Soil Block Home Construction

BTEC Sustainable Buildings III Conference
Santa Fe, New Mexico
October 17-18, 2001

Charles W. Graham, Ph.D., AIA, and Richard Burt, Ph.D, MCIOB.[1]

Abstract

Affordable housing is needed in almost every country of the world. In the United States, the need for affordable housing is especially critical in the Colonias along the Texas-Mexico border. Among the many alternatives available for low-cost housing production in areas like the Colonias, compressed soil block and straw bale construction are two alternatives being studied for their suitability. A research project involving a review of the literature on soil block home construction, comparison of compressed soil block machines, and analysis of procedures for constructing code-compliant housing was completed. The most common field test procedure for soils, the jar or sedimentation test, was studied to see how much variance there was between tests. Six samples of the same soil were tested ten times to measure the amount of variance between the samples. The findings were that the jar tests gave acceptable results if the analyst followed standard practices. This paper presents a summary of the major categories of earth home construction, a review of soil block making machines, and concludes with a summary of the findings of the soil test procedures.

Introduction

Affordable housing is needed in almost every country of the world. In the United States, the need for affordable housing is especially critical in the Colonias along the Texas-Mexico border. Residents in the Colonias neighborhoods make an average household income of only about $11,000 annually (Salinas 1988). Studies have also shown that Colonias residents like to build their own homes to save money. At least 60% of the 300,000 residents who live in approximately 1,500 communities along the Texas-Mexico border provide sweat equity through their own labor and use scavenged, recycled, and low-cost materials to either build their homes entirely, or add major additions onto them to save costs (Roach 1993; Ward and Macoloo 1992).

---

[1] Charles Graham is an architect and the Mitchell Endowed Professor of Housing Research in the Department of Construction Science at Texas A&M University. Richard Burt is an Assistant Professor in the Department of Construction Science at Texas A&M University. Before coming to the United States from England, Dr. Burt was a Chartered Building Surveyor. Dr. Graham can be reached at Dept. of Construction Science, College of Architecture, College Station, Texas 77843-3137, 979-845-0216 (phone), cwgraham@archone.tamu.edu (email). Dr. Burt can be reached at Dept. of Construction Science, College of Architecture, College Station, Texas 77843-3137, 979-845-0994 (phone), rburt@archone.tamu.edu (email).

Among the many alternatives available for low-cost housing production in areas like the Colonias, compressed soil block and straw bale construction are currently being studied for their suitability. Colonias residents are often from Mexico and other Latin American countries and so they readily identify with most forms of concrete or masonry construction, which is popular in these countries. Many have also had experience with adobe bricks and rammed earth construction, but they view them as being inferior to manufactured masonry units such as fired clay bricks and concrete blocks. Few, however, have actually seen compressed soil blocks used in code-compliant home construction.

The trend in Texas is for housing made of compressed soil block to be used for higher income home owners, but studies are underway to determine the efficacy of using compressed soil blocks in home construction for low-income people. Demonstration projects around the world have shown that this approach is feasible. Preliminary studies by architects, engineers, anthropologists, sociologies, and public policy experts have found that compressed soil blocks for the construction of walls are affordable, the materials are readily available, and when homes are designed properly, residents will accept them. What is needed, however, are demonstration projects in the Colonias along the Texas-Mexico border to show the residents there how to build attractive, code-compliant housing that will allow the homeowners to contribute their time and resources in the self-assisted housing construction approaches that they are familiar with. This paper reviews the various methods of earthen construction, discusses compressed soil block construction techniques, and reports the findings of a study in which a simple field test for the composition of the soil from which the blocks are made was evaluated for its accuracy.

Earth Construction Techniques

Houbain (1994) identified three ways in which unbaked earth is used as a building material:

- Unbaked earth in monolithic load-bearing form;
- Unbaked earth in the form of load-bearing masonry; and,
- Unbaked earth in conjunction with a load-bearing structure.

Cob walling, such as used in England, is an example of unbaked earth used in monolithic load-bearing form. Figure 1 shows examples of cob wall construction in England. Another monolithic load-bearing form of earth construction is rammed earth. This is one of the oldest methods, dating back to the medieval ages. Figure 2 shows rammed earth construction in Arizona. Figure 3 shows how unbaked earth is formed to create a monolithic load-bearing wall.

