Northeastern University

Earthquake Engineering Experimental Facility
for Research and Public Outreach

by

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OUTLINE

1. Earthquakes and Devastating Effects

2. Reducing the Seismic Risk

3. EQ Engineering Experimental Facility at NEU

4. Projects conducted using the facility

5. Public Outreach and Educational Use of the Facility

6. Conclusion

1. Earthquakes and Devastating Effects

Adapazari EQ, 1999, M7.9 death toll:45000

Haiti EQ, 2010, M7.0 death toll:316000

Courtesy of Ayhan Irfanoglu

Tohoku Japan EQ, 2011, M9.0 death toll:22000

Van EQ, 2011, M7.0 death toll:604

Courtesy of Reuters

Courtesy of National Turk

Courtesy of Abdurrahman Antakyali

2. Reducing the Seismic Risk

Learning from Earthquakes: Damaged and undamaged structures

⬇

Understanding earthquakes and its effects on our built environment:
Analytically and Experimentally

⬇

Finding solutions and remediation

⬇

Testing the solutions
Analytically and Experimentally

❖ Large-Scale Earthquake Engineering Testing Facilities are efficient in testing more real field problems and the solutions for mitigation

3. Earthquake Engineering Measurement Facility at Northeastern University, Boston MA

1-D Shaking Table (MTS)

➢ 1.5 x 2.0 m

➢ 0-50 Hz

➢ 25 kN load capacity

➢ ± 12.7 cm lateral displacement capacity

➢ NI-DAQ data acquisition card

➢ LAbVIEW data processing software

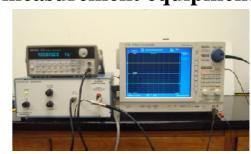# 3. Earthquake Engineering Measurement Facility at Northeastern University, Boston MA

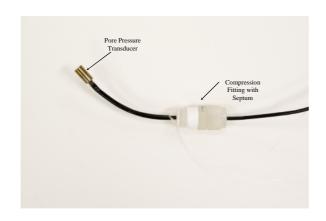**Crossbow Accelerometers (1g, 2g, 4g)**

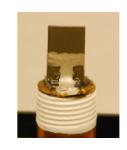**Linear Variable Displacement Transducer (LVDT)**
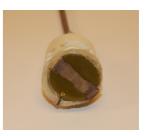

P and S wave measurement equipment
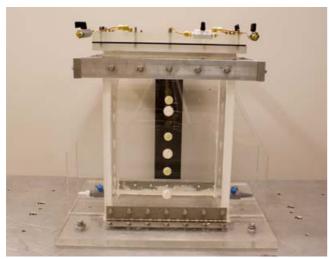

PDCR 81 Miniature Pore Pressure Transducer
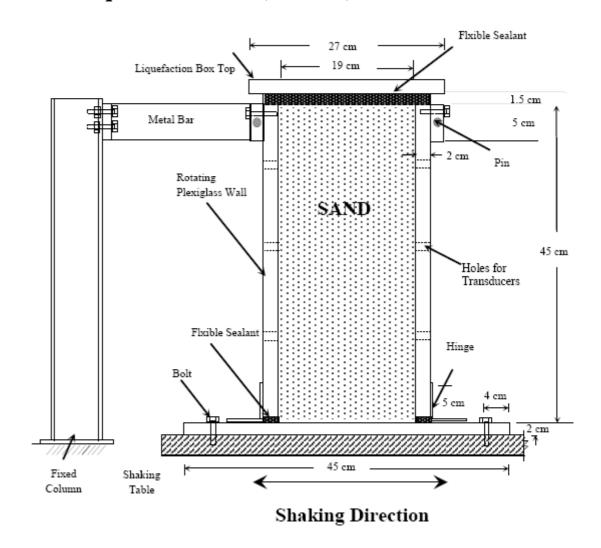
Pore Pressure Transducer

Compression Fitting with Septum

Bender Elements and Bender Disks for S and P Wave Measurements

Cyclic Simple Shear Liquefaction Box (CSLLB)

Size: 19x30x45 cm
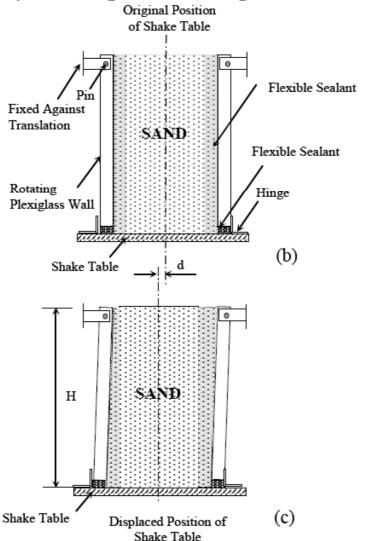
Cyclic Simple Shear Liquefaction Box (CSLLB)

