Liquefaction Mitigation in Silts using Microbially Induced Desaturation

Arash Khosravifar and Diane Moug
Department of Civil and Environmental Engineering
Portland State University
Research Team

Dr. Arash Khosravifar, Assistant Professor

Dr. Ed Kavazanjian, Professor

Dr. Ken Stokoe, Professor

Yumei Wang, Resilience Engineer, DOGAMI (Advisor)

Dr. Diane Moug, Assistant Professor

Dr. Leon van Paassen, Associate Professor
Research Team

Graduate Students:

- Melissa Preciado (Masters Student, PSU)
- Kayla Sorenson (incoming Masters Student, PSU)
- Elizabeth Stallings Young (PhD Candidate, ASU)
- Benchen Zhang (PhD Candidate, UT Austin)
Partners

Industry / State Agencies:
• Condon-Johnson & Associates
• ConeTec
• Portland Bureau of Transportation
• Portland General Electric (PGE)
• Portland Water Bureau
Project Overview / Description

• Field trial of Microbial Induced Desaturation (MID) at Two (2) Sites in Portland, OR

• Nutrients (treatment substrates) are injected to the ground from a central well and extracted from perimeter wells

• Denitrification results in nitrogen and CO2 gas which desaturates the soil

• Unsaturated soil is not liquefiable

SEM image of gas bubble remnant (O’Donnell 2015)
Project Scope / Timeline

• Field shaking with T-Rex at untreated site (July 2019)
• Apply ground treatment for 1 month (August 2019)
• Field shaking with T-Rex at treated site (September 2019)
• Long-term monitoring of treatment using crosshole p-wave velocities (next 3 to 5 years)
Seismicity (Portland, Oregon)

- Cascadia Subduction Zone
  - Magnitude 9, 100 km source-to-site-distance
- Shallow Crustal Faults (Portland Hills Fault)
  - Magnitude 6.8, <10 km
- $\text{PGA}_M = 0.43 \text{ g}$ for liquefaction analysis based on ASCE 7

Source: DOGAMI
Liquefaction Hazard in Portland

- Two sites selected for this study

Harborton (PGE)
12500 NE Marina Way

Sunderland (PBOT)
9325 NE Sunderland Ave

Fugro Consultants Inc. (2015)
• Located in the area of Oregon’s Critical Energy Infrastructure (CEI) hub
• ~90% of Oregon’s fuel is handled through CEI (Oregon Solution, CUPA)
Harborton: subsurface conditions

- Dredged river fill (<100 years) over young, loose alluvial river deposits
- Water level: about 7.5 feet bgs

East extraction 12.5’ to 14’

South extraction 12.5’ to 14’
Sunderland: site location

- Sunderland site (managed by Portland Bureau of Transportation, PBOT) is close to Portland International Airport
Sunderland: subsurface conditions

- Columbia river floodplain deposits of interbedded silts and clays
- Water level: about 3.5 feet bgs

**South extraction**  
16.5’ to 18’

**Injection**  
6.5’ to 8’

**MID treated soil**
Ground Treatment Method

- Microbial Induced Desaturation (MID)
- Desaturation $\rightarrow$ little pp during cyclic loading $\rightarrow$ mitigate effective stress loss
- Suitable for fine-grain soils (e.g. low-plasticity silts)
- Suitable for existing structures

O’Donnell 2016 dissertation
(Data from Ottawa Sand)
Ground Treatment Method

• Nutrients are calcium nitrate (fertilizer) and calcium acetate (food grade), byproducts (nitrogen gas and carbon dioxide) are environmentally benign

• Small amount of nutrients are required for desaturation

  ✓ 10 grams of CA and 10 grams of CN per liter of water
Ground Treatment Method

- Previous tests
  - Lab scale tests and centrifuge tests showed effectiveness
  - Field experience in Japan showed that the effect lasts for decades
  - Field tests are ongoing (Toronto ON, Richmond BC, and Portland)

