NHERI Lehigh Facility User Experience
Seismic Hazard Mitigation with Pressurized Sand Dampers
and their Response in Extreme Temperatures

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NHERI Lehigh Experimental Facility — Researchers Workshop
Prof. J.M. Ricles
Prof. N. Makris

PIs

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Dr. L. Cao

Researchers

Dr. T. Marullo

IT Expert

SMU & ATLSS Research Center Staff and Technicians
How it started?

Quest for velocity-independent (hysteretic) dissipation
Widely used response-modification devices

Response modification devices to serve sustainable infrastructure

Retrofit of Benicia-Martinez Bridge, California

Seismic Retrofit of Richmond-San Rafael Bridge, California
Widely used response-modification devices: Fluid dampers

San Diego Coronado Bridge, California

91/5 overcrossing, southern California

Rion-Antirion cable-stayed bridge, Western Greece

San Francisco-Oakland Bay Bridge, Northern California
Widely used response-modification devices: BRB & ADAS

Kaiser Santa Clara Medical, California

Hildebrand Hall -- UC Berkeley, California

Salt Lake City, Utah

Dalian University of technology, China
Bay Bridge (San Francisco) retrofitting scheme
Bay Bridge (San Francisco) retrofitting scheme
Prototype Pressurized Sand Damper

- **u**: direction of loading
- piston rod
- strain gauge
- pressurized sand
- sphere
- strain gauge
- L
- \( L_{net} \)
- damper housing
- post-tensioned stainless steel rods
- spacer that accommodates the motion of the double-ended rod
- steel plate to mount the PSD on its attachment
- pin to mount the PSD on its attachment
Prototype Pressurized Sand Damper

- Steel plate to mount the PSD on its attachment
- Piston rod
- Damper housing
- Post-tensioned stainless steel rods
- Sphere
- Spacing that accommodates the motion of the double-ended rod
- End-cap
- End seal
Pressurized Sand Damper — Experimental campaign

- Tubes with different diameters and lengths
- Spheres with different diameters
- Subjected to different stroke amplitudes, pressure levels, cyclic frequencies

\[ d = 2r = 2''; \quad d = 2r = 2\frac{1}{4}'' \]

\[ d_r = 1\frac{1}{4}'' \]
Pressurized Sand Damper — Experimental set up

- Actuator
- Load Cell
- Strain Gauge
- Reaction Supports
- Floor Beam
- Pressurized Sand Damper
Behavior of the PSD

$p = 3.0\ \text{MPa}$
$f_0 = 0.10\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 1.89\ \text{cm/sec}$

$p = 4.0\ \text{MPa}$
$f_0 = 0.10\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 1.26\ \text{cm/sec}$

$p = 4.0\ \text{MPa}$
$f_0 = 0.25\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 3.14\ \text{cm/sec}$

$p = 1.0\ \text{MPa}$
$f_0 = 0.25\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 4.71\ \text{cm/sec}$

$p = 2.0\ \text{MPa}$
$f_0 = 0.10\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 1.89\ \text{cm/sec}$

$p = 3.0\ \text{MPa}$
$f_0 = 0.10\ \text{Hz}$
$F_{SD}\ (u=0)$

$v_{max} = 0.63\ \text{cm/sec}$
Normalized loops to the strength of the PSD,  
\[ F_{SD}(u = 0) = \Pi spr^2 + \mu kp\pi d_{rod}L_{net} \]

**Master Curves**

\[ D = 2R = 13.97 \text{ cm} = 5 + \frac{1}{2} \text{ in} \]
\[ d = 2r = 5.08 \text{ cm} = 2 \text{ in} \]

\[ D = 2R = 13.97 \text{ cm} = 5 + \frac{1}{2} \text{ in} \]
\[ d = 2r = 5.72 \text{ cm} = 2 \frac{1}{4} \text{ in} \]

Nonlinear real-time hybrid simulations of structural systems with pressurized sand dampers

