

Rammed Earth Compressive Testing Using Soils From San Luis Obispo

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Rammed earth is a sustainable building technique that has been around for thousands of years, and is still being used today. It minimizes environmental impacts by reducing the need for the many resources we use to produce building materials. The purpose of this paper is to test soils in San Luis Obispo to see if they contain the strength characteristics needed to build structural components using rammed earth. After the soils have been collected they will be mixed with a small percentage of cement, and compacted into test cylinders. A compressive test will be conducted after 7 days, and the results will be compared to strengths that are appropriate for rammed earth applications. The results will indicate the possibility to build structural components using rammed earth in San Luis Obispo.

Keywords: Rammed Earth, Sustainable Building Practices, Soil Properties, Compressive Strength, Cement Stabilized Rammed Earth.

Introduction

There is a lot of history behind rammed earth, and today's applications are being used because of its beautiful aesthetics and sustainable building advantages. Understanding the building techniques behind rammed earth can allow for homes to be built using this ancient, but modernized technique, and save valuable resources. The modern technique, also the technique used in this paper, uses a small percentage of cement to help with strength and durability. To be able to build using rammed earth it's pertinent that it passes a compressive strength test. Understanding the soil before it is tested compressively will help determine if it a good soil to start with. There are many simple tests that can be done at home to help with this. These tests include the jar test, the coil test, and the dropped ball test. Soils reports were also attained in this paper for further examination. Once the soils have been examined they will be rammed into 6" x 12" cylinders, will sit for 7 days, and be tested using a compressive testing machine. This paper focuses on select soils in San Luis Obispo, California, and uses techniques found through a literature review to examine soil, and conduct a compressive strength test to find out if these soils have the compressive strength properties to build structural components using the soils in San Luis Obispo. The following explains the history, sustainable advantages, steps taken to understand the soil better, and compressive strength testing and analysis to determine if these soils can be considered to build with.

Background

Rammed earth has been dated back thousands of years in China, although the exact dates are unknown. "Excavations in China have uncovered rammed earth construction dating from the seventh century B.C." (Easton, 2007). Various ancient forms of rammed earth have been found being used in the Great Wall of China, and areas in Africa. Europeans adopted the method later on, and eventually they brought the building methods to America. It wasn't until the early 1800's until the rammed earth building method was introduced in America. Figure 1 shows the Holy Cross Episcopal Church in Stateburg, South Carolina, built from 1850-1852, and Figure 2 shows the Windhover Contemplative Center built in Stanford, California in 2014. It's great to know that this method of building is still being used today in modern applications, although its popularity has dropped significantly since modern building techniques have taken over.



Figure 1(Left): The Holy Cross Episcopal Church in Stateburg, South Carolina built from 1850-1852.



Figure 2 (Right): Windhover Contemplative Center built in Stanford, California in 2014.

Although rammed earth has been around for so long the building method hasn't changed very much. The difference from the old and the new way of building rammed earth has been the strength and durability factors. They have been increased through the addition of cement, rebar, and the compaction method, which has changed from manually to pneumatically. Although in some places manually compressing the soil is still being used. Some of these places that still compress the soil manually are usually foreign countries with little money to afford the modern approach, and are able to reap the benefits of having great soils where they live. They are located mostly in the tropics because of their laterite soils that suit rammed earth building well. This way they are able to use the soil around them, and not pay for expensive materials, or transportation costs.

Many of today's rammed earth applications in the US are not only used for their building qualities, but used to show off how beautiful a building can be when constructed with rammed earth. This is seen with the Windhover Contemplative Center, from figure 2, the beautiful soil layers developed within the rammed earth. Today's applications include purposely layering the soil with different colors to make the layers the center of attention. Rammed earth is still very prevalent in the US and is a great way to build something if you have the appropriate soils and want to build something with sustainable advantages.

