**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(272)** | | **Transportation Pooled Fund Program - Report Period:**  \_Quarter 1 (January 1 – March 31, 2015**)**  \_ Quarter 2 (April 1 – June 30, 2015)  **X Quarter 3 (July 1 – September 30, 2015)**  \_ Quarter 4 (October 1 – December 31, 2015) | |
| **Project Title:**  Evaluation of Lateral Pile Resistance Near MSE Walls at a Dedicated Wall Site | | | |
| **Name of Project Manager(s):**  Jason Richins | **Phone Number:**  801-360-4985 | | **E-Mail**  jtrichins@utah.gov |
| **Lead Agency Project ID:**  Finet 42053, ePM PIN 11075  UDOT PIC No. UT11.404 | **Other Project ID (i.e., contract #):**  UDOT Contract No. 148434 | | **Project Start Date:**  December 2, 2013 |
| **Original Project End Date:**  September 30, 2016 | **Current Project End Date:**  September 30, 2016 | | **Number of Extensions:** |

Project schedule status:

**X** On schedule \_ 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** |
| $322,000.00 (current contract)  $322,000.00 (total committed) | $128,600.00 | 40% |

***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% | $0 | 66% |

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| **Project Description**:  Pile foundations for bridges with integral abutments must resist lateral loads produced by earthquakes and thermal expansion or contraction. Increasingly, right-of-way constraints are also leading to vertical mechanically stabilized earth (MSE) walls at abutment faces. Currently, there is relatively little guidance for engineers in assessing the lateral resistance of piles located close to these MSE walls. As a result, some designers assume that the soil provides no resistance whatsoever which leads to larger pile diameters and increased foundation cost. Other designers locate the abutment piles six to eight pile diameters behind a wall face to minimize the interaction and use conventional design approaches. However, this approach increases the bridge span and the cost of the bridge structure. Still other designers position the pile close to the wall face and reduce the lateral pile resistance using engineering judgment. However, the appropriate reduction factor to use as a function of pile spacing is not well defined.  Recent testing conducted by Rollins et al (2013) and Pierson et al (2008) indicate that lateral resistance decreases substantially as pile spacing from the wall decreases; however, reinforcing can reduce this effect. Rollins et al also found that p-multipliers defined as a function normalized spacing and reinforcement length seemed to provide reasonable agreement with measured pile response. Furthermore, Rollins et al found that the tensile force in the reinforcements owing to the lateral load on the pile could be estimated for design purposes using a correlation with pile load, spacing behind the wall, and distance transverse from the pile load.    Although the tests to date provide a framework for understanding the mechanisms involved and likely design approaches, the available data is too limited to make firm design recommendations. To improve our understanding of pile-MSE wall interaction, this project will involve construction of a test embankment approximately 80 ft long and 20 ft tall where it will be possible to conduct a number of lateral pile load tests on different pile types behind an MSE wall with both strip and grid type steel reinforcements. Additional contributions to the project will consist of in-kind donations from various contractors and material suppliers.  Objectives for this study include:  1. Measure reduced lateral pile resistance vs. displacement curves for circular, square, and H piles behind an MSE wall with steel strips and grid reinforcement.  2. Measure the increase and distribution of tensile force in the MSE reinforcement induced by lateral pile loading.  3. Measure effect of special pile head geometry (e.g. corrugated pipe sleeves, double plastic sheeting) on lateral pile resistance.  4. Develop design rules (e.g. p-multipliers) to account for reduced pile resistance as a function of spacing and reinforcement.  5. Develop equation to predict reinforcement force induced by pile loading.  6. Develop design equations to account for pile shape and pile head geometry.  Tasks for this study include:  1. Instrument test piles and reinforcements.  2. Drive test piles and construct MSE wall to height of 15 ft.  3. Perform lateral load tests on piles with 15 ft high MSE wall.  4. Reduce data and develop report on the testing for the 15 ft high wall.  5. Determine p-multipliers and reinforcement force equations for 15 ft high wall test results.  6. Perform lateral load tests on piles with 20 ft high MSE wall.  7. Reduce data and develop report on the testing for the 20 ft high wall.  8. Determine p-multipliers and reinforcement force equations for 20 ft high wall test results.  9. Develop design recommendations to account for pile sleeves and plastic sheeting effects.  10. Prepare final report with recommendations based on all tests.  11. Hold Technical Advisory Committee (TAC) meetings.  12. Present results of the study at AASHTO, TRB, and ASCE meetings.  Dr. Kyle Rollins of BYU is the Principal Investigator for this research project. The technical advisory committee (TAC) includes representatives from UT, FL, IA, KS, MA, MN, MT, NY, OR, TX, and WI DOTs. |

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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  Task 5 – 100% Complete  Task 6 – 100% Complete.  Task 7 – Funding is available. Amendment to the contract was completed and signed.  Task 8 – Funding is available. Amendment to the contract was completed and signed.  Task 9 – Funding is available. Amendment to the contract was completed and signed.  Task 10 – Funding is available. Amendment to the contract was completed and signed.  Task 11 – 10% complete. Follow-up teleconferences were held with suppliers of the MSE wall panels and reinforcements and UDOT staff. Plans are underway for a teleconference with the TAC  Task 12 – Funding is available.  Contract – A contract modification was completed to provide funding for all the work tasks. |
| **Anticipated work next quarter**:  Task 1 – Completed.  Task 2 – Completed.  Task 3 – Completed.  Task 4 – Completed  Task 5 – Completed.  Task 6 – Completed.  Task 7 – Data reduction will continue for the 20-ft pile testing.  Task 8 – p-multipliers will be back-calculated based on the results of the test.  Task 9 – Work will begin.  Task 10 – Work will begin.  Task 11 – Plan a date for a TAC meeting to review test results.  Task 12 – None planned. |

