University at Buffalo's NEES Equipment Site

Geotechnical Laminar Box Shaking Facility

S. Thevanayagam

Nurhan Ecemis, PhD Candidate

Department of Civil, Structural and Environmental Engineering
Geotechnical Laminar Box - Details

- Modular Multilayer-Laminate-Bearing Design; 5.0x2.75x6.2m (85 cubic meter maximum capacity)

- Simulate 2-D Ground Response
  - For Soil-Foundation-Structure Interaction Studies at or Near Full Scale
  - For Liquefaction Studies
  - For Others

- 1-g Geotechnical Studies to Compliment Centrifuge
2-D Large Scale Geotechnical Laminar Box

- D Large Scale
- Geotechnical Laminar Box
Shaking Base & 240 Ball Bearings
Shaking Base & Laminar Box
(Half) Box & Shaking Base
Modular Box

Module A1
– On Strong Floor
- 6.2m High
- 2.75 x 5 m Base
- 185 Tons

Module A2
– On Shaking Tables
- 3.1 m High; <100 Tons

Module B1
– 6.2m High
- 2.75 x 2.5 m Base

Module B2
– 3.1 m High
- 2.75 x 2.5 m Base
# Laminar Box Details

<table>
<thead>
<tr>
<th>Module</th>
<th>A2</th>
<th>B1 and B2</th>
<th>A1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box-Internal Base Size (mxm)</td>
<td>2.75x5</td>
<td>2.75x2.5</td>
<td>2.75x5</td>
</tr>
<tr>
<td>Box-Height (m)</td>
<td>3.1</td>
<td>6.2 or 3.1</td>
<td>6.2</td>
</tr>
<tr>
<td>Box-Metal Weight (empty) (tons)</td>
<td>8.5</td>
<td>11.2 or 5.6</td>
<td>17.0</td>
</tr>
<tr>
<td>Box-Max Soil Vol. (m³)</td>
<td>38.6</td>
<td>34.6 or 17.3</td>
<td>77.2</td>
</tr>
<tr>
<td>Support</td>
<td>Steel-bridge-spanning two tables</td>
<td>Steel-bridge-spanning two tables (6.2m) or on a single table (3.1m)</td>
<td>Strong Floor</td>
</tr>
<tr>
<td>Number of Laminates</td>
<td>12</td>
<td>24 (or 12)</td>
<td>24</td>
</tr>
<tr>
<td>Laminate Thickness (m)</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>Interlaminate Bearings</td>
<td>Ball Units</td>
<td>Ball Units</td>
<td>Ball Units</td>
</tr>
<tr>
<td>Spanning-Base Steel Bridge (tons)</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Payload Capacity</td>
<td>40g-ton</td>
<td>40 g-ton (6.2m) or 20 g-ton (3.1m)</td>
<td>0.3g max</td>
</tr>
<tr>
<td>Maximum Weight (incl box &amp; soil)</td>
<td>100 tons</td>
<td>100 tons (6.2m) or 50 tons (3.1m)</td>
<td>185 tons</td>
</tr>
<tr>
<td>Shaking Dir.</td>
<td>Horiz: X, Y</td>
<td>Horiz: X, Y</td>
<td>Horiz: X or Y</td>
</tr>
<tr>
<td>Inter-laminate displ. (nominal) limit (mm)</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Inter-laminate displ. (for special tests) limit (mm) (may increase this limit for 1-D tests)</td>
<td>74</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Permanent Displacement between Laminate</td>
<td>To be decided on a case-by-case-basis</td>
<td>To be decided on a case-by-case-basis</td>
<td>To be decided on a case-by-case-basis</td>
</tr>
</tbody>
</table>
Internal Bearing & I-Beam Assembly
Interlaminate Bearings
Soil

Ottawa F55 Sand; 145 Tons available

Soils Data Report – Grain Size, Undrained Cyclic Triaxial Data & Monotonic Triaxial Data Available (Thevanayagam et al. 2003)

User is responsible for new material, removal, and handling
Sand Construction Method - Hydraulic Filling

Hydraulic Pumps (5hp; 1hp) & 3" Dia Hoses
Available – Useable from March to November
Sand Preparation & Shake Test

Typical Procedure - 3 Weeks

Step 1: Install soil instruments inside the box
Step 2: Fill the box with water up to 2 ft.
Step 3: Controlled Pumping of slurry into laminar; Density control tests
Step 4: CPT or other tests
Step 5: Safety cables, Actuator/sensor/DAQ fine tuning
Step 7: Base Shaking
Step 8: Pump the slurry back to the storage areas
Hydraulic Filling Trial

- Water depth = 1 – 3 ft
- Discharge Pipe horizontally moving
- Diffuser & Nozzle vertical
Soil Placement Density

Depending on discharge velocity and discharge configurations relative density can be controlled within a narrow range.

Density limits - About 30% to 70%.

