**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:**  **x Quarter 1 (January 1 – March 31, 2018)**  \_ Quarter 2 (April 1 – June 30, 2018)  \_ Quarter 3 (July 1 – September 30, 2018)  ­­\_ Quarter 4 (October 1 – December 31, 2018) | |
| **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:**  June 30, 2018 | | **Number of Extensions:**  4 |

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 | $82,500.00 | 90% |

***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** |
| 10% | $11,000.00 | 95% |

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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 – 100% complete. BYU prepared a data reduction report.  Task 5 – 100% complete. BYU prepared an analysis progress report.  Task 6 – 90% complete. Draft final reports include the Task 4 and Task 5 reports. These were provided to the TAC for review.  Task 7 – 80% complete.  Task 8 – 80% complete. A TAC meeting was held via web conference in April to discuss final results and report feedback. Some TAC members expressed interest in having a simplified, early design tool based on the research. UDOT and BYU are considering how best to produce this, in or out of the TPF study.  Contract – No changes. |
| **Anticipated work next quarter**:  Task 1 – None.  Task 2 – None.  Task 3 – None.  Task 4 – None.  Task 5 – None.  Task 6 – Revise and publish the two final reports from Tasks 4 and 5.  Task 7 – No plans.  Task 8 – No plans.  Contract – No changes planned. |

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| **Significant Results:**  This draft final report relative to numerical modeling of PV Drains was distributed to TAC members for review. The abstract for the report is provided below. This report completes all required work tasks and reporting for the study. After incorporating review comments, the final reports (one on laminar box tests and the other on analysis) will be distributed to the TAC members and be available on the UDOT research division website. ABSTRACT The objective of the modeling was to evaluate the reliability of the axisymmetric finite element computer program FEQDrain for computing excess pore pressure ratios (Ru) and settlement at sites treated with prefabricated drains. FEQDrain was found to be capable of successfully modeling measured excess pore pressure ratio time histories from the laminar shear box experiment, as long as an appropriate combination of ‘number of equivalent cycles’ and ‘shaking duration’ was chosen, and sensitive soil parameters were in the range of measured values. Hydraulic conductivity, soil compressibility, and cycles to liquefaction are sensitive parameters and govern the computed Ru values. Computed Ru values decreased as hydraulic conductivity decreased and compressibility decreased. Computed settlement was somewhat overestimated relative to measured values.  Modeling shows that the loading rate in the laminar shear box (15 cycles at 2 Hz) likely induced higher Ru values than would be expected in a typical earthquake event with a longer duration. The longer duration allows the drains to dissipate pore pressures and prevent liquefaction. The number of equivalent cycles and duration of shaking combinations recommended for various moment magnitudes in the FEQDrain user manual predict lower, but similar Ru versus time curves. Thus, suggesting that PVDs would be equally effective for any size earthquake. However, drains are most effective at preventing liquefaction when earthquake ground motions are long and uniform, rather than short and intense.  Results from models in this study compare favorably with those from computer modeling performed by Howell et al. (2014) in connection with centrifuge tests. The drains were more effective at decreasing pore pressures at greater depths than at shallow depths. Similar Ru values can be modeled with different combinations of hydraulic conductivity and compressibility.    Based on computer analyses, wick drains and 2” diameter PVDs were found to be relatively ineffective for preventing liquefaction. However, 3” diameter PVDs are fairly effective but can be overwhelmed during intense shaking. In contrast, 4” diameter and larger PVDs are significantly more effective. |
| **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 June 2018 instead of the original plan. |

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| **Potential Implementation:**  Some TAC members expressed interest in having a simplified, early design tool based on the research. UDOT and BYU are considering how best to produce this, in or out of the TPF study. |