Liquefaction Hazard Assessments

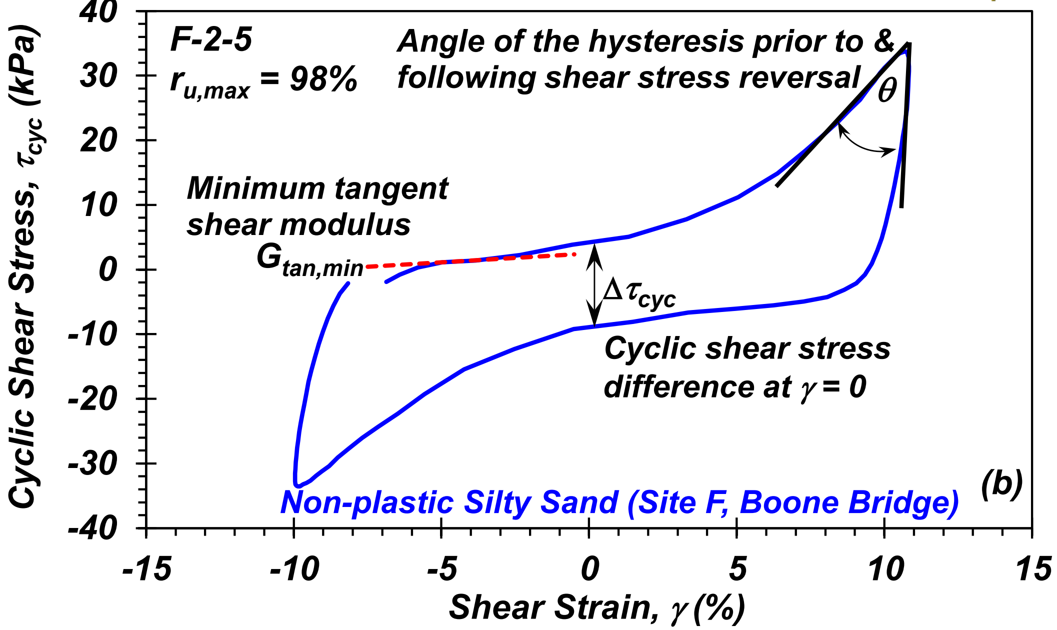
Oregon State University
College of Engineering

PEER NSF FHWA

- ***Governing variables in the PacNW:***
  - **Duration**
  - **Mainshock – Aftershock** (will not address herein)
- Probabilistic models with emphasis on effects of duration and multi-shock sequences must be developed/improved
- Probabilistic or deterministic, liquefaction hazard assessments (LHAs) consist of:
  - Step 1: Susceptibility to **liquefaction** (or **cyclic softening)**
  - Step 2: Liquefaction triggering (or cyclic softening failure)
  - Step 3: Consequences

Armin.Stuedlein@oregonstate.edu

Linking Hysteretic Behavior to Liquefaction Susceptibility



- We can quantify certain hysteretic metrics for an objective assessment of behavior:
  - Angle of γ-τ_{cyc} hysteresis prior to & following unloading
  - Cyclic shear stress difference $\Delta\tau_{cyc}$ at shear strain, $\gamma = 0$
  - Minimum tangent shear modulus, $G_{tan,min}$
  - Maximum excess pore pressure generated, $r_{u,max}$

Normalized by $\tau_{cyc,max}$:

