Cyclic behavior of silt-rich transitional soils of the Pacific Northwest and Alaska

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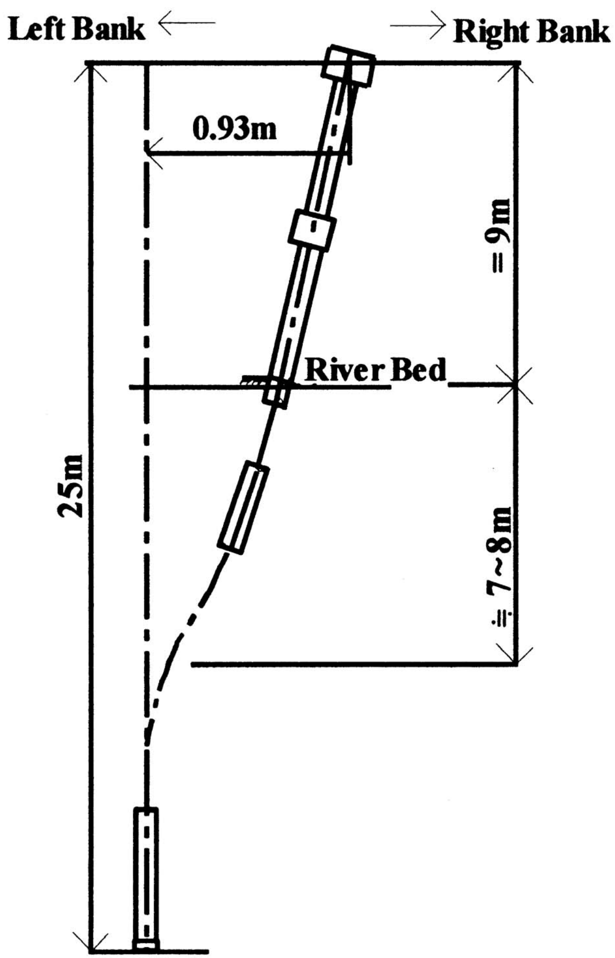
Liquefaction damage to bridges:
Showa Bridge in 1964 Niigata earthquake



Damage to steel piles of Pier 4 of Showa Bridge (PWRI; from Yasuda & Berrill 2001)

Liquefaction damage to dams:
Lower San Fernando Dam 1971 Sylmar earthquake

Liquefaction damage to port facilities: Port of Oakland 1989 Loma Prieta earthquake

Courtesy of John Egan

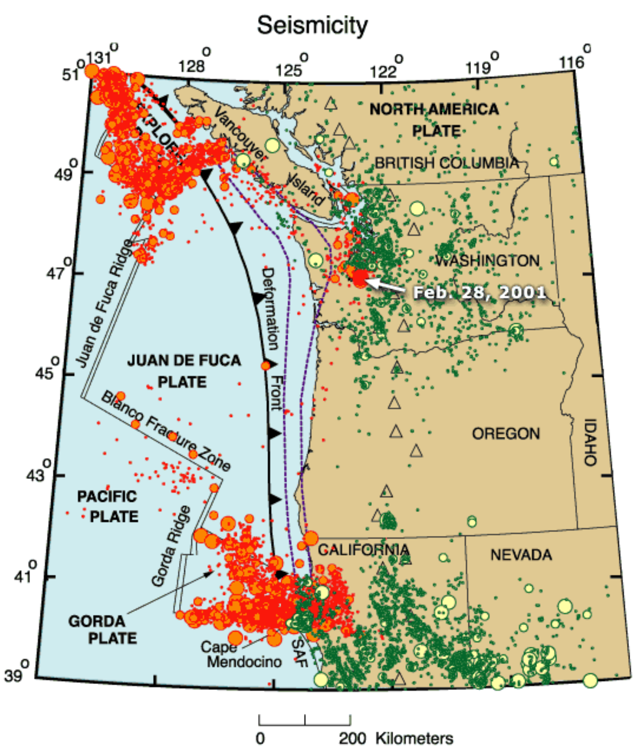
Liquefaction damage to buildings

1999 Kocaeli earthquake Turkey

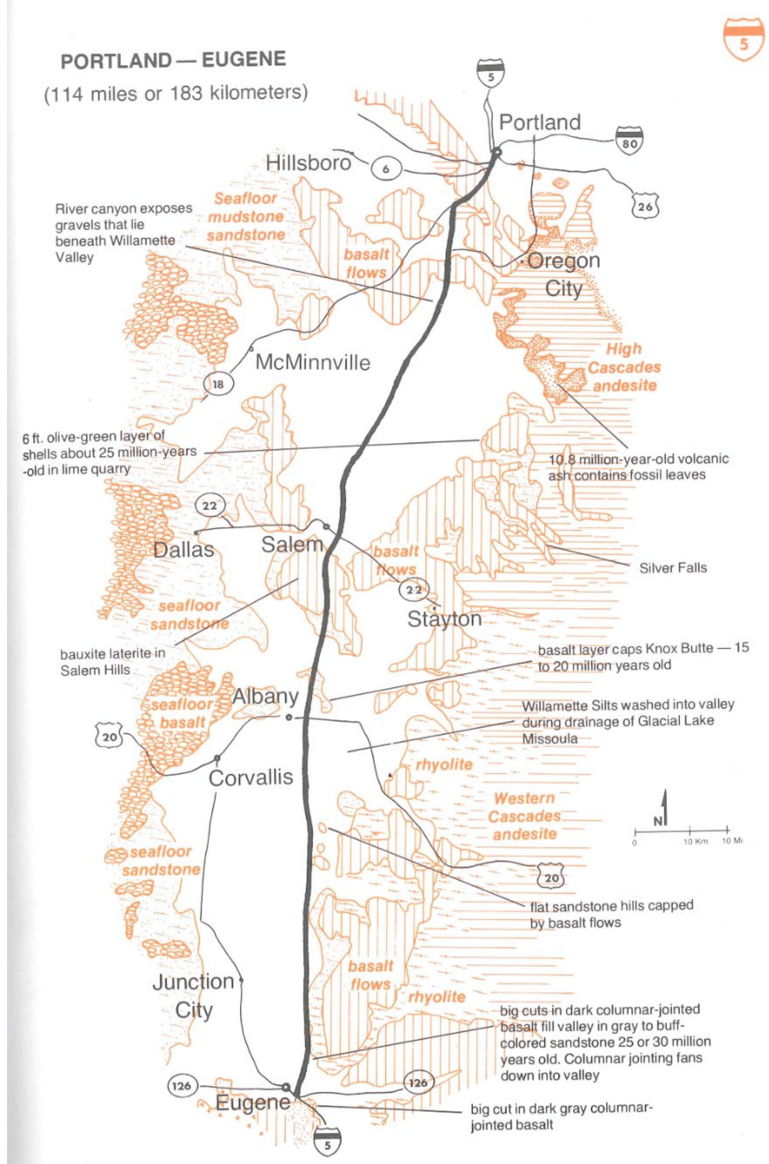
1999 Chichi earthquake Taiwan

Challenges in Liquefaction Evaluations in PACNW

- Intense shaking from CSZ and crustal faults
- Long duration motions (2-4 min shaking from M9 on CSZ)
- Silt-rich soils at infrastructure foundations

