Technical Basis for the Need to Update Guidance on Liquefaction Evaluation for Nuclear Power Plants

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Outline

- Current NRC guidance on liquefaction evaluations
- Focus areas for enhancing NRC guidance
- Example case history
- How the NGL project can address issues
- Conclusions

Current NRC Guidance

- Reg. Guide 1.198, Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites
  - Based on NUREG CR-5741, Technical Bases for Regulatory Guide for Soil Liquefaction

- NUREG 0800, Standard Review Plan → (2.5.4) Stability of Subsurface Materials and Foundations → (2.5.4.8) Liquefaction Potential

- Supporting documentation:
  - Reg. Guide 1.208, A Performance-based Approach to Define the Site-Specific Earthquake Ground Motion

Regulatory Guide 1.198

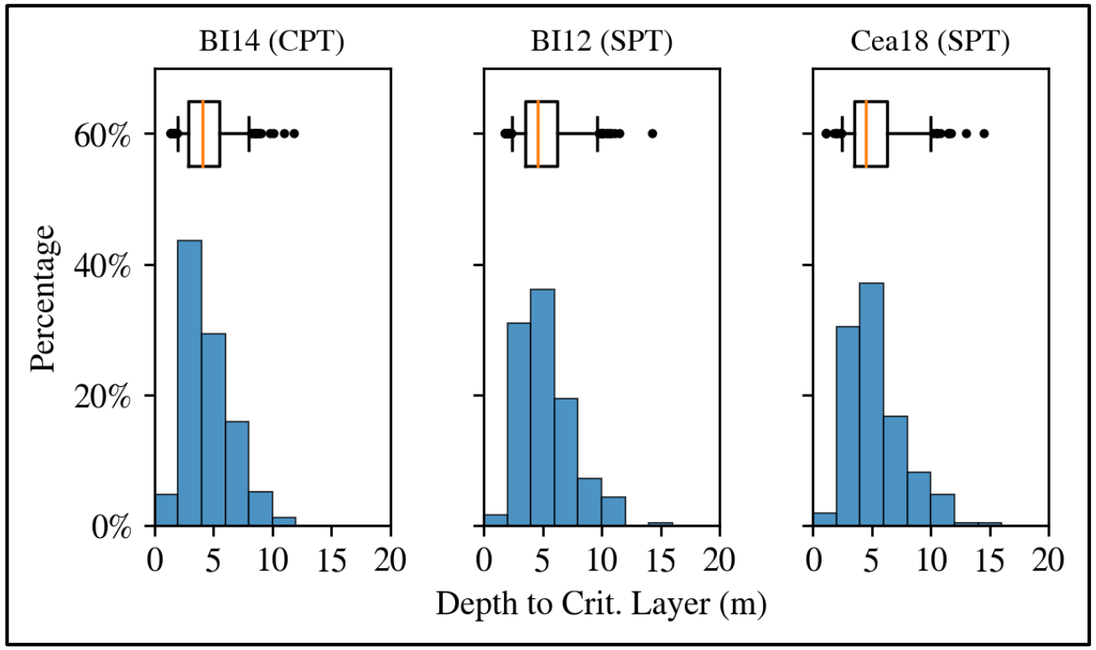
- Published in 2003, provides guidance to the NRC on acceptable methods to evaluate the potential for earthquake-induced instability of soils resulting from liquefaction and strength degradation.
- Based on NUREG/CR-5741 (1999)
- Generally based on the 1996 NCEER and 1998 NCEER/NSF workshops (Youd et al. 2001).
- Focuses on existing deterministic, semi-empirical methods.
  - FS ≤ 1.1: liquefaction should be considered to have been triggered. Use conservative undrained residual strengths for stability and deformation analyses.
  - FS ≥ 1.4: minor cyclic pore pressure generation, use large fraction of drained static shear strength for stability and deformation analyses.
  - 1.1 < FS < 1.4: assign strength values between conditions described above for stability and deformation analyses.
- Analytical methods permitted (e.g. nonlinear site response analysis with appropriate constitutive model).
- Probabilistic approach can be used if sufficiently formulated.

Focus Areas for Enhancing NRC Guidance

- Ground motion intensity measure, current practice
  - From NUREG 0800, 2.5.4.8: "The site specific GMRS (adjusted to the depth of liquefiable layer) … should be used to evaluate the potential for liquefaction."
  - From RG 1.208: Site-specific ground motion response spectrum (GMRS): designed to meet target performance goal (P_F) related to structural performance
    - P_F: frequency [mean annual probability of exceedance] of onset for significant inelastic deformation (FOSID) = 10^{-5}
    - See also ASCE 43-05, "Design response spectra" (DRS)
- Ground motion intensity considerations for future guidance
  - The GMRS is not necessarily associated with a target performance goal related to <u>liquefaction</u>.
  - Using a single hazard-targeted value of PGA could overpredict liquefaction hazard in areas of low to moderate seismicity (Franke et al. 2019).

