OpenSees in Practice:
Soil Structure Interaction

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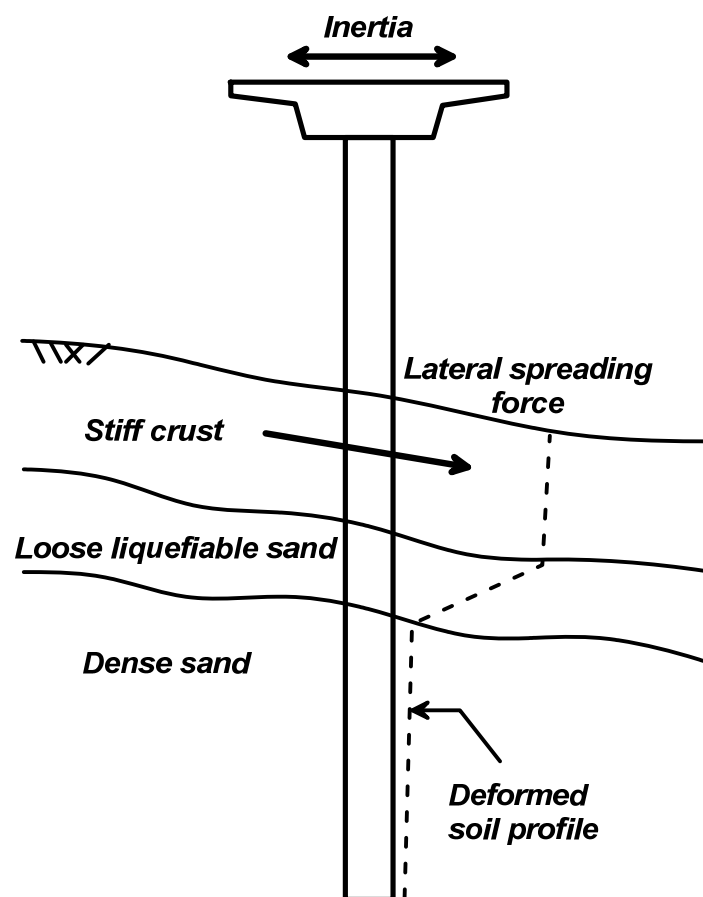# Examples

1. **Piles in Liquefied Soils – 2D Approach** (*UC Davis with Professor Ross Boulanger*)

2. **Piles in Liquefied Soils – 3D Approach** (*UC Davis*)

3. **Soil-Pile-Interaction for a Suspension Bridge** (Fugro)

4. **Seismic Retrofit of an Immersed Tunnel** (Fugro)

5. **OpenSees Components and Calibration Process**

Example 1.
Piles in Liquefied Soils – 2D Approach
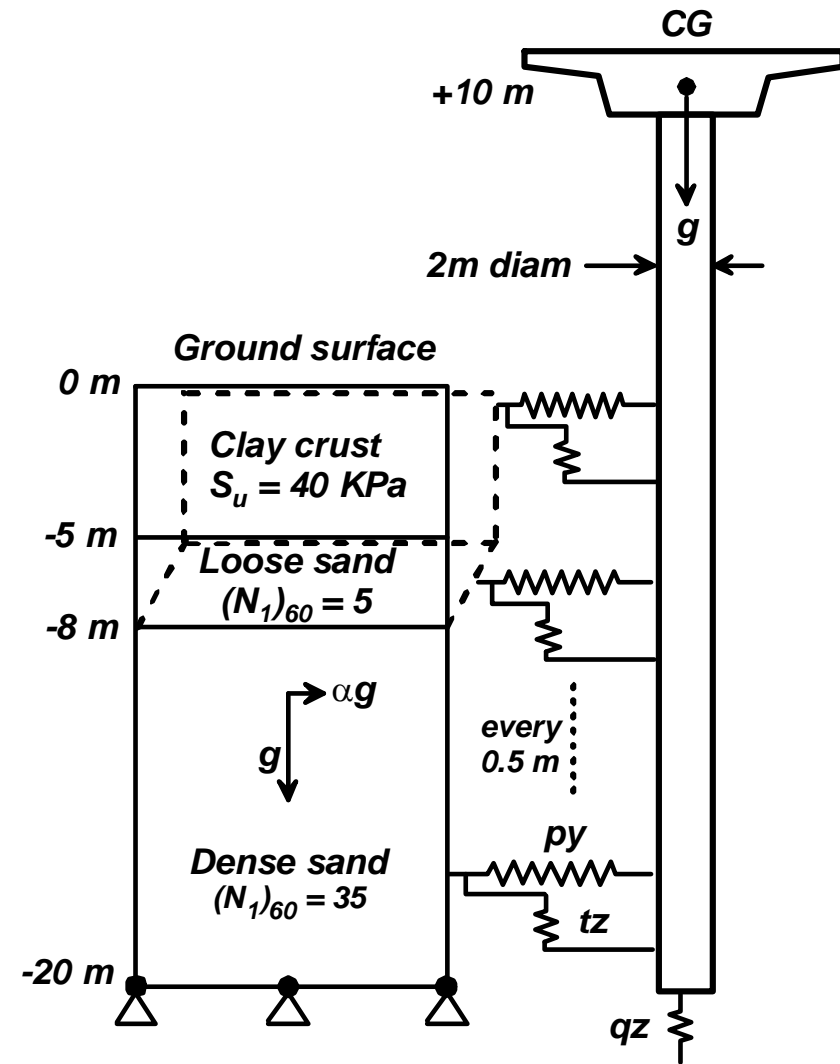
Piles in Liquefied Soils – 2D Approach

- **Large diameter extended pile shafts (2 to 3 m) can be an effective choice in areas of potential lateral spreading.**

Inertia

Lateral spreading force

Stiff crust

Loose liquefiable sand

Dense sand

Deformed soil profile

Piles in Liquefied Soils – 2D Approach

FE model

- **OpenSees FE framework**
- **Soil elements**
    - *9-4 Quad UP*
    - *PDMY02 and PIMY*
- **Pile elements**
    - *Disp-based beam column*
    - *Fiber section*
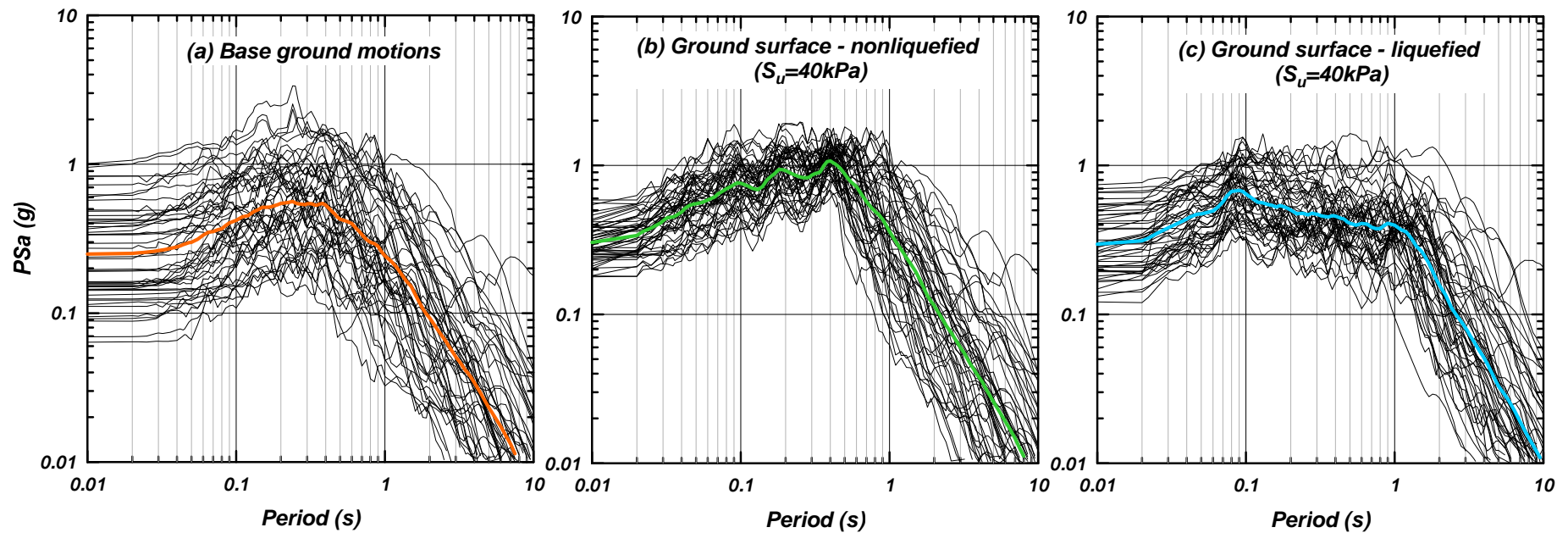- **Interface elements**
    - *PYSimple and PYLiq1*

CG

+10 m

g

2m diam

Ground surface

0 m

Clay crust
$S_u = 40$ KPa

-5 m

Loose sand
$(N_1)_{60} = 5$

-8 m

αg

g

every 0.5 m

py

Dense sand
$(N_1)_{60} = 35$

tz

-20 m

qz

Piles in Liquefied Soils – 2D Approach

Animation

Piles in Liquefied Soils – 2D Approach

(a) Base ground motions

(b) Ground surface - nonliquefied (S_u=40kPa)