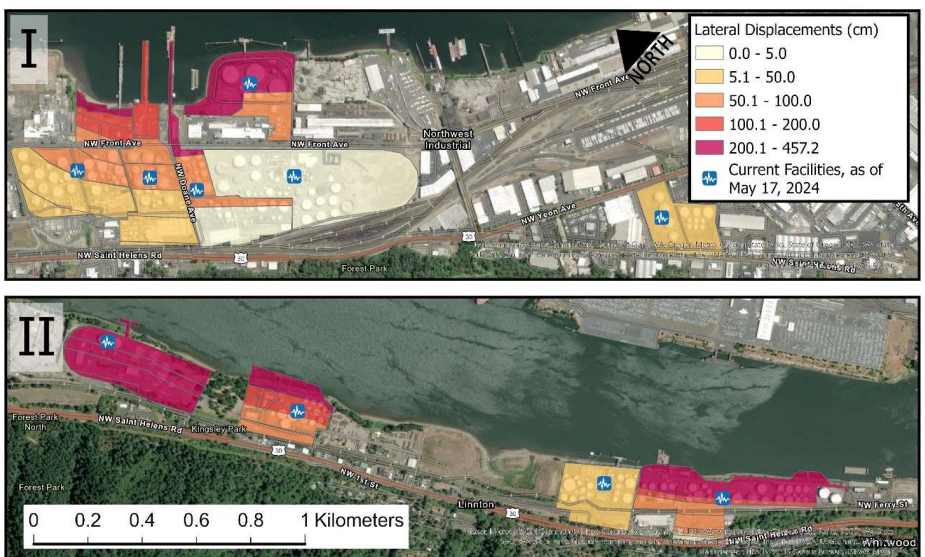


modified from Weaver and Shedlock, 1996

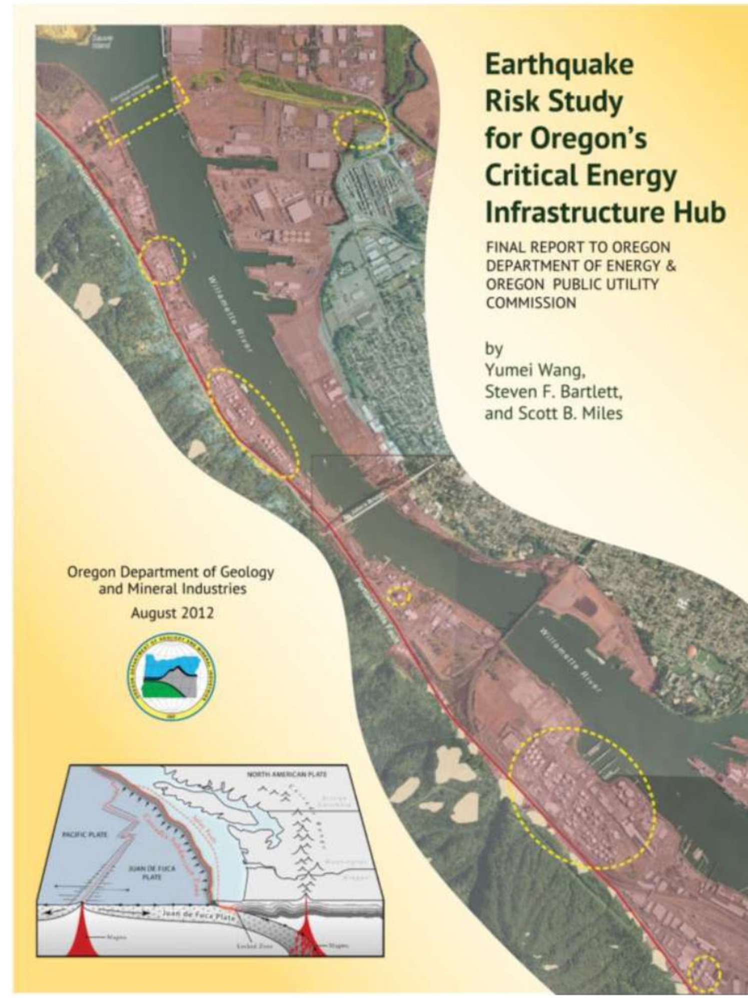


Ground Deformations at Critical Energy Infrastructure Hub

- Critical Energy Infrastructure (CEI) hub Northwest Portland
- 6-mile along the Willamette River
- 90% of Oregon’s liquid fuel supply
- OR Senate Bill 1567 in 2022, DEQ FTSS program
- SVAs: Uncertainties in liquefaction susceptibility of silts

