**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, 2019) \_ Quarter 2 (April 1 – June 30, 2019)**x Quarter 3 (July 1 – September 30, 2019)**\_ Quarter 4 (October 1 – December 31, 2019) |
| **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 |
| **Lead Agency Project ID:**FINET 42051, ePM PIN 10903UDOT 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 31, 2019 | **Number of Extensions:**6  |

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) | $286,500.00 | 85% |

***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% | $0.00 | 95% |

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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 MeetingsPhase 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 codesDr. 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 – 100% complete. Completed work on RC Wingwall case.Task I-6 – 80% 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 previously***
* Passive force-deflection behavior of 5.5 ft abutments with longitudinal reinforced concrete wingwalls *–* ***draft received previously***
* Passive force-deflection behavior of 3.5 ft gravel and Geosynthetic Reinforced Soil (GRS) backfill with transverse wingwalls *–* ***draft received previously***
* Computer model calibration and parametric studies, Part 1 – Passive force-deflection modeling with no wingwall *–* ***draft received previously***
* Computer model calibration and parametric studies, Part 2 – Additional modeling with longitudinal reinforced concrete wingwalls, 45 degree skew, two-lane highway – ***draft received and shared with TAC for review***
* 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 – 90% complete.Task II-1 – 100% complete.Task II-2 – 90% complete. **Draft task report was shared previously with the TAC for review.**Task II-3 – 90% complete. **Draft task report was shared previously with the TAC for review.**Task II-4 – 90% complete. **Draft task report was shared previously with the TAC for review.**Task II-5 – Computer models are being incorporated in the other Phase II reports.Task II-6 – Simplified design models are being incorporated in the other Phase II reports.Task II-7 – None.Task II-8 – None.TAC Meetings – None this quarter.Contract – No changes this quarter. |
| **Anticipated work next quarter:**General plan: Complete, review, revise, and publish final reports from both phases.Task I-1 – None.Task I-2 – None.Task I-3 – None.Task I-4 – None.Task I-5 – None.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 – Prepare to publish a peer-reviewed paper on the study as a reference that could be noted in the AASHTO code. Task II-1 – None.Task II-2 – Receive TAC review comments on the task report and update the report.Task II-3 – Receive TAC review comments on the task report and update the report.Task II-4 – Receive TAC review comments on the task report and update the report.Task II-5 – Continue incorporating computer models in the other Phase II reports.Task II-6 – Continue incorporating simplified design models in the other Phase II reports.Task II-7 – Complete final summary report with design example.Task II-8 – None.TAC Meetings – Plan to hold a web conference TAC meeting to discuss new results, report reviews, and implementation.Contract – No changes planned. |

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| **Significant Results:**This quarter we are focusing attention on a shorter final report that will outline the results from all tests and provide overall summary plots with a simple design example. Fig. 1 shows a summary plot of the passive force reduction factors, Rskew, obtained from each field test conducted in this study, along with the proposed design curve. While there is scatter about the best-fit curve, the agreement is relatively good using this simple model.**Fig. 1 Skew reduction factor for passive force, Rskew, as a function of skew angle for all tests in this study.**The skew reduction factor, Rskew, is given by the equation, Rskew = Pp-skew/Pp-no skew (1)where Pp-skew is the peak passive force for a skewed abutment and Pp-no skew is the peak passive force for no skew. As illustrated in Fig. 1, the best-fit equation for Rskew is given by the simple equation, Rskew = e(-θ/45º) (2)where θ is the skew angle for the bridge. For skew angles less than 60º, Equation 2 gives nearly identical values to those obtained with the equation originally proposed by Rollins and Jessee (2013) based on large-scale laboratory tests in which Rskew was given by the polynomial equation, Rskew = 8x10-5 θ2 – 0.018 θ + 1.0 (3)Based on the results of this study, the Pp-no skew value for sand backfill compacted to 95% of the modified Proctor density can be reasonably estimated using the log-spiral method with a friction angle, ϕ, of approximately 40º, a cohesion of 80 psf, and a wall friction, δ, equal to approximately 0.70 ϕ. In addition, some adjustments are necessary for various wingwall conditions. For example, with wrap-around MSE wingwalls and tapered reinforced concrete wingwalls running parallel to the side of the roadway, field tests indicate that the shear planes are constrained to develop in a plane strain orientation. Therefore, the plane strain friction angle should be used to compute the peak passive resistance. The plane strain friction angle is typically about 10% higher than the triaxial friction angle. This would lead to a friction angle of about 44º for the compacted sand backfill with these wingwall geometries. For wingwalls which extend transverse from the direction of travel, research indicates that the shear planes behind the abutment extend significantly beyond the edge of the abutment thereby increasing its effective width. In these cases, reasonable agreement was obtained with measured passive force by increasing the effective width of the abutment, Be, using the equation,Be = BR3D (4)Where $R\_{3D}=\left[1++\left(K\_{p}-K\_{a}\right)^{0.67}\left(1.1A^{4}+\frac{1.6}{1+5\left(\frac{B}{H}\right)}+\frac{0.4 (K\_{p}-K\_{a}) A^{3}}{1+0.05\left(\frac{B}{H}\right)}\right)\right] $ (5)A = 1 – (H/z) (6)Kp and Ka are Rankine passive and active earth pressure coefficients, respectively, while B, H, and z are the abutment width, abutment height, and abutment embedment below the ground surface, respectively as illustrated in Fig. 2.

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| zAbutment BackwallHB**Figure 2 Illustration of variables defining abutment width, height, and depth of embedment for use in Equations 5 and 6.**  |

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| **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).**Contract end date was extended to December 2019 to allow for completion and TAC review of reports. |

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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. |