TPF-5(433) Behavior of Reinforced and Unreinforced Lightweight Cellular Concrete (LCC) For Retaining Walls

Interim Report on Test of MSE Wall with Soil Slope and Sliver Fill of Reinforced Lightweight Cellular Concrete

Prepared by

Prof. Kyle M. Rollins

Civil & Environmental Engineering Dept.
Brigham Young University
430 EB, Provo, UT 84602

Prepared for

David Stevens, Project Manager

Research & Innovation Division
Utah Department of Transportation
4501 S. 2700 W.
Salt Lake City, UT 84114

October 20, 2020

Background

This test is the second MSE wall test conducted with reinforced lightweight cellular concrete (LCC) backfill under Transportation Pooled Fund Study TPF-5(433). This test involved a 1:1 slope of silty sand with a sliver fill of reinforced LCC behind MSE wall panels. Previous tests were performed using unreinforced LCC backfill behind a reinforced concrete cantilever (RCC) wall as well as an MSE wall with reinforced LCC backfill. Comparisons to the MSE LCC backfill tests are discussed subsequently.

Test Set-up

A schematic profile drawing of the test box is shown in Fig. 1. The box is 10 ft tall x 12.5 ft long x 10 ft wide. Three steel braced walls around the box were stiff enough to constrain lateral movements to less than 0.15 inch at the maximum expected surcharge load of about 64 psi (7200 psf) based on SAP2000 analyses of the steel frame. The test box was designed so that we could apply load independently to six stiff concrete beams (2 ft wide by 10 ft long) using independently activated hydraulic jacks with load cells. 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 (C_u) of 14.8 and a coefficient of gradation (C_c) 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 reinforcement 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/ft^3 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.