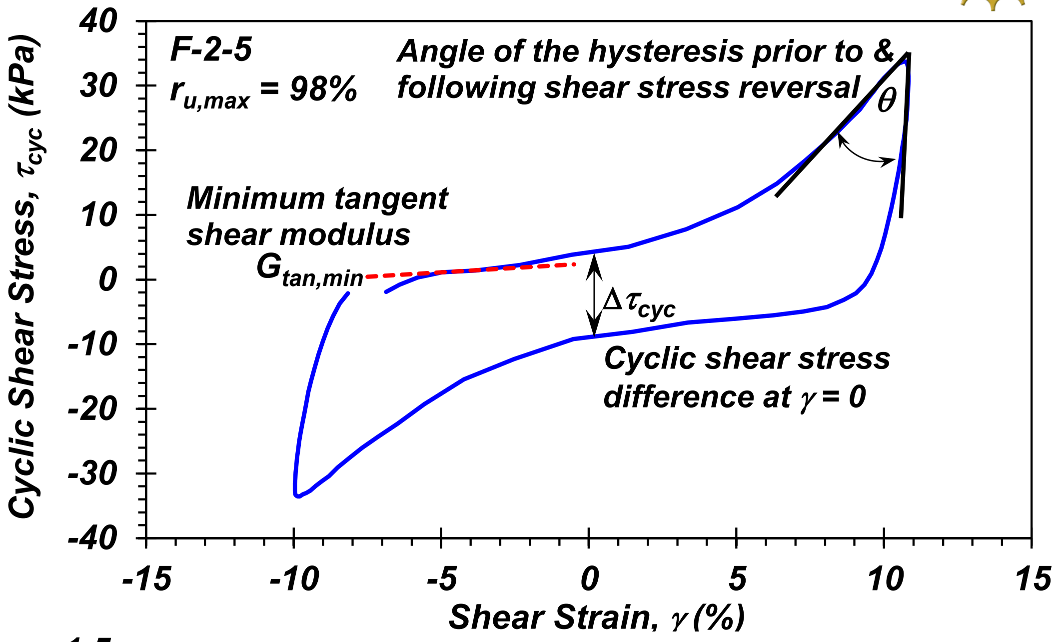
- $\Delta\tau_{cyc}/\tau_{cyc,max}$

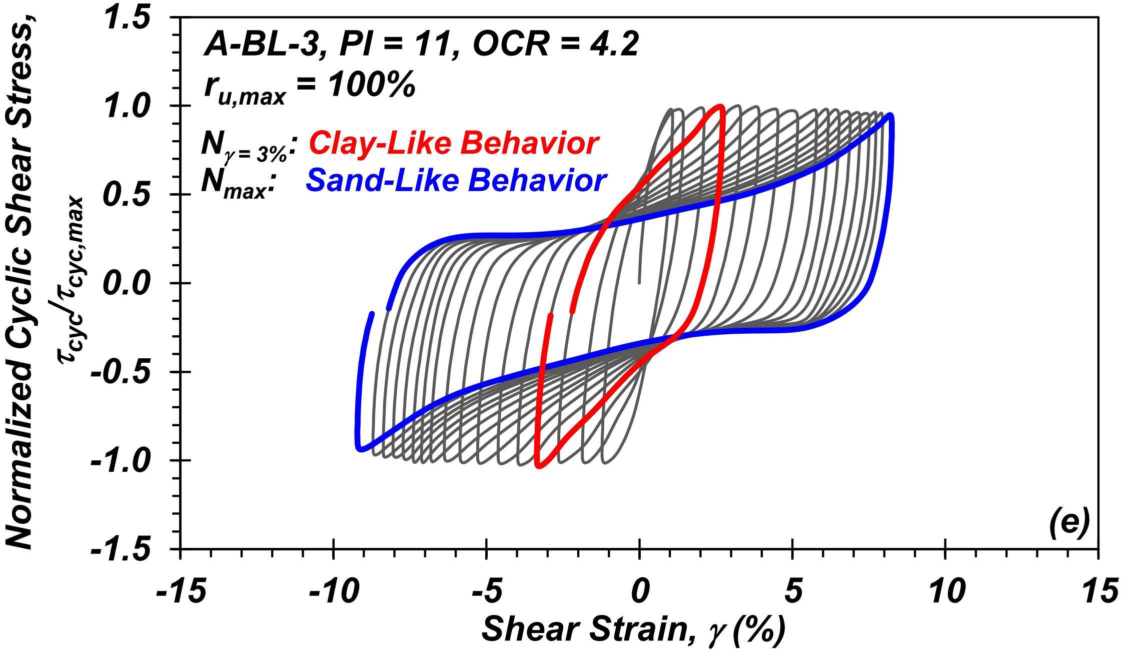
- $G_{tan,min}/\tau_{cyc,max}$

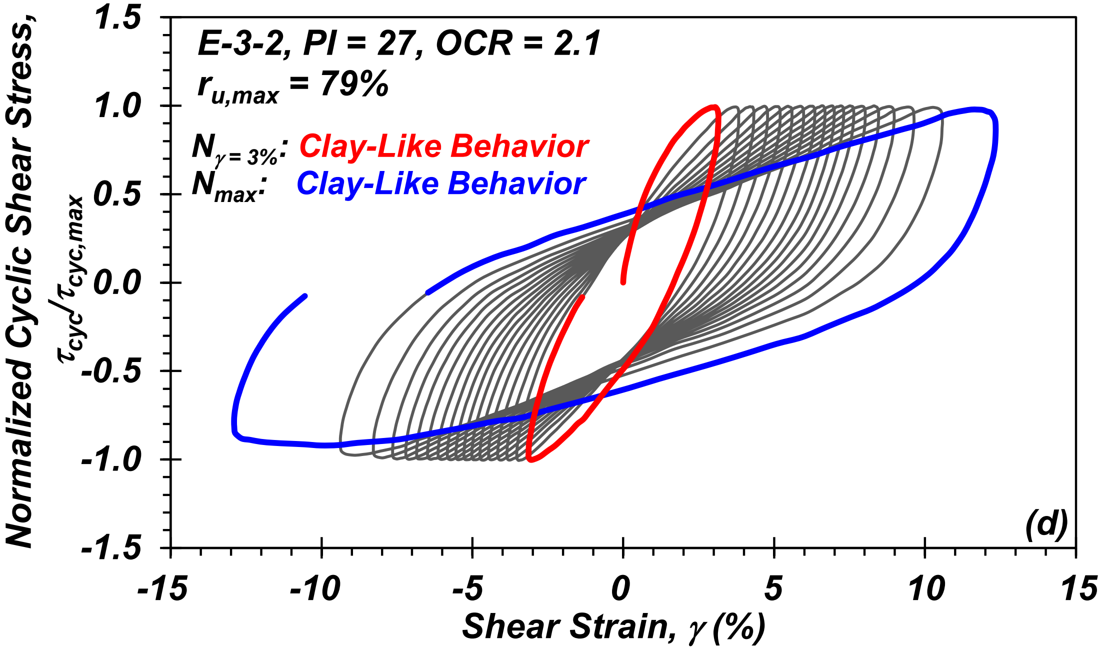
- Can assess differences between key numbers of loading cycles, $N_{\gamma = 3\%}$ and N_{max} (γ_{max} > 5%): duration → ***N***, assess role of duration on evolution of hysteretic behavior → important for transitional soils

Linking Hysteretic Behavior to Susceptibility

We must adequately quantify N for subduction zone motions, given role of duration to produce damage-inducing evolution of stress-strain responses.





