DIAGONAL TENSION TESTING OF INTERLOCKING COMPRESSED EARTH
BLOCK PANELS

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ABSTRACT

Diagonal Tension Testing of Interlocking Compressed Earth Block Panels

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This thesis examines the use of diagonal tension (shear) testing to determine factors affecting shear strength of Interlocking Compressed Earth Block (ICEB) panels. This work expands on the current information available about strength properties of ICEB assemblies, which are dry-stacked, as opposed to having mortared beds. Variables such as block strength, grout strength and grouting pattern can influence the results of these types of tests and are examined in this investigation.

To study variables affecting diagonal shear strength, 9 panels were tested, consisting of blocks produced by a manual block press. Strength testing was adopted from common ASTM standards to determine constituent material properties. A modified version of ASTM E519 test procedure is used to perform diagonal tension testing. Imaging analysis, using a high resolution camera, was run simultaneously during testing to capture displacement histories of select panels.

It was determined that both block and grout strength significantly affect the shear strength of ICEB panels. Additionally, vertical grouting and block type also have a strong influence. Imaging analysis results confirm that the dominant failure mode in ICEB panels is bed joint sliding both pre and post peak load, with noticeable displacements at head joint locations on a few panels. Lastly, diagonal cracking along the block face was noticeable on several panels following peak load. Further testing remains to determine other factors affecting shear strength, namely, the application of normal pre-compression loads to the panel.

Keywords: Compressed Earth Blocks, Dry Stacked Masonry, Diagonal Tension Testing, Diagonal Shear Strength, Splitting Tensile Test, Displacement Counter Map, Imaging Analysis

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"Everything should be made as simple as possible, but not simpler"

-Albert Einstein

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CHAPTER 1: INTRODUCTION

1.1 Introduction

It is estimated that 1.6 billion people around the world live in inadequate shelter, 1 billion of those live in informal settlements, and more than 100 million people worldwide are homeless (Habitat, 2016). The need for sufficient, sustainable housing has fueled the research into various affordable building materials, including natural earth. The usage of natural earth for forming shelters has led to the development of compressed earth block manufacturing and construction.

While the use of earthen construction dates back earlier than 2500 BC (Jagadish, 2007), the modern use of Compressed Earth Blocks (CEBs) originated in 1956, when engineers developed the first widely-used block press (Wheeler, 2004). Since then, researchers have explored and tested machine-pressed soil cement blocks for various uses, and have published a variety of papers regarding the suitability of the blocks as building units.

CEBs are a specialized type of soil-cement masonry that provide several construction benefits including:

- Strengths comparable to other masonry with the ease of simpler, earthen construction
- Exceptional sustainability (using native soil harvested at or near a building site)
- Low energy cost since they don't require the use of a fired kiln or other heat source, like traditional clay masonry

- Interlocking Compressed Earth Blocks (ICEBs) possess interlocking ridges, which makes stacking them much quicker and requires no mortaring. This reduces construction time and requires less skilled labor compared with mortared CMU walls.

Recent research has indicated that the shear capacity of ICEB walls may be affected by a number of factors. The actual parameters and the extent of their influence, however, is still not clear.

1.2 Objectives

The objectives of this research are two-fold. The first part defines a procedure for diagonal shear testing of ICEB panels from creating the blocks through setting up and testing the panels. The second part explores a process for analyzing the relative effects of various parameters on panel performance. Such parameters include block strength, block type, grout strength, vertical grouted area, and channel block usage. Here, a “panel” is referred to as a masonry assembly that is smaller than a full size specimen used in typical shear wall testing.

It should be noted that no research exists for diagonal shear testing of the dry-stacked ICEBs used in this study. Most past studies focus on conventional stone and concrete masonry, usually fully mortared along the bed joints (parallel to block courses) and head joints (perpendicular to block courses). Thus, the results of this research should provide unique developments concerning ICEB construction and guidance for future experimental testing.

1.3 Content Structure

This paper is divided into 6 Chapters:

- Chapter 1 provides an introduction, including a review of block wall testing, and the objectives of the research presented in this paper.
- Chapter 2 is a review of CEB research. This includes a discussion of various test methods for determining CEB unit and assembly properties.
- Chapter 3 provides the materials and equipment used in making and pressing CEBs.
- Chapter 4 describes the methods used to batch CEBs, test CEBs for constituent properties, and the formal test method used to perform diagonal shear testing on CEB panels.
- Chapter 5 provides the analysis and results of testing.
- Chapter 6 details conclusions reached from testing and analysis, along with recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

What follows is a literature review of common block presses, block wall testing and material testing. This review is intended to introduce the reader to the common types of compressed earth blocks, shear failure mechanisms within a block wall or panel, and past research on material testing for block assemblies and individual block and grout units.

2.1 Block Presses

This section details some of the most common block presses used to produce CEBs.

2.1.1 CINVA RAM Block

The first mass production of compressed earth blocks began with the production of steel block presses in 1956. One of the first was by Chilean engineer, Paul Ramirez, who created the CINVA RAM (Wheeler, 2004).

2.1.2 Soeng Thai BP6 Block

The Soeng Thai BP6 Block press was developed in 1983 by the Asian Institute of Technology. This block, known as a “Rhino Block”, includes an interlocking “ridges” on the top and bottom, for ease in stacking and to provide bearing against lateral loading. The interlock also prevents the need to mortar the blocks, hence they are commonly used in “dry-stack” masonry construction, discussed about later in this section. Vertical round grout cores and rectangular keys allow for shear transfer from block to block, and

placement of steel reinforcement. This block type, shown in Figure 1, was used in this project and is discussed more in Chapter 3.

Figure 1 BP6 “Rhino Block”

2.1.3 Hydraform Blocks

Hydraform blocks are one of the earlier hydraulically pressed blocks, and were first developed and used in South Africa. Aside from the saving time and labor, the hydraulic process allows for better control of soil amount and pressing pressure. A typical Hydraform block is shown in Figure 2. Like the BP6 blocks, they are intended for dry-stack construction. Note that these blocks do not have holes for reinforcement, making them most suitable for non-seismic regions.

Figure 2 Hydraform Block (Hydraform 2016)

2.1.4 Vermeer “V-Lock” Block

The Vermeer V-Lock Block combines the interlocking and grouting elements of the BP6 block, but is hydraulically pressed, like the Hydraform block. A $\frac{1}{4}$ ” deep channel underneath the block allows for specialized lateral reinforcement. The V-Lock Block is shown in Figure 3 below.

Figure 3 V-Lock Block (Banker-Hix 2014)

2.2 Mechanisms for Shear Failure

Before reviewing past research on masonry wall testing, it is important to understand the mechanisms affecting shear failure and failure criterion for masonry assemblies.

2.2.1 Characterization of Shear Failure

As defined by Marzahn (1998), shear failure is “characterized by a critical combination of principal tensile and compressive stresses as a result of applying combined shear and compression, and leads to typical diagonal cracks”. There are two well defined types of shear cracks:

1. Joint cracking due to localized bed joint sliding
2. Diagonal cracking, characterized by cracks running through bricks and joints

Typically, at lower axial (compression) loads, frictional stress surpasses bed joint strength, causing joint sliding, while at larger axial loads, diagonal tensile failure develops which forces the block units to crack (shown in Figure 4).

Figure 4 Joint Sliding (left) versus Block Units Cracking (right)

For higher axial loads, Marzahn points out that the tensile strength of the blocks influences the shear strength and that this relationship is non-linear.

To this end, different theories have been presented to relate masonry shear strength using empirical formulas.

Coloumb type failure criterion relates the masonry shear strength directly to the bed joint strength (Lourenco & Ramos, 2004). The empirical equation for this criterion is provided below:

$$\tau = \tau_o + \mu \sigma_n \quad \text{Eq 2.2.1-1}$$

In this equation, the shear strength of the bed joint (τ) is dependent on the shear strength at zero normal compression (τ_o), and the friction developed by the mortar-block interface under compression ($\mu \sigma_n$). Shear strength at zero normal compression is largely based on the shear strength of the mortar alone. Typically, blocks can be stacked and placed in a controlled apparatus to simulate direct shear failure along the bed joints. Turnsek and Cacovic (1970) modeled masonry assemblies as an isotropic material, treating the mortar and blocks the same. The limit state for the assembly comes from when the single homogenous material reaches a maximum tensile stress.

Contrary to Turnsek and Cacovic, Mann and Muller's approach treats a masonry assembly as behaving in two separate parts: block units and mortared joints (Mann & Muller, 1980). Each of these parts has its own limiting stress and mechanical parameters. For the blocks, this is simply block strength in tension. For the mortared joints, this consists of cohesion and friction. Mann and Muller's failure theory also shows that precompression (loading normal to the block courses) is an essential element in developing diagonal cracking and increasing bed joint strength.

2.3 Shear Testing Configurations

Masonry assemblies have been tested using several different loading scenarios (Atkinson, Amadei, Saeb, & Sture, 1989). Some of the main types are illustrated in the figure below.

Figure 5 Masonry Shear Test Configurations (Atkinson et. al 1989)

What follows is a brief summary of research behind each load configuration to provide background to the methods, benefits and limitations of each load type.

2.3.1 Compressive Loading of Prismatic Masonry Specimens (“a”)

This test is widely used by researchers to develop an understanding of the compressive strength of masonry, specifically at the joints. Specimens are positioned with their bed joints placed at an angle to the applied load. This method allows the

researcher to determine factors affecting peak shear strength. Tested factors might include mortar type, brick stacking layout, and absorption. Although this test provides evaluation of peak performance, the tests are mainly undertaken under force-controlled, monotonic conditions (Nus, 1978; Drysdale & Vanderkeyl, 1979), leading to little information about specimen performance beyond peak strength, such as deformation capacity and resistance under cyclic loading.

2.3.2 Diagonal Shear Testing (“b”)

The diagonal shear test has been performed by a large array of researchers over the past 40 years. This test involves taking a small portion of a wall (referred to as a “wallette” or “panel”) and applying a diagonal load to opposing corners until failure. The test objective is to determine parameters affecting the shear strength of a masonry assemblage, and to allow for assessment of stiffness properties (including shearing strain and shear modulus). Since this type of testing can be done in several ways and is the method undertaken in this paper, it warrants an extensive review.

Prior to review of this research, a key point should be made regarding differences in masonry type. In general, two masonry types are available: mortared (bonded) and unmortared (unbonded, or “dry stack”) masonry. This is visually shown in the Figure 6.

Figure 6 Mortared Masonry (left) vs Dry Stacked (right)

Due to a lack of mortar, dry-stacked assemblies rely pre-dominantly on vertical grout cores and bed joint friction (induced by normal loading) for shear resistance.

Gero Marzahn explored dry-stacked masonry and defined important factors influencing masonry shear strength for this construction method (Marzahn, 1998). This paper describes a procedure for determining bed joint parameters, using the triplet test, and block tensile strength, using an axial tensile machine. A diagonal shear test setup is proposed, which includes precompression using post-tensioned cables that run through the vertical grout chambers of the assembly. In this review of shear stress mechanics, the shear load-resisting mechanisms are identified, which depend primarily on bed joint friction and tensile strength of the blocks.

Similar to Marzahn, Calderini and other researchers studied the works of Mann and Muller in diagonal shear tests on masonry piers (Calderini, Cattari, & Lagomarsino, 2009). The researchers present a procedure to use the diagonal shear test to back out values for cohesion and friction coefficient via experimental and numerical modeling.

In contrasting to lab testing, Brignola and others work on characterizing shear strength of masonry walls utilized the diagonal shear test to perform in-situ compression testing of 24 masonry panels (Brignola, Frumento, Lagomarsino, & Podesta, 2009). Panels consisted of regular block masonry and irregularly layed stone masonry. Researchers compared numerical analysis models with ASTM E519 and RILEM TC-76 LUM test methods for diagonal shear tests. Analyses showed that RILEM more accurately predicted the tensile strength and shear modulus of the wall panels, based on principal stresses and strains located at the center of the panel. A linear numerical analysis was carried out to prove that the behavior at the panel center is independent of orthotropy (differences in elastic modulli) and that the effects of the loading shoes (located at panel edges) can be accurately assumed as point loads for analyzing the center of the wall. A non-linear numerical analysis was carried out to determine micro-mechanical parameters affecting bed joint shear strength. Typical failure was characterized by diagonal cracking parallel to the loading direction. For the block walls, this was dominantly step cracking (along bed joints), while for the non-regular masonry walls, cracks passed through the joints between stones.

Petersen (2010) utilized a diagonal shear test to determine if Near Surface Mounted Carbon Fiber Polymer Strips (NSM-CFRP) could improve the in-plane shear behavior of masonry walls. The reinforcement was applied as epoxied strips placed horizontally across three wall specimens and vertically across four wall specimens. The test results showed that the vertical NSM-CFRP reinforcement was most effective, acting in tension to restrain shear induced dilation at the bed joints which reduced horizontal sliding.

Like Brignola and others, Franchi along with other researchers performed in-situ diagonal tensile tests on historic composite masonry panels from a building with seismic damage (Franchi, Crespi, & Ronca, 2014). The panels consisted of two exterior walls (15 cm thick each) connected to an interior grout center (30 cm thick). Unlike in-situ diagonal shear tests performed by other researchers, these tests were displacement-controlled, to evaluate the post peak strength and displacement (for calculation of ductility). Two different wall specimen were tested, one without a grout injection (for retrofit) and one field tested with grout injection. Separate loading was placed on each exterior wall for comparison. Results showed that the retrofitted panels had 3-4 times the strength and ductility as the original panels. The load displacement response of the exterior walls were significantly different for the original walls, but very similar for the retrofitted panels.

Ghanem, Abu-El-Magd, & Hosny (1994) provided modifications to the calculation of diagonal shear parameters from the ASTM E519 test method. Specifically, their work addresses issues with panel size and orthotropy of the masonry, both of which aren't specifically discussed in the ASTM test method. The paper provides results from non-linear finite element analysis used to generate new equations that factor in orthotropic ratio (E_1/E_2) and different panel sizes.

The aforementioned researchers show that the diagonal tensile test can provide a convenient means for studying how various factors affect masonry shear strength for both isolated (lab tested) and in-situ conditions. This test method allows the experimenter to determine tensile strength of the wall and shear properties (modulus and shear strain), along with material constituent and interaction parameters (such as cohesion, friction

angle, and interlocking effects). The loading method (force controlled versus displacement controlled) affects what assembly properties can be determined.

2.3.3 *Racking Test (“c”)*

This test is used to simulate the response of a shear wall to in-plane lateral loading. In contrast to the diagonal shear test, loading is provided by a horizontal force (typically an actuator) at the top of the wall, with normal loading provided to simulate bearing.

Drysdale (2000) tested four “racked” walls for in-plane shear failure using the Azar Dry-Stack Block (shown in Figure 7). These hollow, interlocking CMU blocks were dry-stacked, but fully grouted and reinforced. The findings from these tests indicate a ductile failure of the walls (caused by the steel), with rupture of the steel causing the primary failure. Drysdale suggests increasing the flexural steel within the walls to provide higher lateral loading capacity and induce diagonal cracking (which is the more common failure for these types of tests).

Later tests by Drysdale (2005) using an optimized version of the previous block type, incorporated adhesive at the bed joints. His results showed that higher maximum shear stresses developed in the walls compared with conventional grout-only construction.

Figure 7 Azar Dry-Stack Block (Drysdale 2005)

Past Cal Poly students also performed racking tests to study the effects of in-plane lateral loading on dry-stacked ICEB walls. Since the same block shape is used in this paper, these studies will be summarized with greater detail.

Bland (2011) subjected (3) 1800mm x 1800mm walls to cyclic in-plane lateral loading. Grouting (partial vs full) and horizontal reinforcement were varied to study the effects of these parameters on shear capacity. The wall with transverse reinforcement contained channel blocks located every 4th course up the wall. Bland's results showed that shear strength is significantly enhanced when the walls are fully grouted. The typical failure of the walls was characterized by yielding of the vertical reinforcing steel. Comparing strengths with ACI Masonry Code (ACI 530) showed that the Code greatly overestimates the shear strength of the ICEB walls. For this reason, Bland provides equations that reduce the nominal shear strength for design purposes. Several properties related to the material constituents are also identified in his research (some of which will be discussed in the materials section of this paper).

Based on the test results, Bland recommends future testing that focuses on understanding the effects of grout strength and identifying the interlocking action

between the blocks. Additionally, Bland suggests that more testing be performed on the impact of transverse reinforcing.

Stirling (2011) wrote a companion thesis to Bland's, but constructed specimens so that they would be flexure dominated. Testing consisted of three full-size specimen: a slim wall with a 2:1 height to width aspect ratio, a flanged wall, and a wall with an opening at the center. Following the experiments, two types of analyses to calculate the ultimate capacity of the ICEB walls were performed; a non-linear static analysis model, assuming lumped plasticity, and a plastic analysis model. In addition, he conducted an incremental dynamic analysis to evaluate the seismic performance of flexure dominant ICEB buildings. Stirling found that both the static and dynamic analyses were consistent with experimental results. He recommends further study of the bond between the rebar and grout, and the bond between the grout and ICEBs to better understand bond strength.

2.3.4 Direct Shear Testing (“d and “e”)

Past researchers have studied the shear load-displacement behavior of unreinforced brick masonry by testing old clay specimens from a wall and new clay units constructed in a lab through a direct shear apparatus (Atkinson et. al, 1989). The researcher found that under cyclic shear loading, masonry bed joints show peak strength for the first cycle, followed by a constant residual shear strength thereafter. Softening occurred along the bed joint of the specimens beginning with the first cycle (i.e. initial slope was not constant). The shear strength was represented well by Mohr-Coulomb criteria. In addition, the researchers found a lower-bound friction coefficient and concluded that the cohesion of the bed joint varies widely, depending on mortar and

masonry unit type. Lastly, they observed that the highest amount of dilatancy (bed joint expansion and contraction) occurs at the lowest levels of precompression.

Likewise, both Marzahn and Atkinson, Lourenco et. al (2004) also performed testing on masonry blocks to characterize the Coloumb failure criterion. Dry-stacked couplets (2 blocks stacked on top of each other) were tested under displacement-controlled cyclic loading and studied the effects of surface roughness, dilatancy and inelastic behavior. Results showed that under cyclic loading, the elastic behavior of the first cycle was followed by fully plastic behavior for the remainder of testing. This indicates that the bed joints had no opportunity to recover after the peak was reached in the first cycle. Interestingly, the researchers also observed a change in friction angle, with greater surface roughness generating the highest end friction angles. Unlike Atkinson, the almost zero dilatancy was observed for all loading cycles.

2.4 Prior Research on Material Properties

The behavior of masonry block walls under loading is greatly linked to the complex structure and elements affecting the block, grout and mortar constituents. While several researchers have studied material properties of CMU blocks to gain an understanding of their assembled behavior, CEBs are more challenging, due to the intricate reactions between the soils, cementitious materials, and water. The following research provides a brief overview of past studies on constituent properties and behavior.

2.4.1 Factors Influencing Compressive Strength of Unit/Stacked Blocks

Heathcote (1991) studied the compressive strength of cement stabilized earth blocks in relation to clay content, moisture and density. Heathcote tested blocks made of 8% clay using the CINVA-RAM Machine press. Blocks were tested lengthwise, to

increase the aspect ratio of the blocks, and thus reduce the “platen effects”. Platen effects are caused by the loading plates confining the top and bottom of the blocks. Platen effects cause an overestimate in the compressive strength of prisms with a smaller aspect ratio and are reduced as the aspect ratio (typically the prism height) increases. The results from Heathcote’s research include a formula for determining unit compressive strength, based on cement content and density. The relation shows that compressive strength increases at an exponential rate with block density. He also presents an equation for “effective cement content”, based on the amount of clay (% of total mass) present in the block mix. The clay interferes with the cement hydration process, thus reducing the “full impact” of the cement in the mix. Heathcote qualifies the research, noting that the data and formulas developed relate only to the soil type tested and that no relation yet exists that considers soil type (in terms of clay content) as a variable in determining block density and compressive strength.

Like Heathcote, Morel and others studied factors influencing the compressive strength of CEBs in order to further quantify the effects of aspect ratio (h/l) and other factors influencing strength (Morel, Pkla, & Walker, 2004). The authors tested a number of half CEBs stacked two high and found a linear relationship between cement content and compressive strength. His research also notes a strong relationship between the compressed earth block dry density and the block compressive strength, with denser blocks providing higher strength. When comparing aspect ratios with previous researchers, Heathcote received widely different values, suggesting that block geometry and mortar properties (used to bond blocks) can have a significant influence on the confining effects created during single and stacked block compression testing. Heathcote

also observed that blocks with a high moisture content correlated with a lower compressive strength.

2.4.2 Factors influencing ICEB's

Wyatt Banker-Hix (2014) studied the effects of clay, cement and fibers on the strength and durability of ICEB's. Twenty-seven unique batches (over 185 blocks) of CEBs using the Vermeer BP714 Hydraulic Block Press were produced. The block shape is shown in Figure 3. The study consisted of three different soil types (with varying soil/sand contents) and two fiber types (Forta Ferra and Strux). Banker-Hix performed testing for compressive strength, modulus of rupture (MOR), and absorption based on ASTM standards, while durability tests utilized a unique method of measuring mass loss in wet/dry cycles.

Results from his research showed that no strong trend existed between clay content and strength (contrary to much of the past research on soil-cement mortars and blocks), and that block durability increased as clay content decreased. Detailed data showed that a balance exists between the cement content (for long term cohesion and strength) and required minimal clay content (for short term cohesion-i.e. at the time of manufacturing the blocks). Too much clay, however, undermines the cement paste and bond between paste and fine aggregate (sand).

Banker-Hix also found a linear relationship between cement content and strength. Naturally, as cement content increases, CEB strength increases. This relationship held throughout durability testing. Use of cement contents near 4% or lower had a tremendous impact on durability while cement content near 12% or higher show a lesser impact.

The addition of fibers did not affect peak CEB strengths, but rather had a negative impact on durability. Detailed studies showed that fibers did slightly improve strength during the early stages of loading, but little difference in strength was noted between the use of each tested fiber.

Banker-Hix also examined gross vs net unit strength of CEB's and factored this into considerations for compressive strength and Modulus of Rupture (MOR). ASTM C140 (Standard Test Method for Sampling and Testing Concrete Masonry Units) could not be used to calculate net area (gross area minus area of reinforcing chambers). No direct relationship existed to convert gross compressive to net compressive strength. Similar concerns exist in MOR analysis, as the moment of inertia must be revised to account for the reduced cross section. From his testing, Banker-Hix developed an equation to convert Gross MOR to net MOR and proposed a relationship between MOR and compressive strength.

