

Next-Generation Liquefaction (NGL) Project, Part 1: Overview

DOE/NRC Natural Hazards Phenomena Meeting

NRC Headquarters | October 30, 2024

K. Ulmer¹, K.S. Hudson^{2,3}, S.J. Brandenberg³, P. Zimmaro^{3,4}, S.L. Kramer⁵, J. Stamatakos¹, and J.P. Stewart³

¹*Center for Nuclear Waste Regulatory Analyses (CNWRA®), Southwest Research Institute®, San Antonio, Texas*

²*Hudson Geotechnics, Los Angeles, California*

³*Civil and Environmental Engineering Department, University of California, Los Angeles*

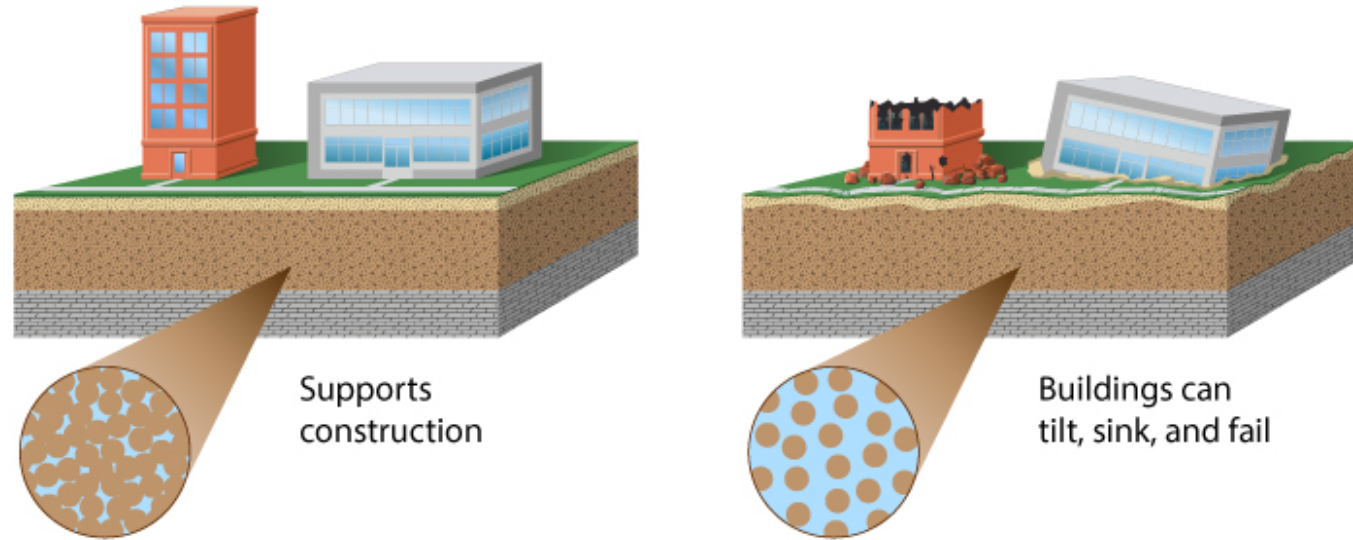
⁴*University of Calabria, Arcavacata di Rende, Italy*

⁵*Department of Civil and Environmental Engineering, University of Washington*

Outline

- What is liquefaction?
- What is the Next-Generation Liquefaction (NGL) project?
- What has NGL accomplished?
- Why does the NGL Project matter for nuclear applications?

What is Liquefaction?



Shaking (usually from earthquakes) causes saturated, contractive, coarse-grained soils to generate excess pore pressures that lead to loss of shear strength and liquid-like behavior

Risk to Infrastructure



Bearing capacity failure, settlement

EERC UC Berkeley



Lateral spread

Geomatrix



Slope failure

EERC UC Berkeley



Uplift pressure on buried utilities

Kang and Lai (2012)

NGL Background

The Next-Generation Liquefaction (NGL) project was launched in 2014 by the Pacific Earthquake Engineering Research (PEER) center following the devastating earthquakes during 2011 in Japan and New Zealand.

The goals of NGL are to:

- Substantially improve the quality, transparency, and accessibility of case history data related to ground failure.
- Provide a coordinated framework for supporting studies to augment case history data for conditions important for applications but poorly represented in empirical databases
- Provide an open, collaborative process for model development in which developer teams have access to common resources and share ideas and results during model development
→ reduce the potential for mistakes and mutually benefit from best practices.