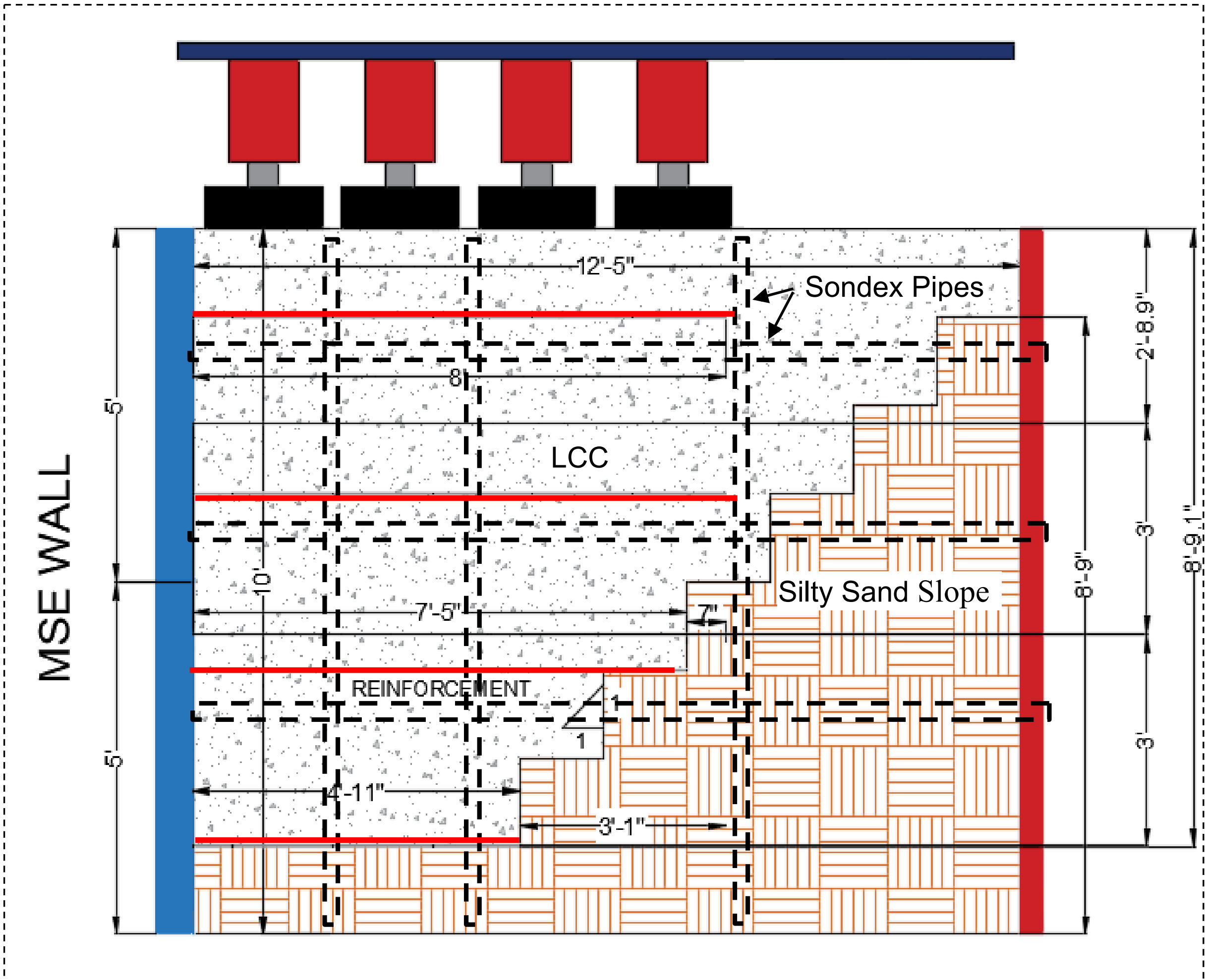

Fig. 1. Schematic profile drawing of the test involving MSE wall with sliver fill of reinforced LCC adjacent to 1:1 stair-stepped silty sand slope. Note: MSE reinforcements in red along with vertical and horizontal corrugated Sondex pipes shown by dashed black rectangles.

Loading Procedure

Photographs of the test box just prior to surcharge loading of the sliver fill are provided in Fig. 2. For each test, 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.. Displacement of each block was monitored with three string potentiometers attached to an independent reference frame. Settlement decreased slightly towards the sides of each block and with distance behind the MSE wall face.

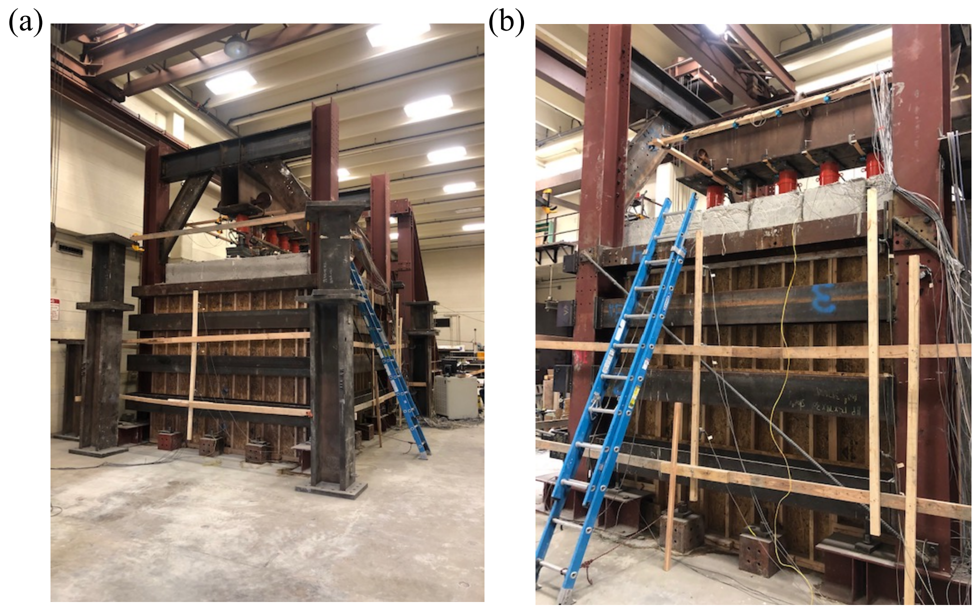

Fig. 2 Photographs showing: (a) the test box from the short side opposite from the retaining wall and (b) the test box from the long side with the concrete surcharge blocks and hydraulic jacks reacting against a longitudinal beam consisting of two deep beams.

Test Results

A plot of the applied surcharge pressure versus axial displacement is provided in Fig. 3. 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.

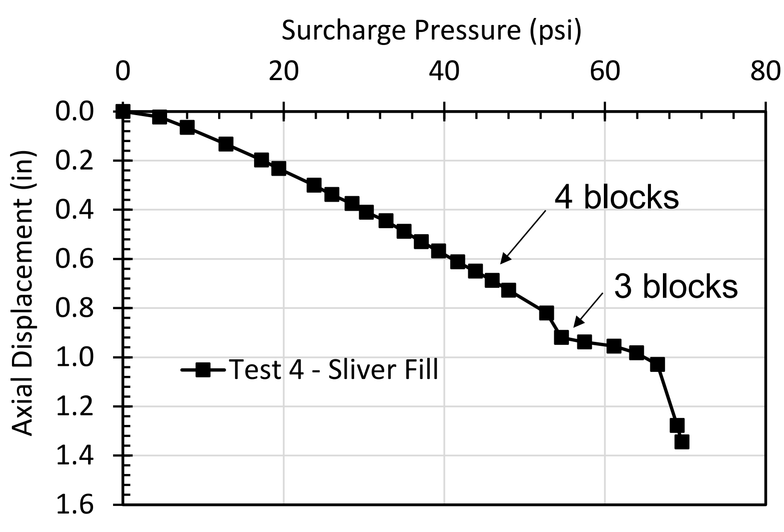

Fig. 3. Applied surcharge pressure versus axial displacement for the sliver fill test.

