and

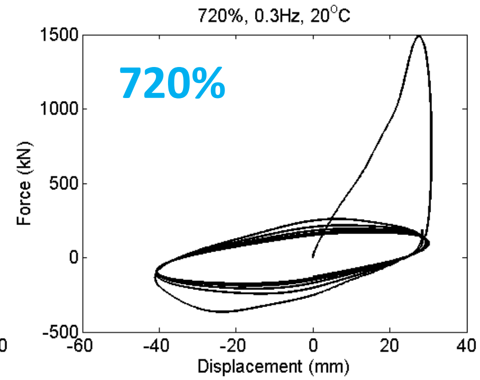
Aftershock

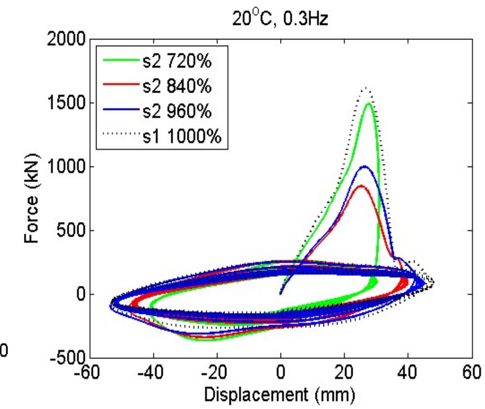
Test Results

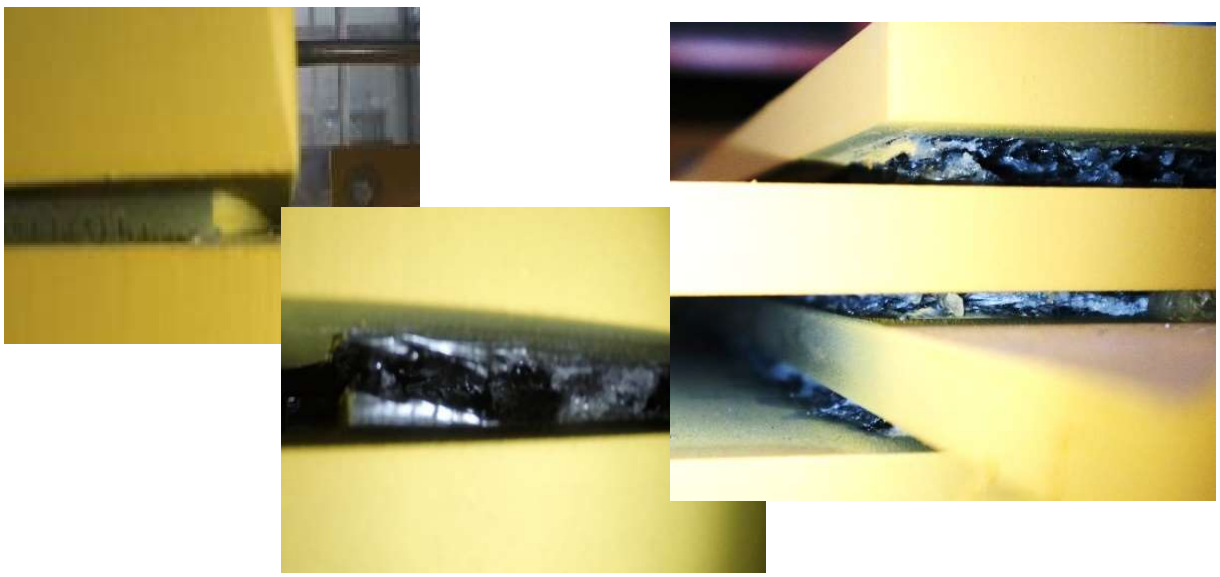
After 720%

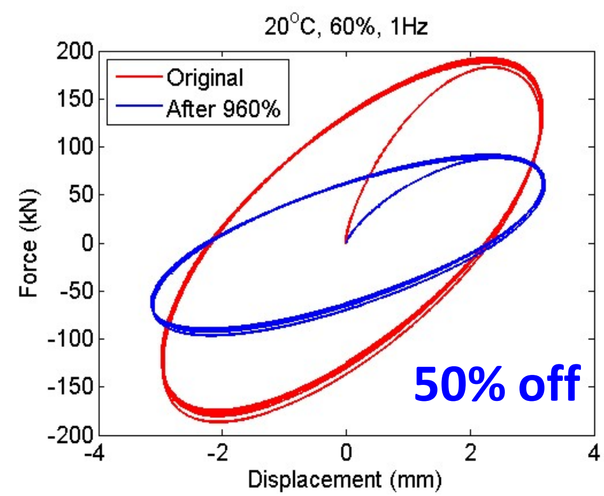












Department of Civil Engineering
National Taiwan University

Viscous Damper (1997~)