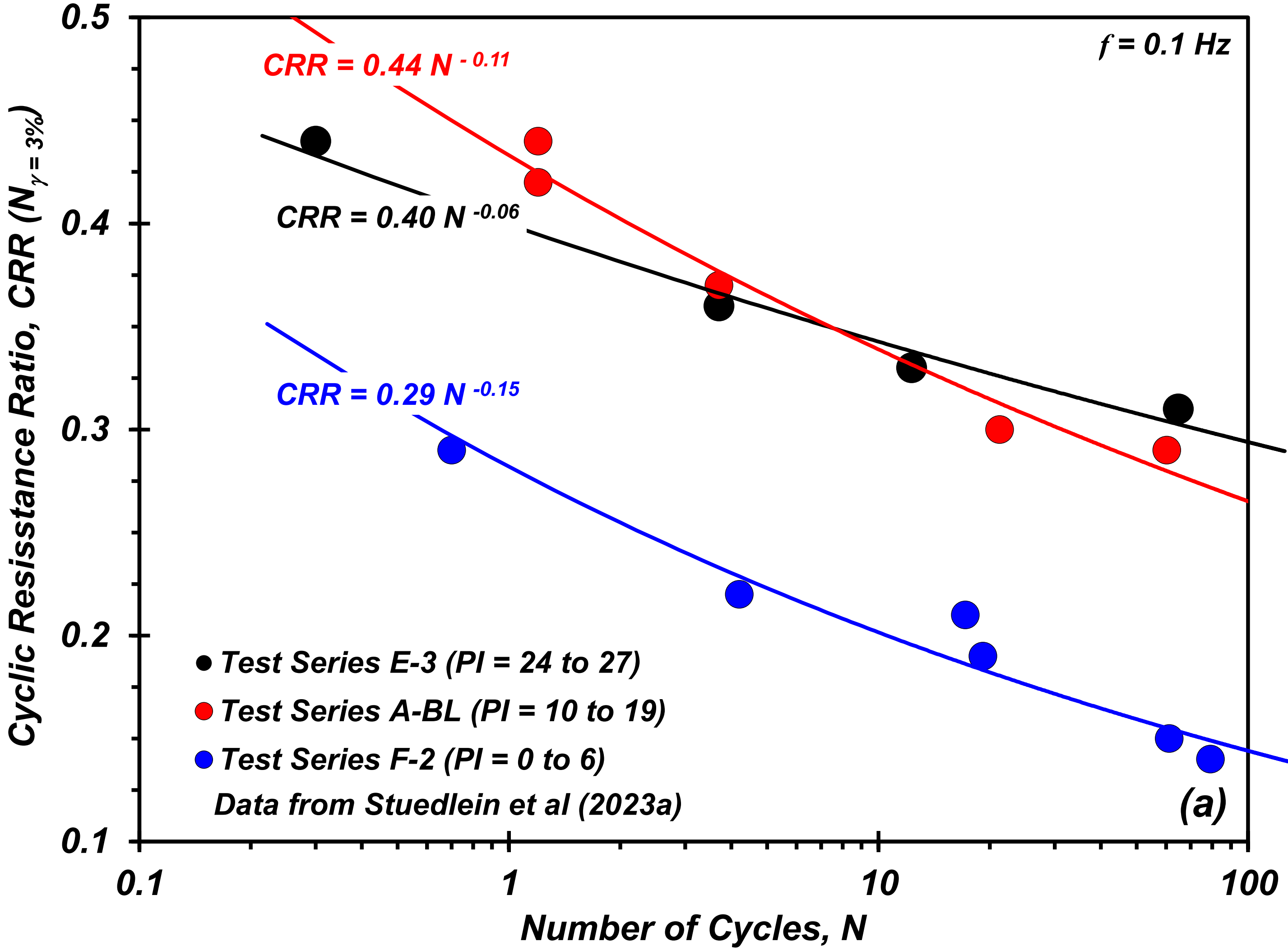


Equivalent No. of Cycles, N_{eq}

Oregon State University College of Engineering

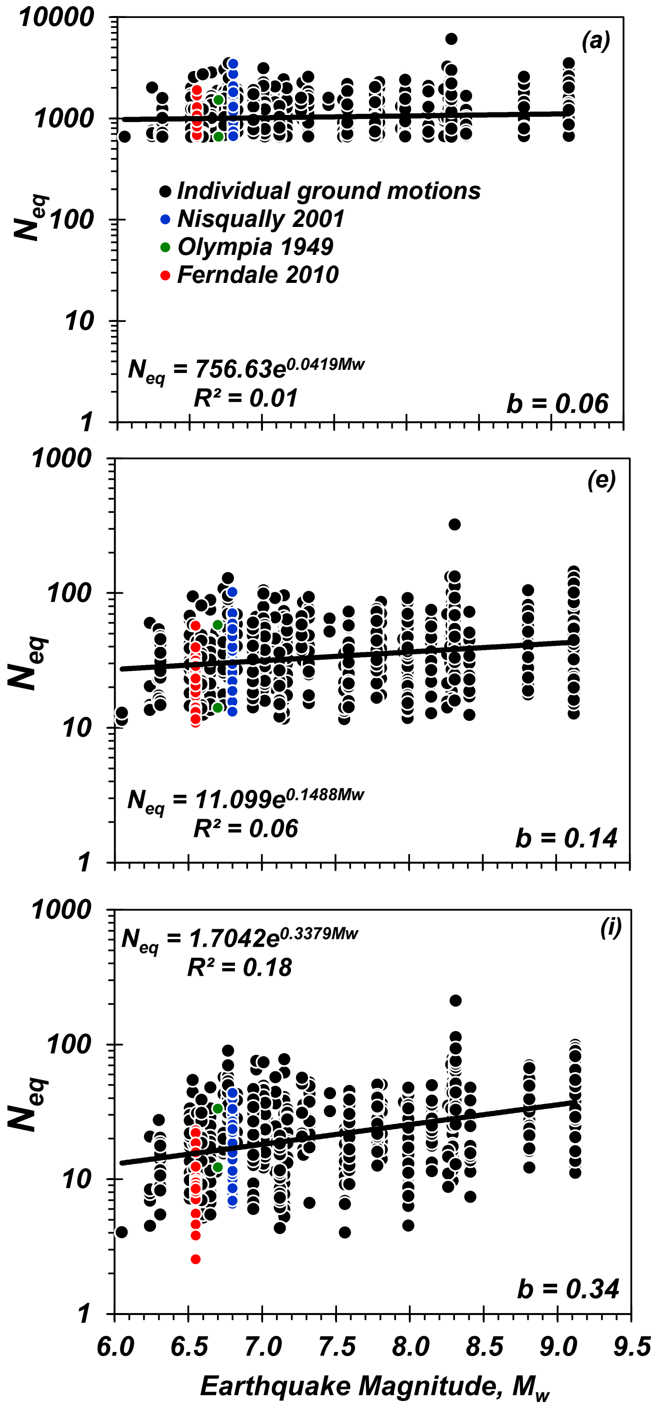
- Three suites of cyclic test data on silts; role of:
  - Duration / ***N***
  - Plasticity Index (***PI***; indicator of clay mineral activity)

  on cyclic resistance
- Exponent b in $CRR = a \cdot N^{-b}$ controls the number of equivalent uniform loading cycles, N_{eq}, associated w/ a given GM
- Preliminary assessment of NGA-Sub GMs instructive



Equivalent No. of Cycles, N_{eq}

- $CRR = a \cdot N^{-b}$, with:
  - Medium to high plasticity silts and clays, *b* = 0.06 (top plot)
  - Non-plastic silts, *b* = 0.14 (middle plot)
  - Dense sands, *b* = 0.34 (bottom plot)
- Sensitivity of N_{eq} to M_w increases with *b*
- Note the ***variability*** in N_{eq}
- **Use of mean N_{eq} alone is questionable**