Figure 1. Cob Walling Construction in England

Figure 2. Rammed Earth Construction in Arizona
(Photo courtesy of Rammed Earth Development Inc. at http://www.rammedearth.com/)

Figure 3. Building a Cob Wall

Unbaked earth may also be formed into masonry units such as bricks or blocks using various techniques. A traditional method used in the Southwest United States is adobe. Adobe bricks are often hand formed in molds and dried in the sun. They are plentiful, they are inexpensive, and when used properly, they can yield good results for home construction because of the durability in service and flexibility in support of different home designs. Figures 4 and 5 show examples of adobe construction.

Figure 4. Adobe Church in New Mexico

Figure 5. Adobe House in Fort Davis, Texas

Another approach to house construction using earthen materials is in conjunction with a support structure. Wattle and daub is an example of this form. A slightly higher level of sophistication to the construction process is required because the earthen materials must be incorporated with carefully placed wooden members to create the walls for structures. One of the benefits of this type of construction, however, is that thinner walls are possible, thereby taking up less floor space. Figures 6 and 7 show examples of wattle and daub construction.

Figure 6. Wattle and Daub Wall Construction

Figure 7. Wattle and Daub Wall Construction

Compressed Soil Block Construction

In contemporary times machines have made it possible to produce higher quality bricks or blocks using soil as the basic ingredient. Sun dried, uncompressed adobe bricks can be improved greatly by compressing the soil to higher densities. In many cases, compressed soil blocks come out of the machine ready to lay in the walls in their "green" condition, without additional drying or baking. This is because the soil is compressed to very high densities. Further, the machines used to compress the soil blocks are capable of making many bricks in a short period of time that are uniform in density, shape and overall dimensions. Machines in use today include both manually operated and mechanically operated methods to compress the soil into bricks. One of the major limitations of the manual machines is that they are slow and one is limited in how much force can be applied to the bricks. Figures 8 and 9 show examples of two manually operated machines.

Figure 8. Cinva Ram Manual Machine

Figure 9. Auram Press Manual Machine

Adding a hydraulic ram to compress the soil and automated conveyors to deliver bricks from the machine to the work area provides a high level of production capacity and quality to the process. As many as 300-320 bricks per hour can be produced from these machines. Compressed soil bricks may have compression strengths of 1,200 –1,400 p.s.i., suitable for load-bearing construction under the right conditions. As noted previously, bricks from these machines are consistent in strength and dimension, as long as standard procedures are followed for quality control (e.g. soil mixes have to have the correct amount of clay and sand, moisture has to be very close to being the same in all units produced, and handling and placement techniques have to follow accepted procedures). The Advanced Earthen Construction Technologies (AECT) machines, produced in San Antonio, Texas, are good examples of quality mechanically operated machines. These machines are available in three different sizes: the Impact 2001 Series, the 3000 Series, and the 4000 Series.

Figure 10 shows the Impact 2001 Series machine. It is a small, trailer-mounted machine that comes with either a 6.5 h.p. gasoline or 7.0 h.p. diesel engine, and either manually operated mold or automatically operated mold. This machine can produce 230 - 300 blocks per hour in a variety of dimensions. For example, 2 1/2 " - 4" (5.0 cm – 4.5 cm) thick, 5.5" (14 cm) wide, and 12" (30.5 cm) long are common. Each block weights between 9-18 pounds (4.1 Kg to 8.1 Kg) depending on the soil and block thickness. Blocks are bonded together using the wet thin soil slurry or other conventional methods. The soil slurry is made with water and screened soil. Blocks can also be placed in the wall using the traditional thick mud mortar method.

The Impact 2001 Series machine uses a wide variety of soils with prepared natural soil moistures in the range of 4-12 percent. Typically, the machine requires soil with a combined clay (15-20 percent) and silt (powder) content of approximately 25-40 percent (by volume), and a sharp sand content of approximately 40-70 percent (by volume). The machine does not require any aggregate (rocks) to make a strong soil block for most applications. The block compressive strengths range from 600 p.s.i. (42 Kg/cm2) to 1,200 p.s.i. (70 Kg/cm2) depending on the soil. A force of approximately 72,000 lbs. is used to produce blocks with 1,091 p.s.i. compressive strength on 5.5 in. x 12 in. x 2.0-4.5 in. block. This machine operates at less pressure placed on the block during block production and thus it can work across a wetter soil range than the larger AECT machines.

