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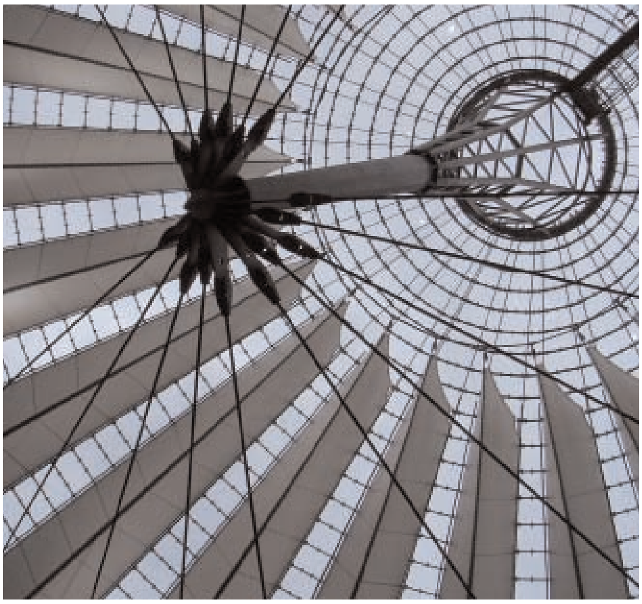

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Compressed Earth Building Blocks For Affordable Housing

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ABSTRACT

This project explored the possibility of using local soils for making compressed earth blocks for the construction of affordable residential buildings. The blocks were made with a block press that delivers a high compressive effort. Blocks were also made from soils with 5% of Ordinary Portland cement and kenaf fiber, an agricultural fiber, respectively. Mortar and plaster were made from clayey soil and a blend of clay and cement. The blocks were tested for compressive strength and modulus of rupture. The results met code requirements for compressed earth block one-story housing construction. The durability of the blocks was also examined.

Keywords: **Compressed earth blocks, Compressive strength, Modulus of rupture, Maximum density, Optimum moisture content.**

1.1 INTRODUCTION

The provision of housing is a challenge around the world, especially in developing countries. The spiraling growth of population, low Gross National Product and the general lack of purchasing power are factors that contribute to the progressive deterioration of the housing situation in developing economies. An impediment to the solution of the problem of housing is the scarcity and/or the high-cost of building materials. Ideally, building materials for low-cost housing must be produced from locally available raw materials. Furthermore, these raw materials must be abundantly available or they should be renewable in nature. The more popular construction materials such as clay bricks and concrete blocks are of good quality but are energy intensive in production, expensive and are usually based on heavy industries. It is incidental that most of the developing nations are in the tropical or subtropical regions of the world. Laterite, a product of tropical/subtropical weathering, occurs abundantly in such regions in the continents of Africa, Asia, South America, and Australia. Laterite denotes all reddish, residual and non-residual tropically weathered soils, which genetically form a chain of materials ranging from decomposed rocks through clays to sesqui-oxide crusts (Gidigasu, 1976). The main constituents of Laterites are oxides of Aluminum, Iron, and Silicon.

The utilization of earth in housing construction is one of the oldest and most common methods used by a larger percentage of the developing countries' population. It is the most readily available and cheap material found everywhere. It is easy to work with, requires less skills and as such, it encourages and facilitates unskilled individuals and groups of people to participate in their housing construction on self-help basis. It offers a very high resistance to fire and provides a comfortable built living environment due to its high thermal and heat insulation value. It also offers other important factors all of which attribute to the achievement of a good house planning/design and construction solution.

Soil is one of the oldest building materials. It has been used in three traditional methods of construction namely: 1. Adobe block; Adobe is sun-dried soil mixed with straw/rice husks to strengthen the blocks, 2. Wattle and daub; this is made up of interwoven timber, reeds or bamboo daubed with soil, and 3. Rammed earth; this is soil mixed with stabilizers and subjected to high compressive pressure. Soil is generally considered to be heavy and of low strength. However, it can be stabilized and compressed to yield high compressive strengths.

Today, earth building production techniques range from the most rudimentary, manual and craft-based to the most sophisticated, mechanized and industrial (Houben et al 1994). With the 1970s and 1980s there appeared a new generation of manual, mechanical and motor-driven presses, leading to the emergence today of a genuine market for the production and application of the compressed earth block (Rigassi 1985, Guillaud, Odul, & Joffroy 1985). The Advanced Earthen Construction Technologies (AECT) and the Vermeer Block Press machines are good examples of quality mechanically operated machines (Graham & Burt 2001).