Konstantinos N. Kalfas, Ph.D. Candidate
Nonlinear real-time hybrid simulations of structural systems with pressurized sand dampers

NHERI Tall Wood Research Project
Double-ended sand damper to be mounted on the CLT rocking wall
Double-ended sand damper to be mounted on the CLT rocking wall


Kalfas KN, L Cao, JM Ricles, and N Makris. 2024. “Seismic response of CLT rocking structures equipped with pressurized sand dampers through real-time hybrid simulations.” *ASCE - J Eng Mech* (under preparation)
Nonlinear RTHS of rocking systems with PSDs
Nonlinear RTHS of rocking systems with PSDs: Input motions
Nonlinear RTHS of rocking systems with PSDs

<table>
<thead>
<tr>
<th>Earthquake name</th>
<th>Near Field (NF)</th>
<th>Far Field (FF)</th>
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<tr>
<td></td>
<td>Max</td>
<td>RMS</td>
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<td>W/o PSDs</td>
<td>With PSDs</td>
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<tr>
<td>Chi-Chi</td>
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</table>
Nonlinear RTHS of rocking systems with PSDs

1989 Loma Prieta, California earthquake

1994 Northridge, California earthquake

1999 Kocaeli, Turkey earthquake

1979 Imperial Valley, California earthquake

1995 Kobe, Japan earthquake

1999 Chi-Chi, Taiwan earthquake

Wall drift [%]

Time [s]
Nonlinear RTHS of rocking systems with PSDs

1989 Loma Prieta, California earthquake

1994 Northridge, California earthquake

1999 Kocaeli, Turkey earthquake

1979 Imperial Valley, California earthquake

1995 Kobe, Japan earthquake

1999 Chi-Chi, Taiwan earthquake
Nonlinear RTHS of rocking systems with PSDs

Real-time Hybrid Simulation of a CLT Rocking Wall System equipped with Pressurized Sand Dampers (PSD) subject to DBE Level Kocaeli Earthquake

Numerical Substructure

SC-CLT Wall Base Shear vs Floor Drift

Time History of Roof Acceleration

Experimental Substructure

Left PSD

Right PSD

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Temperature effect on the response of PSDs
Temperature effect on the response of PSDs

$6 \, ^\circ \text{C} = 43 \, ^\circ \text{F}$: reached after approximately 5 hours

$40 \, ^\circ \text{C} = 104 \, ^\circ \text{F}$: reached after approximately 1 hour and 42 minutes

$60 \, ^\circ \text{C} = 140 \, ^\circ \text{F}$: reached after approximately 2 hours and 20 minutes
Temperature effect on the response of PSDs
Temperature effect on the response of PSDs

(a) 2 cm, 1 MPa, 0.25 Hz
(b) 2 cm, 2 MPa, 0.25 Hz
(c) 1 cm, 3 MPa, 0.10 Hz
(d) 1 cm, 5 MPa, 0.10 Hz
(e) 1 cm, 5 MPa, 0.25 Hz
(f) 2 cm, 1 MPa, 0.50 Hz
REU Experience
• 5/8-scale cross-laminated timber (CLT) rocking wall

• Allow for a drift ratio, \( u/2h \), of 3% ⇒ rocking wall maximum rotation:
  \[ \theta_{\text{max}} \approx \tan \theta_{\text{max}} = u/2h = 0.03 \text{ rad} \]

• Maximum damper elongation:
  \[ e_{1,\text{max}} = (2b + d) \tan \theta_{\text{max}} \approx 2 \text{ in} \]
Future Steps – CLT rocking wall with supplemental damping
The pressurized sand damper project has been funded by the National Science Foundation under grant No. CMMI - 2036131. The SMU - Lehigh collaboration has been funded by the NSF under grant No. CMMI - 2037771. We would like to thank the machinist of SMU, Ken Sangston, as well as the ATLSS Engineering Research Center staff and technicians.
Thank you for your attention!

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