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. 4 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 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.

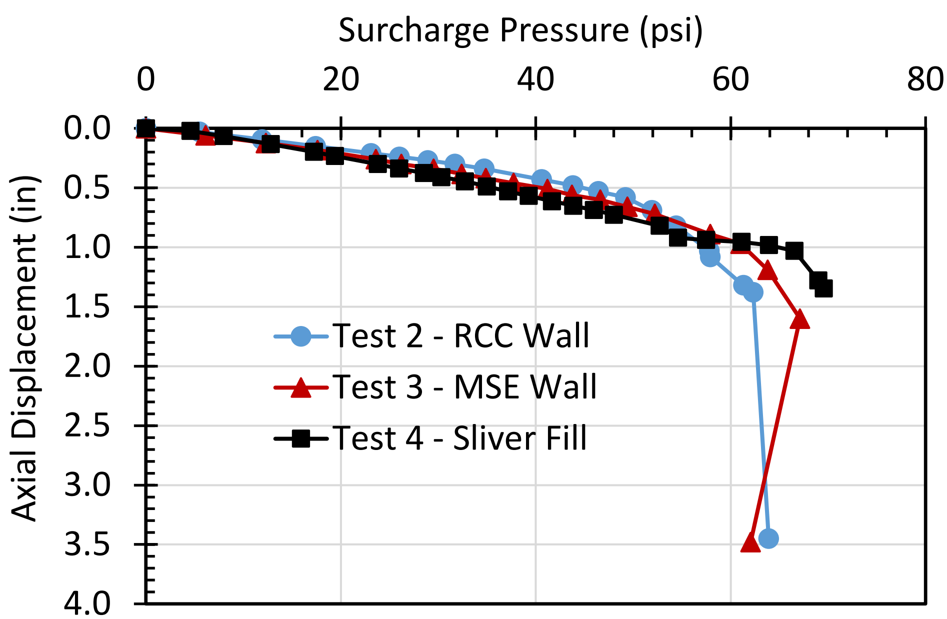

Fig. 4 Comparison of applied surcharge pressure vs. axial displacement for LCC backfill tests with a reinforced concrete cantilever wall (RCC), MSE wall, and a MSE wall with a sliver fill.

A plot of applied surcharge pressure vs. lateral wall displacement is provided in Fig. 5 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.

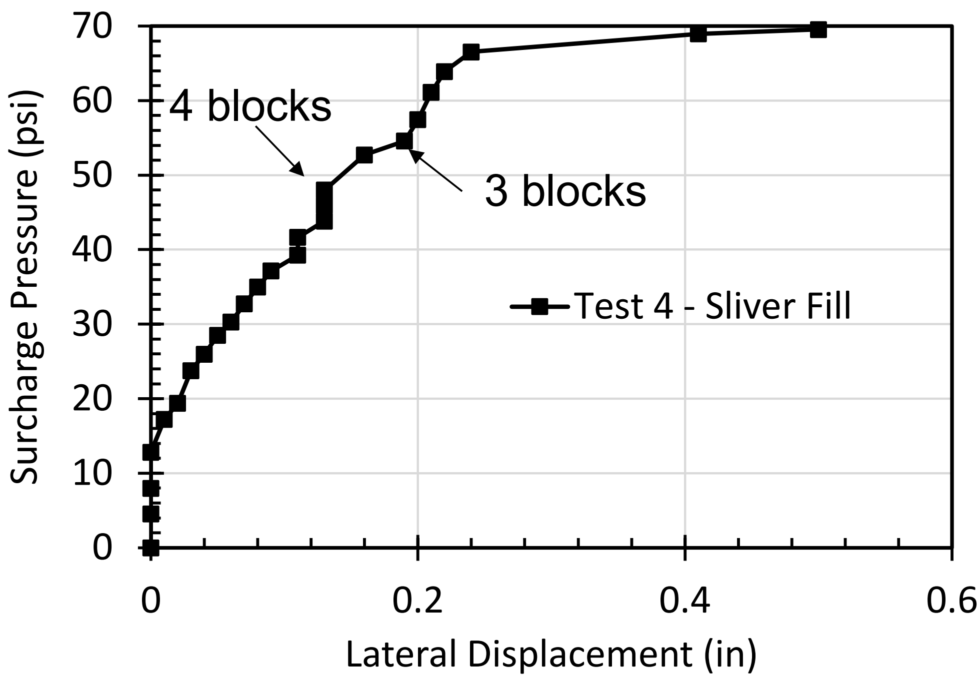

Fig. 5. Applied surcharge pressure vs. lateral displacement at the MSE wall for the sliver fill test.