Building codes have been developed for the use of compressed earth blocks in buildings. The New Zealand Standards (NZS 4297: 1998, NZS 4298: 1998, NZS 4299: 1998, NZS/AS 1530: 1998) for compressed earth construction give the details and specifications for building of compressed earth structures. Manuals and Guides for the construction of earthen structures have also been developed (Rigassi 1985, Guillaud, Odul, & Joffroy 1985). The compaction tests in this project were done according to ASTM D-698. The thickness of the blocks is 4 inches. These blocks when built to specifications can be used as a safe alternative construction material.

Houbain (1994) and Graham and Burt (2001) give examples of houses built with unrammed, rammed and compressed earth. Compressed earth blocks are safe alternatives to masonry. They are low cost and can be designed to be earthquake resistant (NZS 4297: 1998, NZS 4298: 1998, NZS 4299: 1998). Compressed earth blocks are non-toxic, are sound resistant, fire-resistant, and insect-resistant (Vermeer Construction Company, 2001). Compressed earth blocks have excellent insulating properties - reducing heating and cooling costs. For a given soil sample, the optimum moisture/density ratio can be obtained through a standard Proctor test. From this test a range of moisture content at which the soil will give desired densities can be obtained. The compression strengths of the blocks depend on their densities. The compression strength of a soil can be increased by chemical stabilization. This project was designed to prepare locally available soils, make the building blocks with a block press and test for the engineering properties of the compressed earth blocks. The objective was to test local soils to see if they could be used for low-housing construction. This paper gives the results of testing soils from two counties in the lower shore of Maryland and making compressed earth blocks from them. The compressed earth blocks were tested for compressive strength and modulus of rupture.

Soil has been widely used for thousands of years and still is today. It is an effective and an economic form for housing construvction and according to the United Nations, about a third of the world's population live in earthen structures today. Compressed earth blocks are economically and effectively made with the compressed earth block machines. Soil is the most abundant and inexpensive resource and with the block presses that can apply a pressure of 2265 psi on each unit, high quality blocks can be made for housing construction. The hydraulic pressure on the blocks that affect the block density can be adjusted to enhance the performance of a variety of soils. Suitable soil on a building site eliminates transportation costs. Compressed earth blocks are inexpensive, strong, made with locally available materials and are dimensionally uniform. Workers with little prior building knowledge and experience can be used for the wall construction. Compressed earth blocks are resistant to sound transmission, fire, insect damage and durable if properly protected. The mass of the compressed earth block walls makes the walls energy efficient systems. Little energy is needed for their production compared to other wall systems and soil is an environmentally friendly material. The suitability of the soil depends on its constituents: the sand, silt and clay proportions. Too much clay will cause cracks in the blocks while too much sand will cause the blocks to crumble. The suitable soil must contain the right proportions of sand, silt, clay and water. There are several laboratory and field tests that can be performed to determine the constituents and characteristics of the soils. Desirable properties are grain size, cohesiveness, and proportions/constituents. Compressed earth blocks are suitable for low-cost housing. Cement-stabilized blocks may be used after curing for 14 days. Mud slurry may be used as mortar for the walls. The slurry is made after the soil has been sieved. A reinforced concrete bond beam may be used to tie in the building. Surface plaster may be made of the following: open cut paint, lime or cement based plaster, asphalt emulsions, metal and wooden siding and indegenous materials such as clay. To stop rising dampness, stabilized water resistant blocks may be used. A soft plaster consisting of sand, lime, cement and organic binder over chicken wire may be used. Electrical and plumbing fixtures can be installed in several ways including insetting plumbing in the foundation and surface finishing. Sustainable low-cost housing provision..

1.1.2 Objectives

The objectives of the research is to evaluate local soil as a building material on the following factors:

- It meets the technical needs of local production by using local soils, power and resources, minimizing the need for imported building materials, reducing costly transportation and ensuring product availability and dependability.
- Meets social requirements of the local production situation by: using existing or easily transferable skills, avoiding costly training, minimizing displacement of labor, and minimizing social/cultural disruption.
- Meets the economic requirements of the local situation by: reducing dependence on outside sources, ensuring low-cost alternatives, and requiring limited machinery or capital investment.