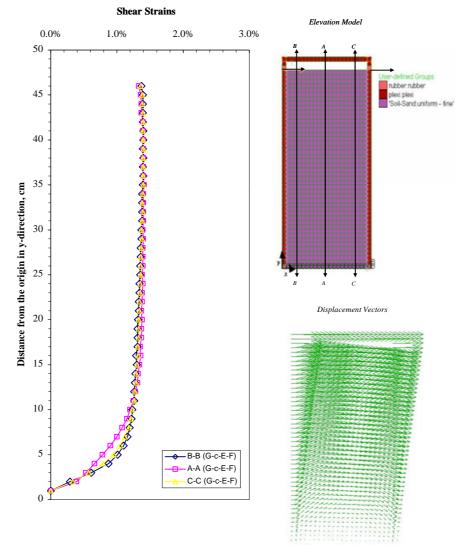
- Fixed to an outsider beam

- 2 rotating (RW) and 2 fixed walls (FW)

- Flexible sealant btw the RW, FW and the bottom plate

- up to 1% strains

**Cyclic Simple Shear
Liquefaction Box (CSLLB)
Modal analysis**

**Elevation Model
Shear Strains @A-A, B-B, C-C Soil Sections
(Free Surface)**

Shear Strains

Distance from the origin in y-direction, cm

- B-B (G-c-E-F)
- A-A (G-c-E-F)
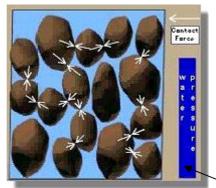- C-C (G-c-E-F)

Elevation Model

Displacement Vectors

4.Projects Conducted using the EQ Eng. Experimental Facility

1. Induced Partial Saturation (IPS) for Liquefaction Mitigation (NSF Award #: CMS-0509894)

2. Foundation Isolation for Seismic Protection Using a Smooth Synthetic Liner (NSF granted)

3. Soil Isolation for Seismic Protection Using a Smooth Synthetic Liner (NSF granted)

4. Evaluation of a Mechanical Isolator for Protecting Four MFA Sculptures Against Earthquakes in Nagoya , Japan

4.Projects

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation

Problem

Liquefaction induced bearing capacity failure of a building after Adapazari EQ, 1999
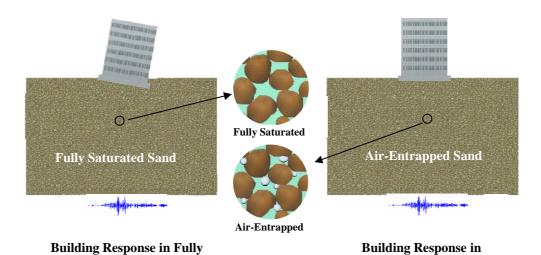

σ'_f $u_f = u_0 + \Delta u$

$$\sigma'_f = \sigma'_0 - \Delta u = 0$$

$$r_u = \Delta u / \sigma'_0$$

$$\sigma'_f = \sigma'_0 (1 - r_u) = 0$$

$$1 - r_u = 0$$

$$r_u = \Delta u / \sigma'_0 = 1$$

Research Goal

Fully Saturated

Air-Entrapped

Fully Saturated Sand

Air-Entrapped Sand

Building Response in Fully Saturated Sand

Building Response in Air-Entrapped Sand

4.Projects

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation
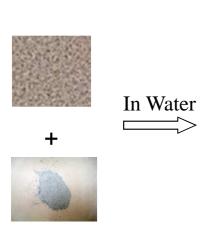
- **IPS Techniques Implemented in the Laboratory**

Sodium Perborate
monohydrate

- Controllable Degree of Saturation

- Uniform Distribution of Gas Bubbles

$$2(NaBO_3 \cdot H_2O) + 2H_2O \longrightarrow 2H_2O_2 + 2BO_3^{-3} + 2Na^+ + 4H^+$$
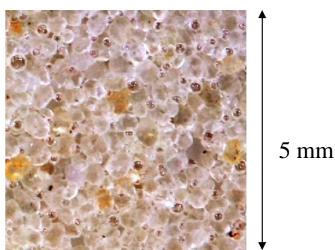
$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