Fig. 6 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. 7 provides plots of the measured horizontal pressure on the MSE wall vs. depth for the sliver fill test at selected applied surcharge pressures. The pressures are based on the measurements from the Geokon pressure plates. As the surcharge pressure increases, the pressures on the wall increase, but then appear to stabilize, for the most part, until surcharge pressure exceeded 55 psi. We speculate that the initial horizontal pressure produced enough wall deflection to mobilize the resistance of the reinforcements which then picked up the additional load on the MSE wall panels.

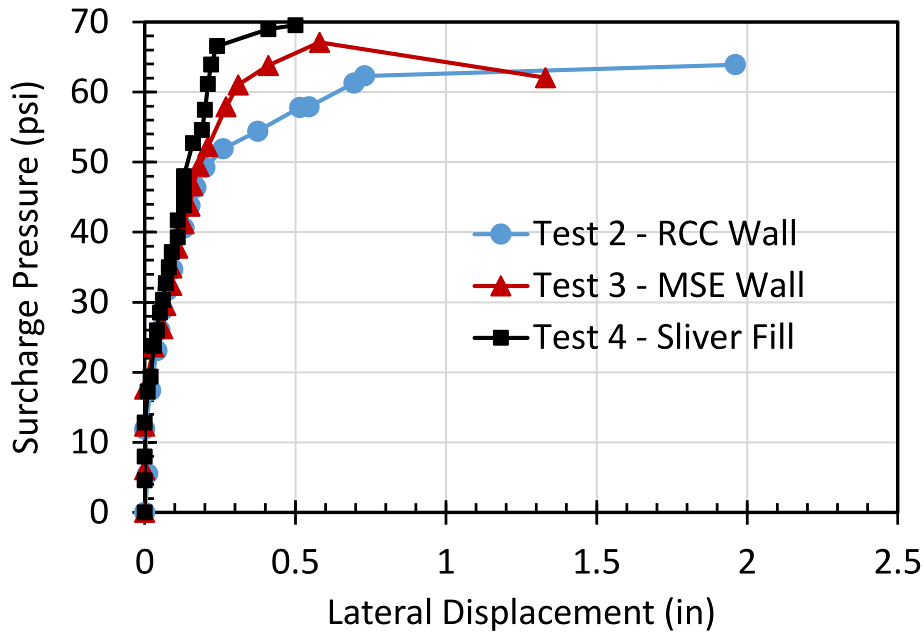

Fig. 6. Comparison of applied surcharge pressure vs. lateral displacement for LCC backfill tests with a reinforced concrete cantilever wall (RCC), MSE wall, and a MSE wall with a sliver fill.

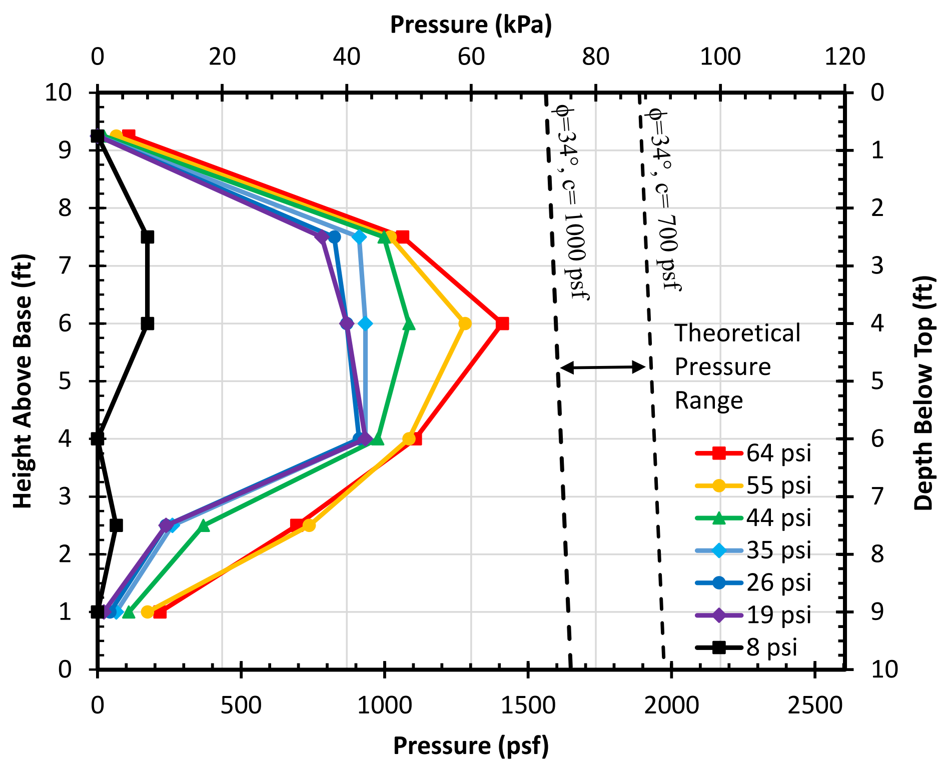

Fig. 7. Horizontal pressure on the MSE wall vs. depth curves for selected applied surcharge pressure values near the wall during the MSE sliver fill test from Geokon pressure plates.

