EARTH BUILDING IN TANZANIA – USE OF SOIL STABILIZED BRICKS AND BLOCKS

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This paper presents experimental results of investigations done on the use of stabilized earth (soil) for the manufacture of bricks and blocks. The soil used was clayey sand of low plasticity. Two types of stabilizers were used to make stabilized bricks and these were cement and a combination of cement and lime. Different stabilizer proportions were employed. Results of tests carried on these bricks at 28 days indicate an optimum mix proportion of 7% cement if cement is used alone and an optimum mix proportion of 5% each if a combination of lime and cement is used as a stabilizer. With these stabilizer contents we obtain bricks of strengths of at least 2.5N/mm^2 with acceptable functional capabilities in a wall for low cost housing. To make bricks comparable in strength with those made of cement and sand with a minimum strength of at least 3.5N/mm^2 for load bearing walls as suggested in the Tanzania Standard, TZS 283:1986, the optimum mix proportion was found to be 8.5% cement and 7% each if cement and lime is used in combination. It is suggested that further research on the effectiveness of the various other stabilizers like bitumen, gypsum, ash/sand, and cow dung is required for the different types of soils commonly found in Tanzania.

Keywords: *Soil stabilization, lime, cement.*

INTRODUCTION

According to Pollock (1999) the use of earth (soil) as a building material dates back to Ubaid period in ancient Mesopotamia (5000-4000 B.C.). Easton (1996) has suggested that at least 50% of the world's population still live in earth houses.

Unfortunately all ancient earth buildings have succumbed to the ravages of time due to poor weather resistance. These buildings were not as weather resistant as the modern buildings constructed out of stone or burnt clay bricks.

Bricks, cement, steel, aluminium, plastic products, paints, polished stone, ceramic products etc. are the commonly used materials of construction today. These materials are energy intensive and are transported over large distances before being used for construction.

Table 1 shows an example of the volume and energy consumption of building materials in India and the energy required for transportation. Nearly all unfired earth building techniques have substantially less energy requirements for production than conventional fired clay bricks. Rammed earth has been calculated as using 1/700th of the energy in the ramming process compared to the energy used in firing bricks of equal weight (Dobson, 2004). The following points should be considered regarding the use of modern materials: energy consumed in the manufacturing process; problems of long distance transportation; natural resources and materials consumed; recycling and safe disposal; impact on environment and long term sustainability. Extensive use of the so called 'modern materials can drain the energy resources and adversely affect the environment (Reddy, 2004).

If we are to meet the increasing demand for buildings there is a need for optimum utilization of available energy resources and raw materials to produce simple energy efficient, environmentally friendly and sustainable building alternatives and techniques and also adopt energy efficient traditional materials like soil, timber etc.

Recently there has been a trend away from the traditional manufactured 'modern' materials to more energy efficient materials like earth. The inherent naturalness of the material, its low embodied energy and its thermal effectiveness have all contributed to resurgence of buildings over the last 25 years (Hearthcot, 2000)

Table 1. Volume and energy consumption of building materials in India (2003) (Reddy, 2004)

Material	Volume of materials manufactured per annum (2000)	Thermal energy (MJ per kg)	Total Energy (GJ)
Bricks	150×10^9 Nos	1.40	630×10^6
Cement	96×10^6 tonnes	4.20	403×10^6
Aluminium	0.80×10^6 tonnes	236.8	189×10^6
Structural steel	11×10^6 tonnes	42.0	462×10^6

Table 2. Energy in transportation of building materials (Reddy, 2004))

Building Material	Unit	Energy in transportation for 100 km (MJ)
Bricks	m^3	200
Sand	m^3	175
Cement	tonne	100
Steel	tonne	100

There are basically three types of earth building techniques:

- Mud brick or Adobe. Adobe bricks are typically 250 mm x 350 mm x 100 mm and are made by pouring a puddle mixture of clay and sand into forms. Once laid the blocks are left to dry in the sun.
- Rammed earth or Pise. Although the technique is centuries old principally the French in the latter part of the 19th century developed this technique. In this method a dry mixture of sandy soil is rammed into wall forms. The thickness of rammed earth is typically around 600mm but recently walls from earth stabilized with cement are being built with thicknesses of around 300mm.
- Pressed earth bricks. This is a development of adobe that surfaced in the second half of last century. In this method a dries soil is placed in a steel mould and compacted under high pressure. Typically densities of around 20,000kg/m3 are achieved compared to densities of around 17,000 kg/m^3 for traditional adobe bricks.

The traditional adobe structure is coated with protective weather proof coating such as stucco and therefore protected from erosion. There is evidence of buildings in France and Italy which have survived with this form of protection after centuries of exposure to driving rain.

To overcome the inherent weakness of earth when exposed to driving rain builders have resorted to the provision of generous eaves or to use stabilizers such as cement, lime, pozzolana and bitumen.