The next higher production capacity is provided by the 3000 Series machine. It has a diesel engine and a large enough hopper to hold soil for dozens of blocks to be produced at a time. This machine is capable of producing 300 blocks per hour and is suitable for the medium capacity contractor. An example of this machine is shown in Figure 11.

Figure 12 gives an example of the largest machine available from AECT, the 5000 Series. This machine has a four cylinder diesel engine and an even larger hopper for soil storage. It utilizes a turntable that has four molds in it. Each time the machine makes a compressed soil block, the turntable rotates 90º. In the first stage the soils are dropped into the mold, in the second stage the soil is compressed, in the third stage the brick is raised up out of the mold, and in the fourth stage the bricks exit onto the conveyor. Bricks come out of the machine at the rate of approximately 800 bricks per hour. Up to 230,000 lbs. of force/pressure is applied to the soil to produce bricks of 1,643 p.s.i. compressive strength on 10”x14” block. The manufacturer claims that it takes six or seven workers to keep up with the machine when removing bricks and stacking them near the work areas.

Figure 10. AECT Impact 2001 Compressed Soil Block Machine

(Photo courtesy of AECT at http://www.webspace4me.net/~fwehman)

Figure 11. AECT 3000 Series Compressed Soil Block Machine

(Photo courtesy of AECT at http://www.webspace4me.net/~fwehman)

Figure 11. AECT 5000 Series Compressed Soil Block Machine
(Photo courtesy of AECT at http://www.webspace4me.net/~fwehman)

Quality Control

To achieve maximum production capacity of the machines, whether manually or mechanically operated, the user must follow certain procedures that have been developed from historical experience and empirical analysis. Essentially, there are two basic areas of quality control: suitability of soil, and suitability of masonry units.

Suitability of Soil

A review of the literature found that there are three characteristics that greatly affect suitability of soil. These include the composition of the soil, the moisture content of the soil, and the plasticity of the soil. An ideal soil would be composed of soil with a combined clay (15-20 percent) and silt (powder) content of approximately 25-40 percent (by volume), and a sharp sand content of approximately 40-70 percent (by volume). The mechanical machines do not require any aggregate (rocks) to make a strong soil block for most applications, however, fine aggregates up to ¼' diameter and not more than 5-10 percent of the volume are sometimes allowed.

Soil moisture content can range from 4-12% by weight, depending upon the soil mix (e.g. sand and clay percentages). As noted previously, the Impact 2001 Series machine by AECT can use slightly wetter soils than the larger machines. The plasticity of the soil is primarily a function of the clay. The higher the plasticity index of the soil the greater its shrink and swell characteristics at different moisture contents. More moisture causes the clay to expand over time, and drying causes the clay to shrink. Clay with plasticity indexes of up to 25 or 30 would be acceptable for most applications. The plasticity index of the mixed soil, including clay, silt, and sand/gravel, should not exceed 12-15 (the difference between the Upper and Lower Atterburg Limits, as determined by laboratory testing). The constructor's goal is to use minimum moisture in a mixture of clay, silt, and sand/gravel that has a plasticity index shown through historical use of the soils to produce blocks that can be laid in the walls without undue drying times. Excellent references for these procedures may be found in McHenry (1984), Easton (1996), and Minke (2000).

Suitability of Masonry Units

Once a suitable soil mixture design and optimal moisture content are defined, blocks may be produced. However, their suitability for construction must be examined carefully, once again following established procedures for analysis. The building codes (e.g. see the New Mexico Adobe and Rammed Earth Building Code, at http://www.earthbuilding.com/nm-adobe-code.html) require that the modulus of rupture, compressive strength, and absorption rate of the brick comply with at least minimum standards. These will not be discussed in great detail here, but another excellent example of the code requirements is Boulder, Colorado's Alternative Building Materials Code, which can be found at http://www.azstarnet.com/~dcat/Boulder.htm. Chapter 97, Earthen Masonry Units, gives the requirements for code-compliant earthen construction.

Jar or Sedimentation Test

An extensive review of the literature conducted by the authors found that one of the most common quality control procedures for soil mix design is the jar or sedimentation test (sometimes also referred to as the shaker jar test). This is one of the most common tests found in the literature on earth building. This test measures the proportions of clay, silt, and sand/gravel.