Users must develop/decide on hydraulic placement methods and controls.
Typical Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Readiness</th>
<th>Total Need</th>
<th>Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D-SAA</td>
<td>Readily Available</td>
<td>48</td>
<td>2 tubes</td>
</tr>
<tr>
<td>Piezometer</td>
<td>Readily Available</td>
<td>12</td>
<td>3 locations</td>
</tr>
<tr>
<td>Y-Acc (Ring)</td>
<td>Readily Available</td>
<td>6</td>
<td>1 location</td>
</tr>
<tr>
<td>X-Acc (Ring)</td>
<td>Readily Available</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>X-Potentiometer</td>
<td>Readily Available</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Y-Potentiometer</td>
<td>Readily Available</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Typical Instrumentation (NS & EW View)

Geotextile to tie PPTs.
Shape Acceleration Array

Features

¾” Diameter Cable enclosing 3 MEMS Accelerometers (X,Y,Z) at 1-ft interval

Total Length = 24 ft

Total Arrays = 4

Used to measure acceleration profile with depth, and displacement profile with depth

Real-time acceleration and shape display
**Typical Instrumentation Table**

<table>
<thead>
<tr>
<th>Meas.</th>
<th>Available</th>
<th>Time Needed for LG-0 Test</th>
<th>Total Need</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq</td>
<td>UB</td>
<td></td>
<td>22</td>
<td>45</td>
</tr>
<tr>
<td>Chan-A</td>
<td>UB</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Chan-M</td>
<td>UB</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>DAQ</td>
<td>UB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAA</td>
<td></td>
<td></td>
<td>2 tubes</td>
<td>4 tubes</td>
</tr>
<tr>
<td>PPT</td>
<td>RPI</td>
<td>10/06 - 10/25</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>X-Acc(Ring)</td>
<td>UB</td>
<td>10/06 - 10/25</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>Y-Acc(Ring)</td>
<td>UB</td>
<td>10/06 - 10/25</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>X-Pot</td>
<td>UB</td>
<td>10/06 - 10/25</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Y-Pot</td>
<td>UB</td>
<td>10/06 - 10/25</td>
<td>5</td>
<td>20</td>
</tr>
</tbody>
</table>
Typical Ground Motion

Any Earthquake or Synthetic Motion Possible subject to $u_{\text{max}} = \pm 6''$ & Overturning Safety considerations.

Horizontal actuator Capacity = Two 100 ton displacement controlled dynamic actuators
## Typical Schedule for Shake Tests

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preparatory Shake Tests</strong></td>
<td>28 days</td>
<td>Mon 9/18/06</td>
<td>Wed 10/25/06</td>
</tr>
<tr>
<td><strong>3m Box Test</strong></td>
<td>14 days</td>
<td>Mon 9/18/06</td>
<td>Thu 10/5/06</td>
</tr>
<tr>
<td>Fill the box with water for leak tests</td>
<td>2 days</td>
<td>Mon 9/18/06</td>
<td>Tue 9/19/06</td>
</tr>
<tr>
<td>Reduce water level to 2ft</td>
<td>1 day</td>
<td>Wed 9/20/06</td>
<td>Wed 9/20/06</td>
</tr>
<tr>
<td>Pump the slurry to theLB up to 3m</td>
<td>3 days</td>
<td>Thu 9/21/06</td>
<td>Mon 9/25/06</td>
</tr>
<tr>
<td>Cone &amp; Bucket Density Tests</td>
<td>3 days</td>
<td>Thu 9/21/06</td>
<td>Mon 9/25/06</td>
</tr>
<tr>
<td>CPT</td>
<td>1 day</td>
<td>Tue 9/26/06</td>
<td>Tue 9/26/06</td>
</tr>
<tr>
<td>Remove top 3m rings</td>
<td>1 day</td>
<td>Wed 9/27/06</td>
<td>Wed 9/27/06</td>
</tr>
<tr>
<td>Install accelerometers top of the</td>
<td>1 day</td>
<td>Wed 9/27/06</td>
<td>Wed 9/27/06</td>
</tr>
<tr>
<td>Safety Cables; Shaking/Actuator</td>
<td>3 days</td>
<td>Wed 9/27/06</td>
<td>Fri 9/29/06</td>
</tr>
<tr>
<td>NDS &amp; DS Shaking</td>
<td>1 day</td>
<td>Mon 10/2/06</td>
<td>Mon 10/2/06</td>
</tr>
<tr>
<td>Pump the slurry back to the store</td>
<td>3 days</td>
<td>Tue 10/3/06</td>
<td>Thu 10/5/06</td>
</tr>
<tr>
<td><strong>Test LG-O</strong></td>
<td>14 days</td>
<td>Fri 10/6/06</td>
<td>Wed 10/25/06</td>
</tr>
<tr>
<td>Put soil instruments inside the box</td>
<td>2 days</td>
<td>Fri 10/6/06</td>
<td>Mon 10/9/06</td>
</tr>
<tr>
<td>Fill the box with water up to 2ft</td>
<td>0.5 days</td>
<td>Tue 10/10/06</td>
<td>Tue 10/10/06</td>
</tr>
<tr>
<td>Pump the slurry to theLB</td>
<td>3.5 days</td>
<td>Tue 10/10/06</td>
<td>Fri 10/13/06</td>
</tr>
<tr>
<td>Cone &amp; Bucket Density Tests</td>
<td>4 days</td>
<td>Tue 10/10/06</td>
<td>Fri 10/13/06</td>
</tr>
<tr>
<td>CPT</td>
<td>1 day</td>
<td>Mon 10/16/06</td>
<td>Mon 10/16/06</td>
</tr>
<tr>
<td>Safety cables, Actuator/sensor/D</td>
<td>1 day</td>
<td>Tue 10/17/06</td>
<td>Tue 10/17/06</td>
</tr>
<tr>
<td>NDS &amp; DS Shaking</td>
<td>1 day</td>
<td>Wed 10/18/06</td>
<td>Wed 10/18/06</td>
</tr>
<tr>
<td>CPT</td>
<td>1 day</td>
<td>Thu 10/19/06</td>
<td>Thu 10/19/06</td>
</tr>
<tr>
<td>Pump the slurry back to the store</td>
<td>4 days</td>
<td>Fri 10/20/06</td>
<td>Wed 10/25/06</td>
</tr>
</tbody>
</table>