State of the Art and Practice in the Assessment of

Earthquake-Induced Soil Liquefaction and Its Consequences

National Academies Report¹

- Establish curated, publicly accessible **databases** of liquefaction case history data
- In **model development**:
 - Incorporate unbiased estimates for input parameters
 - Consider all relevant data (screening requires justification)
 - Use soil mechanics **principles and experimental data** to extrapolate beyond ranges in which field data constrain the empirical relationships
- Models should be unbiased relative to available data, quantify **variability**, and capture **epistemic uncertainties**

¹ NASEM. “State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences.” Washington, DC: National Academies of Sciences, Engineering, and Medicine The National Academies Press. doi: 1017226/23474. 2021.

NGL Progress

- Completed two large technical projects for the Nuclear Regulatory Commission and Bureau of Reclamation in support of developing technical bases for updated regulatory guidance
- Developed and grew the NGL database
- Launched a community-wide collaborative research effort
- Initiated a new technical research project for Federal Highway Administration (FHWA)

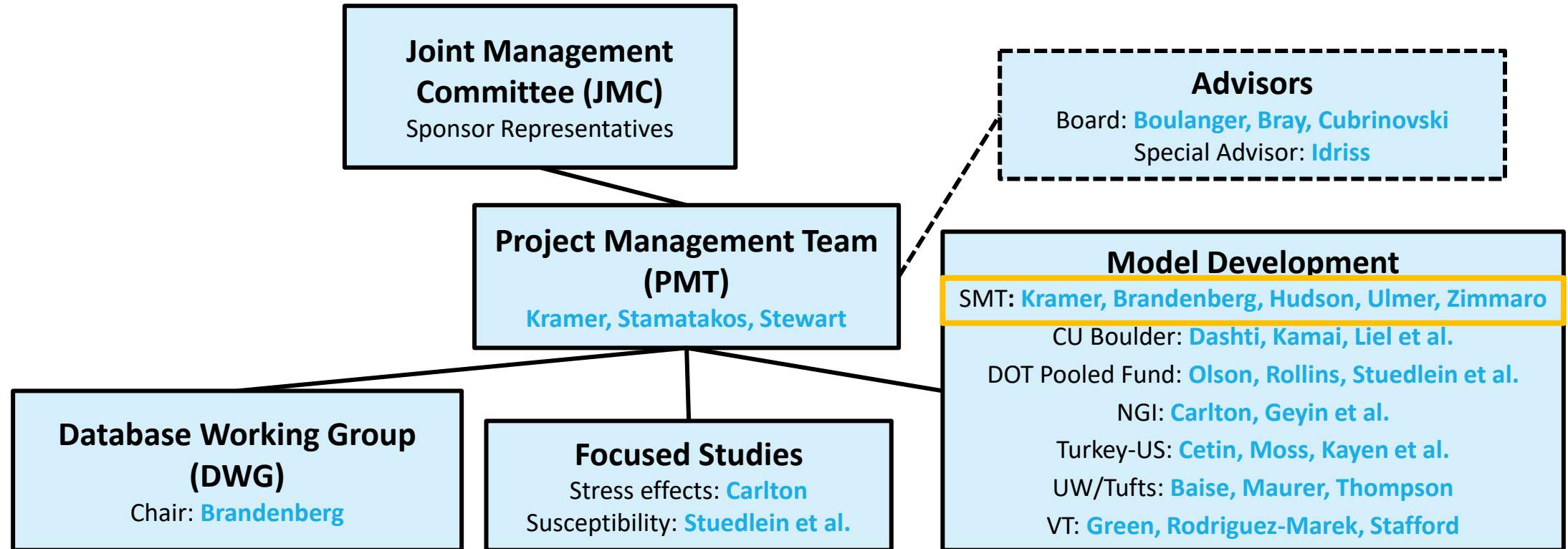
NGL Partners

- **Research organizations:**
 - Pacific Earthquake Engineering Research Center (PEER)
 - Southwest Research Institute (SwRI)
 - Natural Hazards Risk and Resiliency Research Center (NHR3) at UCLA
- **Sponsors:** Caltrans, NRC, PEER, USBR, FHWA, DOT “Pooled fund” study



