2019 UDOT RESEARCH PROBLEM STATEMENT

****** Problem statement deadline is Feb. 6, 2019. Submit statements to UTRAC@utah.gov. ******

Title: Multi-State Transportation Pooled Fund Study: A New Universal Consequences-Based Liquefaction Hazard Analysis Framework for All CPT-CompatibleSoils **No. (Office Use):** 19.04.09

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Select ONE Subject Area ☐ Materials/Pavements ☐ Maintenance ☐ Traffic Mgmt/Safety ☒ Structures/Geotech ☐ Planning ☐ Perf Mgmt/Data Analytics ☐ Public Transportation ☐ Other

1. **Describe the problem to be addressed:**
   Since the early 1970s, geotechnical engineers worldwide have largely relied upon empirical correlations to predict liquefaction susceptibility, triggering, and consequences/damage. Such analyses are necessary to ensure the stability and adequate performance of structures like bridges, retaining walls, and engineered soil slopes in the event of an earthquake. While the geotechnical community largely has accepted these empirical correlations as the state of practice, numerous inconsistencies exist in their application. Traditional correlations apply only to clean quartz and silica sands; different relationships are required for different soils including silty soils, silts, gravels, sands of different mineralogy, and even low-plasticity clays. These predictive correlations are based more on observation and available empirical data than on our understanding of fundamental soil mechanics, resulting in disparate empirical approaches (e.g., penetration resistance-based triggering analysis for sands and plasticity-based susceptibility analysis for silts/clays). Thus, our ability to extrapolate these inconsistent correlations to conditions or soils for which little case history data exists (e.g., soils at depths greater than 12 meters below the ground surface, silty soils, non-silica sands) is severely limited. Significant knowledge gaps exist in our understanding of liquefaction susceptibility, triggering, and consequences for many soils, particularly transitional soils (e.g., silty sands, non-silica sands, silts, and low plasticity clays). These knowledge gaps contribute to our inability to accurately predict the dynamic behavior of these soils, resulting in empirical correlations that are disconnected, inconsistent, and potentially misleading. Recent cyclic laboratory testing of various transitional soil materials from different locations around the country suggests that our ability to accurately predict the dynamic properties of these soils and resulting consequences (e.g., strength and stiffness) is very poor indeed and, in many instances, can even be dangerously wrong. As a result, these unknowns, inconsistencies and uncertainties result in engineers requesting expensive cyclic laboratory testing, making conservative assumptions, and (often) resorting to expensive ground improvement.

2. **Write the project objective (25 words or less):**
   Develop and test a universal consequences-based liquefaction hazard framework that simultaneously considers susceptibility, triggering, and consequences for all CPT-compatible soils including sands, silts, and clays of all mineralogies and mixtures.

3. **Explain why this research is important:**
   (In response, consider addressing specific UDOT goals, applicability in Utah or other states, etc.)
   - The research will create a universal, unifying, singular consequences-based liquefaction hazard framework for liquefaction susceptibility, triggering, and consequences that will reduce many of the inconsistencies and inaccurate predictions that result from conventional, disparate empirical correlations
   - The research will eliminate the need to classify a soil as "clay-like" or "sand-like," thereby eliminating the need for different prediction models and approaches for different CPT- compatible soils and allowing the dynamic properties of all CPT-compatible soils to be predicted consistently using a single in-situ testing device: the CPT
   - The research will provide an SPT and Shear Wave Velocity (Vs) based alternative to CPT for the unified framework
   - The research will provide a new consequences-based framework allowing engineers to evaluate soil strength, stiffness, and performance under partially liquefied conditions without the need for sophisticated numerical simulations and the expensive, complex laboratory testing required to calibrate the advanced constitutive models
   - This research will significantly reduce the need for expensive cyclic testing of soils for the purpose of assessing liquefaction

susceptibility and/or triggering

- The liquefaction hazard framework developed in this research will move engineers away from the incorrect application of clean sand-based analysis methodologies to transitional soils (i.e., silty and clayey soils) and sands of non-silica/quartz mineralogy, which potentially results in inaccurate predictions of soil behavior (strength and stiffness) during an earthquake
- The liquefaction hazard framework developed in this research will reduce the need to resort to expensive ground improvement in soils that don't need it simply because engineers don't have appropriate tools to reduce the uncertainties in their analyses; and conversely, it will increase the appropriate recommendation for ground improvement in soils that really do need it

