Proceedings of The National Conference
On Undergraduate Research (NCUR) 2018
University of Central Oklahoma
Edmond, Oklahoma
April 5-7, 2018

The Use of Geosynthetics for Lateral Stabilization in Earthen Block Construction

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Abstract

The purpose of this project is to study the efficacy of geosynthetics for lateral stabilization in the construction of compressed earth block residential structures. The team is documenting and collecting data for each step to include new testing methods, general strength/stress data, and overall findings. The methodology the research team is following is the generally accepted process of earthen construction – which is qualitative in nature. As such, each step of the process has been evaluated quantitatively. Typically, the soil used in earthen construction is excavated from the site the structure will be built on; the excavated soil is used to make the blocks and mortar-slurry. Because of this, results will vary depending on the geographic location and the soil available in that region. One source pile of soil was processed into finer material removing larger aggregates and proceeding with the fines to make the blocks. The blocks were cured then used to build double-wythe test walls. To build the wall, the fines were processed a second time through a smaller sieve to make the mortar-slurry and bond the blocks when using the soil mortar-slurry. Additional wall models included pre-proportioned commercial mortar mixes. Each step of the process remained consistent with the generally accepted methods, however, the team stopped at each milestone (i.e. made the blocks and tested them for shear strength, made and tested mortar cylinders, made shear test block assemblies) to test the products and acquire information about the material strength characteristics. The geogrid materials have displayed promising results from initial testing. The conclusions are that the geosynthetics will provide the necessary lateral support in the construction of earthen block structures. This study will also provide quantitative data for future studies to reference, compare results, and expand upon.

Keywords: Earthen construction, geosynthetic, Oklahoma

1. Introduction

Earthen construction has existed for thousands of years dating back to 8300 B.C.. It is well known that earthen building materials are strong in compression, but there is little data compiled about the individual aspects and group interactions of the materials. This research aims to quantify the individual components in addition to the assembled structure built of Compressed Earth Blocks (CEB) and show the efficacy of geosynthetic materials as lateral stabilization. The research methods used in this project followed generally recognized practices then quantified them at each step; the blocks were made, then tested for their compressive and shear strengths, likewise with the mortar, then a wall was assembled and tested as a unit to establish a baseline performance expectation. Once a satisfactory base model wall was constructed in a manner that would be reasonably repeated, the research progressed to the addition of the geosynthetic materials and the effect they have on the lateral stabilization of earthen block construction.

2. Research Methodology

The research approach taken was to stay as true to earthen construction techniques in the built environment as possible while applying current engineering technologies to gather quantitative data at each step of the process. The blocks were produced by a three-person team. Using some heavy equipment, soil was processed, mixed, and compressed into their final shape.

The source soil used came from a reclaimed roadway. A basic jar test was performed where a jar is filled approximately half-full of soil, then filled to nearly the top with water leaving a small air space. The jar test was used to determine what components were present in the soil. The lid was replaced and the jar shaken vigorously until all the soil clumps separated. The jar was left to sit for 24 hours. As the particles settle, the expectation is for the materials to separate into layers. If the test yields three distinct layers, the bottom layer is sand, the middle layer is silt, and the top layer is clay. This can visually be split into percentages. The jar test performed for this research showed the soil to be nearly all clay.

Since other materials, like asphalt pieces, could have gotten mixed in with the source soil, it was processed and sorted through a rock crusher onto a sieve with a 0.375-inch aperture. Only the material passing the sieve was used in the block mixture along with 7% type I/II Portland cement by weight, and water. Drier mixtures yield stronger blocks, however the cement needs to be hydrated for strength gain – this balance is achieved once the mixture comes together when a handful of dirt is squeezed together in the hand, similar to the consistency of brown sugar. The mixture is then transferred to the AECT Block Maker which then uses hydraulic pressure of 2000 – 3000 psi to produce 6”x12”x4” blocks. The blocks are stacked and covered for the duration of the 28 day cure. Due to the Oklahoma climate, the blocks were wetted daily to maintain moisture during curing. All of the processes were adapted to the region they’re in as earthen construction exists on every continent.