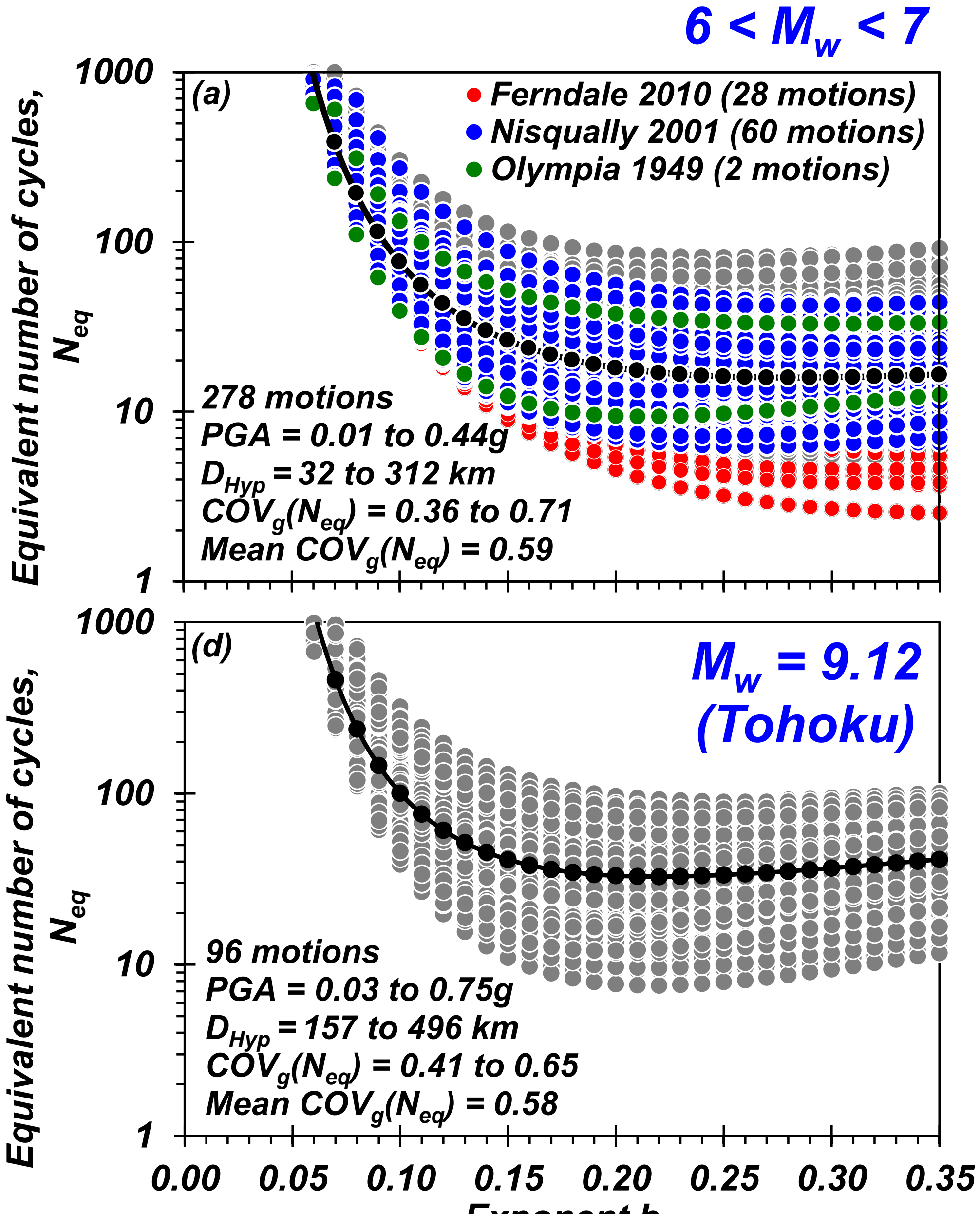


Equivalent No. of Cycles, N_{eq}

- For typical b = 0.1 (low *PI* silts), mean N_{eq} of:
  - M_w = 6.5: $N_{eq} \approx 75$
  - M_w = 7.5: $N_{eq} \approx 80$
  - M_w = 9.1: $N_{eq} \approx 100$

Range in N_{eq}: 30 to 300

- Large N_{eq}; thus, establishing *ultimate hysteretic behavior* important, critical for liquefaction susceptibility determinations
- We must develop probabilistic N_{eq} models; in motion through CRESCENT Seed Grant

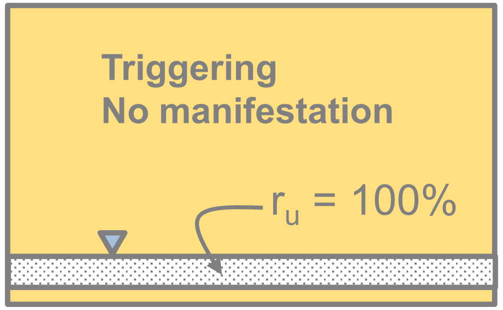


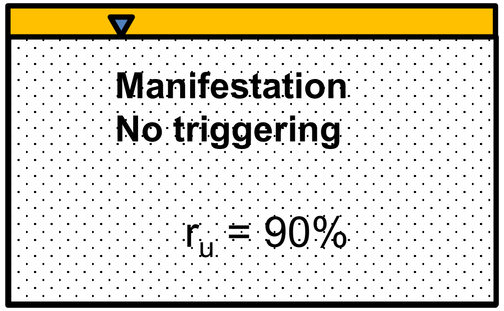
Probabilistic Liquefaction Hazard Assessments:
Next Generation Liquefaction (NGL) Project

- Approach: allows rational consideration of:

