Lecture#6
Large Scale Laminar Box Experimental Simulation of Liquefaction and Effects on Pile Foundations

S. Thevanayagam
University at Buffalo
(Collaborators: Dobry, R., Abdoun, T., Elgamal, A., Zeghal, M.)

Institutions: U. at Buffalo, RPI, UCSD, & SMU

Workshop, Australia, Dec. 14, 2007

Outline

- Underlying Research Objectives
- Laminar Box – Liquefaction – Lateral Spreading Development
- Advanced Sensor Deployment & Performance & New Possibilities
- System Identification
- Lateral spreading Mechanism
- Visualization
- Effect of Gentle Slope on ‘Liquefied’ Ground Response

Underlying Project
Pile Foundation Subjected to Lateral Spreading

Underlying Research Objectives NEESPile Project

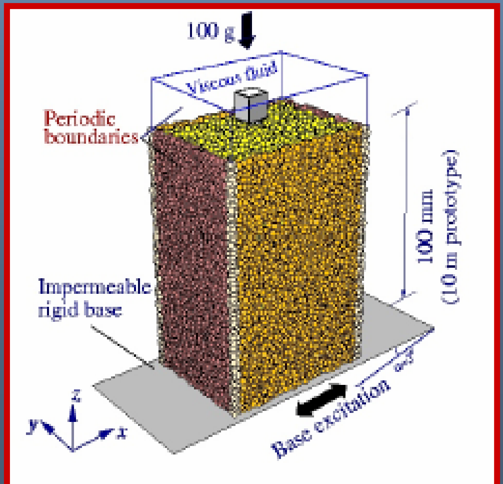
- Understand phenomenon of sand-liquefaction & lateral spreading in vicinity of piles
- Solve questions on how to design piles against lateral spreading:
  - Simplified (p-y)
  - Sophisticated (analytical platform)
- Clarify scaling laws, centrifuge use

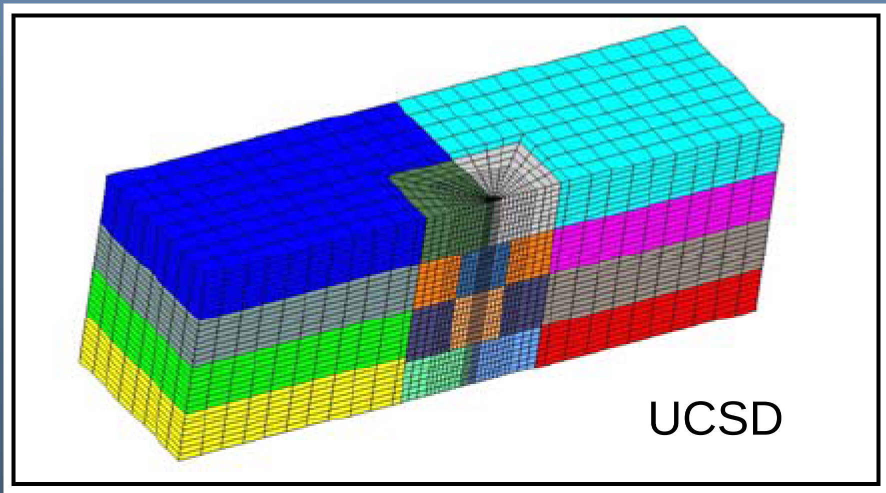
Experimental and Micromechanical Computational Study of Pile Foundations Subjected to Liquefaction-Induced Lateral Spreading

E-Defense (Japan)

RPI

UB

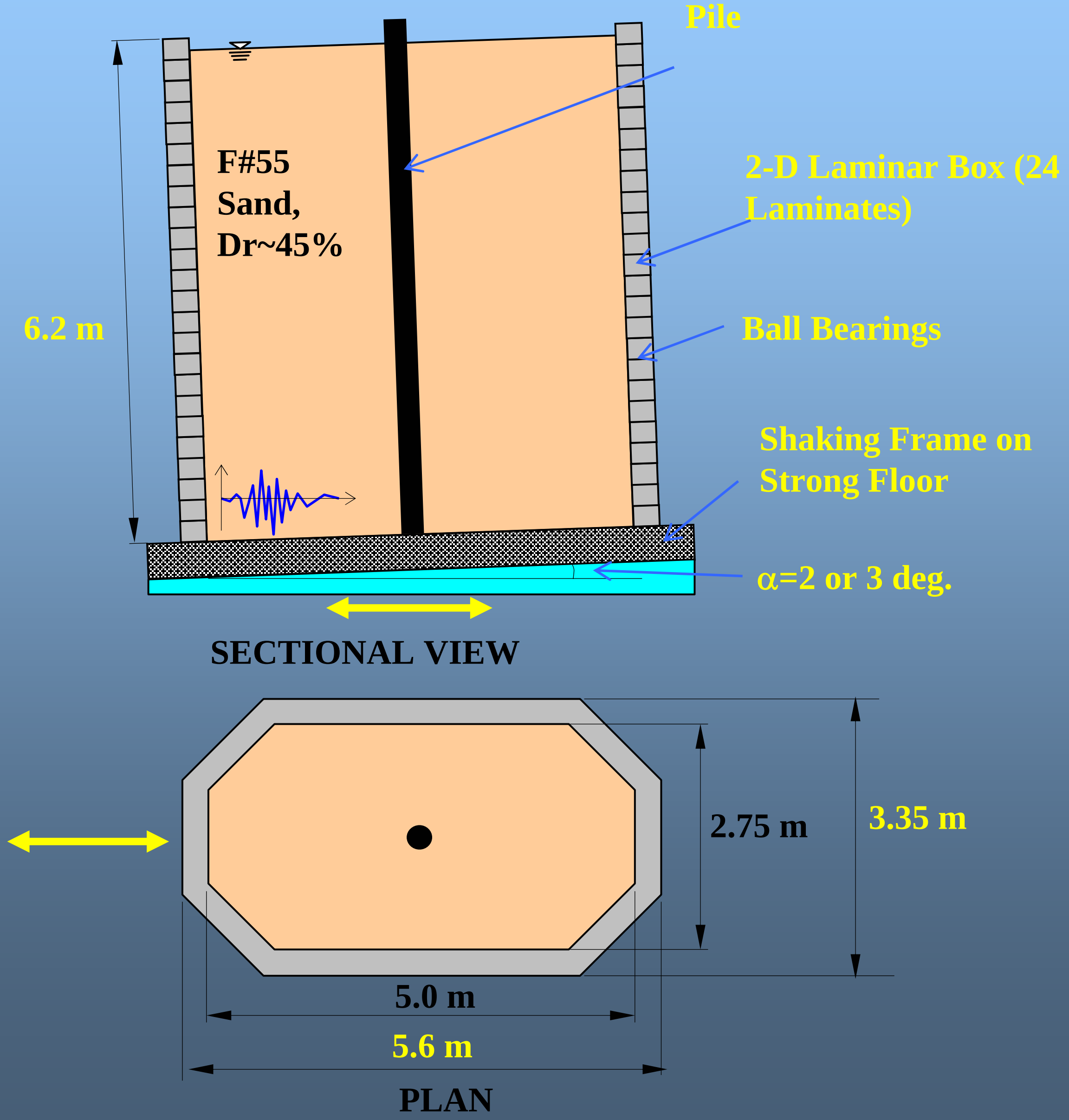




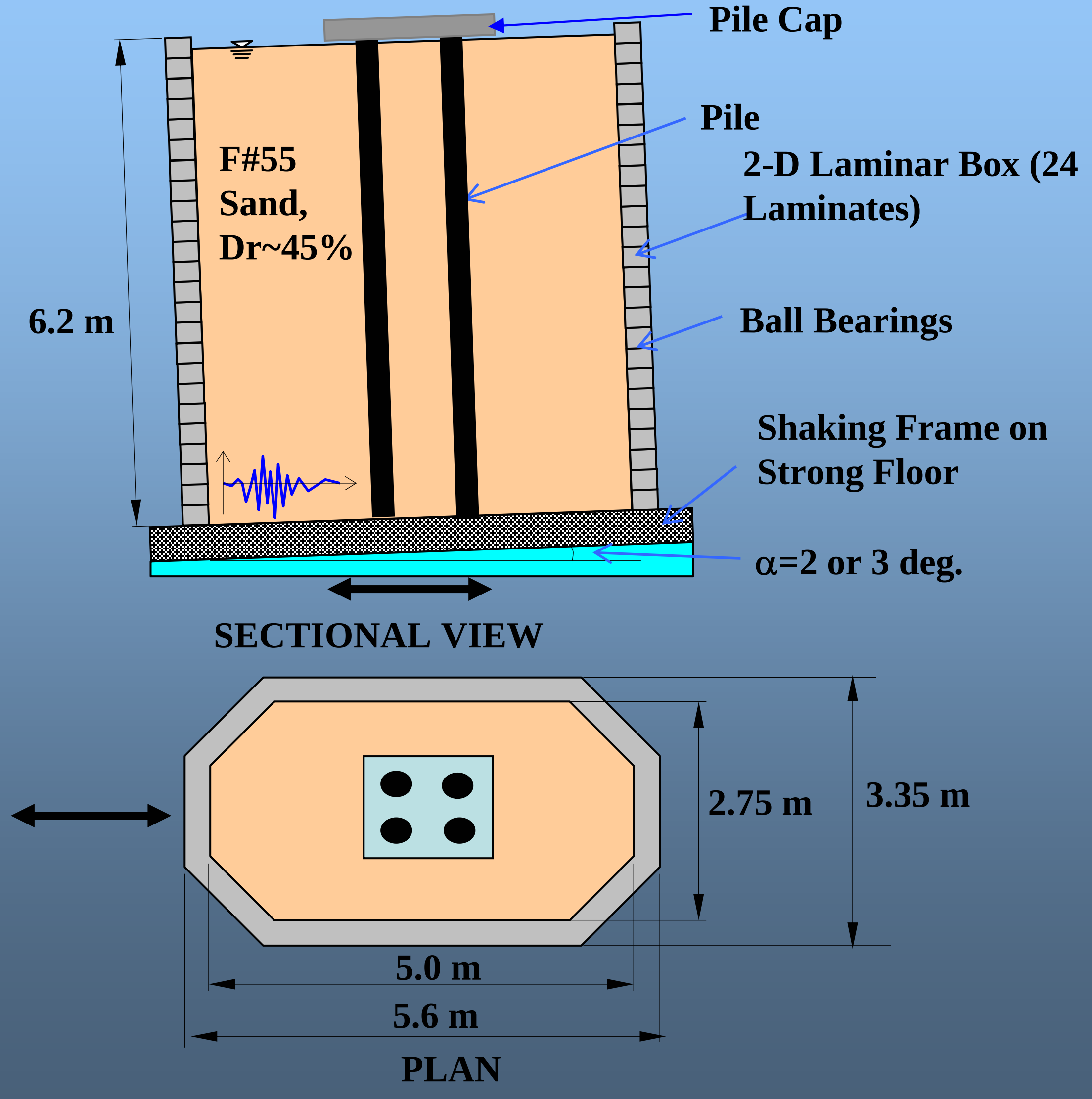
Research Tools

- 1g Laminar Box - U. Buffalo-NEES
- Centrifuge - RPI-NEES
- Advanced Sensors Arrays
- DEM numerical experiments - RPI & Tulane
- FEM numerical simulations & development analytical platform – UCSD
- 3-D Visualization & Advanced analytical framework - RPI

Single Pile


Pile
2-D Laminar Box (24 Laminates)
F#55 Sand, Dr~45%
6.2 m
Ball Bearings
Shaking Frame on Strong Floor
α=2 or 3 deg.
SECTIONAL VIEW
2.75 m
3.35 m
5.0 m
5.6 m
PLAN

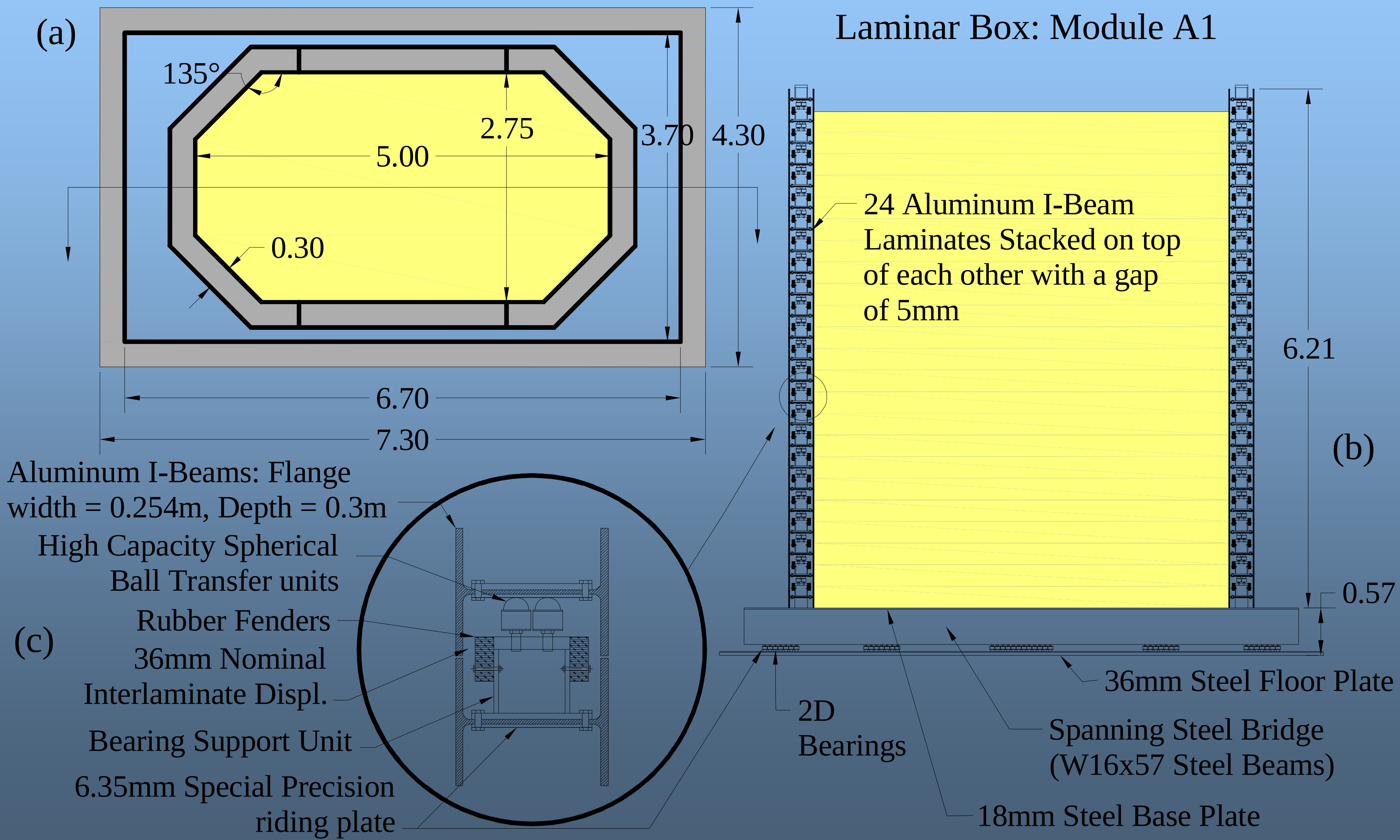
Group Pile



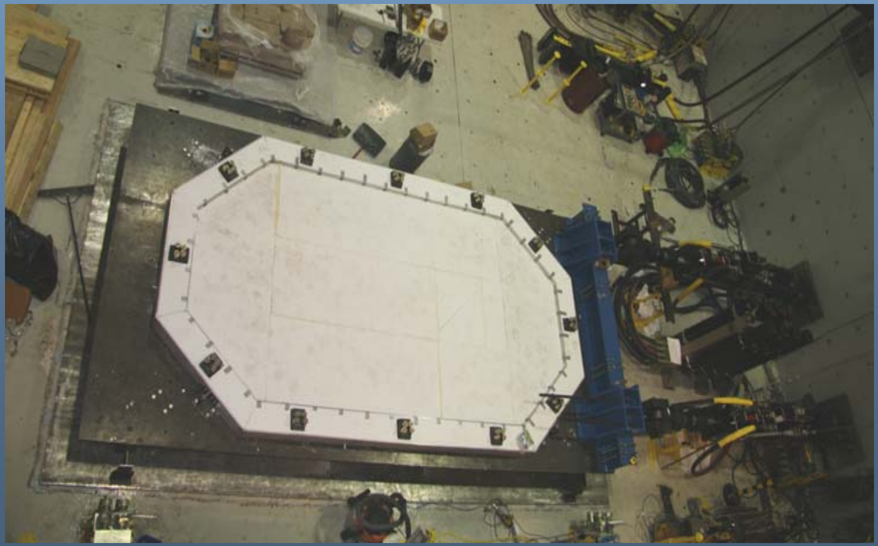
Pile Cap
Pile
2-D Laminar Box (24 Laminates)
F#55
Sand,
Dr~45%
6.2 m
Ball Bearings
Shaking Frame on Strong Floor
α=2 or 3 deg.
SECTIONAL VIEW
2.75 m
3.35 m
5.0 m
5.6 m
PLAN