CHAPTER 3: MATERIALS

This chapter summarizes the materials and equipment used for material testing and panel construction.

3.1 Soil

3.1.1 Soil Harvesting

The soil used for this project was harvested from a construction site near Las Tablas Road, in Templeton, CA in December, 2013 and is shown in the figures below. The soil was excavated from the construction site and placed in a stockpile on the Cal Poly Campus. This soil type was used in a previous Cal Poly ICEB thesis by Banker-Hix (2013). The soil was referred to as “Las Tablas” or “LT” soil during the course of this project.

Figure 8 Las Tablas Soil Map Location (from Banker-Hix 2013)

Figure 9 Las Tablas Soil Project Site (from Banker-Hix 2013)

3.1.2 Soil Testing

Soil was pulverized for lab testing and block batching. The soil was lab tested by Banker-Hix in accordance with the following ASTM Standards:

- ASTM D2487 – Standard Practice for Classification of Soils for Engineering Purposes
- ASTM D4318 – Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- ASTM D4829 – Standard Test Method for Expansion Index of Soils
- ASTM D422 – Standard Test Method for Particle Size Analysis of Soils
- ASTM C128 – Standard Test Method for Density, Relative Density and Absorption of Fine Aggregate

LT soil properties are shown in Table 1. Additional soil information is provided in Appendix A-1.

Table 1 LT Soil Properties (from Banker-Hix 2013)

Atterburg Limits			Expansion	Expansion	Ave Abs
LL (%)	PL (%)	PI (%)	Index	Potential	(%)
44	12	32	32	Low	27

3.2 Sand

The sand used for all blocks and grout on this project was C33 washed concrete sand, provided by a local aggregate plant and stockpiled at the Cal Poly campus. Sand properties can be found in Appendix A-2.

3.3 Cement

Type II/V Portland cement, manufactured by CalPortland company, was used for all block and grout construction. The cement was supplied in 94lb bags by the civil engineering department and kept in a dry lab environment on the Cal Poly campus.

3.4 Lime

Type S hydrated lime was used as an additional stabilizer (in conjunction with Portland cement) for all grout mixes and was picked up in 50lb bags at a local home improvement store.

3.5 Water

All water used for block and grout production came from the laboratory tap water sinks and outside hose bibbs around the civil engineering building on the Cal Poly campus.

3.6 Equipment

3.6.1 Soil Pulverizer

The LT soil contained large chunks of material that needed to be broken down to provide proper compaction and minimize voids within the ICEBs during block production. To break up these chunks, a pulverizer manufactured in Thailand and used by the Center for Vocational Building Technology (CVBT) was utilized. Labeled the “Soeng Thai SP3 Soil Pulverizer”, the machine breaks down large soil particles using a series of rotating steel blades. The soil must be kept dry and loaded slowly to prevent build up on the material screen. The screening contains a #4 sieve which all soil material passes through before depositing into storage containers. This pulverizer has been used on several past Cal Poly theses and was readily available for use on this project. A photo of the pulverizing process can be found in “Block Batching Process”.

3.7 Block Presses

3.7.1 Manual Block Press

The block press used to produce the majority of blocks for this project was the Soeng Thai BP6 block press, developed in 1983 by the Asian Institute of Technology and the Soil Block Development Company. Like the soil pulverizer, this press has been used in several past ICEB theses and is also employed at the CVBT. The blocks contain special recessed inserts that allow for dry stack construction. The ridges on the top of the blocks are meant for quick, easy construction and provide bearing resistance in both the in-plane and out-of-plane directions. Figure 10 shows the typical ICEB block produced by the BP6 press.

Figure 10 ICEB Block From BP6 Block Press (Wheeler 2004)

The BP6 press is capable of producing several types of blocks using special dividers and inserts to modify block shape (see Figure 11). The block shape depends on its location within the wall and reinforcement types being used.

Figure 11 Various ICEB block types (Wheeler 2005)

3.7.2 Hydraulic Block Press

Some of the blocks used in this report were produced using a BP714 Vermeer hydraulic block press. A visual representation of the hydraulic block pressing process is shown in Figure 12 below. The Vermeer press is a newer machine used in the CEB industry. The blocks produced by this press contain much larger reinforcement chambers than the BP6 blocks. Termed “V-Lock” CEBs, these Vermeer blocks contain a 3/8” tall ridge. Block shape and dimensions can be found in Literature Review.

Figure 12 BP714 Block Pressing Process (Chu 2013)

Additional equipment can be used with the BP714 press to make the entire block production process almost completely automated. The specific V-Lock block production process can be found in research by Banker-Hix, who produced only V-Lock Blocks for his research. All V-Lock blocks produced for this project were made at the Cal Poly Campus in spring, 2014. They were palletized and kept under cover until use.

Additional laboratory equipment was used for determining material properties.
This equipment will be discussed accordingly in other parts of this paper.

CHAPTER 4: METHODS

This chapter describes the process for determining block mixture proportions, pressing the blocks, and assembling and testing the panels. Methods for determining constituent properties are also provided in this section.

4.1 Block Batch Design

4.1.1 Soil-Sand Mixing Ratios

Sand is typically mixed with soil during earth block production for several reasons, as mentioned previously. However, no prior testing had been performed using the specific soil and block press type used in this project. For this reason, the first step in determining the block batch design was finding a suitable ratio of soil to sand to use in the manually-pressed ICEBs. As suggested in several research papers and soil-cement reference manuals, one method to determine optimum sand-soil mixtures is by compaction testing. Proctor compaction tests are commonly used by the Geotechnical Engineering field to determine compaction in soil-cement mixtures. Soil compaction is a function of four variables (Holtz, Kovacs, & Sheahan, 2010):

1. Dry density, ρ_d
2. Water Content, w
3. Compactive Effort
4. Soil Type

Dry density and water content are related by the well-known equation provided below:

$$Y_d = \frac{Y}{1 + w} \quad \text{Eq 4.1.1.1}$$

Where Y_d = dry unit weight, Y = wet unit weight, and w = moisture content.

Compactive Effort is quantified based on the mechanical energy applied to the soil-sand mass. The general equation for determining compactive effort is provided by ASTM standards. Specifically ASTM D698 (Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort) and ASTM D1557 (Standard Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort).

The general compactive effort (per unit volume) equation is provided below:

$$\text{Compactive Effort} = \frac{WhIB}{V} \quad \text{Eq 4.1.1.2}$$

Where W is hammer height, h is drop height, I is number of lifts, B is number of blows per lift, and V is compacted volume.

Compactive effort is found in a lab environment by proctor compaction tests, which utilize a ram hammer and mold, as shown in Figure 13. The ram hammer is dropped from a designated height down into the mold, where the soil is placed. This is done in “lifts” to ensure that the soil sample is evenly compacted along its height. The number of blows per lift designates the number of times the hammer is dropped.

Figure 13 Compaction Mold (left) and Ram “drop” hammer (right)

Using the ASTM specified hammer and mold, the compactive efforts can be found, and are summarized in Table 2.

Table 2 Standard and Modified Proctor Compactive Effort

Test Method	Standard Effort (ASTM D698)	Modified Effort (ASTM D1557)
Ram Weight	5.5lb (2.49 kg)	10lb (4.54 kg)
Height of Drop	12 in.	18 in.
Mold Diameter	4 in.	4 in.
Mold Volume	.0333 ft ³	.0333 ft ³
Layers	3	5
Blows per Layer	25	25
Compactive Effort	12,375 ft-lb/ft ³	56,520 ft-lb/ft ³

In order to determine the appropriate compactive effort used by the manual press during block production, the average block pressing pressure was measured. This is typically done by a “pocket penetrometer”. The penetrometer (shown in Figure 14) provides 330 psi or 47,520 psf pressing pressure when it reaches the second groove. Since this pressure is between the standard and modified test methods, adjustments were made to obtain compactive effort closer to the block pressing pressure.

Figure 14 Standard Pocket Penetrometer (From Wheeler 2005)

Table 3 shows the adjusted compactive effort provided for the Proctor compaction tests performed in this research.

Table 3 Adjusted Compactive Effort Based Block Pressing Pressure

Ram Weight	10lb
Height of Drop	18 in.
Mold Diameter	4 in.
Mold Volume	.0333 ft ³
Layers	3*
Blows per Layer	25
Compactive Effort	33784 ft-lb/ft ³

*Note the layer adjustment for a reduced compactive effort compared with the modified method.

With compactive effort around an equivalent 33,800 psf, this was still less than the nominal block pressing pressure but provides a closer (and conservative) approximation to pressure applied by the block press.

4.1.2 Proctor Compaction Tests

Once compaction effort was found, compaction tests were performed on varying soil-sand ratios in accordance with ASTM D558 (Standard Test Method for Moisture-Density Relations of Soil-Cement Mixtures).

The soil was compacted using the specifications from Table 3. In order to find starting moisture contents of the soil and sand, a series of calculations were performed using the procedure outlined below.

Determination of Starting Moisture Content in Proctor Compaction Test

Example: 30% Soil – 70% Sand

MC = Moisture Content

1. Start with stock moisture contents

$$MC = \frac{Mass_{wet} - Mass_{dry}}{M_{dry}} \quad \text{Eq 4.1.2-1}$$

$$MC_{soil} = 5.6\%$$

$$MC_{sand} = 1.3\%$$

2. Assume initial Proctor sample size (here, 4500g, not including cement amount).

This sample weight is the soil plus sand at their stock moisture content.

$$30\% \text{ soil} = 30\% * (4500\text{g}) = 1350\text{g}$$

$$70\% \text{ sand} = 70\% * (4500\text{g}) = 3150\text{g}$$

3. Determine Dry weights

$$M_{Dry} = \frac{M_{wet}}{1 + \frac{MC}{100}} \quad \text{Eq 4.1.2-2}$$

$$M_{Dry, \text{ soil}} = \frac{M_{wet}}{1 + \frac{MC}{100}} = \frac{1350\text{g}}{1 + \frac{5.6}{100}} = 1278.4\text{g}$$

$$M_{Dry, \text{ sand}} = \frac{M_{wet}}{1 + \frac{MC}{100}} = \frac{3150\text{g}}{1 + \frac{1.3}{100}} = 3109.6\text{g}$$

4. Determine total dry weight (assume a % of cement, based on initial sample size)

For 9% Cement:

$$M_{\text{cement}} = .09 (4500\text{g}) = 405\text{g} \text{ (assume cement contains no moisture, MC = 0\%)}$$

$$M_{\text{dry, total}} = 405\text{g} + 1278.4\text{g} + 3109.6\text{g} = 4793\text{g}$$

5. Determine starting moisture content for soil-sand-cement mixture:

$$MC_{\text{soil-sand-cement mix}} = \frac{4500\text{g} - (1278.4 + 3109.6)\text{g}}{4793\text{g}} = \mathbf{2.33\%}$$

Starting moisture content is 2.33% for the sample.

6. Determine the mass of water to be added to raise the water content to the first

water content assumed in testing (i.e. the first point on the Proctor curve):

$$\Delta M_w = \frac{(w_f - w_o) M_{to}}{1 + w_o} \quad \text{Eq 4.1.2-3}$$

Where:

ΔM_w = mass of water to be added to raise moisture content from w_o to w_f

w_f = final (target) moisture content

w_o = initial moisture content

M_{to} = initial total mass

Assuming initial (target) water content of 9%:

$$\Delta M_w = \frac{(.09 - .0233)(4500g + 405g)}{1 + .0233} = \mathbf{319.7} \text{ grams of water}$$

Add 319.7 grams of water to raise the moisture content of the sample from

2.33% to 9%.

7. Repeat Step 6 to obtain future moisture contents during testing (modifying M_{to} as necessary).

To estimate a reasonable range of target moisture points for constructing the Proctor curve, the soil was mixed with the calculated moisture content and then assessed visually based on consistency prior to compaction. Typically, the soil mixture is also formed into a cigar shape, using only hand pressure, and released. Excess mass loss after forming the cigar indicates that the soil was too dry (“dry of optimum”), while very little mass loss indicates that the mixture was too wet (“wet of optimum”). Changes in sample color (from light to dark) and shearing, caused when extruding the sample from the mold, provided further indication of moisture content. These visual indications are shown in Figure 15 and Figure 16.

Figure 15 Soil Dry of w_{opt} (far left) to Soil Wet of w_{opt} (far right)

Figure 16 “Dry” (left) vs “Wet” Extruded Sample (right)

Typically, the mass of the soil plus mold, weighed after compaction, is also a reliable method for determining when the mixture has exceeded its optimum moisture content. When the mass of the soil plus the mold remains constant (or slightly decreases), enough water has been added to achieve a “peak” in the compaction curve. A minimum of four points were always tested to form the compaction curve (as specified in the ASTM standard).

Proctor Compaction tests were performed on Soil-Sand ratios from 30-70 to 70-30 between July and August of 2015. Proctor compaction test data sheets and sieve analyses for each soil mixture can be found in Appendix A-3.

The results from proctor testing were plotted onto a “best fit” curve. From these curves, optimum moisture content (w_{opt}) and maximum dry density (γ_d) can be determined. A typical curve, showing how to extract the moisture-density parameters is illustrated in Figure 17. The curve shows that leading up to the peak, adding water helps increase maximum dry density, due to the water lubricating the soil particles, helping to fill in voids. After the peak, additional water begins displacing the soil particles, lowering the maximum dry density (since water unit weight is less than that of soil). A zero air voids curve (ZAV) is plotted on the same graph to represent the maximum backbone of the curve, assuming 100% saturation (i.e. no air voids) and a specific gravity, G_s . G_s was set to 2.55, based on the material data sheet for the sand used in the mixture.

Figure 17 Typical Moisture-Density Relationship (FHWA 2015)

Graphs from all Proctor tests were plotted onto one set of axes to determine a trend in the results, which is displayed in Figure 18. This graph shows that dry density decreases as soil amount increases. The results of the five completed tests are also summarized in Table 4.

It can be seen from this table that as soil amount increases, the optimum moisture content needed to achieve maximum dry density increases, while the max dry density itself decreases. This is consistent with the testing from Banker-Hix (2014) on varying clay content in V-Lock blocks.

Figure 18 Combined Moisture-Density Results

Table 4 Summary of Proctor Test Results

Soil-Sand Ratio	w_{opt} (%)	γ_d , Mg/m ³	γ_d , lb/ft ³
30-70	13	1.863	116.3
40-60	14	1.788	111.6
50-50	17	1.72	107.3
60-40	16	1.693	105.6
70-30	19	1.627	101.6

To provide a clearer sense for this relationship, a second graph was plotted, to relate maximum dry density to soil content.

Figure 19 Trend Between Maximum Dry Density and Soil Content

Figure 19 clearly shows that maximum dry density decreases with increasing soil content. A linear best fit line provides a rather accurate representation of this trend, and can be stated as follows:

$$Y_{d,max} = -0.57(\text{Soil Content, \%}) + 2.022$$

Eq 4.1.2-4

For SI Units (Mg/m³)

$$Y_{d,max} = -35.38(\text{Soil Content, \%}) + 126.15$$

Eq 4.1.2-5

For British Units (lb/ft³)

Note that these equations are limited to the soil type used in this research and for soil percentages of 30 to 70.

A hypothesis was formed from these results to test whether lower dry densities also correlate to lower block compressive strengths. To confirm the validity of this hypothesis, several batches of blocks with the same soil-sand ratios were made and tested. The method for producing these blocks is found in “Block Batching Process”. The results from compressive strength testing are found in Table 5. Soil percentage was based on the combined mass of soil and sand used in the mixture (cement and water excluded). A half block area of 30.46 in² and a full block area of 60.92 in² were used to determine compressive strength.

Table 5 Compressive Strength for ICEB’s at Varying Soil Contents

	Combined	Full Blocks Only				Half Blocks Only				% Diff.
% Soil	Average stress (psi)	Sample Size	Average stress (psi)	Std. Dev. (psi)	COV	Sample Size	Average stress (psi)	Std. Dev. (psi)	COV	Full vs. Half
30	743	4	764	111	15%	3	715	45	6%	7
40	745	7	780	48	6%	3	664	53	8%	17
50	542	6	603	42	7%	4	451	32	7%	34
60	513	6	552	35	6%	3	433	67	15%	27
70	441	7	441	101	23%	Unstable Specimens				

From the table above, it’s clear that all of the blocks exhibited a rather high standard deviation. This could be the result of three primary factors. The first factor

would be the blocks themselves, which are known to have variability due to the behavior of the soil contained in the block mixture. The second variable comes from the batching process. A detailed batching process was followed and is laid out in this paper as a means to reduce the effects of block manufacturing on the block strength. The third variable is variance found from the test method. For this reason, the compressive strength test method was also rigidly documented and is described in this thesis.

When looking at the coefficient of variance (COV), the largest variance results from the largest standard deviation, which occurs at 70% soil content. It would seem that because this soil content produces the most variable compressive strength results that it would be the least desirable for making blocks.

Also, comparing full block results to individual block results, there is a linear trend noticed between percent differences in compressive strengths when testing full blocks versus half blocks. This could possibly suggest that a higher soil percent reduces the consistency between the test methods for compressing full blocks versus half blocks. In general, testing half blocks provides less variable results than testing full blocks. For this reason, when possible, half blocks were tested for compressive strength later in the project.

The compressive strength results are also plotted in Figure 20.

Figure 20 Block Compressive Strengths for Varing Soil Contents

The decreasing trend matches up with the decreasing trend found on Figure 19 showing that a relationship could exist between max dry density and soil compressive strength. For purposes of future research, a trend line can provide an equation for predicting compressive strength, based on soil content.

A statistical analysis was used to determine the data distribution and the validity of this linear “best fit” trend line. The first step in this analysis is to determine if the data fits a normal distribution by applying a “normality test”. The normality test ranks data points, applies an appropriate “skewness”, which is based on sample size, and involves the computation of a “normality score”. Figure 21 provides the results for this test, using the individual data points for all single block (half and full) compressive strength tests.

Figure 21 Normality Test for Block Compressive Strengths

As shown by the graph, the data follows the normal distribution rather well. Once the data is confirmed to follow a normal distribution, confidence bounds, developed around normal distributed curves, can be applied to determine how much of the data is encapsulated within the specified range.

Since compressed earth material is quite variable, a confidence interval of 99.7% was applied to ensure that most of the data could be represented by the linear equation. These results are plotted on Figure 22.

Figure 22 Block Compressive Strength Data with Confidence Intervals

As seen in the figure, a majority of the data is above the lower bound confidence interval indicating a conservative estimate for prediction of compressive strength. The equation for the lower bound is:

$$f_{CEB} = -9.1729 * (\text{Soil Content, \%}) + 970.34 \quad \text{Eq 4.1.2-6}$$

Where f_{CEB} is block strength (in psi)

Again, it should be noted that this equation is limited to the soil type and cement content used in this research. As many researchers note (Heathcote 1991; Morel et. al 2004), using a different soil type could affect the results. Also, this equation is based on soil content that ranges from 30% to 70%, where percentages were based on the ratio of soil to sand.

A compression test record showing results from individual blocks is found in Appendix A-4. The results of this trial testing are in agreement with the research from

Morel (2004) and others. However, they contradict the research performed by Wyatt Banker-Hix (2014). This could be due to the block type and block pressing strength (which was about twice the amount of BP6 Blocks) used to form the hydraulic blocks in Banker-Hix's research.

4.2 Block Batching Process

The block batching process requires a detailed step-by-step procedure to ensure adequate quality control across several block batches. Past Cal Poly ICEB theses have presented a somewhat brief introduction to the batching process. What follows is an in-depth summary of the procedure used for this project. Note this procedure applies for the BP6 blocks which were manually pressed, as these blocks were used to construct the majority of diagonal tension test panels. The batching process for the V-Lock blocks can be found in research performed by Banker-Hix (2014).

4.2.1 Batching Procedure

Step 1: Determine Batch Proportions

The batch proportions were calculated by creating a spreadsheet that considered the soil-sand ratio and cement amount, along with total batch size. The calculations involved with this spreadsheet are provided in Appendix A-5. This programmed spreadsheet resulted in moisture content variance from batch to batch of less than 1% throughout the course of the day, while helping standardize the soil mixing process.

Step 2: Prepare Soil and Sand for batching

Prior to block pressing, both the sand and the soil must be prepared so that they don't contain any particles larger than a 1/4". Large particles lead to voids in the blocks, which results in lower compressive strengths.

The soil was prepared by using the pulverizer described in "Equipment". The soil must be dried out prior to pulverizing, so that the fine grain particles do not jam the inside sieve. This was achieved by leaving large tubs of soil in the sun a few days prior to pulverizing. Once pulverized, the soil is stored in large, heavy duty totes until batching. The pulverizing process can be seen in Figure 23.

Figure 23 Soil Drying and Pulverizing

The sand is prepared by sieving through a #4 (1/4") sieve, shown in Figure 24, and stored in the same type of totes as the soil, until batching.

Figure 24 Sieving the Sand Through a #4 Sieve Into a Storage Tote

Moisture content samples are taken from both the soil and sand at least 24 hours before batching so that initial moisture contents can be inputted into the batching spreadsheet.

Step 3: Prepare BP6 block press for batching

Since the block press used in this project has been used by several students in the past, its worn condition necessitates adequate cleaning and preparation prior to batching blocks.

Before each batching session, the entire block press was checked for loose lock washers, nuts and bolts to ensure that the assembly was in proper working condition. Next, used motor oil was wiped into the box, along the center inserts (called “frogs”) and on the vertical sliders, as prescribed in the CVBT production manual (Wheeler, 2004) and shown in Figure 25. This lubrication allows for the metal parts to cleanly contact each other during compression and ejection strokes, while reducing wear on the sides of

the box and along the sliders. Lubrication inside the block press took place at the beginning of every batch.

Figure 25 Lubrication of the Block Press Prior to Batching

Step 4: Weigh out Soil, Sand and Cement for batching

The soil, sand and cement was weighed on Ohaus scales used in the civil engineering labs on the Cal Poly campus, as shown in Figure 26. Note these scales are the same ones used to weigh the grout constituents and any other materials used in block and grout production.

Figure 26 Weighing Out Block Ingredients

Step 5: Mix dry materials

After weighing, the soil is first mixed with the sand. Five gallon buckets of alternating materials are placed on a clean concrete surface to allow for adequate pre-mixing before shoveling. The soil and sand is then shoveled prior to the introduction of cement. Once all of the cement is introduced, the pile is blended until it reaches a homogenous color.

The dry mixture is then spread out into a “pancake” formation, as shown in Figure 27 prior to the introduction of water.

Figure 27 Dry Ingredients Spread Out Prior to Adding Water

Step 6: Add water to the mixture

A watering can is filled with water, weighed on the scale and the initial mass of the can plus water is recorded in the spreadsheet. The amount of water needed to get the batch to the target moisture content (found from the Proctor tests studied earlier) provides reference for the final mass of the can plus water. Water is introduced into the spread out mixture in one-third amounts to allow for even distribution across the entire batch. The flattened pile is then re-shoveled and re-flattened for the next water addition.