Views expressed in this presentation do not necessarily reflect the view or regulatory positions of NGL sponsors

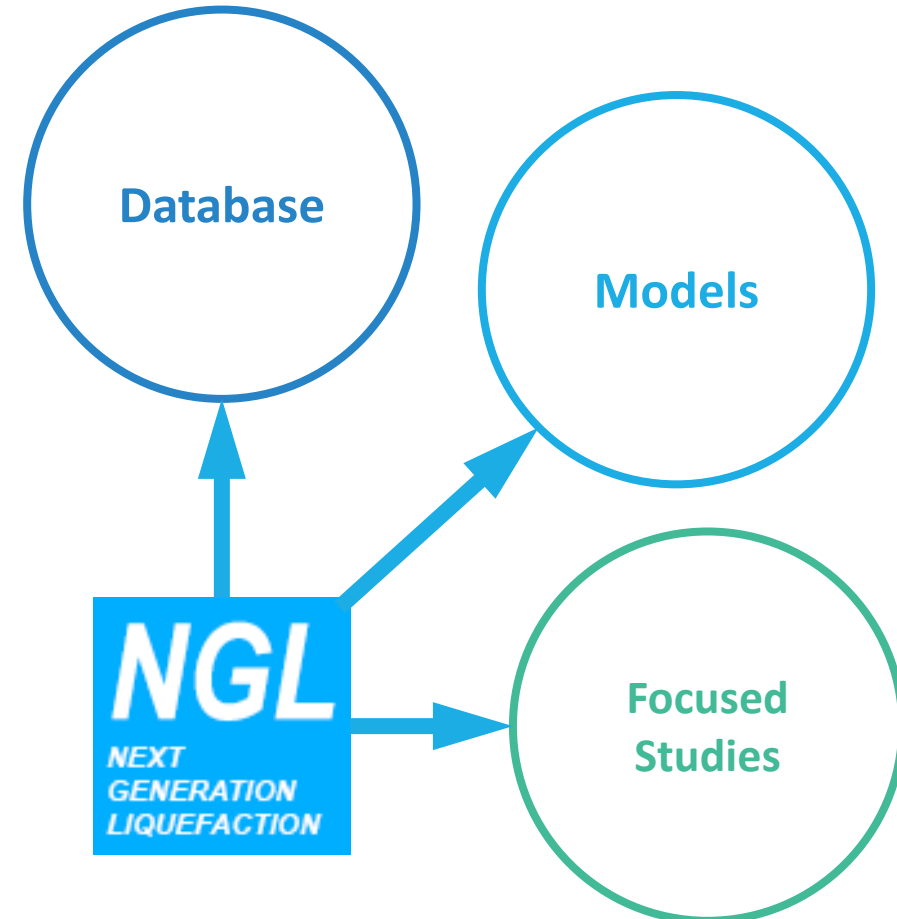
NGL Project Structure



Next-Generation Liquefaction Project

Project innovations

- Relational **database**
 - Interactive tools
 - New classes of case histories
- **Focused studies** to constrain critical effects that cannot be captured through case histories alone
- **Model** formulation



NGL Database – GUI

The screenshot displays the NGL Database GUI. At the top left is the NGL logo (Next Generation Liquefaction) and navigation links: View Data, Interact With Data, and About. A URL box in the top right contains <https://nextgenerationliquefaction.org/> and a Sign In button.

On the left side, there are several filter sections:

- Sites** (dropdown)
- Field Performance** (dropdown)
- Field Investigation** (dropdown)
- Earthquake** section with a text input for "Type event name" and "Magnitude" inputs for "min" and "max".
- A list of search results for earthquakes: M6.9 Kobe, Japan; M6.5 Imperial Valley-06; M7.2 El Mayor-Cucapah; M7.7 Nihonkai-Chubu - I; M6.2 Hokkaido; M8.3 Tokachi; M6.9 Obihiro - Hokkaido; M6.6 New Zealand 02/05.
- Reset** and **Submit** buttons.
- Statistics** (dropdown)

The central part of the interface is a world map showing various sites marked with red and white buoys. The map includes a zoom control (+/-) and a scale bar (3000 km / 2000 mi). The map is labeled with continents: NORTH AMERICA, SOUTH AMERICA, EUROPE, AFRICA, ASIA, and AUSTRALIA, and oceans: Atlantic Ocean, Pacific Ocean, Indian Ocean.