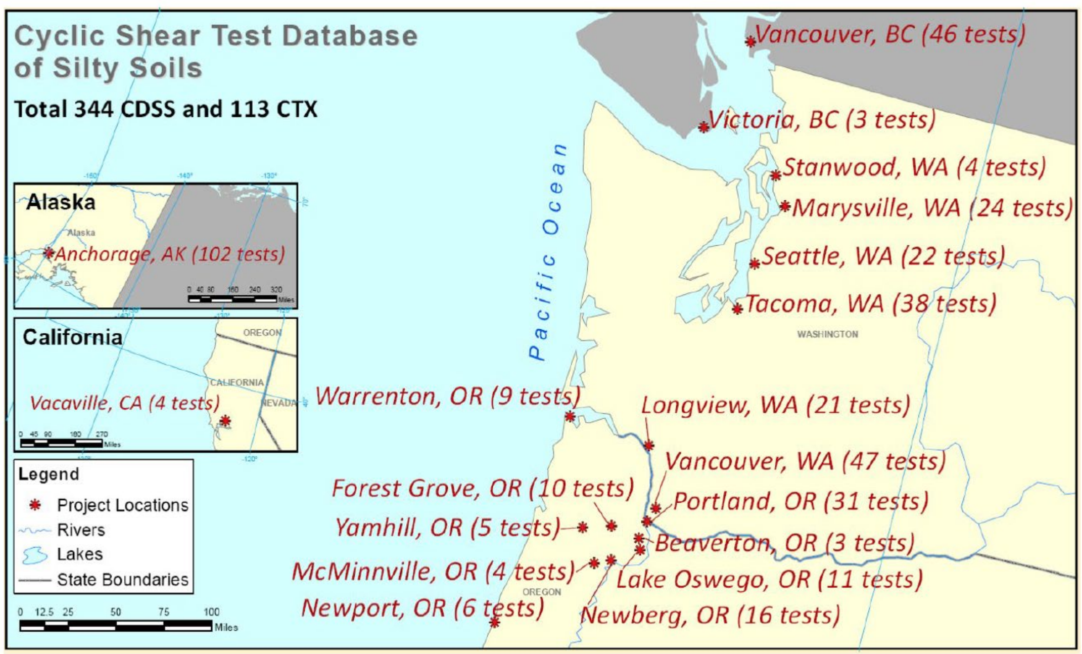


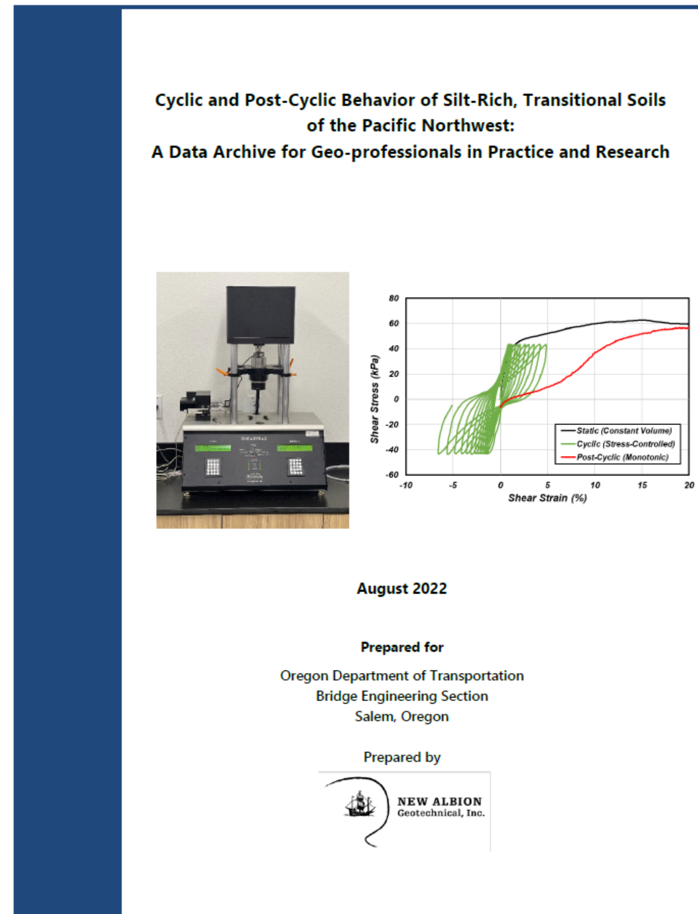
Tijerina Esquino et al. (2026 Geocongress)



Silt Data Archive

- Over 300 cyclic shear tests on silt soils from 40 project sites in Oregon, Washington, British Columbia, and Alaska
- Mostly unpublished data contributed by geotechnical engineers from public and private projects
- 2022 Data Report ODOT (Dickenson et al.)
- http://silt.cee.pdx.edu




Cyclic and Post-Cyclic Behavior of Silt-Rich, Transitional Soils of the Pacific Northwest:
A Data Archive for Geo-professionals in Practice and Research

August 2022

Prepared for
Oregon Department of Transportation
Bridge Engineering Section
Salem, Oregon

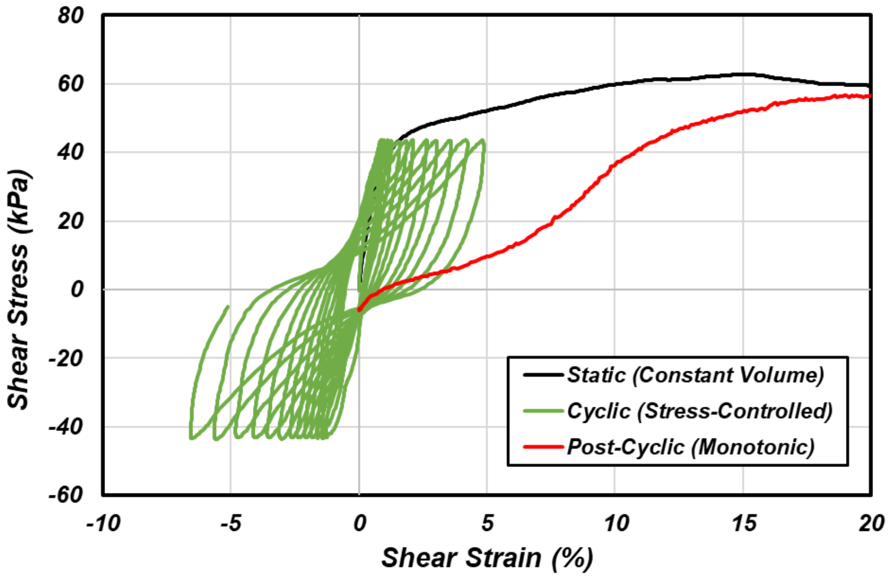
Prepared by
NEW ALBION Geotechnical, Inc.

