**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, 2020)  \_ Quarter 2 (April 1 – June 30, 2020)  \_ Quarter 3 (July 1 – September 30, 2020)  **x Quarter 4 (October 1 – December 31, 2020)** | |
| **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 | **Current Project End Date:**  September 30, 2022 | | **Number of Extensions:** |

Project schedule status:

**X** On schedule \_ 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 = $290,003.00  Remaining on contract = $250,878.00 | Contract spent = $39,125.00  Contract support = $70.41  Total spent = $39,195.41 | 25% |

***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 | 28% |

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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 walls on both sides of LCC and overlapping reinforcements, and * Reinforced LCC Test 4 – Pull-out tests on MSE wall.   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** – 20% complete. Started the literature review and prepared a survey.  **Task 2** – 60% complete. The BYU research team worked on improving the quality control procedure for preparing and placing the LCC for the large-scale testing. They completed LCC material properties lab testing for another iteration of Reinforced LCC Test 1 using lower-strength LCC.  **Task 3** – 100% complete.  **Task 4** – 60% complete. Completed tests with LCC against a soil slope. Completed the large-scale testing for another iteration of Reinforced LCC Test 1 using lower-strength LCC for comparison. This test replaced Reinforced LCC Test 3. BYU prepared and submitted an interim report with preliminary results from the Reinforced LCC Test 2.  **Task 5** – Not started.  **Task 6** – Not started.  **Task 7** – We held a TAC update meeting via web conference in November. In this meeting Dr. Rollins shared additional test results collected to date and gathered input from TAC members on upcoming testing configurations.  **Contract** – No changes were made, although BYU and UDOT prepared to make needed changes. Dr. Rollins collected additional input from TAC members regarding some options for the remaining testing configurations that would be most meaningful to the group and possible based on the lab availability. Based on TAC input, Dr. Rollins informed us that they would be performing a large-scale test for an MSE wall LCC backfill reinforced with welded-wire grids (as a new Reinforced LCC Test 5), and this testing would be performed when the backfill reaches an average UCS of about 100 psi to provide more direct comparisons with the majority of the previous tests. In addition, they would perform 12 pull-out tests using ribbed strips as well as some welded wire grids as part of Reinforced LCC Test 4. |
| **Anticipated work next quarter**:  **Task 1** – Continue the literature review and survey.  **Task 2** – Complete LCC material properties lab testing for Reinforced LCC Tests 4 and 5.  **Task 3** – Completed.  **Task 4** – Complete large-scale testing for Reinforced LCC Test 4 (modified) and Test 5 (additional). Prepare and submit interim reports with preliminary results from the Test 3 (replacement), Test 4, and Test 5.  **Task 5** – Start this task.  **Task 6** – None.  **Task 7** – Schedule or hold a TAC web conference to discuss the most recent testing results.  **Contract** – Modify the contract to include additional scope and funding for additional large-scale testing, based on input from the TAC members. This will include the Reinforced LCC Test 3 replacement, Test 4 modification, and Test 5 addition. Funding would come from a portion of the committed and transferred pooled funding that is not yet on contract. |