Sustainability and Building Advantages

With today's sustainable building practices becoming more prevalent to reduce harmful emissions, the use of rammed earth is another way to build a beautiful structure while helping the environment at the same time. It also has great building properties that contribute to LEED. Rammed earth requires little water use, has great insulating properties, noise reduction properties, is fire proof, eliminates termites and other pests, and gives off no harmful emissions. Although when adding cement there are some emissions given off due to the cement. Because rammed earth needs to be at optimum moisture content when compacting it only needs about 10% of water in the mixture, significantly less than concrete. Rammed earth walls are typically a 1'-2' thick, although you can make them as thick as you want. This creates a slow penetration for hot or cold air to pass through the walls and make for a fairly stable interior. Although rammed earth is a naturally great insulator, the new techniques use interstitial insulation that brings the R-value up higher for a more comfortable setting. Another great attribute from their thickness is that the noise is reduced significantly, and because it is composed of soil the walls are fireproof. The earth also keeps out the termites and any other pests that might live inside your walls.

When building with rammed earth it's also important to build somewhere where the soil is close by or right on the site where you plan to build. It's also worth noting how much concrete contributes to CO₂ emissions. "Over seven percent of global CO₂ emissions come from the production of cement and concrete represents nearly one half of the 136 million tons of construction waste generated each year in the United States"(Dahmen, 2005). When using the

soil that is already available on the site of the project; transportation costs, life cycle costs, and embodied energy will be reduced significantly.

Objective and Goals

This research was conducted to see if San Luis Obispo has quality soil that can be used for rammed earth applications. Collected soils will be examined to find out which type of soil they are, and if they have the properties needed for rammed earth. After they have been inspected they will be compressed into rammed earth and undergo a compressive test to determine if they ultimately have enough strength to be considered in real world applications. This will allow people with an interest with rammed earth to consider using soils within San Luis Obispo.

Methodology

The methods used for this paper were used to fulfill the objectives and goals describe above. The first thing that was done was a literature review to understand rammed earth into further detail, and to understand the soils that best suit rammed earth applications. After an understanding of what rammed earth is and ways to test for good soils these methods will be used in the field. When the soils have been collected they will undergo simple tests that will help evaluate their properties. These tests include; the jar test, the coil test, and the dropped ball test. Along with these tests soils reports will also be used to further understand the soil properties. Some of the soils reports didn't give the exact location of the soil due to being excavated and moved on the jobsite, so these simple tests help understand the soil type. If the soil collected shows promise to be used in rammed earth through these tests and reports, they will be brought back to a workspace to be turned into test samples. The soil will be mixed with a 7% cement mix ratio, brought to optimum water content, and compressed into test cylinders. The rammed earth will sit for a week before compression tests are used on them. The results will determine if the samples that were collected are suitable for rammed earth.

Typical Soils Used For Cement Stabilized Rammed Earth Applications

When building with rammed earth it is important to understand the types of soils that will be used. This eliminates any soils before putting in a lot of time and effort it takes to build using rammed earth. First, topsoil should be avoided because it can contain a lot of organic material that does not perform well in compressive conditions. Soils should be avoided that contain a lot of silts. A good soil ratio for rammed earth should contain about 30-40% clays, and 60-70% sands, gravels, and fines. "Sandy clays, gravelly clays, clayey sands, are three examples of potentially suitable soil types (Easton, 2007). Sometimes soils may need to be imported to acquire this mix if the site you're working at has poor soils for rammed earth applications. After good soil has been acquired a cement mixture from about 6-10% should be used to help with the durability and strength qualities, although it is not required and there are plenty of old buildings that are still in great shape today just using earth.

