**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(433)** | | **Transportation Pooled Fund Program - Report Period:**  \_ Quarter 1 (January 1 – March 31, 2023)  **x Quarter 2 (April 1 – June 30, 2023)**  \_ Quarter 3 (July 1 – September 30, 2023)  \_ Quarter 4 (October 1 – December 31, 2023) | |
| **Project Title:**  Behavior of Reinforced and Unreinforced Lightweight Cellular Concrete for Retaining Walls | | | |
| **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 42096, ePM PIN 17824  UDOT PIC No. UT18.404 | **Other Project ID (i.e., contract #):**  UDOT Contract No. 20-9367 | | **Project Start Date:**  May 21, 2020 (contract) |
| **Original Project End Date:**  September 30, 2022 (scope) | **Current Project End Date:**  September 30, 2023 (scope) | | **Number of Extensions:**  2 |

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** |
| Total commitments = $337,500.00  Obligated to date = $337,500.00  (incl. $7,500 state match on FHWA contrib.)  Contract amount = $325,578.00  Remaining on contract = $129,765.00 | Contract spent = $195,813.00  Contract support = $428.01  Total spent = $196,241.01 | 75% |

***Quarterly*** Project Statistics (on this contract):

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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 | 93% |

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| **Project Description**:  Roadway widening over existing walls and embankments, conflicts with settlement-sensitive utilities, and accelerated schedule delivery have increased demands for alternative lightweight fill materials. Engineers and contractors are increasingly considering Lightweight Cellular Concrete (LCC) backfills for abutments, embankments, and Mechanically Stabilized Earth (MSE) retaining walls; however, the absence of a consistent design methodology has led to a wide range of design approaches with no consensus standard. The most common class of LCC used in previous highway projects does not strictly behave like a soil or like concrete and must be investigated as a new material for engineering applications. Controversy exists within the industry regarding whether LCC should be modeled as a frictional or a cementitious (cohesive) material. In addition, earth pressures for retaining wall design and potential failure mechanisms of LCC are poorly understood for retaining wall applications, including uncertainty in LCC interaction with internal wall reinforcement in MSE wall applications.  Objective: Measure engineering design parameters and failure mechanisms for unreinforced and reinforced LCC backfills based on large-scale laboratory tests.  Funded tasks for this study include the following:  1. Literature review and survey  2. Basic material properties lab testing  3. Unreinforced LCC large-scale testing  4. Reinforced LCC large-scale testing:   * Reinforced LCC Test 1 – MSE wall with LCC backfill, * Reinforced LCC Test 2 – MSE wall with LCC backfill against soil slope, * Reinforced LCC Test 3 – MSE wall test with lower strength LCC backfill, * Reinforced LCC Test 4 – Pull-out tests on MSE wall, and * Reinforced LCC Test 5 – MSE wall test with welded-wire reinforcement   5. Compare results with design methods  6. Final Reports for (a) the unreinforced LCC test and (b) the reinforced LCC tests  7. Meetings and dissemination of results  The Principal Investigators for this study are Dr. Kyle Rollins of Brigham Young University and Ryan Maw, a principal engineer at Gerhart-Cole, Inc. The technical advisory committee (TAC) for the study currently includes representatives from UT, CA, KS, LA, MI, NY, OR, and WA state DOTs and FHWA. TAC meetings will be held periodically during the study and are currently planned to be web conferences. |

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| **Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):**  **Task 1** – 60% complete. Continued the literature review and survey.  **Task 2** – 100% complete.  **Task 3** – 100% complete.  **Task 4** – 100% complete.  **Task 5** – 50% complete. Continued work on Detailed Interim Reports including key parameters from the reinforced tests. Design comparison was found to be challenging. TAC reviewed the interim report on the first MSE LCC test. Conducted additional pull-out tests at high confining pressure to evaluate slope stability methods for internal stability.  **Task 6** – 50% complete. TAC reviewed the Draft Final Report for the unreinforced LCC test.  **Task 7** – 50% complete. No TAC meetings were held this quarter.  **Contract** – No changes were made. |
| **Anticipated work next quarter**:  **Task 1** – Continue the literature review and survey.  **Task 2** – Completed.  **Task 3** – Completed.  **Task 4** – Completed.  **Task 5** – Continue work on Detailed Interim Reports including key parameters from the reinforced tests. Address TAC comments in the updated interim report on the first MSE LCC test.  **Task 6** – Address TAC comments in the updated Final Report for the unreinforced LCC test. Work on the Draft Final Report for the reinforced LCC tests.  **Task 7** – Hold another TAC update meeting (virtual) after more reports are completed.  **Contract** – No changes to the contract are planned. |