1997

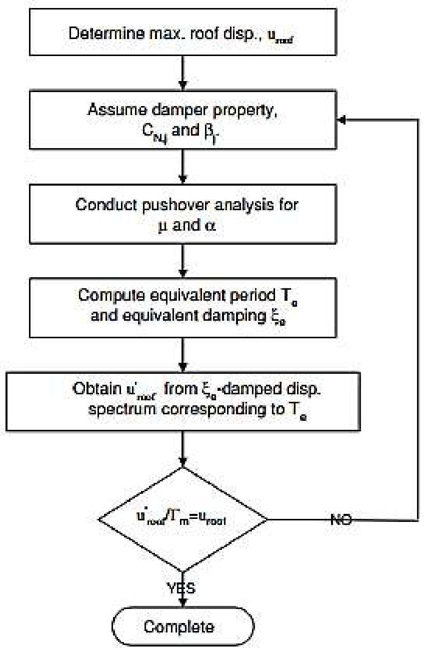
Displacement based design procedure

Chang KC, Lin YY, Chen CY

2000

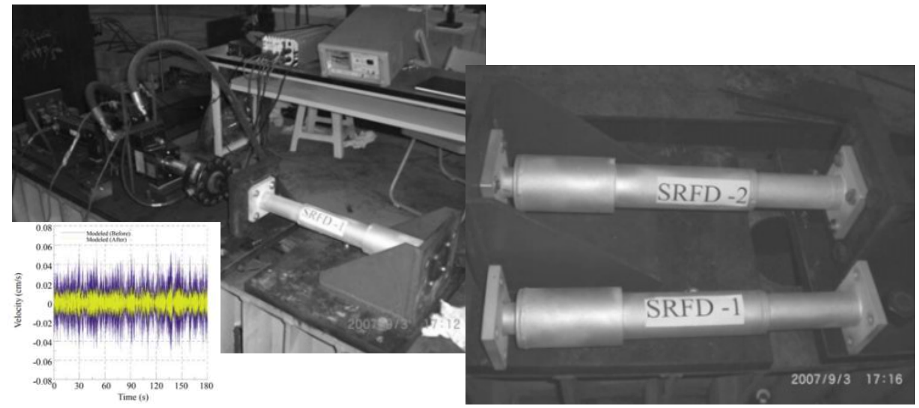
Seismic retrofit of existing building

Chang KC, Hwang JS, Wang SJ, Huang YN, Chen JF



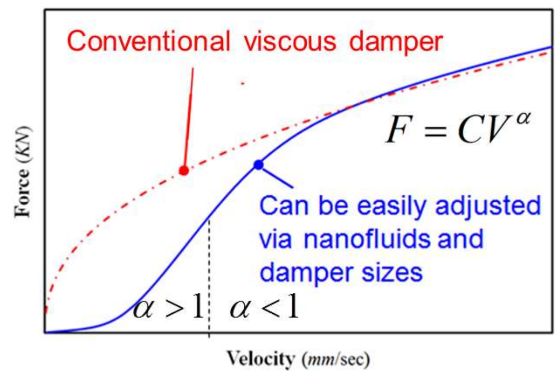
2009 Mitigation of micro vibration

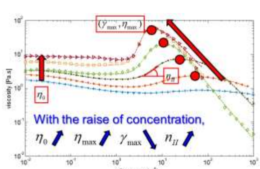
Chang KC, Lin TK, Chen CC, Lin CC



Present **Smart Nanofluid Damper**

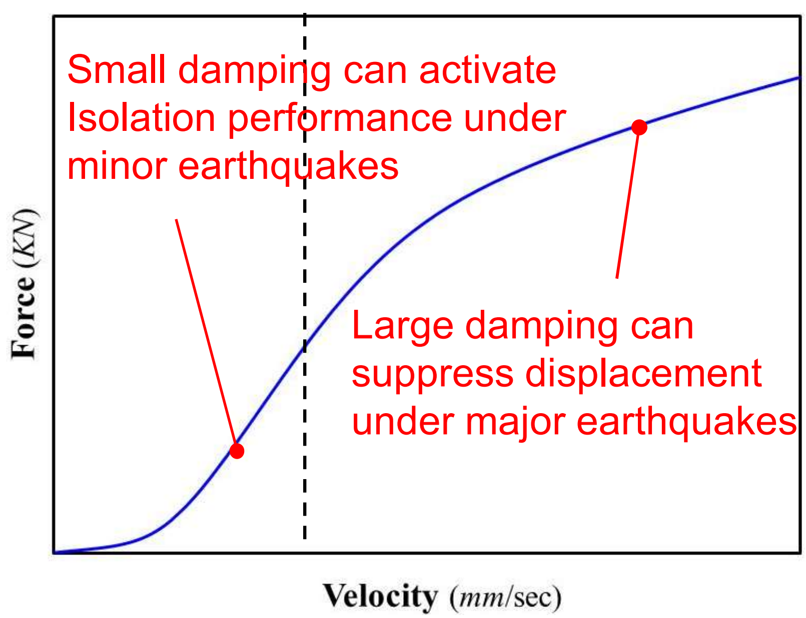
張國鎮、游忠翰、葉方耀、汪向榮、陳宗珷



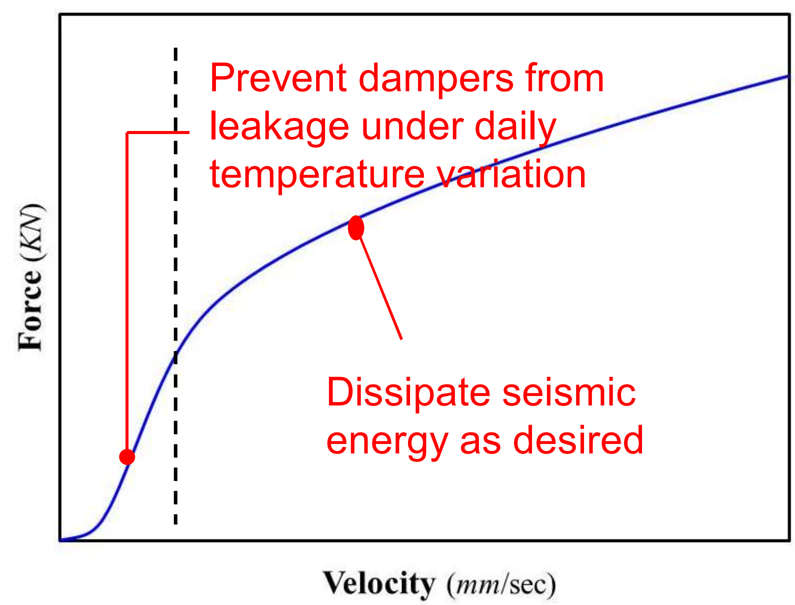


Properties of Nanofluid Damper

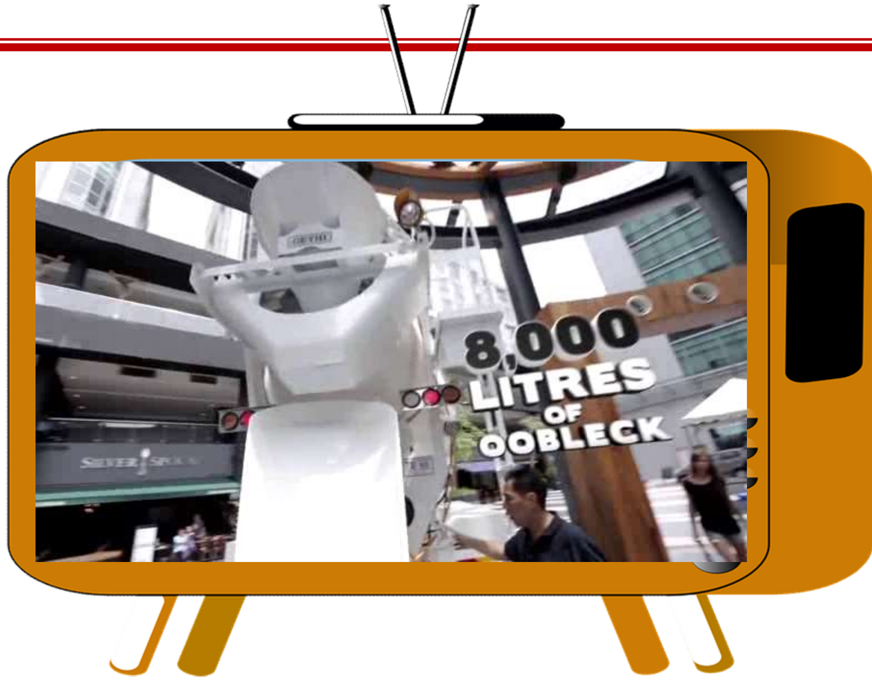
For seismically isolated buildings



For bridges



Properties of Shear Thickening Fluid (STF)



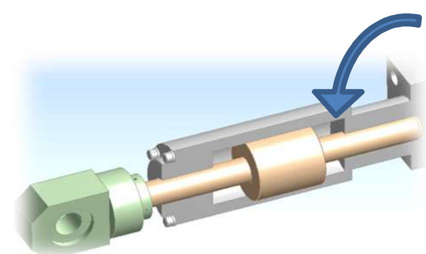
Idea!

Fumed silica particle
(Nano-scale)

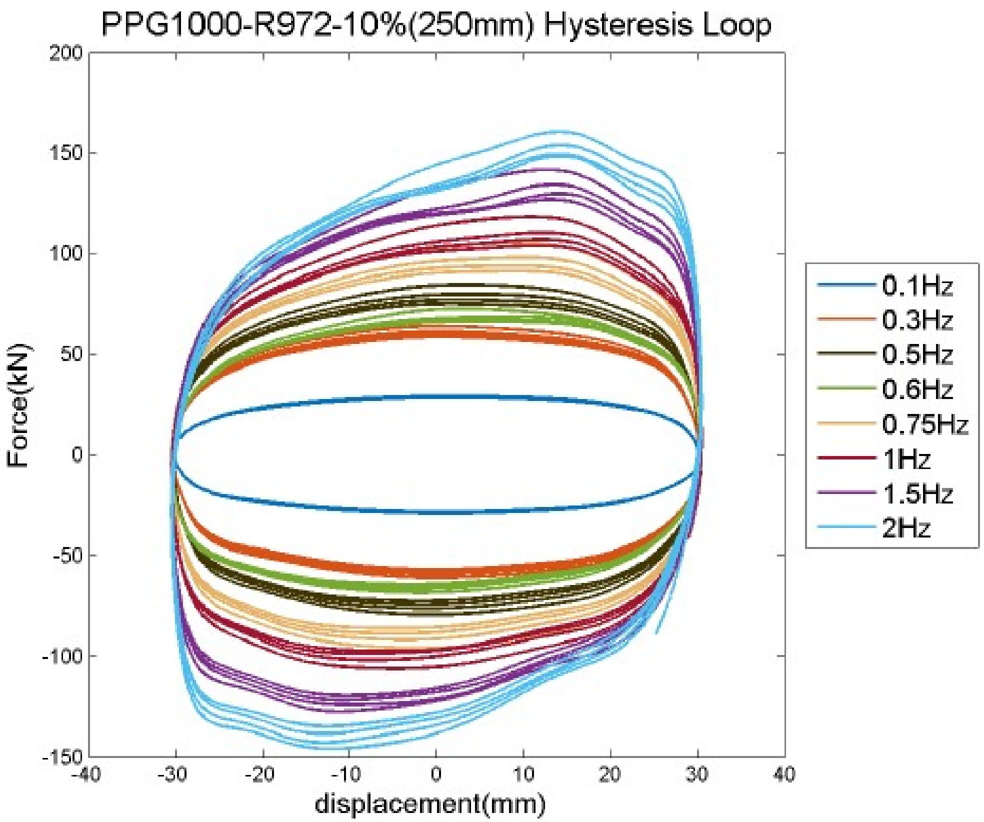
+

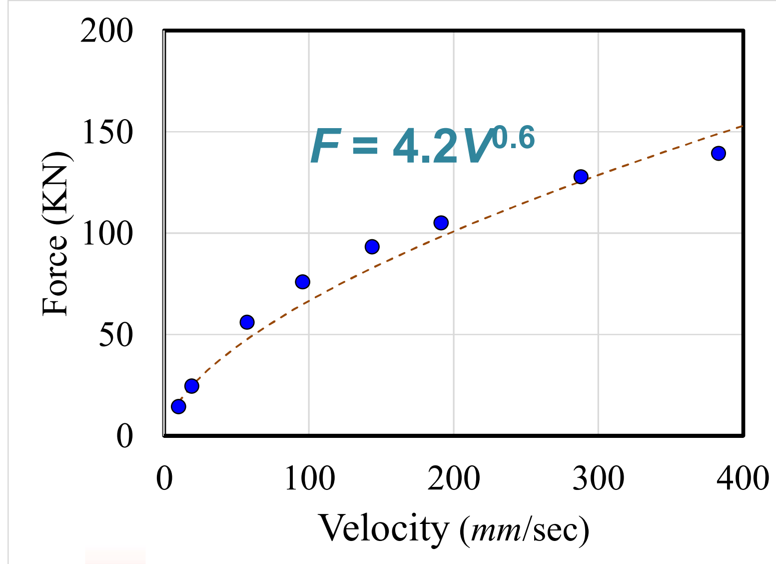
Polypropylene glycol
(PPG)

= **Shear Thickening Fluid**

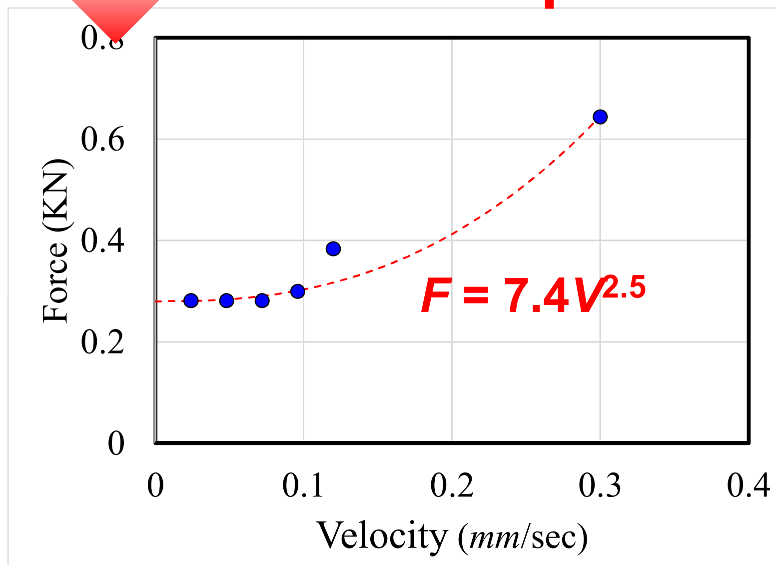


Full-Scale Nanofluid Damper Test





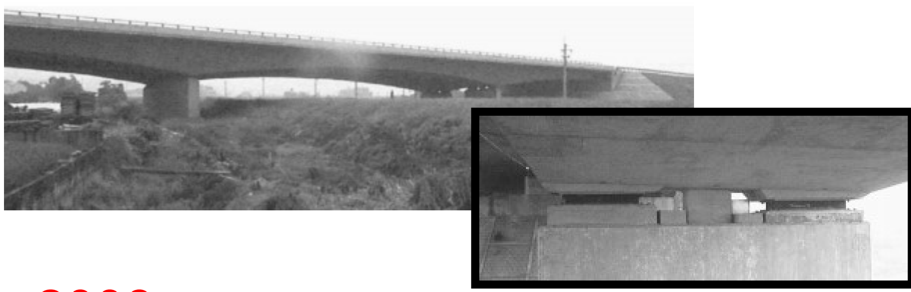
At low speed



Seismic Isolation System (~1994)

1994 ~ 2004 First seismically isolated bridge in Taiwan: design & performance

Chang, K.C., Hwang, J.S., Yeh, M.H., and Chen, C.C.