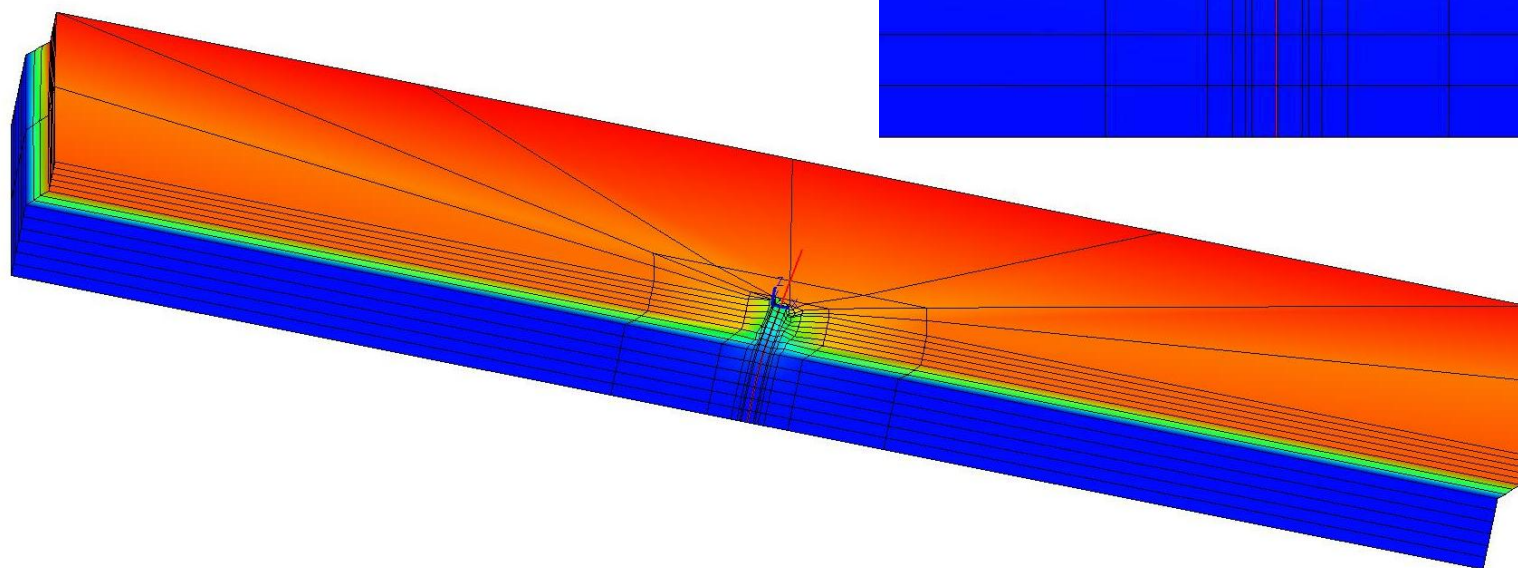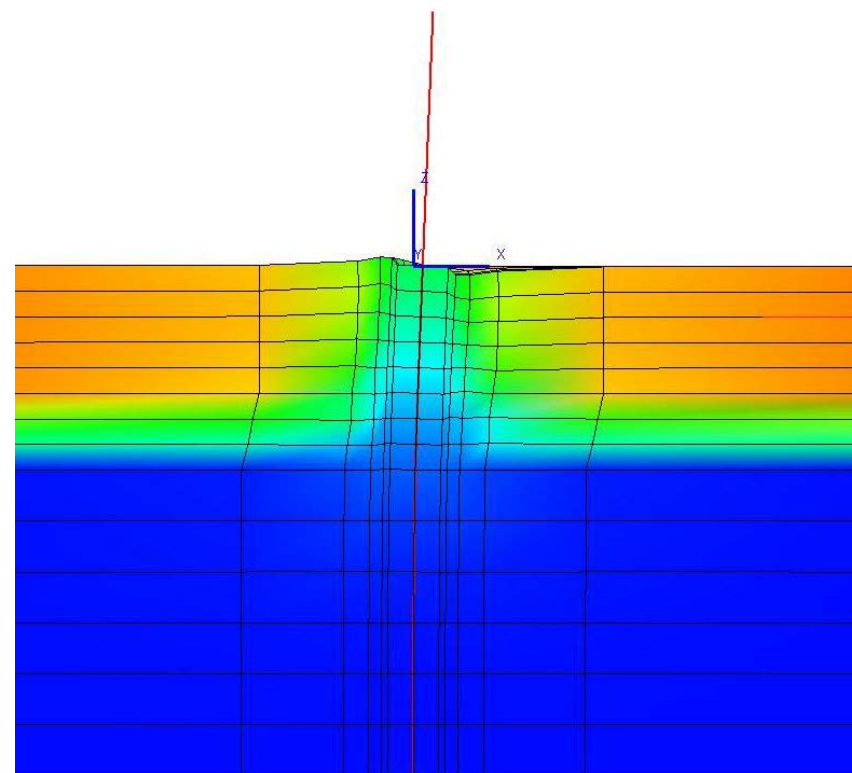(c) Ground surface - liquefied (S_u=40kPa)

Example 2.
Piles in Liquefied Soils – 3D Approach

Piles in Liquefied Soils – 3D Approach

- **Fully coupled (3D continuum)**
    - *Modeled in OpenSeesPL*
    - *No interface element*
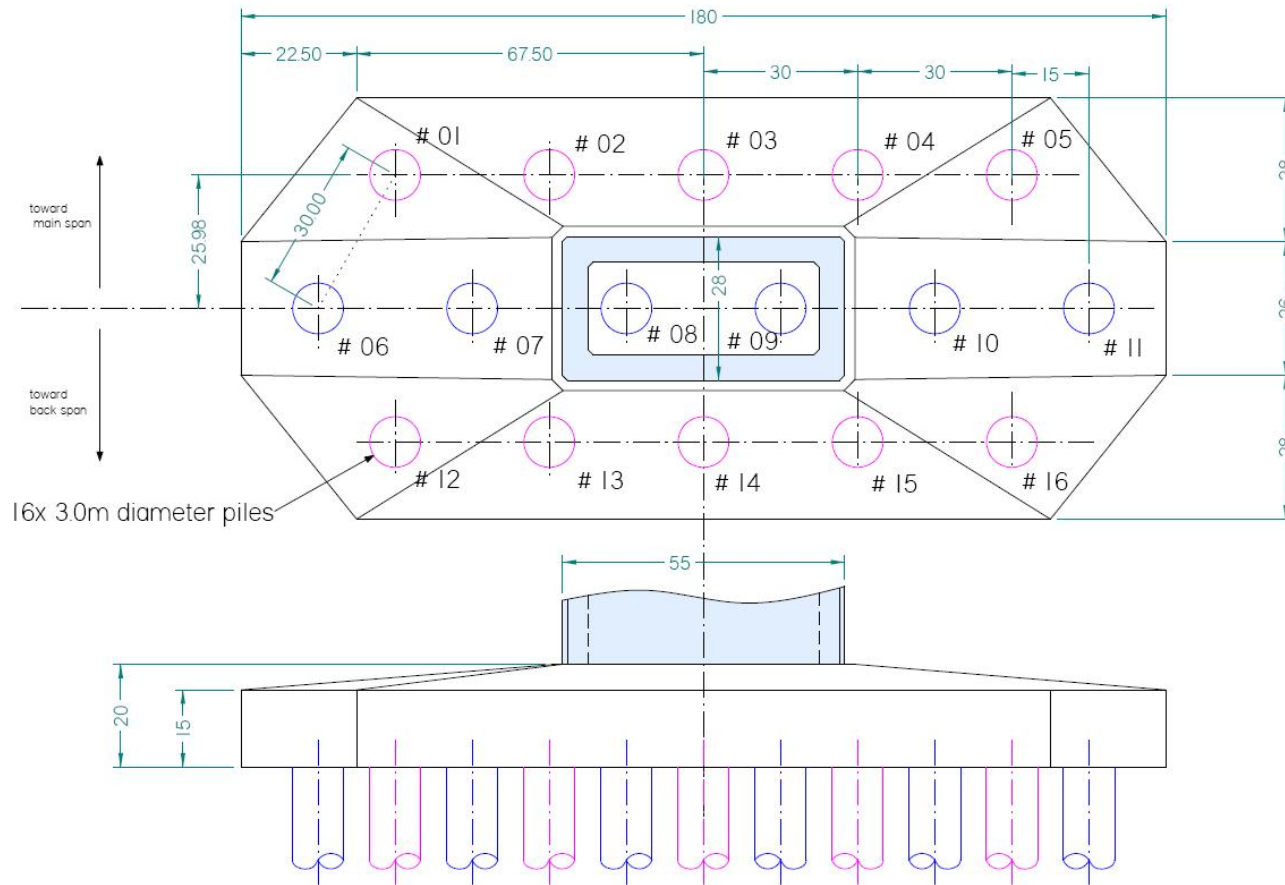   - *Pile occupies a space*