Laminar Box System Development

Large Scale Laminar Box

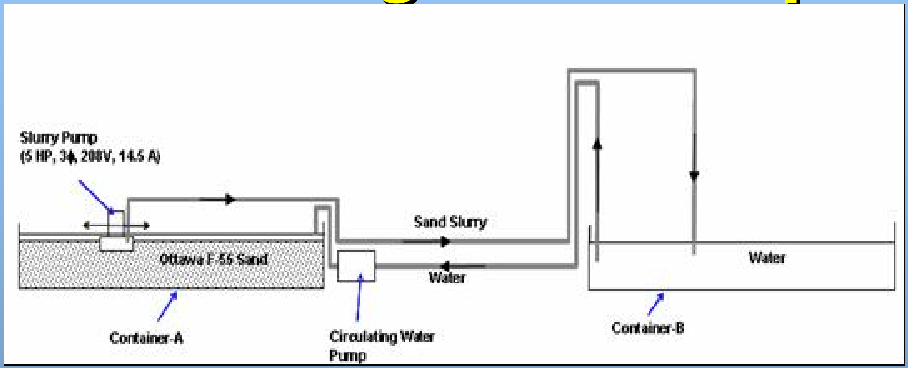


Laminar Box, Base Shaker, Actuators & Control System Development

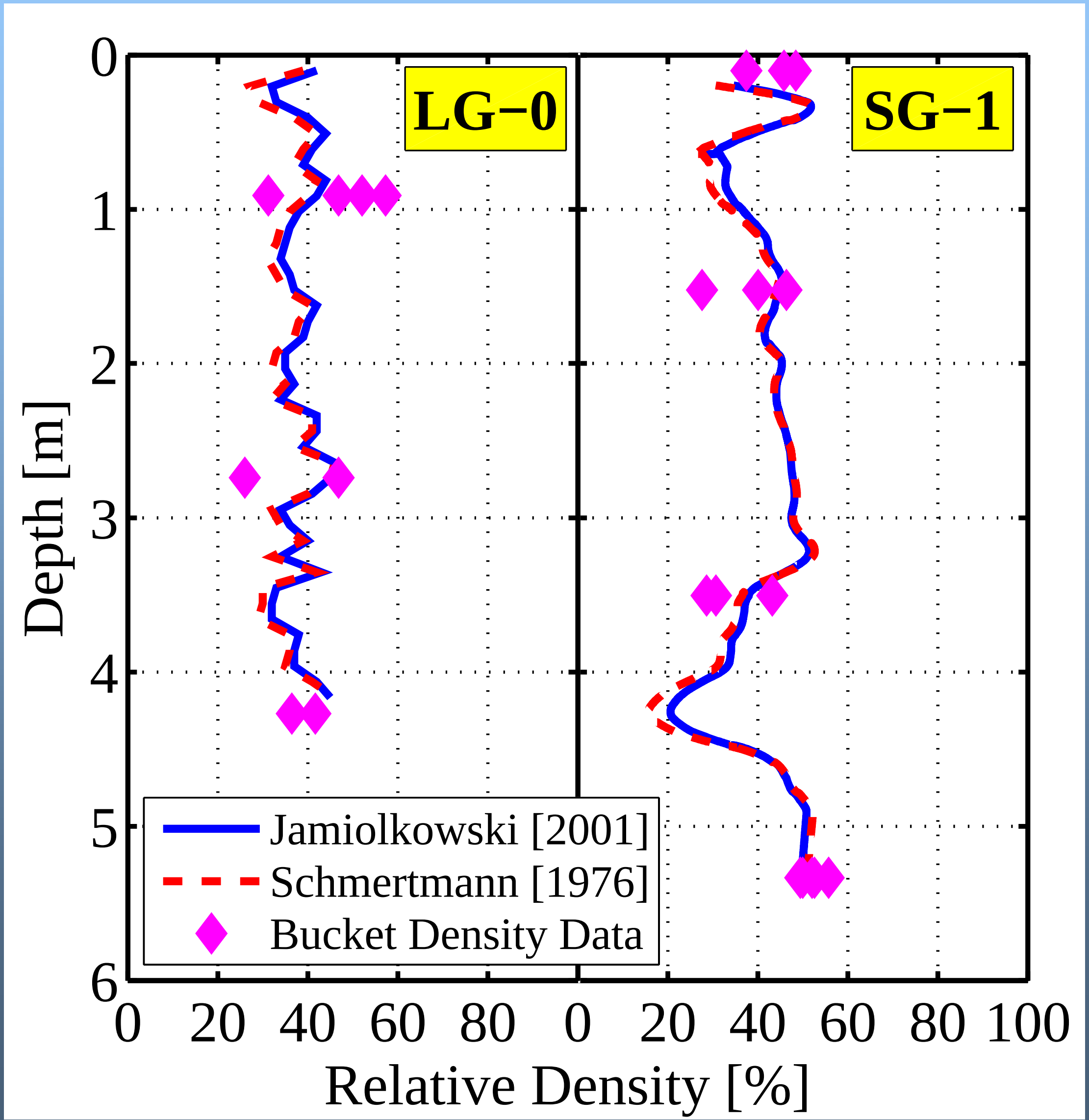


Mimic Hydraulic Filling – Waterfront Sand Construction

Sand Hydraulic Filling, Instrumentation & CPT Testing - Development



Soil Profile: LG-0 & SG-1



Instrumentation: LG-0 & SG-1

Table 1: SG-1 Instrument Notations, quantity and their models

Instruments	Quantity		Model
	LG-0	SG-1	
3D – SAA	2 tubes (288 channels)	2 tubes (315 channels)	ShapeAccelArray MEMS Sensors
Piezometers	13	20	GE Druck Model PDCR 81
X-Acc (Ring and Base)	21	25	Sensotec 10G
Y-acc (Ring and Base)	12	14	
Soil-Acc-x	5	6	
Soil-Acc-y	3	3	
X-Potentiometers	9	11	MTS Temposonic Displacement Transducers
Z-Potentiometers	3	3	
Video	4	4	

Dense Array Instrumentation

Type	Sensors
3D-SAA (Acc.,Disp.)	2 Tubes (144 Acc. 144 Disp.)
Piezometer	20
Y-Acc (Ring&Base)	15
X-Acc (Ring&Base)	27
Y-Acc (Soil)	3
X-Acc (Soil)	6
X-Potentiometer	11
Z-Potentiometer	3
Video	4
Total Sensor =	**377**

System Identification

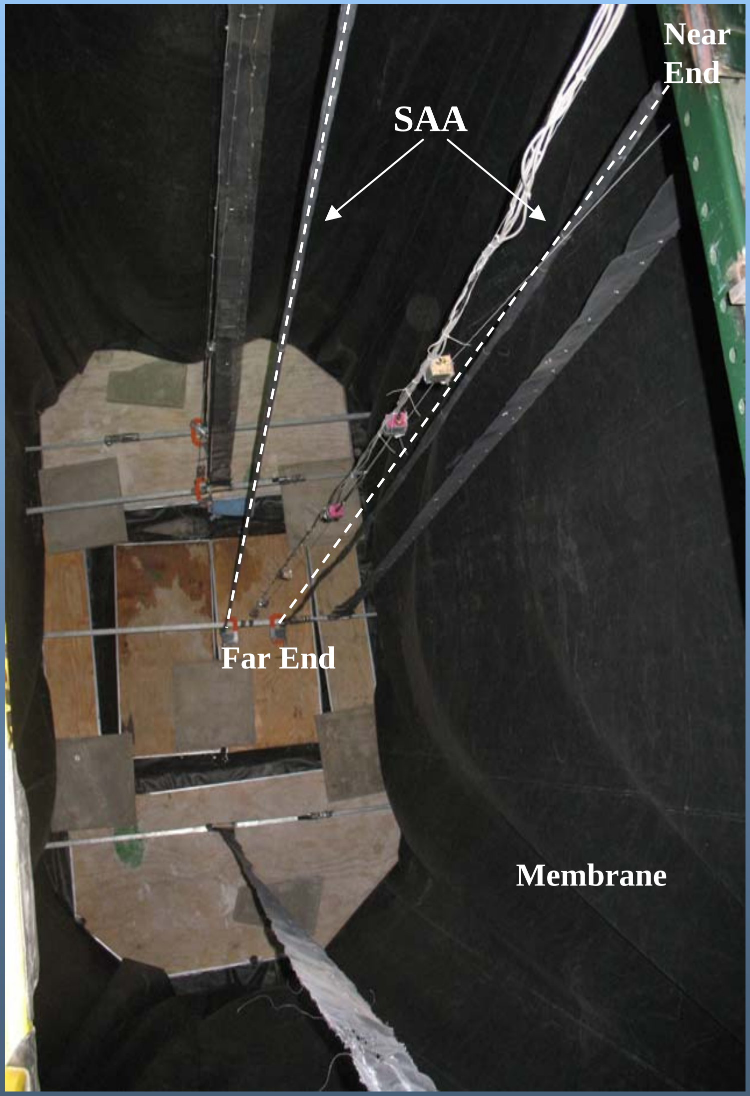
Cross-Sensor Data Quality Verification

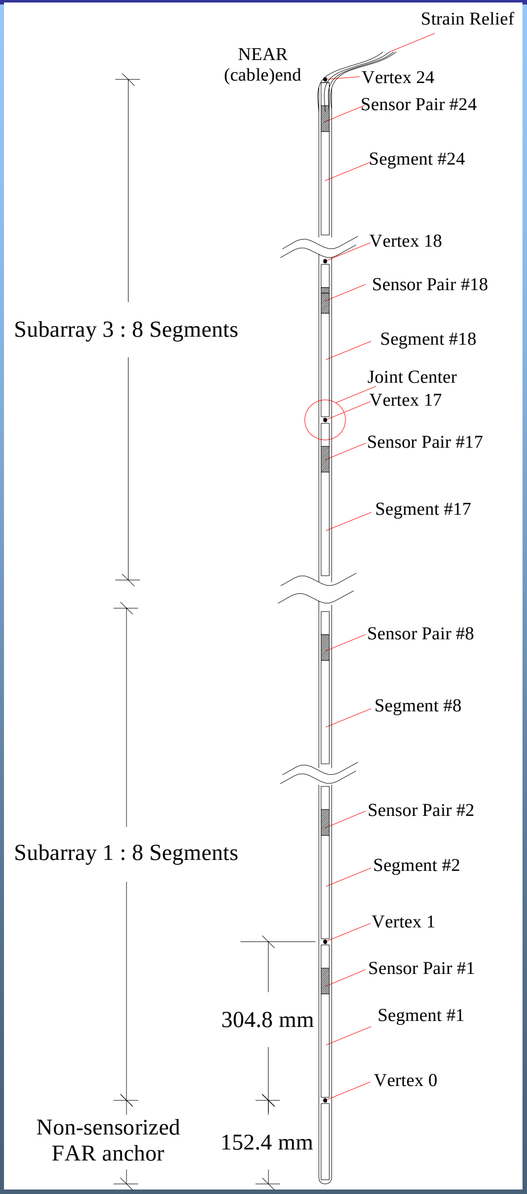
Capture underlying Physics

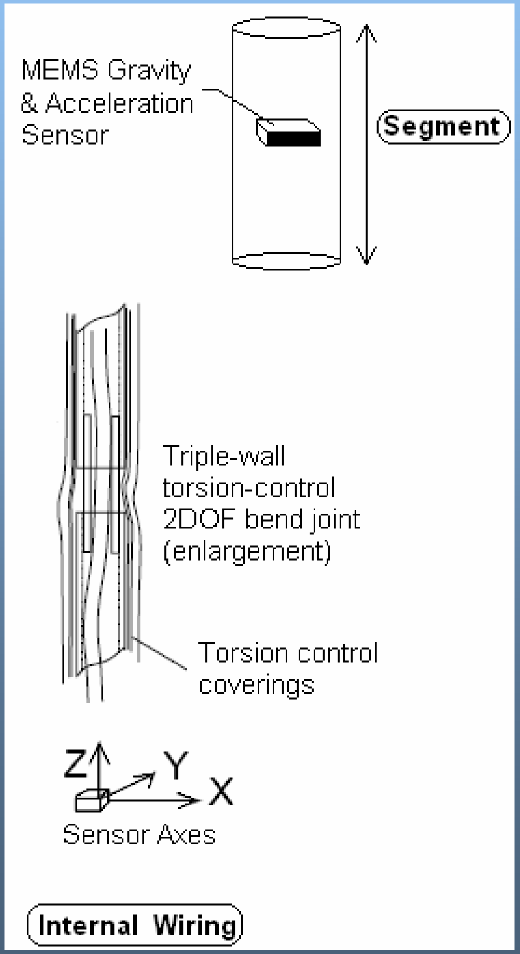
Visualization & Integration with FEM & DEM

Education/Outreach

MEMS Accelerometers



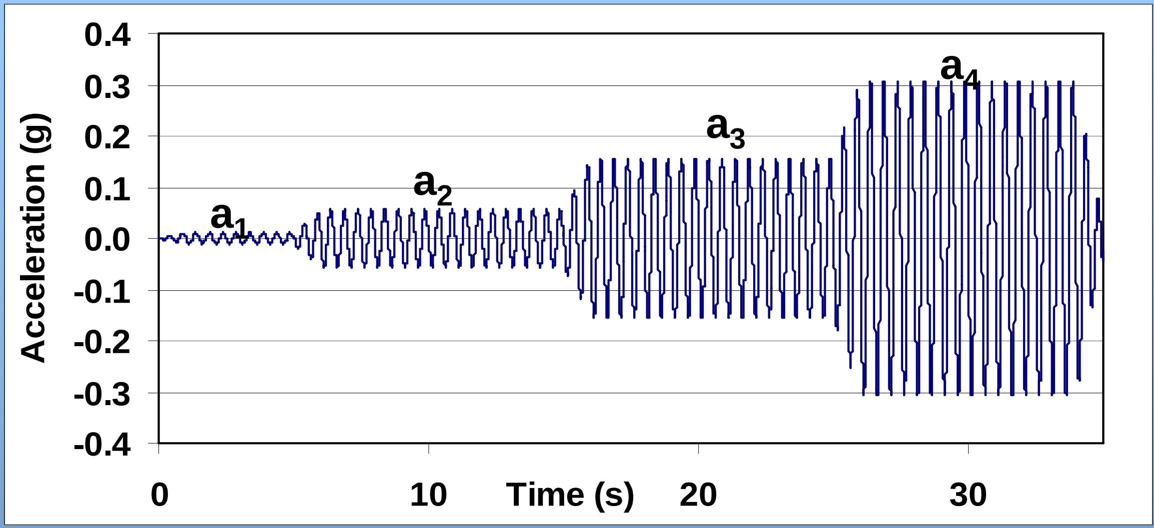


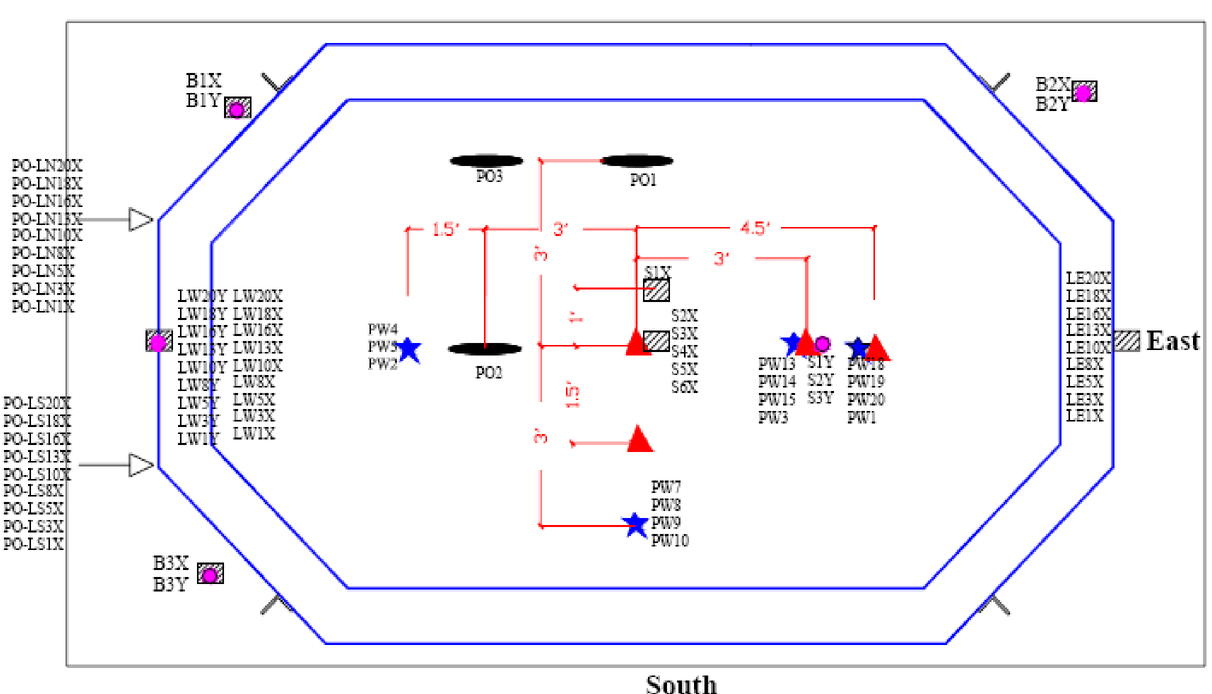


Base Acceleration & Sensor Locations – SG1

Any EQ or Synthetic Motion possible.