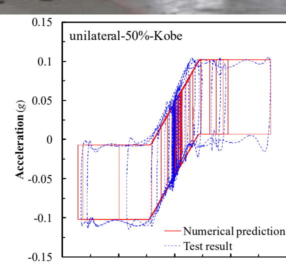


2003~

Sloped Rolling-type Seismic Isolator

Chang, KC, Wang RJ, Ou YC, Lee GC, Wang SJ, Lin WC, Yu CH

bridge with rolling type bearings



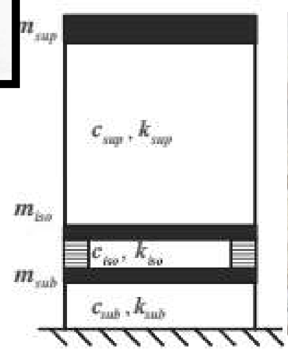
2004 Seismically isolated bridge under near-fault earthquake

KC Chang, J Shen, MH Tsai, GC Lee.

2005

Mid-story seismic isolation design

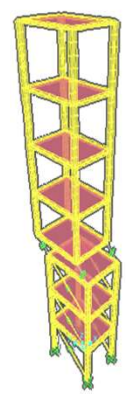
張國鎮、汪向榮、李柏翰、江春琴、林孟慧、洪瑩真

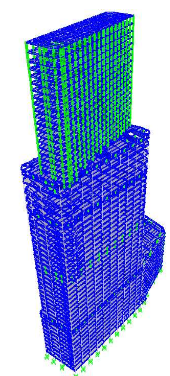


Present

Building mass damper design

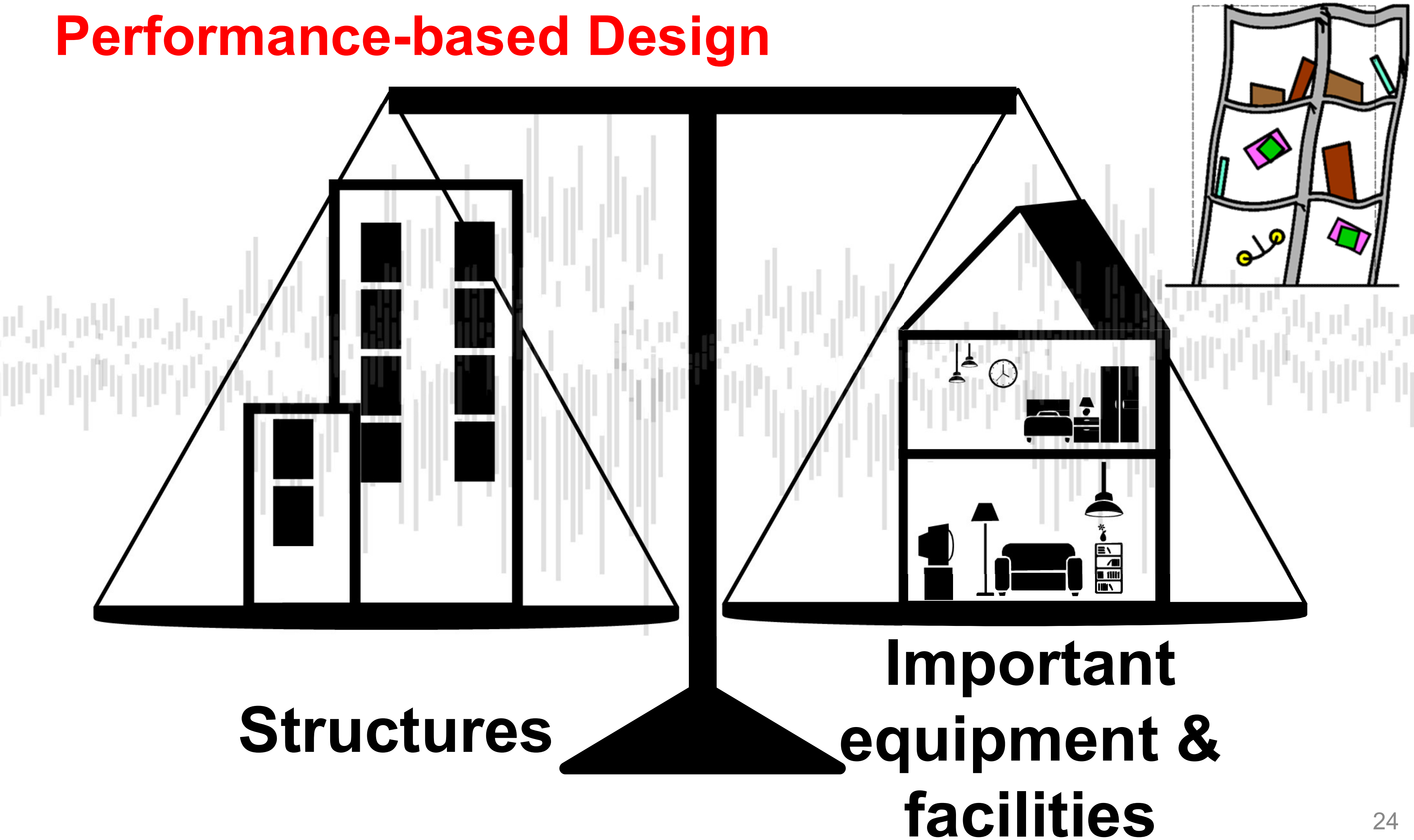
張國鎮、汪向榮、李柏翰、區瑋磯、
簡亭宜、陳穎萱、莊幃竹、郭世璞



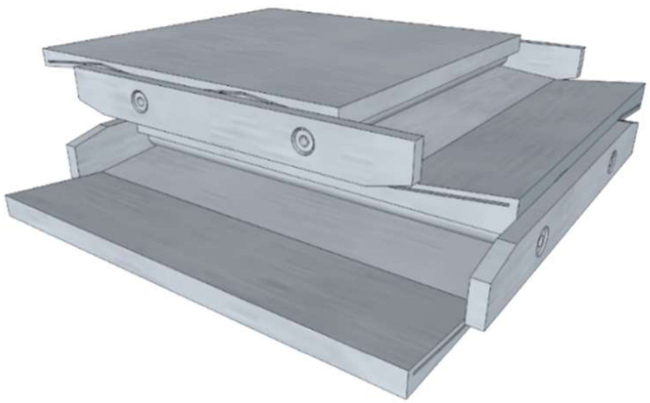


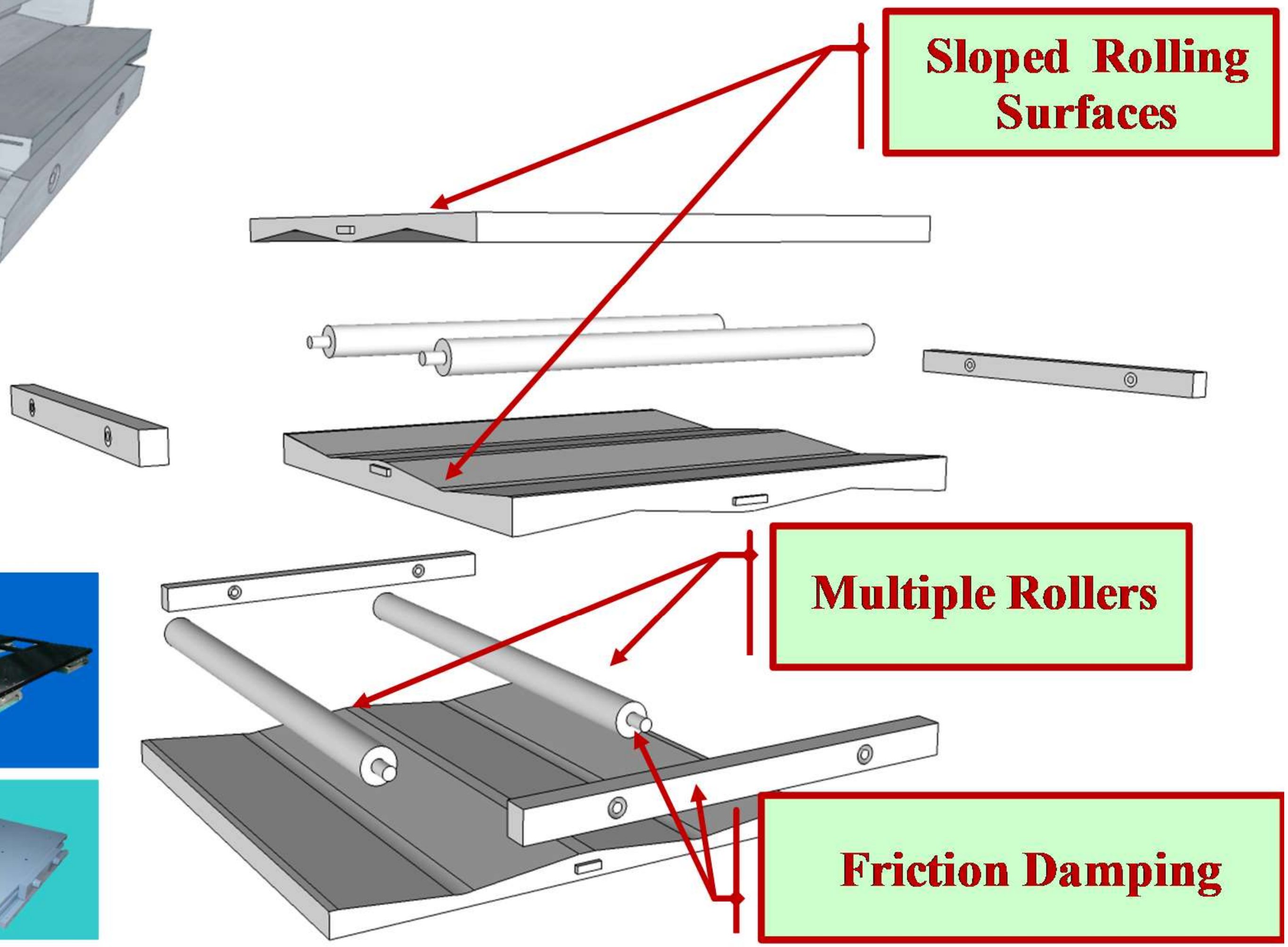
Motivation of Sloped Rolling-type Seismic Isolators