Piles in Liquefied Soils – 3D Approach

Animation

Example 3.
Soil-Pile-Interaction for a Suspension Bridge

Arash Khosravifar, Thaleia Travasarou, Jose Ugalde and Weiyu Chen, Fugro
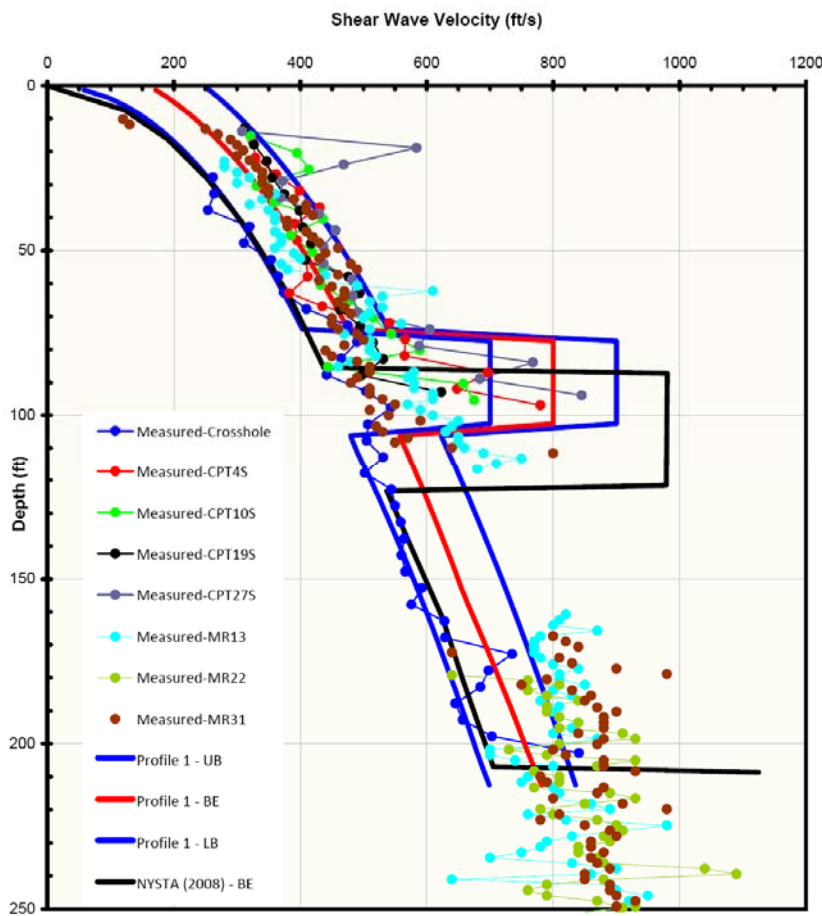
Soil-Pile-Interaction for a Suspension Bridge

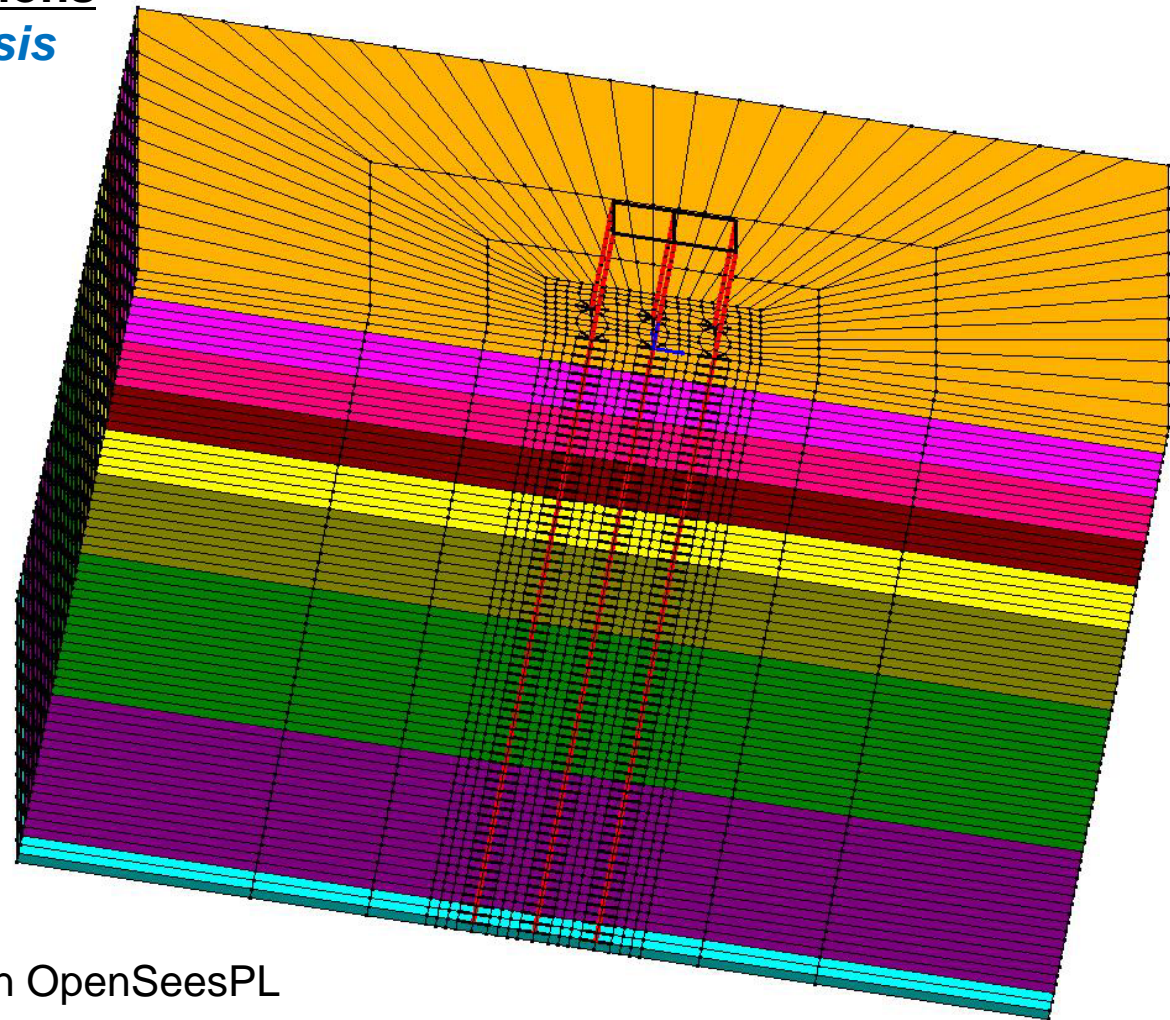**Foundation**

Soil-Pile-Interaction for a Suspension Bridge

Site Investigation
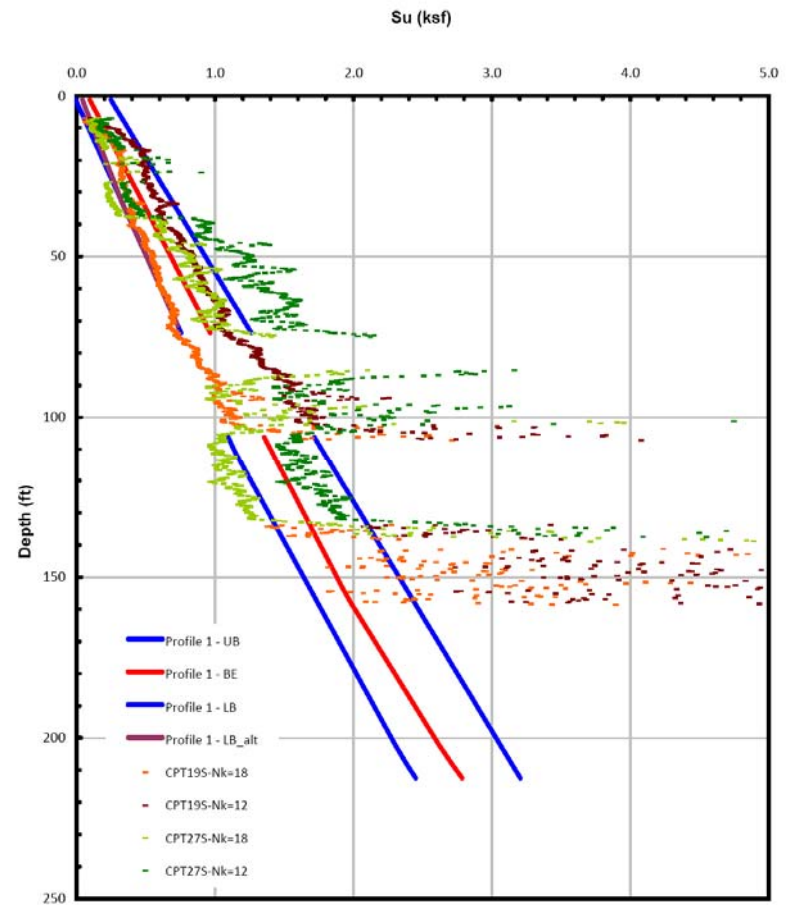
Soil-Pile-Interaction for a Suspension Bridge