Focus Areas for Enhancing NRC Guidance

- Parameter space
  - Semi-empirical triggering models are constrained by the case history database from which they are derived
  - Applicability of these models for high overburden stress is uncertain (such conditions are not well represented in current case history database)
  - Fines content effects?
- Aging
  - Older soils are generally more resistant to pore-pressure generation than younger soils are
  - Most case histories in current databases are either man-made fills or relatively young deposits
  - For some nuclear power plants in the Central/Eastern United States (CEUS), aging may significantly affect liquefaction evaluations (but how?)


BI14 (CPT)
BI12 (SPT)
Cea18 (SPT)
Percentage
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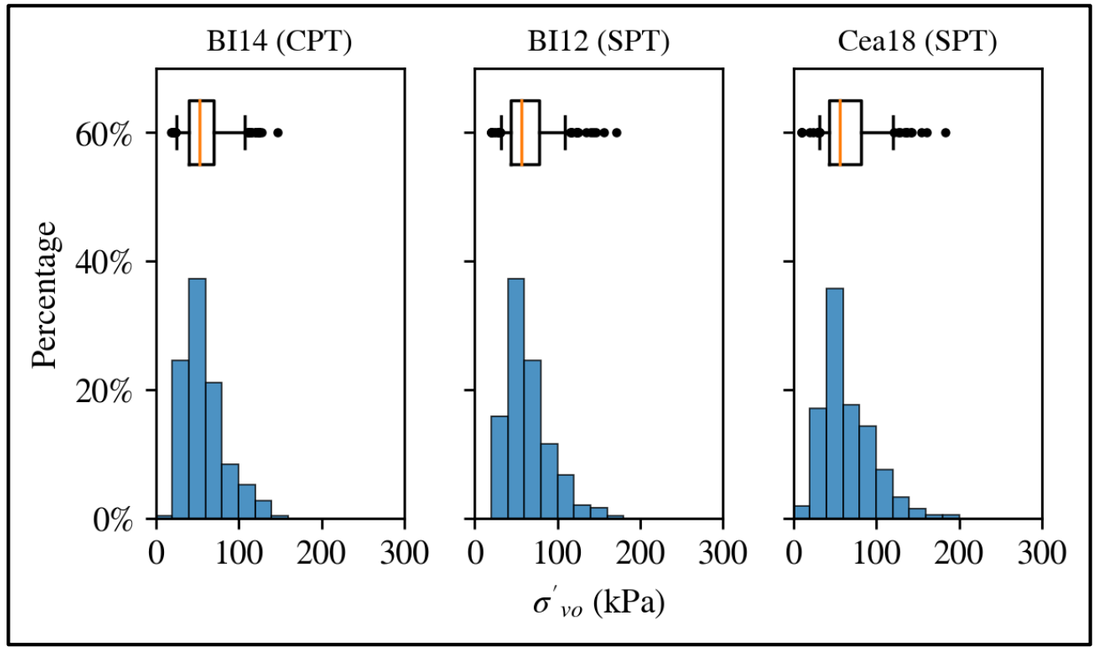
40%
20%
0%
0 5 10 15 20
Depth to Crit. Layer (m)


BI14 (CPT)
BI12 (SPT)
Cea18 (SPT)
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40%
20%
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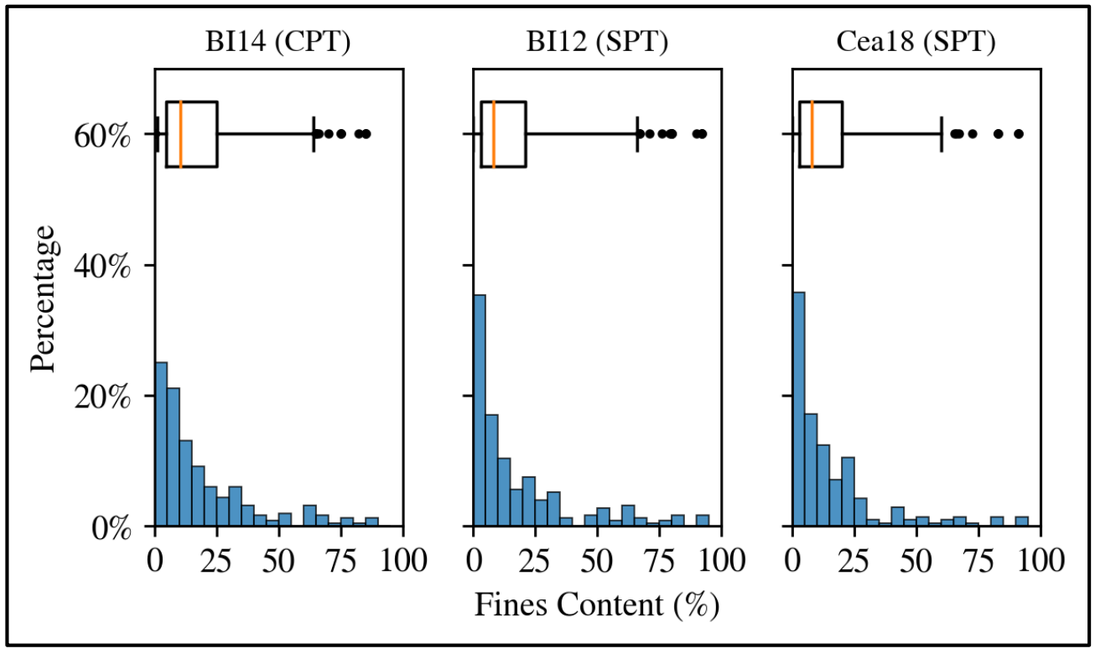
0 100 200 300
σ′vo (kPa)