One of the main objective is to promote compressed earth block building construction as a tool for sustenaible development for affordable housing. Therefore, the tests conducted included finding alternative jointing compound, determine soil properties like permeability, compressibility and soil strength, to make compressed earth blocks with HBP 520 Block Press machine. Durability issues like resistance to erosion and deterioration due to exposure to weather were also examined.

1.1.3 Scope of Work

The scope of this research project is limited to Sommerset and Wicomico Counties in the Eastern Shore of Maryland. Representative soils were taken from the following locations:

Wicomico County:

- Non-cohesive soil in a landfill in Salisbury Maryland. The soil was collected from 4 feet to 5 feet depth. The soil from this location is designated Soil No. 1 in this paper.
- Cohesive soil sample from the Salisbury-Ocean City Regional Airport, taxi-way expansion project. The soil was colected from 4 feet to 5 feet depth. The soil from this location is designated Soil No. 2.

Somerset County:

- Soil from the Education and Social Science Building project site on the UMES campus. The soil was taken at a depth of 5 feet. The soil from this location is designated Soil No. 3.

Compressed earth blocks were made from these soils individual. Some of the blocks were made from blending materials of Soil No. 2 and Soil No. 3.
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1.2 FIELD TESTS ON SOIL SAMPLES

The grain particles were examined with a magnifying glass. The porosity and plasticity were checked by pouring water on a soil sample to see the rate at which it drains through the soil particles and by making wet soil ½ inch diameter ball by rolling between palms as well as rolling the ball into 1/8" diameter thread. In order to determine tentative percentages of sand, silt and clay of soil particles, the soil was subjected to the sedimentation test in which each sample was placed in a glass jar and the jar filled with water and stirred properly. The jar was kept in static condition for the settling of the soil particles. Each of the settled soil layer was measured with a scale rule and approximate percentages sand clay, and silt were obtained

1.2.1 Laboratory Tests On Soils

The soils used for making the blocks were evaluated first by performing some tests for the purpose of classifying and identifying the types of soils. The tests performed were as follows: Soil Particle Size Test, Moisture Content Test, Specific Gravity Tests, the Atterberg Limits Tests and Compaction Test. In the Particle Size (Sieving) Analysis, the soil was first passed through the #10 sieve. The material retained on this sieve was now passed through the stacks of sieves (3" - #10) in the sieve analysis. A portion of the material passing the #10 sieve was used for the hydrometer test. After the hydrometer test, the material was thoroughly washed on a #200 sieve, oven dried and sieved with sieve numbers 10 through 200 (fine sieve analysis). All the soil tests were done using a basic Laboratory Manual (McArthur, T. & Roberts, J., 1996).

After classifying the soils, compressed earth blocks were made from the soils and the blocks were subjected to compression and modulus of rupture (MOR) tests after the blocks have "cured" for several days.

1.3 SOIL-BASED "MORTARS"

An attempt was also made to look for suitable soils that can be used as "mortar" in building the compressed earth block walls. "Mortars" were made from the clayey soil (mud slurry), cement-soil (1:6) and lime-soil (1:6).

Cubes were made from each “mortar” type and the moisture content and compressive strengths were determined after curing for a period. For plastering purposes, a cement-soil mix (1:1) was made and the compressive strength was found as 35.27 psi as shown in the figure.

The compressed earth blocks were made using the HBP 520 Block Press manufactured by Vermeer Manufacturing Company. The characteristics of the block press were discussed in an earlier paper (Arumala, et al., 2004). Figures 1 to 4 show the HBP 520 Press and the block making process.

The compressed blocks were weighed and the dimensions: length, width and height were measured before the compression and modulus of rupture tests were performed.