Produce Kinematic Motions
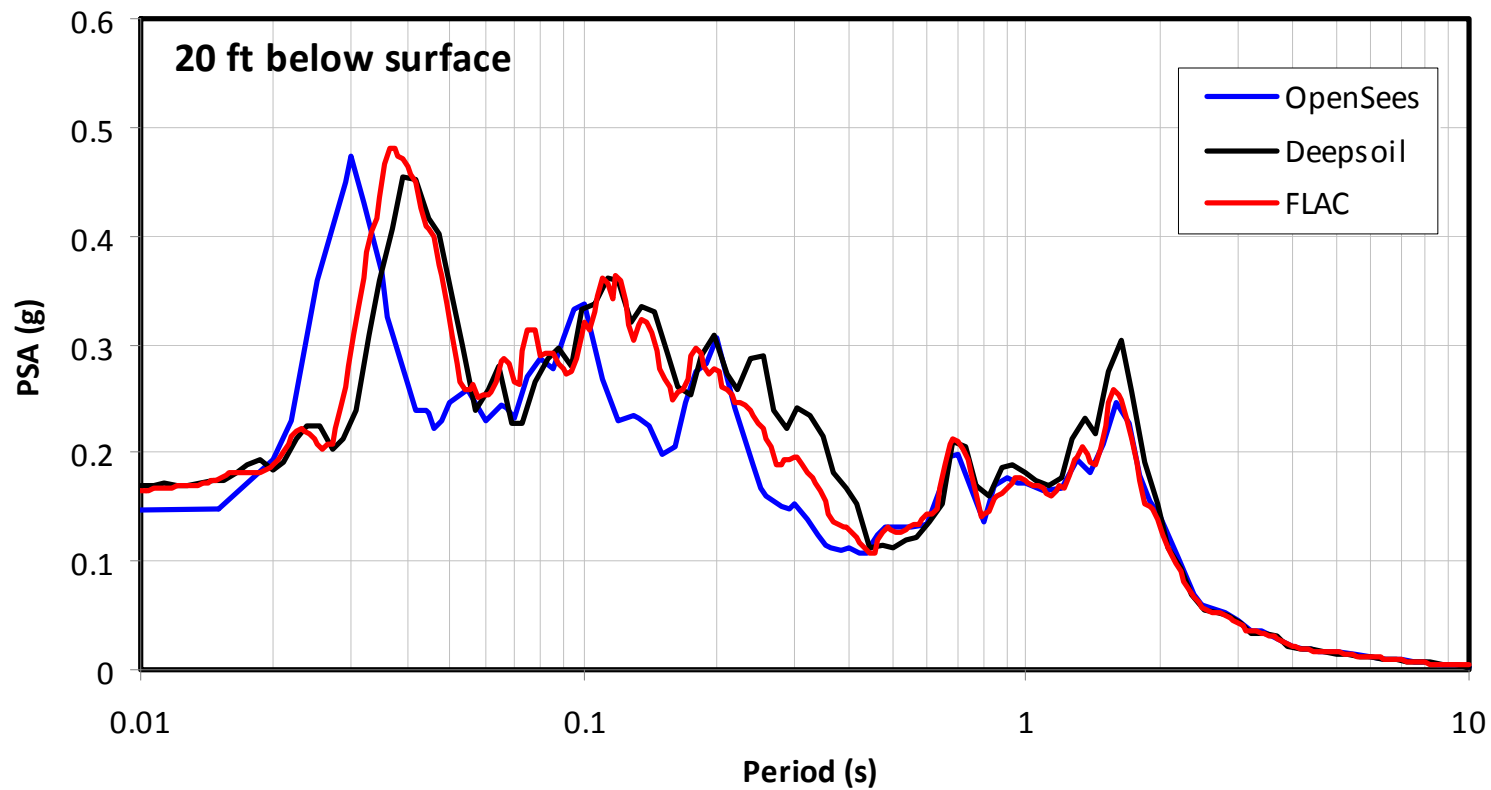
- *Site Response Analysis*
- *Soil-Pile-Interaction*

Modeled in OpenSeesPL

Soil-Pile-Interaction for a Suspension Bridge
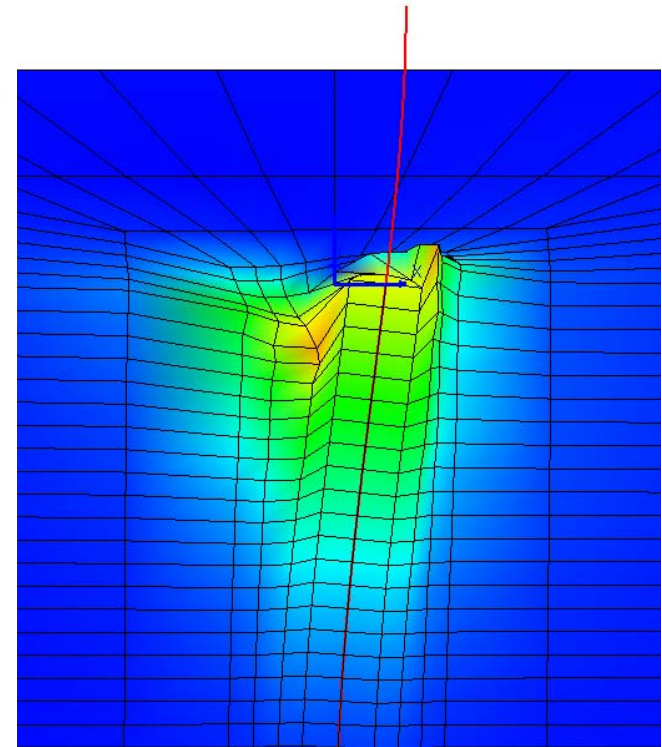
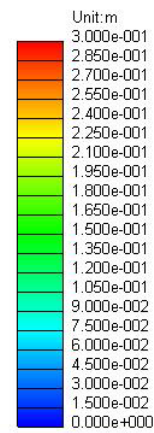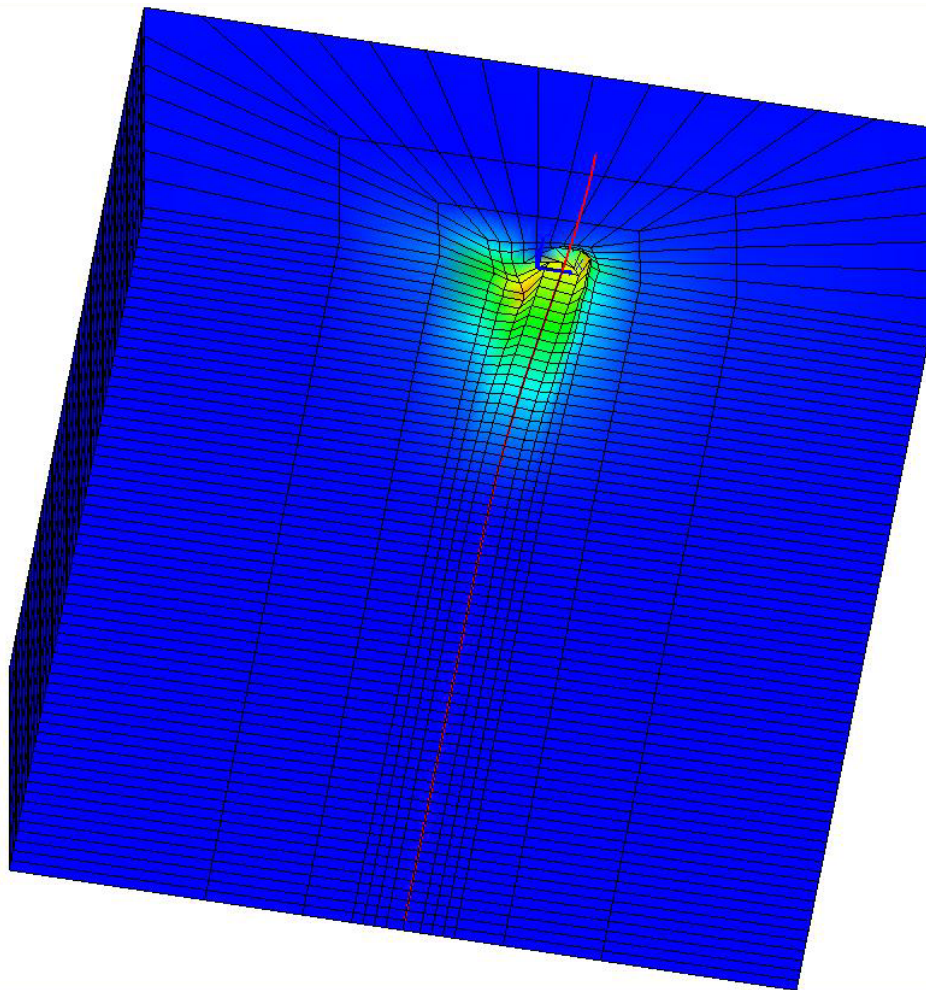## Site Response Analyses Results (no pile)
- *Comparison with FLAC3D and Deepsoil*

Soil-Pile-Interaction for a Suspension Bridge
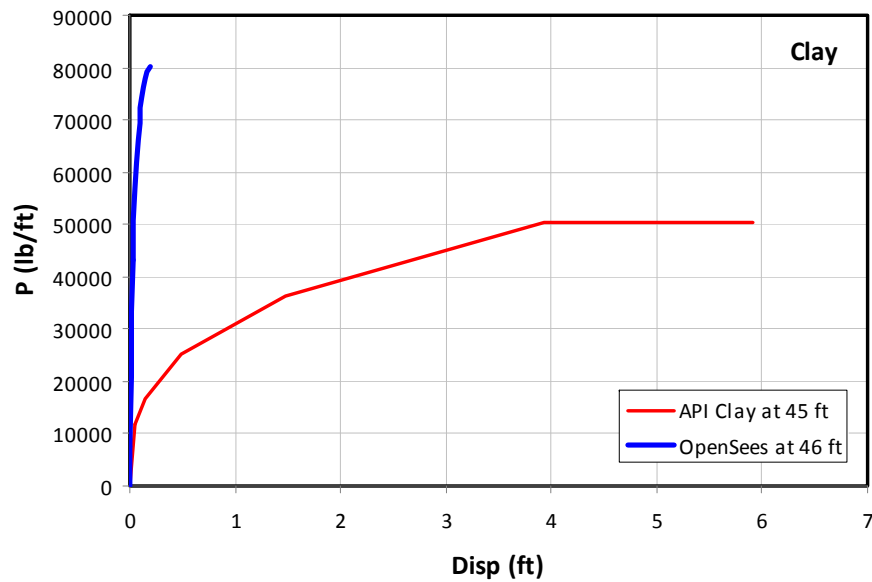
Soil-Pile-Interaction (single pile pushover)

Unit:m
3.000e-001
2.850e-001
2.700e-001
2.550e-001
2.400e-001
2.250e-001
2.100e-001
1.950e-001
1.800e-001
1.650e-001
1.500e-001
1.350e-001
1.200e-001
1.050e-001
9.000e-002
7.500e-002
6.000e-002
4.500e-002
3.000e-002
1.500e-002
0.000e+000