During water addition, the fine materials in the soil will tend to create clumps in the mixture. These balls were broken up by using the flat side of the shovel, and then re-shoveled into the pile.

After adding and mixing the last third of water, the “cigar test” noted earlier should be performed to determine if the moisture content is adequate. Another good indication of whether the mix is wet enough is by observing how many small clumps

form while shoveling. An increasing number of small clumps forming indicates that the batch is approaching its target moisture content.

Step 7: Divide batch into “charges” for pressing

Once the target moisture content is reached, material is then weighed out into “charges” equivalent to a single block, and placed in small buckets for block pressing, as shown in Figure 28.

Figure 28 Block Charges Measured Out

The weight of material per block is found using the batching spreadsheet and varied depending on the type of block being produced. The block weight was found by multiplying the volume of solid material contained in the block by the unit weight found from Proctor compaction testing. A 50% soil-50% sand mixture was selected for batching all blocks used in this research, as it provided sufficient balance between fines content (for early stabilization) and hardened compressive strength. Table 6 shows typical weights per block based on block type, using this soil-sand ratio. Note that the dry unit

weight for a 50-50 soil-sand ratio was found to be 107.3 lb/ft³ from Proctor tests. This value is lower than that used by Bland (2011), which was 115.5 lb/ft³.

Table 6 Block Charge Weight, Based on Block Type

Block Type	Volume (ft ³)	Calculated Charge Weight (lb)	Actual Charge Weight (lb)	Charge Weights from Bland 2011 (lb)
Full Block	0.141	15.14	15.1	17.6
Half Block (2 per full block)	0.139	14.91	14.7	17.6
Full Channel Block	0.12	12.88	13.2	16.1
Half Channel Block	0.118	12.69	13	16.1
Full Corner Block	0.146	15.65	15.9	n/a
Half Corner Block	0.144	15.45	15.7	n/a

Note that actual charge weights varied from calculated values based on adjustments made on batching day. Also, all charge weights were less than those used by Bland (2011) and Stirling (2011) for their research.

Step 8: Add or remove dividers/inserts from the block press (as needed)

Dividers and inserts are placed into or removed from the block press depending on the block type being produced. The block types are listed below with a description of their required divider type.

Full Block: The full block requires no addition or removal of any divider

Half Block: Half blocks are produced by placing a middle divider into the block press, shown in Figure 29.

Figure 29 Middle Divider for Making Half Blocks

Full Channel Block: Full channel blocks are produced by inserting a channel “frog” into the press box, prior to placing soil in the press box, as shown in Figure 30.

Figure 30 Channel “frog” for Producing Full Channel Blocks

Half Channel Blocks: Half channel blocks are produced the same way as full channel blocks, but they also require the middle divider used for normal half blocks.

Full Corner Blocks: Full corner blocks are produced the same way as full normal blocks, except the side frogs are removed from the block press box, as shown in Figure 31.

Figure 31 Removal of Side Frogs to Produce Full Corner Blocks

Half Corner Blocks: Half corner blocks are produced the same way as full corner blocks, except they also require the center divider used in the normal half block.

Step 9: Place charge into block Press

Typically the charge for each block in “loose” condition is larger than the volume of the block press. For this reason, the charge is placed into the block press box using 2 lifts. After the first lift (half way up the press box), the top surface of the mixture is

lightly hand pressed uniformly, as shown in Figure 32. Extra care should be provided to ensure the corners are pressed, as these are typically more fragile areas of the block to handle following ejection.

Figure 32 Hand Pressing the First Lift

Following the second lift, the top surface should be spread uniformly over the top of the box, and any soil covering the center frogs and side channels should be cleaned off. A check should be done to ensure no large voids are in the second lift by lightly tapping a few fingers over the surface and redistributing soil to any shallow areas as shown in Figure 33.

Figure 33 Finishing Second Lift Before Pressing

Step 10: Compress Block Using Full Compression Stroke

Compress block by swinging over the larger pull lever until it reaches a horizontal position, as shown in the Figure 34. The lever should be kept in this position (termed a “compression stroke”) for 2 seconds, prior to releasing, per CVBT recommendations (Wheeler, 2004).

Figure 34 Block Press Lever in Full Compression Stroke

Step 11: Verify Pressing Pressure

The pressing pressure can be verified by lifting the lid of the block press box and using a pocket penetrometer (as described in “Equipment”) to verify adequate pressing pressure. For better accuracy, a concrete penetrometer was used in this project that read out in psi and kg/cm² (shown in Figure 35). Penetrometer values were recorded on the batching spreadsheets at the beginning of each batch and when the block type within the batch changed, for quality control purposes. Ideal penetrometer values may range from 310 psi to 350 psi. Lower penetrometer values indicated that the block was not stabilized enough, and usually fell apart when taken off of the block press. Higher penetrometer values, while desirable, required greater pressing force, which can induce greater wear on the block press and exhibit signs of stress cracking during ejection from the press box.

Figure 35 Using Penetrometer to Verify Pressing Pressure

Step 12: Place Block on Curing Plate and Prepare for Curing

Following a penetrometer check, the block is ejected by lowering the handle and placed onto a plywood curing plate for easy and safe transport. Cured blocks are stacked and placed in an outdoor curing tent, as shown in Figure 36. Blocks are cured for at least the first 3 days following batching in this tent and watered at least twice a day. Watering consisted of spraying the blocks with a bottle sprayer until the blocks could not absorb any further water. A typical indication of this is when the block color continues to show a darker, saturated look following a few minutes after initial spraying. Caution was taken to not overwater the blocks, however, since this could cause excessive swelling/shrinkage, leading to cracks. After this initial curing period, blocks are transferred indoors, stacked onto one another no more than three blocks high, and covered until ready for testing or construction.

Figure 36 Blocks Stacked and Sprayed in Outdoor Curing Tent

4.3 Block Compressive Strength Testing

To assure that the blocks used in this project met the required specifications for panel assemblies, compressive strength tests were run under a standardized method for the duration of this research.

4.3.1 UngROUTED, Single Block Compressive Strength Testing

Both full blocks and half blocks were tested for maximum compressive strength using a testing procedure established for earlier ICEB theses at Cal Poly. The method was modeled after ASTM C1314 – Standard Test Method for Compressive Strength of Masonry Prisms.

The block testing procedure is as follows:

1. Initiate “soft start” loading rate of 0.10 in/min until 500 lbf is reached on the specimen.
2. “Soft start” ends, and loading continues at a loading rate of 6 psi/sec until specimen reaches its peak load
3. Test stops after load drops from peak by 70%.

The typical testing set up for ungrouted full and half blocks is shown in Figure 37.

Figure 37 Test Set up for Half Blocks (left) and Full Blocks (right)

The confining effects of the top and bottom loading plates causes the single blocks to produce a conical failure, consistent with the findings of past Cal Poly ICEB theses, as well as others (like Heathcote, 1991). A typical failure is shown in Figure 38.

Figure 38 Conical Failure of UngROUTED Full and Half Blocks

4.3.2 Grouted Single Block Compressive Strength Testing

Grouted, single blocks were tested using the same procedure as the ungrouted blocks. Grouted specimen were cured adjacent to and under the same type of curing method as the ICEB panels they represented. A similar, conical failure was observed in these blocks. Interestingly, the grout showed little signs of crushing after the test (as seen in Figure 39), indicating that the block itself failed first. Bales et. al (2009) indicates failure modes dominated by splitting of the soil block around the grout at the interface. It appears that most of the single block tests are consistent with these findings. It's noted that even grout cubes and blocks with similar compressive strengths showed this type of failure mode.

Figure 39 Typical Failure Mode for Grouted, Single Blocks

4.3.3 Grouted Prism Compressive Strength Testing

Grouted half blocks were stacked to form prisms and tested to assess the stacked compressive strength. From the research of Heathcote (1991), Morel et. al (2004) and others, the compressive strength of the prism is strongly related to its aspect ratio. From ASTM C1314, prism aspect ratio is defined as:

$$\text{Aspect Ratio} = \frac{h_p}{t_p} \quad \text{Eq 4.3.3-1}$$

Where h_p is prism height, and t_p is the least actual lateral dimension of the prism.

As mentioned in “Literature Review”, as the aspect ratio increases, the compressive strength of the prism decreases. The same finding was made in this project. Also, the “platen effect” reduces as the aspect ratio increases. A typical testing set-up and failure for prism testing is shown in Figure 40. As shown, the failure generates more vertical column-like cracking along the prism.

Figure 40 Set-up and Failure Mode for Prism Specimen

Prism test results are summarized in Table 7 below. Comparing the three types of blocks used in this thesis, they all show between 65% to 85% reduction between their ungrouted single block strengths and their grouted 3 block prisms. Interestingly, the V-Lock blocks show an appreciable drop in strength between their ungrouted and grouted

single blocks. This could perhaps be attributed to water uptake during the grouting process (discussed later). Also, nearly doubling the cement content in high strength blocks (15% compared with 8% for medium strength, see Appendix A-6) only increased block strength by just over 30%, indicating that single block strength does not increase linearly with cement content. Looking at prism (stacked) strengths, this strength difference increases to 60% but still doesn't show a linear relationship. This important conclusion was made by Banker-Hix (2014) on varying cement content in V-Lock Blocks. Banker-Hix notes that the non-linear trend proves how much the fine soil particles are inhibiting compressive strength. At the micro-level, the soil disturbs the cement hydration products from forming and bonding to the “clean” aggregate in the block mix (i.e. the sand and non-clay soil particles).

Table 7 Single Block and Prism Test Results

V-Lock			BP6 Medium Strength		BP6 High Strength	
Test Configuration	average stress (psi)	Ratio	average stress (psi)	Ratio	average stress (psi)	Ratio
ungROUTED	1912	1	540	1	720	1
grouted single stack	896	0.47	532	0.99	763	1.06
grouted double stack	675	0.35	n/a		n/a	
grouted triple stack	445	0.23	155	0.29	258	0.36

4.4 Grout Compressive Strength Testing

Based on the research from past Cal Poly ICEB theses, observations showed that the grout cast in 2” x 2” plastic molds differed from that tested from the ICEB blocks. The reason for this is that the fine grain materials in the blocks absorb a significant amount of water from the grout, lowering the water-to-cement ratio and causing an

increase in compressive strength. To study this affect in this project and obtain a representative estimate of grout strength in the cast ICEB panels, samples of each grout type were tested. To be consistent in terminology with past research, grout cast in the plastic molds were termed “non-porous” samples, while those cast in the blocks were termed “porous” samples.

4.4.1 Non-porous grout samples

Non-porous grout samples were obtained by casting grout into oiled plastic molds and demolding after 24 hours. The demolded cubes were then stored in double zip-lock bags for continued curing until the day of testing.

4.4.2 Porous grout samples

To obtain porous grout samples, four ICEB blocks were arranged to form a square pattern, consistent with ASTM C1019 – Standard Test Method for Sampling and Testing Grout. These blocks were each covered with paper towels to allow for easy demolding afterwards and are shown in Figure 41. A 2” x 2” x ½” tall plastic platform was created and placed in the bottom of the square opening, to allow for a flat casting surface and to raise the specimen above the curved bottom corners of the blocks. Lines were drawn approximately 2” up from the top of the platform to indicate where to finish casting.

Figure 41 Block Formation for Porous Grout Cubes

In deviation to ASTM C1019, neither the porous nor non-porous samples were rodded during casting, due to the high flow of the grout and to mimic the placement technique of the grout in the ICEB panels.

Following casting, cubes were left to cure in the blocks for at least 24 hours before being removed and placed in a double zip-lock bag, where they remained until compression testing. A typical demolded cube is shown in Figure 42.

Figure 42 Demolded Porous Grout Cube

4.4.3 Grout Cube Compressive Strength Testing

Both the porous and non-porous grout cubes were placed in unbonded, neoprene caps for compressive strength testing. Since the porous samples were cast in a block mold, their edges and tops typically had uneven areas. These areas were grinded down until they rested flat within the unbonded caps. For testing purposes, an area of 2" x 2" was used to determine compressive strength. A small trial test was performed to study if the grout cube height affected the compressive strength. It was found that the small variance in cube height made no apparent difference in the compressive strength. Appendix A-7 shows calculations from grout cube trial testing.

Grouted cubes were tested on the same day as the ICEB panel testing, in accordance with ASTM E519. The compression testing procedure for both types of grout cubes was modeled after ASTM C1019 and follows:

1. Initiate "soft start" loading rate of 0.25 in/min until 500 lbf is reached on the specimen.
2. "Soft start" ends, and loading continues at a loading rate of 35 psi/sec until specimen reaches its peak load

3. Test stops after load drops from peak by 50%.

The typical loading set up and failure for grout cubes can be seen in Figure 43. Grout mix designs and compressive strength summaries can be found in Appendix B-1, and are divided up according to the ICEB panel they were used in.

Figure 43 Test Set-up and Failure Mode for Grout Cubes

4.5 ICEB Panel Construction

To analyze diagonal shear capacity of the ICEB panels, a consistent procedure for constructing and testing the panels was established. Initially, two trial panels, one with nominal dimensions 24" x 24" and another measuring 36" x 36" were tested to analyze appropriate methods for building and loading the specimens. These two panels were also tested to decide what panel size to choose for the subsequent panels. From these two trial panels, a consistent construction method was followed for building the nine subsequent panels.

4.5.1 Wood Platforms

Construction of the panels began by laying down a platform to both build the panels on and use for hoisting the panel up to the testing surface. The platforms, shown in Figure 44, were constructed by cutting 2x6 pieces of wood and laying plywood over them

to provide a full bearing surface for the blocks. A cut was made approximately 6" from the end of the platform to allow for application of the mortared loading shoe. The platform was checked for levelness prior to stacking blocks.

Figure 44 Wood Platforms for ICEB Panels

4.5.2 Block Stacking

Blocks were stacked 6 courses high for the 24" x 24" panels and 9 courses high for the 36" x 36" panel. The process for stacking the blocks required great care, due to the uneven heights of the blocks. Each course was checked for levelness and to ensure that any gaps existing between the current course and the course below were minimized. When blocks could not be found to create a level course, nails were sometimes used to lift the blocks and were left in place until after grouting. A similar technique was used by Bland (2011) and Stirling (2011) for their full scale walls.

4.5.3 Making grout

Grout was prepared using a suitable mixture of cement, lime, sand and water.

Trial batching was performed on three distinct grout types, where the cement to lime amounts were varied to study their effects on compressive strength. A summary of this trial batching is shown in Table 8, while the compressive strength results are summarized in Table 9. Grout samples were tested at 21 and 28 days to examine strength gain characteristics. All materials were weighed out for testing, so all percentages listed are by mass.

Table 8 Grout Trial Batching Mix Designs

Cement: Lime 1:2		Cement: Lime 1:1		Cement: Lime 2:1	
Mix 1	weak	Mix 2	medium	Mix 3	strong
Material	% of mix	Material	% of mix	Material	% of mix
Sand	65	Sand	61	Sand	60
Cement	5	Cement	9	Cement	14
Lime	10	Lime	9	Lime	7
Water	20	Water	21	Water	19

Table 9 Grout Trial Batching Compressive Strength Results

Batch ID	21 day (psi)	average (psi)	28 day (psi)	Notes
Weak, 1	170	180	200	porous
Weak, 2	190			porous
Weak, 3	79.25	77.75	92	non-porous
Weak, 4	76.25			non-porous
Med, 1	490	510	740	porous
Med, 2	530			porous
Med, 3	220	215	240	non-porous
Med, 4	210			non-porous
Strong, 1	2170	2135	n/a	porous
Strong, 2	2130			porous
Strong, 3	1020	1030	n/a	non-porous
Strong, 4	1040			non-porous

In order to exercise care and caution during preliminary panel testing, the two trial panels were both grouted using a mix design closest to the “Strong” 2:1 grout mix.

Following the trial testing, subsequent panels were made using grout strengths closer to the block strength. To achieve this, the cement content was decreased, while sand content was increased (resulting in a design strength closer to the “Medium” 1:1 grout mix). Grout mix designs for each panel can be found in Appendix B-1.

4.5.4 Grout Mixing for Trial Panels

Prior to grouting, all blocks used in the panels were sprayed down, termed “pre-wetting” and shown in Figure 45. Pre-wetting reduces the amount of water uptake from the grout caused by shrinkage and swelling of the soil in the blocks.

Figure 45 Pre-wetting Grout Holes Prior to Grouting

The grout used for the first two trial panels was made by mixing cement, sand, lime and water into a concrete mixer, then pouring it into a wheelbarrow. Once in the wheelbarrow, the grout was further mixed using a motorized drill mixer (see Figure 46).

Figure 46 Drill Mixing Grout for Trial Panels

The amount of water added into the grout was based on consistency, rather than measured weight, as shown in Figure 47. This method was not based on any particular ASTM Standard and was similar to the method employed by Bland (2011) and Stirling (2011).

Figure 47 Grout Flow Tested From Wheel Barrow

4.5.5 Grout Mixing for Later Panels

Grout mixing for later panels was done in a large tub, since this eliminated the need for an electric mixer and drill and provided greater ease. In addition, only enough grout for one panel was made at a time to better monitor quality control. Dry ingredients were first mixed, as shown in Figure 48.

Figure 48 Grout Mixing for Later Panels

Water amounts were recorded for grout used in the later panels for quality control purposes. Grout “flow consistency” was measured using a 2” diameter plastic cylinder placed on a glass plate. This was a modified test, based on ASTM D6103 – Standard Test Method for Flow Consistency of Controlled Low Strength Material. Grout was filled to the top of the cylinder, then the cylinder was lifted, and the spread measured. Spread was measured with a ruler, as shown in Figure 49, and recorded on the data sheets for each panel. A typical spread was around 5 ½ - 6”.

Figure 49 Measuring Spread of Grout

4.5.6 *Pouring grout*

To ensure adequate grout coverage through the vertical openings in the blocks, blocks were stacked and grouted in lifts. For the 24" x 24" panel, the first lift consisted of 4 block courses, followed by a second lift of 2 block courses. For the 36" x 36" panel, the first lift consisted of 5 block courses and a second lift of 4 block courses. Grout was always cast only half way up the blocks in the top of the first lift, to reduce the chances of a cold joint forming at this location.

For the first two trial walls, the grout was rodded, per the procedure used by Bland (2011) and Stirling (2011). Inspection of the walls after testing showed that this rodding actually left impressions (i.e. void space) within the vertical grouted elements, reducing the effective area of the grout, as seen in Figure 50.

Figure 50 Voids in Rodded Grout Cores

For this reason, the grout used in the subsequent panels were unrodded. To offset the effects of unconsolidated grout due to no rodding, care was taken to ensure that the grout had adequate flow consistency as described previously.

Plywood plates were placed on each side of the wall and ratchet strapped to allow for the side shear keys to be grouted. Stirling (2011) mentioned in his thesis that these areas typically show the most voids since they have the smallest grouted area. For this reason, the plywood plates were removed and completely filled in while the grout was still plastic, as shown in Figure 51.

Figure 51 Filling in the Side Shear Keys

4.5.7 Curing panels

Following grouting, the first two trial panels were sprayed down and covered with plastic sheeting. The panels were sprayed daily for the first week, then left covered until testing. The outside grout on these panels still showed signs of minor shrinkage cracking on testing day. For this reason, future panels were cured by spraying just once (immediately after grouting) and shrink-wrapping (see Figure 52). This eliminated the need for daily spraying and provided a more efficient means for keeping the grout (and blocks) in a moist curing environment until testing.

Figure 52 Shrink Wrap Curing an ICEB Panel

4.6 ICEB Panel Testing

The typical ICEB panel testing set up required the following preparation sequence:

Day 1: Strap and hoist panel; mortar panel into bottom loading shoe. Wait 24 hours

Day 2: Mortar top loading shoe onto panel

Day 3: Anchor threaded rods onto one side of panel for instrumentation. Allow at least 8 hours for epoxy to cure.

Day 4: Instrument panel with transducers, set up camera imaging system and test

Towards the later part of testing, efficiencies in shoe mortaring allowed for threaded rods to be placed on the panel the same day the top loading shoe was mortared.

This cut down preparation by half a day, while still allowing the mortar sufficient time to cure prior to loading.

4.6.1 Loading Shoe fabrication

The loading shoes used for testing the ICEB Panels were customized to fit the ICEB blocks. Modifications were made based on the dimensions provided in ASTM E519 to produce two different size shoe options in AutoCAD: one with 3/8" thick steel and another with 5/8" thick steel. For both options, an extra gap (approximately 0.88 inches) was left on the longer side of the shoe so that additional mortar could be filled in after the panel was set into place. The 5/8" thickness was selected, as it provided a more durable shoe to tolerate several panel tests. The heavier weight (approximately 30 lbs per shoe) provided the necessary hold down when the shoe was used as the upper loading shoe. The constructed shoe is in Figure 53. Shoe dimensions can be found in Appendix B-2.

Figure 53 Final ICEB Panel Loading Shoe

4.6.2 *Panel Hoisting*

Prior to strapping each panel for hoisting, the panel was unwrapped and left to dry to the ambient lab environment. The end of this drying period was typically indicated by the exposed grout changing from a dark, moist grey to a dryer, lighter grey.

To keep the panel confined during lifting and transporting to the testing machine, the panel was strapped using ratchet straps. Four ratchet straps were used for the 24" x 24" panel and six ratchet straps were used for the 36" x 36" panel. An additional two straps were used on each wall to provide a supporting "cradle" for the panels. One end of each of these two straps was cinched to a carabiner that connected to a 1000 lb power winch. The winch was attached to a 1 ton portable gantry crane. The strapping set up is shown in Figure 54, while the full hoist configuration is depicted in Figure 55.

Figure 54 Strapping a 24 x 24 Panel

Figure 55 Hoist Configuration

4.6.3 Mortaring Loading Shoes

Prior to placing mortar in the loading shoes, metal spacers were taped into the loading shoe to ensure that an appropriately thick mortar layer would be achieved. The spacers also allowed for additional mortar to be hand packed into the shoes once the panel had been set into place. This set up is shown in Figure 56. A layer of plastic wrap was laid over the spacers to provide ease when chiseling out the mortar after testing. Review of the first two trial panels showed that the plastic wrap didn't hinder the bonding of the shoes to the panels.

Figure 56 Spacers Placed Inside Shoes

Prior to mortar mixing, the panel was inspected to ensure that the two loading corners were 90 degrees. Any imposing ridges on the blocks needed to be removed. This was done with a rotary tool, as shown in Figure 57.

