**TRANSPORTATION POOLED FUND PROGRAM**

**QUARTERLY PROGRESS REPORT**

**Lead Agency: Utah Department of Transportation**

**INSTRUCTIONS:**

*Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.*

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| **Transportation Pooled Fund Program Project #**  **TPF-5(350)** | | **Transportation Pooled Fund Program - Report Period:**  \_ Quarter 1 (January 1 – March 31, 2018)  \_ Quarter 2 (April 1 – June 30, 2018)  \_ Quarter 3 (July 1 – September 30, 2018)  **x Quarter 4 (October 1 – December 31, 2018)** | |
| **Project Title:**  Development of Next Generation Liquefaction (NGL) Database for Liquefaction-Induced Lateral Spread | | | |
| **Name of Project Manager(s):**  David Stevens | **Phone Number:**  801-589-8340 | | **E-Mail**  davidstevens@utah.gov |
| **Lead Agency Project ID:**  FINET 42080, ePM PIN 15017  UDOT PIC No. PL05.350 | **Other Project ID (i.e., contract #):**  UDOT Contract No. 17-8236 | | **Project Start Date:**  September 8, 2016 |
| **Original Project End Date:**  March 31, 2019 | **Current Project End Date:**  March 31, 2019 (31 months) | | **Number of Extensions:** |

Project schedule status:

\_ On schedule \_ On revised schedule \_ Ahead of schedule **X** Behind schedule

Overall Project Statistics:

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| **Total Project Budget** | **Total Cost to Date for Project** | **Percentage of Work**  **Completed to Date** |
| $110,354.93 (current contract)  $140,000.00 (total TPF commitments) | $50,000.00 (paid by UDOT)  $51,420.45 (at the U. of Utah) | 70% |

***Quarterly*** Project Statistics:

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| **Total Project Expenses**  **and Percentage This Quarter** | **Total Amount of Funds**  **Expended This Quarter** | **Total Percentage of**  **Time Used to Date** |
| This Quarter = 0% (paid by UDOT)  This Quarter = 0% (at the U. of Utah)  Total Project = 45% (paid by UDOT)  Total Project = 100% (at the U. of Utah) | $0.00 (paid by UDOT)  $0.00 (at the U. of Utah)  (Funding for U of U student from MPC funds) | 90% |

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| **Project Description**:  This research will be conducted in conjunction with the Pacific Earthquake Engineering Research (PEER) Center and various state DOTs via a pool-fund study managed by the Utah Department of Transportation (UDOT). The Mountain Plains Consortium (MPC) is also providing funding for certain aspects of this study, under separate contract with the University of Utah. The research topic addresses the need to improve empirical, semi-empirical, analytical and numerical methods to estimate the amount of permanent ground displacement associated with liquefaction-induced lateral spread resulting from several major earthquakes. This scope of work addresses the development of a lateral spread community database as part of the PEER Next Generation Liquefaction Project (<http://peer.berkeley.edu/lifelines/projects/ngl/>). It does not address predictive model development for lateral spread evaluations, which is future effort planned by PEER, but not included in this work plan.  The primary outcome of this research is a vetted and community database of seismic, topographical, geotechnical and horizontal displacement measurements pertaining to case histories of liquefaction-induced lateral spread for further research and model development by other researchers and investigators under the auspices of the PEER Center (<http://peer.berkeley.edu/>). Secondary outcomes will be web host and publishing required to house and disseminate this database and its supporting information.  Phase I Tasks include (funded):  (1) Kickoff meeting and procurement of software  (2) Development of data quality indicators/metrics, quality assurance and database population protocols  (3) Defining methods for quantifying uncertainty of key inputs  (4) Development and structuring of database  (5) Selection of case histories  (6) Obtaining and screening of case history information  (7) Population of case history database  (8) Phase I Reporting  (9) Database dissemination  Phase II Tasks include (not yet funded):  (10) Review and Development of Screening Criteria for Lateral Spread Potential  (11) Phase II Reporting  The principal investigators for this study will be Drs. Steven Bartlett (U. of Utah), Steven Kramer (U. of Washington and PEER Research Executive Committee Member), Kevin Franke (Brigham Young University) and Daniel Gillins (NOAA and consultant). The technical advisory committee (TAC) for the study currently includes representatives from Utah, California, Oregon, and Washington State DOTs. The MPC is providing additional funding for the study. |