Soil-Pile-Interaction for a Suspension Bridge

Soil-Pile-Interaction (single pile pushover)
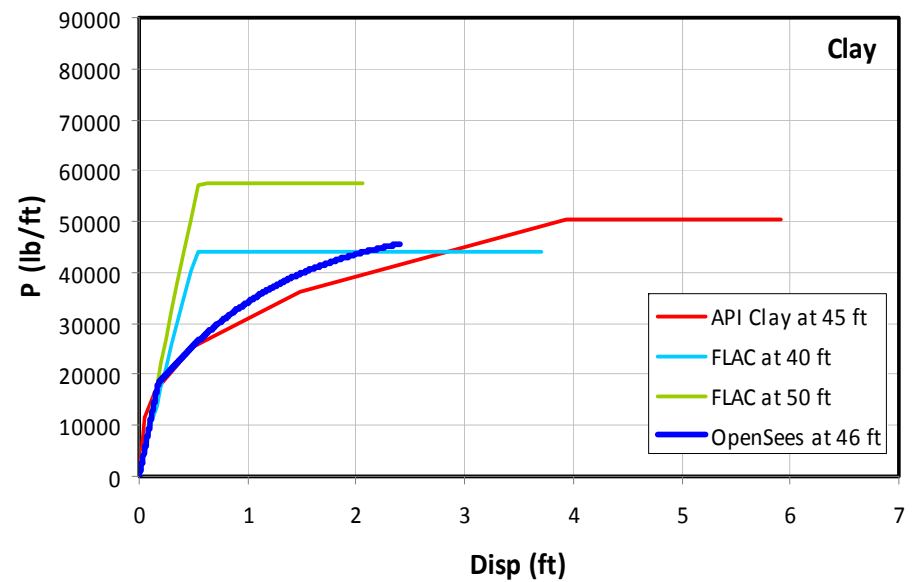
Example 4.
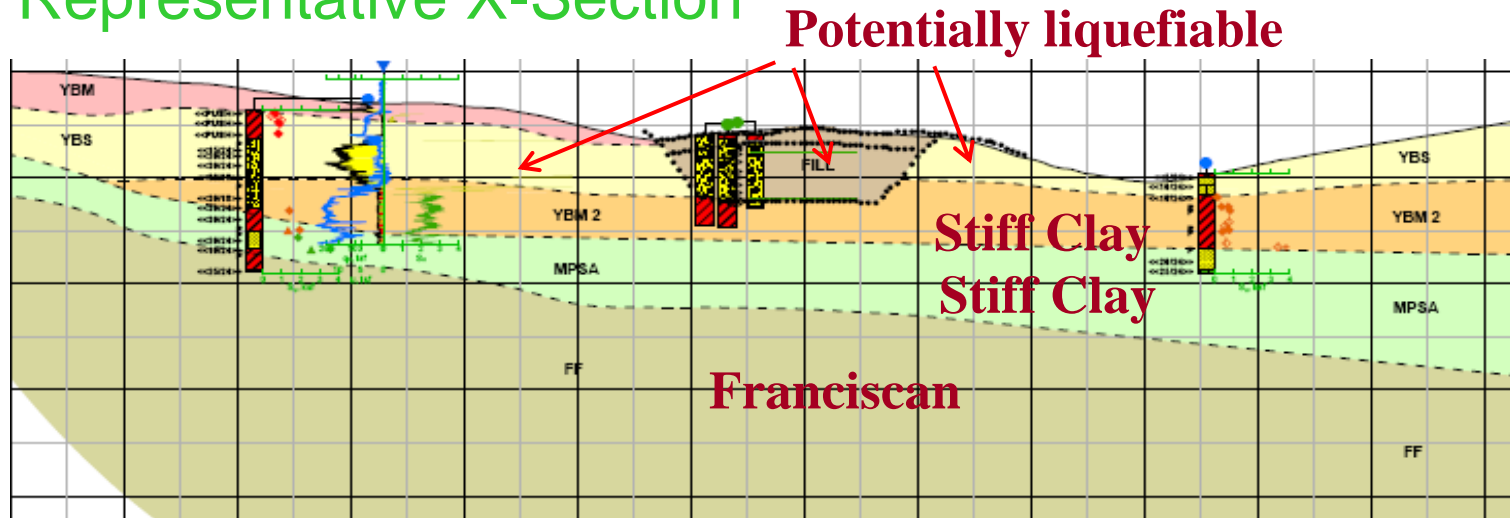# Seismic Retrofit of an Immersed Tunnel

Lanka Ilankatharan and Thaleia Travasarou, Fugro
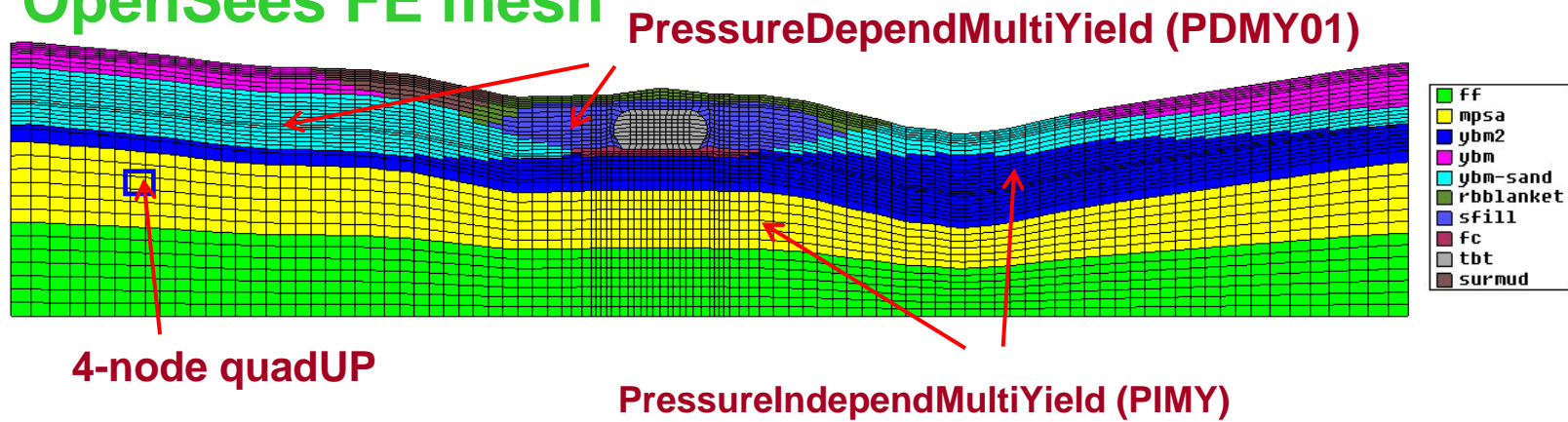
Seismic Retrofit of An Immersed Tunnel

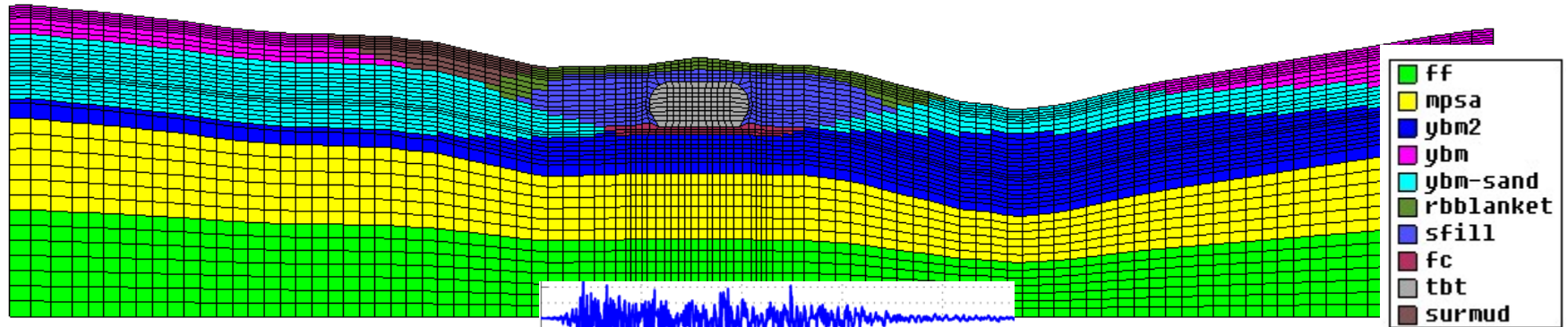Lanka Ilankatharan and Thaleia Travasarou, Fugro

Representative X-Section

Potentially liquefiable

Stiff Clay
Stiff Clay

Franciscan

OpenSees FE mesh

PressureDependMultiYield (PDMY01)

4-node quadUP
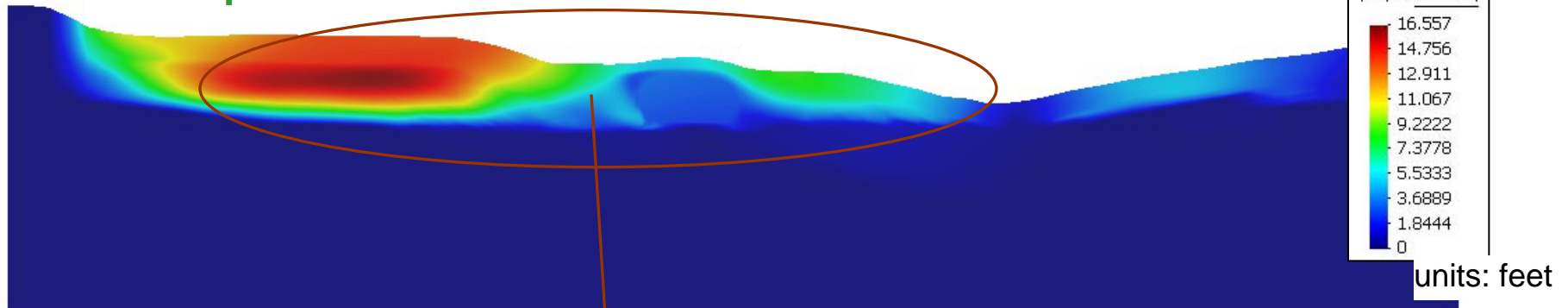
PressureIndependMultiYield (PIMY)
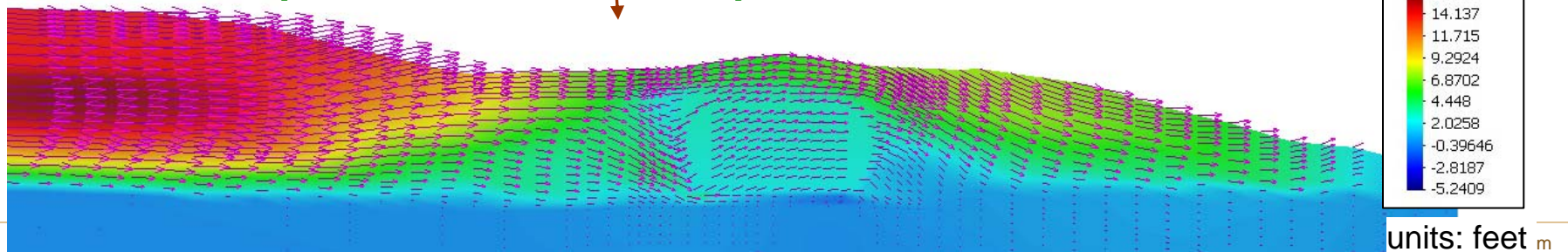
Seismic Retrofit of An Immersed Tunnel