Figure 57 Removing Ridges at Panel Corners

The mortar mix used for all panel tests was a quick setting cement (pre-mixed with sand) combined with water in a 5:1 ratio (cement: water). Additional water was added using a spray bottle, until a putty-like consistency was reached. The mortar was first placed into the shoes, using a trowel to fill in the gaps between the spacers and provided a level coat prior to the lowering of the panel. The panel was then tilted to the conventional 45 degree angle for diagonal loading and brought into the loading shoe for placement and plumbing. Once plumbed and leveled off, additional mortar was filled in to keep the panel from rotating. All exposed mortar was covered with plastic wrap to maintain moist curing conditions, as shown in Figure 58 .

Figure 58 Plastic Wrap Curing for Shoe Mortar

This process was repeated for the top loading shoe. The mortar's putty-like consistency prevented mortar from falling out when the loading shoe was flipped over and placed on the top corner of the panel.

4.6.4 Panel Instrumentation

Instrumentation for testing was provided by way of six displacement transducers (LVDTs), along with the built-in force and displacement transducer on the loading machine. The loading machine used for all panel tests was an MTS 322 Test Frame.

4.6.5 Instrumentation Fabrication

In order to measure displacement across the entire wall panel, custom “arms” were made out of aluminum rod and tubing, hose clamps, and swivel ball joints. A typical transducer arm is shown in Figure 59.

Figure 59 LVDT Arm (Top: Design, Bottom: As Built)

4.6.6 Instrumentation Set-Up

Instrumentation was set up on only one side of the panel and is shown in Figure 60. The largest capacity LVDT's were placed along the principal diagonals. LVDT's

were identified by their reach (e.g. LVDT 0.5B had elongation capacity of +/- 0.5 inches).

Figure 60 Instrumentation Set-up

LVDTs's were mounted to the panel by threaded rod. Holes were step-drilled (from 3/16" to 3/8") into the walls to reduce the chances for cracks and blowouts, and threaded rods were epoxied in at least 8 hours prior to installing the LVDT's. The completed installation is shown in Figure 61.

Figure 61 Completed Installation of Instruments

4.6.7 Testing Protocol

All ICEB panels were tested using the Flex Test software on the MTS machine. The testing was monotonic, with the actuator providing load at a displacement controlled loading rate of 0.003 in/min. The test was run up until the maximum load was achieved and left on until loading had dropped by at least 50% of the maximum load.

4.6.8 Data Acquisition

The software output from testing included timed displays of displacement at all locations every half second. This allowed for adequate assessment of the initial stiffness of each panel.

4.6.9 Imaging System

After trial testing, subsequent panels were tested while a camera system shot photos every 3-10 seconds during testing. The typical “staging” set up for the walls is shown in Figure 62.

Figure 62 Staging Set up for Camera System

These photos were then saved onto a web browser software and used to input into Surfer 8 ®. This program uses the photos to provide contour maps corresponding to displacements across the panel during testing. The system does this by dividing up each image into a grid of elements with a subset size defined by the user. For panel testing, an

element size of around 35 x 35 pixels was used. Since image processing was time intensive, only tests that showed distinctly different force-displacement graphs were used to produce displacement contour maps. More information about these graphs can be found in the analysis section.

4.6.10 Trial Panel Testing

The first two trial panels were set-up and tested in late January, 2016. The 24" x 24" panel displayed a very typical diagonal failure, as shown in Figure 63, while the 36" x 36" panel displayed an unusual failure at the left corner (Figure 64). It was decided that some of this was based on poor panel construction.

Figure 63 Failure of 24 x 24 Trial Panel

Figure 64 Failure of 36 x 36 Trial Panel

Moving forward with further testing, it was decided that a 24" x 24" panel was easier and faster to construct which allowed for more variables to be tested within the same amount of time. Furthermore, the 24" x 24" panels were much easier to hoist into the testing machine and provided a safer route for testing, should the panel completely separate and fall apart during loading.

4.6.11 Panel Testing Program

Once the final panel size was defined, an experimental program was developed to determine what parameters would be tested for each of the panels. Variables to explore included:

- Block Strength
- Grout Strength

- Vertical Grouted Area
- Channel Block Layup
- Block Type

The following testing program, divided up into four series, was established in order to explore these variables:

Series 1

Block Strength/Grout Strength

- Medium Strength Block, High Strength Grout (1)
- High Strength Block, Medium Strength Grout (2)
- Medium Strength Block, Medium Strength Grout* (3)

Series 2

Vertical Grouted Area

- Full Grouting*
- Partial Grouting (4)
- Grout Cores Only (5)
- Shear Keys Only (6)

Series 3

Channel Block Layup

- No Channel Blocks*
- Channel Blocks Every Other Course (7)
- Channel Blocks Every Course (8)

Series 4

Block Type

- BP6 Blocks*
- V-Lock Blocks (9)

The specimens identified with an asterisk (*) indicate the same specimen, which served as a control panel.

Each panel is fully described below with their ID used during testing and for analysis. Note that a range of strengths was deemed acceptable to classify blocks and

grout as “medium strength” and “high strength” given the standard deviation found in earlier compressive strength testing.

Specimen Identifications:

1. MSB-HSG-FG: Medium Strength Block (450-650 psi), High Strength Grout (1300-1400 psi), Fully Grouted (all Grout Cores and Shear Keys)

Figure 65 shows the typical fully grouted (-FG) panel.

Figure 65 Typical “-FG” Panel, Grouted

2. HSB-MSG-FG: High Strength Block (700-900 psi), Medium Strength Grout (600-800 psi), Fully Grouted
3. MSB-MSG-FG-CNTRL: Medium Strength Block, Medium Strength Grout, Fully Grouted, Control Panel
4. MSB-MSG-GC2: Medium Strength Block, Medium Strength Grout, Every Other Round Core Grouted (and all shear keys)

Figure 66 shows the grouted areas visually.

Figure 66 MSB-MSG-GC2 Panel, Grouted

5. MSB-MSG-NSK: Medium Strength Block, Medium Strength Grout, No Shear Keys (Grout Cores filled only)

This panel used all corner blocks, as shown in Figure 67.

Figure 67 MSB-MSG-NSK Panel, Grouted

6. MSB-MSG-SK: Medium Strength Block, Medium Strength Grout, Shear Keys Only

This configuration is shown in Figure 68.

Figure 68 MSB-MSG-SK Panel, Grouted

7. MSB-MSG-CB2: Medium Strength Block, Medium Strength Grout, Channel
Block Every Other Course

This configuration is shown in Figure 69.

Figure 69 MSB-MSG-CB2 Panel, Grouted

8. MSB-MSG-C1: Medium Strength Block, Medium Strength Grout, Channel
Blocks Every Course

The configuration for this wall was similar to MSB-MSG-CB2, except all courses contained channel blocks and were fully grouted.

9. VBLK-MSG-FG: V-Lock Blocks, Medium Strength Grout, Fully Grouted

Fully grouted for this wall indicated that all round cores were grouted (V-lock blocks do not contain shear keys). Since the V-lock blocks are only made in a full size, half blocks were created by cutting full blocks using a table saw. The wall configuration is displayed in Figure 70. As shown, each loading corner needed to be slightly grinded down in order to fit into the loading shoe, as shown.

Figure 70 VBLK-MSG-FG, with Grinded Corners

Thus, in total, 9 panels were constructed and tested as part of the analysis for this project. Note that no vertical or horizontal steel reinforcement was placed into any of the panels, as panel testing was focused only grout and block effects.

CHAPTER 5: RESULTS AND ANALYSIS

This section includes results and analysis for the nine tested panels and is organized based on the series tested. Prior to testing, hypotheses, based on past research and experience, were established to predict how the panels would perform. These hypotheses were then checked with the testing data to verify, qualify or negate them.

All panel testing data sheets to go with these results can be found in Appendix B-1.

5.1 Calculation of Panel Properties

ASTM E519 – Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages provides a determination of diagonal shear strength in masonry panels. It should be noted that past researchers, such as Brignola (2008), have performed numerical simulations to qualify the methods used in ASTM E519. However, since the research presented herein is for comparative purposes, only ASTM E519 has been used to analyze the performance of the ICEB panels.

It should also be noted that ASTM E519 suggests a minimum specimen size of 4ft x 4ft to adequately represent a full size masonry assemblage. However, “Note 1” in the standard states that if the method is only being used for purposes of “evaluating the effects of variables such as masonry unit, mortar, workmanship, etc.” a smaller size specimen can be used. Under this methodology, the 24” x 24” panel size used in this research is being used to evaluate these variable types.

5.1.1 Shear Stress

Figure 71 provides the definition sketch for calculating stress and strain data based on the test setup.

Figure 71 Definition Sketch

In accordance with ASTM E519, Shear Stress is determined by the following equation:

$$S_s = \frac{0.707P}{A_n} \quad \text{Eq 5.1.1-1}$$

Where P is the applied load (lbf), A_n is the net area of the specimen, and S_s is the shear stress on the net area (psi). The shear strength of a panel is determined when P reaches $P_{\max}$.

A_n is found using the following equation:

$$A_n = \frac{w + h}{2} * t * n \quad \text{Eq 5.1.1-2}$$

Where w is the width of the specimen (in.), h is the height of the specimen (in.), t is the total thickness of the specimen (in.) and n is the percent of the gross area of the unit that is solid (expressed as a decimal).

For all of the panels using BP6 blocks, n changed depending on the vertical elements that were grouted for the panel. Net area calculations can be found in Table 10. Note MSB-MSG-FG has the same net area as the other fully grouted (-FG) BP6 block panels.

Table 10 Net Area Calculation

Specimen ID	A _n (in ²)
MSB-MSG-FG	139.3
MSB-MSG-GC2	134.4
MSB-MSG-NSK	130.7
MSB-MSG-SK	129.7
VBLK-MSG-FG	194.3

5.1.2 Engineering Shear Strain

From ASTM E519 (and fundamental material mechanics), engineering shear strain can be calculated as follows:

$$\gamma = \frac{\Delta x}{g_x} + \frac{\Delta y}{g_y} = \epsilon_x + \epsilon_y \quad \text{Eq 5.1.2-1}$$

Where Δx is the extension in the direction perpendicular to loading (in.), Δy is the shortening in the direction parallel to loading (in.), and g_x and g_y are the gage lengths in the x and y directions, respectively. The ratios of Δ and g provide the strains in their respective directions.

5.1.3 Shear Modulus

The Shear Modulus, or Modulus of Rigidity, can be calculated as follows:

$$G = \frac{S_s}{\gamma} \quad \text{Eq 5.1.2-2}$$

It's important to note that ASTM E519 does not explicitly state where to evaluate G . From literature by Milosevic et. al (2012), and Chiostrini et. al (2000), γ used in G was taken at $1/3$ of P_{max} , while other researchers, like Mahmood et. al (2011), have assessed G at 70% of P_{max} . For this project, G was evaluated using a linear regression for data points between $50\mu\epsilon$ and $0.5S_s$.

5.2 Analysis Techniques

Since precise LVDTs were used in the instrumentation set-up, an accurate experimental determination for strength and stiffness parameters can be performed, using the aforementioned equations. In order to determine post peak performance for monotonic loading, either a strain limit is set and strength degradation (force) is measured, or a percent of peak load is measured and the strain determined. Very little literature exists on post-peak analysis using diagonal tension testing. Since the purpose of the panel testing presented here was strictly for relative performance, post peak performance was not formally assessed at a strain or stress limit. Rather, post peak area was used to ascertain how “ductile” a panel behaved following peak load. Additionally, photographs of each panel towards the later part of testing present a visual analysis of the failure. These photos can be found in Appendix B-3.

5.3 Failure Mode Assessment

Failure investigation of the panel was made at the beginning and end of testing to assess the failure mode. A typical panel failure is shown in Figure 72. Some panels showed this classic diagonal cracking failure quite clearly, while others exhibited less cracking on the face (indicative of more internal failure). As mentioned in Literature Review, shear failure is a combination of cracking along the bed joints (from sliding) and

diagonal cracking through the blocks. Thus, both of these contributing factors need to be evaluated for full assessment.

Figure 72 Panel Failure (MSB-MSG-FG-CNTRL)

A high resolution camera took photos of the wall every 5-10 seconds during testing. These photos were matched to the force-displacement data to provide visual analysis of the panel nearing and just following the peak load. An analysis on select panels is included in this chapter.

5.4 Panel Results and Analysis

The following are results and analysis for all tested panels, divided up by series.

5.4.1 *Series 1: Block Strength/Grout Strength*

Hypothesis:

The following hypotheses were used to estimate how block strength and grout strength would affect diagonal shear performance:

- Block compressive strength does not have a significant effect on diagonal shear strength (given the same block type and pressing pressure)
- Grout compressive strength does have a significant effect on diagonal shear strength

Reasoning: Due to the dry-stack nature of the ICEBs, neither the head joints nor the bed joints provide any adhesion to allow the blocks to immediately engage one another and behave as one homogenous material. As a result, it's common to see bed joint sliding and head joint openings as contributors to the panel failure. To counter some of this sliding, the ICEB's are designed with interlocking ridges that provide bearing resistance. However, past ICEB research, like Bland (2011), has suggested that this interlocking mechanism does not begin to engage until a sufficient amount of sliding has already taken place. If this is the case, the grout and blocks could possibly be acting as separate elements. Since the grout is considered to be a "stiffer material" (since it doesn't contain soil or other expansive material), the continuous grouted elements could be providing a majority of the shear transfer across the panel during the earlier parts of testing. This means that the grout strength plays a large factor in the overall shear performance.

To assess how much of a difference the grout strength makes, the control specimen features a medium grout strength and medium block strength.

Table 11 summarizes the properties achieved from testing panels that followed Series 1, while Figure 73 provides the force-strain results from the principal vertical (“0.5B”) and horizontal (“0.5A”) LVDTs. Note that for sign convention, compression was designated as positive displacement (and strain), while tension (i.e. elongation) was designated as negative displacement (and strain).

Table 11 Series 1 Panel Test Results

	Peak Load (kips)	A_n (in ²)	S_s (psi)	G (ksi)
MSB-HSG-FG	5.415	139.3	27.48	51.2
HSB-MSG-FG	4.391	139.3	22.29	69.8
MSB-MSG-CNTRL	3.821	139.3	19.39	32.4

Figure 73 Series 1 Panel Force-Strain Plot

The panel with high strength grout took the largest load, while the control panel took the least. Since the high strength block panel still took more load than the control, it appears that block strength does affect shear strength. However, grout strength also appears to significantly affect the shear strength. When considering panel shear stiffness (G), the high strength block provides the highest shear stiffness, followed closely by high strength grout, while the control panel has the least. This is also seen visually in Figure 74.

Figure 74 Series 1 Stress-Strain Plot

Compressive strength test results for the blocks and grout are provided in Table 12 and Table 13, respectively, to determine if any relationship between block strength, grout strength and panel shear strength exists.

Table 12 Comparison of Block Compressive Strengths

Block* Type	Test Type	Average Block Strength (psi)
High Strength (HSB)	ungROUTED, single block	720
	grouted, single block (multiple types)	703
	grouted, 3 block stack (multiple types)	258
Medium Strength (MSB)	ungROUTED, single block	540
	grouted, single block (multiple types)	532
	grouted, 3 block stack (multiple types)	155

*Block strengths taken from several block batches, including blocks used in Series 1 panels.

Table 13 Comparison of Grout Compressive Strengths

Panel ID	Average Porous (p) Grout Strength (psi)	Average Non-Porous (np) Grout Strength (psi)
MSB-MSG-FG-CNTRL (Medium Strength Grout)	685	345
MSB-HSG-FG (High Strength Grout)	1337	567

Table 12 shows that the high strength blocks are at least 30% stronger than the medium strength blocks. The porous grout strengths in Table 13 show that the high strength grout is at least 64% stronger than the medium strength grout. From this, it's clear that the difference between medium and high strength grout is much larger than the difference between medium and high strength blocks. Looking at the max load achieved between the control panel and the high strength block panel, the increase in max load caused by changing the block strength is 15%. Comparing the control panel with the high strength grout panel, the difference in increasing the grout strength is just over 40%. Thus, this could suggest that the modifications to the block and grout strengths are being similarly matched by the increase in shear strength for their respective panel.

Based on Figure 73, it's clear that the high strength grout (HSG) panel exhibited the most significant post peak shear strength degradation, followed by the high strength block and the control specimen. The HSG panel also begins to pick up load around 1200µε indicating that a new load resisting mechanism may be present (such as the interlocking ridges on the tops of the blocks).

5.4.2 *Series 2: Vertical Grouted Area*

Hypothesis:

The following hypotheses were used to estimate how vertical grouted area would affect diagonal shear performance:

- Vertical grouted area has a significant effect on diagonal shear performance
- Removing shear keys from a panel has a significant effect on displacement along the bed joint (i.e. horizontal sliding)

Reasoning: Bland (2011) suggests that the “grouted region” provides a significant contribution to shearing resistance, with very little being contributed at the dry stacked block interface and by the interlocking mechanism of the blocks. Furthermore, comparing Bland's partially grouted shear walls with his fully grouted shear walls shows that a decrease in vertical grouted area can cause a rather significant decrease in shear capacity. Shear keys in the ICEB walls are the only element that assures “shear continuity” from one block to the next in a given block course, as shown in Figure 75. It is assumed that a removal of these shear keys will dramatically influence inter-block displacement.

Figure 75 Shear Keys Between ICEB Blocks

Table 14 summarizes the properties achieved from testing panels that followed Series 2, while Figure 76 provides the force-strain results from the principal vertical (“0.5B”) and horizontal (“0.5A”) LVDTs.

Table 14 Series 2 Panel Test Results

	Peak Load (kips)	A_n (in ²)	S_s (psi)	G (ksi)
MSB-MSG-CNTRL	3.821	139.3	19.39	32.4
MSB-MSG-GC2	2.978	134.4	15.66	16.8
MSB-MSG-NSK	1.638	130.7	8.86	11.1
MSB-MSG-SK	1.929	129.7	10.52	14.3

Figure 76 Series 2 Panel Force-Strain Plot

The shear strength was the highest for the fully grouted specimen, as expected. The panel that only had shear keys grouted (with a smaller grouted area) produced a higher shear strength and shear stiffness than the panel with only grouted cores. This suggests that the shear keys are producing a more substantial effect on shear stiffness parameters than the grouted cores, influencing both strength and displacement leading up to the peak load. The shear stress-strain plot can be seen in Figure 77.

Figure 77 Series 2 Stress-Strain Plot

Table 10 shows that the decrease in net area (A_n) between the fully grouted panel (MSB-MSG-FG) and the panel with only shear key grouting (MSB-MSG-SK) is only 7% while the decrease in peak load is 45%. This indicates that the shear strength contribution to the panels does not linearly increase with the net area, a similar conclusion reached by Bland (2011).

An analysis of shear strength as a percent of the grouted area can be used to receive a clearer idea of how additional grouted area influences shear performance. Table 15 and Figure 78 are provided to display this information and provide further depth to this analysis.

Table 15 Peak Load vs Vertical Grouted Area (VGA)

Panel ID	VGA (in ²)	Peak Load (kips)	VGA/A _n	VGA/VGA _{CNTRL}	P/P _{CNTRL}
MSB-MSG-FG-CNTRL	18.22	3.821	13.1%	1.00	1.00
MSB-MSG-GC2	13.41	2.978	10%	0.74	0.78
MSB-MSG-NSK	9.62	1.638	7.4%	0.53	0.43
MSB-MSG-SK	8.6	1.929	6.6%	0.47	0.50

Figure 78 Vertical Force vs Vertical Grouted Area

Using data from Table 15 to plot Figure 78, a general relationship can be defined to relate vertical grouted area to vertical force. The relationship is not completely linear, but suggests that a reduction in grouted area can cause a rather equal reduction in peak load. Interestingly, the intercept for the graph is negative. Knowing that with no grouting, there must be at least a minimal amount of resistance, the best fit line would run at or near the origin. Overall, though, the results show that the grouted areas are providing a majority of the shearing resistance.

The general trend for post-peak strength loss tends to indicate that lowering the grouted area reduces the rate of shear strength loss for the specimen. Interestingly, the

specimen with grouted cores only (MSB-MSG-NSK) picks up load towards the later portion of the unloading, perhaps indicating that contact was made with the interlocking ridge on the blocks.

5.4.3 Series 3: Channel Block Layup

Hypothesis:

The following hypotheses were used to estimate how channel block layup would affect diagonal shear performance:

- Increasing Channel Block Courses Increases Diagonal Shear Performance

Reasoning: The typical failure mode for diagonal tension testing is a crack that runs parallel to the loading direction. Adding courses of continuously grouted channel blocks should provide resistance to this failure path, thus increasing shear resistance.

Table 16 summarizes the properties achieved from testing panels that followed Series 3, while Figure 79 provides the force-strain results from the principal vertical (“B”) and horizontal (“A”) LVDTs.

Table 16 Series 3 Panel Test Results

	Peak Load (kips)	A_n (in ²)	S_s (psi)	G (ksi)
MSB-MSG-CNTRL	3.821	139.3	19.39	32.4
MSB-MSG-CB2	3.346	139.3	16.98	31.6
MSB-MSG-C1	2.878	139.3	14.61	33.1

Figure 79 Series 3 Panel Force-Strain Plot

There appears to be a decreasing relationship between shear strength and number of channel block courses. Contrary to the hypothesis, the highest load and shear strength was obtained from the control panel, which contained no channel blocks. One possible explanation for this is that the thinner side walls of a channel block could lead to reduced unit strength, which would create a weak element in the panel. This would result in visible facial cracking along the channel block courses. However, reviewing photos, such as Figure 80, reveal that extensive cracking took place along all courses of blocks within MSB-MSG-CB2, including non-channel block layers. Nevertheless, it is noted that the channel blocks were not tested for compressive strength to compare with the regular blocks used in this project.

Figure 80 Cracking on MSB-MSG-CB2

Another issue to consider is shrinkage of the grout. Inspection of MSB-MSG-C1 after testing revealed gaps at the channel block- grout interface, as shown in Figure 81. This results in lack of full bonding between the grouted channels and the blocks. During grouting, the grout along a channel could also not be making full contact with the course of blocks above, leading to loss in shearing area. A more fluid grout more help mitigate this issue.

Figure 81 Grout Shrinkage at Block-Grout Interface

In terms of shear stiffness, all three panels appear to have very similar values, as shown clearly on Figure 82.

Figure 82 Series 3 Stress-Strain Plot

5.4.4 Series 4: Block Type

Hypothesis:

The following hypothesis was used to estimate how block type would affect diagonal shear performance:

- Changing block type from manually-pressed blocks (BP6) to hydraulically-pressed blocks (V-Lock) will increase shear performance.