Recent investigations by Tiwari et al. (2018) and Black (2018) have concluded that the shear strength of Class II LCC can be approximated using a friction angle (ϕ) of 34° and a cohesion ranging from 700 to 1000 (Black 2018) or 700 to 1600 psf (Tiwari et al. 2018). If this strength model is adopted, then the horizontal pressure (σ_h) versus depth on the wall due to the LCC during surcharge loading can be computed using the equation

$$\sigma_h = \gamma z K_a + q K_a - 2cK_a^{0.5} \quad (1)$$

where $K_a=\tan^2(45-\phi/2)$, $\phi=34^o$, c=700 to 1000 psf, $\gamma=27$ lbs/ft^3, q=surcharge pressure, and z=depth below the ground surface. The range of theoretical horizontal pressures (c = 700 to 1000 psf) on the MSE wall computed using Equation 1 is plotted relative to the measured horizontal pressure in Fig. 7. In the LCC test with the RCC wall, the pressures on the retaining wall approached the limits of the theoretical pressure curves. However, for the MSE sliver fill test, the pressures on the MSE wall panels on average were only about half of the pressure on the RCC wall. Because lateral resistance for an MSE wall is largely designed to be produced by the reinforcements, not the wall, this result is consistent with expectations for this system.

Based on the string potentiometer measurements on the front face of the MSE wall panels, horizontal wall deflection has been plotted as a function of height above the base of the wall for selected surcharge pressures in Fig. 8. The string pots were located at the height of the MSE reinforcement connections. All wall displacements were less than about 0.25 inch for surcharge pressures up to 64 psi. At the peak surcharge pressure of 70 psi, wall deflection exceeded 0.50 inch with the maximum value at the joint between the two wall panels with deflection of about 0.1 inch at the bottom. Overall, displacements of the top panel were greater than those on the bottom panel.

Fig. 9 provides an elevation view of the sliver fill and soil slope along with three plots of settlement vs. depth obtained from the vertical Sondex pipes. For the two pipes under the area loaded by the surcharge, the settlement in the soil below a depth of 8.75 feet is approximately 0.5 inch which equates to a strain of about 3.33%. In addition, settlement in the LCC contributed an additional 0.8 inches of settlement or about 0.75% strain. In contrast, the total settlement in the Sondex just beyond the loaded area was only about 0.5 inches.

Fig. 10 provides an elevation view of the sliver fill and soil slope along with three plots of elongation vs. horizontal distance obtained from the horizontal Sondex pipes. The measured elongation is close to zero from the back side of the box through the soil slope and into the LCC fill for all three profiles. However, at some point along the Sondex pipe, the elongation increases markedly likely indicating the boundary of the failure wedge where tensile stress develops in the LCC. This boundary is identified versus depth by the dashed red curve which extends from the back of the loaded area to the toe of the wall entirely within the LCC backfill. This plot indicates that there is no substantial offset along the interface between the soil slope and the LCC backfill in this test.

(a) (b)