BI14 (CPT)
BI12 (SPT)
Cea18 (SPT)
Percentage
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40%
20%
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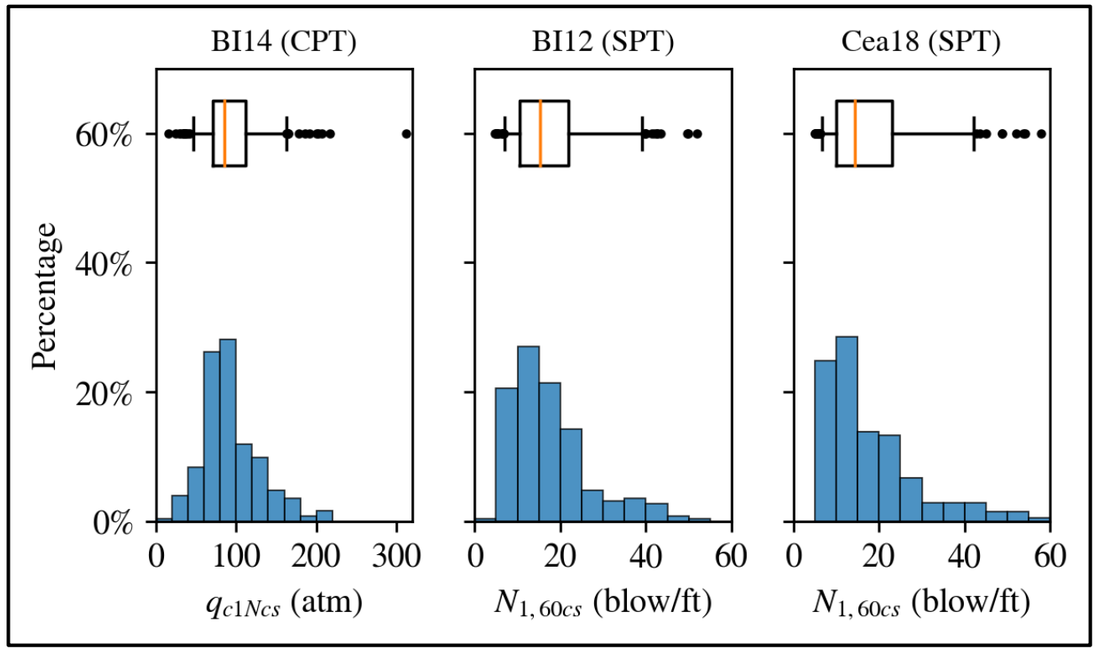
0 25 50 75 100
Fines Content (%)


BI14 (CPT)
BI12 (SPT)
Cea18 (SPT)
Percentage
60%
40%
20%
0%
0 100 200 300
qc1Ncs (atm)
0 20 40 60
N1, 60cs (blow/ft)
0 20 40 60
N1, 60cs (blow/ft)