Reasoning: The V-Lock blocks offer larger grouted cores than the BP6 blocks, providing greater shear resistance due to grouting. Additionally, the hydraulic process allows much higher pressing pressures to be reached in forming the V-Lock blocks, resulting in greater block stiffness and compressive strength.

Table 17 summarizes the properties achieved from testing panels that followed Series 3, while Figure 83 provides the force-strain results from the principal vertical (“B”) and horizontal (“A”) LVDTs.

Table 17 Series 4 Panel Test Results

	Peak Load (kips)	A_n (in ²)	S_s (psi)	G (ksi)
MSB-MSG-CNTRL	3.821	139.3	19.39	32.4
VBLK-MSG-FG	7.195	194.3	26.19	22.5

Figure 83 Series 4 Panel Force-Strain Plot

It is clear that the wall composed of V-Lock blocks provided a much larger load capacity and higher shear strength than the control specimen, composed of BP6 blocks. However, in terms of panel stiffness, the control (made of BP6 blocks) produced a slightly higher shear stiffness, as seen in Figure 84.

Figure 84 Series 4 Stress-Strain Plot

In terms of grouted area, Table 18 provides a comparison between vertical grouting and peak load, based on these two panel tests.

Table 18 Vertical Grouted Area (VGA) vs Peak Load (by Block Type)

Panel ID	VGA (in ²)	Peak Load (kips)	Peak Load, Normalized	Grouted Area, Normalized
VBLK-MSG-FG	28.27	7.19	1.88	2.04
MSB-MSG-FG-CNTRL	13.86	3.82	1	1

A comparison of the normalized areas and loads from this table shows that the increase in peak load almost linearly matches the increase in grouted area, suggesting that grouted area is linearly affecting the peak load, regardless of block type. Considering ungrouted, single block strength (from Table 19), V-Lock blocks were more than three times the compressive strength than the BP6 blocks. However, once grouted and

compression tested stacked, the V-Lock blocks show similar compressive strength reductions to the BP6 blocks, as measured by prism ratio (group stack: single block).

Table 19 Compressive Strengths for V-Lock vs BP6 Blocks

V-Lock Blocks			BP6 Blocks		
Test Configuration	average stress (psi)	Prism ratio	Test Configuration	average stress (psi)	Prism ratio
ungROUTED Single Stack	1912	0.23	ungROUTED Single Stack	540	0.29
grouted triple stack	445		grouted triple stack	155	

Figure 84 also shows that the V-Lock block panel exhibits more significant shear strength reduction than the BP6 panel. This suggests that the manually pressed blocks provide a more ductile performance than the hydraulically pressed blocks.

5.5 Shear Stiffness Results Comparison

The shear modulus, G , obtained from the control panel in this study was 32.4 ksi. This represents shear stiffness from an assembly composed of medium strength blocks (MSB). The shear modulus obtained from the HSB-MSG-FG panel was 69.8 ksi which represents shear stiffness in an assembly composed of high strength blocks (HSB). The masonry code (MSJC 2013), Section 4.2.2.2.2 defines the shear modulus for clay masonry as:

$$E_v = 0.4E_m \quad \text{Eq 5.5-1}$$

Where E_v is the shear modulus (called “ G ” in this thesis), and E_m is the elastic modulus. Based on Section 4.2.2.2.1 of the code, the following approximation is provided for E_m :

$$E_m = 700 f'_m$$

Eq 5.5-2

Where f'_m is the compressive strength of the clay masonry. A calculation of E_m and G based on equations Eq 5.5-1 and 5.5-2 were determined using the prism compressive strengths for the medium and high strength blocks given in Table 12. Comparisons of G are made with the MSJC code, G found experimentally in Bland's fully grouted shear wall (labeled "Wall 2"), and G from panel results in this thesis. These results are summarized in Table 20 below.

Table 20 Shear Stiffness Comparisons

	f'_m (psi) ²	E_m (ksi)	G from MSJC equation (ksi)	G , experimental (ksi)
MSJC estimate using MSB prism strength	155	108.5	43.4	32.4 (MSB-MSG-FG)
MSJC estimate using HSB prism strength	258	181	72.2	69.8 (HSB-MSG-FG)
Bland (2011) ¹	457	320	128	62.2 (Wall 2)
Bland (2011) ³	n/a	83.4	33.4	

¹ E_m value found using MSJC equation (using f'_m)

² f'_m evaluated based on prism tests (3 block stack)

³ E_m found from testing

As shown in Table 20, the G from MSB-MSG-FG is 34% different from G found using MSJC equations. However, G from HSB-MSG-FG is only 3% different from the MSJC estimate. The MSJC results differ much more from experimental results when looking at Wall 2. Comparing experimental results for the panels to Wall 2, however, the G values seem reasonably closer to one another (particularly between HSB-MSG-FG and Wall 2).

5.6 Reevaluation of Shear Stress

Shear stress calculated for all panels was based on the ASTM E519 equation, which uses the net area. Recalculation of shear stress, using VGA instead, can be used to present a more accurate assessment for this strength property, defined as $S_{s, \text{modified}}$. Table 21 below summarizes the results from this study. The average value of the modified shear strength for all panels comes out to 146 psi, with a standard deviation of 15 and coefficient of variance of 11%. Overall, the numbers are close enough to suggest that shear stress remains constant across all panels, and can be reasonably defined based on the grouted area, rather than the net area.

Table 21 Modified Shear Stress for Series 2 Panels

Panel ID	$S_{s, \text{modified}}$ (psi)
MSB-MSG-FG-CNTRL	148
MSB-MSG-GC2	157
MSB-MSG-NSK	120
MSB-MSG-SK	159

Additionally, the results from Table 21 can be compared with results from Bland (2011) who tested a partially grouted wall (Wall 1) and a fully grouted wall (Wall 2). His results are shown in Table 22 and are compared with partially and fully grouted panels from this research to see what relationship exists. From the table, V_{ave} denotes the horizontal component of the max load (P_{max} from Table 14). Grout strengths are also shown in this table since the methodology follows that if the vertical grouting is providing most (if not all) of the shear strength in the ICEB assembly, then the grout compressive strength (not the block strength) is serving as reference.

Table 22 Panel Comparison to Full Size Walls

Specimen ID	Grout Configuration	Grout Strength (psi)	V_{ave} (kips)	VGA (in ²)	A_n	VGA/ A_n	$S_{s,modified}$ (psi)
Wall 1	Partial	1305	5.52	33.11	381.3	9%	167
MSB-MSG-GC2	Partial	740	2.11	13.41	134.4	10%	157
Wall 2	Full	1305	9.53	52.83	401.5	13%	180
MSB-MSG-CNTRL	Full	685	2.70	18.22	139.3	13%	148
MSB-HSG-FG	Full	1337	3.83	18.22	139.3	13%	210

Comparing Wall 1 (partially grouted) with MSB-MSG-GC2 (also partially grouted) shows a 6.4% difference, even though the grout strength between the two panels is different by 76%. For Wall 2, the closest strength is found with MSB-HSG-FG, which has a 16.7% difference, and a closer grout strength (2.5%) as well. Although the intent of this research was not to provide a direct relationship to full scale testing, these results show that some relationship does indeed exist, especially concerning the fully grouted assemblies.

Summarizing the results from this section and Section 5.5 reveal that block strength (reflected in prism tests) is a key parameter for determining shear stiffness, while grout strength is a key parameter for determining shear strength. The results from each of these sections compare well with full scale testing. However, more testing of different grout and block strength panels would help reinforce these two analyses and define an even clearer relationship.

5.7 Imaging Analysis Results

Imaging Analysis was run on select panels that showed distinct load-displacement results. After review of the nine tested panels, MSB-MSG-CNTRL was selected, since it

served as a baseline for all other panels. HSB-MSG-CNTRL was also analyzed to provide reference to factors affecting panel shear stiffness.

5.7.1 MSB-MSG-CNTRL Imaging Analysis

Imaging analysis was performed on MSB-MSG-CNTRL at the locations outlined on the force-displacement plot below. Numbers next to each point represent the camera image in the sequence. Note that displacement corresponds to LVDT 0.5B (direction parallel to loading).

Figure 85 Data Points for CNTRL Imaging

The displacement contour plots for data points 87, 100 and 128 corresponding to horizontal “u” and vertical “v” displacements are shown in Figure 86.

CNTRL 87 ($700 \mu\epsilon = .0187 \text{ in}$)

CNTRL 100 ($830.16 \mu\epsilon = .0222 \text{ in}$)

CNTRL 128 ($1112 \mu\epsilon = .0297 \text{ in}$)

Figure 86 U (left) and V (right) Displacements

Looking at u displacements, a rather distinct concentration of displacements occurs along the bed and head joints nearly parallel to the loading direction (along LVDT 0.5 B). This step formation indicates sliding and is defined dominantly along one set of diagonals, and secondary along another. Leading up to peak load (around CNTRL 128), the formation travels almost completely from the left panel side to the right panel side.

The color difference between the top right portion of the panel and the bottom left indicates that the bottom left is remaining somewhat isolated (i.e. not displacing) relative to the top right. Indeed, as test results showed, the bottom left half completely separated from the top right at the very end of the test.

Also of interest is the displacement concentration on the top left loading shoe. Several numerical models (Brignola et. al 2008) indicated that equal load concentrations should occur at each loading corner. However, the top left loading shoe displaced over .025 inches more than the bottom right shoe, as shown in CNTRL 128. Reason for this could be that the $\frac{1}{2}$ block in contact with the top loading shoe can take larger displacements and perhaps rotate, while the full block, in contact with the bottom loading shoe, can't move about each direction as easily. It's important to note that up to the peak load (point 128), no signs of diagonal block cracking are apparent.

U and V displacements at data point 210 are shown in Figure 87. This figure shows the clearly defined failure pattern developing in both the u and v directions. The lower left half of the panel is moving downward, while the top right appears to have very low vertical movement, but continues sliding to the right. On the v displacement graph, the top left $\frac{1}{2}$ block shows signs of possible rotation, indicated by the contours

underneath and on the right side of the block. Deep vertical contours on the second block course in the u-displacement graph is a crack beginning to emerge in the block.

Figure 87 U (left) and V(right) Displacements (210)

The results of Figure 87 can be seen also on the force displacement plot for MSB-MSG-FG-CNTRL, shown in Figure 88. This graph shows that 0.1B (top of wall, horizontal direction) is displacing more than 0.1A (bottom of wall, horizontal direction), which matches the results of the left graph in Figure 87. Likewise, 0.3B (vertical, left of wall) displaces more than 0.3A (vertical, right of wall), which matches the right graph in Figure 87.

Figure 88 Force-Displacement 0.1,0.3 (CNTRL) Graph

5.7.2 HSB-MSG-FG Imaging Analysis

Following analysis of MSB-MSG-CNTRL (short termed “CNTRL”), imaging analysis was performed on HSB-MSG-FG (short termed “HSB”). The plot for LVDT 0.5B is shown in Figure 89, along with data points used for imaging analysis.

Figure 89 Data Points for HSB Imaging

The displacement contour plots for data points 46, 60 and 70 corresponding to horizontal “u” and vertical “v” displacements are shown in Figure 90.

The first apparent difference between the HSB displacement plots versus CNTRL plots is the detection of the “stepping” failure along the bed and head joints, which becomes defined at an earlier stage in testing than in the CNTRL test. Looking at Figure 89, the initial part of the curve reaching peak load is much steeper than the one on CNTRL, and the peak load is reached much sooner in testing on HSB. One interesting observation is how much more isolated the top left $\frac{1}{2}$ block is compared with the rest of the panel. U displacements appear much more spread out along the top bed course for the CNTRL panel. This provides a rather good sense for how much stiffer the HSB panel is compared with the CNTRL panel. The stepping u displacements also appear to be rigidly lined along a single diagonal, and is not paralleled by another stepping failure as the CNTRL panel (see Figure 86).

HSB 46 ($200\ \mu\epsilon = 0.0054\text{ in}$)

HSB 60 ($300\ \mu\epsilon = 0.008\text{ in}$)

HSB 70 ($400\ \mu\epsilon = 0.011\text{ in}$)

Figure 90 U (left) and V(right) Displacements

U and V displacements at data point 99 is shown in Figure 91. The movement of the top right half of the panel relative to the bottom left follows similarly to the CNTRL panel. Also, the initiation of block cracking on the left graph in the figure nearly matches the same location as the one on CNTRL. However, as noted with CNTRL, diagonal cracking through the blocks did not initiate until after the peak load was reached. Another interesting result from the figure is the negative u displacement on the left graph. This indicates that the left side of the panel isn't completely isolated from the right side, but tends to move left as the other side is moving right.

Figure 91 U (left) and V (right) Displacements (99)

Based on imaging analysis for the CNTRL and HSB panels, it's apparent that the displacement maps allow for a rather accurate assessment of panel behavior, especially before the panel reaches maximum load, allowing for a more complete assessment of shear failure. Combining results from the imaging analysis with photos of the panels as

they near failure (see Appendix B-3), a general trend shows that failure mode is dominated by sliding joint failure prior to peak load, followed by a combination of sliding and diagonal block cracking after the peak.

CHAPTER 6: CONCLUSIONS

This project sought to provide an adequate procedure for performing diagonal shear testing on Interlocking Compressed Earth Blocks (ICEBs). As previously mentioned, ICEBs differ largely from conventional masonry. One of the largest differences in construction methods between ICEBs and other types of masonry blocks is the dry-stacking, which allows for displacements at block bed joints and head joints. A formalized testing matrix was provided to explore the effects of various factors on ICEB panel shear performance, including block strength, vertical grouting, channel block layup and block type. A summary of conclusions from material and panel testing follows, along with recommendations for future testing.

6.1 Material Conclusions

6.1.1 Max Dry Density-Moisture Content Relations

Proctor tests performed on block mixtures with varying soil-sand ratios showed that increasing the soil amount decreased the maximum dry density and increased the moisture content of the mixture. Compressive strengths were also found to decrease as clay content increased, consistent with past research.

6.1.2 Half Block vs Full Block Compressive Strengths

Compressive strength testing performed at the beginning of this project showed that a larger variation exists among full blocks than half blocks, based on the Coefficient of Variance (COV) found from compression tests. This suggests that it is better to test

half blocks for compressive strength to reduce the standard deviation and variance in strength results.

6.1.3 Block Strength Increase vs Cement Content

Results from medium strength and high strength BP6 block testing show that strength increase is not linearly related to cement content. A similar result was reached by Banker-Hix (2014) and others. The soil disturbs the cement hydration products from forming and bonding to the “clean” aggregate in the block mix (i.e. the sand and non-clay soil particles).

6.1.4 Porous vs Non-porous Grout Compressive Strength

As Bland (2011) and other Cal Poly ICEB researchers show, grout cast inside the blocks shows significantly higher compressive strength than that cast into 2x2 plastic molds. The blocks soak much of the water from the grout, lowering the water-cement ratio, which increases compressive strength. Results from this paper show that the ratio of porous to non-porous sample strength is roughly 2:1.

6.2 Panel Construction Conclusions

6.2.1 Grouting Methods

Due to issues in the first two trial panels, it was determined that the grout was best left unrodded during panel construction, contrary to the methods used by Bland (2011) and Stirling (2011). Higher, more fluid grout is necessary to counter the inability to rod. Additionally, grout with sufficient lime content will help to reduce the effects of water uptake during grouting. For panels with channel blocks, it's especially important to make

sure the grout is fluid enough to make contact with the course of blocks above the channel course (to ensure full shear transfer along the bed joints).

6.3 Panel Testing Conclusions

6.3.1 Effects of Changing Block and Grout Type

Results from Series 1 panel testing showed that both block and grout strength influence diagonal shear strength in ICEB panels. It was shown that increasing the strength of each material will result in a nearly linear increase in diagonal shear capacity.

6.3.2 Effects of varying vertical grouted area

Results from Series 2 panel testing showed that increasing the vertical area in the panels increases diagonal shear strength. Similar to findings from Bland (2011), net area does not properly represent the increase in shear strength. Considering only the grouted area proved to be more effective in analyzing the relative difference in strength increase. The grouted shear keys also appear to provide a significant difference on both shear strength and shear stiffness of the panels.

6.3.3 Effects of Channel blocks/ Number of channel block courses

Results from Series 3 panel testing showed that adding courses of channel blocks decreases shear strength in the panels. Reason for this includes shrinkage of the grout, which inhibits full contact at the bed joint between the channel blocks and the block course above. A more fluid grout mix could possibly improve this issue.

6.3.4 Effects of Block Shape

Results from Series 4 panel testing showed that the V-lock block panel has higher shear strength than the BP6 block panel. However, both panels had nearly the same shear stiffness. Additionally, the BP6 panel showed gradual strength degradation following the peak load, indicative of a more ductile performance.

6.3.5 Shear Stiffness and Shear Strength Evaluation

Detailed assessment of shear stiffness and shear strength show that both properties found from panel testing compare reasonably well with past ICEB research on full size wall testing (Bland, 2011). Mainly, block strength is an important parameter affecting shear stiffness, while grout strength is an important parameter affecting shear strength.

6.3.6 Imaging Analysis

The results from imaging analysis on panels MSB-MSG-FG-CNTRL and HSB-MSG-FG reveal a clear assessment of panel behavior even prior to peak load. From this analysis, the dominant failure mode in ICEB panels can be defined as sliding joint failure prior to peak load, particularly a diagonal path is fully formed from the left to right side of the panel. Following peak load, a combination of sliding and diagonal block cracking takes place. Displacement concentrations are also evident on only one of the two loading corners early on in testing.

6.4 Recommendations for Future Work

6.4.1 Future Material Testing

While extensive single block testing was performed in this project, only a select few prism tests were run. It would be helpful to run more tests on grouted and ungrouted prisms (typically 3 block stacks) in order to gain a better sense for the aspect ratio and how it's affected by grouting. Additionally, tests run at different block strengths and block types (i.e. channel block, corner block) could provide more insight into whether the amount of solid area in the block affects the compressive strength of an ICEB assemblage.

6.4.2 Future Diagonal Tension Testing

Since this is the first reporting (to the author's knowledge) of diagonal tension testing of dry-stacked ICEBs, more panel testing is recommended to develop a stronger relationship among the variables tested in this research. To begin with, another control specimen should be tested in order to determine the variance in the ASTM E519 test method.

More panels with varying block and grout strengths should also be tested to analyze their impact on shear strength. Under the methodology that vertical grouted area (VGA) is providing nearly all of the capacity to the panel in shear, then grout compressive strength could provide a connection to expectations from full size wall tests (as shown in Section 5.6). A similar methodology follows for block strength (as shown in Section 5.5)

Additional panels with pre-compression should also be tested, to determine the effects of normal load on bed joint/sliding resistance. Research suggests that this should have a significant impact on diagonal shear strength, particularly dry-stacked masonry (Marzahn, 1998; Mann and Mueller, 1980). Also, looking back at Figure 78, adding precompression could provide the non-zero intercept expected due to bed joint friction.

A panel without interlocking ridges should also be tested to determine how the load-displacement response changes. The current research suggests that the grout may be engaging within the panel before the ridges begin bearing. A test of blocks without ridges would help confirm this theory. See Figure 10 for illustration of the interlocking mechanism.

Imaging analysis showed that displacements in both the “u” and “v” directions are concentrated on the upper $\frac{1}{2}$ block loading corner. A panel should be constructed so that a full block is used as the upper loading corner. Comparison with imaging results can help determine if block dimensions (length vs height) actually makes a difference on the observed displacement concentration.

Lastly, it should be noted that test results in this paper are based on a 24” x 24” nominal panel size. A larger panel size (such as 36” x 36”) should be studied to determine how global and local failures within the panel are dependent on panel size. Ghanem et al (1994) provide rather detailed research on this issue.

6.4.3 Future Shear Tests

Research into direct shear testing (Lourenco et. al, 2004 and others) indicates that simple horizontal shear testing of 2 or 3 block stack can provide further insight into

parameters affecting bed joint strength. Additionally, the use of Interlocking Compressed Earth blocks leads to questions about when the interlocking mechanism begins to engage. Direct shear testing could provide answers to these questions which would assist with future diagonal tension (and racking) tests.

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APPENDICES

APPENDIX A) MATERIAL DATA

Attached are the data sheets for soil and sand testing conducted for this project, along with proctor compaction test results and sieve analyses. Block batching sheets, and grout cube trial tests are also included.