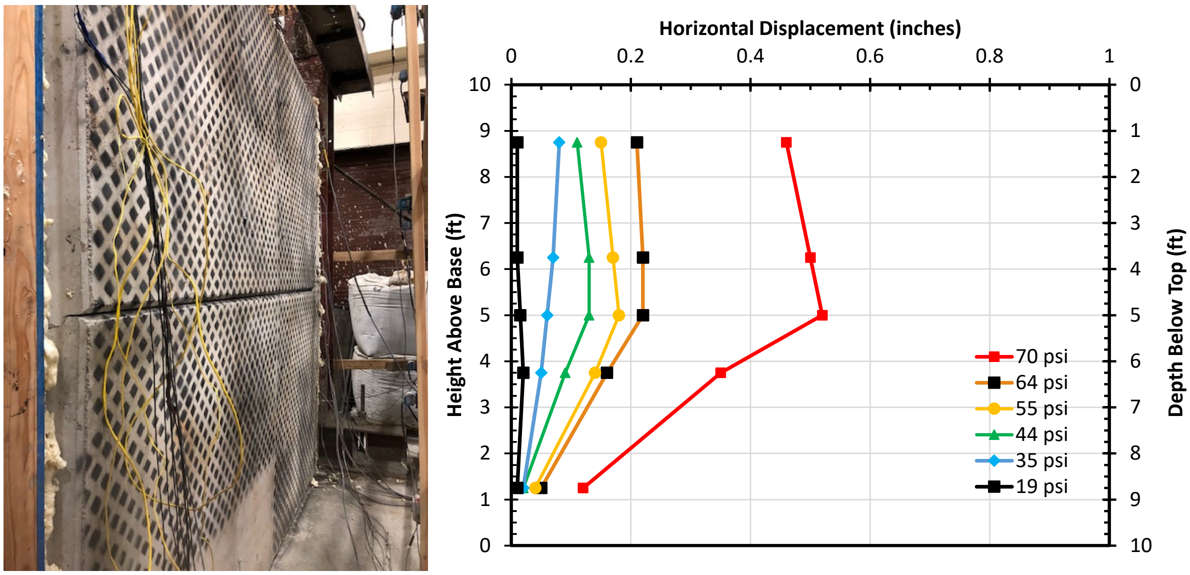

Fig. 8 (a) photograph of MSE wall panel deflection at failure, and (b) measured horizontal deflection of the wall versus height above the base of the wall for selected surcharge pressures.

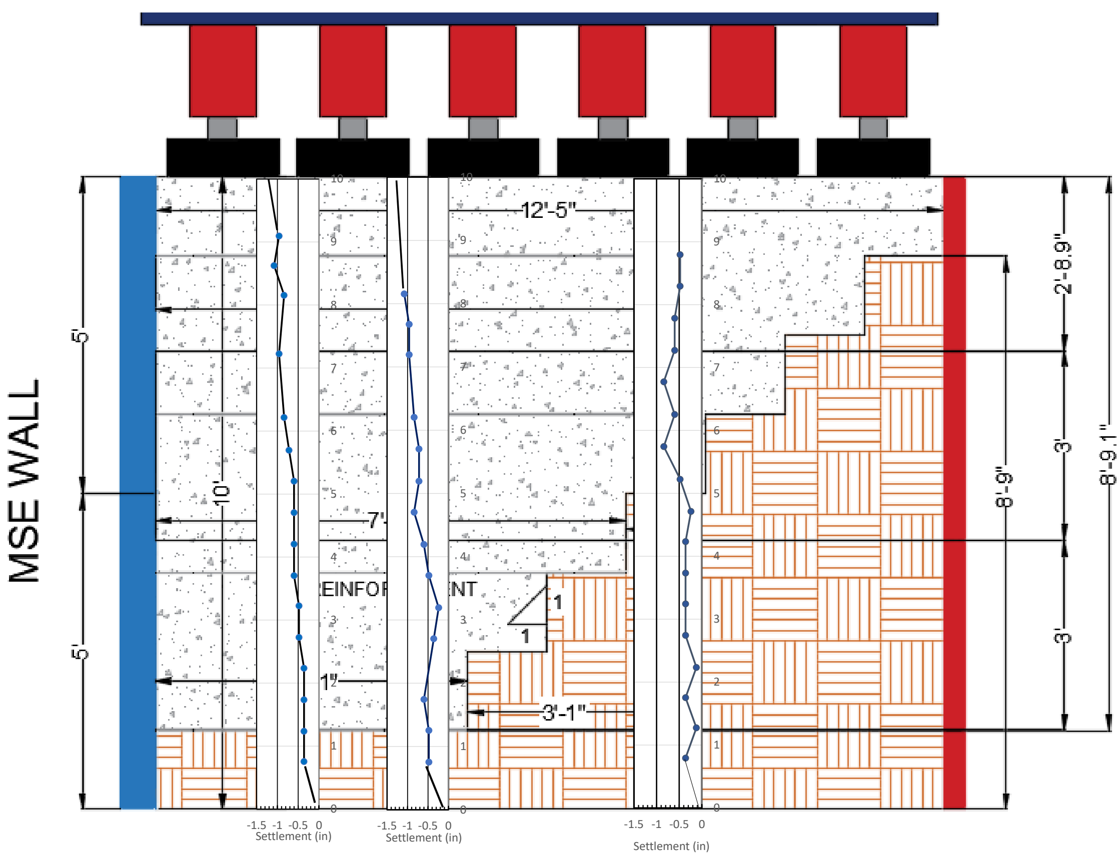

Fig. 9 Cross-section showing settlement vs. depth profiles from vertical Sondex pipes.