Focus Areas for Enhancing NRC Guidance

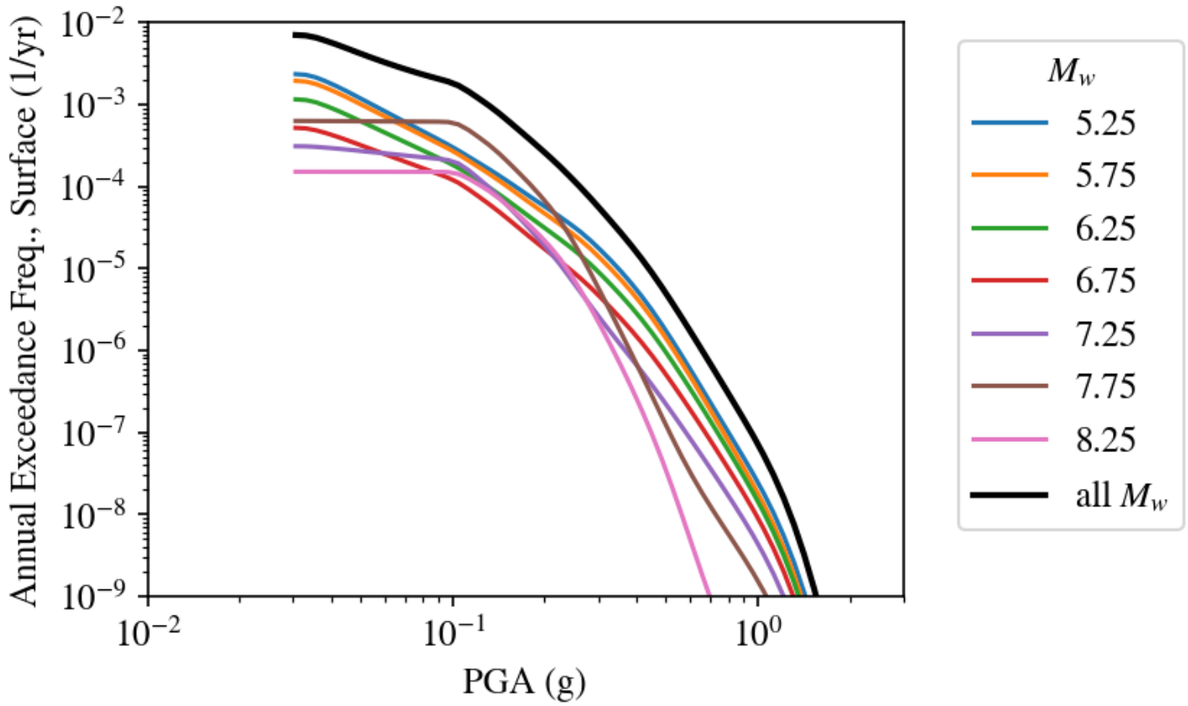
- Probabilistic approach
  - Needs to have a more prominent place in the guidance, consistent with a risk-informed and performance-based regulatory framework
  - Needs more direction about what is a sufficient approach
- Epistemic uncertainty
  - Even with multiple triggering models available today, epistemic uncertainty needs to be better quantified

Example Case History

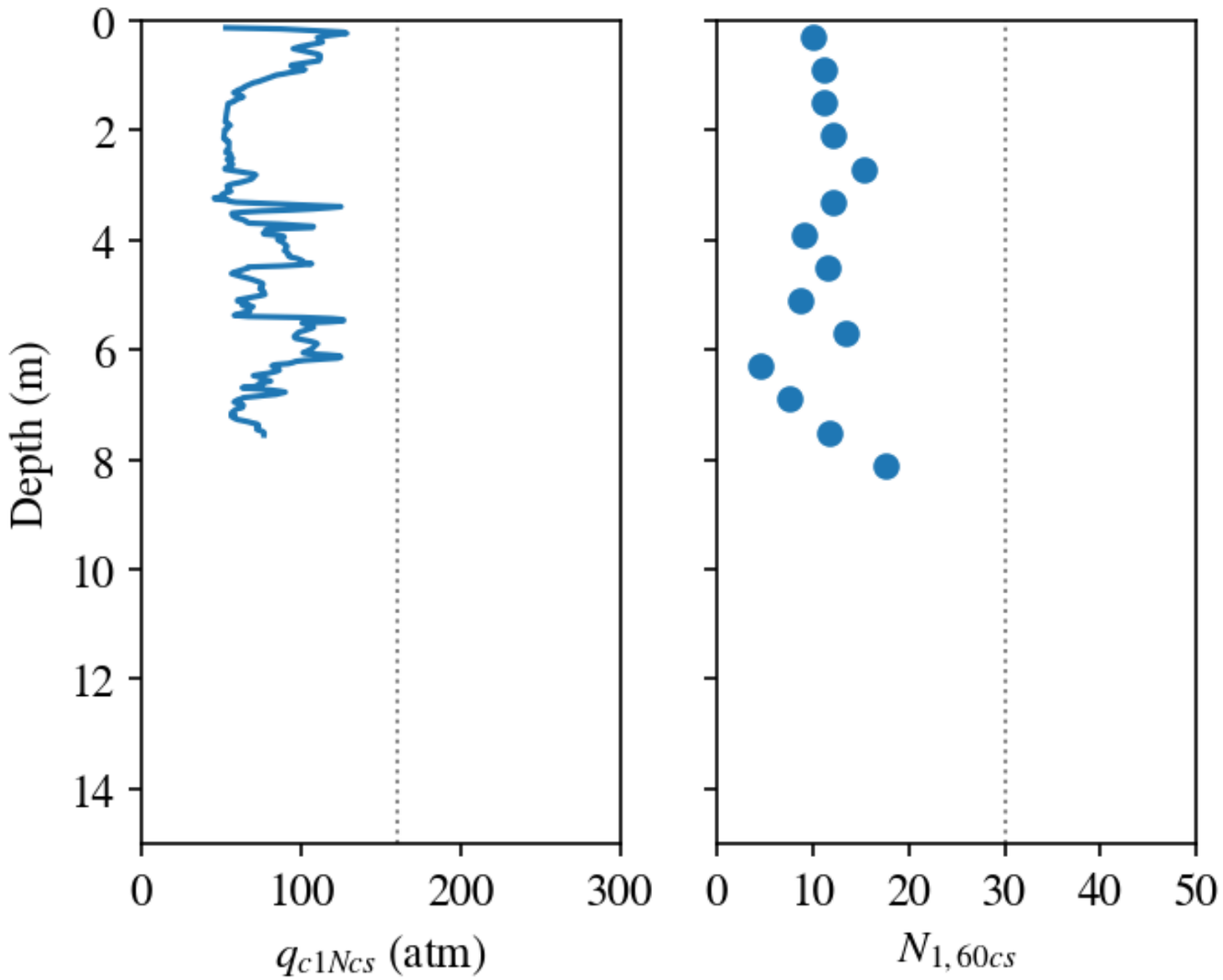
- Compare results from several different methods…
  - CPT (Youd et al. 2001, Moss et al. 2006, Boulanger and Idriss 2014)
  - SPT (Youd et al. 2001, Cetin et al. 2018/2004, Boulanger and Idriss 2014)
- …and two different approaches
  - Pseudo-probabilistic
  - Probabilistic
- Select geotechnical data from a case history that satisfies the following:
  - Both CPT and SPT data available
  - Located close to the triggering curves
  - Effective stress not equal to 1.0 atm (overburden correction is applied)