The soils that were collected in San Luis Obispo were from soil that was excavated on a jobsite. This was important because it eliminated the topsoil. Using a jobsite can be beneficial when collecting soils for this reason. Three different five gallon buckets were used to collect the samples. The samples were denoted sample 1, sample 2, and sample 3. Before leaving the jobsite soils reports were acquired to help with figuring out the soil types of each sample. This is another benefit when using a jobsite as your soil resource. Two of the soil samples were still a little unclear as to their type of soil because the excavated soil was moved to the other side of the jobsite, so a jar test was performed to help out with further examination. If soils reports are unavailable, or it's hard to determine the soil type because it has been moved from its original location, as in this case, a jar test can be used to identify what type of soil you have collected. A jar test won't give exact percentages but will give you a general idea of the amount of each soil. "The jar test is a field-test used to establish an approximate (volume) proportions of the main soil

constituents (Maniatidis & Walker). This is a simple test that is easy to perform. Figure 3, below, shows the jar test results performed on the soils that were collected from the jobsite. The three samples are shown in the picture below are from left to right; sample 1, sample 2, and sample 3. The results from the jar tests below show how soil can be recognized. Notice the larger particle soils at the bottom of each jar, and the finer particles at the top. Just by looking at the jars sample 1 & 2 they seem to have more fine particles indicating their soil contains a lot of clay and less sand. The third sample indicates a better ratio of clay to sand, and even some gravel in the bottom. Another important thing to note is there is not any floating material in the jars. Floating material is usually organic and should be avoided altogether.



Figure 3: Jar Test results



Figure 4: Coil Testing

Although a jar test can help with the soil types, recognizing the difference between silts and clays can be difficult because they are both fine grain soils. Another easy test to perform that can help with this problem is the coil test. This test involves getting the soil wet enough to roll it out into a pencil thin coil. Make sure to remove any big particles in the soil and use only the finer particles. If the coil falls apart there probably isn't enough clay in the mix and it has more silt. If it stays together it is a good indicator of a clayey soil and it possibly has the potential to be used in rammed earth. All three samples that were collected stayed together and showed good potential for rammed earth. Figure 4 above shows a sample put t the test.

Through further investigation of the soils reports, and interpretation of the jar tests and the coil tests, the soils that were collected consisted of two clayey sands and one sandy clay. These types of soils have good potential to be used in rammed earth applications. These soils were now ready to be compacted into test cylinders that will be used for compression testing.

Making Rammed Earth Test Samples

Making rammed earth test samples can be done in various ways. Some ways include making a wall, blocks, or cylinders that will be tested under a compression machine. They are also rammed using a pneumatic rammer or a manual rammer. The manual rammer is less effective to acquire a maximum strength, but was the only way old buildings were made and has stood through the test of time. The method use in this experiment consisted of 6" x 12" plastic cylinders, and the soil was rammed manually. Particle sizes greater than 5/8" were discarded to help better compact the soil with fewer voids. Chunks of dry soil were crushed, using an 8"x8" steel tamper (See figure 5), to meet this requirement. After the soil was brought to acceptable particle sizes the soil was mixed with 7% percent of Portland cement using a mixing tray and a hoe (See figure 6). Mixing cement was done before water was added so it didn't dry out the soil if it was added after, reducing the moisture content. Water was added to the soil to bring it up to optimum moisture content (OMC). Testing the soil for OMC can be done with the simple dropped ball test (See figure 7). The dropped ball test is done by getting soil in your hand and squeezing it together to form a ball. Allow the ball to sit for a minute, and then drop it from shoulder high. If the ball crumbles into little pieces it is too dry, if the ball doesn't break apart at all it is too wet. A good indicator for OMC can be determined when the ball breaks

apart into a few big pieces and other little pieces as shown in the picture below. “To test the humidity, form a ball in your hand, after adding enough water to have it just consistent and malleable enough. Drop it from your shoulder height. When it impacts on the ground the ball must explode in a main heap and little satellites” (Morsier, 2016). A spray bottle was used to spray water evenly over the soil, then it was mixed with a hoe, and repeated until the soil was approved using the dropped ball test. Once it passed the dropped ball test the test cylinders were compacted with soil.



Figure 5(Left): 8”x8” steel tamper used to crush up soil

Figure 6 (Left Middle): Cement mixed in with the soil.

Figure 7(Right Middle, Far Right): Shows the before and after of the ball test.