4. List the major tasks:

Task 1: (Years 1-2; BYU & SDSMT) Field testing (CPT and Vs) and sampling (SPT) at key sites with soils that fill critical mineralogy/gradational/ plasticity data gaps (e.g., nonplastic silt-rich sands, nonplastic to low plasticity silty soils, low plasticity clayey soils, non-silica/quartz sands)

Task 2: (Years 1-2; UIUC) Perform conventional laboratory index testing (mineralogy/x-ray diffraction/SEM imaging, gradation, Atterberg limits/plasticity, specific gravity) of sampled soils

Task 3: (Years 1-3; UIUC) Triaxial mini-cone testing of soil samples to calibrate mini-cone and field Vs, CPT tip resistance and sleeve friction readings.

Task 4: (Years 2-3; BYU @ CU Boulder or UCD) Centrifuge testing with mini-cone and Vs to observe and calibrate dynamic soil behavior (shear and volumetric response) with various levels of seismic loading and pore pressure generation

Task 5: (Years 3-4; SDSMT & UIUC) Numerical modeling using calibrated constitutive model to fill data and experimental gaps, relate properties to performance and consequences

Task 6: (Years 3-4; BYU, SDSMT, & UIUC) Development of new, semi-empirical consequences-based universal liquefaction hazard framework that is consistent with performance-based design paradigms and the work of the NGL program

Task 7: (Years 4-5; BYU, SDSMT & UIUC) Case history verification and validation including: (a) well-known earthquake-induced liquefaction datasets in conjunction with Next Generation Liquefaction Project (1989 Loma Prieta involving liquefaction, settlement, and lateral spreading of clean sands to silts; 1994 Northridge earthquake involving liquefaction, settlement, lateral spreading, and limited dam movements of clean sands to low plasticity clays; 2010-2014 Christchurch sequence involving repeated liquefaction, settlement, and lateral spreading of gravelly sands to silty sands); (b) blast-induced liquefaction and settlement of clean to sandy silts; and (c) static loading-induced flow liquefaction failures of fly ash and tailings sands and slimes [2008 Kingston power plant (USA), 2014 Mount Polley (Canada), 2015 Samarco mine (Brazil), and 2019 Feijao mine (Brazil)]

Task 8: (Year 6; BYU, SDSMT, and UIUC) Education, outreach, and training

5. List the expected deliverables (reports, manual, specification, design method, training, etc.):

1. Quarterly update reports or memos
2. Annual technical reports
3. Journal conference publications summarizing our work and findings
4. A new, universal design method for performing consequences-based liquefaction hazard analysis
5. Training workshops in each of the states that helped fund the study

6. Describe how the research results will be implemented:
(In response, consider addressing UDOT leader support, process or standard improvement, etc.)

This research will likely be implemented in the UDOT Geotechnical Manual of Instruction and be recommended (or required) in the design of bridges, retaining walls, and engineered soil slopes. Additionally, the proposed new liquefaction hazard framework will likely find large audience and application outside of transportation. Our goal is to see this new framework eventually replace the standard of practice in liquefaction hazard analysis.

7. Requested from UDOT: $21,000/year for 6 years **Other/Matching Funds:** $750,000 verbal commitment from 6 other states if UDOT organizes and leads TPF; seeking 3 more states to join the pooled fund; 4 more states expressed extreme interest **Total Cost:** $1,250,000 over 6 years
(or UTA for Public Transportation)

8. Outline the proposed schedule, including start and major event dates:

We anticipate ~2 years following the approval of this project for all 10+ participating states to organize their resources and provide support for the project. Organizing such a large multi-state project requires significant time and effort. However, the potential benefit from the successful completion of this project will be transformational in nature by significantly advancing our ability to predict they dynamic loading behavior of all CPT-compatible soils. If all goes according to plan, we anticipate a start date in summer of 2021.