Example Case History

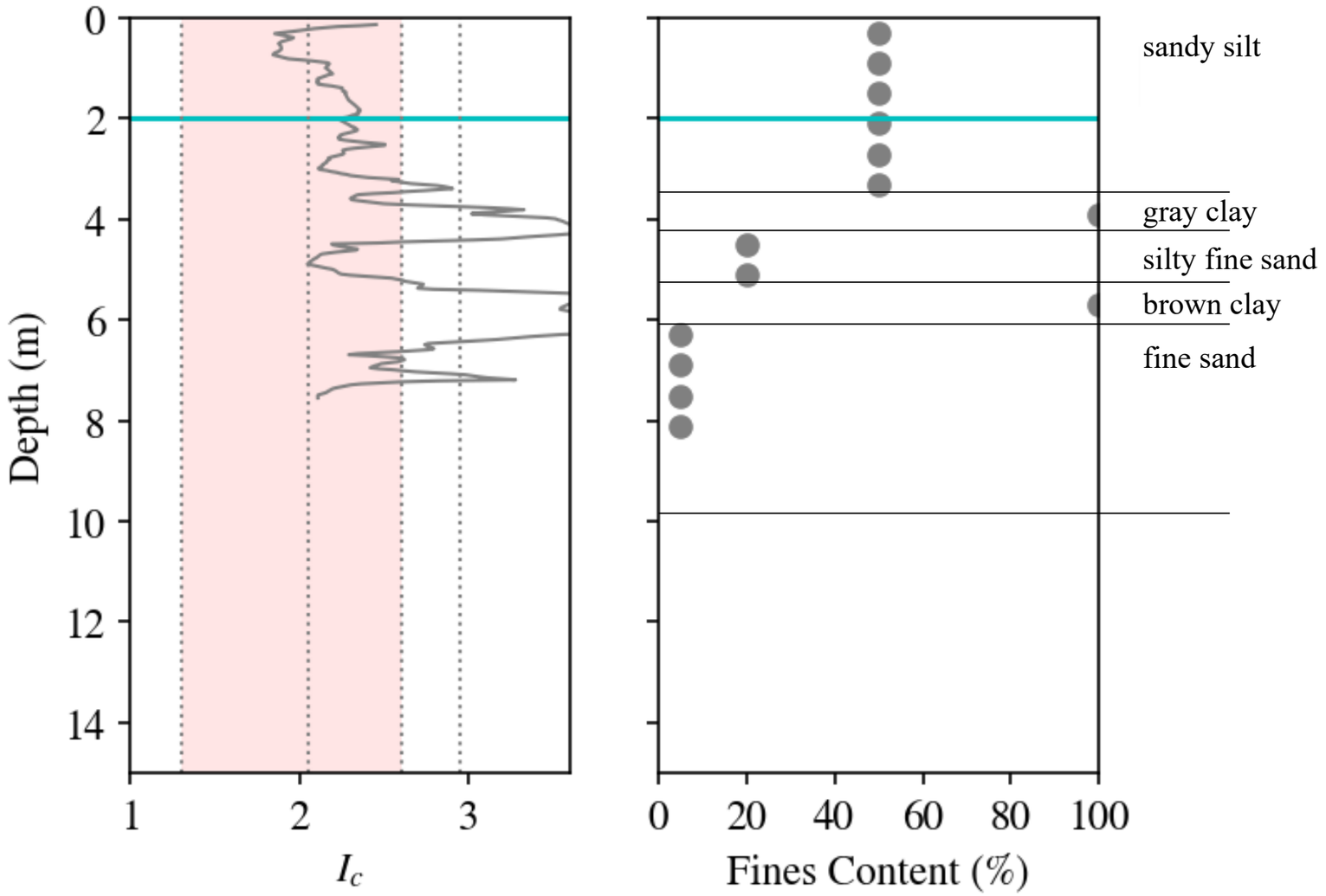
- Located in alluvial plains used for agriculture
- Site-specific PGA hazard curves
  - Shallow V_s profile estimated from SPT and CPT data
  - Site response analyses convolved with rock hazard curves
- $PGA_{1e\text{-}4} = PGA_{GMRS} = 0.26$ g
- M_w 6.3