Pilot site Toronto
Courtesy of Leon van Paassen

O'Donnell et al. (2017)
Sunderland: instrumentation & data collection

- **TREX sensor array:**
  - Measure $V_p$ and $V_s$ with cross-hole and downhole seismic tests
  - Measure cyclic-induced excess pore pressure generation before and after treatment

- **CTD-divers:**
  - Record volumes of injected and extracted water (CTD-divers)
  - Measure salinity (via Electrical Conductivity) of injected and extracted water (CTD-divers)

- **TEROS-12 in-situ sensors:**
  - Measure salinity (via EC) and temperature of groundwater in the monitoring well
Test area setup
• Sunderland
Test area setup
• Sunderland

TEROS sensor data transmitter

Crosshole sensor array

3.5 m
Test area setup
• Harborton (PGE)
Test area setup

- Harborton (PGE)

**Extraction tank (1000 gal)**

**Mixing tote (275 gal)**

**TEROS sensor data transmitter**
Volume of injected treatment

Injection volume (gallons)

- 60% of total pore fluid vol.
- Reduction in $V_p$ measured
- 20% of total pore fluid vol.

Volume of injected treatment:

- 20% of total pore fluid vol.
- 60% of total pore fluid vol.
Injection flow rates

Injection Flow Rate

- Diver data in injection tank
- Flow meter

Gallon / min

Salinity vs. time (CTD divers)

- Submerged in injection and extraction tanks
Salinity vs. time (TEROS-12 sensors)

Salinity

Well screen (5-20 ft)

701x21
8/13/2019
8/23/2019
9/2/2019
9/12/2019

0 25 50 75 100
qt (tsf)

Port 1
Port 2
Port 3
Port 4
Port 5
Port 6

mS/cm

Port 1
Port 2
Port 3
Port 4
Port 5
Port 6


Depth (feet)

Target Depth

40
35
30
25
20
15
10
5
0
TREX sensor array

Crosshole Source Rods

T-Rex Baseplate

Direction of Shaking 2.3 m

Depth based on Screening Test 2 Cross-section View (x-z)

Depth

0.85 m 0.45 m 0.45 m 0.7 m

1G 2G 3G 4G 5G 6G 7G 8G

1P 2P 3P 4P

1R 2R 3R 4R

1.4 m (4.6 ft) 1.5 m (4.9 ft) 1.7 m (5.6 ft) 1.8 m (5.9 ft) 2.1 m (6.9 ft) 2.5 m (8.2 ft) 4.4 m (14.4 ft) 4.5 m (14.8 ft) 4.6 m (15.1 ft)

: Motion Sensor

: Pore Pressure Transducer
TREX sensor array

- P-wave and S-wave velocity crosshole measurements

P-wave velocity (Vp)

- 1.4 m
- 1.8 m
- 2.5 m
- 4.5 m

S-wave velocity (Vs)

- 1.4 m
- 1.8 m
- 2.5 m
- 4.5 m
TREX sensor array preliminary pre-treatment results

2P: Depth = 1.7 m (5.6 ft)
Vp = 580 m/s; Vs = 85 m/s

Excess Pore Water Pressure (cm H2O)

- Shaking Event 1
- Shaking Event 2
- Shaking Event 3
- Shaking Event 4

Crosshole

P-Wave Velocity (m/sec)  S-Wave Velocity (m/sec)

Depth (m)
Summary of results (so far)

- Targeted soil stratigraphy is being treated with MID
  - Salinity sensors show injected solution through soil
  - $V_p$ measurements indicate desaturation through the treated layers
- Some preferential paths between injection and extraction wells
- TREX testing prior to treatment provides a baseline of seismic-induced excess pore pressure generation
What’s next?

- Post-treatment round of TREX testing will quantify reduction in seismic-induced excess pore pressure generation

- Cyclic lab testing
  - Characterize excess pore pressure generation vs. shear strain curve to strains larger than those induced during TREX testing
  - Further characterize cyclic behavior of Portland-area soils

- Long-term monitoring at Sunderland
  - $V_p/V_s$ cross hole seismic measurements
  - Effectiveness of treatment over time

- CPT profile in treated area
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