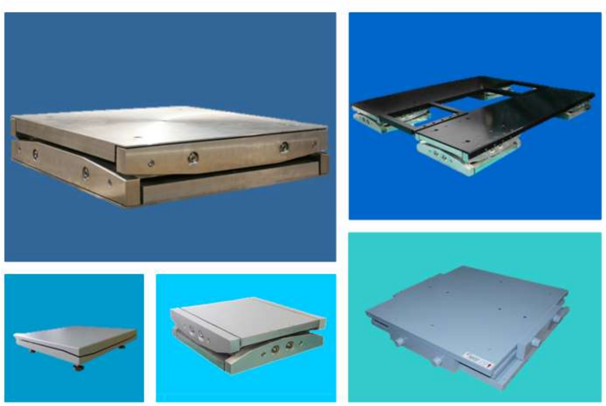
Performance-based Design



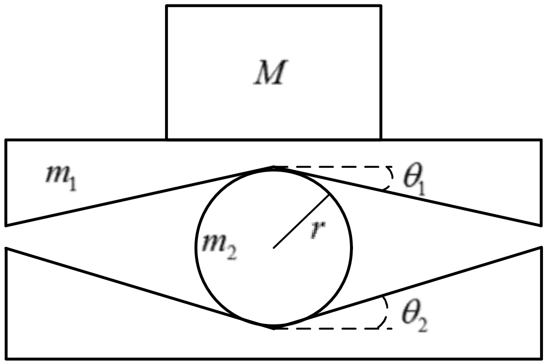
Sloped Rolling-type Seismic Isolators



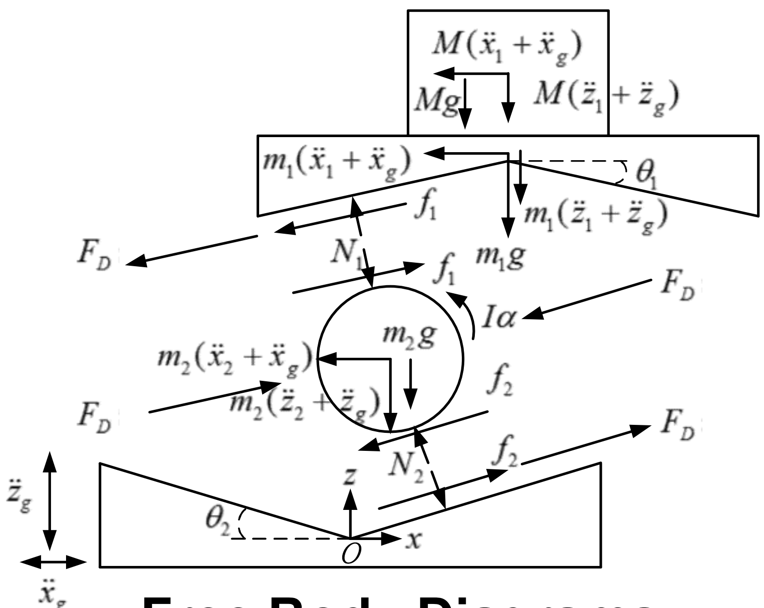




Generalized Equations of Motion



Static Condition



Free Body Diagrams

Dynamic force and moment equilibrium + Compatibility conditions

Nine variables are solved using nine equations

Neglect $m_2/(M+m_1)$

Exact Sol.
developed analysis programs

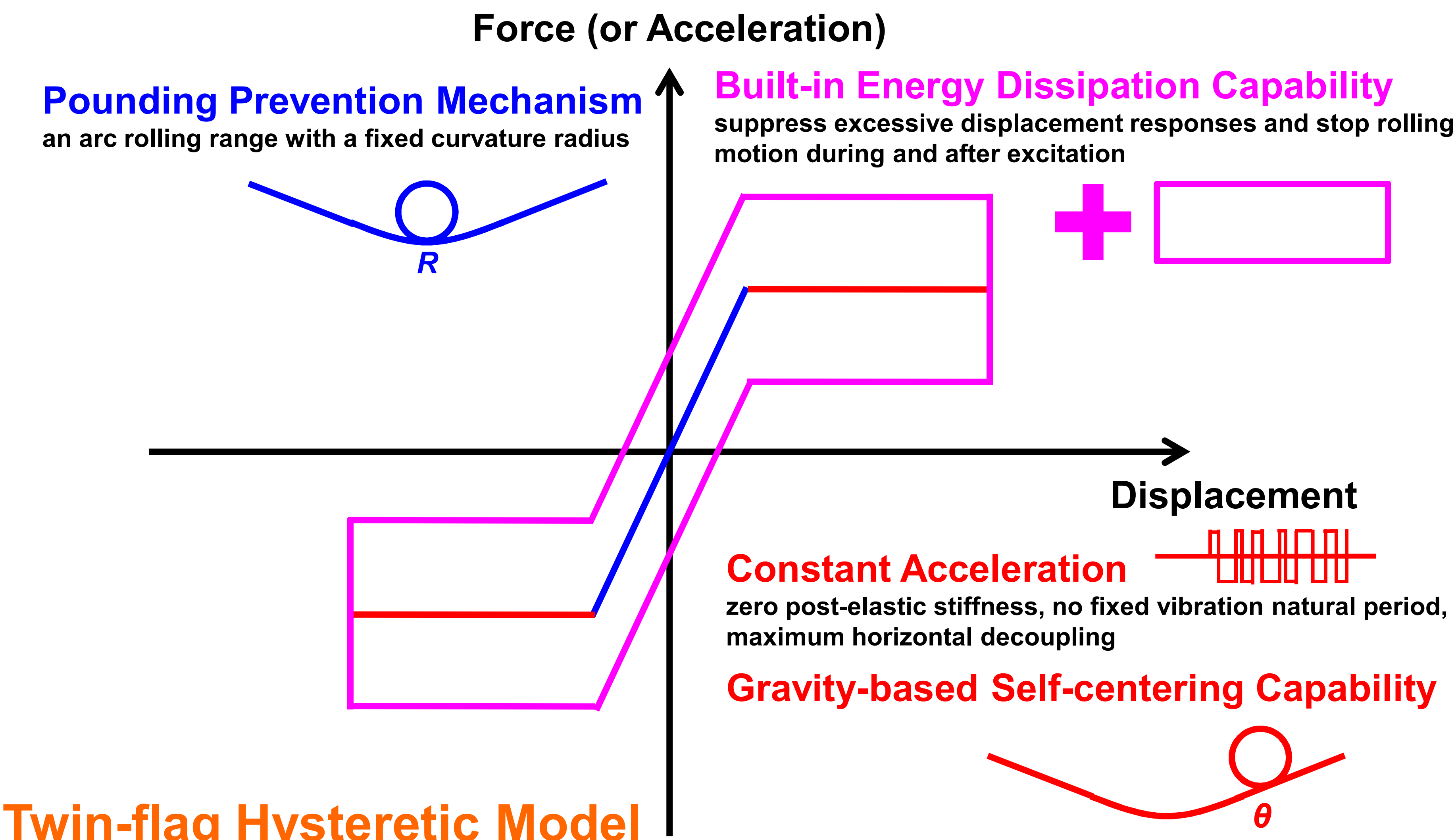
$$\ddot{x}_1 = \frac{-(\cos\theta_1+\cos\theta_2)}{2(M+m_1)[1+\cos(\theta_1-\theta_2)]}\{2F_D\,\mathrm{sgn}(\dot{x}_1) + (M+m_1)[\ddot{x}_g(\cos\theta_1+\cos\theta_2)+(g+\ddot{z}_g)(\sin\theta_1+\sin\theta_2)\mathrm{sgn}(x_1)]\}$$

Neglect higher order terms of θ_1 and θ_2, as well as $\ddot{z}_g$

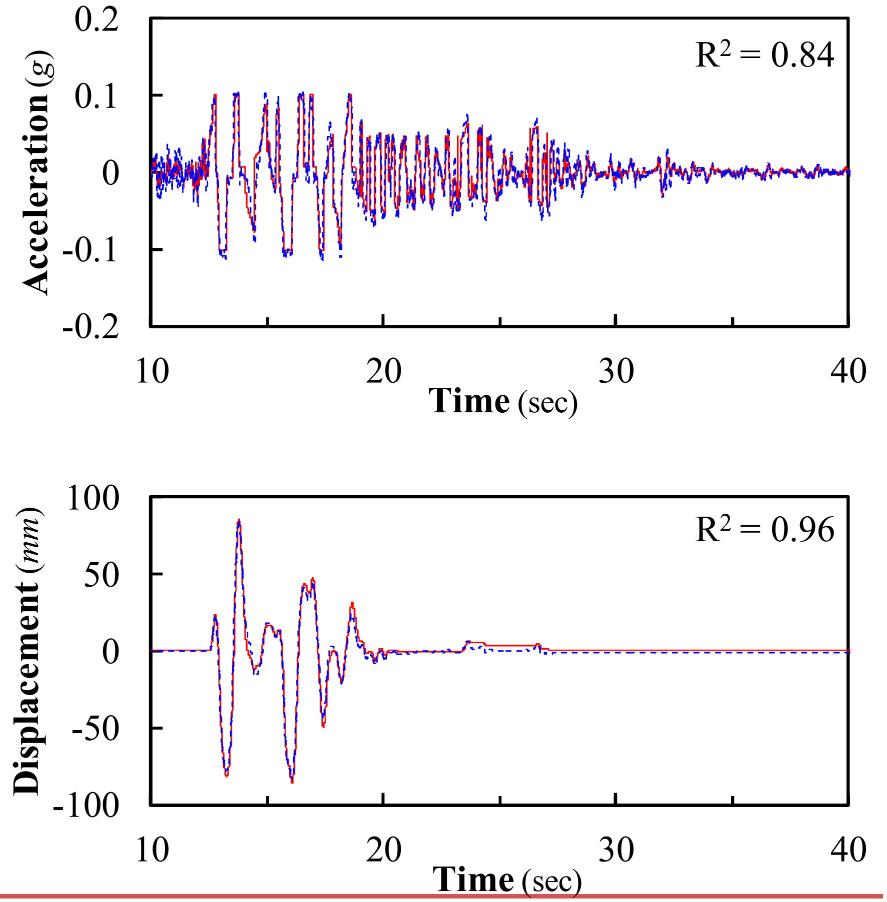
Simplified Sol.
most commercial computational tools