Figure 1 HBP 520 Block Press

Figure 2 Loading Hopper of the Press with Soil

Figure 3 The Compressed Earth Blocks

Figure 4 Some Compressed Earth Blocks

Figure 5 Compression Test Set Up

Figure 6 Crushing of Bottom Blocks After Exposure to Snow and Rain (after 3 months)

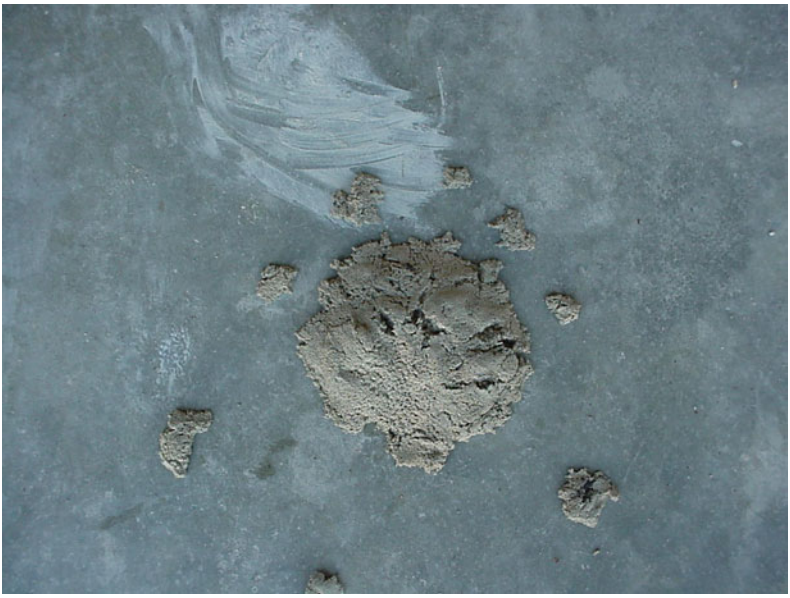

Figure 7 Moisture Content Drop Test

Figure 8 Wall Samples

1.4. TESTING COMPRESSED EARTH BLOCKS

The compressed earth blocks were tested for their compressive strengths and moduli of rupture using a 90,000 lb – Tinius Olsen Universal Testing Machine. The set-up for the compression test is shown in Figure 5.

1.5 RESULTS

Some of the results of this project are shown in the following tables.
Tables 1 to 3 give the results of the particle sieve analysis including the hydrometer and the fine sieve analysis. Table 2 shows that all the soil particles were finer than ¾" and soil Sample 4 had up to 58% of particles finer than sieve #10 (0.0787 inch). Table 4 shows the result of the compression tests on the 24 compressed earth blocks. The average compression strength is 50.43 pounds per square inch. Table 5 gives the results of the moisture content test performed on the first three samples. Sample 2 had the lowest moisture content of 9.95% and sample 3 had the highest moisture content of 17.93%. Table 6 shows the results of the compaction test for sample 4 and it indicates that the optimum dry density is about 118 pounds per cubic feet and the optimum moisture content is about 14%. Table 7 gives the results of the modulus of rupture (MOR) test

and shows that the average value of the MOR for the blocks to be 43.54 pounds per square inch.

1.5.1 Discussion of Test Results

The field classification of the soils taken from depths of 10 inches to 24 inches shows that soils tested contained a range of soil particles from 15% - 90% clay, 10% - 45% sand, 70% silt, 5% gravel and 10% peat. The porosity and the plasticity ranged from medium to high. The sieve analysis shows that over 90% of the soil particles were finer than 3/8 inch sieve size. In the compaction test the optimum dry density is about 118 pounds per cubic feet and optimum moisture content was 14%. 24 blocks of three different sizes were made and cured in natural air duly covered with plastic sheeting to prevent rapid reduction of moisture content. Every block was labeled and measured, to calculate the volume. The tests performed on the soil samples showed the main soil constituents to be:

- Gravel 3%
- Sand 87%
- (Silt and Clay) 10%

The proportions of various kinds of material in the types of soils which are recommended for the manufacture of compressed earth blocks (Houben, Rigassi, & Garnier 1994) are:

- Gravels 0 – 40%
- Sands 25 – 80%
- Silts 10 – 25%
- Clays 8 – 30%.