**Allow a LOT of time for Detailed Planning**
Safety, Safety, Safety

Overturning
Excessive sliding
Water leakage
Overloading
Quicksand/sand boils
Dust exposure
Etc.
Etc.
Etc.
Etc.
Thank You

Questions?
Ongoing Research

“Experimental and Micromechanical Computational Study of Pile Foundations Subjected to Liquefaction-Induced Lateral Spreading”

• A NEESR-SG Grant involving: Rensselaer Polytechnic Institute, University at Buffalo, University of California-San Diego, Tulane, NIED, and Tokyo Institute of Technology

• Leveraging off of the facility infrastructure at the UB-NEES Site; Reaction Wall, Strong Floor, Dynamic Actuators-High Performance Hydraulic System, 2-D Geotechnical Laminar Box and DAQ and Image processing, tests will be performed in years 1-4 (2005-2008)
Ongoing Research ... (Con’t)

- The 2-D Geotechnical Laminar Box is deployed on a 12’x26’ steel plate leveled and secured to the strong floor upon which 240 ball bearings integrated into the base assembly will allow 2-D motions.
- Two dynamic actuators deployed against the reaction wall will be used to “shake” the 170 ton assembly containing 80-cubic meters of sand.
Research Objectives

- *Understand* the phenomenon of sand liquefaction during lateral spreading near pile foundations;
- *Solve* the engineering questions on how to design pile foundations against lateral spreading both in simplified terms as well as in terms of providing a basic understanding for appropriate analytical platforms; and
- *Clarify* the correct way to use centrifuge modeling in future research and engineering applications.
- Research plan also involves:
  - UB NEES 1g 2D shaking, 6m-tall laminar box
  - RPI NEES centrifuge facility, and E-Defense Miki City
  - Advanced sensors and DEM & FEM Analyses
UB Site – Test Schedule

- Equipment Modification & Calibrations (9/05-8/06)
- Free-Field Liquefaction Tests – (9/06-10/06)
- Single Pile – Lateral Spreading – (10/06-5/07)
- Group Pile – Lateral Spreading – (5/07-8/07)
- Group Pile – Lateral Spreading (orthogonal shaking) – (9/07-11/07)
Single Pile (Tests 1 & 2) (shaking in perpendicular directions)

Pile
(Test 1A: High EI pile, Test 1B: Low EI pile)
2-D Laminar Box (24 Laminates)
Ball Bearings

Shaking Frame on Strong Floor

α=2 or 3 deg.

SECTIONAL VIEW

F#55 Sand, Dr~45%

PLAN

6.2 m

5.6 m

5.0 m

2.75 m

3.35 m
Group Pile (Tests 3 and 4) (shaking in perpendicular directions)

F#55 Sand, Dr~45%

Shaking Frame on Strong Floor

α=2 or 3 deg.

Pile Cap

Pile

2-D Laminar Box (24 Laminates)

Ball Bearings

SECTIONAL VIEW

PLAN

5.0 m

3.35 m

2.75 m

6.2 m

5.6 m
Soil-Pile Instrumentation

Schematic Diagram - Sectional Views

- Strain Gauge
- Piezometer
- Accelerometer
- Potentiometer

MEMS Shape Cable
Soil-Pile Instrumentation

Schematic Diagram – Plan View
Instrumentation Summary

**Soil Sensors**
- 34 Accelerometers
- 54 Piezometers
- 40 Potentiometers
- 4 MEMS Shape Cables & Accelerometers
- Krypton Imager – Field of View
- Digital Video

**Pile Sensors**
- Many Strain gauges
- 2 MEMS Shape Cables
- Krypton Imager - Field of View: Pile Cap
Year-1 Progress Summary

- Laminar Box Shaking System Development & Shaking Controls
- Hydraulic Fill Sand Construction & Density Controls
- Instrumentation Procurement & Calibrations
- Project Test Plans & Instrumentation Plans
- Laminar Box - Free Field Liquefaction Testing – (in progress)
- Data Archival Plans
Ground Motion

$u_{\text{max}} = \pm 0.74''$

$u_{\text{min}} = \pm 0.01''$

$f = 2 \text{ Hz}$
Thank You!

Questions?