Hydrogen Peroxide
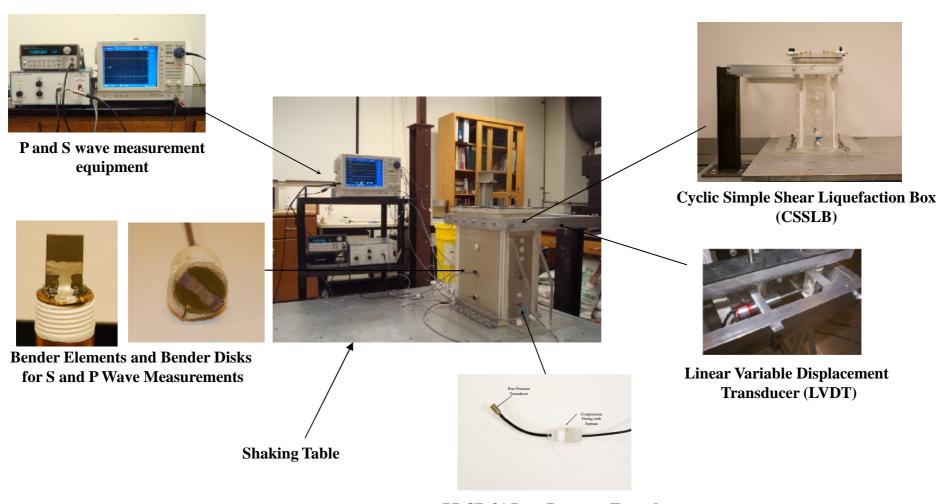

+

In Water

S = 40-90%

5 mm

Average Particle Size: 0.3-0.4 mm

Average Bubble Size: 0.18 mm

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation

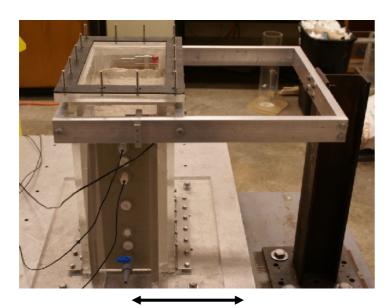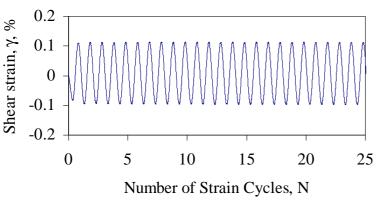**Integrated Experimental Setup for Evaluation of Cyclic Response of Fully and Partially Saturated Sands**

P and S wave measurement equipment

Bender Elements and Bender Disks for S and P Wave Measurements

Cyclic Simple Shear Liquefaction Box (CSSLB)

Linear Variable Displacement Transducer (LVDT)

Shaking Table

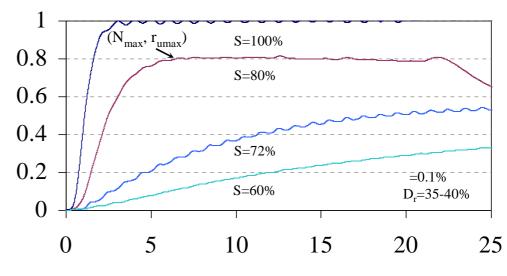**PDCR 81 Pore Pressure Transducer**

4.Projects

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation

■ Excess Pore Water Pressures in Partially Saturated Sands

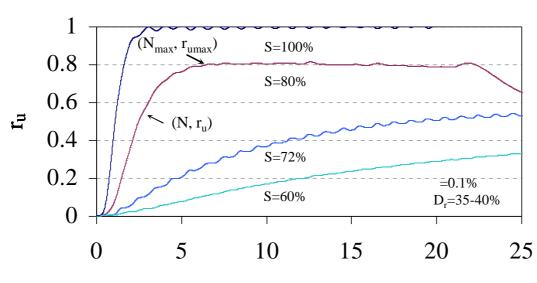

■ Cyclic Simple Shear Strains with amplitudes =0.01-0.3% applied on specimens with

- ➤ D_r=20-65%
- ➤ S=100-45%

■ r_{umax} is reduced as S decreases

■ N_{max} gets larger as S decreases

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation

$$r_u = f(S, D_r, \gamma, \sigma', M)$$

(N_{max}, r_{umax}) S=100%

S=80%

(N, r_u)

