**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(264)** | | **Transportation Pooled Fund Program - Report Period:**  \_ Quarter 1 (January 1 – March 31, 2016)  \_ Quarter 2 (April 1 – June 30, 2016)  \_ Quarter 3 (July 1 – September 30, 2016)  **x Quarter 4 (October 1 – December 31, 2016)** | |
| **Project Title:**  Passive Force-Displacement Relationships for Skewed Abutments | | | |
| **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 42051, ePM PIN 10903  UDOT PIC No. UT11.406 | **Other Project ID (i.e., contract #):**  UDOT Contract No. 138123 | | **Project Start Date:**  August 13, 2012 |
| **Original Project End Date:**  September 30, 2014 | **Current Project End Date:**  December 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** |
| $400,000.00 (current contract)  $400,000.00 (total committed) | $226,500.00 | 60% |

***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** |
| 14% | $54,200 | 70% |

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| **Project Description**:  At present, about 40% of the 600,000 bridges in the FHWA database are constructed at a skew angle (Silas Nichols, Personal Communication). There is considerable uncertainty about the passive force on skewed abutments where the passive force develops at an angle relative to the longitudinal axis of the bridge structure. Although current design codes (AASHTO 2011) consider that the ultimate passive force will be the same for a skewed abutment as for a non-skewed abutment, numerical analyses performed by Shamsabadi et al. (2006) indicate that the passive force will decrease substantially as the skew angle increases. Reduced passive force on skewed abutments would be particularly important for bridges subject to seismic forces or integral abutments subject to thermal expansion. Unfortunately, there have not been any physical test results for skewed abutments reported in the literature which could guide engineers in making appropriate adjustments for skewed conditions. Nevertheless, some field evidence has clearly shown poorer performance of skewed abutments during seismic events and distress to skewed abutments due to thermal expansion (Shamsabadi et al. 2006, Steinberg and Sargand 2010).  This study builds on previous pooled fund testing conducted by Rollins and his students at BYU to evaluate passive force-deflection relationships for non-skewed abutments (TPF-5(122), Dynamic Passive Pressure on Abutments and Pile Caps, Rollins et al, 2010). The test facilities can readily be modified to allow for the test program with relatively small additional costs because of the test fixtures (reaction shafts, reaction walls, and pile supported cap) which are already constructed at the site. Results from this study can be compared with previous testing to assess overall performance.  Four objectives are outlined for Phase I of this study:   1. Determine static passive force-displacement curves for skewed abutments with and without wingwalls from large scale tests. 2. Provide comparisons of behavior of skewed abutments with that of normal abutments. 3. Evaluate the effect of wingwalls on skewed abutment response. 4. Develop design procedures for calculating passive force-displacement curves for skewed abutments.   Phase II objectives focus on passive force-deflection relationships for Controlled Low-Strength Material (CLSM) (a.k.a. flowable fill, cellular concrete, etc.) backfill and the influence of skew angle and rotation.  Phase I tasks for this study include:  I-1. Literature Review and Collection of Existing Test Data  I-2. Perform Laboratory Passive Force-Deflection Tests on 2 ft High Wall with Skew Angles of 0º, 15º, 30º, and 45º  I-3. Perform Field Passive Force-Deflection Tests on 5.5 ft High Wall with Skew Angles of 0º, 15º, and 30º and Transverse Wingwalls  I-4. Perform Field Passive Force-Deflection Tests on 5.5 ft High Abutment with Skew angles of 0º, 15º, 30º and MSE Wingwalls  I-5. Calibrate Computer Model and Conduct Parametric Studies  I-6. Preparation of Final Report  I-7. Perform Additional Field Passive Force-Deflection Tests on 5.5 ft High Abutment with a Skew Angle of 45º with and without MSE Wingwalls  I-8. Perform Field Passive Force-Deflection Tests on 3.0 ft High Unconfined Backfill with Skew Angles of 0º and 30º  I-9. Perform Field Passive Force-Deflection Tests on 5.5 ft High Pile Cap with Concrete Wingwalls and Skew Angles of 0º and 45º  I-10. Perform Field Passive Force-Deflection Tests on 3.5 ft High Unconfined Gravel Backfill with Skew Angles of 0º and 30º  I-11. Perform Field Passive Force-Deflection Tests on 3.5 ft High GRS Gravel Backfill with Skew Angles of 0º and 30º  I-12. Present the Results of the Study at TRB