Lanka Ilankatharan and Thaleia Travasarou, Fugro

Total displacement contours

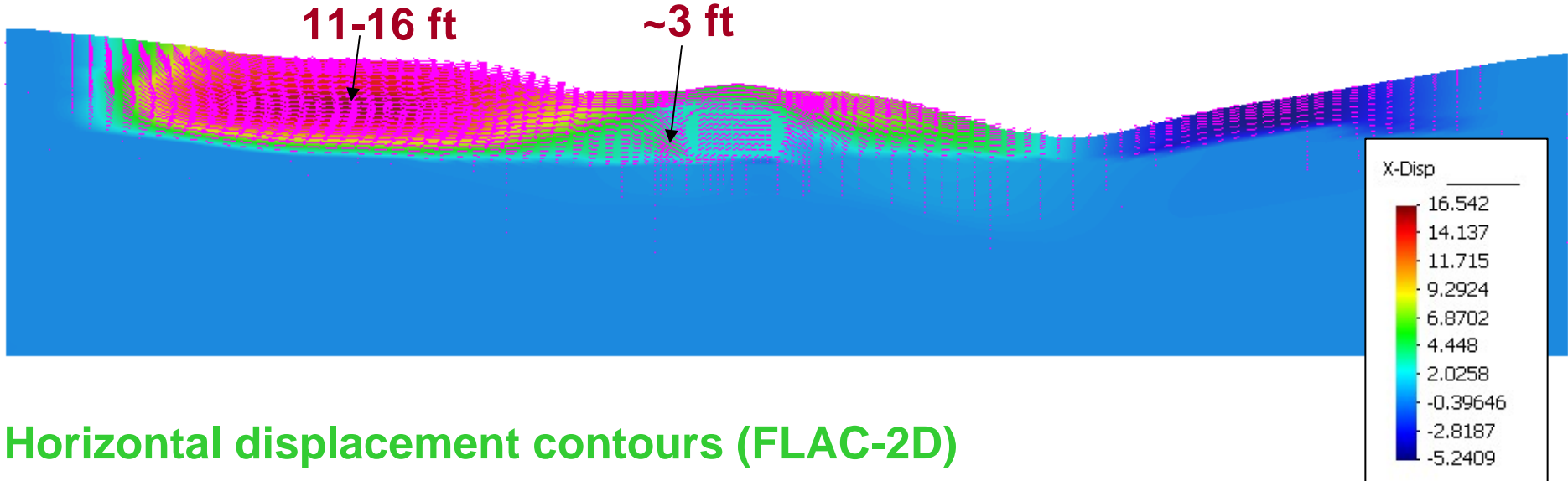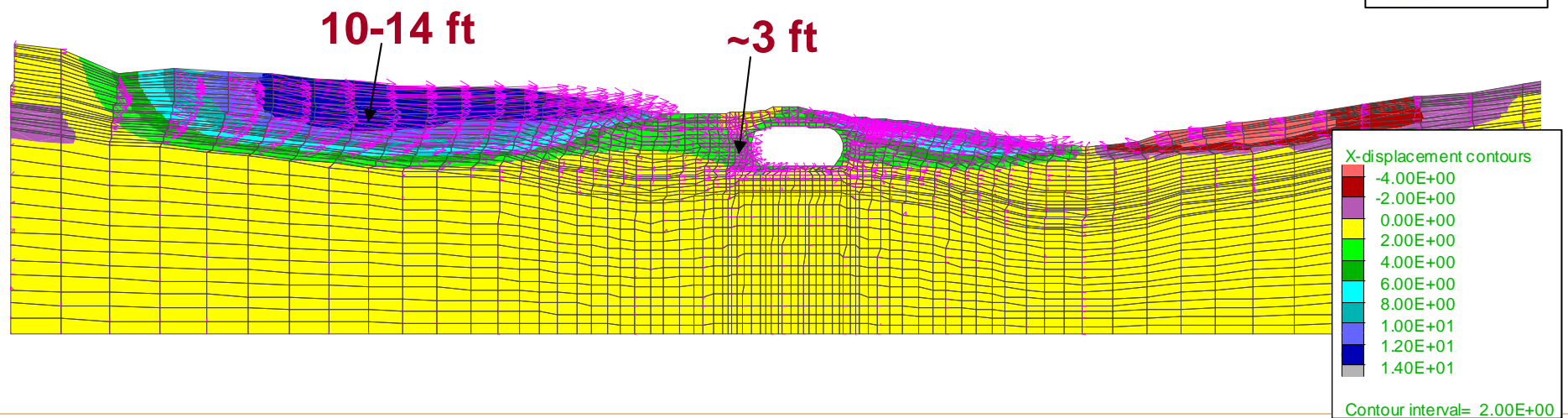**Horizontal disp. contours & Total disp. vectors**

units: feet

units: feet

Seismic Retrofit of An Immersed Tunnel

Lanka Ilankatharan and Thaleia Travasarou, Fugro

Horizontal displacement contours (OpenSees)

11-16 ft

~3 ft

X-Disp

16.542
14.137
11.715
9.2924
6.8702
4.448
2.0258
-0.39646
-2.8187
-5.2409

Horizontal displacement contours (FLAC-2D)

10-14 ft

~3 ft

X-displacement contours

-4.00E+00
-2.00E+00
0.00E+00
2.00E+00
4.00E+00
6.00E+00
8.00E+00
1.00E+01
1.20E+01
1.40E+01

Contour interval= 2.00E+00

www.fugro.com

# Example 5.
OpenSees Components and Calibration

OpenSees Components and Calibration

- **Soil models**
  - *9-4 Quad UP, Quad UP, Brick UP elements*
  - *PDMY02 and PIMY*
- **Pile elements**
  - *Disp-based beam column, Flexibility-based beam column*
  - *Fiber section*
- **Interface elements**
  - *PYSimple1, TZSimple1, QZSimple1*
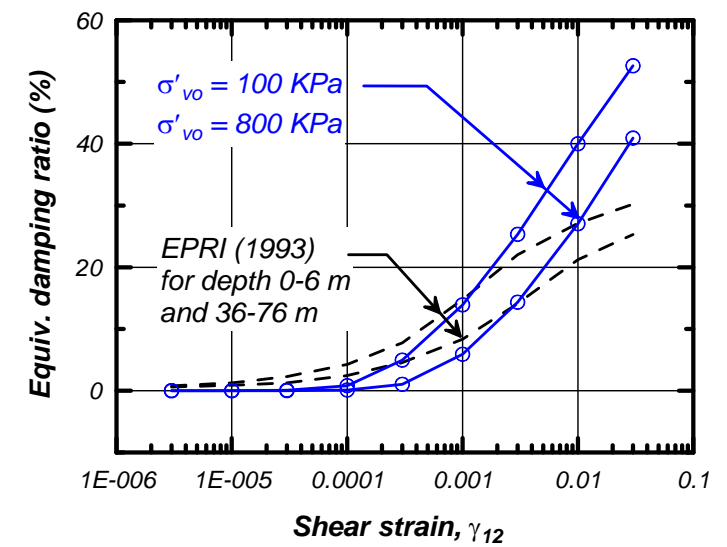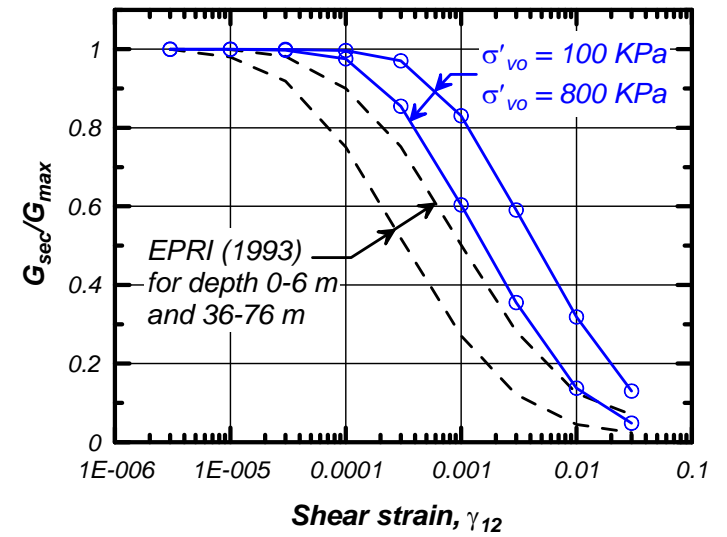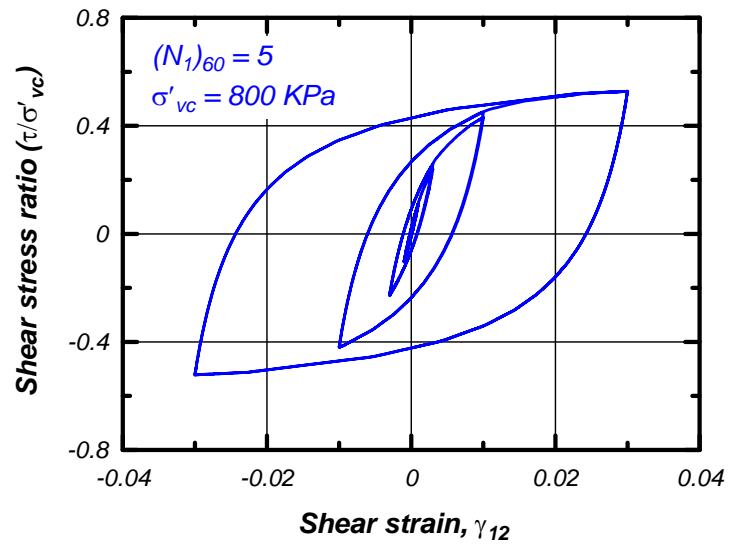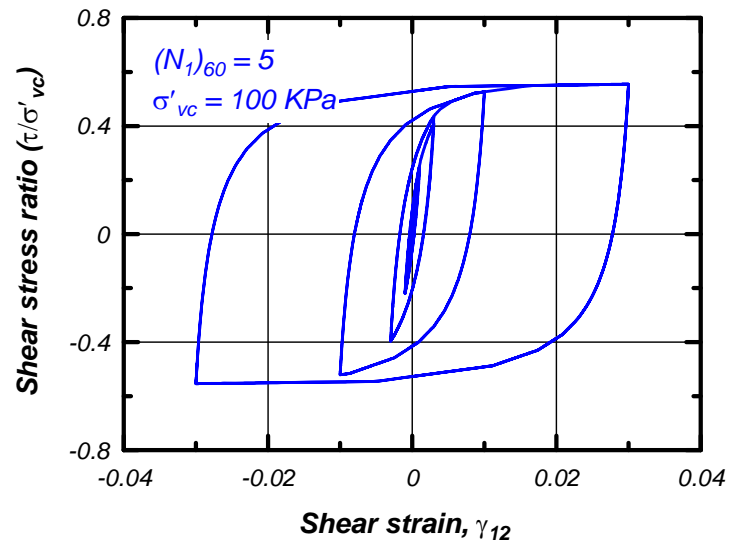 - *PYLiq1, TZLiq1 (for liquefaction)*