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| **Significant Results:**  ***P-multipliers for All Pile Tests***  Using the computer program LPILE p-multipliers have been developed for all of the 24 tests conducted on piles at the 15 and 20 ft levels. Piles consisted of circular pipe, square and H steel sections which were close to 12 inches in width/diameter. MSE reinforcements consisted of ribbed strip reinforcement as well as welded wire reinforcement. Back-analysis was performed using the LPILE computer model. For each set of tests with piles spaced at 5, 4, 3, and 2 pile diameter spacing from the back face of the MSE wall, a best-fit computer model was developed for the pile at the greatest spacing from the wall. Then for other spacings, the soil model properties were held constant and the soil resistance was adjusted using a constant p-multiplier to provide the best agreement with the measured load-deflection curve. The resulting p-multipliers are plotted as a function of normalized pile spacing (spacing from the center of the pile to the back of the MSE wall divided by the pile width or diameter) in Fig. 1. In addition to the results from this study, the p-multipliers obtained from 8 tests conducted previously by Rollins, Price, and Nelson (2013) are also shown on the plot. For piles with normalized spacing of 3.8D (3.8 pile diameter) or more, the back-calculated p-multiplier is approximately one indicating that the pile had the same resistance as if there were no wall present. Another way to think about this is that the reinforcements in the MSE wall provided enough lateral restraint for this pile spacing so that there was no reduction in lateral resistance. There may still be interaction between the pile and wall that displaces the wall or develops tensile force in the MSE reinforcements. At closer spacings, the reduction in lateral pile resistance can be accounted for using a p-multiplier which decreases linearly with normalized spacing such that the p-multiplier is approximately 0.1 at a spacing of one pile diameter. The p-multipliers from this study are in very good agreement with those developed previously based on the testing by Rollins et al (2013) although there is scatter about the best-fit line. In our opinion, this scatter is likely due to natural variations in relative compaction of soil near the wall face of an MSE wall caused by the use of walk-behind compactors near the face of the wall.    Pmult=0.34(S/D)-0.283      , Circular  , Circular  , Circular  , Circular  **Fig. 1 Plot showing back-calculated p-multipliers vs normalized pile spacing to account for the presence of the pile near an MSE wall face. The best-fit curve is also shown relative to the test data.**  Despite the significant variations in pile type, reinforcement type, wall heights, and reinforcement lengths within the data set, there are no apparent trends obvious in the data. One equation appears to provide a reasonable fit for all of the data.  **Predicting Tensile Force in Reinforcements**  Preliminary analysis of the reinforcement data indicated that separate equations would be necessary to predict the tensile force in the ribbed strip reinforcement relative to the welded wire reinforcement. The regression equation for the ribbed strip reinforcement was provided in a previous quarterly report. In the past quarter, multi-variable regression analyses were also performed to investigate the factors influencing the maximum tensile force on the welded-wire reinforcement during lateral pile loading, and the factors found to be statistically significant are shown in Fig. 2. The maximum tensile force in the reinforcement, F, is given by the equation  F = 10^[0.2023 + 0.0272P - 0.0003P2 - 0.008T + 0.0005σv - 2x10-7σv2 - 0.038(S/D) - 0.001z] (1)    where: P is the pile head load (kips),  T is the transverse spacing from the center of the pile to the reinforcing (in.),  σv is the vertical stress on the reinforcement (psf), and  S is the distance from the center of the pile to the back face of the wall (ft), and  D is the pile diameter (ft).  z is the depth to the reinforcement below the top of the wall as illustrated in Fig. 2.  This equation is based on the eight lateral load tests on circular piles for the MSE wall at 15 ft and 20 ft levels. In the data set, maximum reinforcement force was taken for each instrumented reinforcement for each test at each deflection increment, not just at the maximum deflection. The r2 coefficient for the data set is about 0.64 which indicates that about 64% of the variation in the measured force is accounted for by the equation. Considering that unit friction on MSE wall reinforcements is notoriously variable even in well-controlled pull-out tests, the predictive power of the equation seems to be reasonably good. A plot of measured versus computed tensile force is provided in Fig. 3. Generally the agreement is reasonable except for a few of the reinforcements where there may be some problems with the interpreted strain. Additional effort will be made to investigate these outliers to determine if there is some problem with the data.    **Fig. 2 Definition of parameters found to be statistically significant in predicting the maximum tensile force induced in MSE reinforcements as a result of lateral loading.**    **Fig. 3 Comparison of measured and computed tensile force induced in the MSE reinforcement due to lateral pile loading.** |
| **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).**  None to report. |

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| **Potential Implementation:**  The consistency of the data suggests that the p-multiplier equation to account for presence of the MSE face may be worthy of implementation in the near future. |