**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, 2014)\_ Quarter 2 (April 1 – June 30, 2014)**x Quarter 3 (July 1 – September 30, 2014)**\_ Quarter 4 (October 1 – December 31, 2014) |
| **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 |
| **Lead Agency Project ID:**FINET 42046, ePM PIN 9933UDOT 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:** March 31, 2016 | **Number of Extensions:** |

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 | $6,500.00 | 20% |

***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** |
| 0% | $0 | 50% |

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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 – 80% complete. BYU completed shaking table tests with drains at 4 ft spacing. TAC members remotely viewed some live and recorded testing.Task 3 – 80% complete. BYU completed shaking table tests with drains at 3 ft spacing. TAC members remotely viewed some live testing.Task 4 – 10% complete. BYU began the test data reduction and analysis.Task 5 – No work yet.Task 6 – No work yet.Task 7 – No work yet.Task 8 – 15% complete. We held a web-conference TAC meeting between Task 2 testing and Task 3 testing, to view and discuss the basic Task 2 testing results and to review the plan for Task 3 testing. |
| **Anticipated work next quarter**:Task 1 – None.Task 2 – Prepare and submit the Test 1 summary report for TAC review.Task 3 – Prepare the Test 2 summary report for TAC review.Task 4 – Continue with test data reduction and analysis.Task 5 – NoneTask 6 – None.Task 7 – None.Task 8 – Plan to hold another TAC web-conference to review and discuss preliminary results from the testing. |

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| **Significant Results:** During the past quarter, two test series were performed in the laminar shear box at SUNY-Buffalo. In the first series of tests conducted in late August 2014, the drains were spaced at 4 ft on centers and in the second set of tests, conducted in mid-September, drains were spaced at 3 ft on centers. For each drain spacing, the soil profile was subjected to a total of nine motions. Prior to the first set of motions, a seismic CPT sounding was made, permeability measurements were performed in three intervals, and initial readings from the vertical profilometer were obtained. The profile was then subjected to 15 cycles of sinusoidal motions with peak base accelerations of 0.05g, 0.10g, and 0.20g. At the end of each 15 cycles of shaking, the settlement of the soil profile was measured, permeability was measured, and the volume of water exiting the profile was pumped away and measured. At this point, another seismic CPT sounding was made to account for the increase in density produced by the shaking. Thereafter, the profile was again subjected to base motions with peak accelerations of 0.05g, 0.10g, and 0.20g and the process was repeated a third time. Fig. 1 provides plots of the cone tip resistance as a function of depth for the four CPTs performed during the tests with the drains on 4 ft centers. After each sequence of shaking, the cone tip resistance clearly increased as the soil became more compact. Nevertheless, the qc values are very low and more representative of soil with a relative density of 15 to 35% despite the fact that the measured relative density is between 40 to 45% according to the bucket weight measured during deposition. Perhaps the structure of the sand has not yet developed a strength that is compatible with the density state.Fig. 2 Provides a plot showing sand settlement versus depth in the profile along with excess pore pressure ratios measured by three vertical arrays for the shake test with 15 cycles of 0.05g acceleration. In this test an excess pore pressure of 1.0 (liquefaction) developed to a depth of 6 ft; however, the excess pore pressure ratio decreases with depth below 6 ft and is as low as 0.2 at 13.5 ft below the ground surface. Similar plots are provided with measured excess pore pressure ratios for the tests with 0.10g and 0.20g in Figs. 3 and 4. As the acceleration increases, the excess pore pressure generally increases despite the presence of the drains. The results from the tests all show that drains are more effective in the lower part of the profile because the sand drains from the bottom to the top create greater demand on the drains in the upper part of the profile. Similar results have been noted by other researchers.Fig. 5 provides a summary plot showing settlement vs number of tests for the 9 tests conducted with the drains at 4 ft centers in comparison with settlement of untreated sand. The results suggest that the drains were successful in substantially reducing the measured settlement in comparison with the untreated sand profile. Typically, settlement with the drains in place was about 50% of the settlement of the untreated drains. Similar results have been obtained in centrifuge testing where settlement was substantially reduced even though excess pore pressures did not remain below 1.0 in all cases. In the centrifuge testing the reduced settlement appeared to be associated with the reduction in the time for which the sand experienced an excess pore pressure greater than 60%. .  **Fig. 1 Cone tip resistance versus depth plots after each round or three shaking tests (0.05g, 0.10g, and 0.20g)****Fig. 2 Settlement versus depth plots from two Sondex profilometers and surface string potentiometers (left) and excess pore pressure ratio versus depth plots for three vertical pore pressure arrays during first shaking test with 15 cycles of shaking and a 0.05g peak acceleration.****Fig. 3 Excess pore pressure ratio versus depth plots for three vertical pore pressure arrays during first shaking test with 15 cycles of shaking and a 0.10g peak acceleration.**.**Fig. 4 Excess pore pressure ratio versus depth plots for three vertical pore pressure arrays during first shaking test with 15 cycles of shaking and a 0.20g peak acceleration.** 0.1g base motion0.2g base motion0.1g base motion**Fig. 5 Cumulative settlement versus number of test plots for the tests with drains at 4 ft centers (PVD1) in comparison with test results for tests in untreated sand (LG1) or partially treated sand (IPS1) tests with settlement scaled to give settlement for the full thickness of untreated sand.** |
| **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).** |

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| **Potential Implementation:**  |