Table 1 Quantities Of Soil Used In The Particle Grading Analysis

Soil	Sieve Analysis (gm)	Hydrometer Analysis (gm)	Fine Sieve Analysis (gm)
1	1269	100	79.9
2	1246.3	50	17.5
3	669.7	-	-

Table 2 Results Of The Sieve Analysis

Sieve Information		Soil1	Soil 2	Soil 3
Sieve No.	Sieve Size	(%) Finer	(%) Finer	(%) Finer
3"	3"	100	100	100
2"	2"	100	100	100
1-1/2"	1-1/2"	100	100	100

1"	1"	100	100	100
¾”	0.75"	100	100	100
½”	0.5	98.97	98.34	100
3/8”	0.375"	96.0	93.05	100
# 4	0.187”	76.25	63.35	97.15
# 10	0.0787”	47.85	16.36	94.98
Pan	-			
Total Wt.	-	1269	1246.3	669.7

Table 3 Results Of The Fine Sieve Analysis

Fine Sieve Information		Soil 1	Soil 2
Sieve No.	Sieve Size	(%) Finer	(%) Finer
# 10	0.0787”	99.875	100
# 40	0.0165”	62.825	81.14
# 100	0.0059”	4.625	8.57
# 200	0.0029”	0.125	0.57
Pan	-		
Total Wt.	-	79.9	17.5

Table 4 Compression Test for Compressed Earth Blocks

Type	Moisture Content (%)	Density (pcf)	Compressive Strength (psi)	Modulus of Rupture (psi)
Soil	10.54	129.46	178	33
Soil + 5% fiber	11.2	127.72	189	38
Soil + 5% cement	14.76	134.56	260	53

Table 5 Moisture Content Test

		Soil 1	Soil 2	Soil 3
1	Wt. Sample + Tare (Wet)	125	44.9	75.6
2	Wt. Sample + Tare (Dry)	101.8	39	70.6
3	Wt. Of Water	23.2	5.9	5
4	Tare Weight	21.9	21.5	21.9
5	Wt. Of Dry Sample	79.9	17.5	48.9
6	Moisture Content (%)	29.04	33.71	10.27

Table 6 Compaction Tests

Soil #1		
Samples	Moisture Content (%)	Dry Density (pcf)
A	9.36	114.3
B	9.94	120.4
C	10.05	130.79
D	10.3	126.93
E	10.63	116.41

Soil #2		
Samples	Moisture Content (%)	Dry Density (pcf)
A	13.33	96.92
B	13.83	106.48
C	14.44	112.54
D	14.7	102.37
E	15.15	98.89

1.5.2 Average Moisture Content and Densities of Earth Blocks

Table 7 Average Densities, Compressive Strengths and Modulus of Rupture

No. of Blocks	Maturity (days)	Average Density (pcf)	Average Compressive Strength (psi)	Average Modulus of Rupture (psi)
5	65	130.06	365.79	-
10	105	124.84	354.31	-
13	240	122.62	294.13	-
6	281	124.69	373.90	-
Average Density = 125 pcf Average Compressive Strength = 349 psi				
15	205	130.93	-	65.34
6	281	128.31	-	72.57
Average density 129 pcf Average Modulus of Rupture = 69 psi				

Comparing the results to these guidelines, it can be seen that the local soil is deficient in the clay and silt proportions. Although it is understood that these guidelines are rarely enough for soil selection purposes, knowing these proportions is an important indicator of the suitability of soils for compressed earth blocks manufacture (Houben, Rigassi, & Garnier 1994).

The compressed earth blocks made with such soil gave an average dry density of 125 pounds per cubic feet (pcf), and an average compressive strength of 349 psi. The average modulus of rupture of the blocks was 69 psi. These values are higher than the code requirements for this form of construction. Building codes like the Uniform Building Code, and the New Mexico Adobe Rammed Earth Building Code, require average block compressive strengths of 300 pounds per square inch and an average modulus of rupture of 50 pounds per square inch for compressed earth block one story buildings. These local soils meet such code requirements and therefore can be used for the stipulated type of housing.

One of the claims made by compressed earth equipment manufacturers is that the use of on-site soils (local soils on a given site) to make the compressed earth blocks eliminates material transport and reduces material handling and labor costs. This may not be possible in many instances as this project shows. If on-site soils are to be used under these circumstances extensive blending of different soil sizes some of which may be imported from other places and some form of chemical stabilization (addition of cement or lime) will have to be done. While these activities may be possible, they will introduce additional cost to the total cost of construction where introduced. Tests in this project confirmed that the addition of 5% of ordinary Portland cement and Kenaf fibers enhanced the properties of the blocks.