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| **Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):**  **Task 1** – Completed.  **Task 2** – Completed. Draft documents to be included in interim report.  **Task 3** – In progress. This task will continue as other data are added to the dataset.  **Task 4** – Completed.  **Task 5** – In progress. BYU working on 2010 Maule, Chile; 2011 Tohoku, Japan, 2010 Darfield and 2011 Christ Church Earthquakes.  **Task 6** – See summary of progress below in “Significant Results”.  **Task 7** – Continuing.  **Task 8** – Draft interim report finalized.  **Task 9** – Not started.  TAC meetings – None were held this quarter.  Contract – No changes. |
| **Anticipated work next quarter**:  **Task 1** – Completed.  **Task 2** – Completed  **Task 3** – Continue to inventory methods of quantifying uncertainty and data quality.  **Task 4** – Completed.  **Task 5** – In progress. BYU working on 2010 Maule, Chile; 2011 Tohoku, Japan, 2010 Darfield and 2011 Christ Church Earthquakes.  **Task 6** – Obtaining of data in progress.  **Task 7** – Continue population of data set for U.S. Case histories.  **Task 8** – Continuing.  **Task 9** – Not started.  TAC meetings – Consider holding a TAC web conference to discuss progress to date, next steps, and questions.  Contract – Amend the research contract to include additional tasks with the available funds. One change is requested, involving the addition of screening criteria to the contract. Requested funding for this task is $29,645.07, which is all of the remaining available funding. Revised total contract amount will be $140,000.00.  ***The Univ. of Utah has requested that screening criteria be funded and has offered the approach for Phase I – Task 9 (new). We request that this approach be reviewed and commented on by the TAC:***  Engineering practice has a general need to define “screening” or “susceptibility” criteria for liquefaction-induced lateral spread. These should include the range of sediment, site and seismological characteristics necessary to produce lateral spread. Unfortunately, some engineering practitioners misapply MLR models and attempt to predict lateral spread displacement by extrapolating the input variables (i.e., independent variables) beyond the conditions or data bounds represented in the regression of the original dataset. For example, misuse can occur by inferring critical layer continuity when it may not exist, or by extrapolation of the model to thin layers (i.e., layers less than 1.0 m), or by using the MLR equations to predict displacement in predominately non-plastic silts, etc. (Youd, 2018).  As a possible solution to this problem, we propose to develop a probabilistic-based method to predict lateral spread susceptibility based on implementation of the following conditional probability statement:  *P*[*Ls | F, PI, SI, T, D, Z, G. R, Mw, Xn*] Eq. 1  where *Ls* is the probability of occurrence of lateral spread conditioned on the soil and seismological factors such as fines content, *F*, plasticity index, *PI*, soil index, *SI*, layer thickness, *T*, soil density *D*, depth of critical layer, *Z*, relative geologic susceptibilty, *G*, seismic source distance, *R*, and earthquake magntiude, *M*w, and represent other possible variables to be evaluated as part of the research, *Xn*. These independent variables are further described later in this section.  We propose to use logit analysis to determine the probability of occurrence of lateral spread for a given site using Eq. 1 as a framework. The logistic model (or logit model) is a widely used statistical model that uses a logistic function to model a dichotomous (binary) dependent variable (<https://en.wikipedia.org/wiki/Logistic_regression>). Logistic regression is used to explain the relationship between one dependent binary variable and one or more nominal, ordinal, interval or ratio-level independent variables. In our case, we will use the logistic model to predict the probability of occurrence (or non-occurrence) of liquefaction-induced lateral spread. We emphasize that the purpose of the logistic model is not to predict the amount of horizontal displacement resulting from lateral spread, DH; hence it does not replace existing MLR predictive equations such as those developed by Youd et al., 2002 and Gillins and Bartlett, 2013, or by others.  