No Manifestation ≠ No Triggering — $P[NT|NM] < 1.0$ — $P[T|NM] > 0.0$

Manifestation ≠ Triggering — $P[T|M] < 1.0$ — $P[NT|M] > 0.0$





- Current functional form:

$$P[T|M] = \frac{P[M|T]P[T]}{P[M]} = \frac{P[M|T]P[T]}{P[M|T]P[T] + P[M|NT](1-P[T])}$$

Need three probabilities:

- Probability of manifestation given triggering, *P[M|T]*
- Probability of manifestation without triggering, *P[M|NT]*

} Probabilistic manifestation model; informed by case histories in the NGL Database

- Probability of triggering before incorporation of case history data, *P[T]* - prior probability

Probabilistic Liquefaction Hazard Assessments

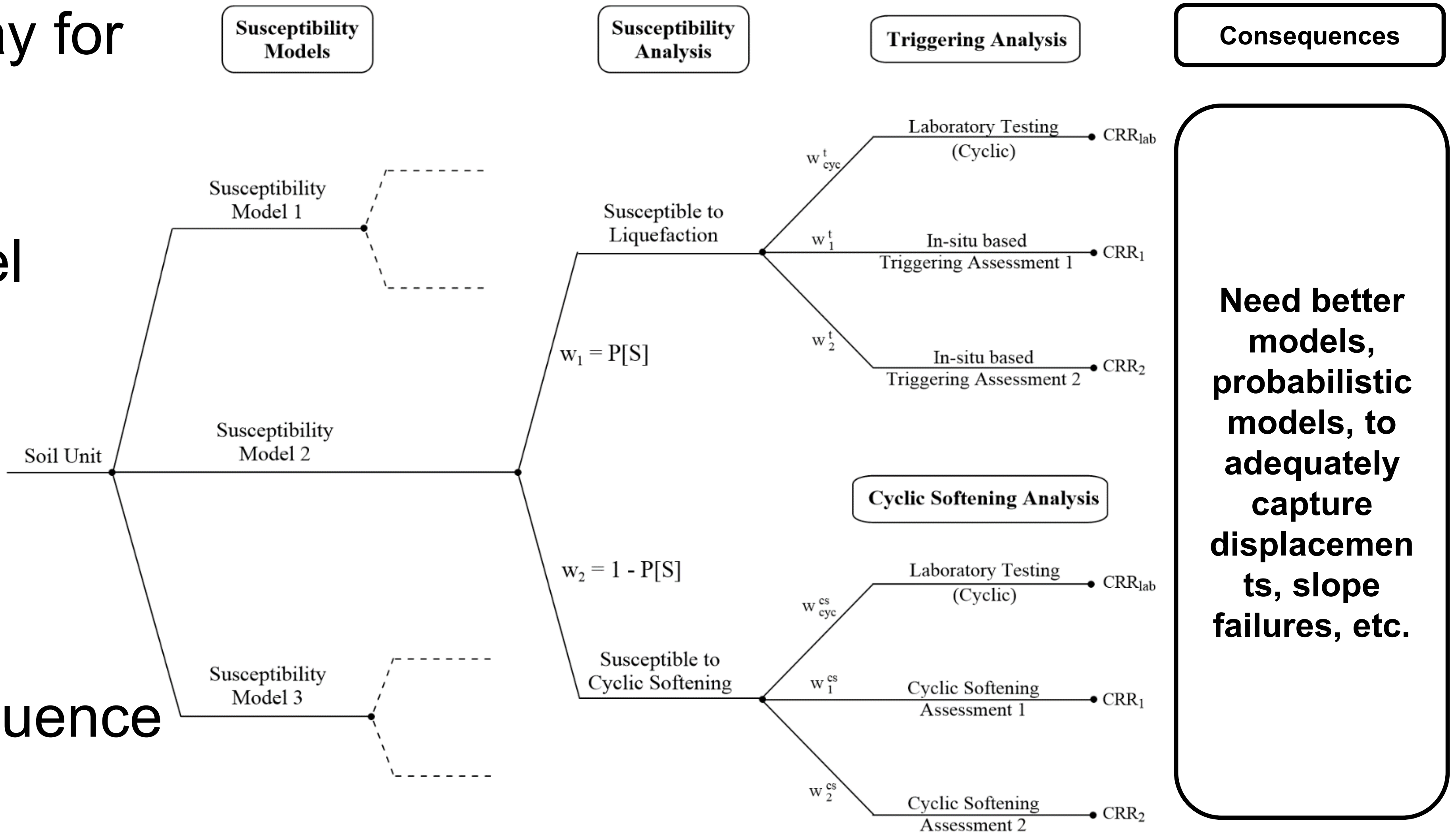
- Previously, the laboratory-based "prior" assumed $P[S] = 1.0$
- Characterize probability of liquefaction susceptibility, $P[S]$:
  - SPT-based triggering: *PI*
  - CPT-based triggering: *PI* and CPT I_c