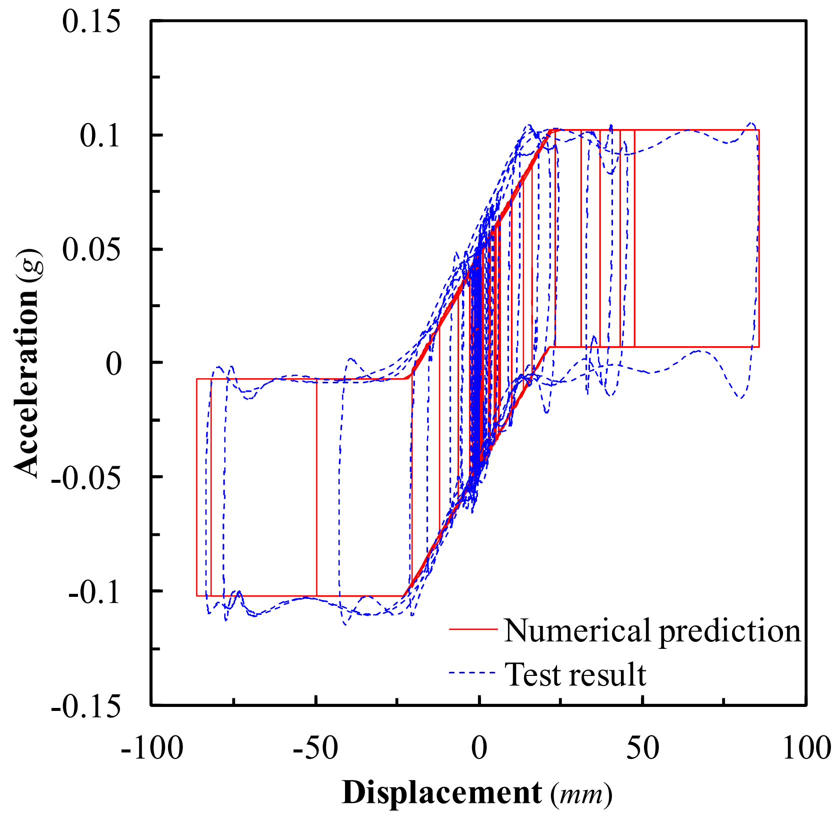
$$\ddot{x}_1 = \frac{-(\cos\theta_1+\cos\theta_2)}{4(M+m_1)}[2F_D\,\mathrm{sgn}(\dot{x}_1)+(M+m_1)g(\sin\theta_1+\sin\theta_2)\mathrm{sgn}(x_1)] - \ddot{x}_g$$

Hysteretic Model (Features)



Experimental & Numerical Results

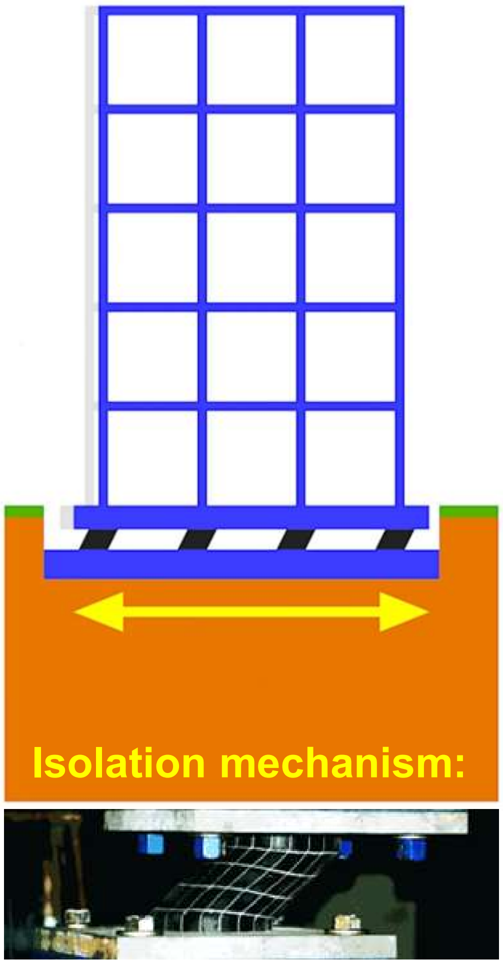




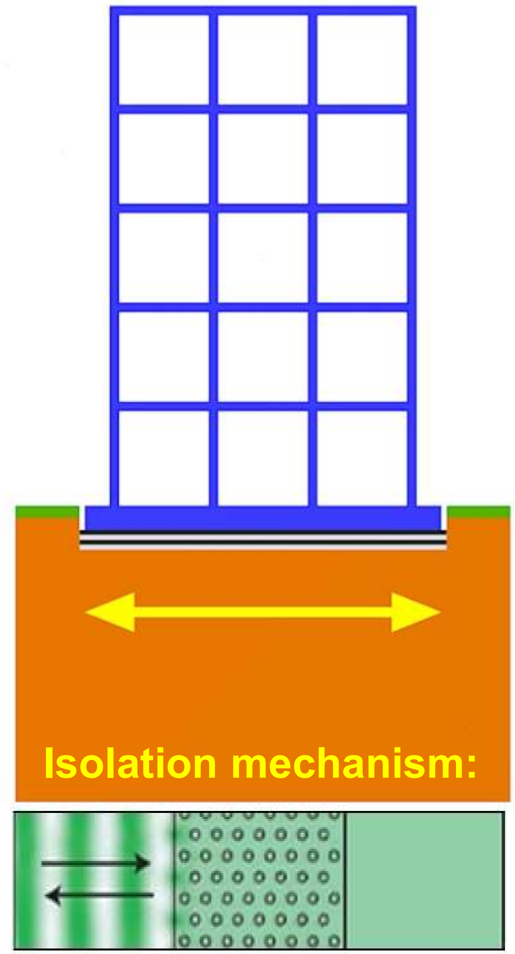

921地震模擬
隔震文物展示櫃耐震測試
未隔震
有隔震
未隔震
有隔震

Seismic Periodic Foundation (Joint Research with Houston University)

Structure with conventional base isolation

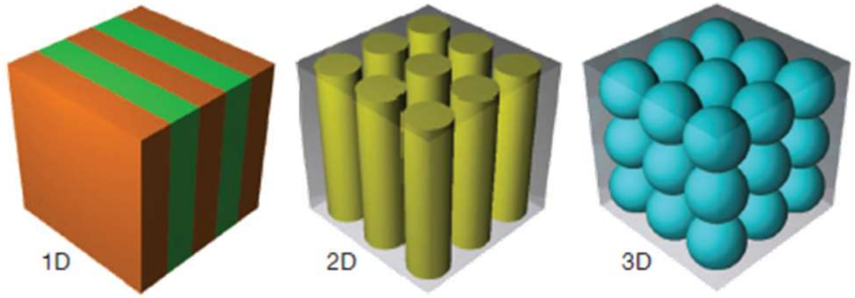


Structure with periodic foundation

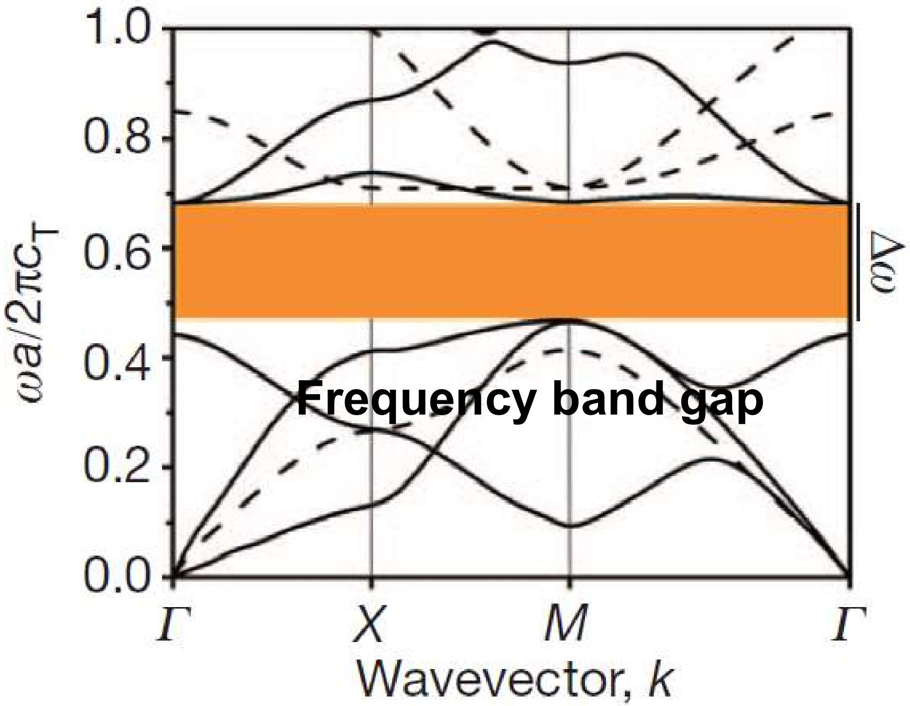


Basic Concept

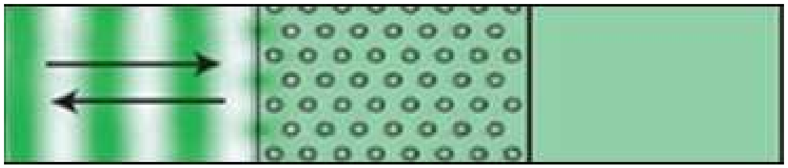
Different types of Phononic Crystal developed in solid-state-physics