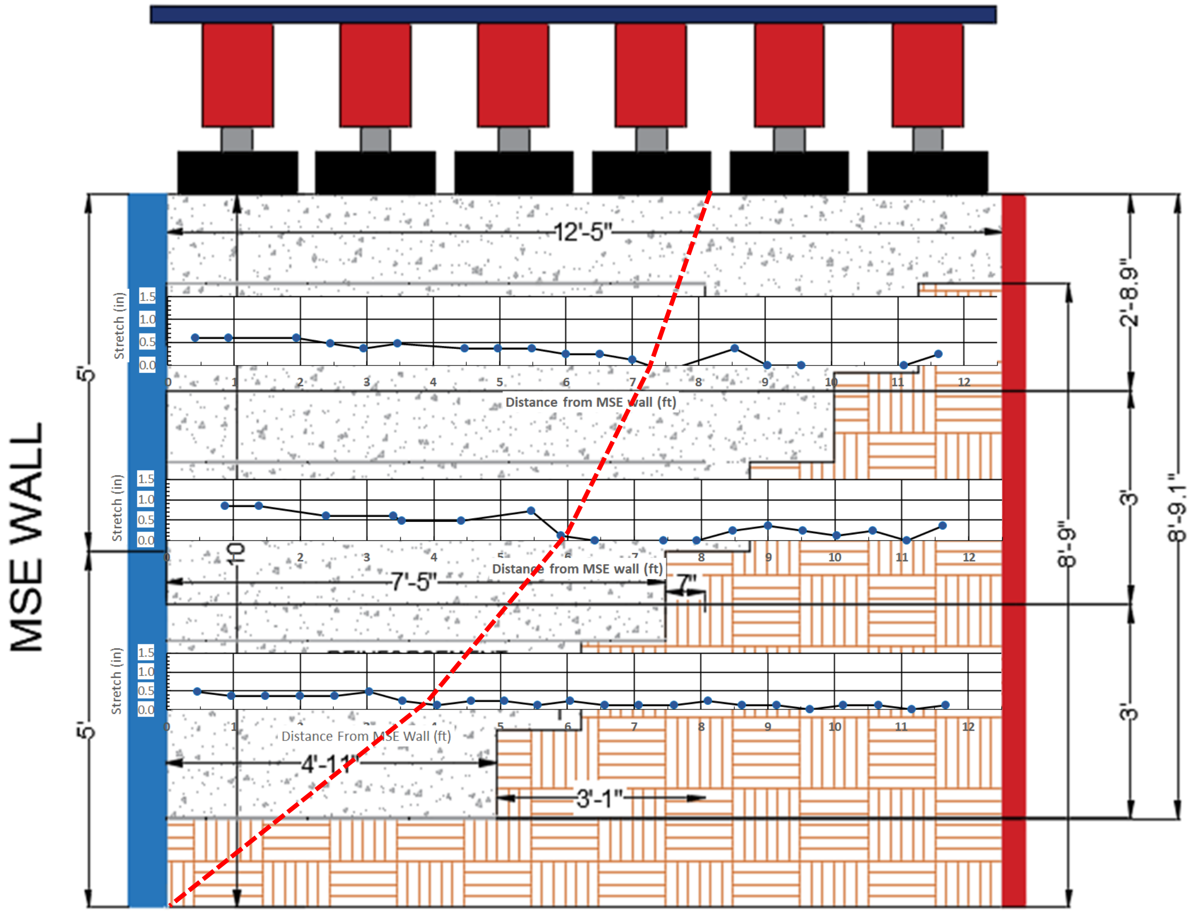

Fig. 10 Cross-section showing elongation vs. distance plots from horizontal Sondex pipes.

At the completion of the surcharge load test, one side wall was removed to provide a view of the crack patterns produced by the load test. A photograph of the sidewall is shown in Fig. 11. The cracks have been spay-painted green to improve visibility. The stair-stepped soil slope is clearly visible in Fig. 11 in contrast to the LCC backfill. Although the horizontal steps are slightly sloped downward in some cases, there is no indication of failure of the soil at the interface between the soil and LCC. There are fewer cracks in the LCC backfill in this test in comparison to previous tests likely because much less lateral wall displacement developed in this test relative to the previous tests. This is likely a result of the higher unconfined compressive strength of the LCC in this test. However, once again vertical cracking is more prevalent in the upper half of the LCC fill. The red dashed curve defining the boundary of extensional displacement identified by the three horizontal Sondex pipes is also superimposed in Fig. 11. Generally, this curve bounds the observed cracks.