Penetration Resistance

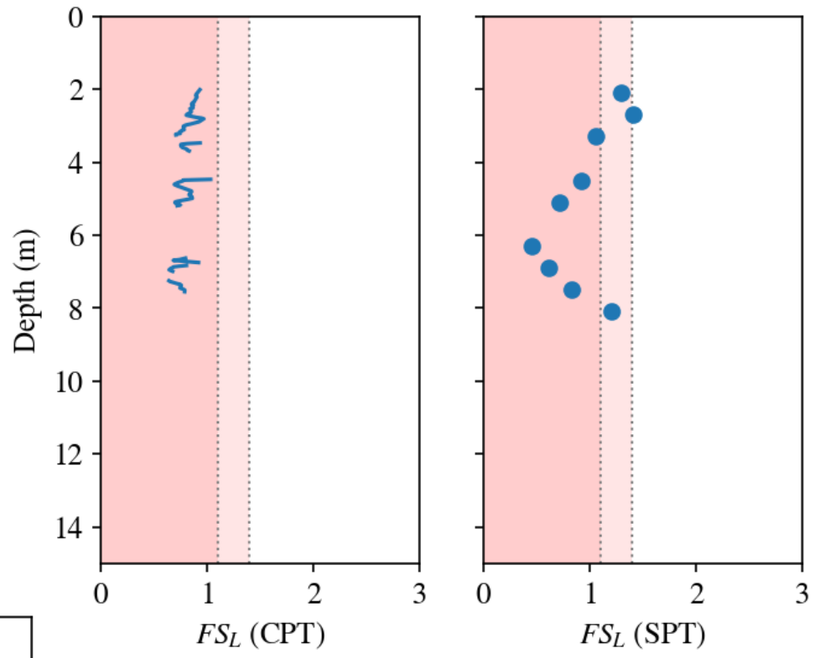


Fines Content, Soil Type, I_c

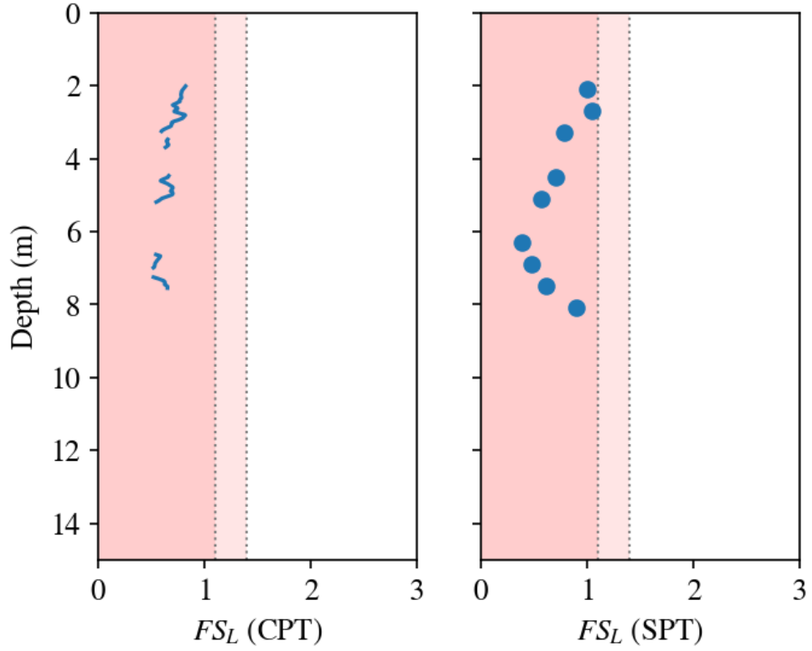


- $PGA_{1e\text{-}4} = PGA_{GMRS} = 0.26$ g