Following the cure, some blocks were selected at random and tested in a universal testing machine. To quantify the material shear strength, the blocks were tested vertically – with the 4”x6” face in compression. Initially, the test was performed with the 6”x12” face in compression, however it was determined that, once constructed, the other configuration would be more indicative of the expected shear capacity of the blocks.

The first wall was built using a soil-base mortar slurry. The fines were processed through a #10 sieve then mixed with 14% type I/II Portland cement by weight. Once the dry ingredients were thoroughly blended, copious amounts of water were added, as the slurry requires 250-300% water-to-cement by weight. This ensures the block’s ability to absorb the slurry and bind with the other blocks. To build the wall a frame was attached to a W36x130 beam set in a four foot thick slab of concrete – known as the strong floor. The frame is bolted down and the edges and any holes in the beam flange are taped over. Like traditional masonry construction a mortar bed is poured, then the first course of blocks are laid. The slurry is poured between each course of the wall. The first three courses are laid in a running bond pattern, then in the fourth course the blocks are rotated 90° to lock the wall together as a header course. Figure 1 below shows the anatomy of a CEB wall.

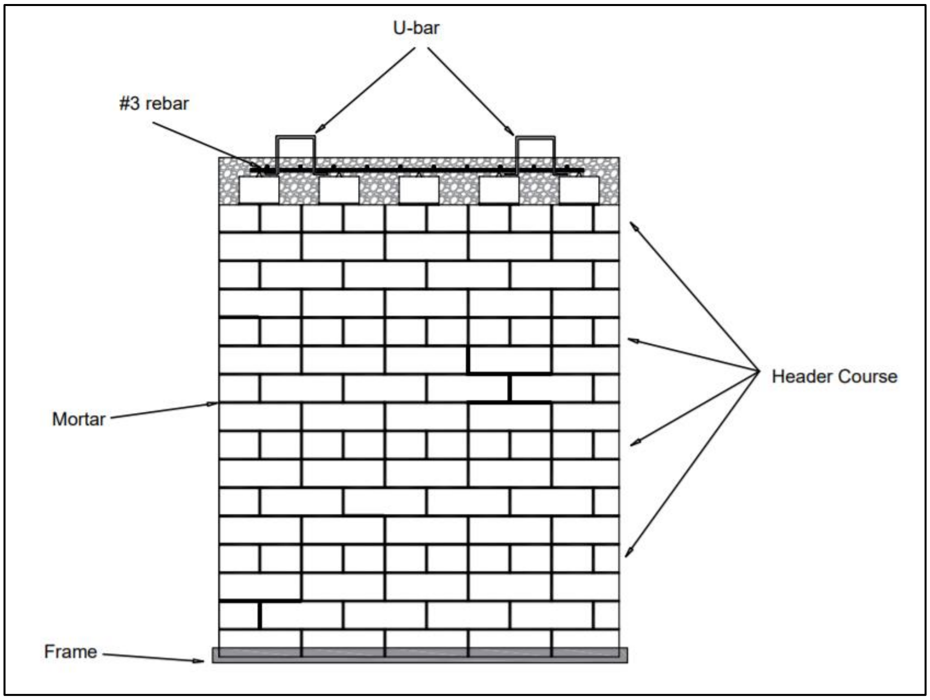

Figure 1: Anatomy of a compressed earth block wall

Following the test of the first wall, more mortar options were explored to find a mortar that was a better strength match to the strength of the blocks. The soil mortar slurry was evaluated at five different water contents, and two commercial premixes were tested at two different water contents each. The soil slurry was tested by making mortar cylinders and curing them in a temperature and humidity controlled room adhering to the specifications of ASTM C192. Mortar cylinders were made as opposed to mortar cubes due to the difficulty of accurately casting mortar cube specimen. The second mortar test was used to make a three block assembly using the different mortars under consideration. The blocks were then cured for 3-8 days and tested. The first commercial blend tested was Quikrete Mortar Mix. It was mixed with the manufacturer's suggested water content 1,650 mL, and at a 125% water to cement ratio using approximately 2,050 mL of water. The second commercial premix tested was Versabond LFT. It was also mixed at the manufacturer's suggested water content, and at 125% of the suggested water content. The results of the mortar testing are discussed in the discussion and application of results section. Moving forward the Quikrete mortar mix at a 125% water content was selected.