The jar test consists of the following steps:

1. Filling a quart canning jar up to 1/3 of its volume with dry soil;
2. Adding clean water up the second-third of the jar's height;
3. Adding a pinch of salt to the water;
4. Mixing the soil, water and salt with a paddle or other device;
5. With the lid on the jar, shaking the jar vigorously until the soil particles are in suspension;
6. Letting the jar sit for one hour;
7. Again, with the lid on the jar, shaking it vigorously, and allowing it to sit for one minute;
8. After one minute, marking the height of the fine gravel and sand, which will readily settle to the bottom of the jar, as T1;

9. After 30 minutes, add a second mark to the point where the fine gravel, sand and silt have settled out of the water, as T2;
10. After another 24 hours, adding a mark at the highest level of the fine gravel, sand, silt, and clay, just where the water and soil contents have separated visually, as T3; and,
11. Calculating the percentages of the ingredients of the soil by following the equations where T1 = depth of sand, T3-T2 = depth of clay, T2-T1 = depth of silt, and where each depth is divided by T3 and then multiplied by 100.

Statistical Reliability of Jar Tests

An analysis of the statistical reliability of the jar test found that it is reliable if certain procedures are followed. To study the reliability of the jar test, six samples of soils were tested 10 times in a laboratory setting. The goal was to compare the results of the measurements recorded with each other to see how much variance there was between the readings. The sample readings were recorded independently by two graduate students with civil engineering undergraduate degrees in the Department of Construction Science at Texas A&M University over the summer of 2001. Figure 12 shows the jar after the soil has finally settled.

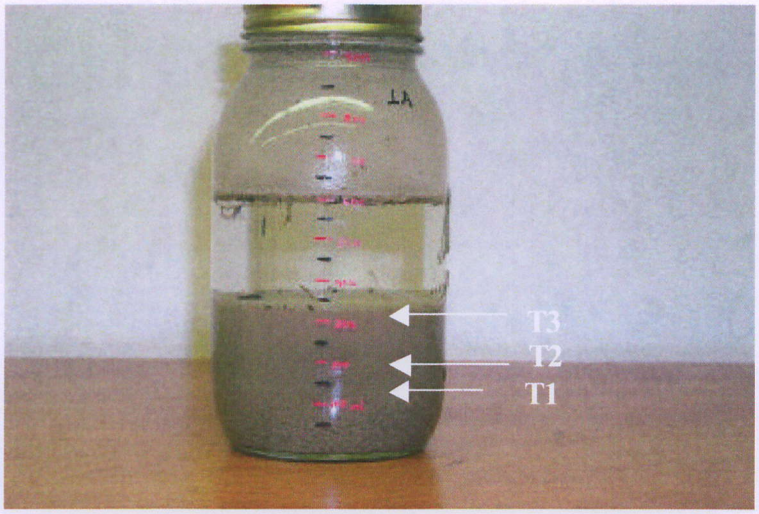

Figure 12. Jar or Sedimentation Test Performed at Texas A&M University

Jar 1	**Sand**	**Silt**	**Clay**	**Jar 2**	**Sand**	**Silt**	**Clay**
Mean	44.0	24.8	31.1	Mean	40.9	17.9	41.2
StDev	1.6	3.6	3.2	StDev	1.7	2.6	1.5
95UCI	45.0	27.0	33.1	95UCI	41.9	19.5	42.2
95LCI	43.0	22.6	29.1	95LCI	39.9	16.3	40.3
Max	47.0	30.0	34.0	Max	44.3	21.4	42.9
Min	42.0	19.0	26.0	Min	38.6	12.9	39.1
Range	5.0	11.0	8.0	Range	5.7	8.6	3.7
Jar 3	**Sand**	**Silt**	**Clay**	**Jar 4**	**Sand**	**Silt**	**Clay**
Mean	45.6	22.9	31.9	Mean	49.5	16.0	34.4
StDev	1.3	5.2	4.6	StDev	3.0	3.0	1.2
95UCI	46.5	26.1	34.8	95UCI	51.4	17.9	35.2
95LCI	44.8	19.7	29.0	95LCI	47.7	14.2	33.6
Max	47.8	30.3	38.6	Max	54.3	21.1	36.4
Min	43.9	14.3	24.2	Min	45.1	11.7	32.4
Range	3.9	16.0	14.3	Range	9.2	9.4	4.0
Jar 5	**Sand**	**Silt**	**Clay**	**Jar 6**	**Sand**	**Silt**	**Clay**
Mean	43.1	24.9	32.0	Mean	45.9	25.2	29.1
StDev	2.0	3.8	3.3	StDev	2.6	3.3	2.6
95UCI	44.3	27.2	34.1	95UCI	47.5	27.2	30.7
95LCI	41.8	22.6	30.0	95LCI	44.3	23.1	27.5
Max	47.1	33.3	35.2	Max	50.7	32.3	31.8
Min	40.8	21.4	24.6	Min	42.4	22.4	24.6
Range	6.3	11.9	10.6	Range	8.3	9.9	7.2