- M_w 6.3

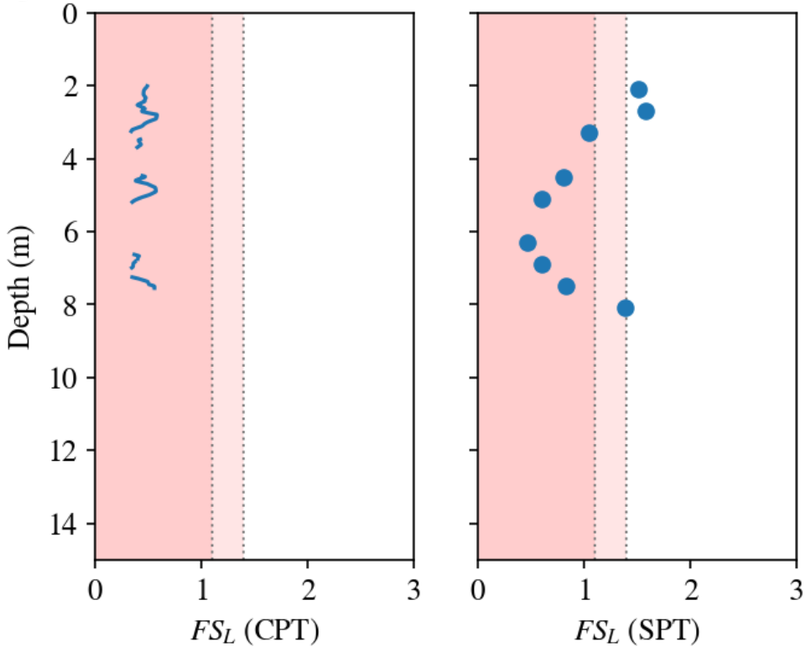
Youd et al. (2001)



Boulanger and Idriss (2014)

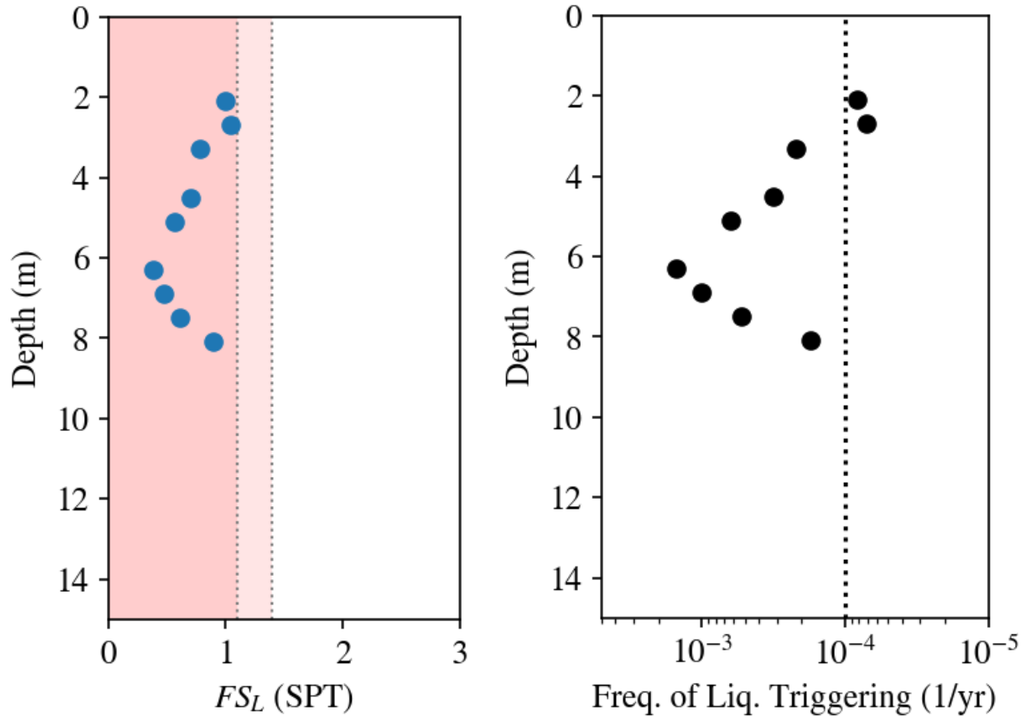


Moss et al. (2006), Cetin et al. (2018)