Silt Data Archive

- Cyclic and post-cyclic tests
- Most include Atterberg limits, gradation data, consolidation, Vs (bender element) and in-situ (SPT, CPT, Vs)

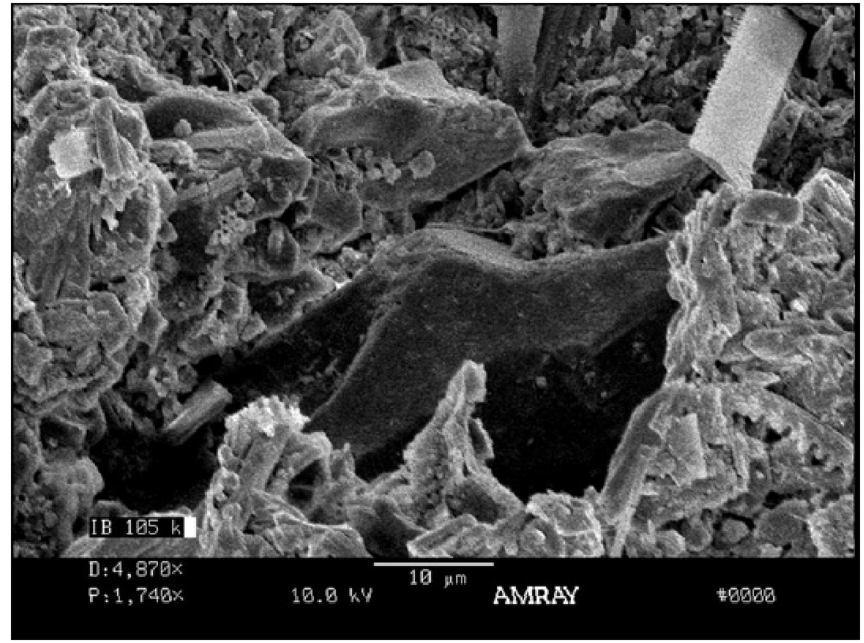
Test Type	Approximate Number of Tests
Cyclic DSS (stress-controlled)	180
Cyclic DSS (strain-controlled)	52
Cyclic TX (stress-controlled)	68
Post-cyclic shear resistance (DSS)	151
Post-cyclic 1D volumetric strain (DSS + TX)	55

Example test results from Willamette River Silt

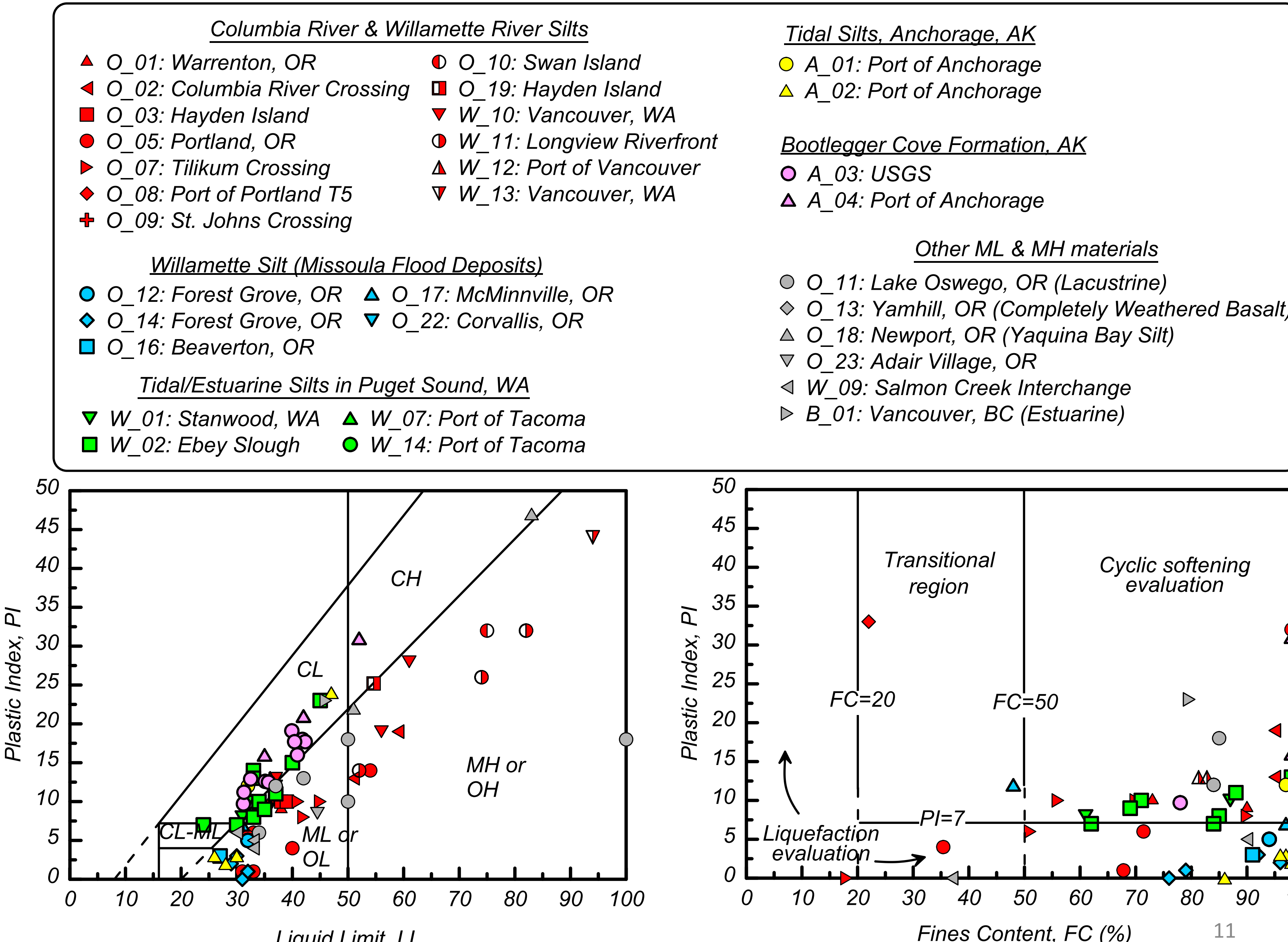


Silt Data Archive

- Depositional environment:
  - ✓ Fluvial (e.g., overbank, floodplain, glacial outwash)
  - ✓ Estuarine (e.g., mudflat, slough, inter-tidal zone)
  - ✓ Coastal near-shore (in shallow to intermediate water depths)
  - ✓ General Alluvial
  - ✓ Mine Tailings (e.g., gravel processing and wash tailings)