Before the soil was compacted into the cylinders the appropriate amount of soil was measured out to ensure the compacting that was being done was sufficient enough for the samples. The volume of the soil used for the rammed earth should be 140-150% of the test cylinder. Once the appropriate amount of soil was collected it was compacted in three successive 4” lifts manually, using the butt end of a digging bar (See figure 8 & 9). For each lift the soil was placed into the test cylinder two inches higher to where the finished compacted soil shall be. So for the first lift the soil took up 6 inches of the test cylinder and was compacted down to the 4 inch mark. If the soil still feels like it needs to be compacted more, keep going until the rammer is almost bouncing back. This will ensure the soil has been compacted effectively. Once all three lifts have been completed the cylinder was left to sit for 7 days. After the test samples have sat for 7 days they were tested for their compressive strengths. The results are below in table 1.



Figure 8(Left): First layer being compacted into a test cylinder.

Figure 9(Right): Digging bar used to compact soil.

Compressive Testing

This test used the compressive testing machine at the Cal Poly, San Luis Obispo’s concrete lab. The test samples were put through the same machine concrete samples is tested in. This machine helped give an accurate reading to the test samples and ultimately decided their compressive strength fate. Sample 1 and 2 were fairly similar soils with the amount of clay in them determined from the soils reports, and simple tests explained earlier. They were classified as clayey sand. The percentage of clay was around 40%. This was high for having cement mixed in. The

3rd sample had more sand mixed in it and was classified as a sandy clay. This sample should have a stronger bond due to the higher percentage of sand. When building with unstabilized rammed earth the clay acts as cement, so clay content of 30-40% is usually good. But when building with stabilized rammed earth the cement acts as the clay so more sand is considered to give it more strength. This also goes back to the ingredients in concrete. There is no clay in a concrete mix. Table 1 below shows the results from the testing. Figure 10, Figure 11, and Figure 12 shows pictures from the tests.

Compressive Testing Results:

Sample #, Description	P.S.I.
1, Clayey Sand	179
2, Clayey Sand (Dark yellowish brown)	179
3, Sandy Clay	250

Table 1



Figure 10 (Left): Rammed earth samples that were just taken out of the molds. Notice the dark color of the soil, these samples could still use some curing time to get their full strength potential.

Figure 11 (Middle): Here is a sample in the compressive strength machine prior to being crushed.

Figure 12 (Right): The end result from being compressed. Notice the diagonal fracture running through the sample.

Analysis

Rammed earth doesn't really have a building code like masonry walls, concrete, etc. This makes rammed earth unique in its own way. Through the literature review there was a lot of findings about rammed earth in New Mexico, and the North American Rammed Earth Builders Association (NAREBA). New Mexico is one of the only places in North America that have standards and specifications they build from. "There is no specific provision or mention of rammed earth in the building codes used in almost all of North America. While a few exceptions exist, most notably the U.S. state of New Mexico (Chapter 7, Part 4—The NM Earthen Building Materials Code) [1] and Tucson/Pima County, Arizona (Appendix Sustainability 2013, 5 402 Chapter 71, Earthen Materials Structures) [2], most local building departments have neither an understanding of rammed earth nor a local example from which to form an opinion or to create a construction and inspection protocol. This can present challenges when rammed earth is introduced to a new locale." (Windstorm & Schmidt, 2013). The New Mexico Earthen Building Code mentions that after a sample has sat for 6days its compressive strength needs to be at a minimum 200 psi, and ultimately reach a psi of 300 or greater. This makes sample 1& 2 unlikely to build with rammed earth, but sample 3 passes the test with this standard. These are New Mexico standards and there isn't any reason to be bringing soil from SLO to New

Mexico so these results couldn't be conclusive for building with rammed earth in SLO. The NAREBA gave more light to building in other places than New Mexico.