S=72%

γ=0.1%

S=60% D_r=35-40%

r_u

Number of Strain Cycles, N
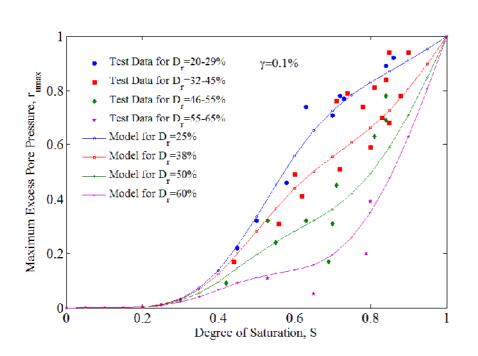
1) $r_{u\,max} = \left[\sqrt{S} \times e^{-\left[\frac{1-S}{0.54}\right]^4} \right] \left[1 - 8.75 \times (D_r - 0.2) \times (1-S) \times e^{\left[-\frac{(1-S)^2}{2\times(1-S_{md} \times (0.2/D_r)^2)^2} \right]} \right] \left[1 - 1.75 \times (-\log \frac{\gamma}{0.001}) \times (1-S) \times e^{\left[-\frac{(1-S)^2}{2\times(1-S_{mg})^2} \right]} \right]$

2) $r_u = r_{u\,max} \times f\left(\dfrac{N}{N_{max}} \right)$
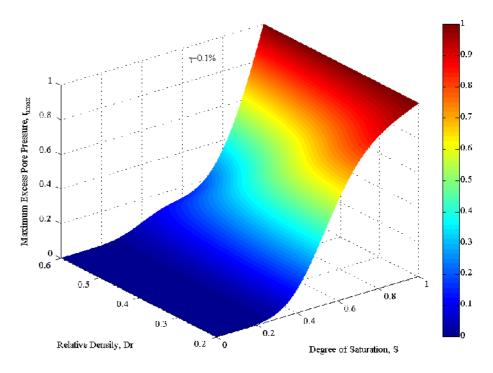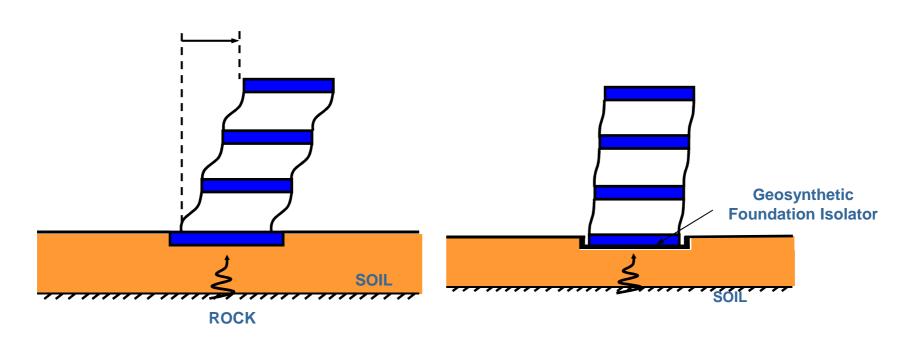
where $f\left(\dfrac{N}{N_{max}} \right)$ is a function of S, D_r, γ, σ', M

1-Induced Partial Saturation (IPS) for Liquefaction Mitigation

r_{umax} Model

2-Foundation Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner
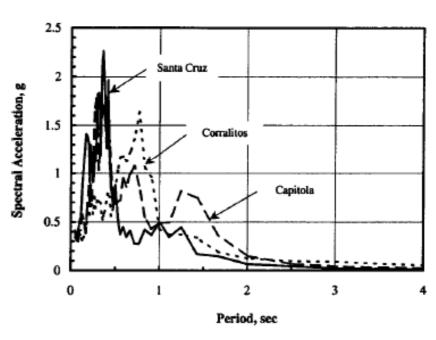
➢ An alternative low- cost seismic protection solution

➢ Within several synthetic materials tested, "geotextile/UHMWPE" found to be the most efficient due to:

    ➢low friction coefficient (0.11) with slightly higher static friction coefficient than dynamic friction coefficient (0.06-0.08) .