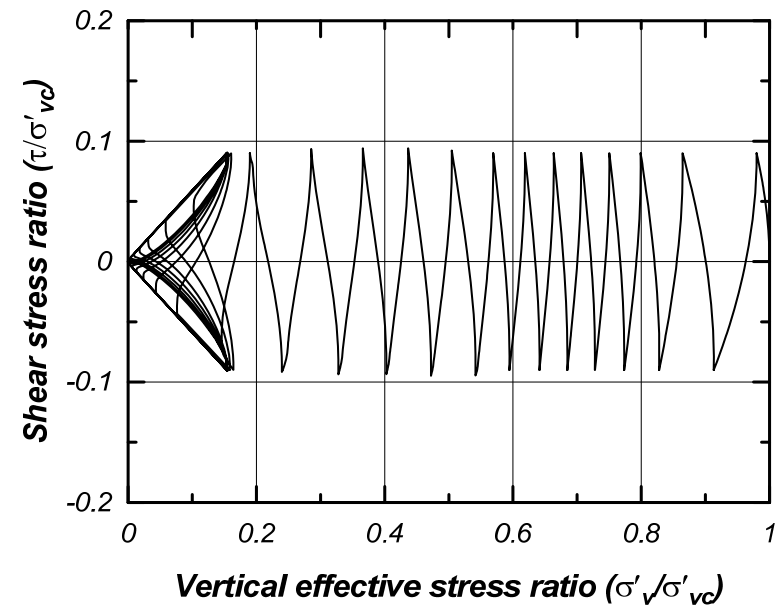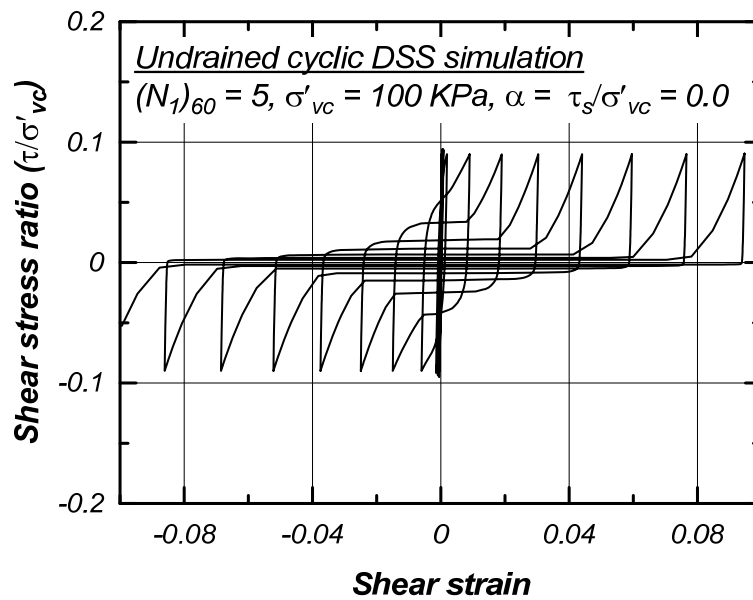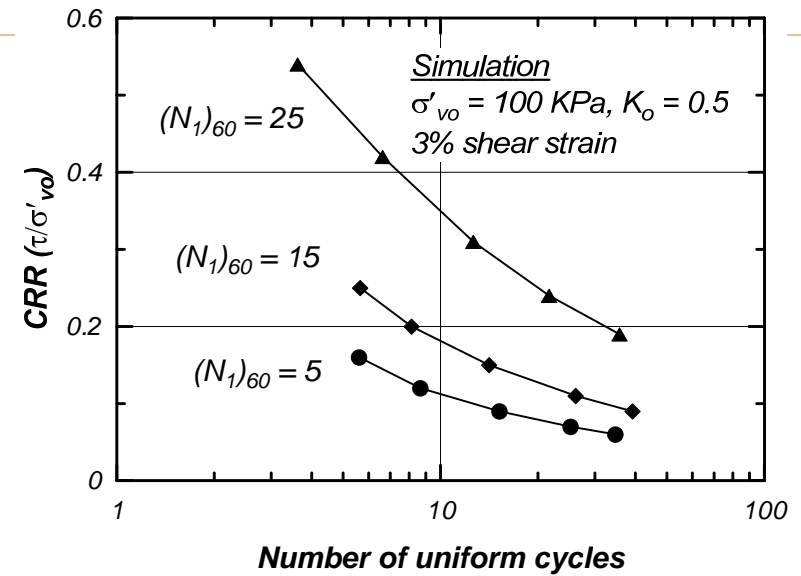# Undrained Monotonic Direct-Simple-Shear Test (DSS)
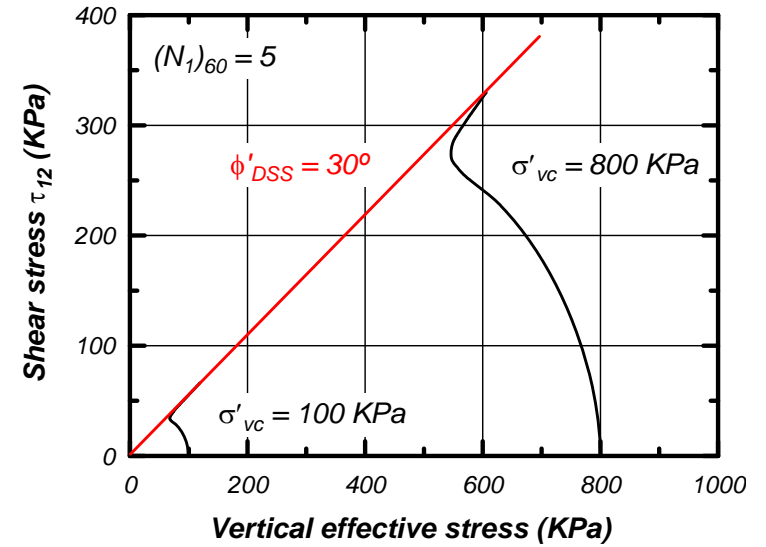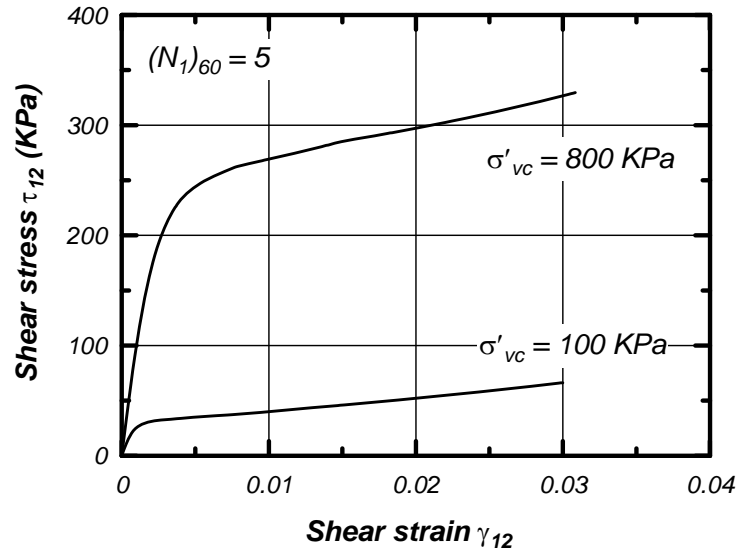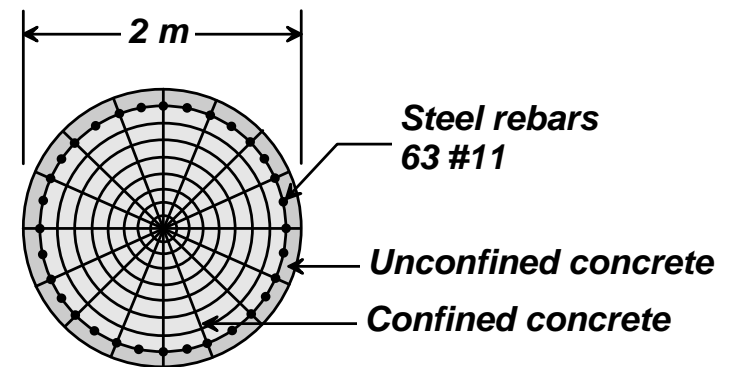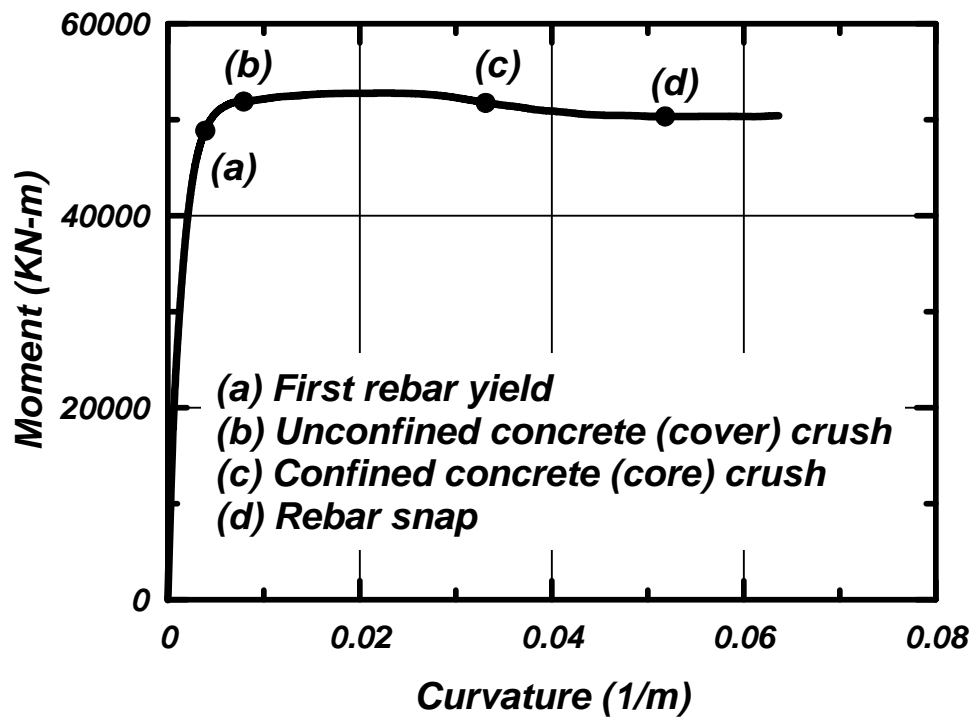