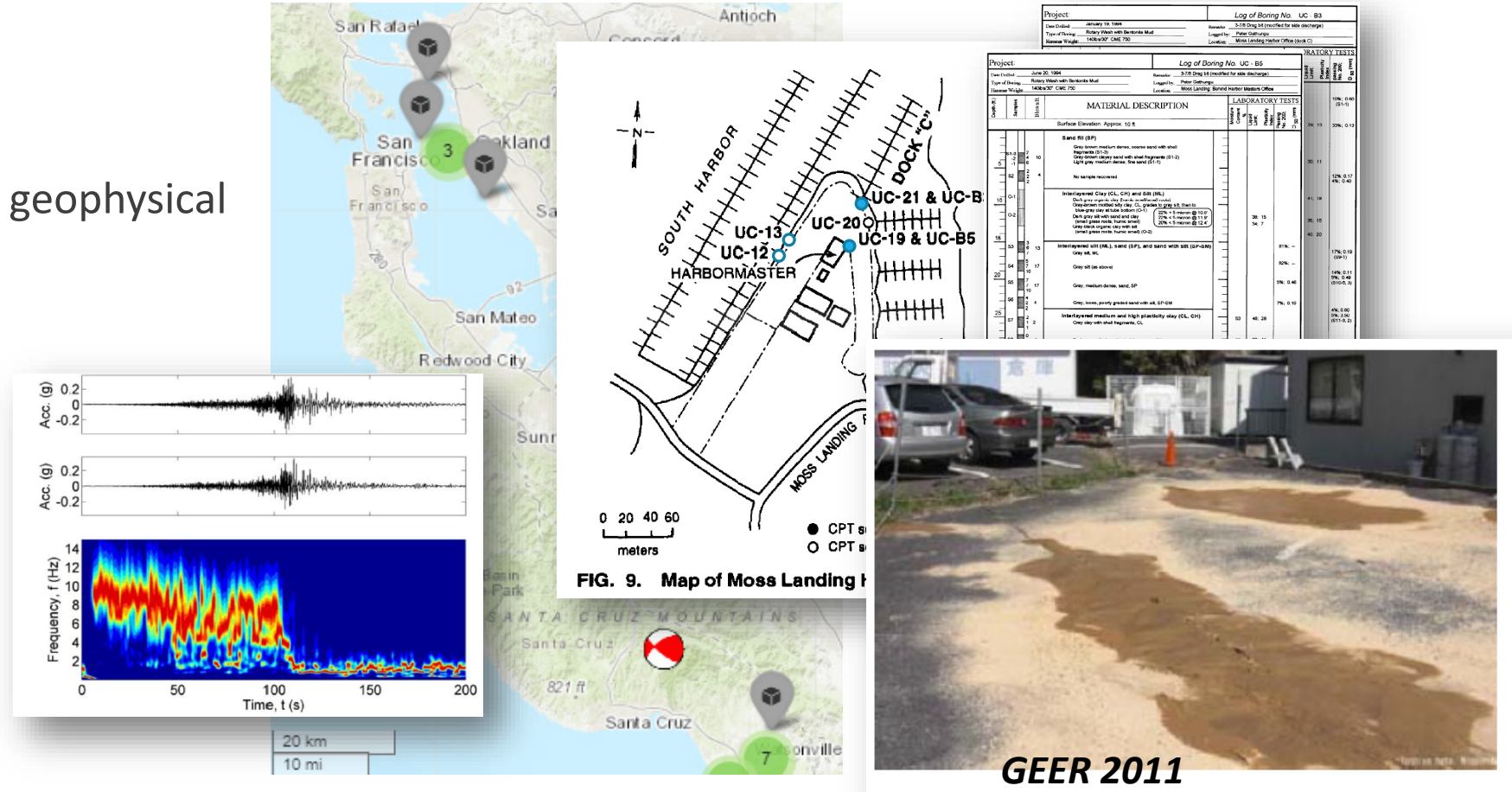
On the right side, there is a panel for "Event Information" and "General description":

- Event Information:** Event
- General description:** Site, Boreholes, CPT, Test Pits, Non-Invasive Geophysical, Invasive Geophysical, Water Table, Stratigraphic Units, Detailed Soil Description, Samples.