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| **Significant Results:**  In the 4th quarter of 2020, we conducted two tests with MSE wall panels with reinforced LCC backfill. The first test involved a “sliver fill” where the LCC was placed over a slope consisting of silty sand as shown in Fig. 1. An interim report with the preliminary results of this test has been posted on the TPF website. Some highlights from that report are included in this report.  .    Fig. 1. Schematic profile drawing of the test involving MSE wall with sliver fill of reinforced LCC adjacent to 1:1 stair-stepped silty sand slope. Note: MSE reinforcements in red along with vertical and horizontal corrugated Sondex pipes shown by dashed black rectangles.  Prior to LCC placement, a stair-stepped silty sand slope (1H:1V) was constructed. The silty sand was non-plastic and was compacted to 95% of the standard Proctor density at an optimum moisture content of 8%. Classifying as SM or A-4 material, the backfill consisted of about 40% silt and 60% sand with a coefficient of uniformity (Cu) of 14.8 and a coefficient of curvature (Cc) of 2.8.    The MSE wall panels were nominally 5 ft tall by 10 ft wide and 0.5 ft thick. Reinforcements consisted of ribbed-strip reinforcements that were 50 mm wide and 5 mm thick, provided by Reinforced Earth Company (RECo). The top two reinforcements were 8 ft long while the third and fourth reinforcements were 7.42 and 4.92 feet long, respectively. The cellular concrete, provided by Cell-crete, had an average cast unit weight of 31 lbs/ft3 and an unconfined compressive strength (UCS) of about 145 psi at the time of the load test. The cellular concrete was placed in about 36 inch-thick lifts to a height of 10 feet behind the MSE wall panels over a three-day period (one pour per day).  Six Geokon pressure cells were placed at approximately 1.5 ft vertical intervals on the back face of the MSE wall panels to monitor interface pressure on the wall during the backfill placement, curing, and surcharge loading. Displacement of the MSE wall panels, the top of the LCC backfill and the test box was monitored using a series of string potentiometers from fill placement to failure that were connected to a data acquisition system. A digital image correlation (DIC) system was also used to monitor the deflection of the MSE wall panel face to create a color contour map of wall displacements. Three vertical and three horizontal corrugated plastic Sondex pipes were installed in the backfill, as shown in Figure 1. These pipes made it possible to monitor lateral and vertical displacements within the backfill at 0.5 ft intervals. Finally, at the conclusion of the test, the sides of the box and the surcharge panels were removed to identify shear plane and crack patterns in the LCC.    We applied the surcharge load incrementally at 25,000 lbs to 50,000 lbs load increments or 2.0 to 4.0 psi pressure increments. For this test, the load was applied to the first four surcharge blocks (8 ft) adjacent to the MSE wall as illustrated schematically in Fig. 1. This deviation from previous tests, which involved surcharge over a 6 ft width, was intended to place the failure surface in the LCC closer to the interface between the soil slope and LCC. However, it reduced the maximum surcharge pressure that could be applied without damaging the load frame to about 55 psi. The load was quite uniformly distributed over the four blocks in each case, but each block was free to settle independently.  **Test Results**  A plot of the applied surcharge pressure versus axial displacement is provided in Fig. 2. The curve is relatively linear but does exhibit some non-linear behavior initially. At the maximum pressure that could be applied with four surcharge beams (55 psi) there was no sign of failure, therefore, the surcharge pressure was reduced to three surcharge beams (6 ft width) so that the pressure could be increased to a maximum pressure of 70 psi. Maintaining the pressure at 70 psi led to increased displacement reaching 1 inch or about 1% axial strain.    Fig. 2. Applied surcharge pressure versus axial displacement for the sliver fill test.  In previous testing, significant axial displacements occurred at 62 to 67 psi as axial strains reached about 1 to 1.25%. Therefore, we were likely approaching incipient failure, in this case. We expect that the higher pressure required to induced significant vertical displacement is a result of the higher compressive strength (145 psi vs. 100 psi) of the LCC in this test.  Fig. 3 shows a comparison of the surcharge pressure vs. axial strain curves for the RCC, MSE, and the MSE sliver fill tests. The curves are remarkably similar for these three tests up to a surcharge pressure of about 50 psi, although there is a little more settlement for the sliver fill test at a given pressure, presumably because of compressibility of the underlying soil. Beyond a surcharge pressure of 50 psi, the sliver fill experiences less axial displacement than the other curves because a failure state had not been reached. This is likely a result of the fact that the unconfined compressive strength of the LCC backfill for the sliver test was higher than for the other tests (145 psi vs. 100 psi) as discussed previously.    Fig. 3 Comparison of applied surcharge pressure vs. axial displacement for LCC backfill tests with a reinforced concrete cantilever wall (RCC), MSE wall, and a MSE wall with a sliver fill.  A plot of applied surcharge pressure vs. lateral wall displacement is provided in Fig. 4 for the sliver fill test. Almost no displacement occurs until a surcharge pressure of 12 psi and then the curve became relatively linear. At the maximum pressure that could be applied with four surcharge beams (55 psi) there was no indication of failure, therefore, the surcharge pressure was reduced to three surcharge beams (6 ft width) so that the pressure could be increased to a maximum pressure of 70 psi. Maintaining the pressure at this level led to increased displacement reaching about 0.5 inch.  Fig. 5 provides a comparison of the surcharge pressure vs. lateral wall displacement for the RCC, MSE wall, and the MSE sliver fill tests. The initial pressure vs. displacement curves are very similar for all three tests up to a pressure of about 45 psi. Wall deflection begins to develop at a surcharge pressure of about 12 to 16 psi and the stiffness for all tests is essentially linear up to a surcharge pressure of about 45 psi. At this point, the RCC wall begins displacing more rapidly and reaches a peak strength of 63 psi where failure occurs (displacement increases with no increase in strength). The MSE wall develops additional resistance up to a peak of 67 peak and then experiences some post-peak decrease in strength as wall displacement accelerates. The sliver fill, with a higher unconfined compressive strength (145 psi vs. 100 psi), does not begin to reach a peak until surcharge pressure or 70 psi. It should be noted, that the surcharge pressure at failure in all cases was considerably lower than the unconfined compressive strength.    Fig. 4. Applied surcharge pressure vs. lateral displacement at the MSE wall for the sliver fill test.    Fig. 5. Comparison of applied surcharge pressure vs. lateral displacement for LCC backfill tests with a reinforced concrete cantilever wall (RCC), MSE wall, and a MSE wall with a sliver fill. |
| **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 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. |