Drained Monotonic DSS
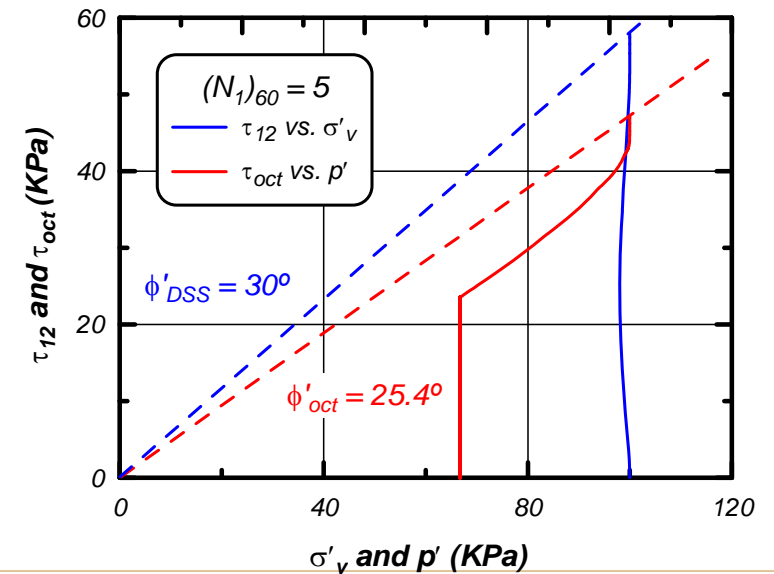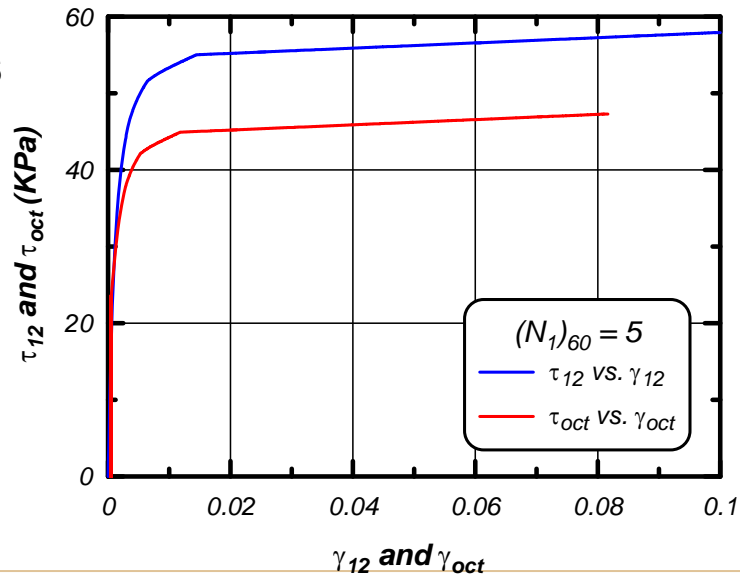
Drained Cyclic DSS

Undrained cyclic behavior

• **Calibrated for Cyclic Resistance Ratio (CRR)**

Simulation
$\sigma'_{vo} = 100\ KPa,\ K_o = 0.5$
3% shear strain

$(N_1)_{60} = 25$

$(N_1)_{60} = 15$

$(N_1)_{60} = 5$

CRR (τ/σ'_{vo})

Number of uniform cycles

Undrained cyclic DSS simulation
$(N_1)_{60} = 5,\ \sigma'_{vc} = 100\ KPa,\ \alpha = \tau_s/\sigma'_{vc} = 0.0$

Shear stress ratio (τ/σ'_{vc})

Shear strain

Shear stress ratio (τ/σ'_{vc})

Vertical effective stress ratio (σ'_v/σ'_{vc})

Structural Elements

- **Fiber sections**

- **Displacement-based nonlinear beam column elements**

(a) First rebar yield
(b) Unconfined concrete (cover) crush
(c) Confined concrete (core) crush
(d) Rebar snap

Soil Springs

- **Update properties based on PWP**

- **Allow gap formation**
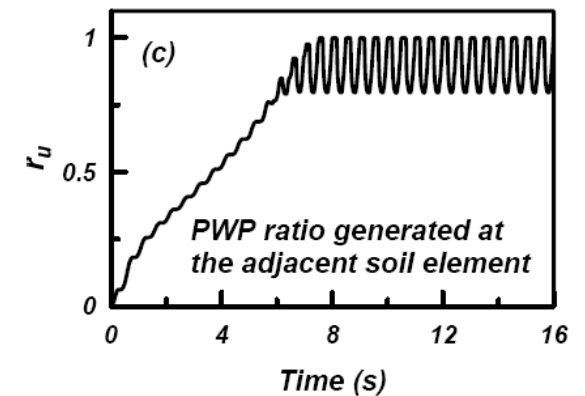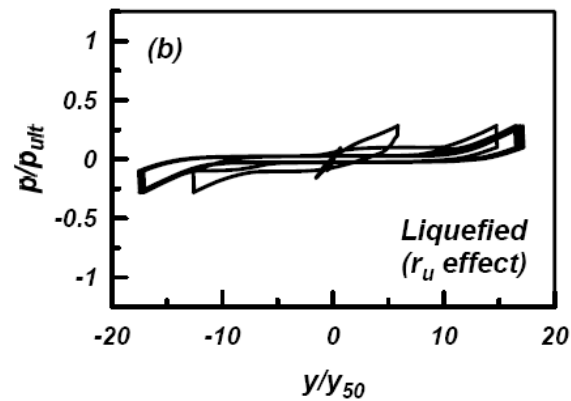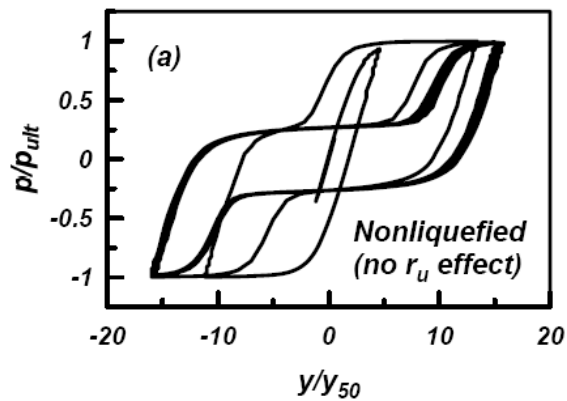
THANK YOU
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