  } Susceptibility defined using hysteretic behavior
- Evaluate sensitivity $P[S]$ models to soils with differing fines contents, and fines of differing plasticity
- Functional form of model:

$$P[T|M,S] = \frac{P[M|T] \cdot P[T|S] \cdot P[S]}{P[M|T] \cdot P[T|S] \cdot P[S] + P[M|NT] \cdot (1 - P[T|S]P[S])}$$

Probabilistic Liquefaction Hazard Assessments

- Envisioned pathway for PLHA: Logic tree
- Probabilistic susceptibility model provides weights
- Cyclic resistance models weighted based on fines contents, plasticity
- Then on to consequence evaluation



Liquefaction Hazard Assessments

Oregon State University
College of Engineering

PEER NSF FHWA

- ***Governing variables in the PacNW:***
  - **Duration**
  - **Mainshock – Aftershock**
- Probabilistic liquefaction hazard assessments (PLHAs) require new models for Step 3: Consequences
  - Flow failure
  - Lateral spreading
  - Settlement

Armin.Stuedlein@oregonstate.edu

Oregon State University
College of Engineering

– Thank you –

Armin.Stuedlein@oregonstate.edu

References

Oregon State University
College of Engineering

- **Slides 2, 3:**
  - Studlein, A.W., Dadashiserej, A., Jana, A., Evans, T.M. (2023). “Liquefaction Susceptibility and Cyclic Response of Intact Nonplastic and Plastic Silts.” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 149, No. 1, 04022125.
  - Stuedlein, A.W., Alemu, B., Evans, T.M., Kramer, S.L., Stewart, J.P., Ulmer, K., Ziotopoulou, K., (2023a), “PEER Workshop on Liquefaction Susceptibility,” PEER Report 2023/02, Pacific Earthquake Engineering Research Center, Berkeley, California, DOI: 10.55461/BPSK6314.
  - Sahin, A., Jana, A., Beyzaei, C.Z., Sancio, R., Ulmer, K.J., Brandenberg, S.J., Kramer, S.L., Stewart, J.P. and Stuedlein, A.W., "Next Generation Liquefaction Laboratory Database for Susceptibility and Cyclic Strength Assessment." In Geotechnical Frontiers 2025, pp. 238-247..
- **Slides 4 – 6:** Dadashiserej, A., Jana, A., Stuedlein, A.W., Evans, T.M. (2024). “Cyclic Resistance Models for Transitional Silts with Application to Subduction Zone Earthquakes.” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 150, No. 2, 04023135.
- **Slides 7, 8:** Ulmer, K.J., Hudson, K.S., Brandenberg, S.L., Zimmaro, P., Pretell, R., Carlton, B., Kramer, S.L., and Stewart, J.P., (2024), “Next Generation Liquefaction Models for Susceptibility, Triggering, and Manifestation,” U.S. Nuclear Regulatory Commission.
- **Slide 9:** Sahin, A., Jana, A., Ulmer, K.J., Brandenberg, S.J., Evans, T.M., Kramer, S.L., Stewart, J.P. and Stuedlein, A.W., “Application of Liquefaction Susceptibility Criteria within a Logic Tree Framework.” *GeoExtreme 2025. In press.*

Armin.Stuedlein@oregonstate.edu