**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, 2016)**\_ Quarter 2 (April 1 – June 30, 2016)\_ Quarter 3 (July 1 – September 30, 2016)\_ Quarter 4 (October 1 – December 31, 2016) |
| **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:** December 30, 2016 | **Number of Extensions:**1 |

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 | $40,000.00 | 45% |

***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 | 80% |

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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. Report completedTask 5 – 30% complete. BYU continued evaluating predictive methods.Task 6 – No work yet.Task 7 – No work yet.Task 8 – 30% complete.Contract – Amended the contract with a no-cost time extension to Dec. 2016. |
| **Anticipated work next quarter**:Task 1 – None.Task 2 – None.Task 3 – None.Task 4 – Report submittedTask 5 – Continue with evaluating predictive methods.Task 6 – None.Task 7 – None.Task 8 – Plan to hold another TAC web-conference to review and discuss additional results from the study.Contract – No adjustment anticipated. |

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| **Significant Results:** In preparation for computer modeling, the modulus of volume compressibility, Mv, for each test was back-calculated from the measured performance of the sand in the laminar shear box. This modulus is a critical parameter in analyses using computer programs such as FEQDrain (Pestana et al, 1997). Back-calculation was accomplished by dividing the measured volumetric strain within an interval by the change in vertical effective stress. The change in vertical effective stress was equal to the increase in excess pore pressure. Assuming that nearly all the settlement was associated with excess pore pressure change, the initial modulus of volume compressibility, Mvo, prior to pore pressure development was then computed using relationships developed by Seed and Booker (1977). Mvo versus depth profiles were then developed for each of the 18 tests conducted during this study. The Mvo values were typically 5 to 10 times higher than recommended by Seed and Booker (1977) based on cyclic triaxial shear testing and case histories of field performance. This result, suggests that the sand in the laminar shear box is more compressible than sand in the field as was suspected based on the rate at which pore pressures generated during the laminar shear box testing. For the first round of tests at each drain spacing, the value of Mvo versus depth was somewhat variable, but for subsequent rounds of testing, the value decreased somewhat and the variability decreased substantially.The shear stress-shear strain behavior of the sand in the laminar shear box was also computed for each test as a function of depth. The shear stress and shear strain were obtained using the measured acceleration and displacement data respectively, for each ring of the laminar shear box using general procedures suggested by Zeghal and El Gamel (2001). The shear stress-strain plots do exhibit a substantial decrease in stiffness (shear modulus) as excess pore pressures reach 100%; however, the typical banana shape was not generally evident in which shear stress drops to zero. In contrast the curves had a more rectangular shape with a finite strength. It may be that the excess pore pressure relief provided by the drains prevents the full development of shear strain. This may help to explain why volumetric strains were reduced by a factor of 50% with the presence of drains even in cases where liquefaction (ru =100%) developed. In the upcoming quarter, we will plot the shear modulus relative to the initial shear modulus (G/Go) as a function of shear strain and excess pore pressure to explore this phenomenon further. |
| **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 is needed to complete reports and reviews by the TAC. Therefore the contract was amended to reflect the project ending in December 2016 instead of the original plan. |

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| **Potential Implementation:**  |