A.1 Las Tablas Soil Testing (from Banker-Hix, 2014)

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Atterberg Limits Measurements

Test Method: ASTM D4318, D2487

Project Name	LT Thesis Testing	Project No.	-----
Tested By	WBH	Testing Date	4/12/2014

SPECIMEN ID AND CLASSIFICATION					
Boring No.	-----	Sample No.	-----	Depth (ft)	-----
Soil Description	Lean Clay (CL): Yellowish Brown				

LIQUID LIMIT			
Target Range of Blows	40-30	30-25	25-20
Actual Number of Blows	34	24	19
Dish ID	24	208	52
Mass of Dish (g)	30.70	30.15	31.09
Mass of Moist Soil + Dish (g)	39.43	37.07	37.55
Mass of Dry Soil + Dish (g)	36.84	34.97	35.53
Water Content	42.2%	43.6%	45.5%

PLASTIC LIMIT		
Dish ID	93	226
Mass of Dish (g)	30.41	30.25
Mass of Moist Soil + Dish (g)	37.46	43.14
Mass of Dry Soil + Dish (g)	36.72	41.69
Water Content	11.7%	12.7%

SUMMARY	
Liquid Limit	44
Plastic Limit	12
Plasticity Ind.	32

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Hydrometer Analysis

Test Method: ASTM D422, D2487

Project Name	LT Thesis		
Tested By	WBH	Testing Date	4/8/2014
Soil Description	Lean Clay (CL): Yellowish Brown		

GRAVEL GRADING					
Tray ID	I	Air-Dry Soil Mass (g)	266.07	Corrected Dry Mass (g)	256.74

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	Combined % Passing
3 in	76.2	0.00	0.00	0.0%	100.0%
2 in *	50.8	0.00	0.00	0.0%	100.0%
1 in *	25.4	0.00	0.00	0.0%	100.0%
3/4 in *	19.1	0.00	0.00	0.0%	100.0%
1/2 in *	12.7	0.00	0.00	0.0%	100.0%
3/8 in *	9.50	1.52	1.52	0.6%	99.4%
No. 4 *	4.75	5.27	6.79	2.6%	97.4%
Pan		259.28	266.07	Sieve Continuity	100.0%

WATER CONTENT OF MINUS #4 =			3.6%	#4 BY #10 GRADING	
Dish ID	2	Moist Soil + Dish (g)	54.46	Mass of Air-Dried Soil (g)	120.34
Dish Mass (g)	30.78	Dry Soil + Dish (g)	53.63	Corrected Dry Mass (g)	116.12

Sieve No.	Size, mm	Mass Retained (g)	% Retained	% Passing	Combined % Passing
No. 10	2.00	10.87	9.4%	90.6%	88.2%
Pan		109.46	Split Minus #10 for Hydrometer Test (152H)		

Post Wash ID	B-I	Dry Mass Post Wash (g)	212.86	#16 BY #200 GRADING		
Sieve No.	Size, mm	Mass Retained (g)	Cum. Ret. (g)	% Retained	% Passing	Combined % Passing
No. 16	1.180	14.62	14.62	6.9%	93.1%	82.2%
No. 30	0.600	15.18	29.80	14.0%	86.0%	75.9%
No. 50	0.300	15.38	45.18	21.2%	78.8%	69.5%
No. 100	0.150	20.42	65.60	30.8%	69.2%	61.0%
No. 200	0.075	24.06	89.66	42.1%	57.9%	51.1%
Pan		0.83	90.49	Sieve Continuity		235.2%

HYDROSCOPIC WATER CONTENT =				HYDROMETER	
Dish ID	76	Moist Soil + Dish (g)	90.70	Mass of Air-Dried Soil (g)	49.13
Dish Mass (g)	30.58	Dry Soil + Dish (g)	88.35	Corrected Dry Mass (g)	47.21
				Composite Correction	6

Time (min)	Hydro. Reading	Temperature (°C)	Effective Depth	Diameter (mm)	% Passing	Combined % Passing
2	31.0	21.0	11.2	0.0314	52.4%	46.3%
5	28.0	21.0	11.7	0.0203	46.1%	40.7%
15	27.0	21.0	11.9	0.0118	44.0%	38.9%
30	25.0	21.0	12.2	0.0085	39.8%	35.2%
60	24.0	21.0	12.4	0.0060	37.7%	33.3%
90	23.0	21.0	12.5	0.0050	35.6%	31.5%
120	23.0	22.0	12.5	0.0042	35.6%	31.5%
240	22.0	22.0	12.7	0.0030	33.6%	29.6%
480	21.0	23.0	12.9	0.0021	31.5%	27.8%
1440	21.0	23.0	12.9	0.0012	31.5%	27.8%

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Expansion Index

Test Method: ASTM D4829

Project Name	Las Tablas	Project No.	-----
Tested By	WBH	Testing Date	4/19/2014

SPECIMEN ID AND CLASSIFICATION					
Boring No.	-----	Sample No.	-----	Depth (ft)	-----
Soil Description	Lean Clay (CL): Yellowish Brown				

Moisture Content	
Tare No.	15
Wet soil + tare, g	685.65
Dry soil + tare, g	675.96
Water, g	9.69
Tare, g	633.71
Soil, g	42.25
% Water	22.93

SPECIMEN MASS	
Height, in	0.99
Diameter, in	4.01
Ring No.	201 GM
Ring, g	200.72
Ring + soil, g	510.80
Wet density, pcf	94.02
Dry density, pcf	76.48

EXPANSION READINGS			
DATE	TIME	DIAL READING, in.	REMARKS
4/13/2014	10:30	0.0309	10 min after loading
4/14/2014	20:30	0.0616	FINAL READING

SATURATION:	51.5
EI MEASURED:	31
EI at 50% SAT:	32

Low Expansion Potential

Absorption Test (Ret #20)		
Trial	1	2
SSD Sand (g)	1120.0	1104.5
Oven Dry Sand (g)	894.6	855.2
Absorption (%)	25.2	29.2

A.2 Sand Testing Data Sheet (from Hanson Aggregates)

Sisquoc Washed Concrete Sand

The Sisquoc Washed Concrete Sand supplied by Hanson Aggregates meets the requirements of the referenced specifications. This aggregate is produced at the Sisquoc, California Plant, SMARA No. 91-42-0003. The typical physical properties of the aggregate are summarized below.

800101-Sand Concrete

Procedure	Sieve/Test	Average	Unit	ASTM C33
	3/8" (9.5mm)	100	%	
	#4 (4.75mm)	99	%	95-100
	#8 (2.36mm)	88	%	80-100
	#16 (1.18mm)	75	%	50-85
	#30 (0.6mm)	52	%	25-60
	#50 (0.3mm)	22	%	5-30
	#100 (0.15mm)	5	%	0-10
	#200 (75µm)	1.9	%	0-3
	Pan	0.0	%	
	FM	2.58		2.3-3.1
	SE	83	%	>71
Durability Index	67	60 Min		
Specific Gravity, Bulk S.S.D.	2.55			
Absorption	2.0%			
Organic Impurities, C 40	Lighter			
Rel. Mortar Strength, CT 515	95%	95% Min		
Sodium Sulfate Soundness C 88	2.3%	10% Max		
Deleterious Substances				
Clay & Friables, C 142	0.5%	3% Max		
Lt. Wt. Particles C 123/295	0%	1% Max		
Asbestos, EPA 600/\$-93-116	None Detected			
Alkali Reactivity, C 289	Innocuous			
C 1260 Expansion	0.22%			

A.3 Compaction Tests and Sieve Analyses

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Proctor Compaction

Test Method: ASTM D558

Project Name	Pringle_ICEB	Project No.	09C-70SAND-30SOIL
Tested By	SP	Testing Date	8/4/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

EQUIPMENT AND PROCEDURE					
Test Method (D698/D1557)	D558	Ram. Mass (g)	2490	# of Lifts	3
Mold Volume (cm ³)	944	Mold Mass(g)	2017	Blows/ Lift	25

DENSITY AND MOISTURE MEASUREMENTS					
Mass of Soil + Mold (g)	3852	3922	4003	4014	3976
Dish ID	A-3	A-4	A-5	A-7	A-10
Mass of Dish (g)	8.47	8.47	8.58	8.50	8.52
Mass of Moist Soil + Dish (g)	181.11	280.60	223.60	266.85	233.46
Mass of Dry Soil + Dish (g)	166.47	254.23	198.92	234.30	201.34

RESULTS					
Water Content	9.3%	10.7%	13.0%	14.4%	16.7%
Dry Density (Mg/m ³)	1.779	1.822	1.862	1.849	1.779
Lab Max. Dry Density (Mg/m ³)	1.863		Optimum Water Content (%)		13.0%
Lab Max. Dry Unit Wt. (lbs/ft ³)	116.3

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Mechanical Sieve Analysis

Test Method: ASTM D6913, D2487

Project Name	ICEB Thesis	Project No.	70% Sand - 30% Soil
Tested By	SP	Testing Date	8/10/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

SIEVE MEASUREMENTS					
Dish ID	I-29	Moist Soil + Dish (g)		Water Content	
Dish Mass (g)	633.00	Dry Soil + Dish (g)	1033.00	Dry Post-Wash (g)	400.00

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	% Passing
3 in	76.2	0.00	0.00	0.0%	100.0%
2 in *	50.8	0.00	0.00	0.0%	100.0%
1 in *	25.4	0.00	0.00	0.0%	100.0%
3/4 in *	19.1	0.00	0.00	0.0%	100.0%
1/2 in *	12.7	0.00	0.00	0.0%	100.0%
3/8 in *	9.50	0.00	0.00	0.0%	100.0%
No. 4 *	4.75	6.00	6.00	1.5%	98.5%
No. 10	2.00	69.00	75.00	18.8%	81.3%
No. 16	1.19	45.00	120.00	30.0%	70.0%
No. 30	0.595	85.00	205.00	51.3%	48.8%
No. 50	0.297	107.00	312.00	78.0%	22.0%
No. 100	0.150	61.00	373.00	93.3%	6.8%
No. 200	0.075	16.00	389.00	97.3%	2.8%
Pan	--	9.00	398.00	Sieve Continuity	100.5%

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Proctor Compaction

Test Method: ASTM D558

Project Name	Pringle_ICEB	Project No.	09C-60SAND-40SOIL
Tested By	SP	Testing Date	7/28/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

EQUIPMENT AND PROCEDURE					
Test Method (D698/D1557)	D558	Ram. Mass (g)	2490	# of Lifts	3
Mold Volume (cm ³)	944	Mold Mass(g)	2017	Blows/ Lift	25

DENSITY AND MOISTURE MEASUREMENTS					
Mass of Soil + Mold (g)	3776	3886	3948	3911	
Dish ID	A-3	A-5	A-6	A-10	
Mass of Dish (g)	8.50	8.58	8.57	8.49	
Mass of Moist Soil + Dish (g)	187.62	203.61	249.73	220.69	
Mass of Dry Soil + Dish (g)	172.32	183.02	214.25	185.41	

RESULTS					
Water Content	9.3%	11.8%	17.3%	19.9%	
Dry Density (Mg/m ³)	1.704	1.771	1.745	1.673	
Lab Max. Dry Density (Mg/m ³)	1.775		Optimum Water Content (%)		13.0%
Lab Max. Dry Unit Wt. (lbs/ft ³)	110.8

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Mechanical Sieve Analysis

Test Method: ASTM D6913, D2487

Project Name	ICEB Thesis	Project No.	60% Sand - 40% Soil
Tested By	SP	Testing Date	8/3/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

SIEVE MEASUREMENTS					
Dish ID	I-59	Moist Soil + Dish (g)		Water Content	
Dish Mass (g)	633.00	Dry Soil + Dish (g)	1323.00	Dry Post-Wash (g)	690.00

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	% Passing
3 in	76.2	0.00	0.00	0.0%	100.0%
2 in *	50.8	0.00	0.00	0.0%	100.0%
1 in *	25.4	0.00	0.00	0.0%	100.0%
3/4 in *	19.1	0.00	0.00	0.0%	100.0%
1/2 in *	12.7	0.00	0.00	0.0%	100.0%
3/8 in *	9.50	0.00	0.00	0.0%	100.0%
No. 4 *	4.75	6.00	6.00	0.9%	99.1%
No. 10	2.00	130.00	136.00	19.7%	80.3%
No. 16	1.19	100.00	236.00	34.2%	65.8%
No. 30	0.595	144.00	380.00	55.1%	44.9%
No. 50	0.297	175.00	555.00	80.4%	19.6%
No. 100	0.150	92.00	647.00	93.8%	6.2%
No. 200	0.075	25.00	672.00	97.4%	2.6%
Pan	--	18.00	690.00	Sieve Continuity	100.0%

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Proctor Compaction

Test Method: ASTM D558

Project Name	Pringle_ICEB	Project No.	09C-50SAND-50SOIL
Tested By	SP	Testing Date	8/31/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

EQUIPMENT AND PROCEDURE					
Test Method (D698/D1557)	D558	Ram. Mass (g)	2490	# of Lifts	3
Mold Volume (cm ³)	944	Mold Mass(g)	2017	Blows/ Lift	25

DENSITY AND MOISTURE MEASUREMENTS					
Mass of Soil + Mold (g)	3756	3805	3868	3920	3928
Dish ID	A-3	A-4	A-5	A-7	A-10
Mass of Dish (g)	8.46	8.52	8.56	8.54	8.50
Mass of Moist Soil + Dish (g)	179.38	250.88	272.23	272.52	289.29
Mass of Dry Soil + Dish (g)	162.06	222.95	237.18	234.01	243.75

RESULTS					
Water Content	11.3%	13.0%	15.3%	17.1%	19.4%
Dry Density (Mg/m ³)	1.655	1.676	1.700	1.722	1.696
Lab Max. Dry Density (Mg/m ³)	1.720		Optimum Water Content (%)		17.0%
Lab Max. Dry Unit Wt. (lbs/ft ³)	107.3

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Mechanical Sieve Analysis

Test Method: ASTM D6913, D2487

Project Name	ICEB Thesis	Project No.	50% Sand - 50% Soil
Tested By	SP	Testing Date	12/21/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

SIEVE MEASUREMENTS					
Dish ID	SΦ3-5B	Moist Soil + Dish (g)		Water Content	
Dish Mass (g)	337.00	Dry Soil + Dish (g)	601.00	Dry Post-Wash (g)	264.00

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	% Passing
3 in	76.2		0.00	0.0%	100.0%
2 in *	50.8		0.00	0.0%	100.0%
1 in *	25.4		0.00	0.0%	100.0%
3/4 in *	19.1		0.00	0.0%	100.0%
1/2 in *	12.7		0.00	0.0%	100.0%
3/8 in *	9.50		0.00	0.0%	100.0%
No. 4 *	4.75	5.00	5.00	1.9%	98.1%
No. 10	2.00	63.00	68.00	25.8%	74.2%
No. 16	1.19	43.00	111.00	42.0%	58.0%
No. 30	0.595	52.00	163.00	61.7%	38.3%
No. 50	0.297	52.00	215.00	81.4%	18.6%
No. 100	0.150	0.00	215.00	81.4%	18.6%
No. 200	0.075	42.00	257.00	97.3%	2.7%
Pan	--	6.00	263.00	Sieve Continuity	99.6%

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Proctor Compaction

Test Method: ASTM D558

Project Name	Pringle_ICEB	Project No.	09C-40SAND-60SOIL
Tested By	SP	Testing Date	7/28/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

EQUIPMENT AND PROCEDURE					
Test Method (D698/D1557)	D558	Ram. Mass (g)	2490	# of Lifts	3
Mold Volume (cm ³)	944	Mold Mass(g)	2017	Blows/ Lift	25

DENSITY AND MOISTURE MEASUREMENTS					
Mass of Soil + Mold (g)	3717	3776	3847	3886	3886
Dish ID	A-3	A-5	A-6	A-10	A-7
Mass of Dish (g)	8.47	8.55	8.51	8.51	8.53
Mass of Moist Soil + Dish (g)	215.04	212.56	173.64	210.74	290.16
Mass of Dry Soil + Dish (g)	195.64	189.34	152.51	180.50	241.94

RESULTS					
Water Content	10.4%	12.8%	14.7%	17.6%	20.7%
Dry Density (Mg/m ³)	1.632	1.651	1.691	1.684	1.641
Lab Max. Dry Density (Mg/m ³)	1.693		Optimum Water Content (%)		16.0%
Lab Max. Dry Unit Wt. (lbs/ft ³)	105.6

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Mechanical Sieve Analysis

Test Method: ASTM D6913, D2487

Project Name	ICEB Thesis	Project No.	40% Sand - 60% Soil
Tested By	SP	Testing Date	8/3/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

SIEVE MEASUREMENTS					
Dish ID	I-29	Moist Soil + Dish (g)		Water Content	
Dish Mass (g)	633.00	Dry Soil + Dish (g)	933.00	Dry Post-Wash (g)	300.00

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	% Passing
3 in	76.2	0.00	0.00	0.0%	100.0%
2 in *	50.8	0.00	0.00	0.0%	100.0%
1 in *	25.4	0.00	0.00	0.0%	100.0%
3/4 in *	19.1	0.00	0.00	0.0%	100.0%
1/2 in *	12.7	0.00	0.00	0.0%	100.0%
3/8 in *	9.50	0.00	0.00	0.0%	100.0%
No. 4 *	4.75	6.00	6.00	2.0%	98.0%
No. 10	2.00	73.00	79.00	26.3%	73.7%
No. 16	1.19	44.00	123.00	41.0%	59.0%
No. 30	0.595	63.00	186.00	62.0%	38.0%
No. 50	0.297	56.00	242.00	80.7%	19.3%
No. 100	0.150	39.00	281.00	93.7%	6.3%
No. 200	0.075	13.00	294.00	98.0%	2.0%
Pan	--	8.00	302.00	Sieve Continuity	99.3%

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Proctor Compaction

Test Method: ASTM D558

Project Name	Pringle_ICEB	Project No.	09C-30SAND-70SOIL
Tested By	SP	Testing Date	8/5/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

EQUIPMENT AND PROCEDURE					
Test Method (D698/D1557)	D558	Ram. Mass (g)	2490	# of Lifts	3
Mold Volume (cm ³)	944	Mold Mass(g)	2017	Blows/ Lift	25

DENSITY AND MOISTURE MEASUREMENTS					
Mass of Soil + Mold (g)	3752	3781	3838	3869	3840
Dish ID	A-3	A-4	A-5	A-7	A-10
Mass of Dish (g)	8.48	8.48	8.56	8.54	8.51
Mass of Moist Soil + Dish (g)	245.52	206.87	176.63	228.55	261.34
Mass of Dry Soil + Dish (g)	215.60	178.89	150.40	189.91	212.86

RESULTS					
Water Content	14.4%	16.4%	18.5%	21.3%	23.7%
Dry Density (Mg/m ³)	1.606	1.605	1.628	1.617	1.561
Lab Max. Dry Density (Mg/m ³)	1.627		Optimum Water Content (%)		19.0%
Lab Max. Dry Unit Wt. (lbs/ft ³)	101.5

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Mechanical Sieve Analysis

Test Method: ASTM D6913, D2487

Project Name	ICEB Thesis	Project No.	30% Sand - 70% Soil
Tested By	SP	Testing Date	8/10/2015

SPECIMEN ID AND CLASSIFICATION					
Boring No.	n/a	Sample No.	n/a	Depth (ft)	n/a
Soil Description	Las Tablas Soil				

SIEVE MEASUREMENTS					
Dish ID	I-59	Moist Soil + Dish (g)		Water Content	
Dish Mass (g)	633.00	Dry Soil + Dish (g)	1033.00	Dry Post-Wash (g)	400.00

Sieve No.	Size, mm	Mass Retained (g)	Cumulative Retained (g)	% Retained	% Passing
3 in	76.2	0.00	0.00	0.0%	100.0%
2 in *	50.8	0.00	0.00	0.0%	100.0%
1 in *	25.4	0.00	0.00	0.0%	100.0%
3/4 in *	19.1	0.00	0.00	0.0%	100.0%
1/2 in *	12.7	0.00	0.00	0.0%	100.0%
3/8 in *	9.50	0.00	0.00	0.0%	100.0%
No. 4 *	4.75	6.00	6.00	1.5%	98.5%
No. 10	2.00	100.00	106.00	26.5%	73.5%
No. 16	1.19	67.00	173.00	43.3%	56.8%
No. 30	0.595	75.00	248.00	62.0%	38.0%
No. 50	0.297	71.00	319.00	79.8%	20.3%
No. 100	0.150	48.00	367.00	91.8%	8.3%
No. 200	0.075	19.00	386.00	96.5%	3.5%
Pan	--	14.00	400.00	Sieve Continuity	100.0%

A.4 Trial Batch Compression Test Record

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Compression Test Record

Test Method: Compressed Earth Block.prc

Casting Date: 9/4/2015

F = Full Block

H = Half Block

Block					
Date Tested	Soil Type	Max Load (lbf)	Type	Stress, psi	Notes
9/29/2015	30	36,794	F	604	failure near crack
9/29/2015	30	47167	F	774	more conical type break (typical)
9/29/2015	30	50981	F	837	
9/29/2015	30	20696	H	680	
9/29/2015	30	51274	F	842	
9/29/2015	30	21284	H	699	
9/29/2015	30	23324	H	766	
9/29/2015	40	50401	F	827	More conical break than 30%
9/29/2015	40	41,751	F	685	Higher on one side (crushed more on one side too)
9/29/2015	40	46,850	F	769	Higher on one side, but no observed crushing on one side
9/29/2015	40	50,099	F	822	one side crushed more
9/29/2015	40	48,500	F	796	
10/1/2015	40	22,074	H	725	Chips on corner before test started. Bottom started chipping out first at 10,000 lb
10/1/2015	40	48,000	F	788	
10/1/2015	40	46,833	F	769	Taller Side Crushed First
10/1/2015	40	19,217	H	631	
10/1/2015	40	19,392	H	637	Taller on one Side
10/1/2015	50	36,091	F	592	Taller on one Side
10/1/2015	50	13,104	H	430	
10/1/2015	50	14,616	H	480	
10/1/2015	50	14,514	H	477	Much Larger Conical
10/1/2015	50	12,744	H	418	Fracture on 50% than 40%
10/1/2015	50	41,808	F	686	
10/1/2015	50	35,002	F	575	
10/1/2015	50	34,915	F	573	
10/1/2015	50	36,749	F	603	
10/1/2015	50	35,928	F	590	1 side taller
10/1/2015	60	32,592	F	535	1 side taller
10/1/2015	60	34,656	F	569	more even on each side
10/15/2015	60	37,171	F	610	
10/15/2015	60	30,864	F	507	
10/15/2015	60	33,312	F	547	

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Compression Test Record

Test Method: Compressed Earth Block.prc

10/15/2015	60	33,264	F	546	
10/15/2015	60	14,976	H	492	
10/15/2015	60	10,968	H	360	
10/15/2015	60	13,654	H	448	
10/15/2015	70	34,800	F	571	1 side slightly higher
10/15/2015	70	36,374	F	597	1 side slightly higher
10/15/2015	70	24,672	F	405	1 side slightly higher
10/15/2015	70	25,776	F	423	1 side slightly higher
10/15/2015	70	22,320	F	366	1 side slightly higher
10/15/2015	70	22,368	F	367	1 side slightly higher
10/15/2015	70	21,684	F	356	1 side slightly higher

A.5 Block Batching Calculations

Calculation for Block Batching Proportions (Used in Block Batching Spreadsheet)

Note: All calculations are by mass, not volume (unless noted otherwise)

Example:

50 : 50 Las Tablas Soil: Sisquoc Sand

9% Cement (by dry mass of soil + sand)

1. Gather moisture contents of soil and sand

$$MC = \text{moisture content} = \frac{(\text{mass of stock}_{\text{wet+pan}}) - (\text{mass of stock}_{\text{dry+pan}})}{(\text{mass of stock}_{\text{dry}} + \text{pan}) - \text{mass}_{\text{pan}}}$$

Summarize in a table:

Pre-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	2.0%	243.56	239	8.56	S1-4A
Sand MC (%):	8.4%	240	222	8.23	S1-4A
Batch MC (%):	4.7%				

Note Batch MC:

$$\text{Batch MC} = \frac{\text{NCD (as defined below)} - M_{\text{soil,dry}} - M_{\text{sand,dry}}}{1.09 * (M_{\text{soil,dry}} + M_{\text{sand,dry}})}$$

$$\text{Where } M_{\text{soil,dry}} = \frac{M_{\text{soil,stock}}}{1+MC} \text{ and } M_{\text{sand,dry}} = \frac{M_{\text{sand,stock}}}{1+MC}$$

Batch MC is the starting moisture content, MC_o

2. Define NCD (Non-Cement Dry) Stock weights

NCD is the sum of soil and sand stock weights, before the addition of water in the batch.

$$\text{NCD} = M_{\text{soil,stock}} + M_{\text{sand,stock}}$$

NCD will be a variable and depends on batch size

3. Compute dry masses of soil and sand

$$0.50 * \text{NCD} = M_{\text{soil,dry}} = M_{\text{sand,dry}}$$

4. Compute starting mass of batch, M_o (prior to addition of water)

$$M_o = 1.09 * \text{NCD}$$

5. Look up what the final batch moisture content MC_f should be, based on Proctor Compaction Testing:

Soil	MDD (lb/ft ³)	MC (%)
30%	116.3	13%
40%	111.6	14%
50%	107.3	17%
60%	105.6	16%
70%	101.6	19%

50% Soil

Note: Add 0.5% additional to the moisture content, to account for absorption of water on the concrete floor and any evaporation.

$$MC_f = 17 + 0.5 = 17.5\%$$

6. Compute the amount of water required to reach target moisture content

$$\Delta M_w = \frac{(MC_f - MC_o)MC_o}{1 + MC_o}$$

7. Calculate total batch size:

$$\text{Batch Size} = 1.09NCD + \Delta M_w$$

8. Determine the batch size required, based on block charge weight

Given:

Full block volume = 0.14 ft³

From the compaction table, MDD (Max Dry Density) = 107.3 lb/ft³.