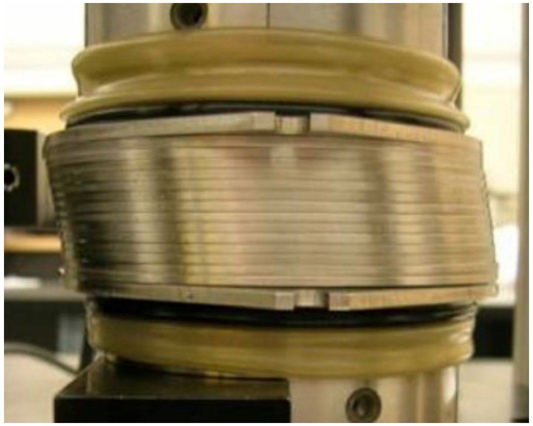


SEM image of Holocene Elliott Bay Estuarine (He) Silt, showing mixture of mineral grains and biogenic particles. Courtesy of Dr. Dickenson

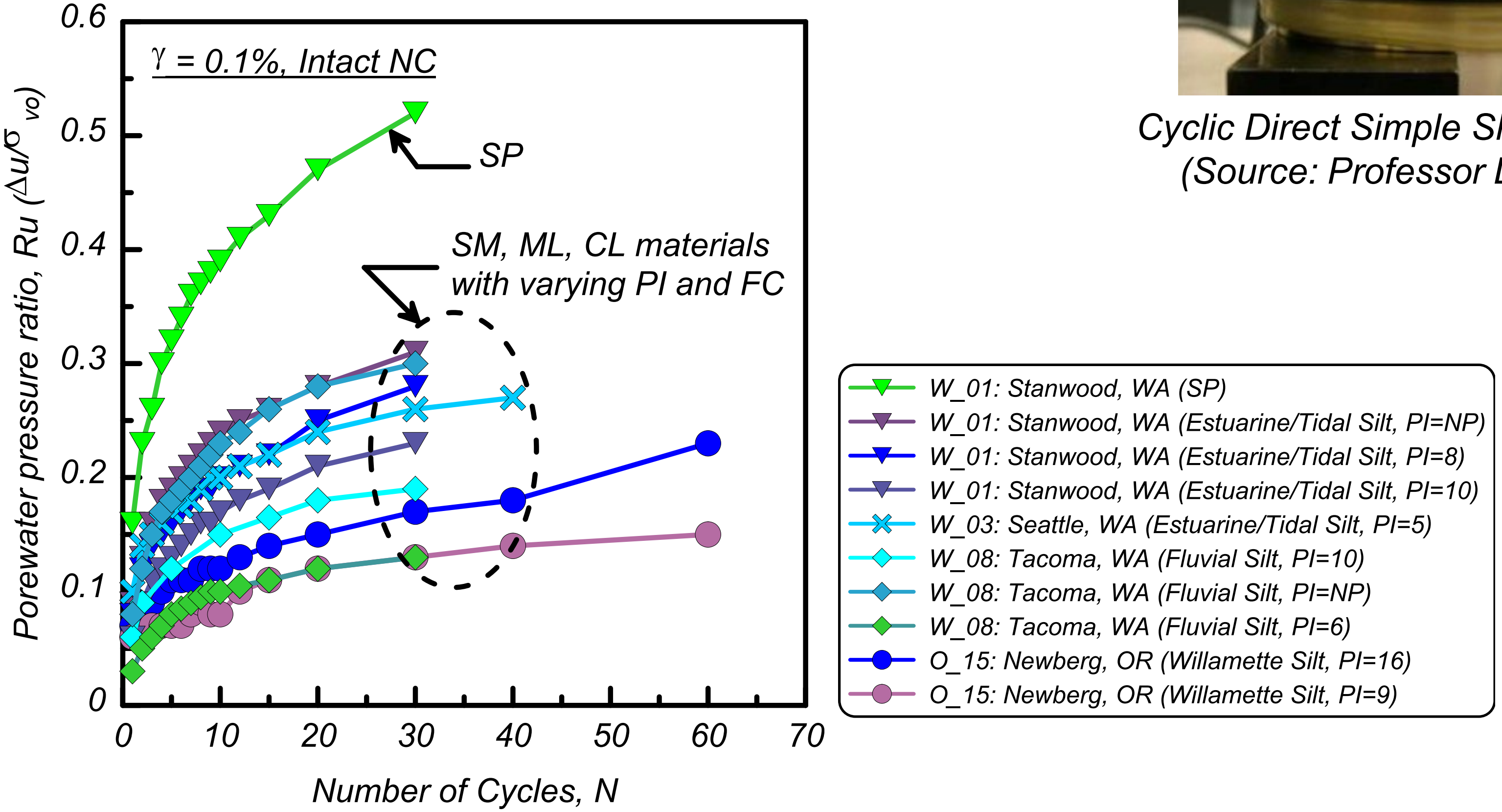

Columbia River & Willamette River Silts
O_01: Warrenton, OR
O_02: Columbia River Crossing
O_03: Hayden Island
O_05: Portland, OR
O_07: Tilikum Crossing
O_08: Port of Portland T5
O_09: St. Johns Crossing
O_10: Swan Island
O_19: Hayden Island
W_10: Vancouver, WA
W_11: Longview Riverfront
W_12: Port of Vancouver
W_13: Vancouver, WA
Tidal Silts, Anchorage, AK
A_01: Port of Anchorage
A_02: Port of Anchorage
Bootlegger Cove Formation, AK
A_03: USGS
A_04: Port of Anchorage
Willamette Silt (Missoula Flood Deposits)
O_12: Forest Grove, OR
O_14: Forest Grove, OR
O_16: Beaverton, OR
O_17: McMinnville, OR
O_22: Corvallis, OR
Tidal/Estuarine Silts in Puget Sound, WA
W_01: Stanwood, WA
W_02: Ebey Slough
W_07: Port of Tacoma
W_14: Port of Tacoma
Other ML & MH materials
O_11: Lake Oswego, OR (Lacustrine)
O_13: Yamhill, OR (Completely Weathered Basalt)
O_18: Newport, OR (Yaquina Bay Silt)
O_23: Adair Village, OR
W_09: Salmon Creek Interchange
B_01: Vancouver, BC (Estuarine)
Plastic Index, PI
Liquid Limit, LL
CH
CL
CL-ML
ML or OL
MH or OH
Plastic Index, PI
Fines Content, FC (%)
Transitional region
Cyclic softening evaluation
FC=20
FC=50
PI=7
Liquefaction evaluation
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100