Table 1. Statistical Results of Jar or Sedimentation Test

Table 1 shows the results of the tests on the six jars. The results show that there is some variation between the results recorded for each jar. The silt result for Jar 3 is of particular interest as the minimum value was 14.3% and the maximum value was 30.3%, a range of 16%. This would appear to indicate a large amount of variation for this test. However, the range between the upper and lower 95% confidence intervals is only 6.4%, suggesting that this test has greater precision if more tests are carried out. This experiment only evaluated the variance within each sample and did not test the soil composition against other methods of testing. The next phase in this research is to compare the accuracy of the jar test with a laboratory method for soil analysis, such as particle size analysis by sedimentation/sieving.

The New Mexico Adobe and Rammed Earth Building Code states that "Each of the tests prescribed in the code shall be applied to sample units selected at random at a ratio of 5 units/25,000 bricks to be used or at the discretion of the building official" (http://www.earthbuilding.com/nm-adobe-code.html). This test is to establish the suitability of the blocks produced. The jar test will help to make sure that a good soil mixture, with a high probability of meeting the finish block requirements, can be produced. The experiment with the jar test indicates that the more samples one tests, the closer one will get to finding an accurate representation of the soil being used. The authors would recommend that at least 5 random soil samples from various locations in the mixed batch of soil, as it would go into the hopper of the machine, should be tested. More samples would be better, but 5 should be the minimum. Following the code requirement to test brick samples at a ratio of 5 units/25,000 bricks, one would then sample the soil at a minimum of 5 locations in the same quantity of soil necessary to produce 25,000 bricks. Again, these are minimum requirements for soils analysis. Other tests such as plasticity, sieve analysis, drop test, moisture content and slump need to be incorporated into the process of determining the suitability of the soil for making code-compliant bricks.

Recommendations for Future Research.

The quality control of soil block manufacture is a fruitful area for research. Research at Texas A&M University will be focused initially on the accuracy and reliability of field tests for the composition of the soil used in the manufacture of the soil blocks. Future research will also focus on the soil block units themselves. The New Mexico Adobe and Rammed Earth Building Code requires an average compressive strength of 300 pounds per square inch and a modulus of rupture of 50 pounds per square inch for compressed soil block units. Research will be conducted to identify the composition of soils in Texas that will produce blocks to meet these requirements. The research will also investigate if the compressive strength or modulus of rupture of the compressed soil blocks can be predicted by a number of independent variables such as the composition of the soil.

References

Easton, David. 1996. The Rammed Earth House. White River Junction, Vermont: Chelsea Green Publishing.

Houben, Hugo. (1994) *Earthen Architecture and Modernity.* Proceedings of the *'Out of Earth'* Conference 1994, Centre for Earthen Architecture, University of Plymouth, England.

Roach, Katherine. 1993. "Investigation of Colonias Residents' Potential for Self-Help Housing Construction" (unpublished thesis). Department of Construction Science, Texas A&M University.

McHenry, Paul Graham. 1984. Adobe and Rammed Earth Buildings. New York: John Wiley & Sons.

Minke, Gernot. 2000. Earth Construction Handbook. Southampton, U.K.: WIT Press.

Salinas, E. (1988). The Colonias Factbook: A survey of living conditions in rural areas of South Texas and West Texas Border Countries. Survey for the Texas Department of Human Services. Austin, Texas: Office of Strategic Management, Research, and Development. June.

Ward, Peter; and Macoloo, G. Chris. 1992. "Articulation Theory and Self-Help Housing Practices in the 1990s." *International Journal of Urban and Regional Research* (March), vol. 16, no. 1.