With the new mortar selection, the second wall was built. The general wall construction method stayed the same with the only change being the mortar. This decision was made for two reasons. First, the team wanted homogeneous behavior of the wall as a composite of both block and mortar, so the best way to achieve that was by switching to a higher-strength mortar. The second motivator was the man-hour expenditure in making the soil mortar mixture -- it was more efficient to use a premixed mortar.

The mortar was mixed in small batches during the wall build to prevent unsatisfactory drying of the mortar during building. Additionally the wall was wrapped in shrink wrap to maintain moisture during the mortar cure. Testing the second wall, results are discussed later, showed that the mortar and blocks were behaving together as a rigid body. Achieving the desired behavior from the materials the team moved forward to the third wall.

Wall three was built using the same methods of the first two walls, only with the addition of the geogrid. The first geogrid tested was Synteen SF-11 installed with the machine direction running vertically up the wall. The geogrid was secured through the wall with nylon twine. The twine was spaced every six inches on each course of blocks. The end pieces of twine were left in place and kept clean to secure the geogrid up the wall after the mortar hardened. The geogrid was cast into the bond beam at the top of the wall and secured along the ends with a combination of nylon ties and zip ties.

The test methods and set-up were the same for all three walls. Four wire potentiometers (wire pots) were installed to measure the deflection of the walls. Two wire pots were used to measure any vertical deflection due to lifting at the base of the wall and two wire pots measured the horizontal deflection. The hydraulic actuator was attached to the angle beam to push at the middle of the bond beam. A spacing block was used between the load cell and the wall to transmit the load evenly across a larger area of the bond beam. Additionally a toe plate was installed at the bottom of the wall to ensure no sliding movement of the lower portion; this was a redundant feature as the Hydrostone is also used to lock the base of the wall in place. The load was then applied at a constant even rate until failure. Failure was defined visually and by when the wall no longer supported additional loading.

3. Discussion and Application of Results

The results of the testing have been organized into and are discussed in three main categories: blocks, mortar, and walls in the following sections.

3.1 Blocks

The blocks were tested for their shear strength in a Baldwin Universal testing machine. The data was collected using LabView installed on a data acquisition system connected to the universal testing machine. Using Equation 1 the shear stress at break was calculated using the load for each break and the area of the blocks at 24 in^2. The results of the block testing are summarized in Table 1 in the following.

$$Shear\ stress\ at\ break = \frac{Load\ at\ break}{Area} \tag{1}$$

Table 1: Block test results

block positioning	block name	Load at break (lbf)	Compressive stress at break (psi)	shear stress at break (psi)
vertical	1T	20673	861.4	430.7
vertical	2	19188	799.5	399.8
vertical	unstabilized block 1	3591	149.6	74.8
vertical	unstabilized block 2	4548	189.5	94.8
horizontal	1M	133952	1860.4	930.2
horizontal	9W	112423	1561.4	780.7

Due to the fact that Oklahoma does not have a prescriptive code for earthen buildings, the New Mexico Earthen Building Materials Code was used which stipulates that earthen materials must have a compressive strength of 300 psi; this was set as the block compressive strength reference. The stabilized blocks all satisfy this requirement. The unstabilized blocks do not meet this compressive strength requirement, but that was expected. With satisfactory block test results and the verification that the stabilized blocks exceeded the minimum compressive strength requirement, the first wall was built.

3.2 Mortar

The mortar test cylinders provided data correlating to the optimum water content of the soil/Portland cement slurry. The cylinders were cured and tested at three days, 14 days, and 28 days. The test results are summarized for the 28 day test in Table 2 below and are represented visually in Figure 2. This is the standard testing pattern for cementitious materials to obtain the full strength curve. The seven day strength was not tested as it occurred over a holiday.