ND Motion followed by Strong Shaking





East – Reaction Wall & Actuators;

PO-Potentiometer

PW – Piezometer

S – Accelerometer in soil;

L – Accelerometer on ring

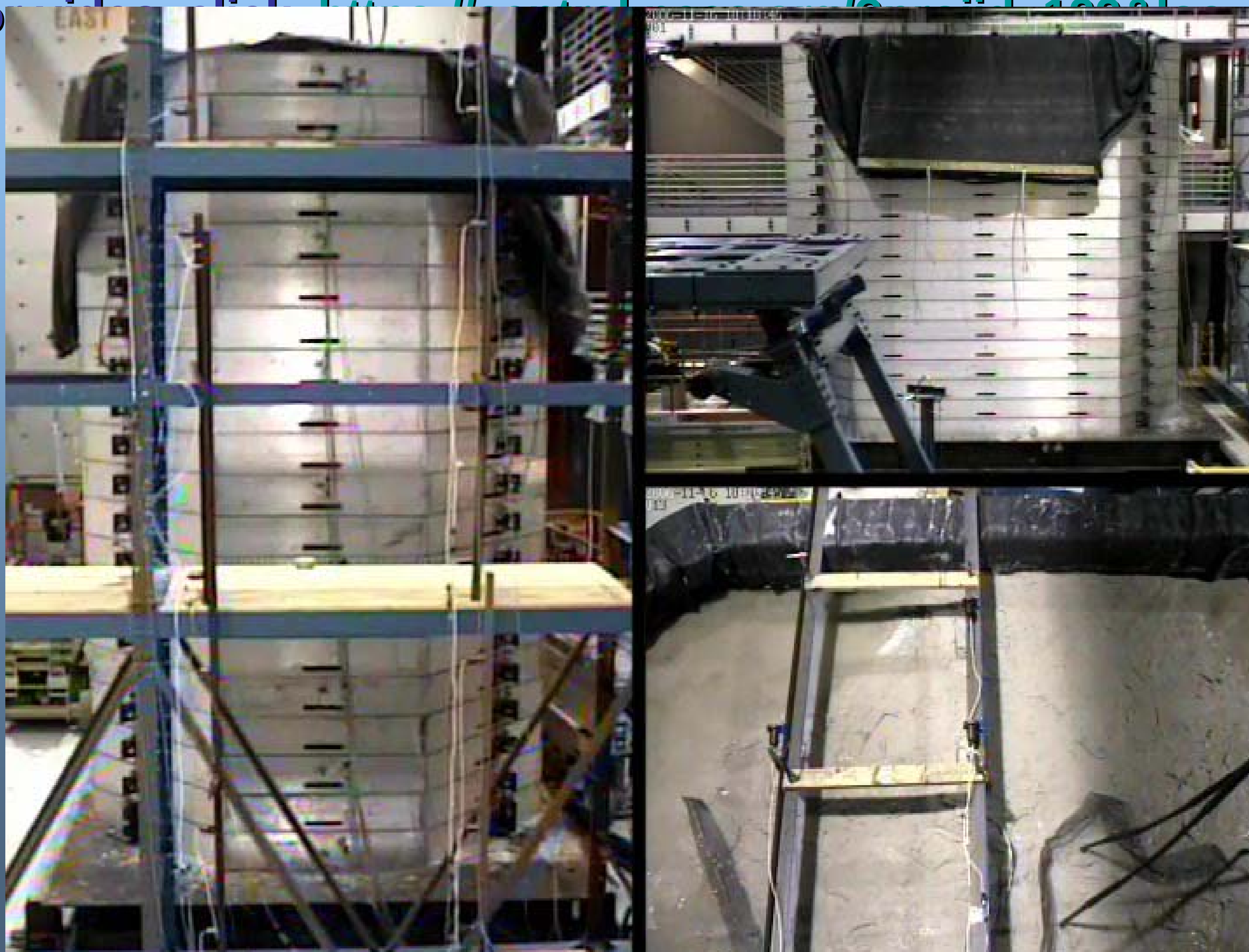
B – accelerometer on shaking base;

Red triangle – Shape Accel Array

Level Ground Liquefaction Demo

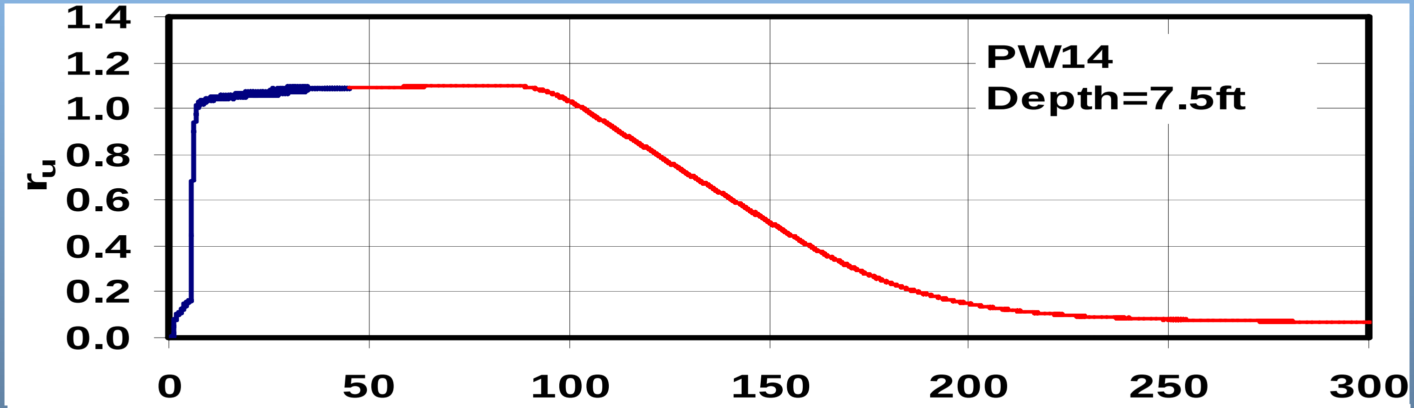
- Test LG0

(Fo … Public#)

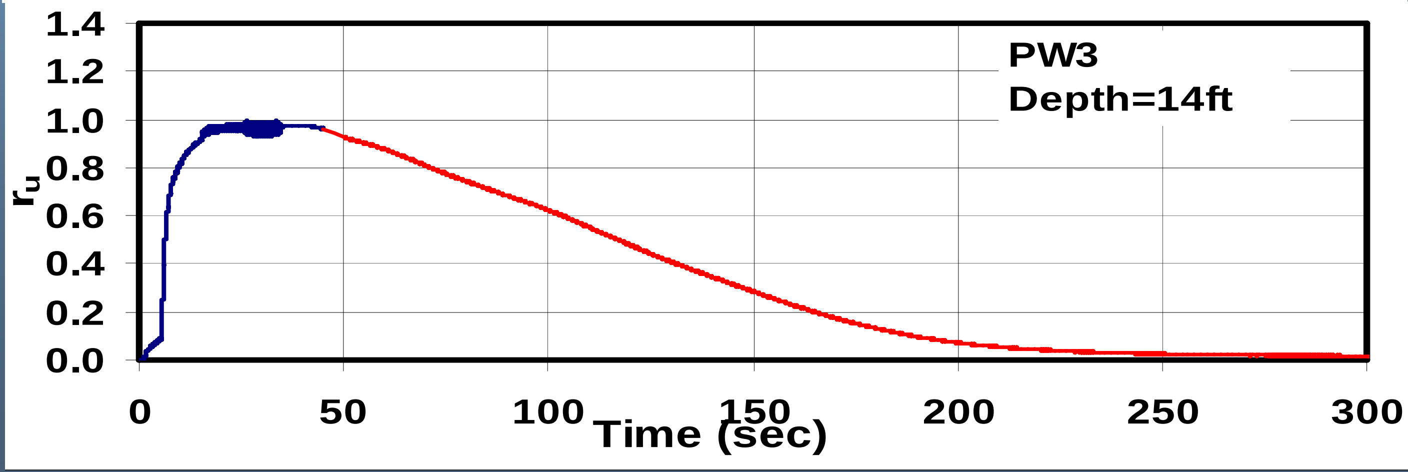


Pore Pressure Response
LG-0

7.5ft



14ft

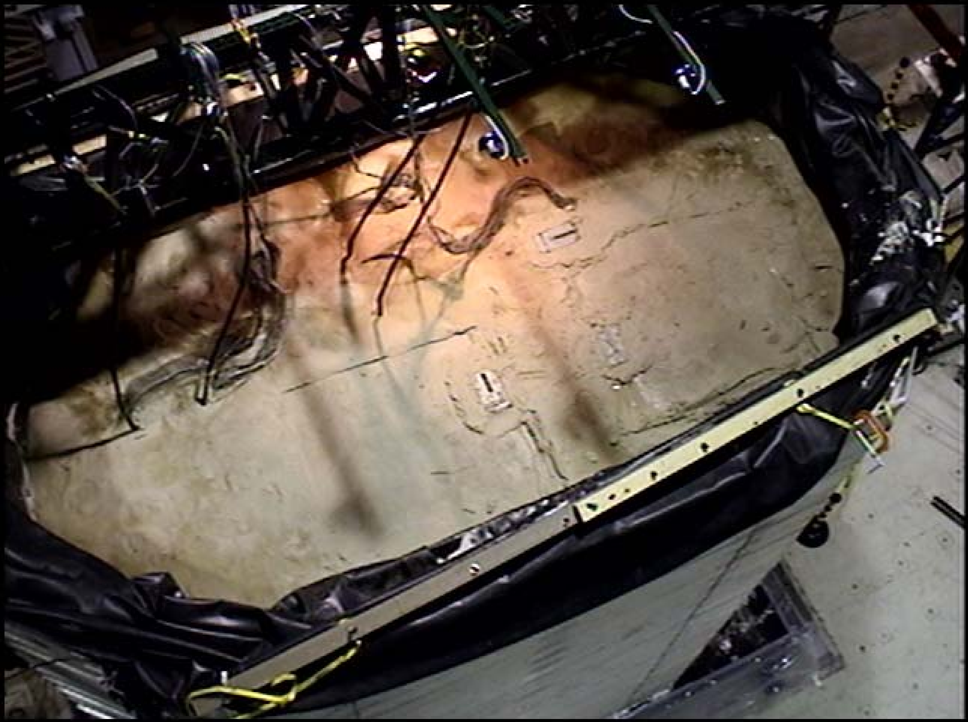


Lateral Spreading - Test SG-1 Objectives & Challenges

- Inclined Box (2 deg)
- Mimic Water Sedimentation & Density Control
- Induce Liquefaction & Assess feasibility of lateral spreading sufficient for Pile Tests
- Control base shaking and control excessive deformation (if occurs)
- Use SG-1 data to design Pile Test Parameters, Inclination, Shaking Intensity for subsequent Tests