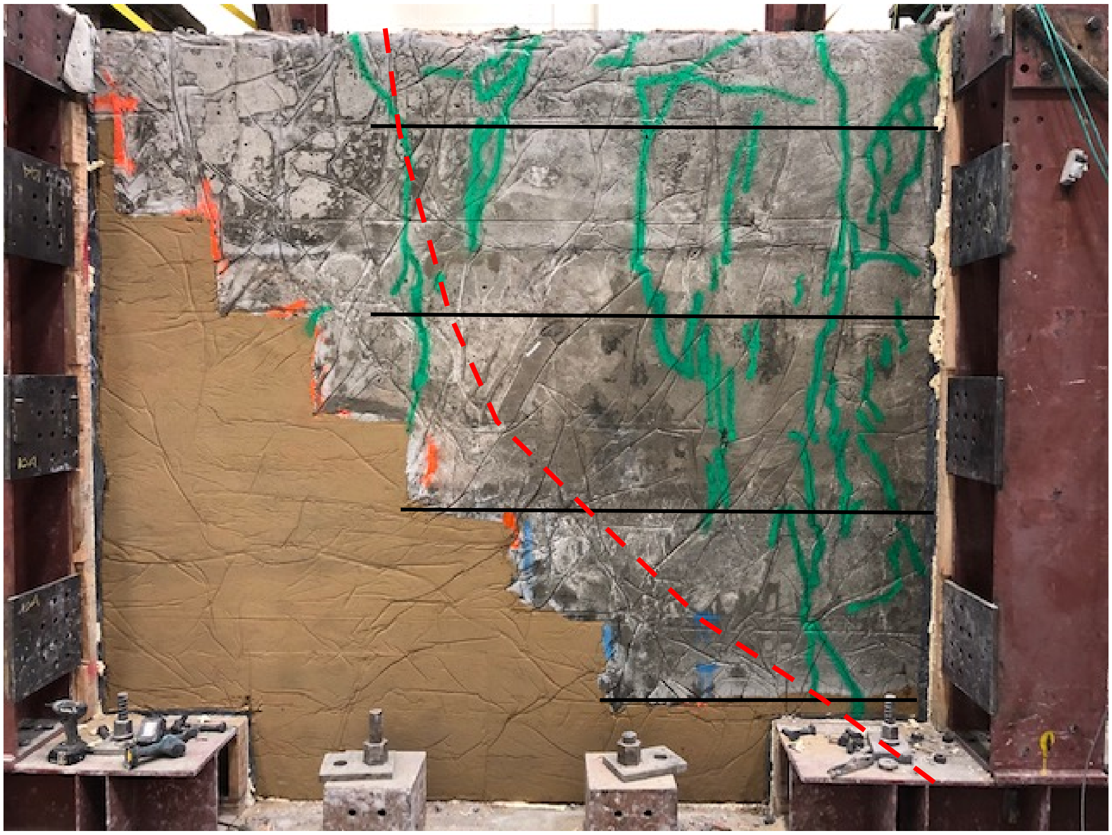

Fig. 11 Photograph showing the green crack patterns adjacent to the MSE wall with the eight-foot wide surcharge load at the surface. Reinforcement locations are shown by horizontal black lines. Red dashed line is boundary of extension from Sondex measurements.

Preliminary Conclusions

1. MSE walls with LCC sliver fills adjacent to soil slopes can successfully withstand significant surcharge loadings with limited axial and lateral deformations. However, failure or excessive displacement occurs at surcharge pressures about half of the unconfined compressive strength (UCS).

2. The surcharge pressure vs. axial settlement curve for the sliver fill test was remarkably consistent with curves from previous tests with a RC cantliever wall and an MSE wall prior to failure. However, the failure load in this case was somewhat higher owing to the higher UCS for the LCC in this case.

3. The presence of an MSE wall significantly increased the strength of the LCC block and led to a more ductile failure in contrast to the brittle failure of unreinforced LCC observed in previous tests. This result strongly indicates the improved performance produced by the MSE reinforcements.

4. Measured horizontal pressures at the back of the MSE wall panels were lower than would be expected using Rankine earth pressure theory with a friction angle (ϕ) of 34° and a cohesion of 700 to 1000 psf. This result is anticipated because the MSE reinforcements are expected to carry the lateral pressure rather than the wall panels.

5. There was no indication of failure at the interface between the LCC and the stair-stepped soil slope in this test. The failure surface was entirely contained within the LCC fill and had a relatively steep slope in the upper-half of the LCC which then sloped towards the toe of the wall in the bottom-half of the LCC. This failure surface is generally consistent with observations from previous surcharge load tests.

References:

Black, Rebecca. 2018. “Large-scale testing of low-strength cellular concrete for skewed bridge abutments.” M.S. Thesis, Civil & Environ. Engrg. Dept., Brigham Young University, Provo, UT, 96 p.

Tiwari, Binod, Beena Ajmera, Ryan Maw, Ryan Cole, Diego Villegas, and Peter Palmerson. 2017. "Mechanical Properties of Lightweight Cellular Concrete for Geotechnical Applications." *Journal of Materials in Civil Engineering* 1-7.