and AASHTO Meetings  Phase II tasks for this study include:  II-1. Conduct literature review to define typical characteristics of CLSM backfill  II-2. Perform lab-scale passive force test with CLSM  II-3. Conduct large-scale passive force field tests with CLSM  II-4. Perform large-scale passive force tests with rotation and longitudinal displacement  II-5. Validate or calibrate computer models  II-6. Develop simplified design models to simulate observed performance  II-7. Prepare final report with design examples for typical cases  II-8. Disseminate results and work with sponsors and AASHTO to implement findings into future codes  Dr. Kyle Rollins of BYU is the Principal Investigator for this research project. Individual task reports will be prepared for Tasks I-1 through 5 and I-7 through 11, and for Tasks II-1 through 6, when these are completed. Phases I and II will have separate final reports. Two in-person meetings with the multi-state technical advisory committee (TAC) were 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 I-1 – 100% complete.  Task I-2 – 100% complete.  Task I-3 – 100% complete.  Task I-4 – 100% complete.  Task I-5 – 80% complete. Continued work on RC Wingwall case.  Task I-6 – 50% complete. Progress was made on multiple draft final reports to be published. UDOT and the TAC continued reviewing draft final reports. Planned list of final reports is as follows:   * Passive force-deflection behavior of 5.5 ft skewed abutments with transverse wingwalls (45 degree skew tests added) * Passive force-deflection behavior of 5.5 ft skewed abutments with longitudinal MSE wingwalls (45 degree skew tests added) * Passive force-deflection behavior of 3 ft skewed abutments with transverse wingwalls (larger width-to-height ratio tests) *– draft received* * Passive force-deflection behavior of 5.5 ft abutments with longitudinal reinforced concrete wingwalls *– draft received* * Passive force-deflection behavior of 3.5 ft gravel and Geosynthetic Reinforced Soil (GRS) backfill with transverse wingwalls *– draft received* * Computer model calibration and parametric studies, Part 1 – Passive force-deflection modeling with no wingwall *– draft received* * Computer model calibration and parametric studies, Part 2 – Additional modeling with longitudinal reinforced concrete wingwalls, 45 degree skew, two-lane highway * Summary report on passive force-deflection behavior of skewed abutments (short report up to 20 pages)   Task I-7 – 80% complete. Continued data analysis and worked on task report.  Task I-8 – 90% complete. Draft final report for this task is complete.  Task I-9 – 90% complete. Draft final report for this task is complete.  Task I-10 – 90% complete.  Task I-11 – 90% complete. Combined draft final report for Tasks 10 and 11 is complete.  Task I-12 – 80% complete.  Task II-1 – 90% complete. Literature review task report was included in the Task II-2 report.  Task II-2 – 90% complete. Draft task report for lab-scale CLSM testing was completed and shared with the TAC.  Task II-3 – 80% complete. Field tests have been completed. Progress was made on task report.  Task II-4 – 80% complete. Field tests have been completed. Progress was made on task report.  Task II-5 – None.  Task II-6 – None.  Task II-7 – None.  Task II-8 – None.  TAC Meetings – None this quarter.  Contract – No changes this quarter. |
| **Anticipated work next quarter:**  Task I-1 – None.  Task I-2 – None.  Task I-3 – None.  Task I-4 – None.  Task I-5 – Continue work on RC Wingwall case.  Task I-6 – Continue work on multiple draft final reports to be published, including UDOT and TAC reviews. Combine portions of other task reports for the Final Summary Report.  Task I-7 – Complete the draft final report for this task.  Task I-8 – Revise the draft final report for this task based on TAC feedback.  Task I-9 – Revise the draft final report for this task based on TAC feedback.  Task I-10 – Revise the draft final report for this task based on TAC feedback.  Task I-11 – Revise the draft final report for this task based on TAC feedback.  Task I-12 – Refine proposed code changes with the TAC in preparation for 2017 interaction with AASHTO SCOBS. Prepare to publish a peer-reviewed paper on the study as a reference that could be noted in the code.    Task II-1 – None.  Task II-2 – Receive TAC review comments on the task report and update the report.  Task II-3 – Complete the task report and submit for TAC review.  Task II-4 – Complete the task report and submit for TAC review.  Task II-5 – Start to calibrate computer models with the lab and field test data.  Task II-6 – None.  Task II-7 – None.  Task II-8 – None.  TAC Meetings – Plan to hold a web conference TAC meeting this quarter to discuss new results, report reviews, and implementation.  Contract – No revision planned. |