Pore-water Pressure from Cyclic Loading

- PWP ratio (Ru) in silts is smaller than sands at same shear strain (γ) and number of cycles (N)

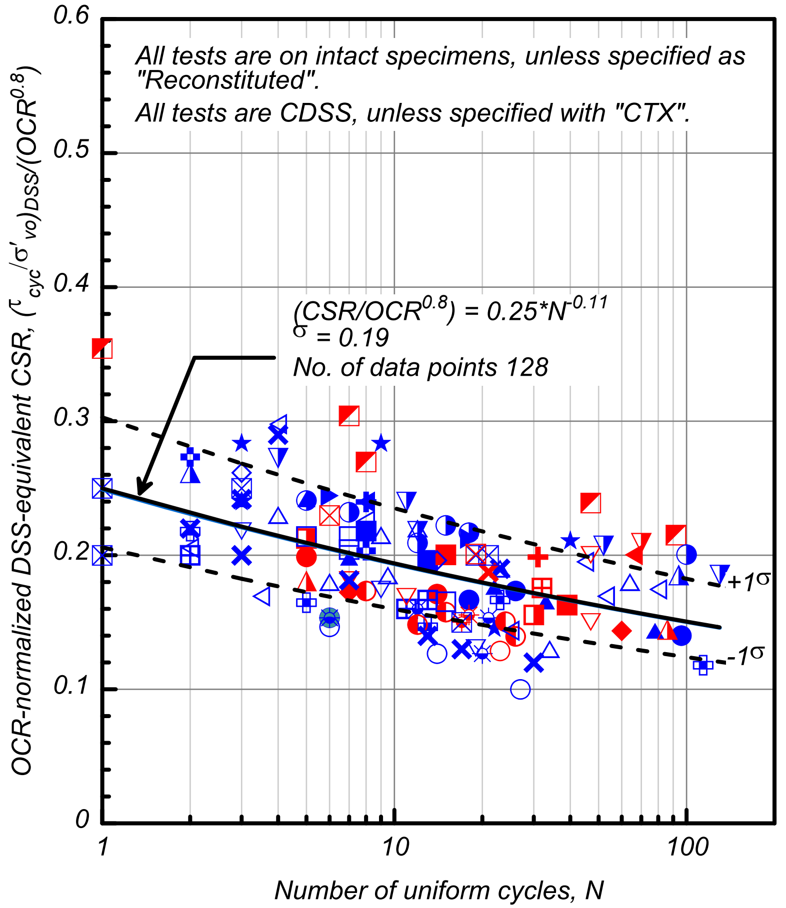


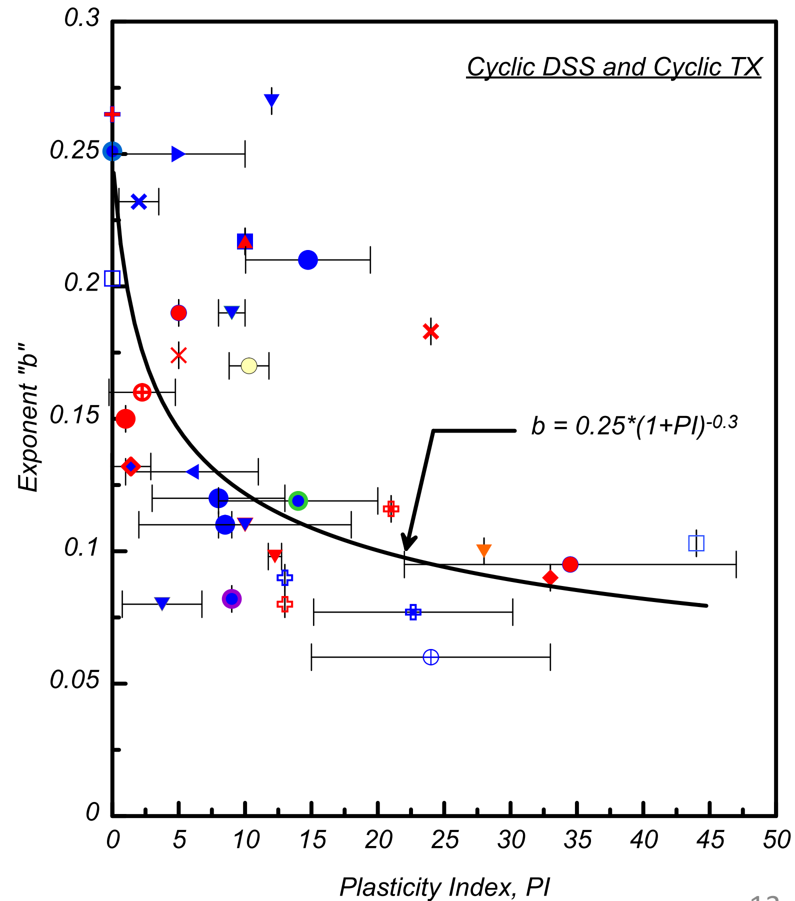
Cyclic Direct Simple Shear device
(Source: Professor DeJong)



Liquefaction Resistance

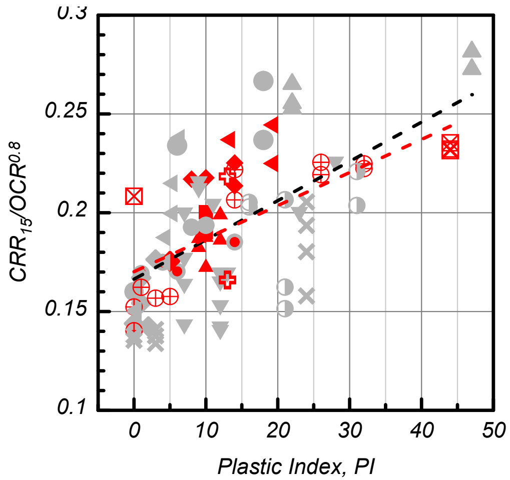
- Cyclic resistance ratio (CRR) increases with overconsolidation ratio (OCR)
- Power fit exponent (b-value) decreases with PI