Thus,

$$\text{Weight/Block} = 15.14 \text{ lb}$$

Assuming 10 blocks per batch,

$$\text{Total batch size} = 151.4 \text{ lb.}$$

9. Match total batch size from step 8 with required batch size from step 7, by changing the NCD. This iteration can easily be performed using "Goal Seek" in Excel.
10. Fill in mix proportions using soil, sand, water and cement amounts once NCD has been determined. Adjust for OD weight using moisture content equation (note: cement carries 0% moisture).

A.6 ICEB Batch Sheets

CEB Pressing Data Sheet

Batch #	1	Soil	Sand	Full	Half	Channel
Time:	9:00:00 AM	Soil-Sand Ratio:	30% 70%	Water Added: (lb)	10.5	No./Type of Blocks Made:
Date:	9/5/2015	Soil Type/ID:	LT-30-9	5	4	n/a
Temp/Humidity:	60 deg F.	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				
Pre-Batch Moisture Contents				Post-Batch Moisture Contents		
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID	
Soil MC (%):	17.9%	255.55	217.96	8.5	A-3	
Sand MC (%):	0.9%	247.16	245.04	8.57	A-5	
Batch MC (%):	5.0%					

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	200 psi					CRACKED					

Batching Notes:

LT Soil, container 1
 16.3 lbs for Full Blocks
 16.1 lbs for Half Blocks
 Signs of cracking during ejection and handling (1 block fell apart)

TRIAL BATCHING BLOCKS

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.9%	35.7	30.2	23%
Sand	0.9%	83.2	82.5	62%
Cement	-	10.7	10.7	8%
Water	-	10.5	10.5	8%
Total	-	140.0	133.8	100%

CEB Pressing Data Sheet

Batch #	2	Soil	Sand	Full	Half	Channel
Time:	10:00:00 AM	Soil-Sand Ratio:	40% 60%	Water Added: (lb)	10.8	No./Type of Blocks Made:
Date:	9/5/2015	Soil Type/ID:	LT-40-9	7	3	n/a
Temp/Humidity:	65 deg F.	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	17.9%	255.55	217.96	8.5	A-3	Batch MC (%):	14.5%	216.65	190.23	8.55	A-4
Sand MC (%):	0.9%	247.16	245.04	8.57	A-5						
Batch MC (%):	6.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	200										

Batching Notes:

Soil 1 TRIAL BATCHING BLOCKS
 Added extra lb water
 15.5 lb - 1st Block
 15.8 lb - 2nd Block
 16 lb - 3rd block (note half blocks get about .2 lbs less)
 softer in corners, center gets best compression

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.9%	47.8	40.5	31%
Sand	0.9%	71.7	71.0	54%
Cement	-	10.8	10.8	8%
Water	-	9.8	9.8	7%
Total	-	140.0	132.1	100%

CEB Pressing Data Sheet

Batch #	3	Soil	Sand	Full	Half	Channel
Time:	11:15:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	17.3	No./Type of Blocks Made:
Date:	9/5/2015	Soil Type/ID:	LT-50-9		6	6
Temp/Humidity:	68 deg F.	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	5.7%	190.24	180.36	8.48	A-4	Batch MC (%):	15.6%	173.17	150.9	8.58	A-5
Sand MC (%):	0.9%	247.16	245.04	8.57	A-5						
Batch MC (%):	3.0%										

Penetrometer Readings:

Block ID:	1								
Reading (psi):	300 (c) weak corners								

c = center, e = edge

Batching Notes:

Soil 2
1st Block Broke
15 lb per block

TRIAL BATCHING BLOCKS

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	5.7%	56.3	53.2	39%
Sand	0.9%	56.3	55.8	41%
Cement	-	10.1	10.1	7%
Water	-	17.3	17.3	13%
Total	-	140.0	136.4	100%

CEB Pressing Data Sheet

Batch #	4	Soil	Sand		Full	Half	Channel
Time:	1:10:00 PM	Soil-Sand Ratio:	60%	40%	Water Added: (lb)	17.8	No./Type of Blocks Made:
Date:	9/5/2015	Soil Type/ID:	LT - 60-9		7	4	n/a
Temp/Humidity:	80 deg F.	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					
Pre-Batch Moisture Contents				Post-Batch Moisture Contents			
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		
Soil MC (%):	5.7%	190.24	180.36	8.48	A-4		
Sand MC (%):	0.9%	247.16	245.04	8.57	A-5		
Batch MC (%):	3.4%						

Penetrometer Readings:

Block ID:	1				
Reading (psi):	350 (e & c)				

c = center, e = edge

Batching Notes:

soil 2
 14.8 lb per block
 Half Blocks have 0.2 lb less (typ.)
 Note the added 2.1 lbs of water

TRIAL BATCHING BLOCKS

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	5.7%	68.4	64.7	48%
Sand	0.9%	45.6	45.2	33%
Cement	-	10.3	10.3	8%
Water	-	15.7	15.7	12%
Total	-	140.0	135.9	100%

CEB Pressing Data Sheet

Batch #	5	Soil	Sand	Full	Half	Channel	
Time:	2:00:00 PM	Soil-Sand Ratio:	70% 30%	Water Added: (lb)	9.7	No./Type of Blocks Made:	8 4 1
Date:	9/5/2015	Soil Type/ID:					
Temp/Humidity:	80 deg F.	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					
Pre-Batch Moisture Contents				Post-Batch Moisture Contents			
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		
Soil MC (%):	17.9%	255.55	217.96	8.5	A-3		
Sand MC (%):	0.9%	247.16	245.04	8.57	A-5		
Batch MC (%):	11.2%						

Penetrometer Readings (psi, UNO)

Block ID:							
Reading (psi)/Block Wt	450 C						

c = center, e = edge

Batching Notes:

soil 1
12.5 lb for channel blocks
14.4 lb/ Block

TRIAL BATCHING BLOCKS

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	18%	83.7	71.0	56%
Sand	0.9%	35.9	35.6	28%
Cement	-	10.8	10.8	8%
Water	-	9.7	9.7	8%
Total	-	140.0	126.9	100%

CEB Pressing Data Sheet

Batch #	1	Soil	Sand		Full	Half	Channel
Time:	8:30:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	15.2	No./Type of Blocks Made:	8 2 0
Date:	11/22/2015	Soil Type/ID:	LT-50-9				
Temp/Humidity:	Cool, high 50's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents					Post-Batch Moisture Contents						
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	11.9%	1151	1096	633	M3-5B	Batch MC (%):	15.9%	765	706	336	Sφ3-5B
Sand MC (%):	3.6%	1291	1268	631	M2-5B						
Batch MC (%):	7.0%										

Penetrometer Readings:

Block ID:	1				
Reading (psi):	320 at center, 130 at corner				

Batching Notes:

2 matching corners showed compressive strength of 130 psi
 Other corners show compressive strength of 380 psi
 Centers show consistent strength of 320 psi
 Similar observations to these are noted on 1/2 blocks

15.1 lb per block worked well (1/2 Blocks about 14.8 lb)

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	11.9%	68.9	61.6	40%
Sand	3.6%	68.9	66.5	43%
Cement	-	12.4	12.4	8%
Water	-	14.8	14.8	10%
Total	-	165.0	155.3	100%

CEB Pressing Data Sheet

Batch #	3	Soil	Sand	Full	Half	Channel
Time:	12:15pm	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	14.9	No./Type of Blocks Made:
Date:	11/22/2015	Soil Type/ID:	LT-50-9		8	2
Temp/Humidity:	Hot, Sunny, 75F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	11.9%	1151	1096	633	M3-5B	Batch MC (%):	16.9%	828	767	407	Sφ2-5B
Sand MC (%):	3.6%	1291	1268	631	M2-5B						
Batch MC (%):	7.0%										

Penetrometer Readings:

Block ID:	1 (Full Block)				
Reading (psi):	300 psi at center, 280/230 at corners				

Block ID:	2 (half block)				
Reading (psi):	260 psi at center, 200 psi at corners				

Batching Notes:

Note: Batch 2 was discarded due to moisture issues
 15.1 lb per block worked well (1/2 Blocks about 14.8 lb)

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	11.9%	68.9	61.6	40%
Sand	3.6%	68.9	66.5	43%
Cement	-	12.4	12.4	8%
Water	-	14.8	14.8	10%
Total	-	165.0	155.3	100%

CEB Pressing Data Sheet

Batch #	4	Soil	Sand		Full	Half	Channel
Time:	1:10pm	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	15.2	No./Type of Blocks Made:	8 2 0
Date:	11/22/2015	Soil Type/ID:	LT-50-9				
Temp/Humidity:	Hot, Sunny, 75F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	11.9%	1151	1096	633	M3-5B	Batch MC (%):	16.3%	879	809	379	Sφ2-5A
Sand MC (%):	3.6%	1291	1268	631	M2-5B						
Batch MC (%):	7.0%										

Penetrometer Readings:

Block ID:	1				
Reading (psi):	330 at center, 230 at corner				

Batching Notes:

15.1 lb per block worked well (1/2 Blocks about 14.8 lb)

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	11.9%	68.9	61.6	40%
Sand	3.6%	68.9	66.5	43%
Cement	-	12.4	12.4	8%
Water	-	14.8	14.8	10%
Total	-	165.0	155.3	100%

CEB Pressing Data Sheet

Batch #	5	Soil	Sand		Full	Half	Channel			
Time:	11:45:00 AM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	14	No./Type of Blocks Made:	8	2	0
Date:	11/29/2015	Soil Type/ID:		LT-50-9						
Temp/Humidity:	Sunny, Hot, 70's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)								

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	11.9%	1151	1096	633	M3-5B	Batch MC (%):	15.7%	541	519	379	Sφ2-5A
Sand MC (%):	3.6%	1291	1268	631	M2-5B						
Batch MC (%):	7.0%										

Penetrometer Readings:

Block ID:	Full Block	1/2 Block							
Reading (psi):	260 all around	500 middle/330 Center							

Batching Notes:

block pressures were pretty uniform. Full block pressing strength a little low
15.1 lb per block worked well (1/2 Blocks about 14.8 lb)

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	11.9%	68.9	61.6	40%
Sand	3.6%	68.9	66.5	43%
Cement	-	12.4	12.4	8%
Water	-	14.8	14.8	10%
Total	-	165.0	155.3	100%

CEB Pressing Data Sheet

Batch #	1	Soil	Sand		Half Regular	Half Channel	Full Channel
Time:	9:15:00 AM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	11.3	No./Type of Blocks Made:
Date:	1/10/2016	Soil Type/ID:	LT-50-9		2	2	6
Temp/Humidity:	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)						

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	12.9%	568	550	410	S1-4B	Batch MC (%):	18.0%	721	670	387	I-2
Sand MC (%):	7.2%	675	657	407	S1-3B						
Batch MC (%):	9.1%										

Penetrometer Readings:

Block ID:	1								
Reading (psi):	360 psi (center)								

Batching Notes:

At Block 5, reduced block weight to 14.8 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	12.9%	67.7	60.0	41%
Sand	7.2%	67.7	63.2	43%
Cement	-	12.2	12.2	8%
Water	-	11.3	11.3	8%
Total	-	159.0	146.7	100%

CEB Pressing Data Sheet

Batch #	2	Soil	Sand		Full Regular	Half Regular
Time:	11:30:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	11.3	No./Type of Blocks Made:
Date:	1/10/2016	Soil Type/ID:	LT-50-9		6	8
Temp/Humidity:	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	12.9%	568	550	410	S1-4B	Batch MC (%):	16.7%	1010	924	410	S3-4B
Sand MC (%):	7.2%	675	657	407	S1-3B						
Batch MC (%):	9.1%										

Penetrometer Readings:

Block ID:	1						
Reading (psi):	350 center 320 Corner						

Batching Notes:

Varied between 14.4 - 14.7 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	12.9%	67.7	60.0	41%
Sand	7.2%	67.7	63.2	43%
Cement	-	12.2	12.2	8%
Water	-	11.3	11.3	8%
Total	-	159.0	146.7	100%

CEB Pressing Data Sheet

Batch #	3	Soil	Sand	Half Channel	Half Reg.	Full Channel
Time:	1:30:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	11.3	No./Type of Blocks Made:
Date:	1/10/2016	Soil Type/ID:	LT-50-9	2	2	6
Temp/Humidity:	wet/rainy	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				
Pre-Batch Moisture Contents				Post-Batch Moisture Contents		
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID	
Soil MC (%):	12.9%	568	550	410	S1-4B	
Sand MC (%):	7.2%	675	657	407	S1-3B	
Batch MC (%):	9.1%					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID	
Batch MC (%):	17.8%	1011	920	408	S1-5B	

Penetrometer Readings:

Block ID:	1 (Channel)				
Reading (psi):	400 psi				

Batching Notes:

Channel blocks - 14.8 lb for half blocks
13.0 lb Full Channel Blocks

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	12.9%	67.7	60.0	41%
Sand	7.2%	67.7	63.2	43%
Cement	-	12.2	12.2	8%
Water	-	11.3	11.3	8%
Total	-	159.0	146.7	100%

CEB Pressing Data Sheet

Batch #	1	Soil	Sand		Full	Half	Channel
Time:	1:00:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	7.46	No./Type of Blocks Made:	
Date:	2/24/2016	Soil Type/ID:	LT-50-9				
Temp/Humidity:	72 deg. Hot, Sunny, Dry	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	17.8%	632	595	387	I-2
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	330 psi (center)	310 psi/255 psi (Center/Edge)									

Batching Notes:

Full Blocks were 15.1 lb
Half Blocks were 14.8 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	78.0	65.3	39%
Sand	4.5%	68.3	65.3	39%
Cement	-	13.2	13.2	8%
Water	-	9.0	24.6	15%
Total	-	168.4	168.4	100%

CEB Pressing Data Sheet

Batch #	2	Soil	Sand	Full	Half	Channel
Time:	1:40:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	5.58	No./Type of Blocks Made:
Date:	2/24/2016	Soil Type/ID:	LT-50-9	8	6	
Temp/Humidity:	72 deg. Hot, Sunny, Dry	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	17.4%	680	640	410	S3-4B
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):		330/255 (Center/Edge)	330/310 (Center/Edge)					400/330 (Center/Edge)		380/340 (Center/Edge)	

Batching Notes:

Blocks 9, 10 and 11 were half blocks

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	78.0	65.3	39%
Sand	4.5%	68.3	65.3	39%
Cement	-	13.2	13.2	8%
Water	-	9.0	24.6	15%
Total	-	168.4	168.4	100%

CEB Pressing Data Sheet

Batch #	3	Soil	Sand	Full	Half	Channel
Time:	2:27:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	7.35	No./Type of Blocks Made:
Date:	2/24/2016	Soil Type/ID:	LT-50-9		7	6
Temp/Humidity:	72 deg. Hot, Sunny, Dry	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	15.4%	602	576	407	S1-4B
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	400/370 (Center/Edge)	400/380 (Center/Edge)						450/410 (Center/Edge)			

Batching Notes:

Blocks 8,9,10 were half blocks

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	78.0	65.3	39%
Sand	4.5%	68.3	65.3	39%
Cement	-	13.2	13.2	8%
Water	-	9.0	24.6	15%
Total	-	168.4	168.4	100%

CEB Pressing Data Sheet

Batch #	HS 5	Soil	Sand	Full	Half*	Channel
Time:	10:07:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	11.84	No./Type of Blocks Made:
Date:	2/28/2016	Soil Type/ID:	LT-50-15		7	4
Temp/Humidity:	68F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	17.8%	546	522	387	I-2
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	C (300) E(330)	C(340) E(340)	C(330) E (340)					C (380) E (370)			C (330) E (330)
	15.1 lb	15.2 lb				14.9 lb					

Batching Notes:

C= center E = Edge

1/2 Blocks showed slight signs of cracking across corners

*Note that 4 half blocks means that 8 actual half blocks were produced

1/2 blocks were 14.9 lb

Full block were 15.1 lb

High Strength Block (HSB) Batch

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	73.9	61.9	36%
Sand	4.5%	64.6	61.9	36%
Cement	-	26.3	26.3	15%
Water	-	9.0	23.8	14%
Total	-	173.8	173.8	100%

CEB Pressing Data Sheet

Batch #	HS 6	Soil	Sand		Full	Half	Channel
Time:	11:15:00 AM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	12.04	No./Type of Blocks Made:
Date:	2/28/16	Soil Type/ID:	LT-50-15		4	7	
Temp/Humidity:	72F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	17.4%	715	670	411	S3-4B
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	C (330) E (320)	C (310) E (400)			C (310) E (320)	C (410) E (300)					

15.2 lb 14.9 lb

Batching Notes: C= center E = Edge

half blocks were 14.9 lb

*Note that 4 half blocks means that 8 actual half blocks were produced

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	73.9	61.9	36%
Sand	4.5%	64.6	61.9	36%
Cement	-	26.3	26.3	15%
Water	-	9.0	23.8	14%
Total	-	173.8	173.8	100%

CEB Pressing Data Sheet

Batch #	7	Soil	Sand	Full	Half	Channel
Time:	12:10:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	9.05	No./Type of Blocks Made:
Date:	2/28/16	Soil Type/ID:	LT-50-9	6	5	
Temp/Humidity:	75F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	16.4%	685	646	408	S1-5B
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	C (360) E (280)		C (440) E (400)		C (310) E (340)	C (400) E (400)	C (440) E (350)				
	15.1 lb		15 lb			14.8 lb		14.7 lb		Full Block	

Batching Notes:

C= center E = Edge

Only block 5 was 15 lb

Half blocks were 14.7 lb

*Note that 4 half blocks means that 8 actual half blocks were produced

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	78.0	65.3	39%
Sand	4.5%	68.3	65.3	39%
Cement	-	13.2	13.2	8%
Water	-	9.0	24.6	15%
Total	-	168.4	168.4	100%

CEB Pressing Data Sheet

Batch #	8	Soil	Sand		Full	Half	Channel			
Time:	1:53:00 PM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	9.3	No./Type of Blocks Made:	3	8	
Date:	2/28/16	Soil Type/ID:	LT-50-9							
Temp/Humidity:	75F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)								

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	19.4%	687	642	410	S3-4B	Batch MC (%):	17.0%	585	549	337	S1-1A
Sand MC (%):	4.5%	732	718	407	S3-5B						
Batch MC (%):	10.5%										

Penetrometer Readings:

Block ID:	1	2	3	4	5
Reading (psi):	C (360) E (420)	C (400) E (420)		C (450) E (380)	

15.1 lb

14.8 lb

Batching Notes:

C= center

E = Edge

*Note that 4 half blocks means that 8 actual half blocks were produced

6	7	8	9	10	11
C (460) E (320)	C (440) E (400)				

14.7 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	19.4%	78.0	65.3	39%
Sand	4.5%	68.3	65.3	39%
Cement	-	13.2	13.2	8%
Water	-	9.0	24.6	15%
Total	-	168.4	168.4	100%

CEB Pressing Data Sheet

Batch #	1	Soil	Sand		Full	Half	Channel
Time:	9:45:00 AM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	9	No./Type of Blocks Made:
Date:	3/8/2016	Soil Type/ID:	LT-50-9				
Temp/Humidity:	51 F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)					
Pre-Batch Moisture Contents				Post-Batch Moisture Contents			
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		
Soil MC (%):	18.0%	--	--	--	--	Batch MC (%):	14.1%
Sand MC (%):	13.2%	1332	1233	483	S01-3B		947
Batch MC (%):	14.3%						878
							388
							S1-5A

Penetrometer Readings:

Block ID:	2	4							
Reading (psi):	400 (c) 280 (e)	370 (c) 330 (e)							

c = center, e = edge

Batching Notes:

Corner Blocks (No Shear Keys)

15.9 lbs - full

15.7 lbs - half

Note something was misweighed, since 14 blocks were generated

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	18.0%	73.4	62.2	43%
Sand	13.2%	73.4	64.8	45%
Cement	-	13.2	13.2	9%
Water	-	4.5	4.5	3%
Total	-	164.5	144.7	100%

CEB Pressing Data Sheet

Batch #	2	Soil	Sand	Full	Half	Channel
Time:	11:05:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	7.68	No./Type of Blocks Made:
Date:	3/8/2016	Soil Type/ID:	LT-50-9		8	3
Temp/Humidity:	64 F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				
Pre-Batch Moisture Contents				Post-Batch Moisture Contents		
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID	
Soil MC (%):	18.0%	--	--	--	--	
Sand MC (%):	13.2%	1332	1233	483	S01-3B	
Batch MC (%):	14.3%					

Penetrometer Readings:

Block ID:	1	2	10 (Half Block)						
Reading (psi):	410 (c) 370 (e)	510 (c) 340 (e)	410 (c) 320 (e)						

c = center, e = edge

Batching Notes:

Corner Blocks (No Shear Keys)

15.9 lbs - full

15.7 lbs - half

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	18.0%	73.4	62.2	43%
Sand	13.2%	73.4	64.8	45%
Cement	-	13.2	13.2	9%
Water	-	4.5	4.5	3%
Total	-	164.5	144.7	100%

CEB Pressing Data Sheet

Batch #	3	Soil	Sand		Full	Half	Channel
Time:	1:10:00 PM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	7.38	No./Type of Blocks Made:
Date:	3/8/2016	Soil Type/ID:	LT-50-9				
Temp/Humidity:	64 F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	18.0%	--	--	--	--	Batch MC (%):	16.4%	1089	993	409	S1-4B
Sand MC (%):	13.2%	1332	1233	483	S01-3B						
Batch MC (%):	14.3%										

Penetrometer Readings:

Block ID:	1	2	9 (Half Block)						
Reading (psi):	340 (c) 290 (e)	440 (c) 320 (e)	450 (c) 270 (e)						

c = center, e = edge

Batching Notes:

Corner Blocks (No Shear Keys)

15.9 lbs - full

15.7 lbs - half

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	18.0%	73.4	62.2	43%
Sand	13.2%	73.4	64.8	45%
Cement	-	13.2	13.2	9%
Water	-	4.5	4.5	3%
Total	-	164.5	144.7	100%

CEB Pressing Data Sheet

Batch #	4	Soil	Sand	Full	Half	Channel
Time:	2:15:00 PM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	8.04	No./Type of Blocks Made:
Date:	3/8/2016	Soil Type/ID:	LT-50-9		8	3
Temp/Humidity:	64 F	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)				

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	18.0%	--	--	--	--	Batch MC (%):	16.5%	1223	1108	411	S3-4B
Sand MC (%):	13.2%	1332	1233	483	S01-3B						
Batch MC (%):	14.3%										

Penetrometer Readings:

Block ID:	1	2	9 (Half Block)						
Reading (psi):	380 (c) 320 (e)	460 (c) 360 (e)	420 (c) 390 (e)						

c = center, e = edge

Batching Notes:

Corner Blocks (No Shear Keys)

15.9 lbs - full

15.7 lbs - half

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	18.0%	73.4	62.2	43%
Sand	13.2%	73.4	64.8	45%
Cement	-	13.2	13.2	9%
Water	-	4.5	4.5	3%
Total	-	164.5	144.7	100%

CEB Pressing Data Sheet

Batch #	11	Soil	Sand	Channel Full	Channel Half
Time:	10:54:00 AM	Soil-Sand Ratio:	50% 50%	Water Added: (lb)	9.82
Date:	3/20/2016	Soil Type/ID:	LT-50-9	No./Type of Blocks Made:	8
Temp/Humidity:	Cool, Sunny, low 60's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)			

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	17.8%	547	523	388	S1-5A	Batch MC (%):	17.9%	502	477	337	S3-5B
Sand MC (%):	6.1%	597	582	337	S3-5B						
Batch MC (%):	10.7%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	12
Reading (psi):	(450)C (380)E	(450)C (440)E	(430)C (380)E	(340)C (420)E							(440)C (380)E
Half/Full block:	Full	Full	Full								Half
Batching Notes:			C= center	E = Edge							

Note 4 half blocks really means 8 separate half blocks

1st block - 13.9 lb - discarded

2nd block - 13.7 lb - pressing pressure a little high

3rd block - 13.5 lb - pressure still high

4th block - 13.2 lb - stayed here

Half blocks - 13 lb - very consistent. Easy pulling on the lever

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.8%	81.4	69.1	39%
Sand	6.1%	73.3	69.1	39%
Cement	-	13.9	13.9	8%
Water	-	9.3	25.8	14%
Total	-	177.8	177.8	100%

CEB Pressing Data Sheet

Batch #	12	Soil	Sand		Normal Full	Normal Half	Channel
Time:	12:20:00 PM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	9.3	No./Type of Blocks Made:
Date:	3/20/2016	Soil Type/ID:	LT-50-9		8	3	
Temp/Humidity:	breezy, a little hotter. M to H 60's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)					

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	17.8%	547	523	388	S1-5A	Batch MC (%):	17.4%	611	578	388	S1-5A
Sand MC (%):	6.1%	597	582	337	S3-5B						
Batch MC (%):	10.7%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	(340) C (290) E	(400) C (380) E								(460) C (340) E	(380) C (340) E

Half/Full block: Full Full

Batching Notes:

C= center E = Edge

Note 4 half blocks really means 8 separate half blocks
 1st full block - 15.1 lb - kept for all of the other full blocks
 Half blocks - 14.8 lb - kept for all half blocks

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.8%	81.4	69.1	39%
Sand	6.1%	73.4	69.1	39%
Cement	-	13.9	13.9	8%
Water	-	9.3	25.8	14%
Total	-	178.0	178.0	100%

CEB Pressing Data Sheet

Batch #	13	Soil	Sand		Normal Full	Half	Channel
Time:	2:45:00 PM	Soil-Sand Ratio:	50%	50%	Water Added: (lb)	9.5	No./Type of Blocks Made:
Date:	3/20/2016	Soil Type/ID:	LT-50-9				
Temp/Humidity:	Hot, M to H 70's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %,Cement % (based on solid stock wts)					
Pre-Batch Moisture Contents				Post-Batch Moisture Contents			
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		
Soil MC (%):	17.8%	547	523	388	S1-5A	Batch MC (%):	17.8%
Sand MC (%):	6.1%	597	582	337	S3-5B		
Batch MC (%):	10.7%						

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	(360) C (300) E									(390) C (310) E	

Half/Full block: Full

Batching Notes: C= center E = Edge

Note 4 half blocks really means 8 separate half blocks

Full Blocks were all 15.1 lb

Half Blocks were all 14.8 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.8%	81.4	69.1	39%
Sand	6.1%	73.4	69.1	39%
Cement	-	13.9	13.9	8%
Water	-	9.3	25.8	14%
Total	-	178.0	178.0	100%

CEB Pressing Data Sheet

Batch #	14	Soil Sand	
Time:	3:50:00 PM	Soil-Sand Ratio:	50% 50%
Date:	3/20/2016	Soil Type/ID:	LT-50-9
Temp/Humidity:	Hot, H 70's, L 80's	LT = Las Tablas Soil, Sisquoc Sand UNO., Number Denotes Soil %, Cement % (based on solid stock wts)	

Water Added: (lb)	No./Type of Blocks Made:	Normal Full	Normal Half	Channel
		8	3	

Pre-Batch Moisture Contents						Post-Batch Moisture Contents					
	MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID		MC (%)	Pan +Wet (g)	Pan+Dry (g)	Pan Wt (g)	Pan ID
Soil MC (%):	17.8%	547	523	388	S1-5A	Batch MC (%):	17.1%	558	532	380	S2-5A
Sand MC (%):	6.1%	597	582	337	S3-5B						
Batch MC (%):	10.7%										

Penetrometer Readings:

Block ID:	1	2	3	4	5	6	7	8	9	10	11
Reading (psi):	(380) C (340) E	(350) C (370) E							(410) C (350) E		

Half/Full block: Full Full Half

Batching Notes: C= center E = Edge

Note 4 half blocks really means 8 separate half blocks

Full Blocks were all 15.1 lb

Half Blocks were all 14.8 lb

Material	Measured MC (%)	Stock Weight (lb)	OD Weight (lb)	% Total Mix
Soil	17.8%	81.4	69.1	39%
Sand	6.1%	73.4	69.1	39%
Cement	-	13.9	13.9	8%
Water	-	9.3	25.8	14%
Total	-	178.0	178.0	100%

A.7 Grout Cube Trial Testing

Cube Compressive Strength Comparison					
Cast Date: 4/13/2016			Test Date: 5/4/2016		
Height (in)	Strength based on 2" square (psi)	Max Force (lb)	Side length 1 (in)	Side length 2 (in)	Strength, based on actual area (psi)
1.84	730	2920	2.03	1.97	730.164287
1.85	870	3480	2.14	1.99	817.169962
2.32	780	3120	2	1.9	821.0526316
1.90	850	3400	2.02	2.05	821.0577155
2.06	740	2960	1.9	1.96	794.8442535
1.85	720	2880	2.04	2.01	702.3705004
2.28	880	3520	2	2.05	858.5365854
1.94	760	3040	1.94	2	783.5051546

mean based on 2" square area: 791.3 psi
 mean based on actual area: 791.1 psi

1st Three Point Average Comparison		
		difference:
1st three average (assuming 2" area):	793	0.5%
actual 1st three average:	789	
2nd three average (assuming 2" area):	770	0.4%
actual 2nd three average:	773

Conclusion:

1. Area of a porous grout cube can be approximated as 4 in²
2. Cube height does not have a significant effect on grout strength

APPENDIX B) PANEL TESTING

This appendix includes panel testing data sheets, the loading shoe design and panel photos taken during testing.

B.1 Panel Testing Data Sheets

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-HSG-FG			days 8
¹ Masonry Strength, f'm (ICEB.PRC):	534 psi		Date Cast:	2/25/2016	
² Grout Strength, f'g (ASTM C1019):	1337 psi		Date Tested:	3/4/2016	
Loading Machine:	MTS 322	Data Acquisition Device: MTS FlexTest SE			
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners					
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min					
Test Start Time:	1:02:32 PM		Test Duration (min) :	27.6	
Test End Time:	1:30:06 PM				

Specimen Set-up:

ID:	Instrument	Gage Length, L _g (in)
1	LVDT 0.1B	18.0
2	LVDT 0.1A	18.0
3	LVDT 0.3A	19.625
4	LVDT 0.5A	26.375
5	LVDT 0.3B	18.25
6	LVDT 0.5B	27.0

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P _{max}	Max vertical force (k)	5.415
A _n	Net specimen area (in ²)	139.3
S _s	Maximum Shear Stress (psi)	27.48
V _{Pmax}	Shearing Strain, at P _{max} (in/in)	0.000963
G	Shear Modulus, at P _{max} (psi)	28553

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.82	0.61	6.43	13%	f'c, average (p)	f'c average (np)
Sand	28.7	3	31.7	64%	1337 psi	567 psi
Lime	1.9	0.2	2.1	4%		
Water	9	0	9	18%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing

2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-CB2		
¹ Masonry Strength, f'm (ICEB.PRC):	534 psi		Date Cast:	3/7/2016
² Grout Strength, f'g (ASTM C1019):	570 psi		Date Tested:	3/30/2016
Loading Machine: MTS 322		Data Acquisition Device: MTS FlexTest SE		
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners				
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min				
Test Start Time:	3:03:58 PM		Test Duration (min) :	38.7
Test End Time:	3:42:38 PM			

days
23

Specimen Set-up:

ID:	Instrument	Gage Length, L _g (in)
1	LVDT 0.3B	19.625
2	LVDT 0.3A	20.125
3	LVDT 0.1B	17.75
4	LVDT 0.5A	26.75
5	LVDT 0.1A	18.25
6	LVDT 0.5B	26.875

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P _{max}	Max vertical force (k)	3.346
A _n	Net specimen area (in ²)	139.3
S _s	Maximum Shear Stress (psi)	16.98
γ _{Pmax}	Shearing Strain, at P _{max} (in/in)	0.001738
G	Shear Modulus, at P _{max} (psi)	9770

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	3.45	0	3.45	8%	f'c, average (p)	f'c average (np)
Sand	33	0	33	72%		
Lime	2.2	0	2.2	5%		
Water	7.38	0	7.38	16%		
					p = porous, np = nonporous	

Notes:

1. Masonry strength based on single block testing. Channel blocks not tested for compressive strength
2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Hydraulically Pressed Vermeer Blocks (V-Lock Block)

Specimen Identification:		VBLK-MSG-FG		
¹ Masonry Strength, f'm (ICEB.PRC):	1912 psi		Date Cast:	3/10/2016
² Grout Strength, f'g (ASTM C1019):	793 psi		Date Tested:	4/4/2016
Loading Machine: MTS 322		Data Acquisition Device: MTS FlexTest SE		
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners				
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min				
Test Start Time:	1:49:16 PM	Test Duration (min) :		28.5
Test End Time:	2:17:46 PM			

Specimen Set-up:

ID:	Instrument	gage Length, L_g (in)
1	LVDT 0.3B	24.0
2	LVDT 0.3A	24.0
3	LVDT 0.1B	22.0
4	LVDT 0.5A	32.75
5	LVDT 0.1A	22.375
6	LVDT 0.5B	32.75

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P_{max}	Max vertical force (k)	7.195
A_n	Net specimen area (in^2)	194.25
S_s	Maximum Shear Stress (psi)	26.19
$\gamma_{P_{max}}$	Shearing Strain, at P_{max} (in/in)	0.00228
G	Shear Modulus, at P_{max} (psi)	11474

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.4	0	5.4	9%	f'_c , average (p)	f'_c average (np)
Sand	43.2	0	43.2	74%	793 psi	340 psi
Lime	2.88	0	2.88	5%		
Water	7.28	0	7.28	12%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing (ungrouted)

2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-SK	
¹ Masonry Strength, f'm (ICEB.PRC):	534 psi	Date Cast:	3/14/2016
² Grout Strength, f'g (ASTM C1019):	598 psi	Date Tested:	4/7/2016
Loading Machine:	MTS 322	Data Acquisition Device:	MTS FlexTest SE
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners			
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min			
Test Start Time:	3:16:50 PM	Test Duration (min) :	35.0
Test End Time:	3:51:52 PM		

days
24

Specimen Set-up:

ID:	Instrument	Gage Length, L_g (in)
1	LVDT 0.3A	20.0
2	LVDT 0.3B	19.75
3	LVDT 0.1B	18.0
4	LVDT 0.5A	27.125
5	LVDT 0.1A	18.50
6	LVDT 0.5B	26.9375

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P_{max}	Max vertical force (k)	1.929
A_n	Net specimen area (in ²)	129.69
S_s	Maximum Shear Stress (psi)	10.52
$\gamma_{P_{max}}$	Shearing Strain, at P_{max} (in/in)	0.00121
G	Shear Modulus, at P_{max} (psi)	8697

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass	f'c, average (p)	f'c average (np)
Cement	5.4	0	5.4	9%	598 psi	283 psi
Sand	43.2	0	43.2	69%		
Lime	3	0	3	5%		
Water	10.93	0	10.93	18%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing

2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-GC2		
¹ Masonry Strength, f'm (ICEB.PRC):	534 psi		Date Cast:	3/19/2016
² Grout Strength, f'g (ASTM C1019):	740 psi		Date Tested:	4/11/2016
Loading Machine:	MTS 322	Data Acquisition Device:	MTS FlexTest SE	
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners				
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min				
Test Start Time:	4:32:02 PM	Test Duration (min) :		15.5
Test End Time:	4:47:32 PM			

days
23

Specimen Set-up:

ID:	Instrument	Gage Length, L_g (in)
1	LVDT 0.3A	20.375
2	LVDT 0.3B	19.875
3	LVDT 0.1B	17.875
4	LVDT 0.5A	27.75
5	LVDT 0.1A	18.75
6	LVDT 0.5B	26.50

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P_{max}	Max vertical force (k)	2.978
A_n	Net specimen area (in^2)	134.4
S_s	Maximum Shear Stress (psi)	15.66
$\gamma_{P_{max}}$	Shearing Strain, at P_{max} (in/in)	0.001268
G	Shear Modulus, at P_{max} (psi)	12350

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.4	0	5.4	9%	f'_c , average (p)	f'_c average (np)
Sand	43.2	0	43.2	72%	740 psi	355 psi
Lime	3	0	3	5%		
Water	8.76	0	8.76	15%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing
2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		HSB-MSG-FG		
¹ Masonry Strength, f'm (ICEB.PRC):	720 psi		Date Cast:	3/22/2016
² Grout Strength, f'g (ASTM C1019):	715 psi		Date Tested:	4/14/2016
Loading Machine:	MTS 322	Data Acquisition Device:	MTS FlexTest SE	
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners				
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min				
Test Start Time:	8:49:36 PM	Test Duration (min) :		35.2
Test End Time:	9:24:50 PM			

days
23

Specimen Set-up:

ID:	Instrument	Gage Length, L _g (in)
1	LVDT 0.3A	20.5
2	LVDT 0.3B	20.125
3	LVDT 0.1B	17.75
4	LVDT 0.5A	27.4375
5	LVDT 0.1A	18.0
6	LVDT 0.5B	26.75

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P _{max}	Max vertical force (k)	4.3912
A _n	Net specimen area (in ²)	139.3
S _s	Maximum Shear Stress (psi)	22.29
γ _{Pmax}	Shearing Strain, at P _{max} (in/in)	0.000717
G	Shear Modulus, at P _{max} (psi)	31082

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.4	0	5.4	9%	f'c, average (p)	f'c average (np)
Sand	43.2	0	43.2	71%	715 psi	370 psi
Lime	3	0	3	5%		
Water	8.89	0	8.98	15%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing

2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-CNTRL		
¹ Masonry Strength, f'm (ICEB.PRC):	586 psi		Date Cast:	3/25/2016
² Grout Strength, f'g (ASTM C1019):	685 psi		Date Tested:	4/20/2016
Loading Machine:	MTS 322	Data Acquisition Device:	MTS FlexTest SE	
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners				
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min				
Test Start Time:	4:28:12 PM	Test Duration (min) :		30.7
Test End Time:	4:58:56 PM			

days
26

Specimen Set-up:

ID:	Instrument	Gage Length, L _g (in)
1	LVDT 0.3A	19.9
2	LVDT 0.3B	20.4375
3	LVDT 0.1B	18.0
4	LVDT 0.5A	27.125
5	LVDT 0.1A	18.125
6	LVDT 0.5B	26.75

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P _{max}	Max vertical force (k)	3.821
A _n	Net specimen area (in ²)	139.3
S _s	Maximum Shear Stress (psi)	19.4
γ _{Pmax}	Shearing Strain, at P _{max} (in/in)	0.001476
G	Shear Modulus, at P _{max} (psi)	13140

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.4	0	5.4	9%	f'c, average (p)	f'c average (np)
Sand	42.2	0	42.2	69%	685 psi	345 psi
Lime	3	0	3	5%		
Water	10.43	0	10.43	17%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing
2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-NSK			
¹ Masonry Strength, f'm (ICEB.PRC):	689 psi		Date Cast:	4/5/2016	days 22
² Grout Strength, f'g (ASTM C1019):	705 psi		Date Tested:	4/27/2016	
Loading Machine: MTS 322		Data Acquisition Device: MTS FlexTest SE			
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners					
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min					
Test Start Time:	7:22:34 PM		Test Duration (min) :		31.0
Test End Time:	7:53:32 PM				

days
22

Specimen Set-up:

ID:	Instrument	Gage Length, L_g (in)
1	LVDT 0.3A	20.0
2	LVDT 0.3B	20.5
3	LVDT 0.1B	18.75
4	LVDT 0.5A	27.875
5	LVDT 0.1A	18.125
6	LVDT 0.5B	26.75

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P_{max}	Max vertical force (k)	1.638
A_n	Net specimen area (in ²)	130.66
S_s	Maximum Shear Stress (psi)	8.86
$\gamma_{P_{max}}$	Shearing Strain, at P_{max} (in/in)	0.00218
G	Shear Modulus, at P_{max} (psi)	4064

Grout Mix Design: Cast: 8 porous 2x2 cubes, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.7	0	5.4	9%	f'_c , average (p)	f'_c average (np)
Sand	42.2	0	42.2	69%	705 psi	365 psi
Lime	3	0	3	5%		
Water	10.32	0	10.32	17%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing.

2. Grout Strength represents porous grout strength

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Diagonal Compression Testing

Test Method: ASTM E519/E519M-15

Masonry Material Description: Interlocking Compressed Earth Blocks (BP6)

Specimen Identification:		MSB-MSG-C1			days 21
¹ Masonry Strength, f'm (ICEB.PRC):	689 psi		Date Cast:	4/13/2016	
² Grout Strength, f'g (ASTM C1019):	791 psi		Date Tested:	5/4/2016	
Loading Machine: MTS 322		Data Acquisition Device: MTS FlexTest SE			
Method for Applying Load: Vertical, Monotonic Loading at Specimen Corners					
Loading Protocol: Constant, displacement controlled loading rate, 0.003 in/min					
Test Start Time:	2:37:58 PM		Test Duration (min) :	43.0	
Test End Time:	3:20:56 PM				

days
21

Specimen Set-up:

ID:	Instrument	Gage Length, L _g (in)
1	LVDT 0.3A	20.125
2	LVDT 0.3B	20.25
3	LVDT 0.1B	18.5
4	LVDT 0.5A	27.4375
5	LVDT 0.1A	18
6	LVDT 0.5B	26.875

Notes:

1 = very front (closest to wall)

6 = very back (furthest from wall)

Test Results:

Symbol	Term	Value
P _{max}	Max vertical force (k)	2.878
A _n	Net specimen area (in ²)	139.3
S _s	Maximum Shear Stress (psi)	14.61
γ _{Pmax}	Shearing Strain, at P _{max} (in/in)	0.002385
G	Shear Modulus, at P _{max} (psi)	6125

Grout Mix Design: Cast: 8 porous 2x2 cubes in BP6 block, 6 nonporous cubes

	base (kg)	addtl (kg)	total (kg)	% by mass		
Cement	5.7	0	5.7	9%	f'c, average (p)	f'c average (np)
Sand	42.2	0	42.2	69%	791 psi	405 psi
Lime	3.13	0	3.13	5%		
Water	9.86	0	9.86	16%		

p = porous, np = nonporous

Notes:

1. Masonry strength based on single block testing. Channel blocks not tested for compressive strength
2. Grout Strength represents porous grout strength

B.2 Loading Shoe Design

B.3 Panel Photos

Specimen ID: MSB- HSG-FG

Strain values taken from LVDT 0.5B

Failure Description:

Cracks propagating from both loading corners, with large head joint displacements at courses 3 and 4.

Specimen ID: HSB-MSG-FG

Strain values taken from LVDT 0.5B

Failure Description:

Cracks propagating from top left loading corner, with noticeable head joint displacements at courses 2 and 3.

Specimen ID: MSB-MSG-CNTRL

Strain values taken from LVDT 0.5B

Failure Description:

Crack propagating from top left loading corner and extending through to opposite corner. Modest head joint displacements at courses 2, 3. Larger head joint displacement at course 4.

Specimen ID: MSB-MSG-GC2

Strain values taken from LVDT 0.5B

Failure Description:

Late cracks propagating near center of panel, with large head joint displacements at courses 2, 3 and 4.

Specimen ID: MSB-MSG-NSK

Strain values taken from LVDT 0.5B

Failure Description:

Cracks propagating from both loading corners, with very large head joint displacements at courses 3 and 4.

Specimen ID: MSB-MSG-SK

Strain values taken from LVDT 0.5B

Failure Description:

Cracks propagating near center of panel, with large head joint displacement at course 4.

Specimen ID: MSB-MSG-CB2

Strain values taken from LVDT 0.5B

Failure Description:

Cracks propagating from left corner and visibly through to the lower right corner. Little visible signs of head joint displacement (likely caused by cracking/block rotation).

Specimen ID: MSB-MSG-C1

Strain values taken from LVDT 0.5B

Failure Description:

Late signs of visible displacement and cracking. Cracks propagating from left loading corner, with head joint displacements at courses 2, 3 and 4 (largest forming at course 4).

Specimen ID: VBLK-MSG-FG

Strain values taken from LVDT 0.5B

Failure Description:

Cracks show up at early strain values, starting towards center of panel and propagating to both loading corners. Very little noticeable head joint displacements.