At the bottom left, there is another NGL logo.

Database Contents

- Events
- Sites
- In-situ Tests (SPT, CPT, geophysical tests)
- Observations
- Laboratory Tests

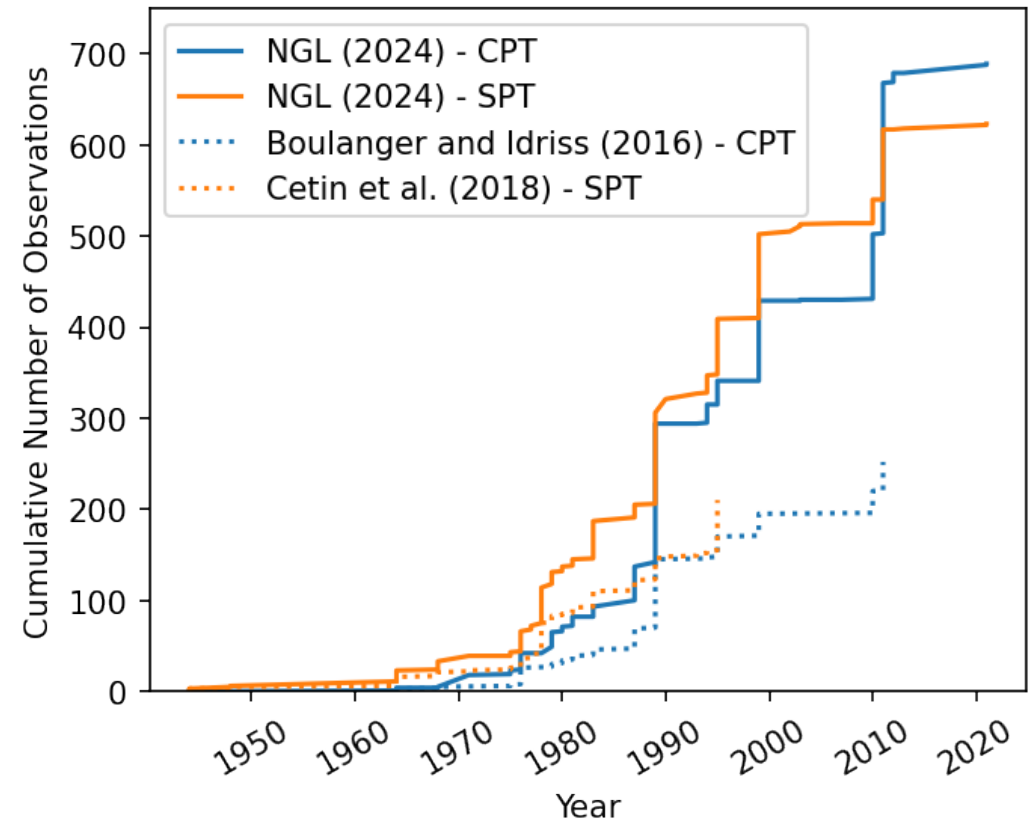


GEER 2011

Database Contents

Case histories by event year

Here, NGL “Case history” = field observation with paired boring or CPT (within the site)



Why does the NGL Project matter
for nuclear applications?

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 (2003)