In general, these latter MLR models can be used to predict the probability that lateral spread horizontal displacement, DH, exceeds some threshold value, y, of engineering interest (e.g., 0.1, 0.3 m, etc.). This is done by evaluating:  Eq. 2  where Φ is the standard cumulative normal distribution; and, σ*Log(DH)* is the standard deviation of the predicted variable and  is the mean value of the logarithm of the lateral spread displacement (*DH* is in meters) predicted from the respective MLR model (Youd at al. 2002, Gillins and Bartlett, 2013).  To join the logistic model with the MLR displacement model, we propose the following conditional probability statement:  *P*[*DH > y*] *= P*[*DH > d | Ls*] *· P*[*Ls | F, PI, SI, T, D, Z, G, R, Mw, Xn*] Eq. 3  This conditional probability statement has a distinct advantage over previous approaches by defining factors or conditions that are correlated with the occurrence of lateral spread (i.e., screening criteria) with the prediction of *DH*. Because the proposed approach is fundamentally probabilistic, it can more rigorously deal with uncertainty in the various input factors. For example, Bartlett and Youd (1992; 1995) showed that relatively loose, saturated, sandy deposits are required to generate lateral spread. They proposed that such sediments generally have SPT N160 values less than 10 and almost always have SPT N160 less than 15. However, if the SPT N160 values slightly exceed 15, is it still possible to generate lateral spread under certain conditions (e.g., close-by, large magnitude earthquakes)? Although the probability may be small, it is not zero. Conversely, if a borehole at a site has a saturated sandy layer with SPT N160 values less than 15, the likelihood of lateral spread has increased, but its occurrence is not certain. Therefore, the logistic model will allow for the quantification of this probability by including the combined influence of other important independent variables.  Gillins (2012) has proposed that Eq. 3 be conditioned on the probability of liquefaction, *L*, and not the probability of lateral spread, *Ls*.  Eq. 4  While this equation is often used for performing probabilistic-based lateral spread evaluations that are coupled with probabilistic liquefaction triggering evaluations and probabilistic seismic hazard analysis (PSHA), Eq. 4 is not necessary as long as Eq. 3 contains independent variables that are correlated with the occurrence of lateral spread and liquefaction. The use of Eq. 3 instead of Eq. 4 in the final probability chain is similar to the approach taken by Franke and Kramer (2014) in developing their predictive equations for lateral spread displacement. These authors introduced a performance-based procedure built upon a probabilistic framework to compute the mean annual rate of exceeding some lateral spread displacement (i.e., *DH*> *d*). Their approach modifies the Youd et al. (2002) model by grouping together all of the model variables related to seismic loading (i.e., *MW* and *R*) and designating them as an apparent loading parameter, L. Because L is a function of parameters *MW* and *R*, it is analogous to a ground motion attenuation relationship and can be treated in a similar manner (Sharifi-Mood et al., 2018). Therefore, we propose that Eq. 5 can be used either deterministically for a given earthquake and source distance, or combined with PHSA to perform probabilistic mapping and performance-based assessments:  *P*[*DH > d*] *=* [*DH > d | Ls*] *· P*[*Ls | F, PI, SI, T, D, Z, R, Mw, Xn*] *· P*[*Mw, R*] Eq. 5  where the *P*[*Mw, R*] is obtained from the PHSA for each magnitude-distance pair at the grid point of interest. Ultimately, Eq. 5 can be summed across all possible magnitude-distance pairs (*Mw, R*) using the individual probabilities as weights for each magnitude-distance pair at a given grid point to determine the mean annual rate that *DH* exceeds, *d*.  **Influence of Fines Content (F)** – The fines content is that percentage of the soil distribution that is finer than 0.075 mm. Field case histories indicate that fine-grained sediment such as those beneath Adapazari, Turkey, although susceptible to liquefaction, were not susceptible to lateral spread. Also, clay-like soils appear to be immune to lateral spread. Empirical models based on SPT sampling suggest that lateral displacement decreases markedly with increasing fines content (Bartlett and Youd 1995, Youd et al., 2002). This finding needs additional definition and confirmation. Predicted lateral spread displacements from CPT methods (e.g., Zhang et al. 2004) do not similarly show the impeding effects of fine-grained soils on lateral spreads. Therefore, the influence of fines content on the probability of lateral spread needs further exploration.  **Influence of Plasticity Index (PI)** – The plasticity index is the liquid limit of the soil minus the plastic limit of the soil, as defined by Atterberg (<https://en.wikipedia.org/wiki/Atterberg_limits>). Monotonic and cyclic undrained loading test data for silts and clays show that they transition, over a fairly narrow range of plasticity indices (PI), from soils that behave more fundamentally like sands (sand-like behavior) to soils that behave more fundamentally like clays (clay-like behavior). Boulanger and Idriss (2006) propose for practical purposes, clay-like behavior is expected for fine-grained soils that have a plasticity index (PI) equal to or greater than 7. Bray and Sancio (2006) concluded that loose soils with PI < 12 and *wc* / LL> 0.85 were susceptible to liquefaction, and loose soils with 12 < PI < 18 and *wc* / LL > 0.8 were systematically more resistant to liquefaction. Soils with PI > 18 tested at low effective confining stresses were not susceptible to liquefaction. Influence of Soil Index (SI) – Gillins and Bartlett (2013) found that the soil classification obtained from borehole logs could supplant the use of fines content and mean grain size in MLR models and develop a soil type factor called the soil index, SI. Because often there are descriptions or classifications of the soil recorded on the case history borehole log with the corresponding SPT N values, SI might be useful to replace F15 and D5015 in the logit analyses (Table 3). Table 3. Descriptions and distributions of *T15* layers in Youd et al. (2002) database   |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | | Soil Descriptions | Count *n* | (mm) | *σD50* (mm) | (%) | *σFC* (%) | General USCS Symbol | Soil Index *SI* | | Silty gravel with sand, silty gravel, fine gravel | 6 | 5.69 | 4.26 | 18.3 | 6.4 | GM | 1 | | Very coarse sand, sand and gravel, gravelly sand | 7 | 2.15 | 0.83 | 7.5 | 6.4 | GM-SP | 2 | | Coarse sand, sand with some gravel | 32 | 0.62 | 0.18 | 7.0 | 4.2 | SP | 2 | | Sand, medium to fine sand, sand with some silt | 76 | 0.35 | 0.02 | 4.6 | 2.3 | SP-SM | 3 | | Fine sand, sand with silt | 50 | 0.17 | 0.05 | 14.3 | 11.0 | SM | 4 | | Very fine sand, silty sand, dirty sand, silty/clayey sand | 39 | 0.11 | 0.12 | 36.6 | 12.4 | SM-ML | 4 | | Sandy silt, silt with sand | 38 | 0.07 | 0.08 | 57.9 | 12.2 | ML | 5 | | Silty clay, lean clay | -- | -- | -- | -- | -- | CL | 6 |   **Influence of Layer Thickness (T)** – Bartlett and Youd (1992, 1995) showed that cumulative thickness of the loose, saturated, sandy deposits influences the occurrence of lateral spread and the resulting amount of horizontal displacement. They defined thickness factors (i.e., independent variables) in their MLR analysis that accounted for the effect of thickness. These were T10, T15, and T20, where T is the cumulative thickness of saturated, granular deposits with N160 values less than 10, 15, and 20, respectively. Bartlett and Youd (1992, 1995) were careful not to infer that these independent variables represented the thickness of the “liquefied zone.” Instead, they were introduced in their evaluation simply as soil factors that were correlated with lateral spread displacement (hence useful without the need of performing liquefaction analysis procedures). Regarding this, the thinnest T15 layer in the Bartlett and Youd (1995) dataset in which measurable lateral spread displacement occurred was about 1.0 m. The thinnest layer observed in CPT data is about 0.6 m (Youd, 2018). Hence, it appears that layers with a thickness less than this are either not continuous across the site or do not have a sufficient thickness to generate sufficient water migration to induce lateral spread displacement (Bartlett and Youd, 1992).  **Influence of Soil Density (D)** – From their MLR database, Bartlett and Youd (1992) and Youd et al. (2002) concluded that sediments susceptible to lateral spread generally have SPT N160 values less than 10 and almost always have SPT N160 less than 15. Nonetheless, the influence that soil density (i.e., SPT N values) has on the probability of lateral spread occurrence will be more rigorously explored using logistic analyses.  **Influence of Depth (Z) –** Bartlett and Youd (1992) found that the depth to the critical zone, defined as the lowest N160 value in saturated, granular deposits, was almost always in the upper 15 m of the soil profile. Therefore, the influence of depth will also be explored during this research.  **Influence of Relative Geologic Susceptibility (G)** – Table 4 will be used to score the relative susceptibility of the deposits according to depositional environment (i.e., type of deposit) and age. G will be scored as 5 for very high, 4 for high, 3 for moderate, 2 for low and 1 for very low in the logit evaluations.  Table 4. Estimated susceptibility of sedimentary deposits to liquefaction during strong seismic shaking (after Youd and Perkins 1978)   |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | | Type of Deposit | General Distribution of Cohesionless sediments in deposits | Likelihood that Cohesionless Sediments, When Saturated, Would be Susceptible to Liquefaction (by Age of Deposit) | | | | | <500 yr | Holocene | Pleistocene | Pre-Pleistocene | | (1) | (2) | (3) | (4) | (5) | (6) | | (a) Continental Deposits | | | | | | | River Channel | Locally Variable | Very High | High | Low | Very Low | | Floodplain | Locally Variable | High | Moderate | Low | Very Low | | Alluvial Fan and Plain | Widespread | Moderate | Low | Low | Very Low | | MarineTerraces/ Plains | Widespread | ----- | Low | Very Low | Very Low | | Delta and Fan-delta | Widespread | High | Moderate | Low | Very Low | | Lacustrine and Playa | Variable | High | Moderate | Low | Very Low | | Colluvium | Variable | High | Moderate | Low | Very Low | | Talus | Widespread | Low | Low | Very Low | Very Low | | Dunes | Widespread | High | Moderate | Low | Very Low | | Loess | Variable | High | High | High | Unknown | | Glacial Till | Variable | Low | Low | Very Low | Very Low | | Tuft | Rare | Low | Low | Very Low | Very Low | | Tephra | Widespread | High | High | ? | ? | | Residual Soils | Rare | Low | Low | Very Low | Very Low | | Sebkha | Locally Variable | High | Moderate | Low | Very Low | | (b) Coastal Zone | | | | | | | Delta | Widespread | Very High | High | Low | Very Low | | Esturine | Locally Variable | High | Moderate | Low | Very Low | | Beach |  |  |  |  |  | | High Wave Energy | Widespread | Moderate | Low | Very Low | Very Low | | Low Wave Energy | Widespread | High | Moderate | Low | Very Low | | Lagoonal | Locally Variable | High | Moderate | Low | Very Low | | Fore Shore | Locally Variable | High | Moderate | Low | Very Low | | (c) Artificial | | | | | | | Uncompacted Fill | Variable | Very High | ----- | ----- | ----- | | Compacted Fill | Variable | Low | ----- | ----- | ----- |   **Influence of Seismic Source Distance (R)** – For similar magnitude earthquakes, liquefaction effects are known to attenuate with decreasing seismic energy associated with further distances from the seismic source (Youd and Perkins, 1987; Ambraseys, 1988; Bartlett and Youd, 1992, 1995; Youd et al., 2002). The effects of source distance on lateral spread will also be explored and evaluated.  **Influence of Earthquake Magnitude (Mw)** – At susceptible sites and all other factors being equal, the occurrence of lateral spread and the magnitude of the associated displacement increases with earthquake magnitude (Bartlett and Youd, 1992; 1995).  **Influence of Other Variables (Xn) –** Other variables, not mentioned above, may be defined and evaluated during the research. |

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| **Significant Results:**  The following table includes a summary of progress made on **Phase I, Task 6, Obtaining and screening of case history information**. |
| **Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that**  **might affect the completion of the project within the time, scope and fiscal constraints set forth in the**  **agreement, along with recommended solutions to those problems).**  Contract extension is requested by BYU. Proposed contract extension end date is April 30, 2020. U of U will assist BYU in completing their case histories and work on the screening criteria task (described above) during this extension. |

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| **Potential Implementation:**  None yet. |