**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(244)** | | **Transportation Pooled Fund Program - Report Period:**  \_ Quarter 1 (January 1 – March 31, 2017)  **x Quarter 2 (April 1 – June 30, 2017)**  \_ Quarter 3 (July 1 – September 30, 2017)  ­\_ Quarter 4 (October 1 – December 31, 2017) | |
| **Project Title:**  Shaking Table Testing to Evaluate Effectiveness of Vertical Drains for Liquefaction Mitigation | | | |
| **Name of Project Manager(s):**  David Stevens | **Phone Number:**  801-589-8340 | | **E-Mail**  [davidstevens@utah.gov](mailto:davidstevens@utah.gov) |
| **Lead Agency Project ID:**  FINET 42046, ePM PIN 9933  UDOT PIC No. UT07.708 | **Other Project ID (i.e., contract #):**  UDOT Contract No. 138731 | | **Project Start Date:**  May 1, 2013 |
| **Original Project End Date:**  March 31, 2016 | **Current Project End Date:**  December 31, 2017 | | **Number of Extensions:**  3 |

Project schedule status:

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

Overall Project Statistics:

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| **Total Project Budget** | **Total Cost to Date for Project** | **Percentage of Work**  **Completed to Date** |
| $115,000.00 | $71,500.00 | 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** |
| 9% | $10,000.00 | 90% |

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| **Project Description**:  The vision for this study is to determine the viability of large diameter (100 mm) prefabricated vertical drains for preventing liquefaction and associated settlements or lateral spreading under full-scale conditions. If viable, drainage alternatives offer substantial advantages in comparison to conventional densification approaches. In production, drains can often be installed at 25% to 40% of the cost of stone columns. In addition, the drains can be installed in about one-third to one-half of the time required for stone columns. Finally, the time and cost associated with post-treatment in-situ testing to evaluate improvement produced by densification may not be required with drains. In an era when construction budgets are becoming increasingly tight and projects are increasingly placed on fast-track schedules, innovative alternative solutions are required to deal with liquefaction hazards.  Although limited blast liquefaction testing (Rollins et al. 2003, Rollins et al. 2004), vibration testing (Chang et al. 2004) and centrifuge testing (Yang et al. 2004 ) suggest that vertical drains can be effective, no full-scale drain installation has been subjected to earthquake induced ground motions. This lack of performance data under full-scale conditions has been a major impediment to expanding the use of this technique. To remedy this problem we will conduct full-scale tests with vertical drains in liquefiable sand using the laminar shear box and high speed actuator system at NEES-Univ. at Buffalo. Tests will involve level ground conditions with two drain spacings and will be integrated with a previously funded NEESR study currently underway so that the control tests without drains will already be available. We will use the same sand installation techniques, as well as the same instrumentation plan and shaking protocols which have already been developed and proven successful. This collaborative approach will significantly reduce the cost of the study in comparison to a completely independent study. In addition, it will provide a comparison between the performance of the soil profile with drains relative to subsequent tests where piles will be involved. If full-scale tests prove the effectiveness of the drainage technique, significant time and costs savings can be achieved for both new construction and for retrofit situations.  Three objectives are outlined for this study:  1. Evaluate the ability of earthquake drains to reduce excess pore pressure and settlement for level ground conditions at progressively higher acceleration levels.  2. Define the influence of drain spacing on the effectiveness of the drains for mitigating liquefaction hazard.  3. Provide well-documented case histories which can be used to calibrate/validate numerical models for predicting the performance of vertical drains.  The scope of work consists of eight specific tasks:  1. Perform a literature review to summarize the state of the art in the area of liquefaction mitigation through drainage.  2. Conduct level ground shaking table tests with drains at 4 ft spacing.  3. Conduct level ground shaking table tests with drains at 3 ft spacing.  4. Reduce the test data, analyze, and compare with previous test on untreated sand.  5. Evaluate predictive methods by comparing measured behavior with behavior computed using computer models and simplified models.  6. Prepare a final report on effectiveness of the drain technique.  7. Disseminate the research results.  8. Hold technical advisory committee meetings.  Dr. Kyle Rollins of BYU is the Principal Investigator for this research project. The TPF-5(244) testing was performed at the SUNY-Buffalo shaking table testing facility in the summer of 2014. BYU was approved for shared-use status on the NEES-Buffalo shake table. Individual task reports will be prepared for Tasks 1 through 5 when these are completed. Up to two in-person meetings with the multi-state technical advisory committee (TAC) are planned to be held in Salt Lake City, Utah during the project. Other TAC meetings will be tele-conference or web meetings. |