Table 2: 28-day mortar cylinder strength data

28-day mortar cylinder test			
w/c	**avg load (pounds)**	**avg compressive stress (psi)**	**avg shear stress (psi)**
1.0	3051.5	432	216
1.5	4471	632.5	316.25
2.0	3598	509	254.5
2.5	1908.5	270	135
3.0	1056.5	149.5	74.75

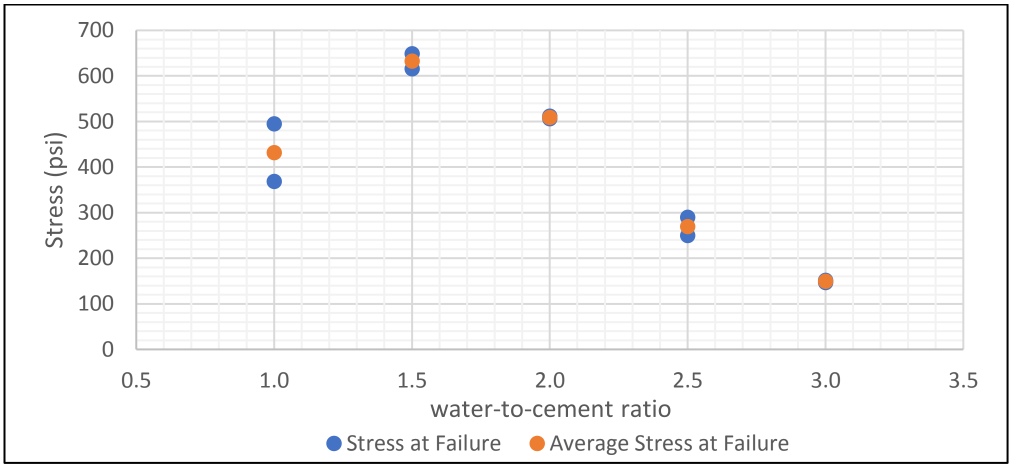

Figure 2: 28-day water-to-cement ratio vs. stress at failure

Although the 14-day strength tests identify the optimum water-to-cement ratio as being 1.0, the 3-day and 28-day cures both identify the optimum as 1.5 – then a sharp decline in strength is observed above the 1.5 water-to-cement ratio. Knowing the blocks need a high water content for the mortar to be effective at bonding the blocks, moving into the shear test specimen, only the 2.0 and 2.5 water-to-cement ratios were evaluated.

The three-block shear specimens were assembled by offsetting the middle block between two outer blocks and bonding them together with small batches of test mortar. To test the blocks they were stood up in the Baldwin universal testing machine with the two outer blocks acting as the base. Then load was applied to the single, elevated middle block until the mortar surfaces were sheared.

The majority of the blocks with Quikrete mortar at a standard water content (QS) were too dry and did not bond the blocks together at all — the test values labeled as "broken" separated before they could be tested. The Versabond LFT samples at both the manufacturer's suggested water content and an increased water content provided superior mortar results; the faces of the blocks broke before the mortar broke, which led to the conclusion that the mortar was far stronger than the blocks and therefore did not allow the specimen to act as a coherent unit. The specimen using the soil-based slurry provided adequate results but were difficult and time consuming to work with. Overall the Quikrete with the increased 125% water content (QE) proved to be the best mortar/water combination for wall building purposes as it provided a strength close to that of the blocks and was more time/cost effective to work with. Tables 3 and 4 summarize the shear strength test results of the mortar blends the team determined to be the best match for the next step in the research process.

Table 3: 3-day shear test specimen results

		Test 1	Test 2	Test 3	Load at break (lbf)	Shear stress at break (psi)
3-day	w/c 2.0	3200	3650	2150	3000.0	20.8
	w/c 2.5	2400	1400	1500	1766.7	12.3

Table 4: 8-day soil mortar shear specimen and 7-day premix mortar shear specimen results

		Test 1	Test 2	Test 3	Test 4	Load at break (lbf)	Shear stress at break (psi)
7 Day	QE	3590	3310	4100	7680	4670.0	32.4

3.3 Walls

When testing the first wall, the wall sheared at the base which is typical of compressed earth block walls. The failure load was approximately 750 pounds or an overall stress of 1-psi. Figure 3 in the following graphically represents the load and deflection data from the first wall test. The almost immediate base shearing of the wall under the applied load indicated that the mortar was significantly lower in strength than the blocks. This was an unsatisfactory result since it indicated that the wall was not behaving as a single rigid body. Following the sub-par results, several mortar variations were considered to try in the wall two build.