The NAREBA is a not for profit organization that promotes rammed earth buildings methods across the country. NAREBA is a collaborative association that brings many rammed earth builders together to understand rammed earth building techniques and its possibilities. They have their own building specifications and standards that have been incorporated into construction documents for many residential, commercial, and institutional projects. The standards and specifications document has a minimum building code and helps design professionals work with rammed earth on projects. Their minimum building standards include; getting the structural rammed earth strength of 900 psi, it must have a mix design testing protocol, it's required to have a mock-up for each project for testing, and you have to establish what the minimum thickness of the wall may be. There are many other standards and specifications, but the compressive strength is the one that needs to be analyzed for this experiment. Looking at the test results from figure 10, having a minimum of 900 psi doesn't look to promising. Although the test samples 1, 2, and 3 were not fully cured it seems unlikely they will reach this psi, but cannot be ruled out because they were not fully cured, and they ultimately will not be acceptable for building in San Luis Obispo if this is this case.

Another thing that was found about rammed earth applications to help analyzing the compression strength results was that builders commonly use the concrete and masonry building codes for rammed earth because they have nothing else to go off of. These codes specify that minimum compression should be at 2500 psi. This is another indication that the rammed earth samples that were tested from San Luis Obispo were not up to code and therefore would not be approved by an engineer.

There are many factors to take in when analyzing the compression testing results such as; the soil used, the way it was rammed, the amount of cement used, the time the samples sat for, and the pounds per square inch (PSI) they witheld prior to being crushed all factor into the analysis. When the rammed earth samples were taken out of the molds they were still damp, and seemed to have a lot more time to cure to get to its maximum strength. And upon being crushed half of the mold crumbled apart indicating a weakness. There was a distinct diagonal fracture similar to concrete that indicated some strength. If these samples sat for a longer period of time it is possible they would have stayed together without half of it crumbling apart. But to have an acceptable rammed earth building material they must be approved by an engineer. There needs to be further testing to come to a final understanding.

Conclusion/Findings

There is a lot to learn about building with rammed earth. It is a very unique approach to building and has many sustainable advantages that go along with it. Rammed earth has been around for a very long time and there are still no set standards and specifications to build with it, besides New Mexico and Arizona, although the North American Rammed Earth Building Association (NAREBA) is making an effort to establish these across the country. All rammed earth projects must be approved by an engineer, and are usually based off of the concrete specifications and standards. The samples that were collected in this project showed little promise to build by these standards.

All 3 samples underwent the same methods to achieve a rammed earth state. Using the jar test, coil test, and the dropped ball test were great easy ways to test soil. Upon the compression testing it was noted that the soil still looked damp when the rammed earth samples were extracted from their molds. This seemed to be a sign of weakness and maybe the testing should have been delayed longer to get a better reading of their strengths. Sample 3 ended up having the greatest strength overall at 250 psi after 7 days. The other two samples were only recorded at 178 psi. Upon the crushing of the samples as figure 13 shows, the samples all had a diagonal fracture like concrete, but a lot of the sample crumbled apart indicated a poor result. Sample 3 showed the most promise, but there was still a lot that could be done to find out for sure if these samples had what it takes to build with.

Future Research

There is a lot more that can be done to further understand the soils used in this experiment. The approach that was taken in this paper consisted of ways to build with rammed earth just by using simple tests. The jar test, the coil test,

and the dropped ball test. A more scientific approach could be used to fully understand the exact soil types and their exact optimum moisture content. When these soils were ready to be rammed, plastic 6" x 12" cylinders were used. A better approach would be to use ABS pipe or a metal casing for a more rigid encasement when ramming the soil. The manual ramming technique could be replaced by a pneumatic tamper for higher compression. When using the manual rammer it was hard to tamp the very top of the cylinder. Using a pneumatic tamper could have helped a lot with getting better compaction at the top. Another good recommendation would be to use a rigid container higher than 12 inches to get a more compact top portion then shave off the top back to 12 inches. The samples that were collected should have sat longer to really find out their maximum strengths. In the future it would be advisable to have samples tested at different periods of time such as; 7, 14, 21, and 28 days, similar to concrete. Based on the results that were obtained from this paper, future research is needed to fully rule out these soil types as a promising soil to build with.

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