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| **Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):**  Task 1 – 100% complete.  Task 2 – 100% complete.  Task 3 – 100% complete.  Task 4 – 90% complete. BYU prepared a data reduction report.  Task 5 – 70% complete. BYU continued evaluating predictive methods.  Task 6 – 50% complete. BYU prepared portions of the final report.  Task 7 – No work yet.  Task 8 – 40% complete.  Contract – Extended the contract end date to allow for report completion and reviews. |
| **Anticipated work next quarter**:  Task 1 – None.  Task 2 – None.  Task 3 – None.  Task 4 – Post the revised task report on the TPF website. Provide a data reduction report for TAC review.  Task 5 – Continue with evaluating predictive methods. Provide a predictive methods report for TAC review.  Task 6 – Complete the draft final report for TAC review.  Task 7 – None.  Task 8 – Plan to hold another TAC web-conference to review and discuss final results from the study. Consider travel and implementation support needs of the TAC members.  Contract – No changes planned. |

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| **Significant Results:**  During this quarter the input parameters for the finite element program FEQDrain (Pestana et al, 1997) were refined based on the measurements from the laminar shear box experiments. These parameters included relative density, hydraulic conductivity, and modulus of compressibility along with other lesser quantities. Interpolation procedures were developed to define parameters for shake tests where tests were not performed immediately prior to the shake test. Using the input parameters developed from the experimental data, the computer program was used to compute time histories of excess pore pressure ratio (Ru) and compared with measured response. Some adjustments to the modulus of compressibility were necessary to optimize agreement with measured response (peak Ru and rate of dissipation). Figures 1 through 3 provide comparisons of measured and computed excess pore pressure ratio time histories for the shake tests at 0.1 g for rounds 1, 2, and 3 for the 3-ft drain spacing. Similar comparison curves have also been developed for each shake test for each pore pressure transducer depth. Generally, the computer model is reasonably capturing the basic features of the Ru time histories, but there are discrepancies in some instances.  The modulus of compressibility (mv) values used in the computer program are provided in Figure 4. The mv values are plotted versus depth for each shake test and for each drain spacing in Figure 4. Generally, the back-calculated mv values plot within the center of the range of mv values obtained experimentally, as illustrated in Figure 4 and increase with depth. This agreement suggests that the mv values are reasonable values considering the potential for local variations in the measured settlement versus depth curves. The back-calculated mv values are generally higher than those tabulated by Pestana et al (1997) in the user’s manual for the FEQDrain program for cyclic triaxial shear test specimens. This could be due to the nature of the deposition process in the laminar shear box which appears to produce a loose, unstructured soil deposit which is more compressible than conventional soils.    **Figure 1 Comparison of measured and computed excess pore pressure ratio time histories at six depths using back-calculated mv to fit Ru time histories for 3-foot drain spacing, Round 1, amax=0.10g. (measured-solid blue curve and computed-dashed black curve)**    **Figure 2 Comparison of measured and computed excess pore pressure ratio time histories at six depths using back-calculated mv to fit Ru time histories for 3-foot drain spacing, Round 2, amax=0.10g. (measured-solid blue curve and computed-dashed black curve)**    **Figure 3 Comparison of measured and computed excess pore pressure ratio time histories at six depths using back-calculated mv to fit Ru time histories for 3-foot drain spacing, Round 3, amax=0.10g. (measured-solid blue curve and computed-dashed black curve)**    (a)    (b)  **Figure 4. Modulus of compressibility values used to produce agreement with pore pressure response in comparison with range of experimental compressibility values for all shaking tests with the (a) 3-ft. and (b) 4-ft. drain spacings.** |
| **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).**  Additional time was needed to complete reports and reviews by the TAC. Therefore the contract was amended to reflect the project ending in December 2017 instead of the original plan. |

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| **Potential Implementation:** |