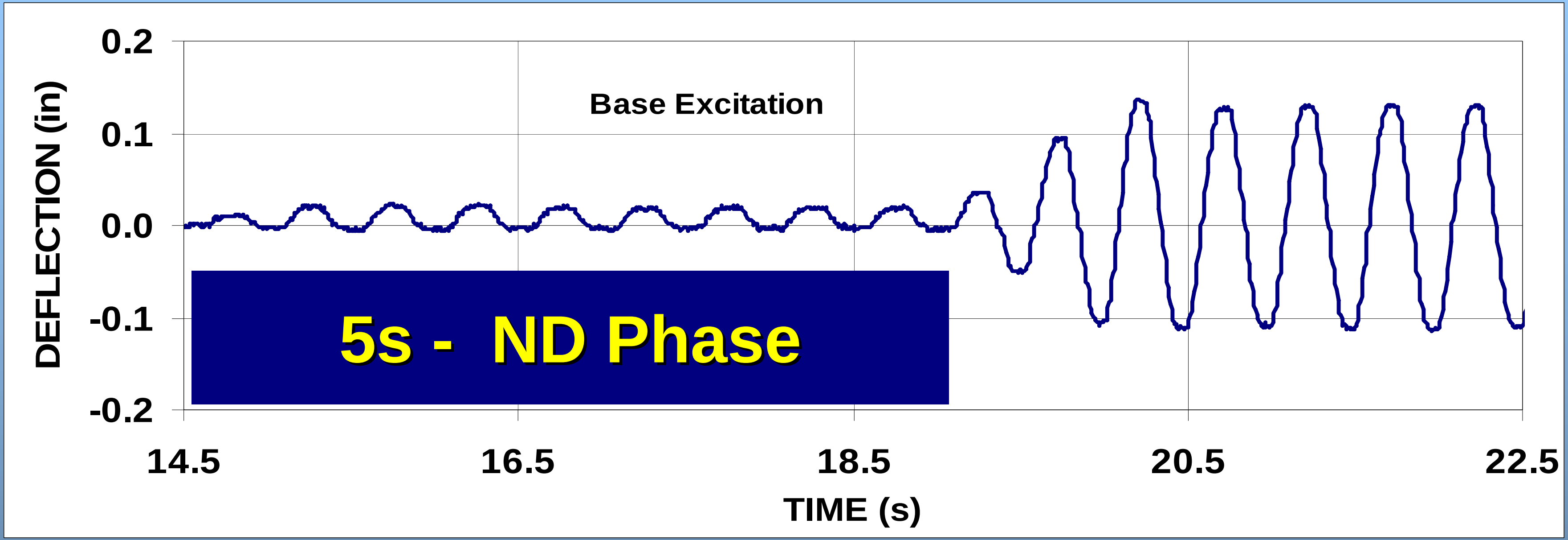
Liquefaction & Lateral Spreading

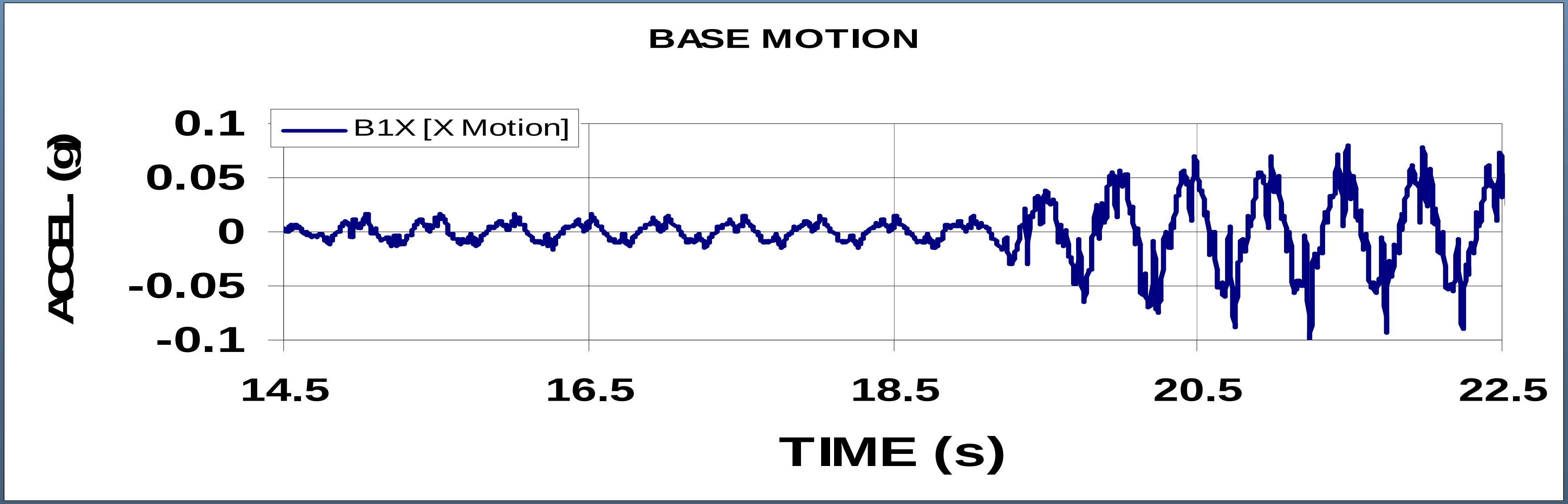
Top View



Side View

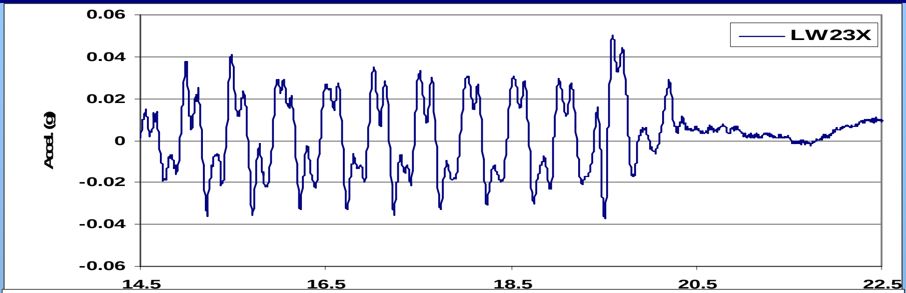
Input Base Motion

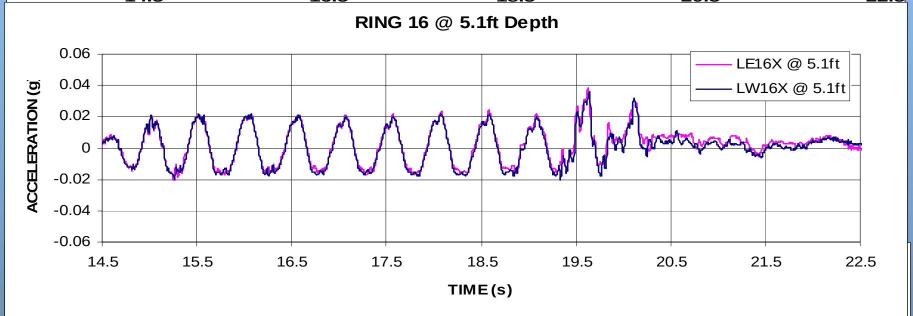


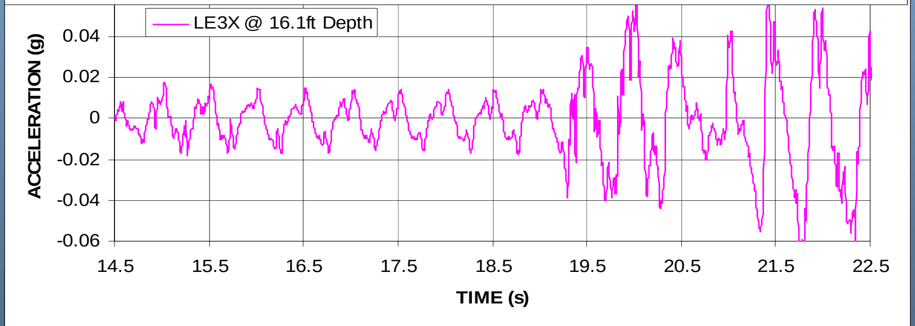


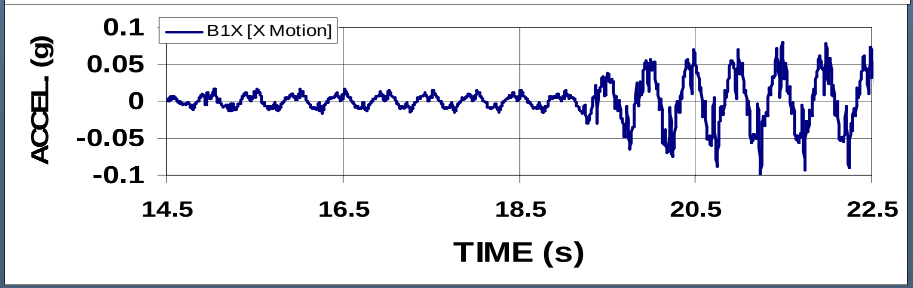
Soil Accelerations

X- Accelerations

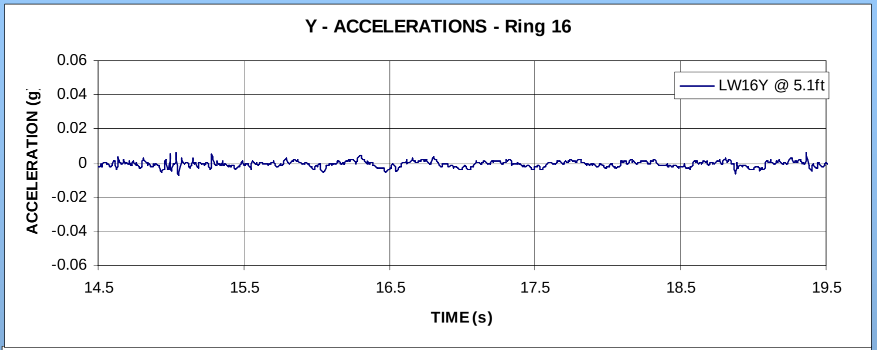


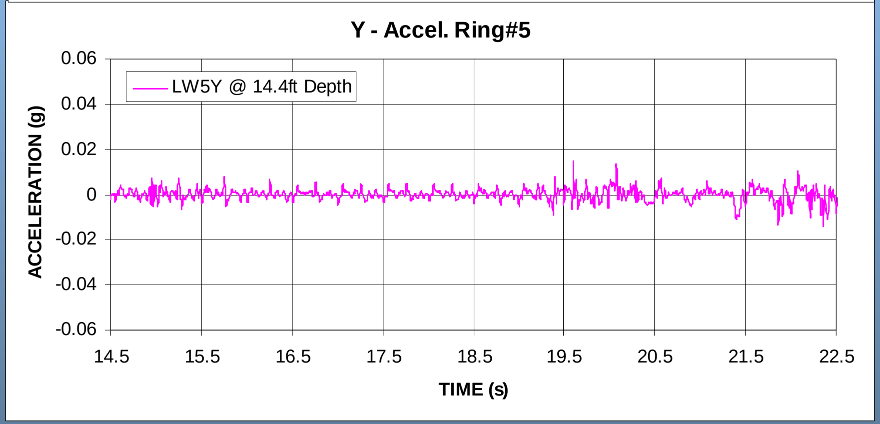




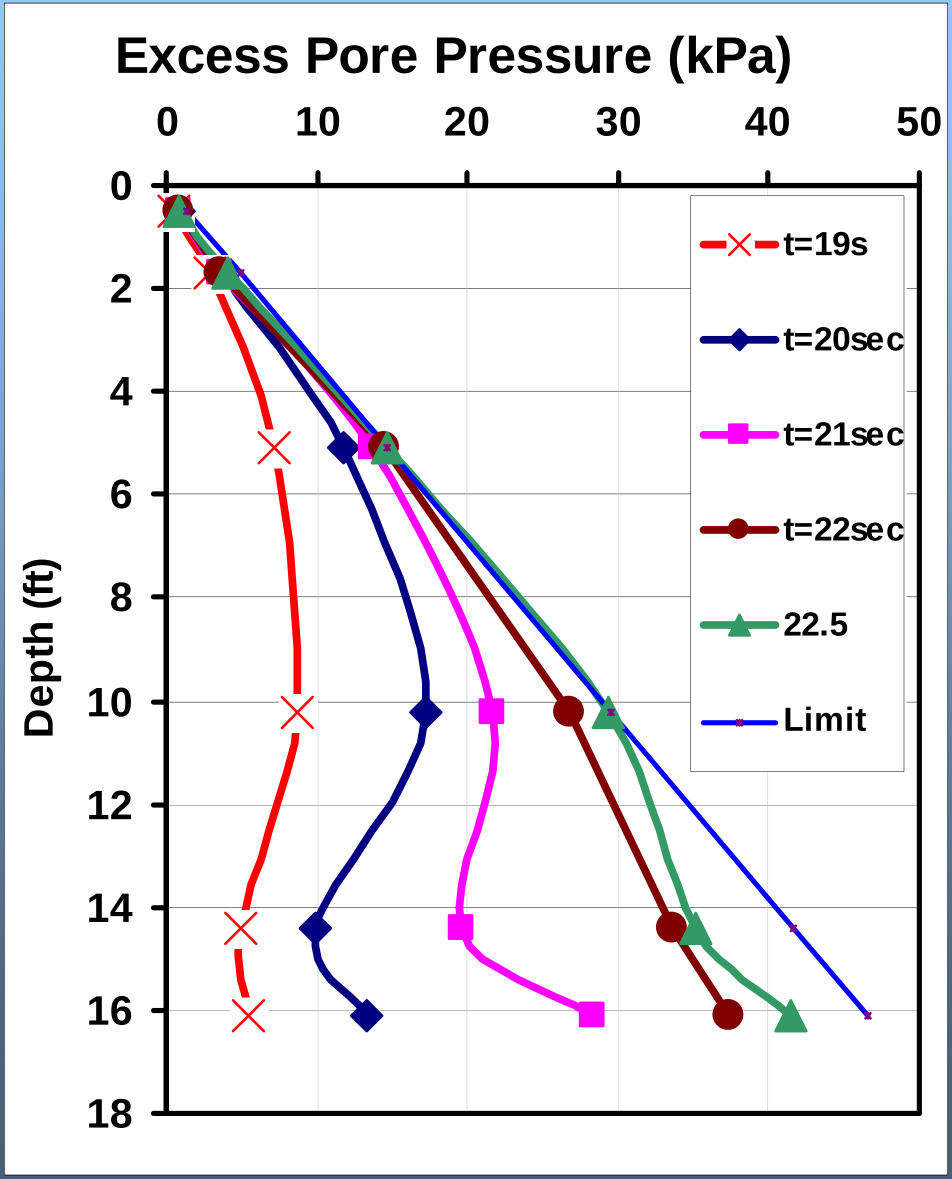


Negligible Y-Accelerations





Pore Pressure Development

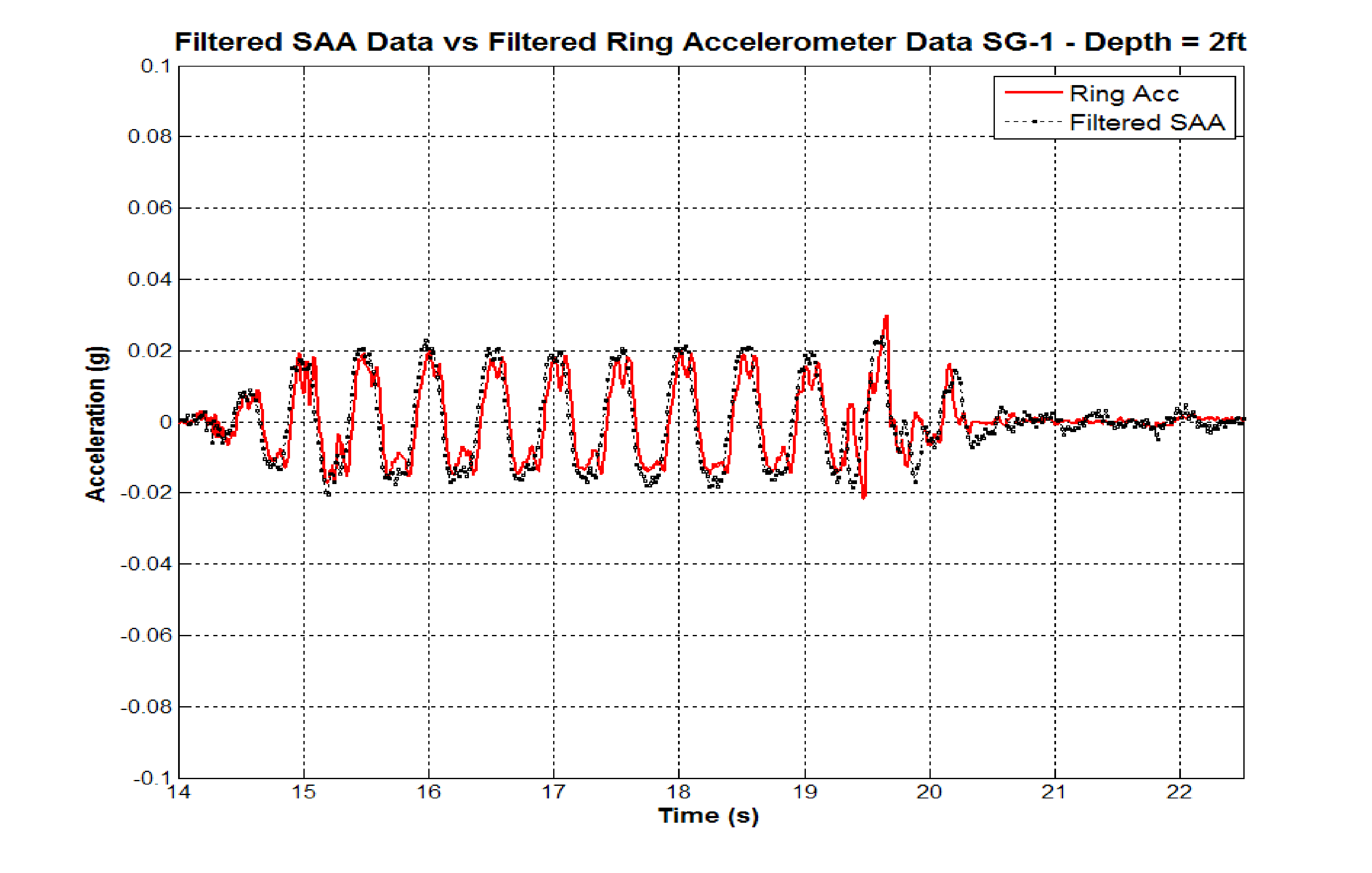


Cross-Sensor Comparisons

MEMS versus Traditional Accelerometers

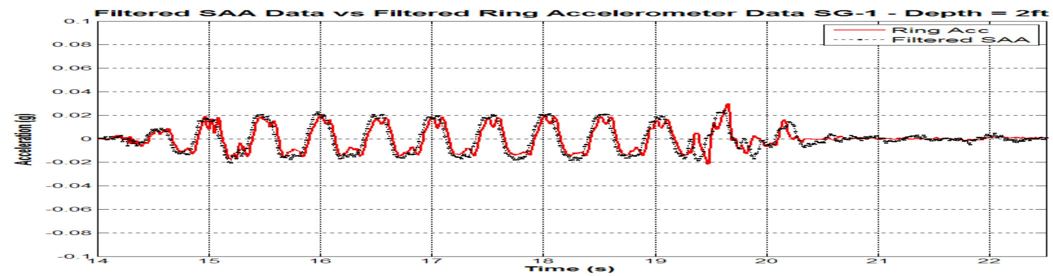
SAA vs Ring Accelerometer

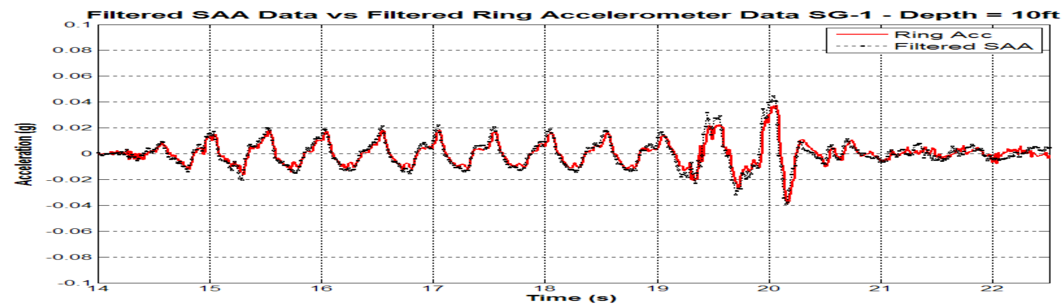
2-ft Depth
Excellent Agreement

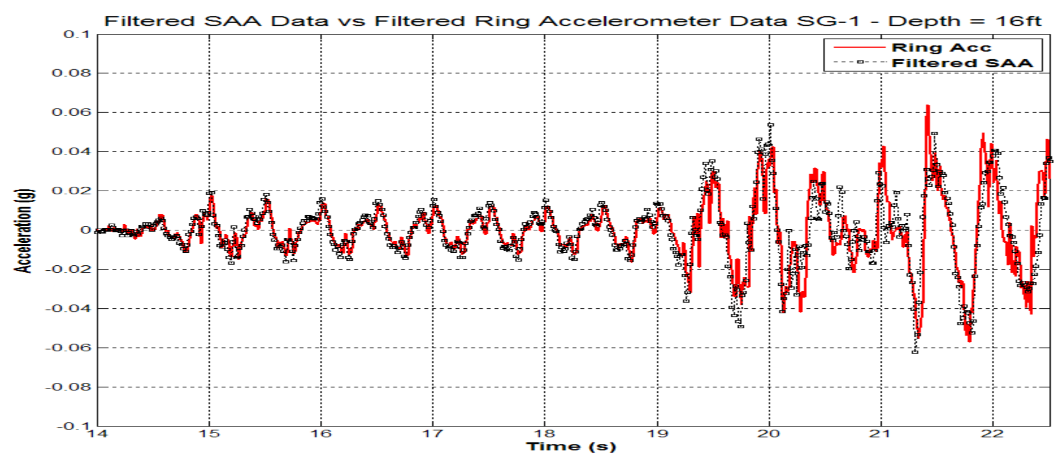


SAA vs Ring Acceleration

Depth Profile – Excellent Agreement



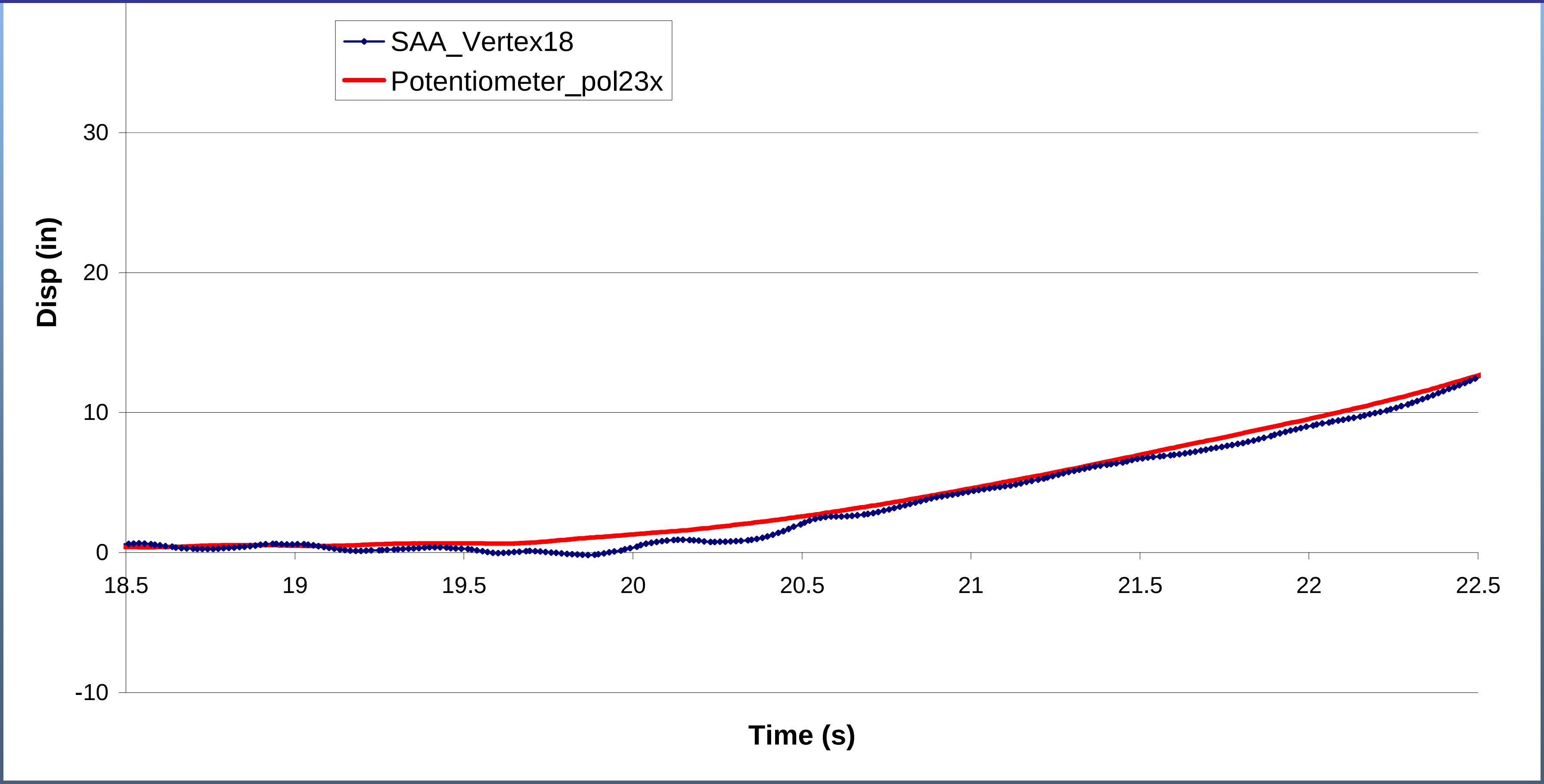




