**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:** **x Quarter 1 (January 1 – March 31, 2020)** \_ Quarter 2 (April 1 – June 30, 2020)\_ Quarter 3 (July 1 – September 30, 2020)\_ Quarter 4 (October 1 – December 31, 2020) |
| **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:** May 31, 2020 | **Number of Extensions:**7  |

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 | 97% |

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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 were made.  |
| **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:**During this quarter progress was slowed due to the COVID-19 pandemic which impeded interactions with graduate students and support staff. However, some additional work has been completed related to summary plots of normalized passive pressure as a function of normalized displacement. In previous work normalized curves were computed for each test and plotted together. Then a generic curve shape was developed to provide a shape typical of the average curve based on a simple visual assessment. While the curve appeared to provide reasonable agreement with the measured curves, no statistical assessment was possible. To alleviate this problem, the individual data points from each of the 14 individual curves were separated out and sorted by displacement. Then mean and standard deviation bounds were computed for a significant number of displacement intervals to produce a mean normalized force vs. normalized displacement curve along with mean ± one standard deviation curves. To develop a generic curve shape for cases where the abutment height is variable, we have normalized the longitudinal deflection, Δ, by the abutment wall height, H, and we have normalized the passive force, P, by the peak passive force, Pmax. The resulting normalized passive force vs. normalized longitudinal displacement curves for 14 lateral abutment tests at various skew angles of 0°, 15°, 30° and 45° are plotted in Fig. 1. Despite the variation in skew angle, the variation in backfill height, and the variation in wingwall geometries (e.g. parallel, transverse, MSE), the standard deviation bounds form a relatively narrow band relative to the mean curve. The average coefficient of variation (COV), which is given by the standard deviation divided by the mean, is 0.11. The normalized passive force is between 92% and 98% between normalized displacements of 3% and 5%. This is consistent with the fact that peak passive force typically develops between a normalized displacement of 3% and 5%. The peak passive force tends to decrease somewhat at normalized displacements greater than about 5% with an average reduction of about 20%. However, it should be recognized that there are much fewer data points defining behavior beyond 5% displacement so these results should be viewed with some caution. Our experience is that soil compacted to more than 96 or 97 % of the modified Proctor maximum dry density will experience some decrease in passive force as a result of soil dilation during shearing. Two generic curve shapes have been developed to match the measured mean normalized passive force-normalized curve shape as shown in Fig. 1. The first curve shape is a hyperbola given by the equation $$\frac{P}{P\_{max}}= \frac{110 (∆/H)}{[0.6+\left(\frac{∆}{H}\right)]} $$where (P/Pmax) and (Δ/H) are both expressed as percentages. This is the same curve originally developed previously by eye from 10 curves. The agreement is very good with the computed curve following on top of the measured mean curve for almost all displacements up to 5% normalized displacements. Agreement is very good for displacements less than 2% of H but is slightly lower than the mean for higher displacements. However, the hyperbola equation is unable to capture the post-peak reduction in passive force.A second curve shape is given by a hyperbolic tangent given by the equation$$\frac{P}{P\_{max}}= 100 Tanh\left[0.71\left(\frac{Δ}{H}\right)\right]$$where (P/Pmax) and (Δ/H) are both expressed as percentages. This curve shape equation is somewhat simpler but does not fit the mean curve as well as the hyperbola equation. Relative to the measured curve, the hyperbolic tangent curve underestimates measured passive force for normalized displacements less than 1.2% and overestimates for higher values. Based on this comparison, the hyperbola equation is the superior curve for predicting passive force development with displacement. **Fig. 1 Normalized passive force vs. normalized longitudinal displacement curves for 14 large-scale abutment lateral load tests conducted during this study along with two possible generic curve shapes.**All analysis has now been completed to allow preparation of a final summary paper describing the overall testing program and test results. |
| **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 May 2020 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. |