**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)\_ Quarter 3 (July 1 – September 30, 2015)**X** **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 11075UDOT 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 | 76% |

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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% CompleteTask 4 – 100% CompleteTask 5 – 100% CompleteTask 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 – CompletedTask 5 – Completed.Task 6 – Completed.Task 7 – Analysis completed report in preparationTask 8 – Analysis completed report in preparationTask 9 – Analysis under wayTask 10 – Report is in preparationTask 11 – Plan a date for a TAC meeting to review test results.Task 12 – None planned. |

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| **Significant Results:****Predicting Peak Tensile Force in Reinforcements** During this quarter additional effort has been made in developing regression equations to predict the measured peak tensile force in the reinforcements for all of the tests with all pile types. Analysis of the reinforcement data indicates that separate equations are necessary to predict the tensile force in the ribbed strip reinforcement relative to the welded wire reinforcement. Multi-variable regression analysis indicates that the five factors shown in Fig. 1 are statistically significant in relation to the measured peak tensile force in the reinforcements. Including the L/H ratio increases the complexity of the regression equation but also increases the R2 value from around 0.62 to around 0.75. An R2 value generally indicates how much of the variability in the predicted value is captured by the regression equation.  The maximum tensile force for the welded wire reinforcement, Fw, is given by the equation$$F\_{w}=10\^(-0.045+0.025P-2.2x10-4P2-0.077^{T}/\_{D}+4.6x10-4σv-0.045^{S}/\_{D}+$$$$0.62^{L}/\_{H}-6.5x10-4σv^{L}/\_{H})-1$$ where: P is the pile head load (kips), T is the transverse spacing from the center of the pile to the reinforcement (ft) σv is the vertical stress on the reinforcement (psf), S is the distance from the center of the pile to the back face of the wall (ft), D is the pile diameter (ft), and L/H is the ratio of the reinforcement length to height (considering surcharge) as illustrated in Fig. 1.**Fig. 1 Illustration of variables found to be statistically significant in predicting the peak tensile force induced in MSE reinforcements owing to lateral pile loading near an MSE wall face.**This equation is based on eight lateral load tests on circular piles for the MSE wall at 15 ft and 20 ft levels and four lateral load tests on square piles at the 20 ft level. In the data set, maximum reinforcement force was taken for each instrumented reinforcement (6 longitudinal wires) for each test at each deflection increment, not just at the maximum deflection. Regression was performed on the log of the tensile force to account for a log normal distribution in the data. The R2 coefficient for the data set is about 0.77 which indicates that about 77% of the variation in the measured force is accounted for by the equation. A plot of measured versus computed tensile force after taking the anti-log in both cases is provided in Fig. 3. The maximum tensile force for the ribbed strip reinforcements, Fs, is given by the equation$$F\_{s}=10\^(-4.6+0.028P-2.0x10-4P2-0.0090^{T}/\_{D}-0.0021P(^{T}/\_{D})-0.035^{S}/\_{D}+7.2^{L}/\_{H}-2.8\left(^{L}/\_{H}\right)2$$$$-0.0022σV^{L}/\_{H}+0.0032σV-5.8x10-7σV2)-1$$Where the variables are all the same as described previously. This equation is based on eight lateral load tests on circular piles for the MSE wall at 15 ft and 20 ft levels and four lateral load tests on H piles at the 15 ft level. 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. Regression was performed on the log of the tensile force to account for a log normal distribution in the data. The R2 coefficient for the data set is about 0.76. A plot of measured versus computed tensile force after taking the anti-log in both cases is provided in Fig. 3. Considering that unit friction on MSE wall reinforcements is notoriously variable even in well-controlled pull-out tests, the predictive power of the equations seem to be reasonably good. R2=0.77**Fig. 2 Plot of measured versus predicted tensile force for all pile tests and pile types with welded wire reinforcement.****Fig. 3 Plot of measured versus predicted tensile force for all pile tests and pile types with ribbed strip reinforcement.****Lateral Load Behavior of Sleeved Piles**During the past quarter we have been evaluating methods for predicting the lateral resistance of a 12.75 inch steel pipe pile surrounded by a 24 inch corrugated metal pipe (CMP) sleeve. Two lateral load tests were performed on these corrugated metal sleeve (CMS) piles, one with a pea gravel backfill in the annular space and one with a sand backfill. The measured lateral load versus deflection curves for these two test are provided in Fig. 4 and the two curves are quite consistent with each other although the pea gravel backfill ultimately yielded a somewhat higher resistance. Using LPILE, the lateral load vs deflection curve for the pipe pile was first computed assuming no lateral soil resistance from the load point (1 ft above the backfill surface) to the base of the 20 ft long CMP sleeve as is commonly assumed in engineering practice. The measured curve is shown in Fig. 4 for comparison and almost no lateral load is predicted relative to the measured load. Clearly, this assumption fails to capture the behavior of the pile in the field.Two additional lateral load-deflection curves were also computed using LPILE. In one case the lateral resistance of the 12.75 in pile was computed assuming that the pipe pile were surrounded by the sand backfill without any CMP sleeve. In the second case, the EI of the 12.75 pipe pile was used but the diameter of the CMP pipe was used in the LPILE analysis in place of the 12.75 diameter. This approach to EI seems reasonable because the EI of the CMP is very small. At small deflections, less than 0.5 inch, the measured curve is similar to that computed by LPILE for a 12.75 pile in sand. Apparently the lateral restraint provided by the backfill in the annular space with the CMP casing is sufficient to provide as much lateral resistance as a 12.75 in pipe pile in sand backfill at small deflections. However, at larger deflections (>1.75 inches), the measured lateral resistance exceeds the resistance of the 12.75 inch pile and begins to behave as if it were 24 inches in diameter. Apparently, at this deflection level the pile and the backfill in the annular space have engaged the CMP and both are moving into the surrounding soil more or less as a composite pile. Between these two extremes the lateral resistance makes a rather linear transition between the two computed curves. In fact, a very reasonable approximation of the composite behavior can be obtained by simply plotting a linear transition between the two computed curves between a displacement of 0.5 inch and 1.75 inches. **Fig. 3 Comparison of measured lateral load-deflection curves for Corrugated Metal Sleeve (CMS) piles in comparison with curves computed using LPILE with various assumptions.** |
| **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. |