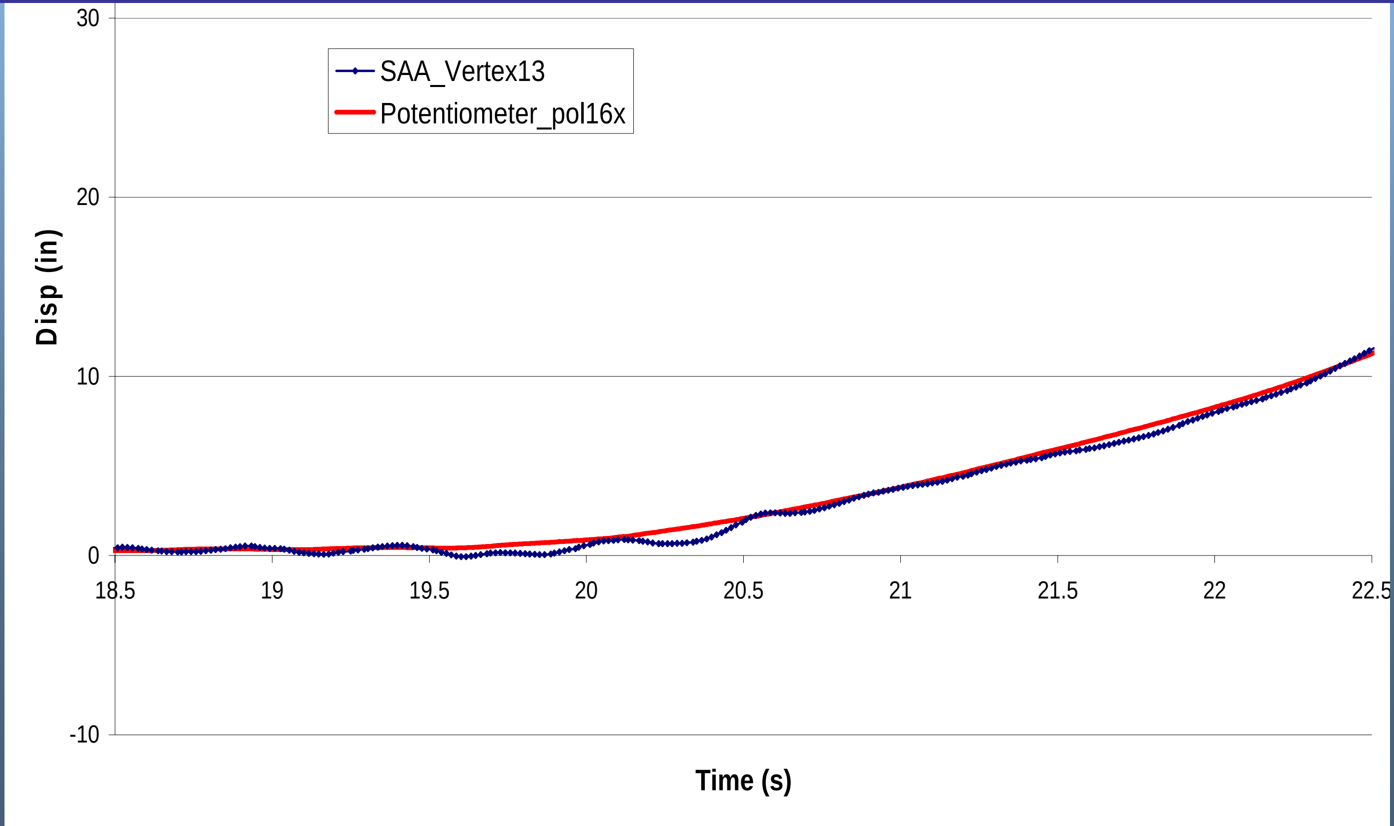
Cross-Sensor Comparisons

MEMS versus Traditional Displacement Sensors

Lateral Spreading SAA vs Potentiometer @ Surface – Excellent Agreement

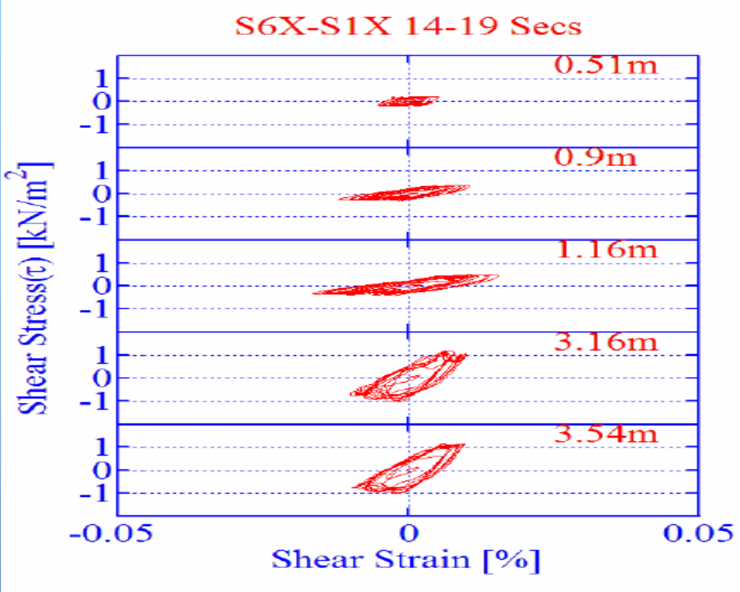


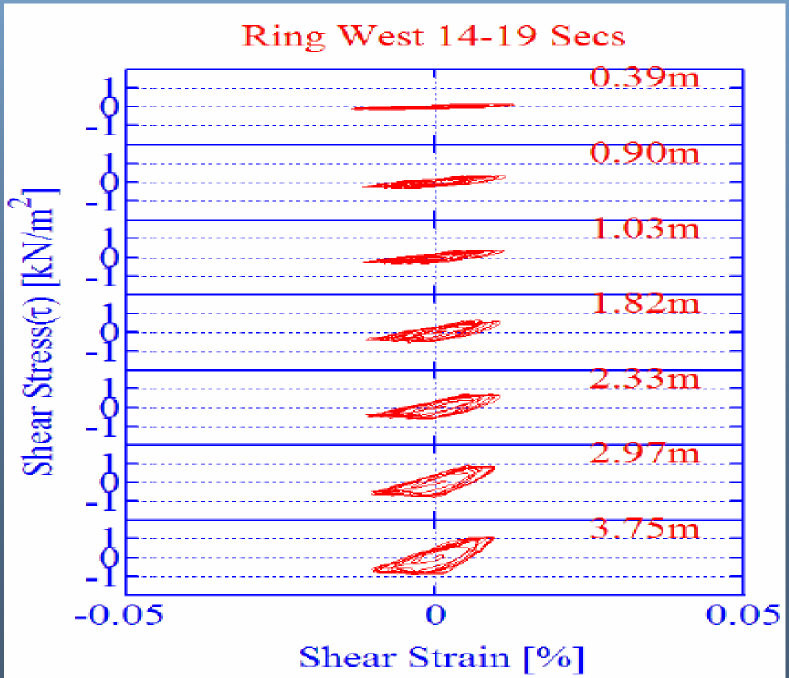
Lateral Spreading
SAA vs Potentiometer @ 5ft Depth

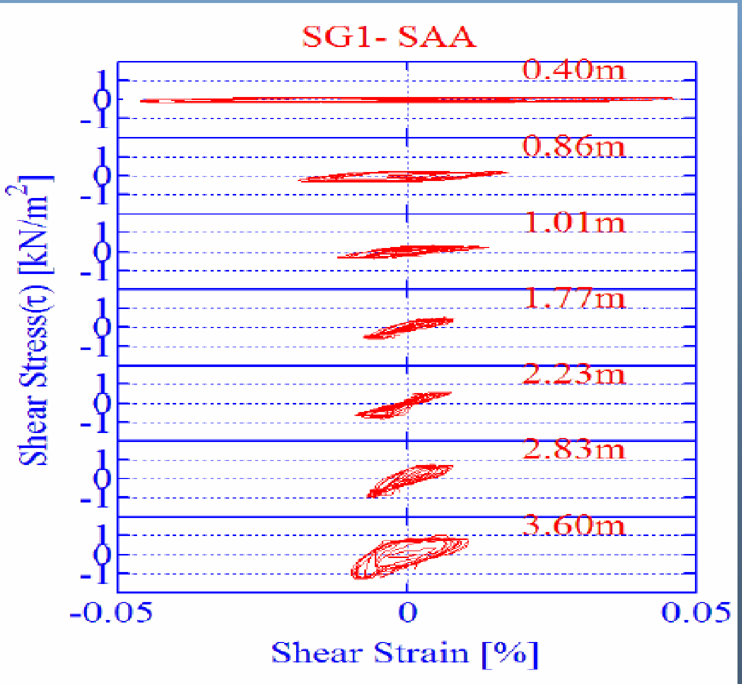


System Identification

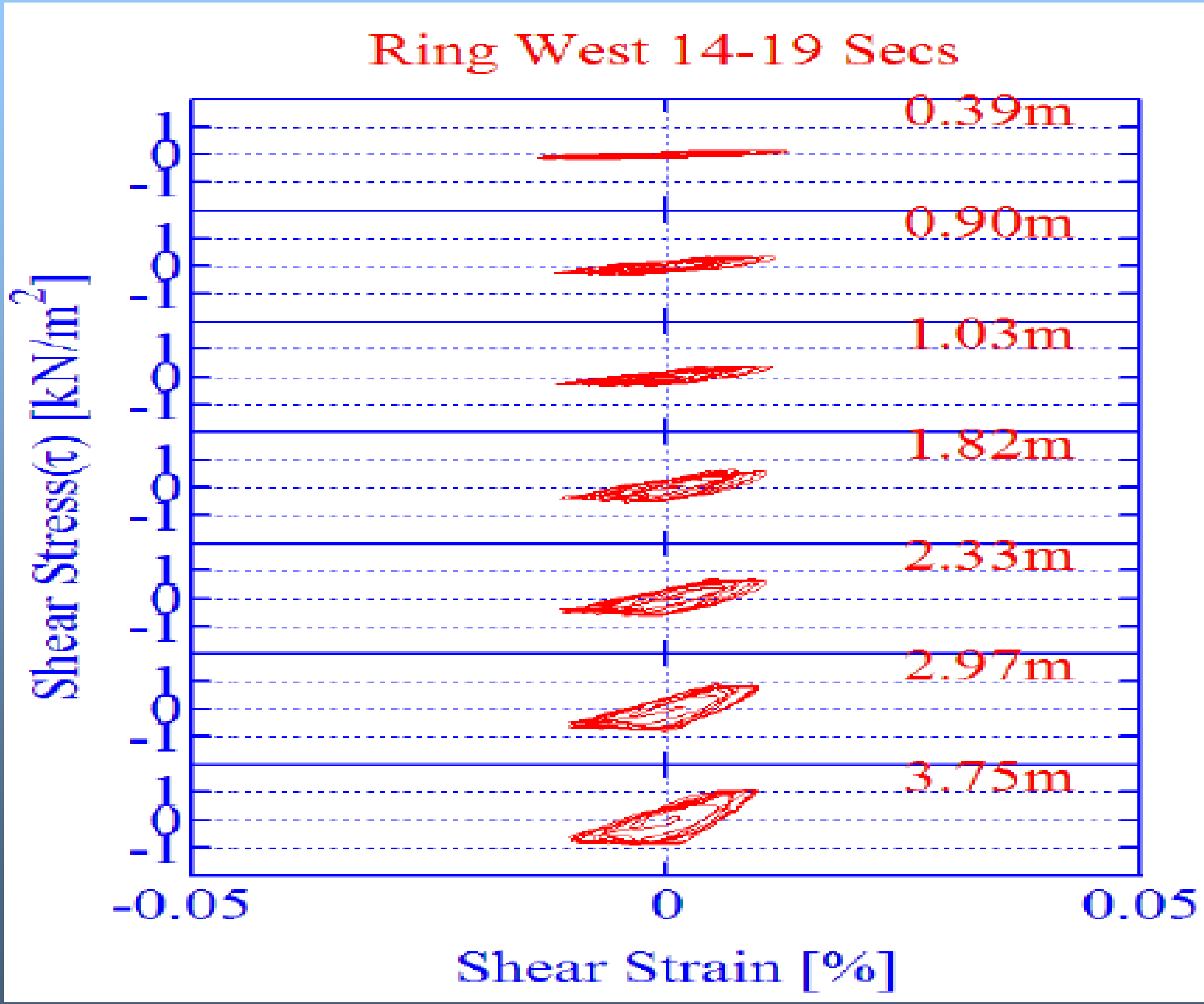
- Stress-strain Loops determined from SI
  - MEMS SAA
  - Ring Accel
  - Soil Accel
- Comparable stress-strain hystresis from each type of sensor
- Comparable G_{max} and Vs Profile



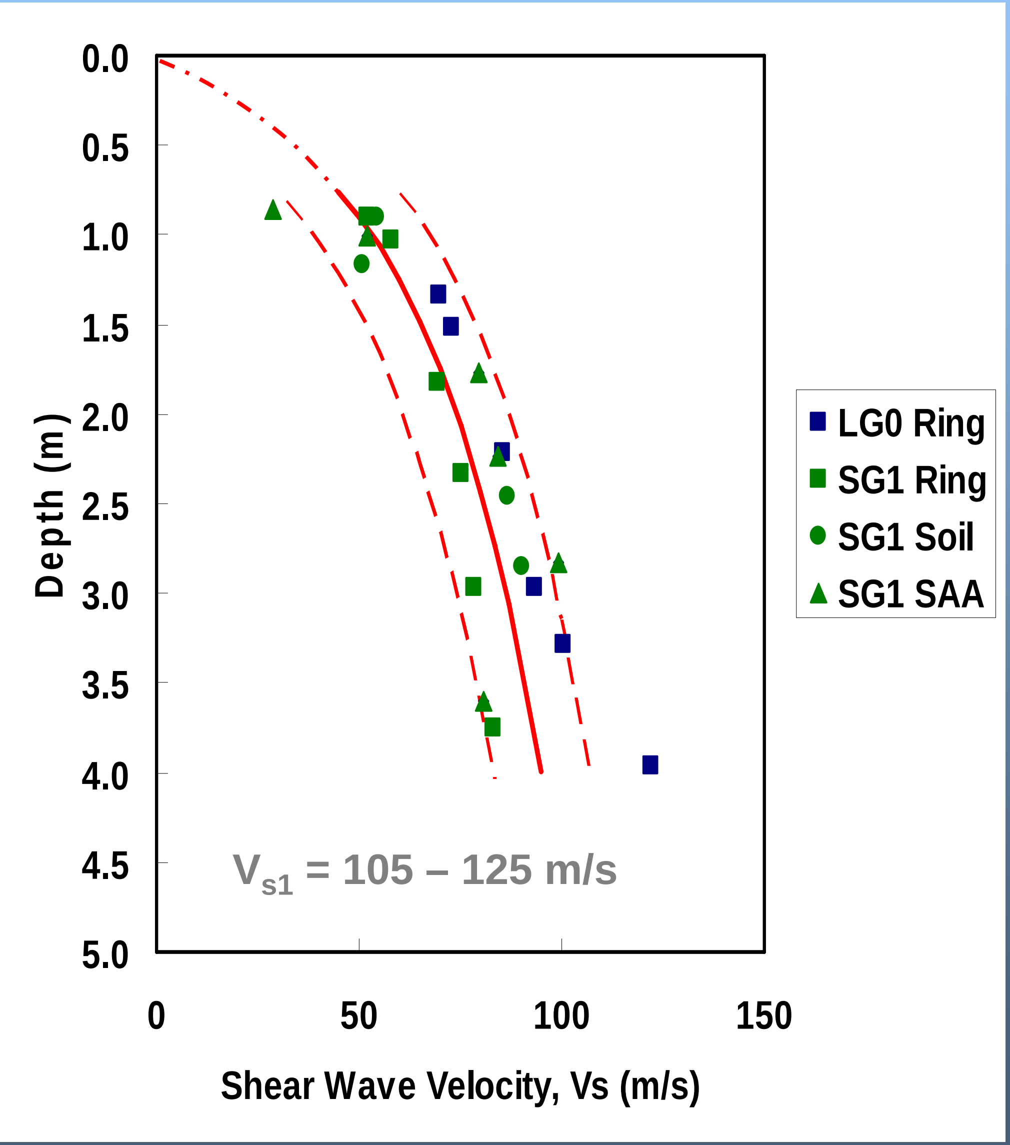




Stress-Strain Hysteresis Loops



Shear Wave Velocity Profile from System Identification Analysis



2 Different Tests

3 Different Sensor Types

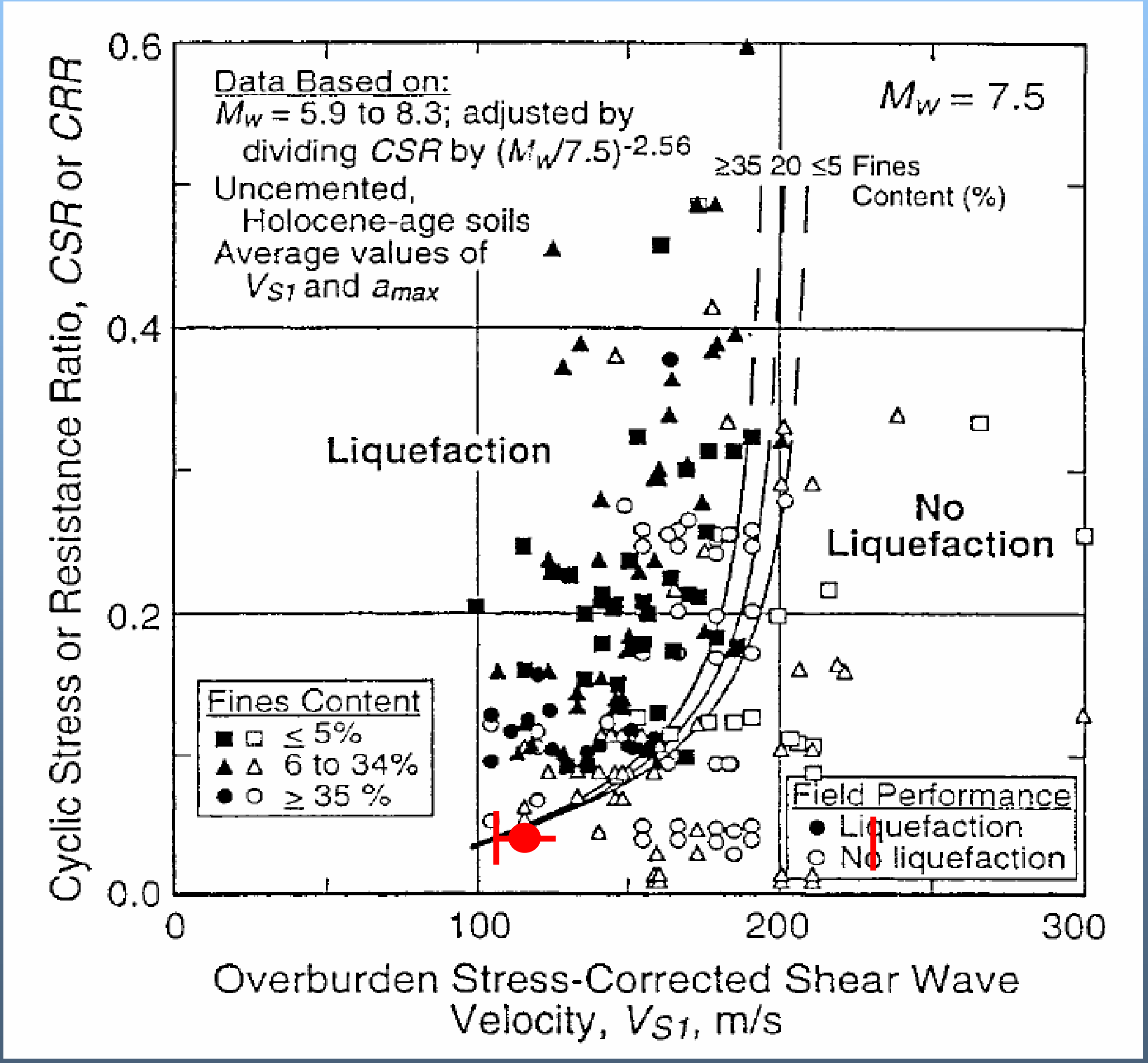
Sensor Location:
Inside Soil or
On the Ring

All converge to the same Vs profile!