    ➢Independent of the sliding velocity, little effect of normal stress at low values (40-100 kPA), number of cycles or sliding distance.
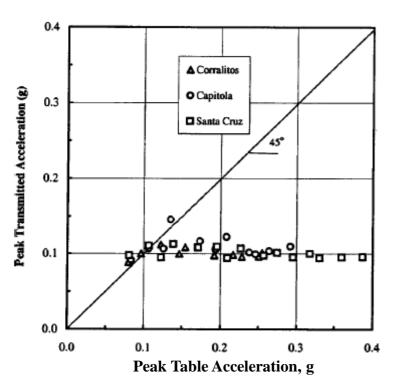
2-Foundation Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner
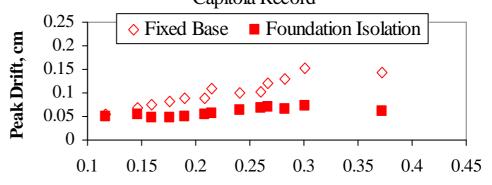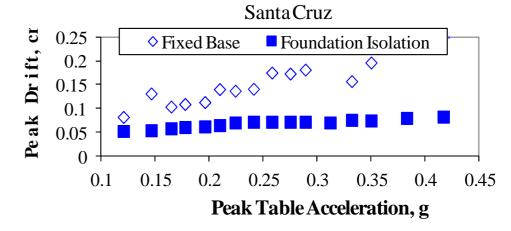
➤ A single story model tested under 3 records of 1989 Loma Prieta Earthquake
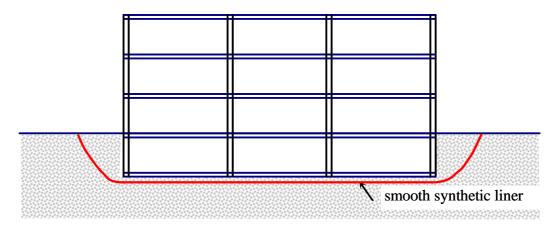
2-Foundation Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner
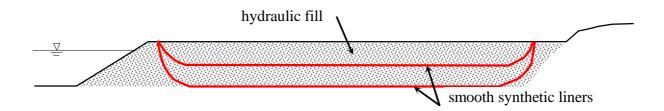
➢Transmitted accelerations stayed more or less around 0.1 g

➢The peak drift of the foundation isolated model is much smaller than the non-isolated and remains almost constant

3-Soil Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner

smooth synthetic liner
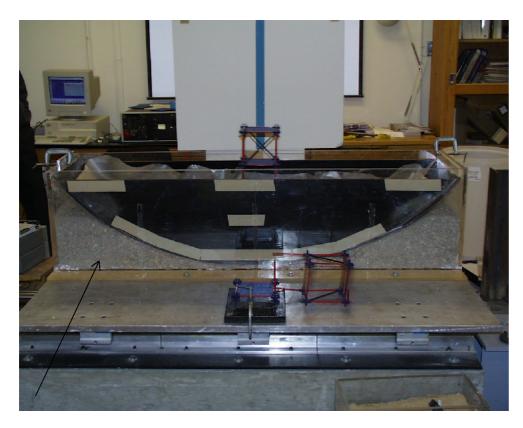
(a) Soil Isolation for buildings

hydraulic fill

smooth synthetic liners
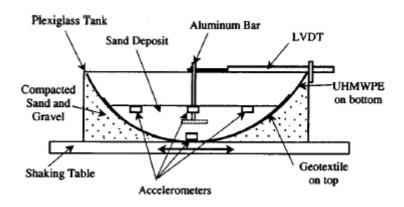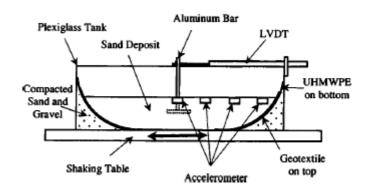
(b) Soil Isolation for reclaimed land

➢ the liner is placed within the soil profile to absorb seismic energy before it arrives at the ground

➢horizontal earthquake energy is dissipated through slip deformations along the liner