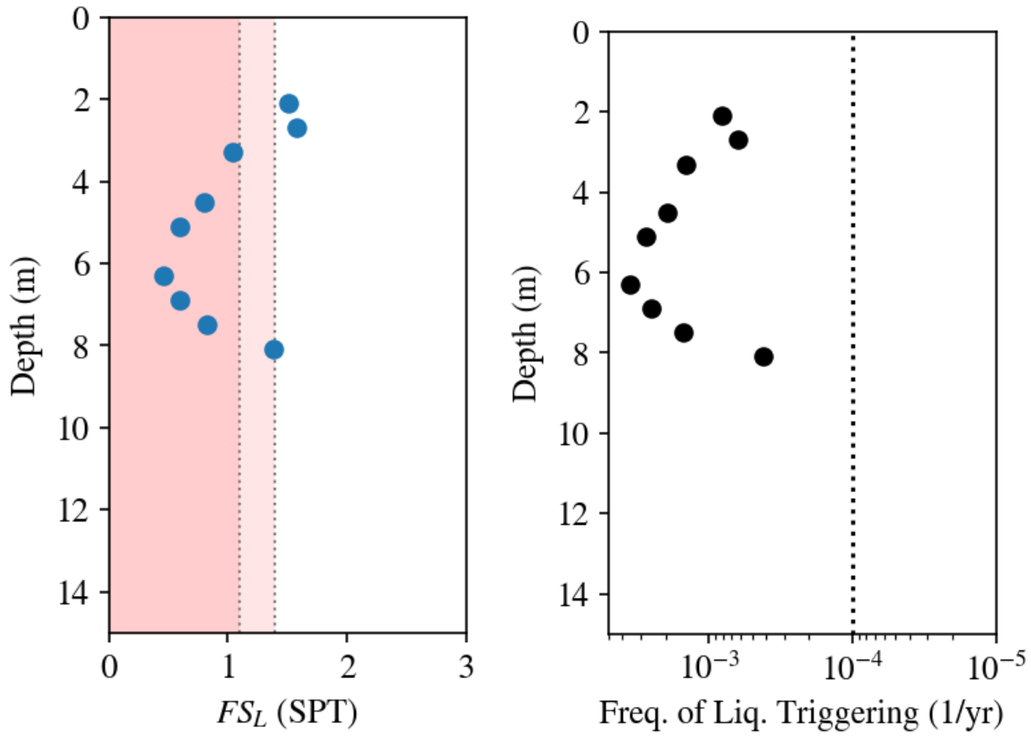


Pseudo-Probabilistic vs. Probabilistic

Boulanger and Idriss (2014)



Cetin et al. (2018)



Questions To Be Answered

- How does using a seismic hazard curve instead of a single hazard-targeted PGA affect our conclusions about the shear strength of different layers?
- How do we capture or properly account for epistemic uncertainty?
- How might system response play a role (e.g., effect of the clay layers)?

How the NGL Project Can Help

- Open, transparent, updated database
  - Extend the parameter space
- Collaboration between researchers across the globe
  - Characterize epistemic uncertainty from different modeling decisions
- Develop a new probabilistic model
  - Clarify what constitutes a sufficient probabilistic approach
  - Identify appropriate ground motion intensity measure for desired liquefaction performance
  - Provide guidance about using a single intensity value vs. convolving with the hazard curve

Conclusions

- Current semi-empirical methods are constrained by the case history database from which they are derived
  - Limits their applicability in evaluating liquefaction hazards at nuclear power plants
- Challenges associated with using a single peak ground acceleration
  - Annual rate of liquefaction triggering may not align with AEF of GMRS
- Epistemic uncertainty of triggering models not adequately characterized
- Research efforts in coordination with the NGL project aim to resolve these issues and provide technical bases for future liquefaction guidance that is consistent with a risk-informed and performance-based framework

Questions

- Franke, K., Lingwall, B., Youd, T., Blonquist, J., and Liang, J. H., "Overestimation of liquefaction hazard in areas of low to moderate seismicity due to improper characterization of probabilistic seismic loading." *Soil Dynamics and Earthquake Engineering*, 116:681-691. https://doi.org/10.1016/j.soildyn.2018.10.040.
- National Academies of Sciences, Engineering, and Medicine. *State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences*, 2016. Washington, DC: The National Academies Press. https://doi.org/10.17226/23474.
- NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, LWR Edition," USNRC, March 2007.
- NUREG/CR-5741, "Technical Bases for Regulatory Guide for Soil Liquefaction," USNRC, March 2000.
- Regulatory Guide 1.198, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites," USNRC, November 2003.
- Regulatory Guide 1.208, "A Performance-based Approach to Define the Site-Specific Earthquake Ground Motion," USNRC, March 2007.