SI – Powerful Tool for Soil characterization

Liquefaction – V_{s1} versus CSR

ND Shaking – SG-1



Andrus and Stokoe, 2000

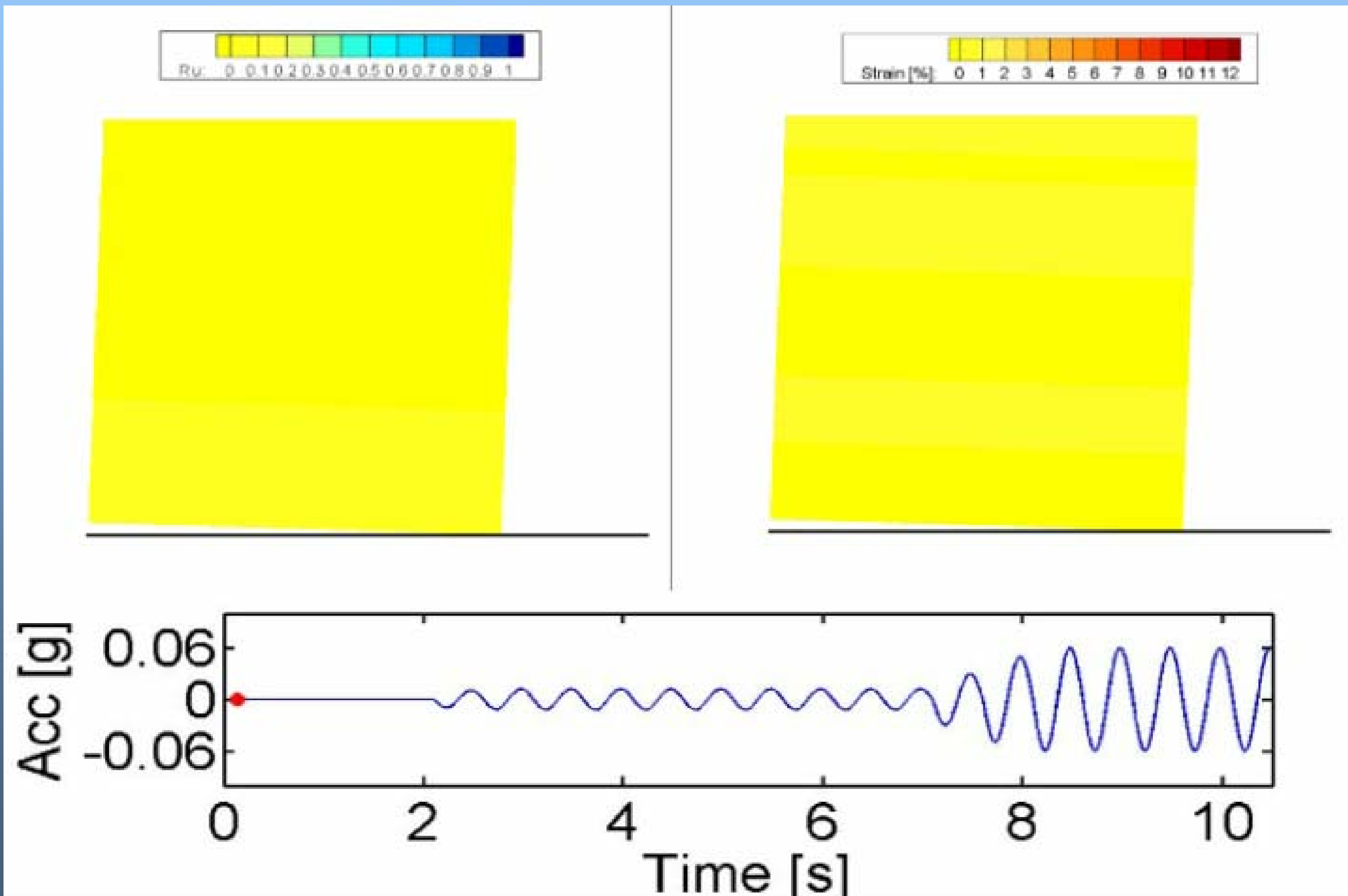
CSR – Just below liquefaction line

Inferred Vs1 from SI – lower end of measured values for loose young deposits

3-D Visualization, Integration & Mechanics of Lateral Spreading

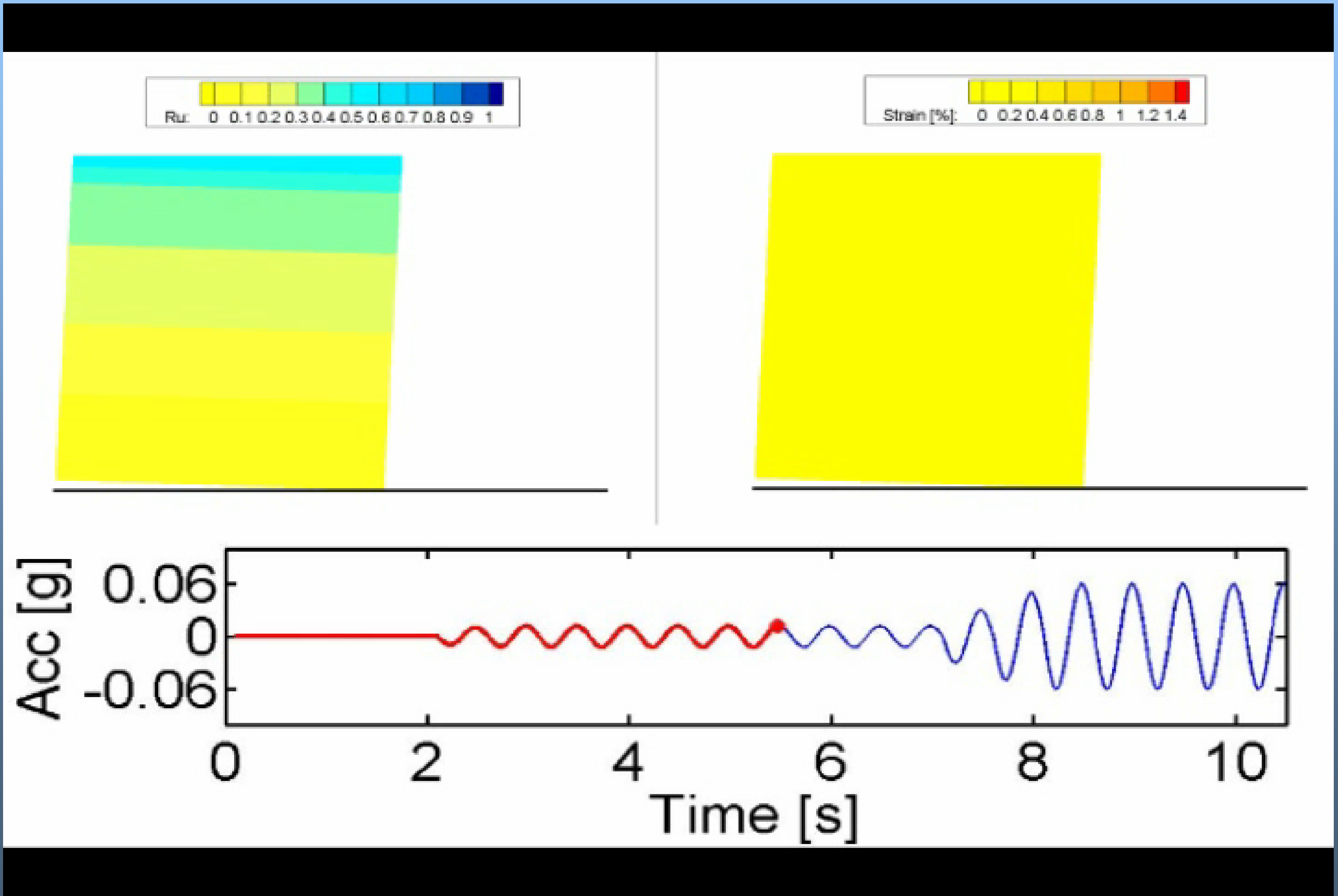
Visualization SG1 (12~22.5s, x5)

Pore Pressure Shear Strain

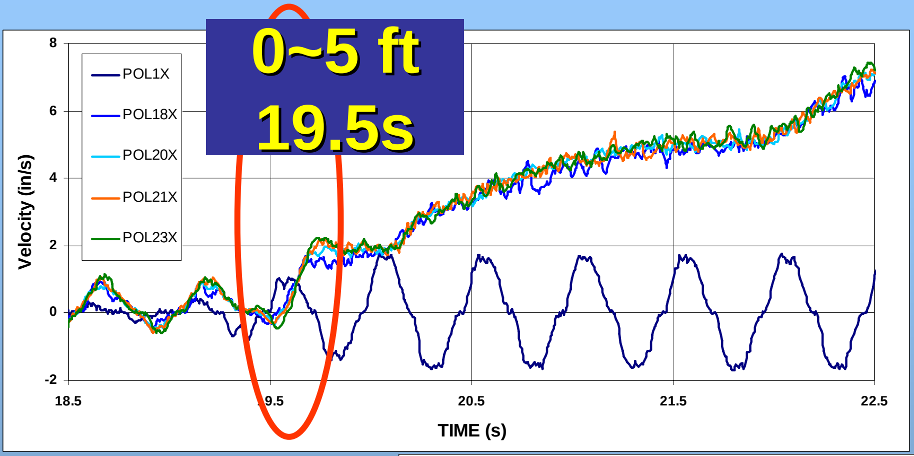


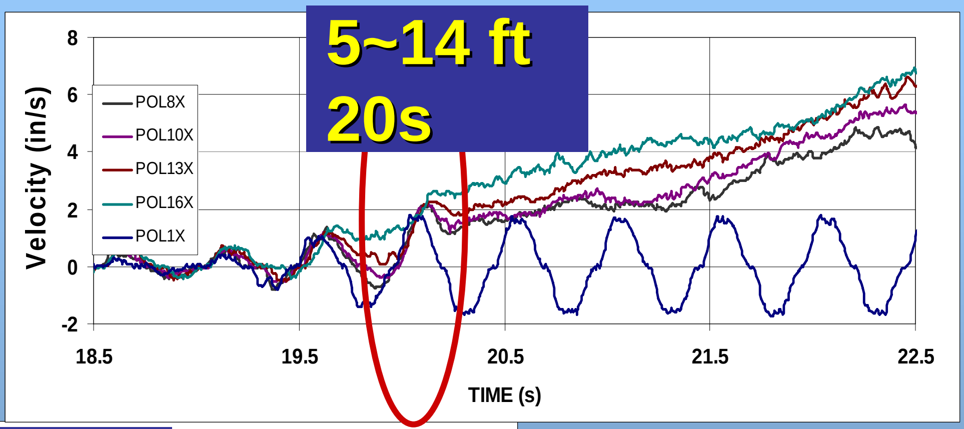
Visualization SG1 (17.5~21.5s, x10)

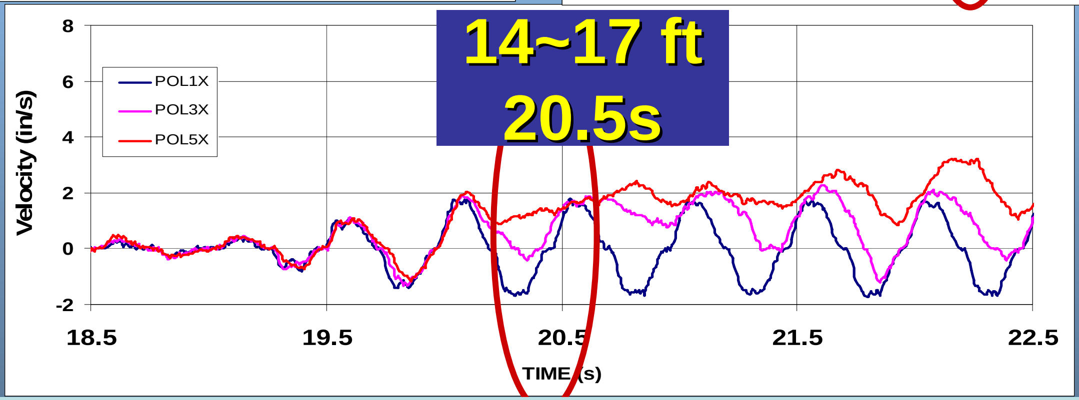
Pore Pressure Shear Strain



Lateral Spreading: Velocity & Mechanics





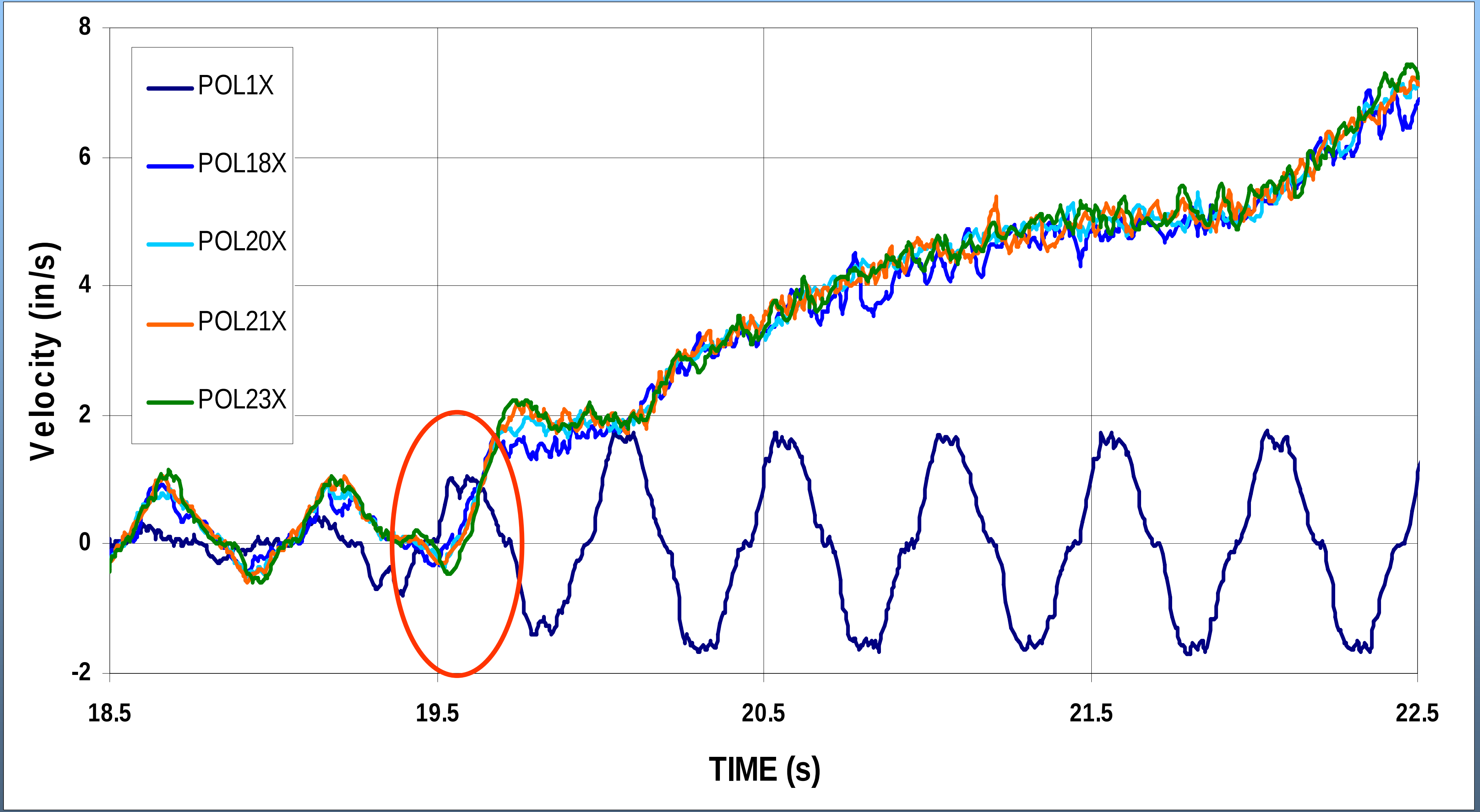


Top 5ft takes off ~ 19.5s; 5 - 14 ft ~ 20.0s; 14-17 ~ 20.5s

Each spread – One cycle apart & Coincides with peaks. Parting velocity begins when the base turns 'up-slope' & when soil could not follow the base

