**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)  \_ Quarter 2 (April 1 – June 30, 2023)  **x 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:**  March 31, 2024 (scope) | | **Number of Extensions:**  3 |

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 | 80% |

***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 | 87% |

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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.  **Task 6** – 50% complete.  **Task 7** – 50% complete. No TAC meetings were held this quarter.  **Contract** – The contract scope of work end date was extended to March 2024. |
| **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. **Discuss with the TAC whether LCC backfill should be designed with cohesion, and incorporate TAC input in the study reports.**  **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 reviewed by TAC)   + Sliver fill MSE LCC test (Draft completed – to be submitted in Oct. 2023)   + Pull-out resistance (draft almost ready)   + Slope stability (draft almost ready)   + Lower strength MSE LCC test (draft ready in Oct. 2023)   + Welded wire reinforcement (draft almost ready) * **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 reviewed by TAC)   + Reinforced LCC tests (Lit. review, summary of all reinforced tests, comparison of all tests, pull-out resistance, and slope stability) (draft ready in a couple of months)   In the third quarter we continued working on the detailed interim reports for each of the large box tests. One more was completed in the third quarter, and we are expecting that two more will be completed in the fourth quarter.  In reviewing the pullout resistance factors (F\*) for all of the pullout testing performed in this study, we typically found that F\* decreased with increasing vertical stress but in a non-linear fashion. To provide a roughly lower-bound value for F\* vs. pressure we resorted to using several different straight-line segments which would require different equations for each pressure increment. To overcome this problem, we have explored the possibility of producing one equation to define the F\* vs. pressure curves over the entire pressure range. This greatly simplifies the calculation process relative to multiple straight-line segments.  Fig. 1 provides a plot of the F\*(St/t) versus vertical pressure data points for all the pull-out tests on 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 reach a value of about 2 at 10,000 psf. A proposed lower bound curve defining the variation of F\* with pressure is also provided in Fig. 1 and a single equation defining this curve is shown on the plot.    **Fig. 1 Plot of apparent friction coefficient (F\*) vs. vertical pressure for Welded-Wire reinforcements.**  Fig. 2 provides a plot of F\* versus vertical effective pressure data points for the ribbed strip pullout tests in Class II LCC performed by BYU as well as those performed by the Univ. of Kansas that have been previously published. The vertical pressures for the pullout tests range from very low values to nearly 9000 psf. The test results from BYU and the Univ. of Kansas are in good agreement as noted previously. A proposed lower bound design curve defining the variation of F\* with vertical pressure is also provided in Fig. 2 along with a single equation to define the variation shown in the test results. As in previous work involving pullout resistance with soils, the lower bound curve has been used to provide a conservative assessment of F\* considering the variation in F\* that is observed particularly at low vertical stresses or shallow depths. Use of a single equation simplifies the selection of an appropriate F\* value in comparison with the multiple line segments that were provided in previous quarterly reports.    **Fig. 2 Plot of apparent friction coefficient (F\*) vs. vertical pressure for Ribbed-Strip reinforcements.** |
| **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 were allowed to continue at BYU with additional health precautions related to COVID-19. |

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