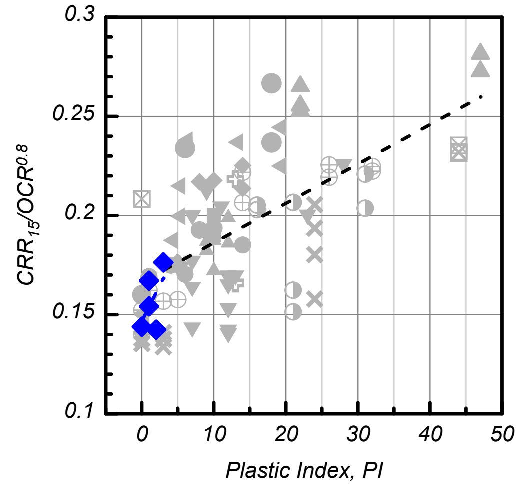


Effect of Depositional Environment

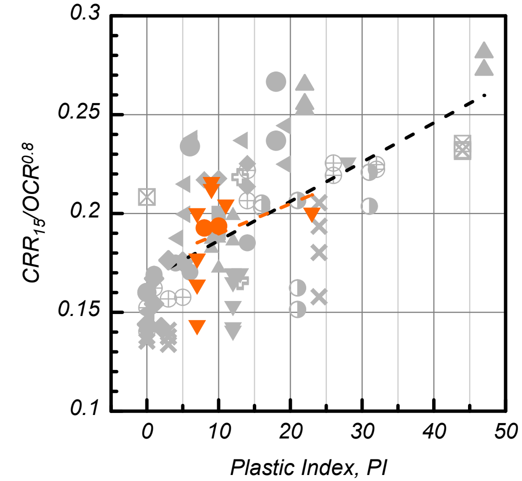
Alluvial Columbia River Silt and Willamette River Silt



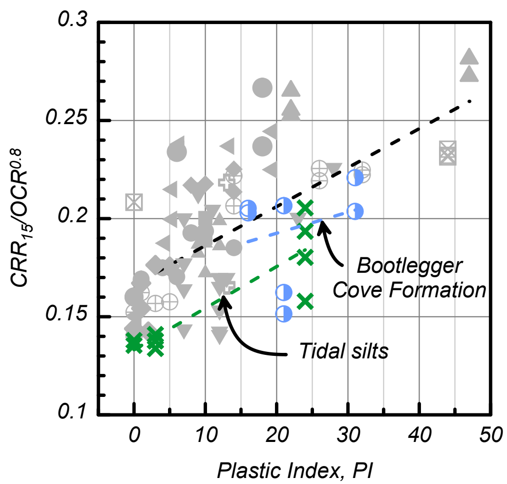
Fine-grained Missoula Flood Deposit



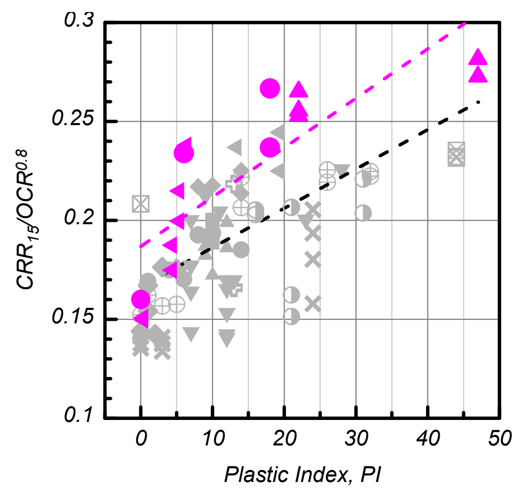
Tidal Silts in Puget Sound



Bootlegger Cove Clay and Tidal Silts (Anchorage, AK)

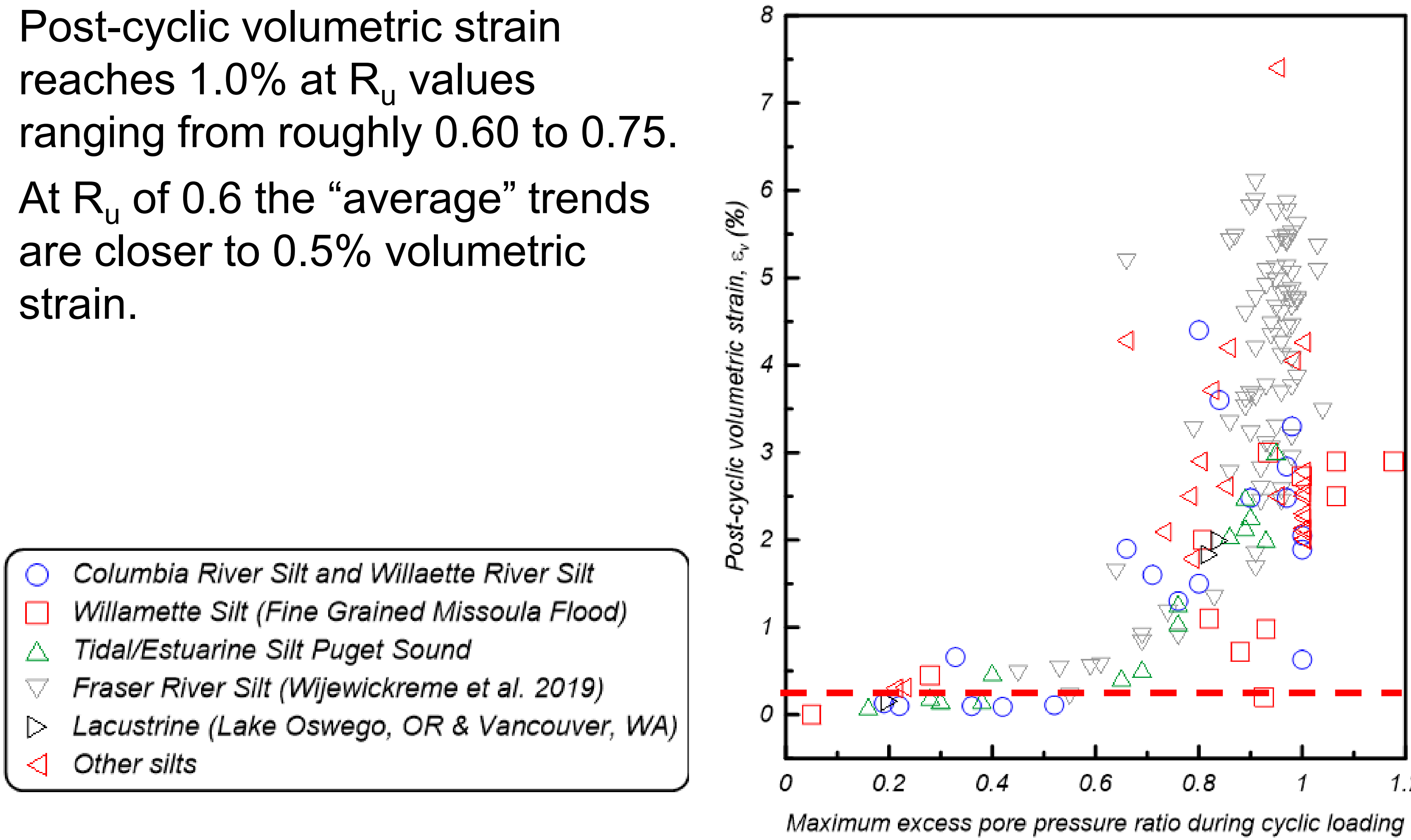


Lacustrine and Estuarine (Lake Oswego, Newport, OR)