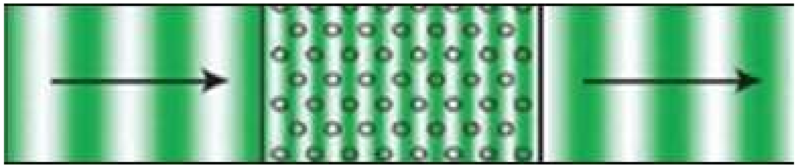
Typical Dispersion Curve



Wave Propagation



Wave propagation with frequency within the frequency band gap



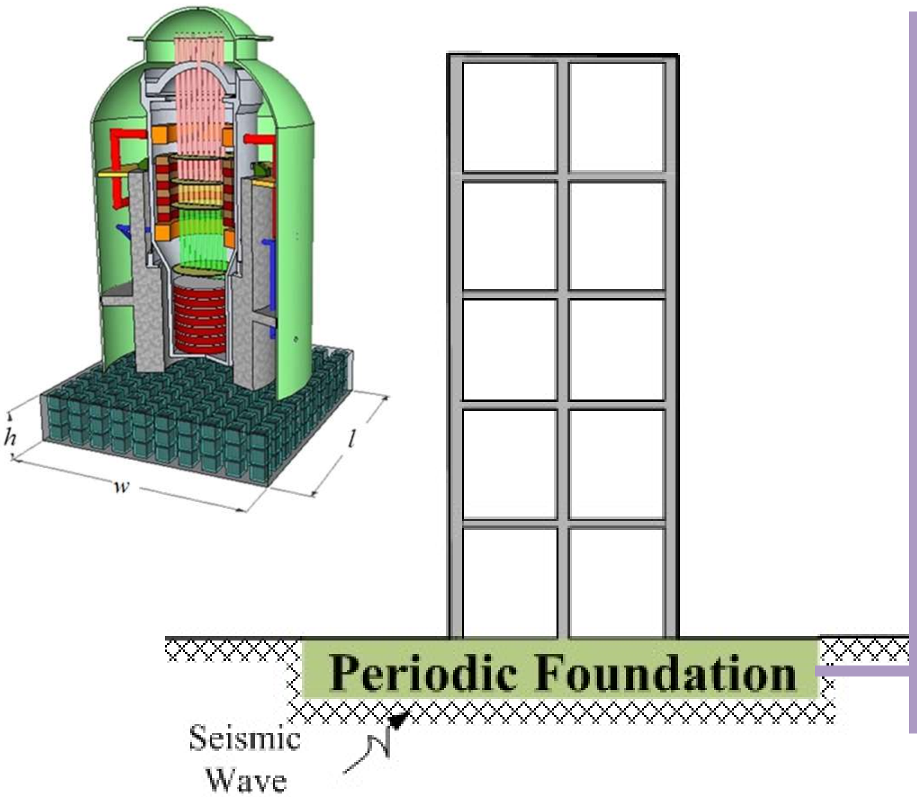
Wave propagation with frequency outside of the frequency band gap

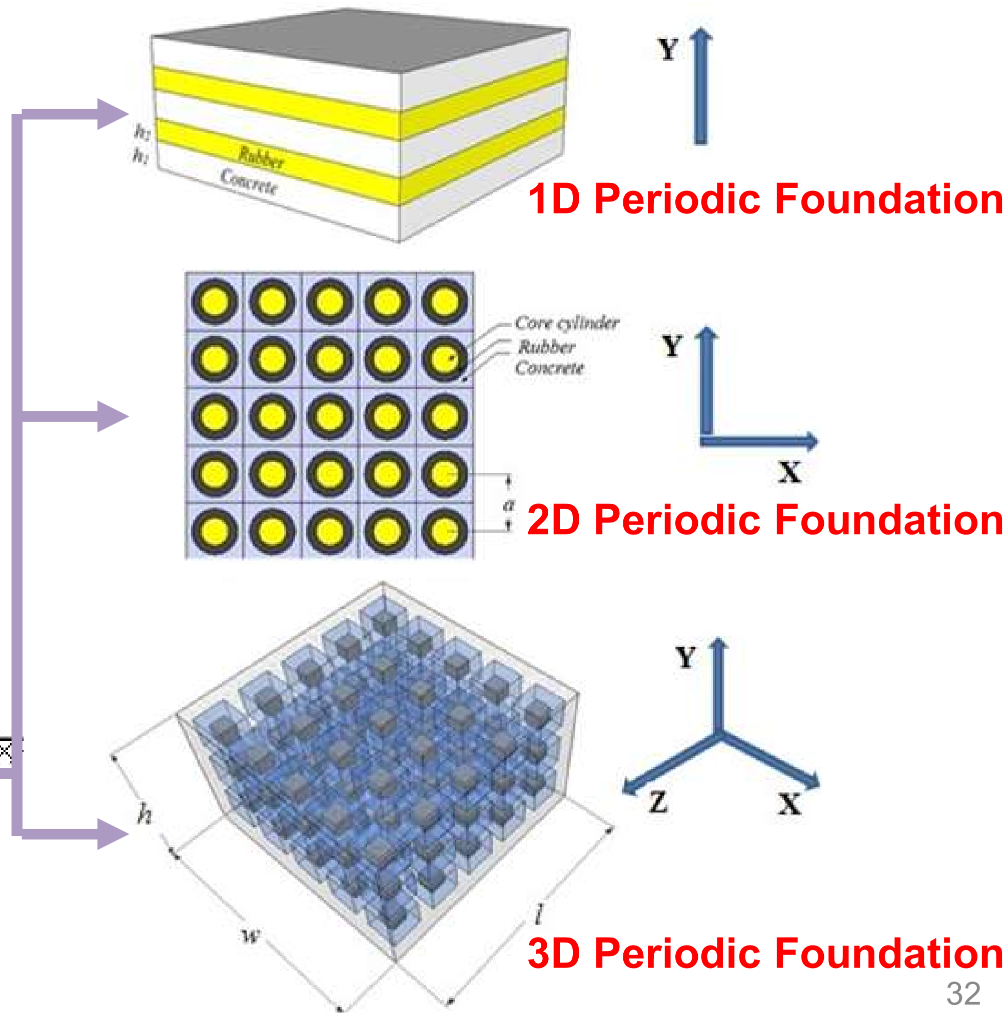
Wave Equation → **Dispersion Relation** → **Frequency Band Gaps**

Applied to Civil Engineering Field

Critical facilities

e.g. nuclear power plants (NPPs) and high-tech factories

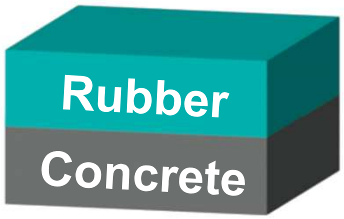




Materials: Concrete, Rubber

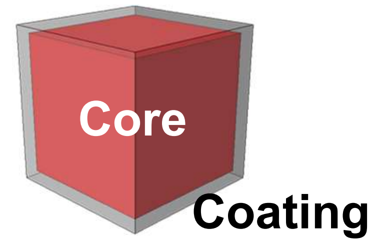
Parametric Study

1D Periodic Foundation



- Rubber material properties (Young's modulus, density, and Poisson's ratio)
- Concrete material properties (Young's modulus, density, and Poisson's ratio)
- Geometric properties (Rubber-to-concrete thickness ratio)
- Cross section sizes
- Number of unit cell
- Combined unit cells
- Damping

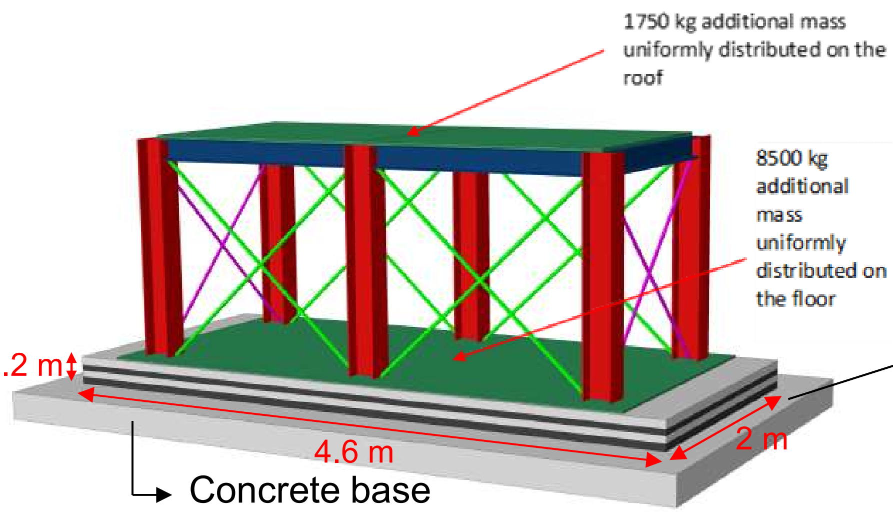
3D Periodic Foundation



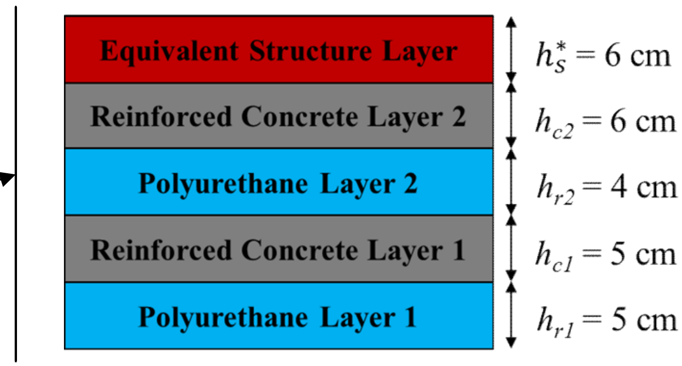
- Material properties (Young's modulus, density, and Poisson's ratio)
- Geometric properties (Filling ratio)
- Number of unit cell in horizontal direction
- Number of layers in vertical direction
- Damping