4.Projects
3-Soil Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner
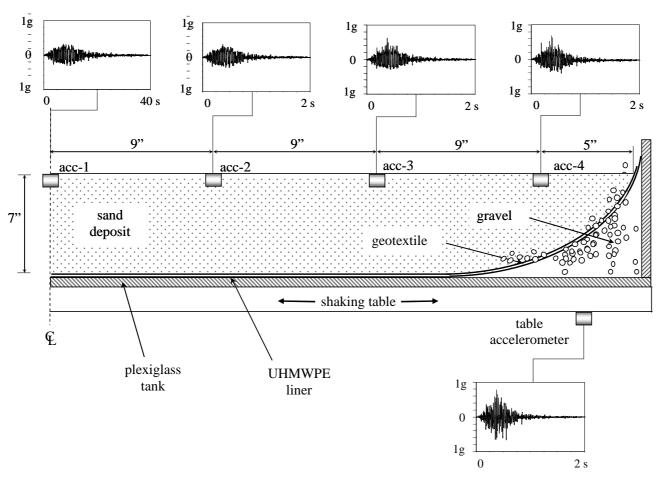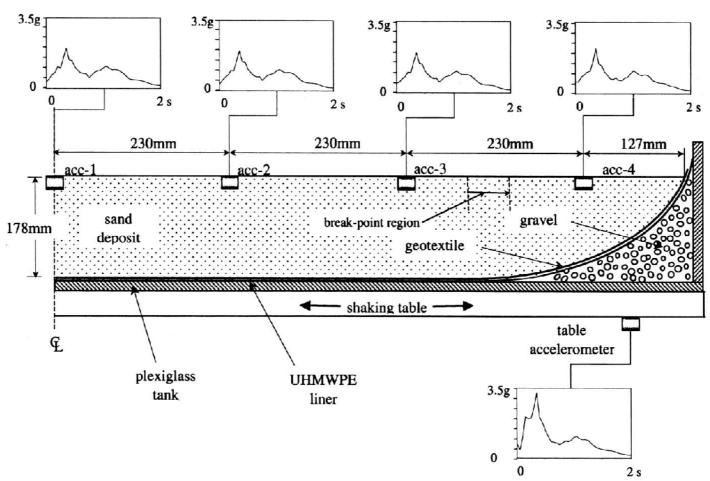
179 cm x 46 cm x 46 cm
Plexiglas tank
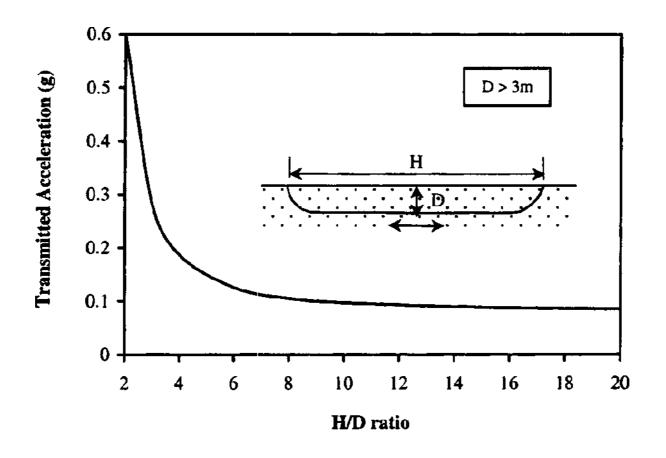
➢Both cylindirical and tub-shaped liners were tested and tub-shaped liner was found to be more effective.

4.Projects
3-Soil Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner

➢Both harmonic and earthquake excitations were applied.

➢Under Santa Cruz record scaled up to 0.8g, when the peak acceleration of the table was greater than 0.2g, the peak transmitted accelerations in the central region of the sand were much smaller than the peak table accelerations

4.Projects
3-Soil Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner

➢Significant reductions in spectral accelerations
➢Side effects diminished in spectral accelerations

4.Projects
3-Soil Isolation for Seismic Protection Using a Smooth GeoSynthetic Liner
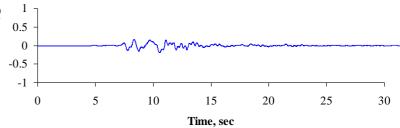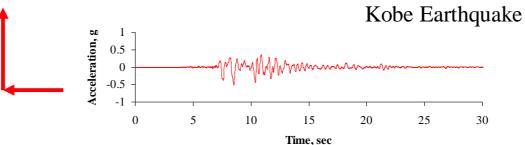
➢Experimental results are very important to first understand the physical behaviors however have constrains in terms of side effects or the size of the models
➢Analytical studies should confirm the field scale applications
➢Effect of H/D on transmitted accelerations determined analytically