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| **Significant Results:**  Additional study reports are being prepared for TAC review. The plan and status for the study reports are shown below:   * **Short Interim Reports: (to post final on TPF website; BYU’s format; UDOT won’t publish)**   + Unreinforced LCC testing (posted on TPF website)   + Reinforced LCC Test 1 – MSE wall with LCC backfill (posted on TPF website)   + Reinforced LCC Test 2 – MSE wall with LCC backfill against soil slope (posted on TPF website)   + Reinforced LCC Test 3 – MSE wall test with lower strength LCC backfill (posted on TPF website)   + Reinforced LCC Test 4 – Pull-out tests on MSE wall (posted on TPF website)   + Reinforced LCC Test 5 – MSE wall test with welded-wire reinforcement (posted on TPF website) * **Detailed Interim Reports: (to post final on TPF website; BYU’s format; UDOT won't publish)**   + 1st MSE LCC test (draft received and in TAC review)   + Sliver fill MSE LCC test (Draft completed-submitted in next two weeks)   + Pull-out resistance (draft almost ready)   + Slope stability (draft almost ready)   + Lower strength MSE LCC test (draft ready in 2-3 months)   + Welded wire reinforcement (draft ready in 2-3 months) * **Short Report: (to post final on TPF website; BYU’s format; UDOT won't publish)**   + Pile lateral analysis in MSE LCC * **Final Reports: (to post final on TPF website; UDOT’s format; UDOT will publish)**   + Unreinforced LCC RCC tests (draft received and in TAC review)   + Reinforced LCC tests (Lit. review, summary of all reinforced tests, comparison of all tests, pull-out resistance, and slope stability) (draft ready in 3 to 6 months)   In the previous quarter the research team completed six pull-out tests at high confining pressures of (4000 to 9800 psf) to define the friction coefficient, F\*, for use in slope stability analyses of LCC. Previously, our pull-out test data set only had tests with a maximum vertical pressure of 1400 to 1800 psf on the reinforcements (46 to 60 ft of LCC self-weight). In contrast, the maximum pressure during failure of the reinforced LCC in the large box was five times this value (about 9500 psf). To obtain a factor of safety of 1.0 in the slope stability model when the surcharge pressure was equal to that in the box, we previously found that the F\* value had to be reduced relative to that for a pressure of 1400 psf. These additional tests made it possible to confirm the reduced F\* by direct measurements.  Fig. 1 shows a photograph of the pull-out load test arrangement. The reaction beam made it possible to apply vertical pressures of 4000 to 10,000 psf to the LCC blocks during pullout testing. Pull-out tests were performed on three ribbed-strip reinforcements and three welded-wire reinforcements. Test results and F\* values for the ribbed-strip reinforcements were provided in the previous quarterly report. This report provides similar results for the welded-wire reinforcements.  Fig. 2 provides a plot of the F\*(St/t) versus vertical pressure data points for all the pull-out tests of welded-wire reinforcements conducted in LCC by BYU over a wide range of pressures as part of this study. In addition, F\*(St/t) data is also plotted from tests conducted by SSL, Inc. To facilitate comparisons between the various tests with different cross-bar spacings (St) and cross-bar diameters (t), F\* values have been normalized by dividing by the ratio t/St. The results from the SSL, Inc. tests follow the trend from the BYU tests but are higher than those from BYU because of the low vertical stresses associated with their tests. The F\*(St/t) decreases from 100 to 10 as vertical stress increases to 1000 psf, then drop below 5.5 at pressures greater than about 3000 psf. The most recent tests at pressures between 5000 and 9800 psf indicate that the F\* value continues to decrease gradually with increasing pressure and reaches a value of about 2 at 10,000 psf. A tentative lower bound curve defining the variation of F\* with pressure is also provided in Fig. 2 composed of linear segments. However, an equation for a continuous curve is being considered.    **Fig. 1. Photo of the pull-out load test on ribbed-strip and welded-wire reinforcements from LCC blocks. Vertical pressure was applied to the LCC blocks with a hydraulic jack at the top of conventional reinforced concrete blocks that were 2 feet wide and 10 ft long. A reaction beam was positioned over the center of each block. This was the same loading system used for the tests in the box.**    The back-calculated F\*(St/t) values obtained with the slope stability program UTEXAS4 are also plotted in Fig. 2 at the pressure range in the 10 ft wide x 13 ft long x 10 ft tall test box with welded-wire reinforcement when slope failure occurred. For this condition, the factor of safety against failure can be assumed to be 1.0. The back-calculated F\*(St/t) values from the slope stability calculations are in very good agreement with the measured pull-out resistance tests. This agreement strongly suggests that the slope stability approach, using appropriate F\*(St/t) values for the reinforcements, can provide a viable method for predicting failure of an MSE wall with surcharge loadings.  It should be noted that the strength of the LCC in the slope stability calculations was defined using a friction angle (ϕ ) of 34° and a drained cohesion of 1600 psf. These strength properties are consistent with average values for Class II LCC (Tiwari et al. 2017). They are also consistent with strength properties when the slope stability program produced a factor of safety of 1.0 at failure for the unreinforced LLC wall in the large-scale tests. Of course, lower cohesion values, even zero, could be assumed to provide a more conservative design in practice.  Fig. 3 provides a plot of F\* (St/t) versus vertical pressure data points for pressures less than 1600 psf which is the vertical pressure produced by a 60 ft high LCC wall. A comparison plot of a typical AASHTO F\* vs. vertical pressure curve for soil is provided relative to our suggested curve for LCC. The pull-out tests for LCC show higher values than those for soil at vertical pressures less than about 1000 psf, but are quite similar to curves for soil from 1000 to 1600 psf. The reduction in F\*(St/t) with pressure observed at higher pressures in Fig. 2 are relatively inconsequential for pressures less than 1600 psf.        **Fig. 2 Plots of F\*(St/t) vs. vertical pressure for welded-wire reinforcements obtained from pull-out tests conducted by BYU and SSL, Inc. for vertical pressures from 0 to 10,000 psf. Tentative design curves are provided that envelope the lowest measured values. A back-calculated F\*(St/t) value obtained from a slope stability calculation with a factor of safety of one from the large-box test also plotted and are in excellent agreement with the measured F\*(St/t) values from the pull-out tests.**    **Fig. 3. Comparison of F\*(St/t) vs. vertical pressure curves for welded-wire reinforcements in LCC and conventional soil backfill at pressures less than 1600 psf.** |
| **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).**  No delays at this time. Testing and analysis for this research has been allowed to continue at BYU with additional health precautions related to COVID-19. |

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| **Potential Implementation:**  None yet. |