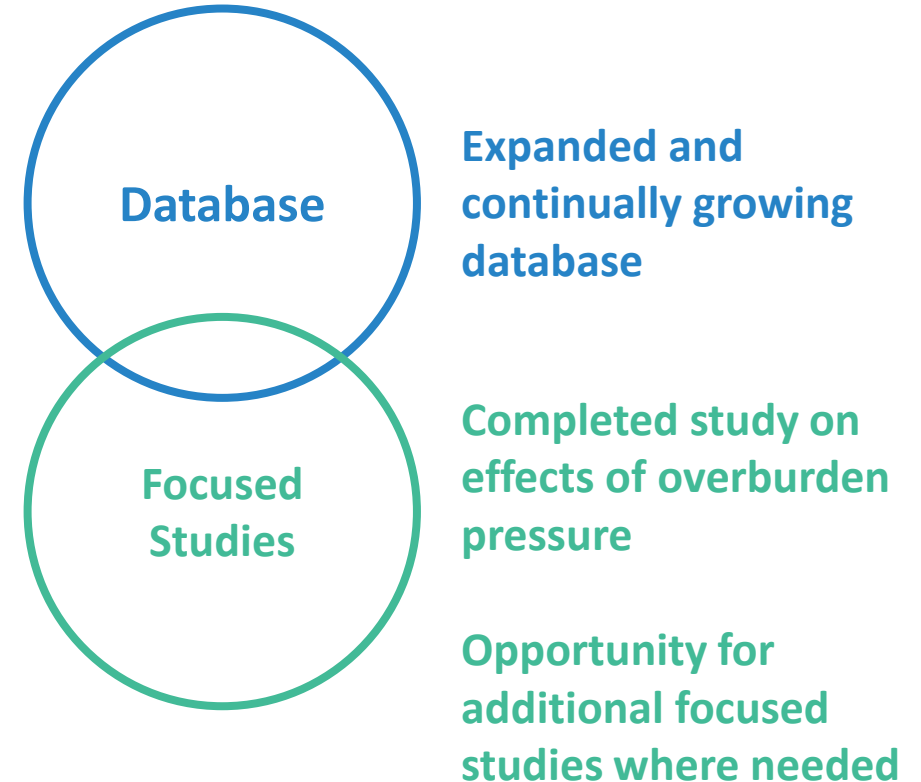
- Provides guidance to the NRC on acceptable methods to evaluate the potential for earthquake-induced instability of soils resulting from liquefaction and strength degradation.
- Generally based on the 1996 NCEER and 1998 NCEER/NSF workshops (Youd et al. 2001).
- Focuses on deterministic, semi-empirical methods.
- Factor of safety (FS) used to recommend next steps (e.g., use conservative undrained residual strengths for stability and deformation analyses).
- Analytical methods permitted (e.g., nonlinear site response analysis).
- Probabilistic approach can be used if sufficiently formulated.

Updating Guidance

- In the last two decades, liquefaction research has continued to advance the state-of-the-art
- Several focus areas of improvement, discussed in subsequent slides
 - Not just for NRC guidance (other organizations as well)
 - Extends to general engineering practice for evaluating liquefaction hazards for nuclear facilities
- The NGL project is well-suited to help
 - Recent projects have already provided support in some focus areas
 - Current and future work could provide support in additional focus areas

Focus Areas for Improvement

- Parameter space
 - Semi-empirical triggering models are constrained by the case history database from which they are derived
 - What to do for conditions that are not well represented in the case history database?



Focus Areas for Improvement

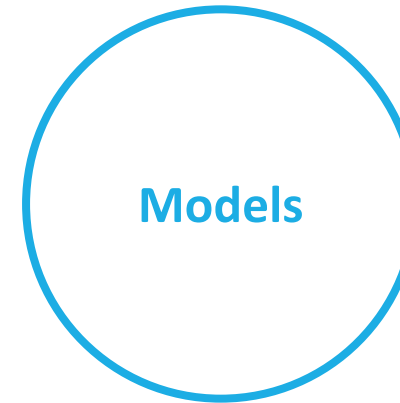
- Aging
 - Older soils are generally more resistant to pore-pressure generation than younger soils are
 - Most case histories in current databases are man-made fills or relatively young deposits
 - For some nuclear power plants in the Central/Eastern United States (CEUS), aging may significantly affect liquefaction evaluations (but how?)



Opportunity for additional focused studies where needed

Focus Areas for Improvement

- Probabilistic approach
 - Needs 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, epistemic uncertainty needs to be better quantified



SMT models developed using probabilistic approach

Future collaborations with other NGL teams could address epistemic uncertainty

Conclusions

- The NGL project aims to advance the state-of-the-art in liquefaction research through database development, focused studies, and model development.
- The expanded case history database is available and actively being used.
- Recent work by the SMT yielded a suite of models for liquefaction susceptibility, triggering, and manifestation **(discussed in next presentation)**.
- Research efforts in coordination with the NGL project aim to resolve issues and provide technical bases for future liquefaction guidance that is consistent with a risk-informed and performance-based framework.

Questions

Email: kulmer@swri.org

References

Next Generation Liquefaction (NGL). <https://nextgenerationliquefaction.org>

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.