4-Evaluation of a Mechanical Isolator for Protecting Four MFA Sculptures Against Earthquakes in Nagoya , Japan
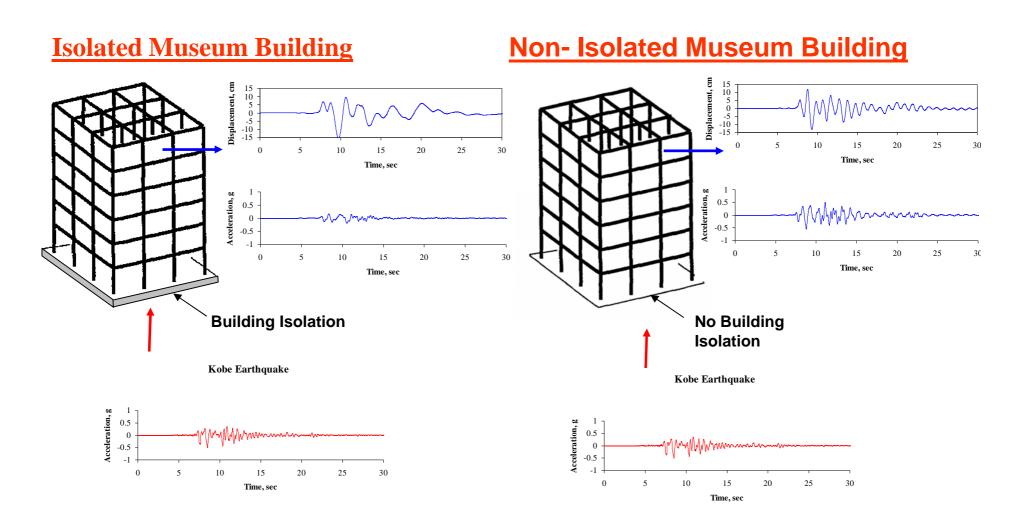
Isolated Building Response
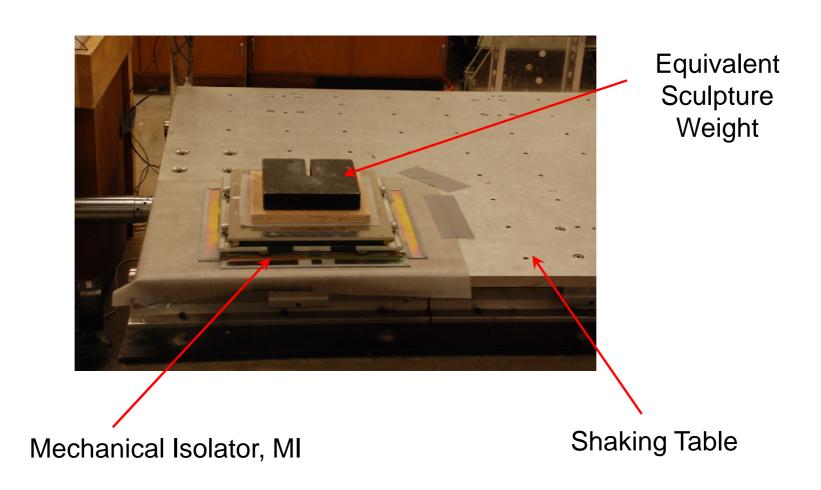
Kobe Earthquake

4-Evaluation of a Mechanical Isolator for Protecting Four MFA Sculptures Against Earthquakes in Nagoya , Japan

Isolated Museum Building

Non- Isolated Museum Building

Building Isolation

No Building Isolation

Kobe Earthquake

Kobe Earthquake

4-Evaluation of a Mechanical Isolator for Protecting Four MFA Sculptures Against Earthquakes in Nagoya , Japan

Equivalent Sculpture Weight

Mechanical Isolator, MI

Shaking Table

4.Projects

4-Evaluation of a Mechanical Isolator for Protecting Four MFA Sculptures Against Earthquakes in Nagoya , Japan
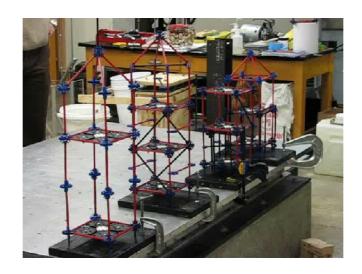
5. Public Outreach and Educational Use of the Facility

To raise awareness and interest of Women, Minorities, Middle and High School Students in Engineering and Earthquakes

5. Public Outreach and Educational Use of the Facility

NSF Young Scholar Program : High school students spend 6 weeks in summer in research

5. Public Outreach and Educational Use of the Facility

In Earthquake Engineering Lectures

6. Conclusion

Earthquake Engineering Experimental Facility is essential in seismic rehabilitation since it can

➢ provide high quality data that can advance fundamental knowledge of the behavior of geotechnical and structural elements,

➢ validate analytical models

➢ help explore development of innovative, cost-effective seismic mitigation technologies

➢ encourages educational and outreach activities and awareness of earthquake risk