Design of Specimen with 1D Periodic Foundation

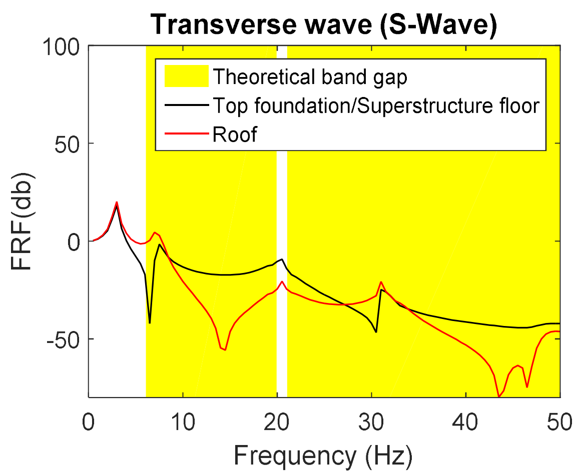
Designed structural system



Designed periodic foundation unit cell



Frequency response function (FRF)



$$\mathrm{FRF} = 20\log(\delta_{out} / \delta_{inp})$$

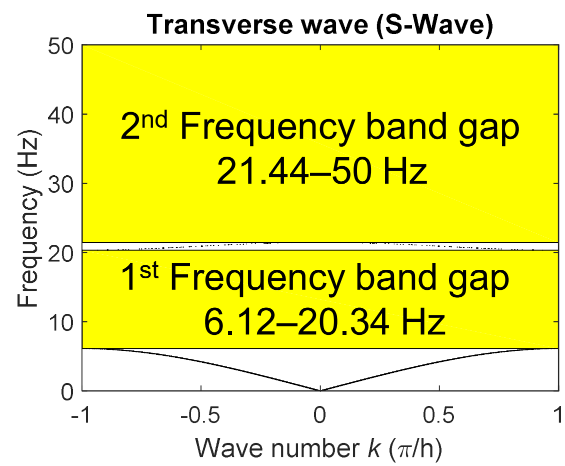
where:

δ_{out} = amplitude of output disp

δ_{inp} = amplitude of input disp

If FRF = -20, the vibration response is reduced to 10%.

Theoretical frequency band gap



Fabrication of 1D Periodic Foundation

Construction of superstructure

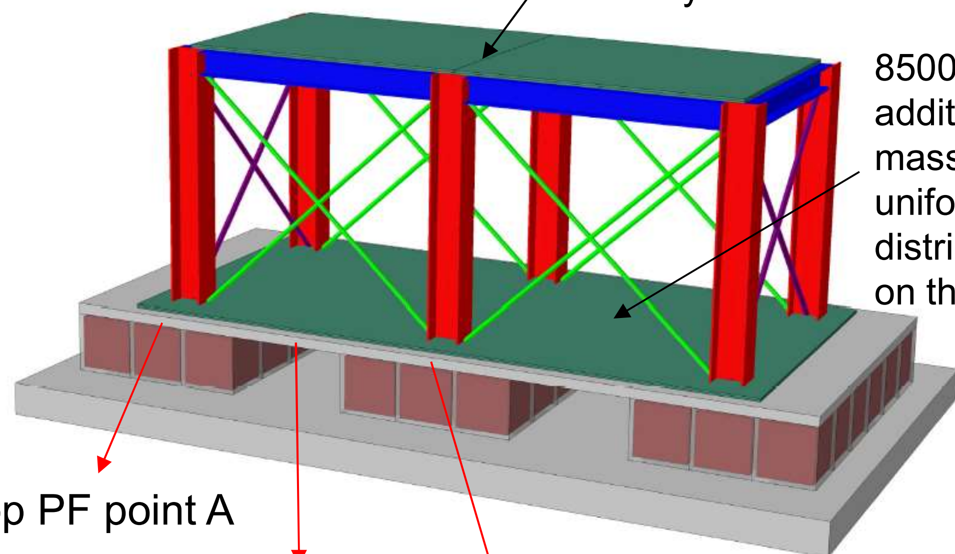
Casting of concrete layers

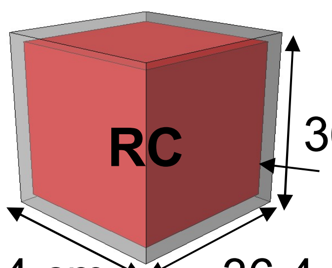
Resin solution and polyurethane glue

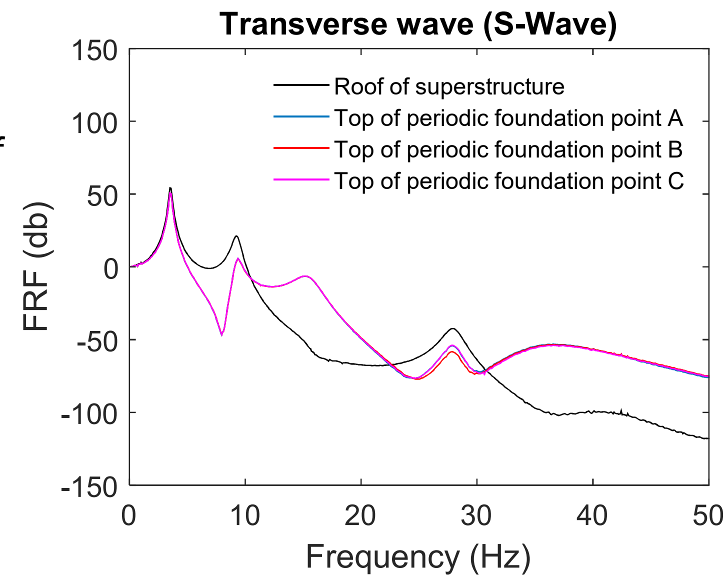
Construction of 1D periodic foundation

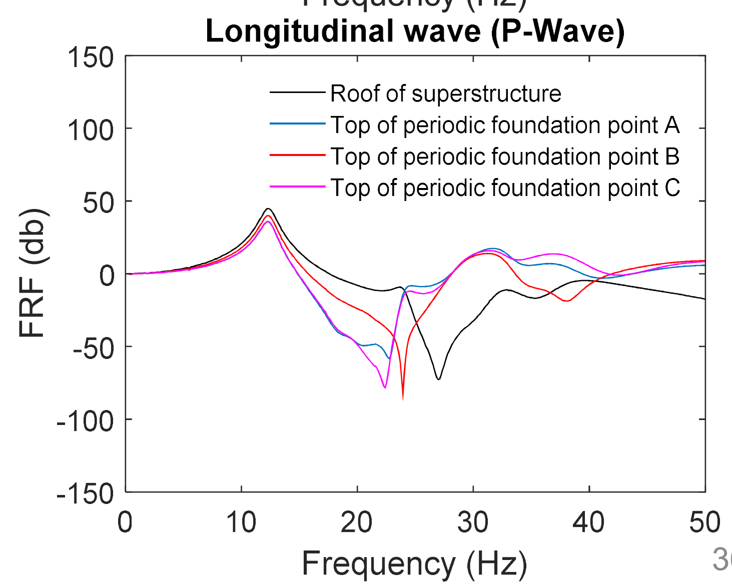
Design of Specimen with 3D Periodic Foundation

Designed structural system









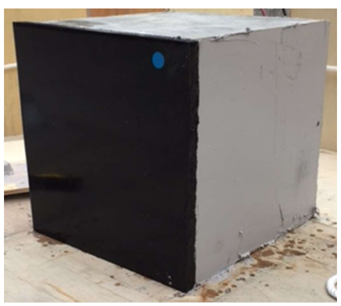
Fabrication of 3D Periodic Foundation

Casting of concrete cores



Resin solution and polyurethane glue

Construction of 3D periodic foundation







Shaking Table Test Cases

RC foundation only

1D periodic foundation only

3D periodic foundation only

RC foundation +
structure system

1D periodic foundation +
structure system

3D periodic foundation +
structure system

[redacted]

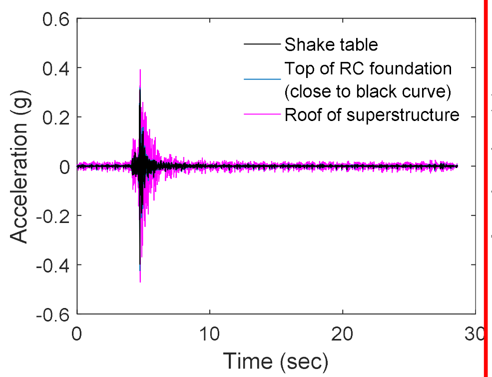
Examples of Test Results – 1D Periodic Foundation

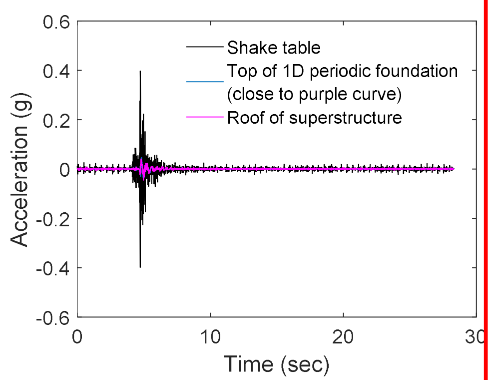
Horizontal Shaking

Structure with **RC foundation**

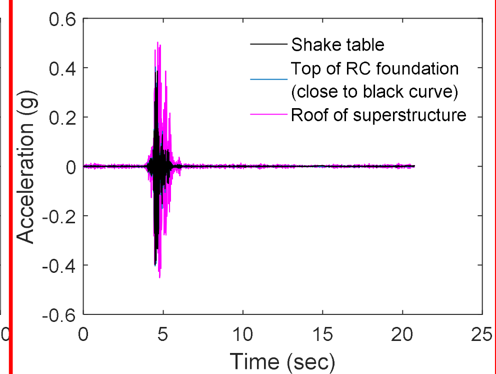
Structure with **1D periodic foundation**