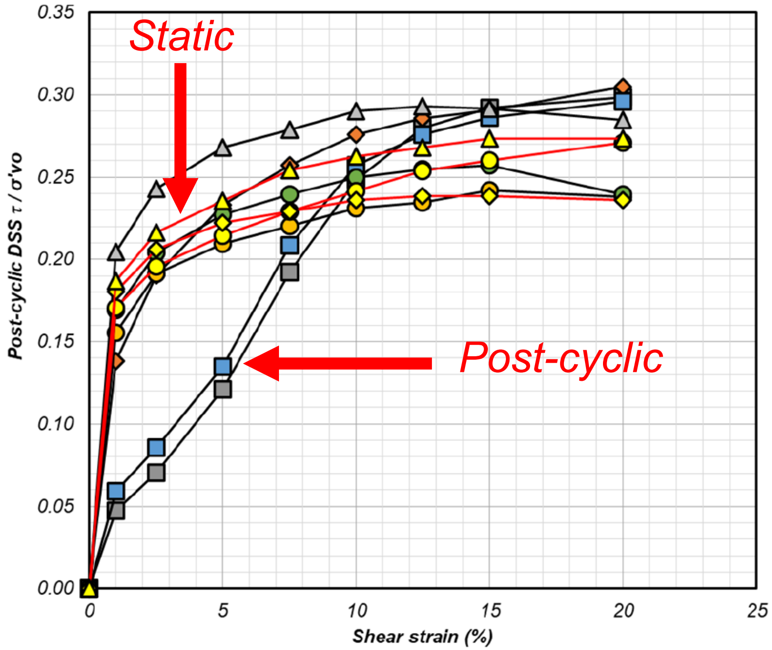
Post-Cyclic Reconsolidation (Settlement)

- Post-cyclic volumetric strain reaches 1.0% at R_u values ranging from roughly 0.60 to 0.75.
- At R_u of 0.6 the "average" trends are closer to 0.5% volumetric strain.

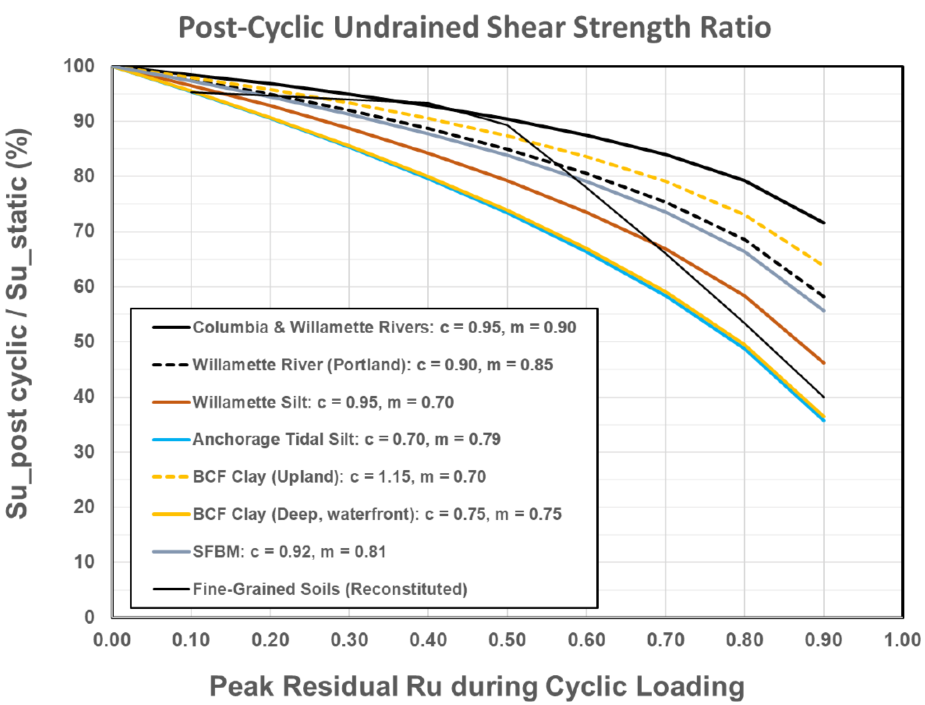


Post-Cyclic Shear Response

- Post-cyclic shear response is affected by pore pressure developed during cyclic loading
- Cyclic degradation of shear strength in silts is smaller than sands



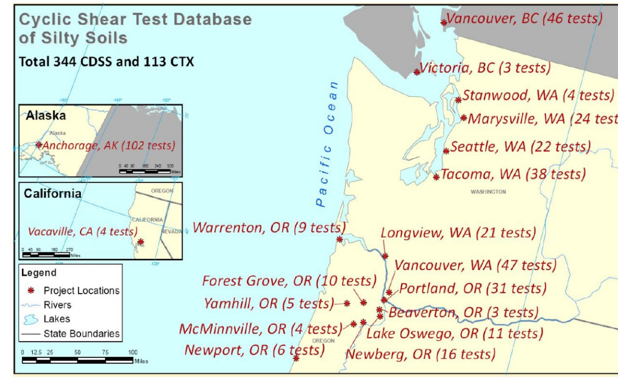
Ebey Slough site (project W_02)



Dickenson et al. (2022)

Summary

- An archive of over 300 cyclic and post-cyclic shear tests on silt-rich soils from 40 sites in PACNW and Alaska is available in a 2022 report to ODOT and at http://silt.cee.pdx.edu



Acknowledgement

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