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| **Significant Results:**  **Comparison of Measured and Computed Passive Force for Cellular Concrete Backfill**  To define the basic strength properties of the cellular concrete a series of triaxial shear tests were performed three specimens at three different confining pressures. Mohr circles for each of the tests are plotted in Fig. 1 and indicate that there was no consistent increase in shear strength with increasing confinement. Instead, the results are similar to the behavior of clay specimens where the failure envelope is horizontal (ϕ = 0) and the shear strength is equal to the average cohesion obtained from the three tests.    Fig. 1. Mohr circles from triaxial shear tests on cellular concrete at three different confining pressures.  A total of 50 to 60 unconfined compressive strength tests were performed on test cylinders for each backfill test. The compressive strength versus strain curves typically exhibited significant ductility and did not indicate any significant decrease in strength with strain beyond the peak. In fact, some tests showed an increase in resistance with strain. Typically, about 75 to 85% of the average compressive strength at 28 days was developed within 7 days of curing. The compressive strength was rather poorly correlated with curing time but was better correlated with unit density as shown in Fig. 2. Despite the variation in curing time for the specimens, there is a clear upward trend in compressive strength with small increases in wet density.  Fig. 2. Plot of unconfined compressive strength as a function of wet density for tests specimens from the 0 skew backfill test. Data points are plotted without reference to curing time which accounts for some of the scatter in the data.  Because the strength was relatively independent of confining pressure, shear strength was evaluated using a strength equal to one-half of the compressive strength assuming a 0º friction angle. In this case the Kp value becomes 1.0. The ultimate passive resistance, Pp, can then computed using the Rankine theory with the equation  Pp = 0.5γH2B + 2cHB (1)  where:  γ = unit weight of backfill = 28.6 to 29.6 pcf  H = height of backwall = 5.5 ft  B = width of backwall = 11.7 ft  c = cohesion = shear strength = one-half of the average compressive strength of 51 to 58 psi  The computer spreadsheet PYCAP, developed by Duncan and Mokwa (2000), was used to compute the passive force-deflection curve for each case based on measured strength parameters while parameters governing the stiffness were back-calculated to fit the measured response. Fig. 3 provides a comparison of the measured and compute passive force-deflection curves using the average compressive strength values at the time of testing. The agreement between measured and computed ultimate resistance is within about 5% for the 30º skew test but is about 20% off for the 0º test. The initial stiffness was 50 to 100 times the compressive strength and the maximum strength was mobilized at 1.7 to 2.4% of the wall height. This displacement is lower than the 3-5% which has been observed for granular backfill materials but similar to the 0.75-2% displacement observed for conventional flowable fill backfills.  Fig. 3. Comparison of measured passive force-displacement curves for cellular concrete backfill with curves computed using the PYCAP computer program using the Rankine method with strength equal to one-half the compressive strength. |
| **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).**  Reports are being completed relative to the Phase I work tasks. The Phase II work plan for additional field testing with CLSM backfill and push-and-rotate tests was incorporated into a new contract amendment which extended the contract end date. |
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| **Potential Implementation:**  UDOT is considering early adoption of the skew reduction factor for passive force based on the laboratory and field test results. In June of 2013, 2014, and 2016, Dr. Rollins presented the results of the research to date to technical committees at the AASHTO Subcommittee on Bridges and Structures Annual Meetings in Oregon, Ohio, and Minnesota on behalf of the project TAC. This interaction is intended by the TAC and Dr. Rollins to prepare the way for design code revisions once the research is completed. Caltrans is also promoting use of the research results in their design methods. Dr. Rollins is proposing changes to the AASHTO code, and we will continue to promote these to the TAC and AASHTO SCOBS. |