**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)  **x Quarter 2 (April 1 – June 30, 2014)**  \_ 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](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:**  March 31, 2016 | | **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** |
| $115,000.00 | $6,500.00 | 6% |

***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** |
| 2% | $1,500 | 40% |

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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 is scheduled to begin at the SUNY-Buffalo shaking table testing facility in the summer of 2014. BYU has been 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 – 10% complete. Dr. Rollins visited SUNY-Buffalo again to coordinate on the upcoming tests.  Task 3 – No work yet.  Task 4 – No work yet.  Task 5 – No work yet.  Task 6 – No work yet.  Task 7 – No work yet.  Task 8 – 10% complete. |
| **Anticipated work next quarter**:  Task 1 – None.  Task 2 – The final testing schedule will be shared with the TAC. Dr. Rollins will coordinate with faculty at UB to prepare for the BYU test and to explore opportunities for the TAC to remotely view related testing going on at the facility and the BYU tests. The revised schedule calls for the first and second BYU tests to be performed July-September 2014 on the NEES-Buffalo shake table. *Updated layout and schedule information for Test 1 is given below under “Significant Results.”*  Task 3 – The revised schedule calls for the first and second BYU tests to be performed July-September 2014 on the NEES-Buffalo shake table.  Task 4 – None.  Task 5 – None.  Task 6 – None.  Task 7 – None.  Task 8 – Plan to hold a TAC web conference between the first and second BYU tests this summer. |

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| **Significant Results:**  Following are the updated layout of drains and instrumentation, procedure, and anticipated schedule for the Task 2 testing.  **Anticipated Layout of Drains and Instrumentation for Test 1**    Drains will be placed in a triangular pattern with a center-to-center spacing of 4 ft as shown in Fig. 1 prior to placement of sand with a relative density between 30% and 45%. The density of the soil will be measured using small buckets during soil placement. In addition, a seismic CPT test will be performed after placement to provide cone tip resistance (qc), friction ratio (fr), and shear wave velocity Vs profiles within the sand. As shown in Fig. 1, three casings with slotted sections from 0-5 ft, 5-10 ft and 10 to 15 ft will be positioned across the box so that borehole permeability tests can be performed to identify the horizontal permeability coefficient with these three intervals. After permeability testing, these casings will be either sealed or filled up with sand. Based on previous testing conducted by Prof. Yegian of Northeastern, the permeability of the sand in the box is about 0.05 cm/sec.  Three surface settlement plates will be located along the mid-line of the test area to measure total settlement, and two Sondex profilometers will be located as shown in Fig. 1 to define settlement as a function of depth within the sand. Three vertical arrays of pore pressure transducers will be located as shown in Fig. 1 to define the generation and dissipation of pore pressure versus depth. One array will be located 1 ft from the center of a drain, while the other two arrays will be located at 2 ft from the center but at different positions relative to the surrounding drains. A distance of 2 ft from the drain represents the critical point where water has the furthest distance to travel to reach a drain. In addition, one pore pressure transducer will be located at a depth of 7.5 ft within the center drain to monitor the actual pressure within the drain itself. Because of failure of miniature pore pressure transducers at the Buffalo test facility and a lack of funds to replace these sensors, BYU will purchase an additional 9 pore pressure transducers to enable adequate monitoring during the testing in lieu of our obligation to NEES@Buffalo to replace damaged sensors. Lastly, the volume of water flowing out of one of the drains will be monitored as shown in Fig. 1. Water will flow into a tub suspended just above the ground surface by steel cables. The cables will be supported by a single cable attached to a sensitive load cell which will be tied into the overall data acquisition system to allow the volume of outflow to be determined as a function of time during each test.    **Legend**  Pre-fabricated vertical drains (3.5 inch inside diameter, 3.7 inch outside diameter with filter fabric)  Surface settlement plates  Sondex settlement profilometers  Vertical arrays of pore pressure transducers at 2.5, 5, 7.5, 10, 12.5, and 15 ft depths  Drain with connection to monitor water outflow  Slotted pipes for measuring horizontal permeability  Fig. 1 Anticipated layout of drains and instrumentation for Test 1.  In addition to the instrumentation within the sand, accelerometers will be located at approximately 1 ft intervals along the height of the box to define the acceleration profile induced by the shaking at the base. Furthermore, LVDTs will be positioned at approximately every foot to define the deflection profile as a function of time. Four video cameras will record the test from different angles for each test.  **Testing Procedure**  To maximize the information obtained from the testing program, a series of tests will be performed rather than only a single test as originally anticipated. For each test, 15 cycles of acceleration will be applied with peak accelerations of 0.015g, 0.05g, 0.1g, 0.2g and 0.3g and a frequency of 2 Hz. At the completion of each set of 15 cycles at a given acceleration level, the pore pressure will be allowed to dissipate prior to the application of the higher acceleration level. Testing conducted by RPI and Northeastern indicates that the sand tends to densify in the lower third of the box with repeated shaking while it remains relatively unchanged in the upper two-thirds of the box. Prior to subsequent testing, another CPT test will be performed to characterize the sand and the shaking sequence will be repeated. This should help identify the performance of the drains for several relative densities. For the last test we plan to apply the Yerba Buena rock motion recorded during the 1989 Loma Prieta earthquake to the base of the laminar shear box to observe performance.  **Anticipated Schedule for the First Drain Test**  The drains with filter fabric “socks” have arrived at the UB test site and BYU graduate students are now at the University of Buffalo where they are observing testing being performed by researchers from Northeastern and gaining experience with the test setup. If the Northeastern tests are completed on time, the current schedule for BYU testing is as follows:  July 28 - Aug. 1 – Installation of drains and instrumentation  Aug. 4 - Aug. 8 – Placement of sand into laminar box using hydraulic filling techniques  Aug. 11 - Aug. 15 – CPT testing and Shake testing  Aug. 18 - Aug. 21 – Removal of sand from laminar box |
| **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).**  Due to some technical difficulties on other projects currently being tested at the SUNY-Buffalo facility, there has been a delay in starting testing for this pooled fund project at the facility as previously planned for summer or fall of 2013. Dr. Rollins has been notified that the pooled fund project testing is scheduled for July through September 2014. |

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| **Potential Implementation:** |