1.6 DURABILITY

One of the weaknesses of earth in building construction is its low resistance to moisture (water) destructive effect. A partial wall was built in the summer and left in a place where it was not completely protected from wind driven rain and snow. In the winter after the wall has been exposed to moderate rain and snow, it was observed that the blocks at the bottom were crushed due to the wetting and thawing of the blocks, see Figures 6. This sensitivity to water and lack of durability in its untreated form highlights the main reservation on the wide use of compressed earth as a building material. The wall surface must be protected by the application of rain resisting “plaster” to prevent this type of deterioration and wall protected from wind-driven rain by appropriate overhang of the roof over the walls. Cement-clay (1:1) plaster could be used to reduce cost. The cement-clay plaster made in this project had a high compressive strength of 35 psi.

1.7 GENERAL REQUIREMENTS FOR COMPRESSED EARTH BLOCK CONSTRUCTION

1.7.1 Soils

Soil needs soaking at lease 12 hours before making blocks. The soil should have clumps less than 10-12 mm. the coarse grain size should be 25 mm. the moisture content should be between 13.85% and 14.62% for good workability. The additives should be mixed and blended properly. The mixed material should be used within one hour to make blocks.

1.7.2 Mortar

Cement-soil based mortar should not be re-constituted once it has attained its initial set. Cement soil ratio shall be 1:6. Water is used to mix the materials for proper consistency. The minimum moisture content is always maintained for good workability and proper bedding of the compressed earth blocks.

1.7.3 Moisture Content Drop Test

A handful of the mortar mixed ready to be placed is squeezed in the palms of the hand, held shoulder high and dropped to a hard flat surface. Too wet mortar should never be used. The spread of mortar suitable for use is as shown in the Figure 7 below.

1.7.4 Compressed Earth Block Drop Test

Compressed earth blocks of 7 and 28 days are used for this test. The block shall be dropped so that it will hit a flat horizontal surface with a vertical diagonal as shown in the Figure. If the block does not break or corners are missing material less than 100 mm, the block is ready for use.

1.7.5 Compressed Earth Block Erosion Test

The erosion test for compressed earth blocks is done by allowing water to fall over a height of 400 mm on the block unit.

1.7.6 Making Compressed Earth Block Wall

Two wall samples using the compressed earth block were made. See Figure 8.

1.8 SUMMARY

It is recommended that to use clayey sandy soil with Ordinary Portland cement as admixture for long lasting compressed earth blocks masonry construction. The final recommendations are:

1.8.1 Block Making

For making compressed earth blocks use a soil with these constitutes: Ordinary Portland cement 5%, sand, 8% and clay, 87%.

1.8.2 Mortar Mix

For mortar use the materials in this proportion: Clay, 85% and ordinary Portland cement, 15%.

1.8.3 Plaster

For wall plastering purposes use materials in the following proportions: Clay 50% and ordinary Portland cement, 50%.

It is proposed that in order to simplify the initial evaluation of the types of soils available, series of tests as carried out in this project be performed on different types of soils with a view of seeking a correlation between different types of soils and the compression strengths of the compressed earth blocks made from them. This will help in the initial evaluation of the suitability of the soils for the type of houses to be built. The results of such tests may also be evaluated to see if there are other parameters that may assist in assessing the quality and strength of the compressed blocks made from available soils. The aim here is to come up with a simple method for determining the qualities of compressed earth blocks made from different soils. It is also proposed to add different percentages of agricultural fibers and other elements like Portland cement to the soils and to see what extent the strength of the blocks will be enhanced. To keep costs down, additives should be easily acquired at low cost.

1.9

CONCLUSION

This research project was based on evaluating local soils to determine their suitability for making compressed earth blocks for use in affordable residential buildings. The local soil constituent proportions were compared to recommended guideline proportions and found to be suitable for use in one story buildings. The compressed earth blocks made gave an average dry density of 125 pounds per cubic feet (pcf), an average compressive strength of 343 psi and a modulus of rupture (MOR) of 65 psi. These are comparable to recommended values of 300 psi for compressive strength and 50 psi for modulus of rupture. The project has demonstrated that compressed earth blocks made from local soils may be suitable for code-complaint structures. The properties of the compressed earth blocks may be improved by the addition of 5% of ordinary Portland cement and kenaf fibers. Mortars and plasters may be made from clays and cement. When compressed earth blocks are made as indicated in this project, with local/on-site soils, the cost of building houses can be reduced and made affordable.

1.10 ACKNOWLEDGEMENTS

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