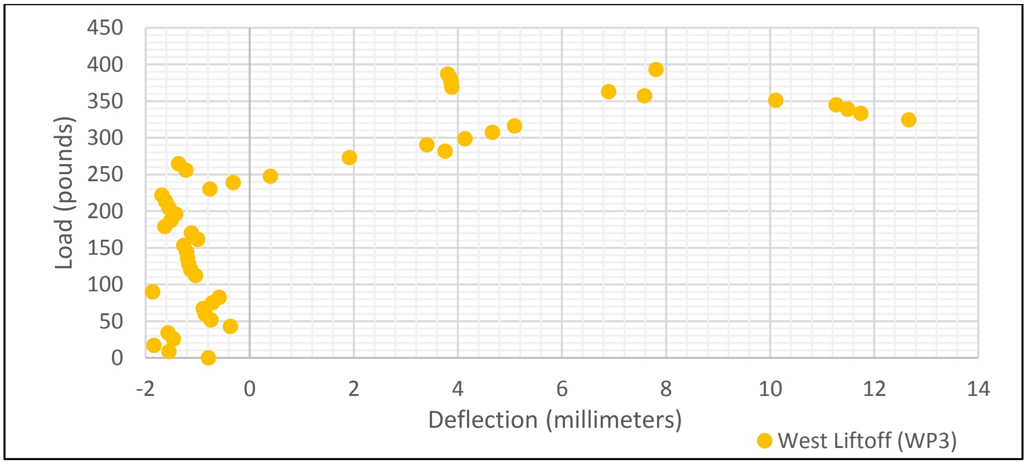

Figure 3: Wall 1 load-deflection data

Wall 2 sheared at 2787.5 pounds along the base. This exceeded the results of Wall 1 by nearly 4 times, which sheared at 750 pounds. The shearing at the base was not the desired result, but a typical mode of failure in earthen construction. The test was a success in that the wall surpassed the previous failure loading of only 750 pounds and displayed rigid body movement, meaning that the wall was acting as a single, coherent unit. Figure 4 shows the load to deflection data for the Wall 2 test.