➢ demonstrate the important role engineers play in seismic mitigation

Thank you

6.Detection and Long-Term Sustainability of Entrapped Air/Gas

- Tests performed under hydrostatic, vertical and horizontal hydraulic gradient flow.
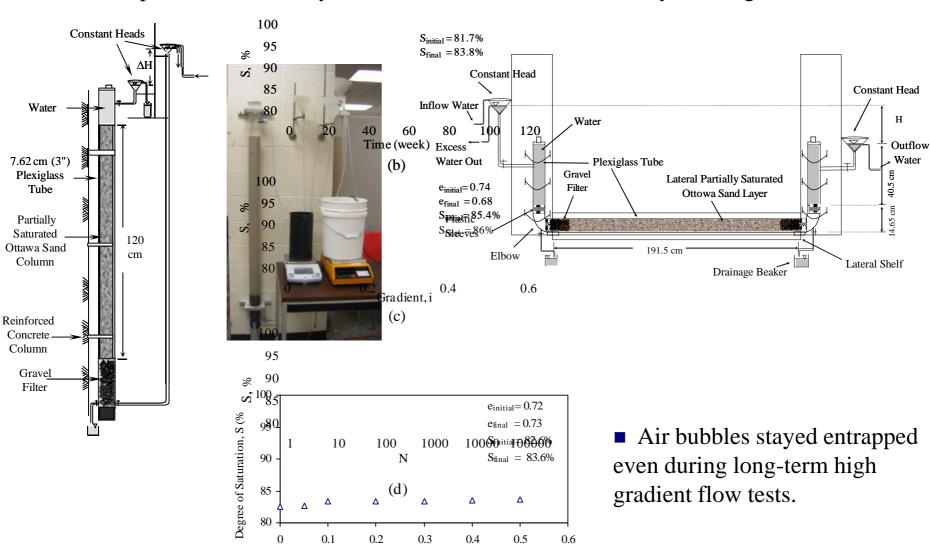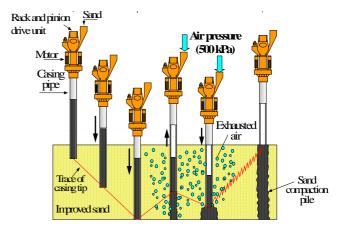

Constant Heads

ΔH

Water

7.62 cm (3")
Plexiglass
Tube

Partially
Saturated
Ottawa Sand
Column

120
cm

Reinforced
Concrete
Column

Gravel
Filter

$S_{initial} = 81.7\%$
$S_{final} = 83.8\%$

S, %

100
95
90
85
80

0   20   40   60   80   100   120
Time (week)
(b)

$e_{initial} = 0.74$
$e_{final} = 0.68$
$S_{initial} = 85.4\%$
$S_{final} = 86\%$

100
95
90
85
80

0   0.2   0.4   0.6
Gradient, i
(c)

Constant Head

Inflow Water

Water

Excess
Water Out

Plastic
Sleeves

Gravel
Filter

Elbow

Plexiglass Tube

Lateral Partially Saturated
Ottowa Sand Layer

191.5 cm

Constant Head

H

Outflow
Water

40.5 cm

14.65 cm

Lateral Shelf

Drainage Beaker

Degree of Saturation, S (%)

100
95
90
85
80

0   0.1   0.2   0.3   0.4   0.5   0.6
Gradient, i

S, %

100
95
90
85
80

1   10   100   1000   10000   100000
N

$e_{initial} = 0.72$
$e_{final} = 0.73$
$S_{initial} = 82.6\%$
$S_{final} = 83.6\%$

(d)

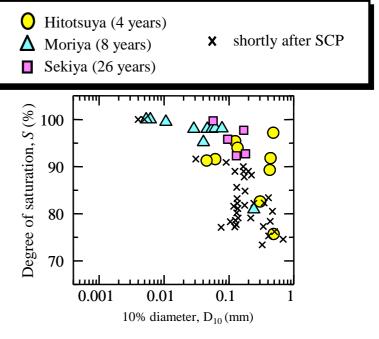- Air bubbles stayed entrapped even during long-term high gradient flow tests.

6. Long-Term Sustainability of Entrapped Air/Gas

Evidence on long-term sustainability of air from Mitsu Okamura's study :

➤ Tested samples taken from SCP treated sites, after 4 yrs, 8yrs and 26 yrs.

➤ Evaluated degree of saturation.

➤ Air entrapped in the voids of granular soils for a long time.

Soil Improved with Soil Compaction Pile (SCP) Technique
from Mitsu Okamura, 2005

from Mitsu Okamura, 2005