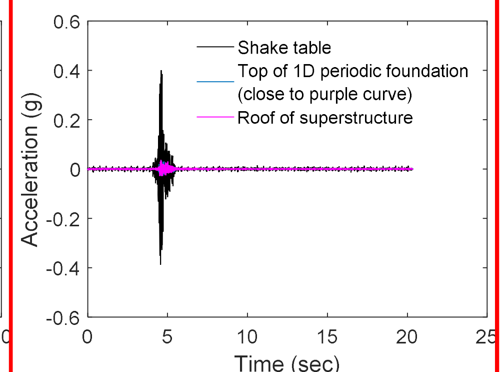
Anza earthquake



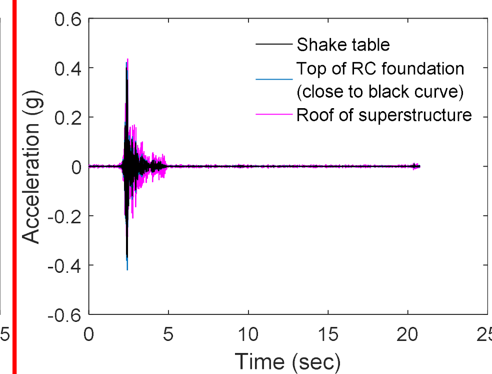


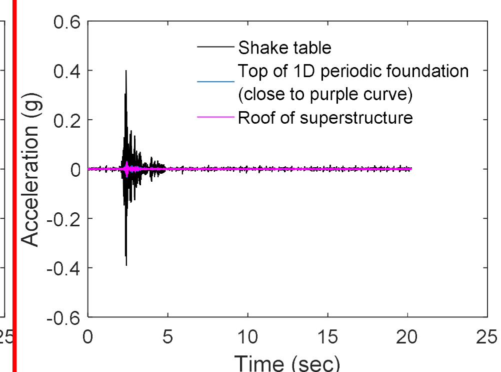
Bishop earthquake





Oroville earthquake





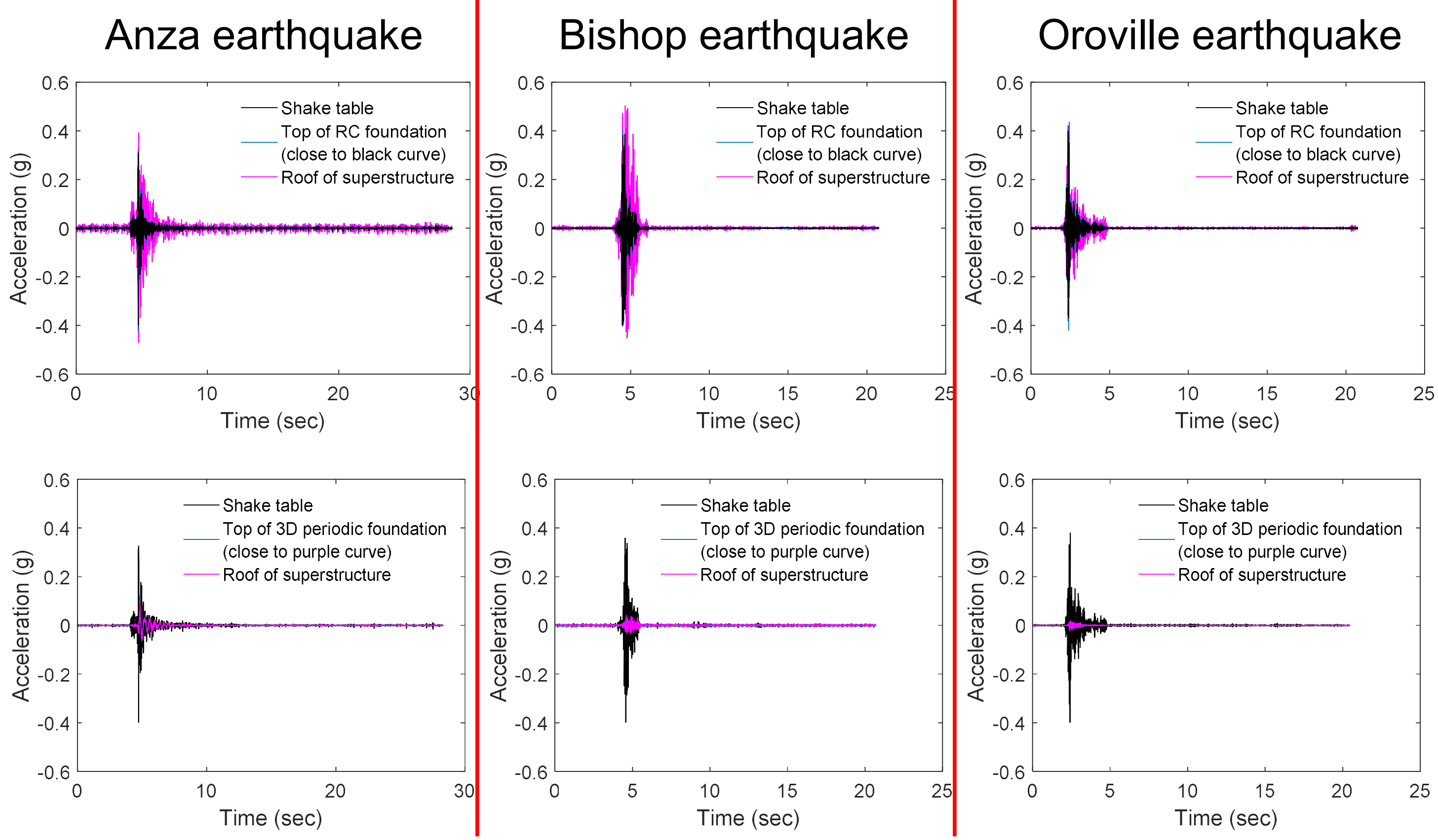
- PGA at shake table is 0.4g
- Main frequency content of each earthquake is inside frequency band gap of 1D periodic foundation

Example of Test Results – 3D Periodic Foundation

Horizontal Shaking

Structure with
RC foundation

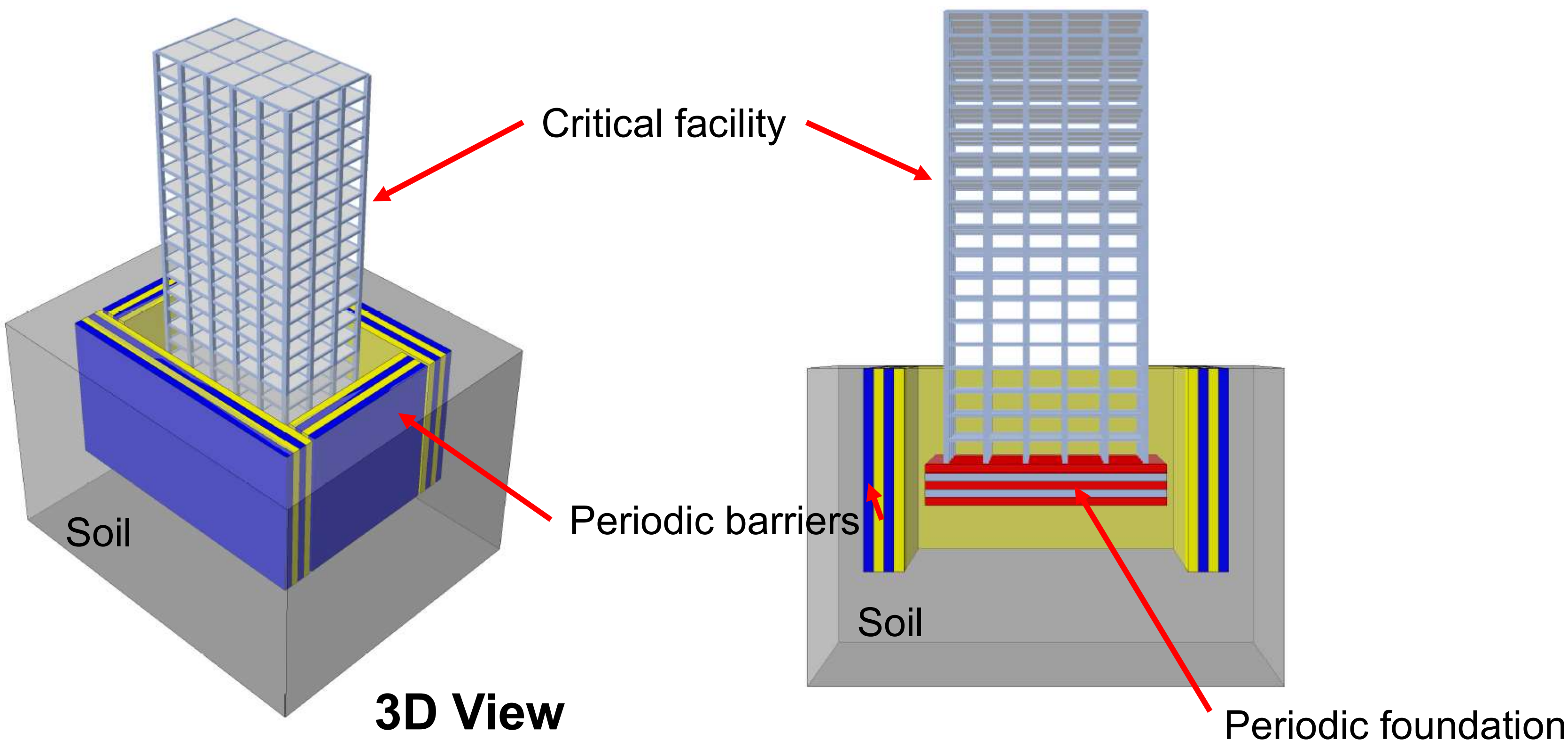
Structure with
3D periodic



- PGA at shake table is 0.4g
- Main frequency content of each earthquake is inside frequency band gaps of 3D periodic foundation

Future Study

Periodic Barrier



Cross Section View

Thank You for Your Attention!