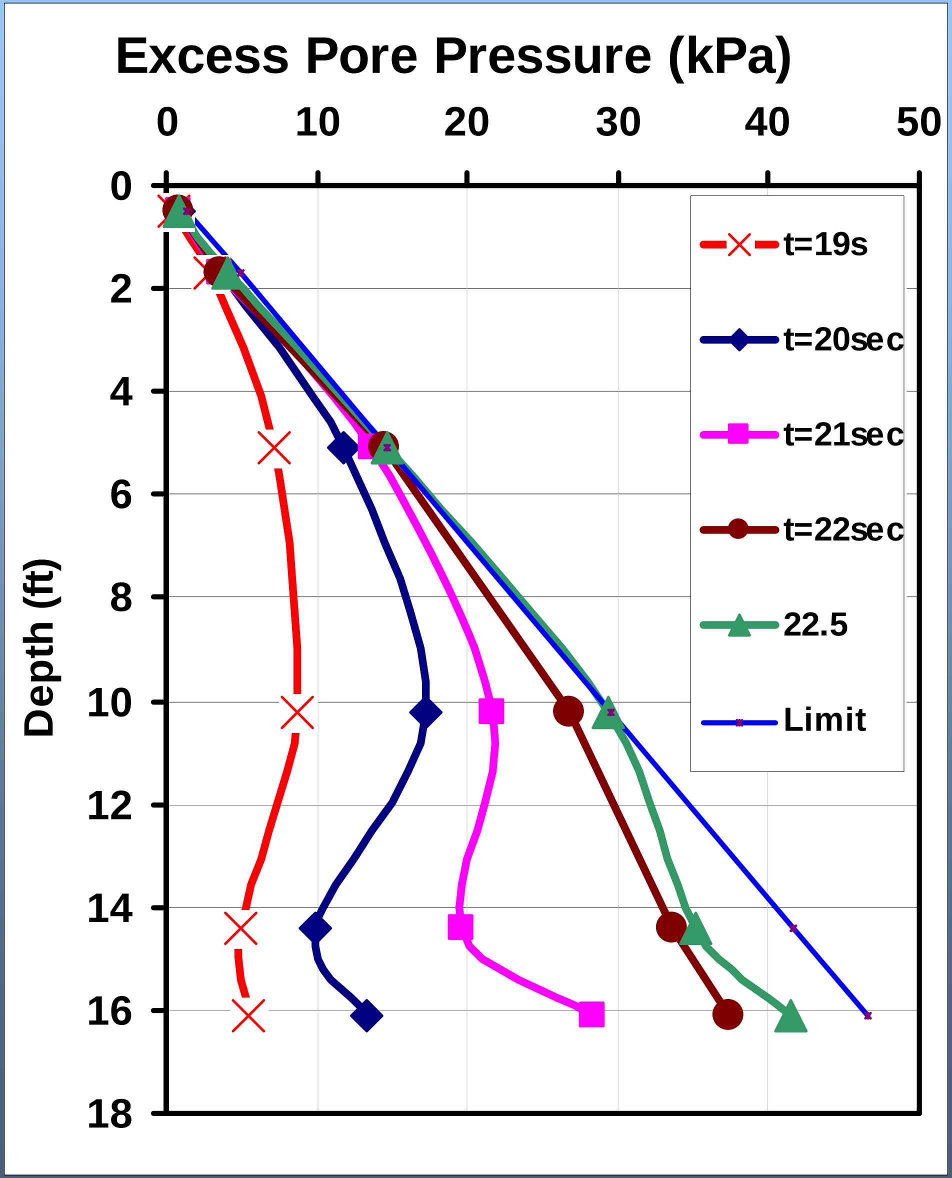
Bottom soil shows a clear Newmark type response

Lateral Spreading - Velocity Initiation of Sliding: Top 4 ~ 5 Feet

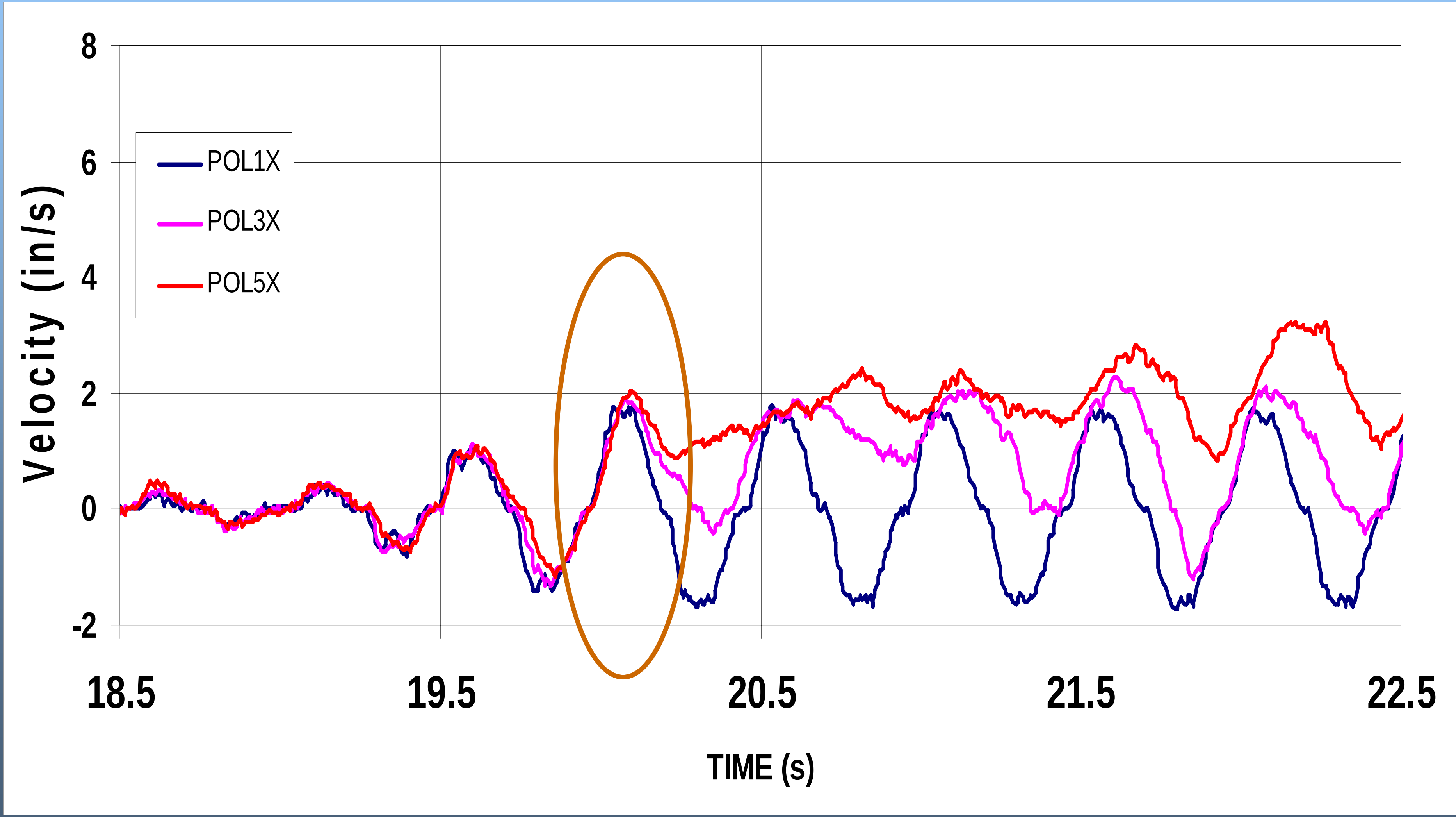


Top 4~5 ft initiates sliding as a 'block' sliding on a softened soil plane underneath; Not fully liquefied yet

Pore Pressure Development

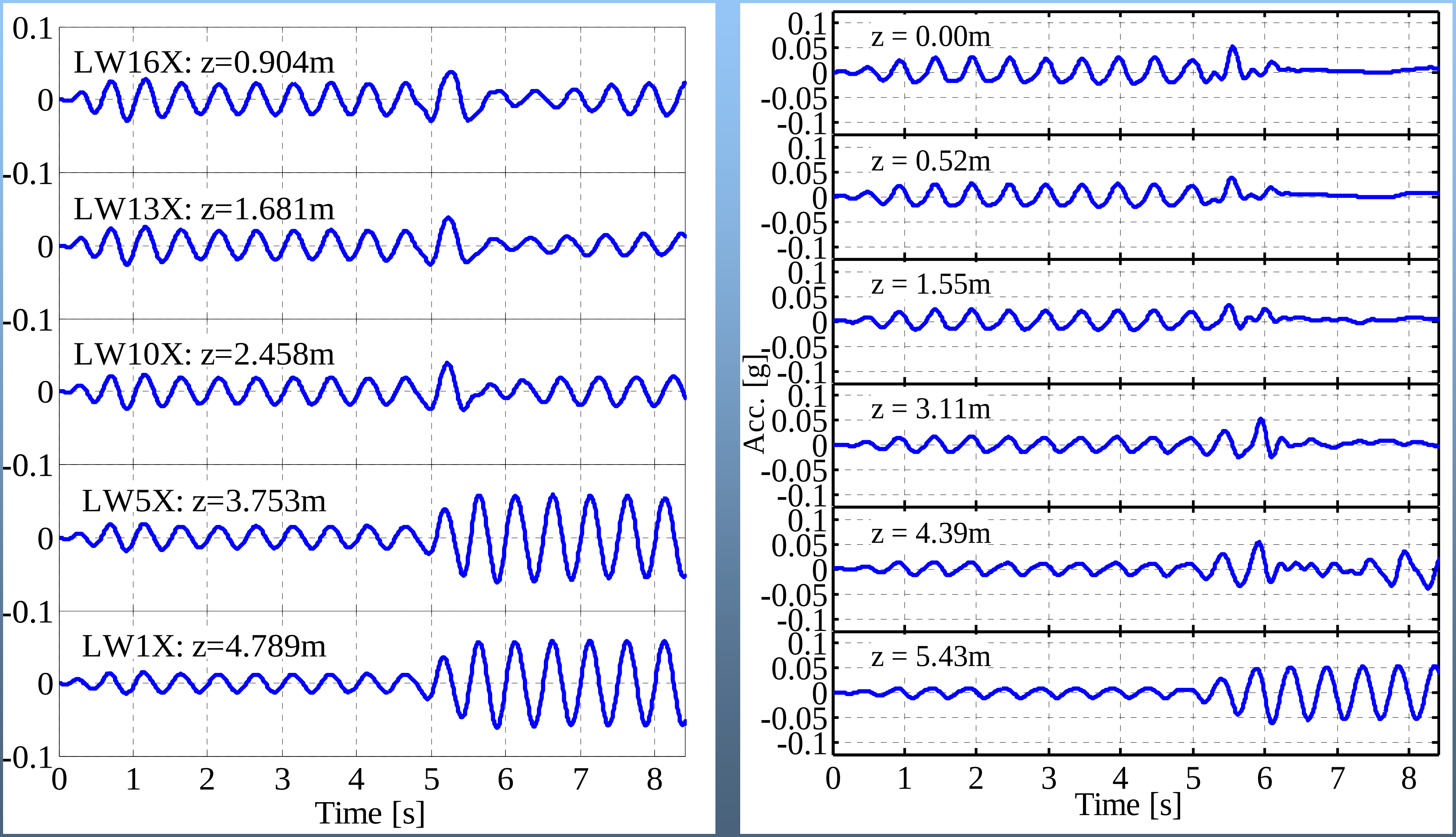


Lateral Spread - Velocity
Newmark Type Motion: Bottom 14~17 ft



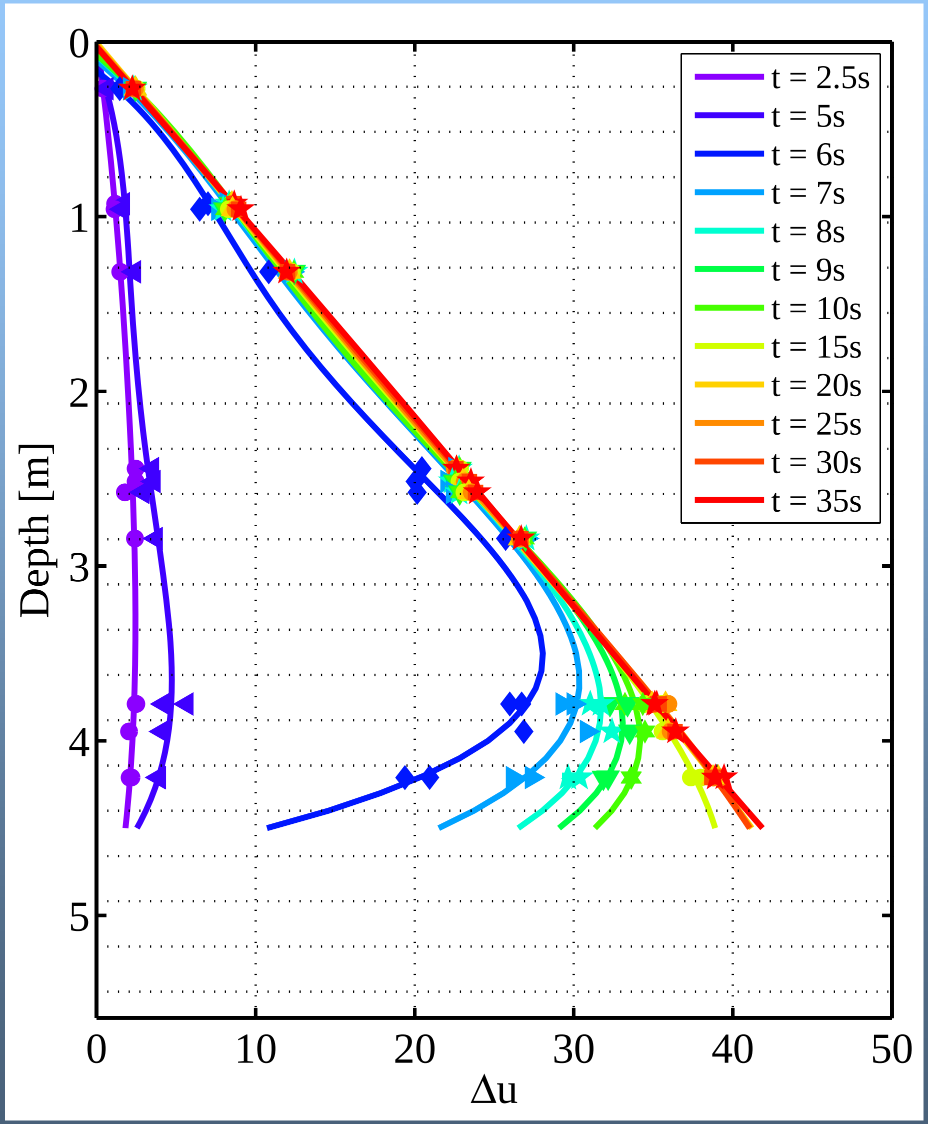
Effect of Gentle Slope on Ground response