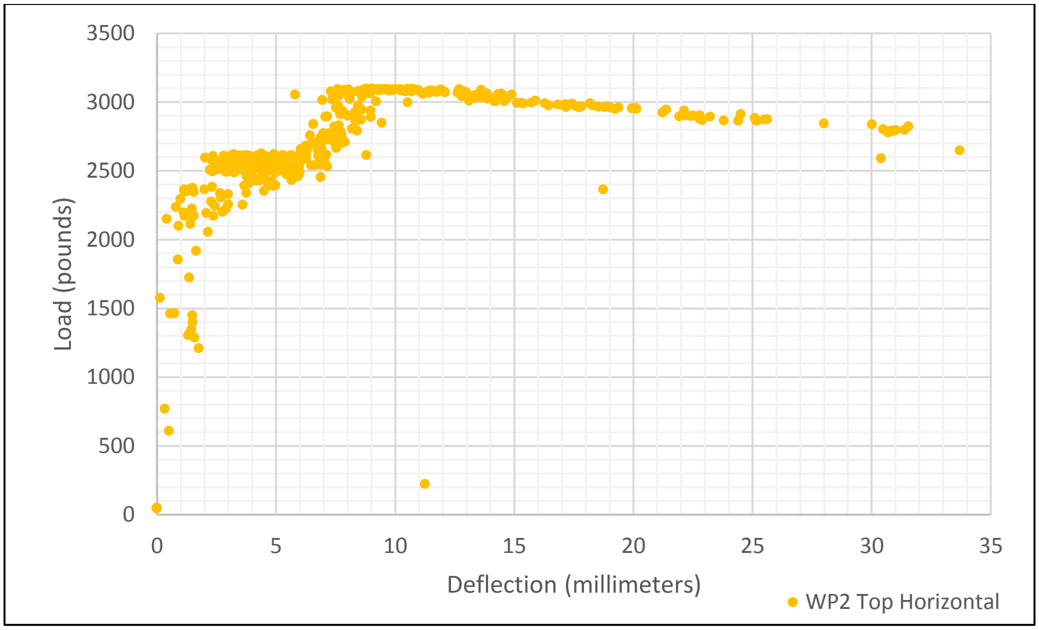

Figure 4: Wall 2 load-deflection data

When testing wall three LabView and the data acquisition system were unavailable so the team adapted and collected data using a load cell readout and inch calipers. The load cell connects to a yellow box to read the applied load off the screen. The calipers were used to measure deflection from the same location at specified load intervals. At 3,000 pounds it was realized that the geogrid was not installed tightly enough to engage immediately, so the wall continued to lift almost another 1.5 inches before the geogrid was engaged. Once the geogrid was engaged, the wall was able to withstand increased loading as is displayed in Figure 5 in the following.

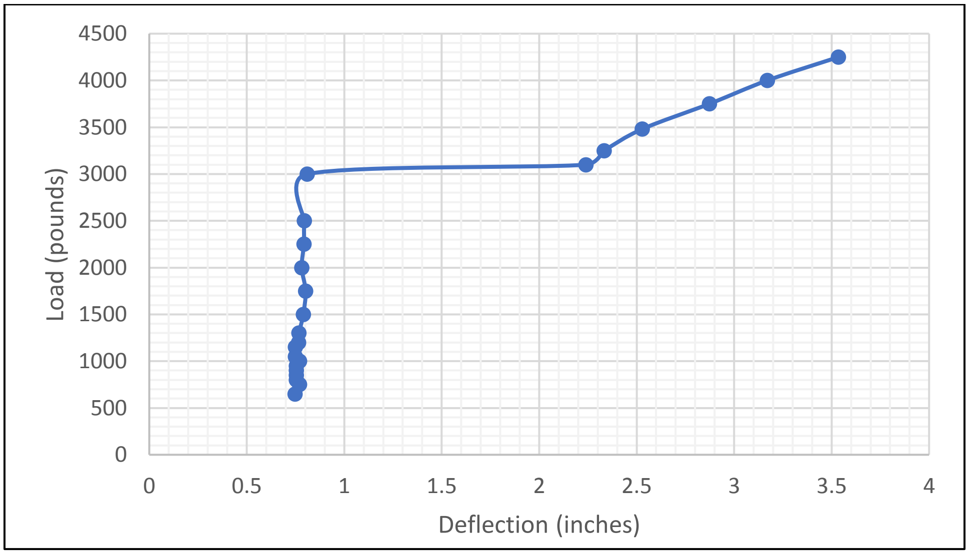

Figure 5: Wall 3 load-deflection data

With the addition of the geogrid material, the maximum load the wall could withstand was 4,600 pounds before the test was terminated. The geogrid was not at a failure state at the test termination, rather it was terminated out of an abundance of safety for both personnel and laboratory equipment.

4. Conclusions

The blocks are strong in compression but weak in tension; this is a well-known property of soil that readily transfers to the block properties. This lack of tensile strength in soil creates a need for geotextiles or geogrids to provide stabilization against lateral forces in earthen block construction, similar to how rebar provides stability in tension for concrete. After the Wall 1 model was discarded and some improvements were made, Wall 2 was able to provide higher lateral stability before reaching failure. However, Wall 3 with the addition of geogrid resulted in a wall with a higher shear stress resistance and an all-around safer model. The addition of the geogrid increased the wall's load-bearing capacity by over 50% while still not pushing the geogrid to its rupture limits. These findings can be applied to earthquake engineering, wind loading, and other areas of interest in the future.

5. References

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