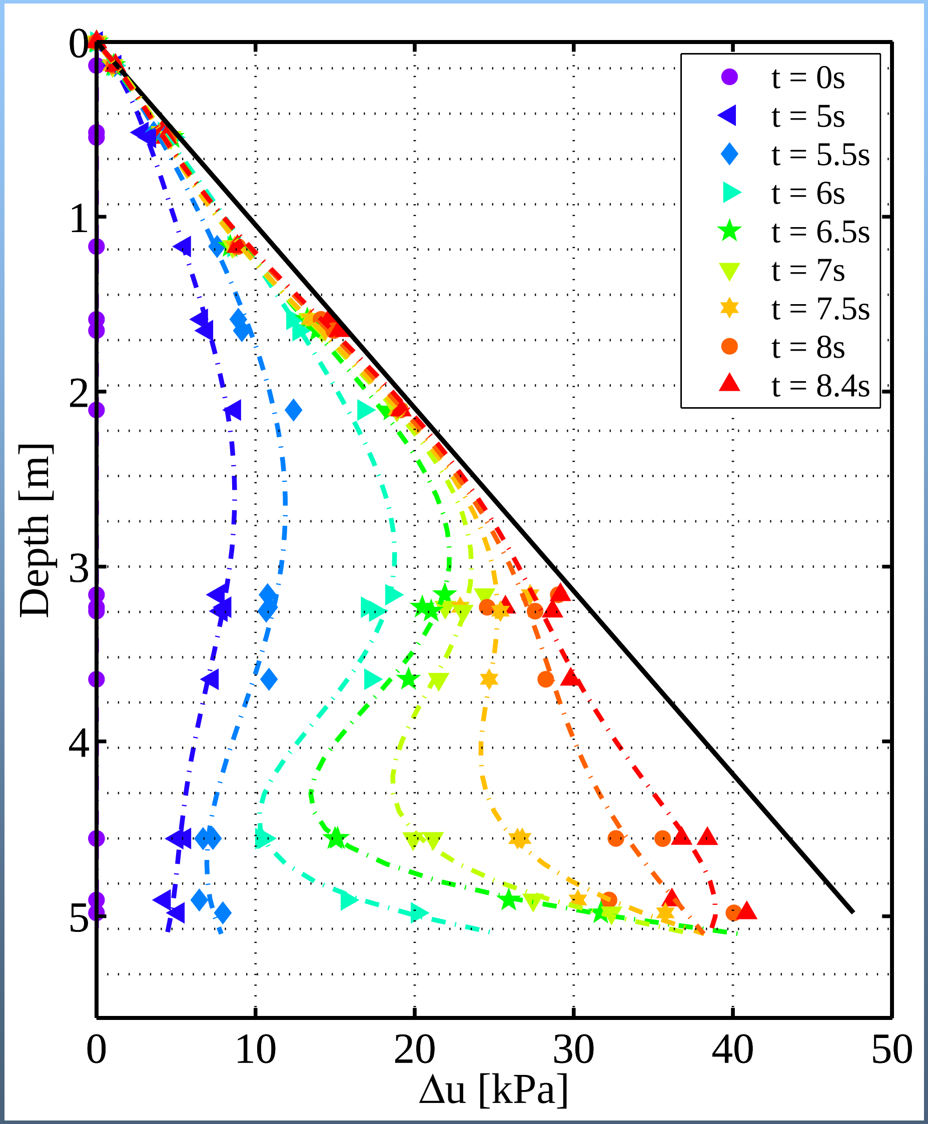
Accelerations: LG-0 Vs SG-1



Lack of accelerations after 6s in SG-1

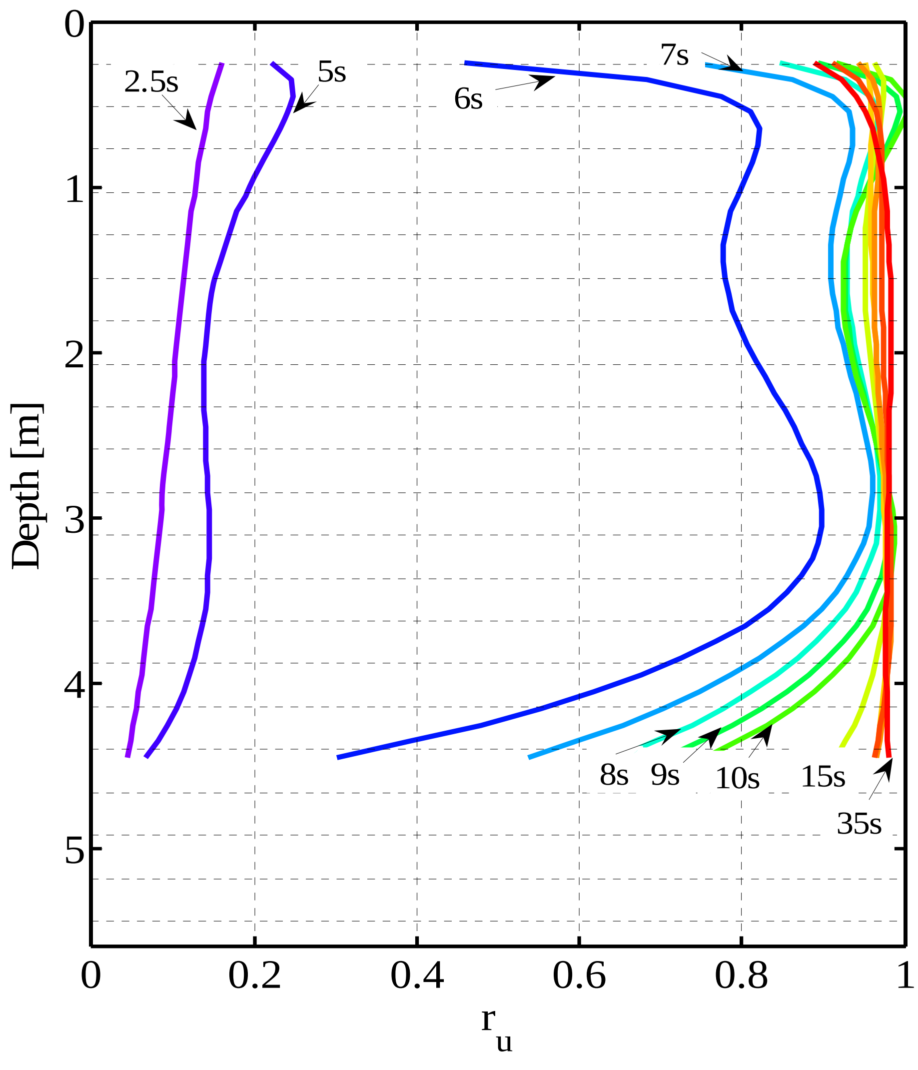
Pore Pressures: LG-0 Vs SG-1

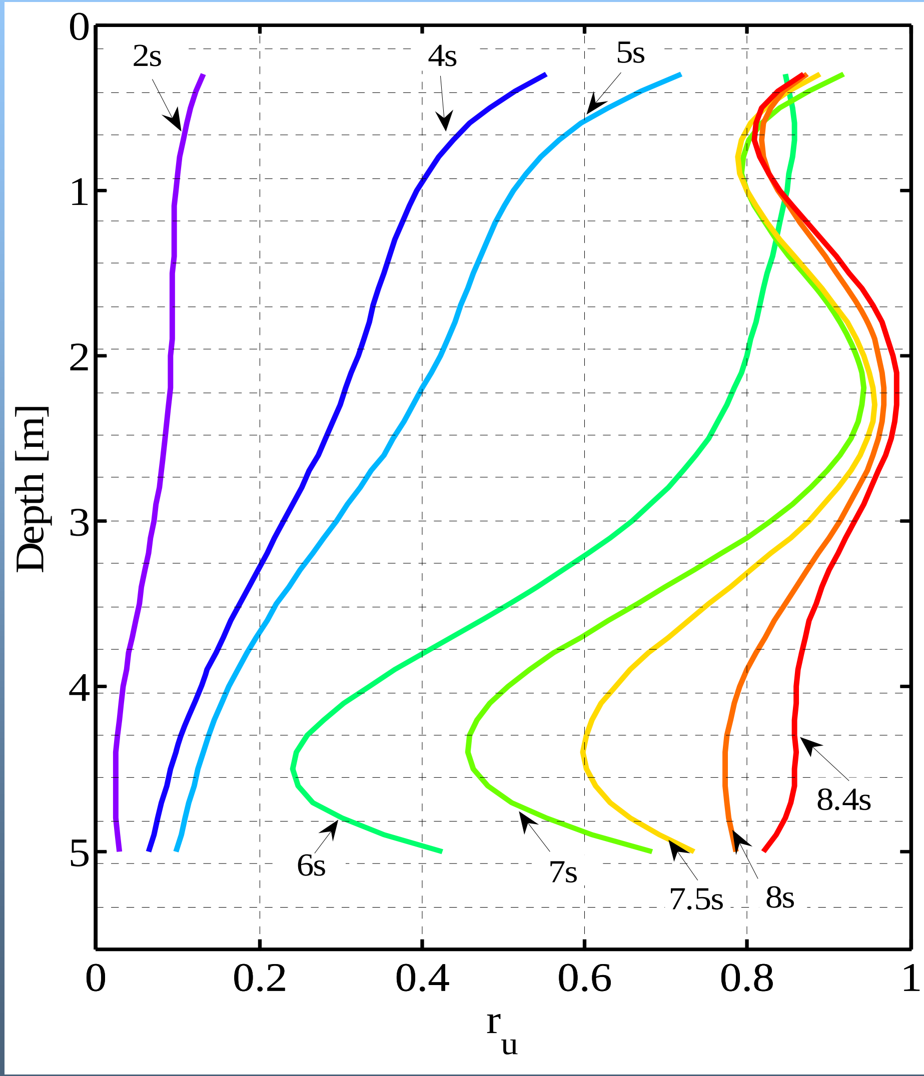




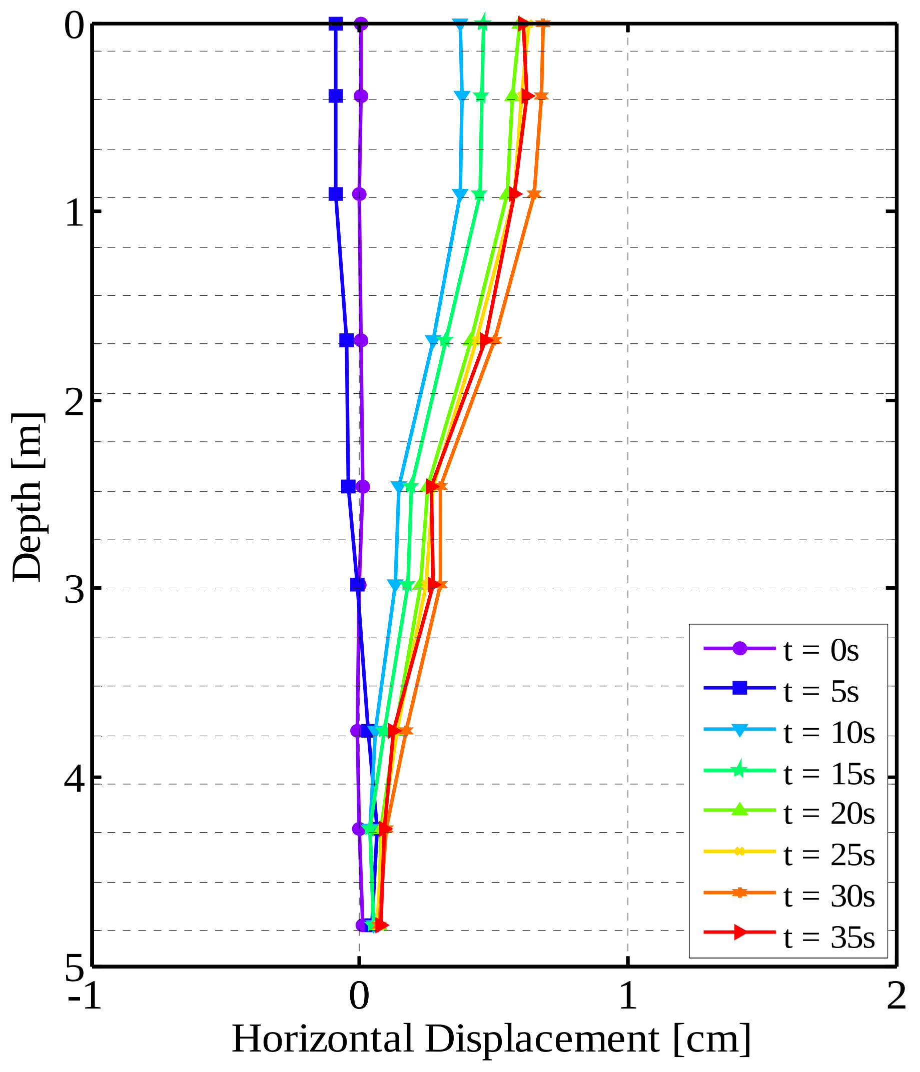
Significant Build up of pwp

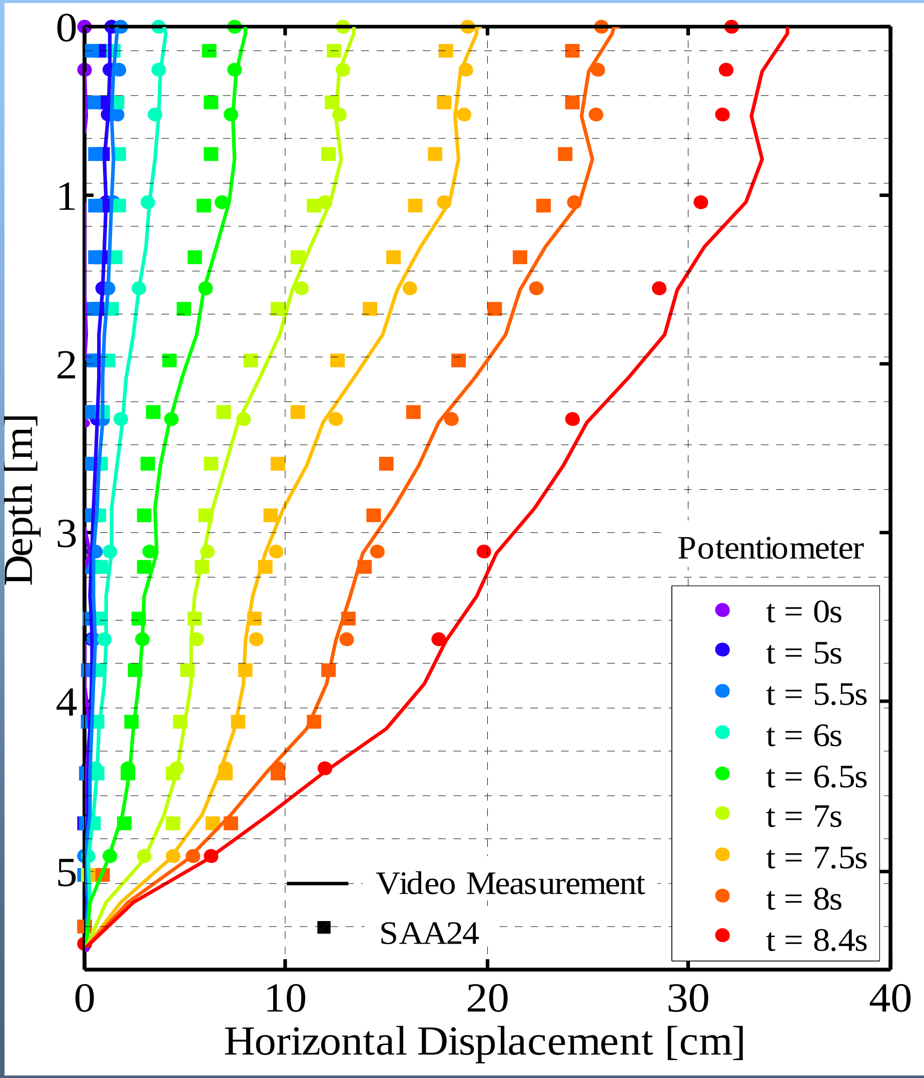
Pore Pressure Ratio: LG-0 Vs SG-1





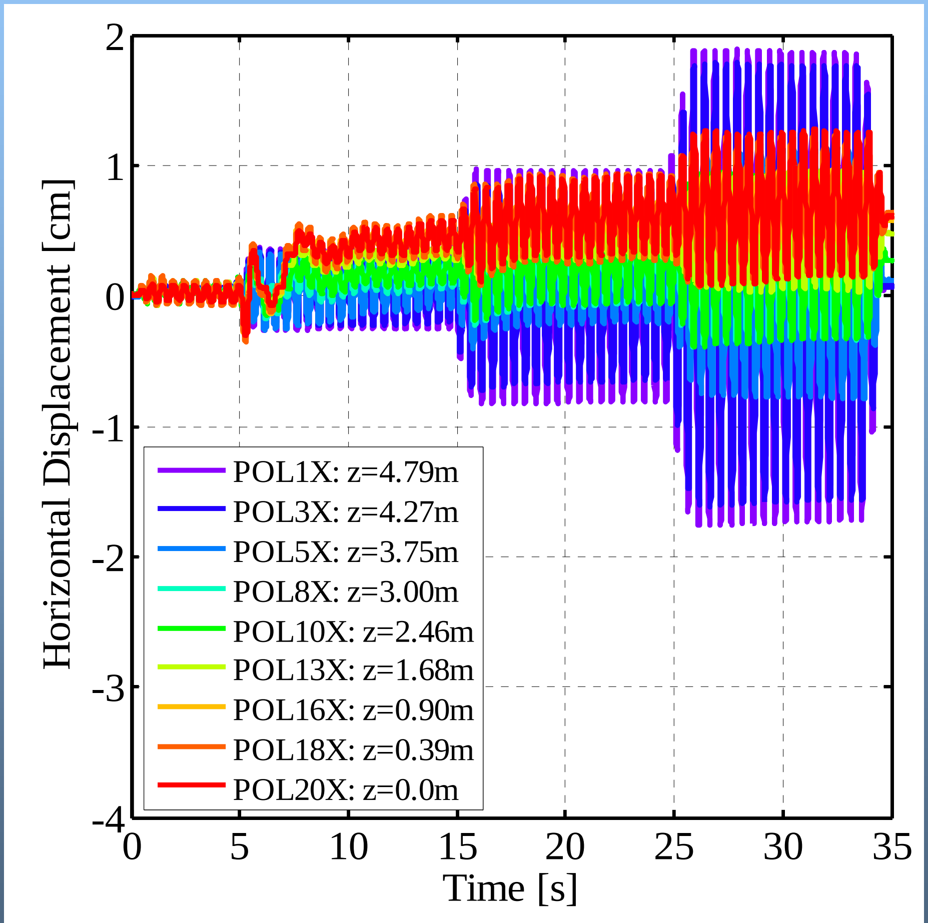
Horiz Displacements: LG-0 Vs SG-1

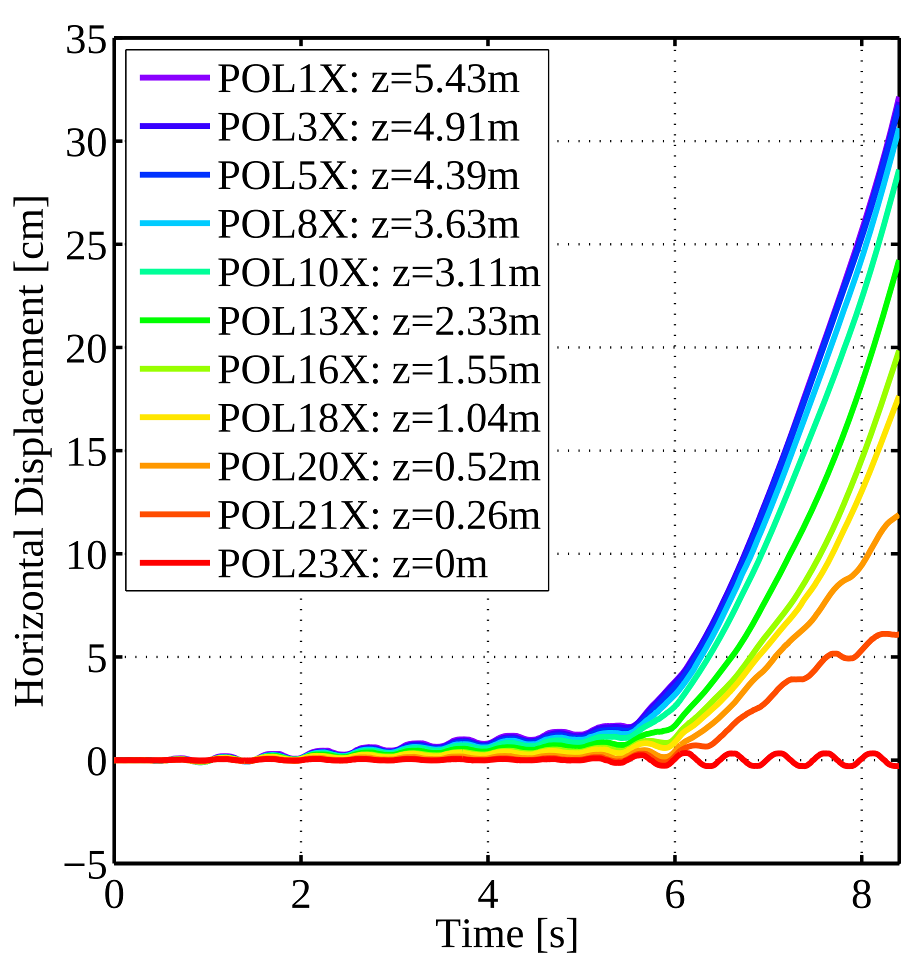




Significant Horiz. Displ. In SG-1

Horiz Displacements: LG-0 Vs SG-1





Significant Horiz. Displ. In SG-1

Mechanism of Initiation of Lateral Spreading – Under Study

New Possibilities and Boundaries

- Feasible to mimic Hydraulic Fill Sand at research quality
- Large Scale Liquefaction & Lateral Spreading experiments with Dense Array Instrumentation & High Quality Data
  - Provides Verifiable & Detailed Response Data
- ND Shaking & SI for 'In-situ' soil characterization
- Possible to study mechanisms of lateral spreading, soil-foundation-structure interactions, etc. with close scrutiny at near full-scale at 1-g
- Use 1-g Laminar box system as a center-piece coupled with centrifuge, FEM/DEM, and field observations to solve large & complex problems

Thank You

Questions?