OBJECTIVES OF RESEARCH

The objective of the research was to investigate whether the soil in Changanyikeni village, a village close to the University of Dar es Salaam was suitable for the production of soil stabilized bricks and if so, which was the most appropriate mineral binder to use and in what mix proportions. The findings could help the villagers build better houses at lower costs. Also this initial investigation could be the basis for further research to the suitability for stabilization of the different types of soils found in Tanzania

STABILIZED EARTH (SOIL) BRICKS AND BLOCKS

These are dense solid bricks/blocks compacted using a machine with a mixture of soil, sand, stabilizer and water. After 28 days curing, the stabilized bricks/blocks are used for wall construction. The compressive strength of the brick/block greatly depends upon the soil composition, density of the bricks/blocks and the percentage of stabilizer. Sandy soils with 7% cement have been known to yield wet compressive strengths of 3-4 MPa. (4). In Australia common stabilizers are: for rammed earth 6% cement, for adobes 3% bitumen, for prestressed earth bricks 8% cement and for poured earth 12% cement. Higher strengths can be obtained by increasing the quantity of stabilizer (Dobson, 2004).

Figure 1. Production of Stabilized earth bricks

The advantages of stabilized earth bricks are:

- Energy efficient, do not require burning, 70% energy saving when compared to burnt bricks
- Economical, 20-40% savings in cost when compared to brick masonry
- Plastering can be eliminated and
- Better finish and aesthetically pleasing appearance.

Fig.1 shows the production of stabilized earth bricks using a manual press and Fig. 2 shows a stabilized earth block residential building, (Reddy, 2004).

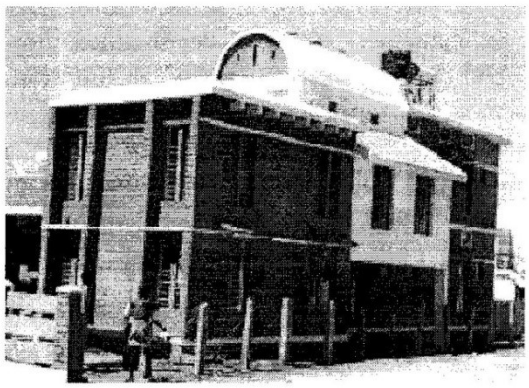

Figure 2. Soil cement block building

REVIEW OF EARTH BUILDING IN TANZANIA

Most people in rural areas in Tanzania and indeed in rural Africa live in mud huts with walls reinforced with timber or grass fibres and normally with thatched roofs. In some other few areas people use adobe bricks in wall construction but these buildings are not weather resistant. A few years ago people have been advised to use burnt clay bricks for more durable constructions but the problem has been that of deforestation and environmental degradation. For example in some places in Tanzania you can hardly find firewood even for domestic use.

A considerable work has been done in Tanzania by the National Building Research Agency (NBRA) on stabilized soil bricks using cement and/or lime as a stabilizer. They have suggested that soils which work best with lime are gravelly clay, sandy clay, silty clay, clayey gravel and clayey sand. It is suggested that when the soil to

be stabilized has too much clay (as determined from field tests), the combination of lime and cement can be used (BRU, 1974). The NBRA recommends that if lime will not react enough with the soil to waterproof it, cement can be added in equal parts with the lime and the contents should range between 4% - 8%. A similar range has been suggested by Marthur G.C. (1987). NBRA's findings have, however, hardly been implemented because this knowledge has not been disseminated in rural areas.

Cement is now easily available in Tanzania but it is very expensive for the low income earners. Lime on the other hand can be obtained more easily and cheaply from the abundant limestone deposits in Tanzania by burning the limestone followed by slaking. Lime is a material exceptionally well suited for small scale production because

- The technology involved is very simple; no special machines or materials are required
- Widespread and easily available raw materials namely calcium carbonate ($CaCO_3$) and burning materials(any solid fuel will do e.g. rice husks and coal)
- Quality of product is insensitive to small changes in production conditions, such as composition of raw materials, burning temperatures and duration of burning and therefore not much skills are required in the production, and
- Easy handling of manufactured product.
- Since lime is not a traditional material in Tanzania, introduction of the technology alone is not sufficient. In order to boost up both production and consumption education of people at village level and promotion of use of lime is needed.

REVIEW OF EXISTING SPECIFICATIONS AND TEST METHODS FOR ASSESSING DURABILITY OF EARTH WALLS

The main challenge of using earth (soil) as a construction material whether stabilized or not is that of durability

Heathcote and Moor (2000) have extensively reviewed the existing specifications and test methods for assessing durability of earth walls. In New Mexico and the U.S.A where protective coating is used the question of durability relates more to the permeability of the wall and the effect moisture has on the strength of the wall. In New Mexico the State Code requires a minimum compressive strength of earth bricks to be 2kPa.

Craterre (1989) also has similar strength requirement for dry bricks but additionally requires that the ratio of wet to dry strength be not less than 0.5

In Israel, Cytryin (1957) recognized that a test that simulated the action of rain was needed to test for resistance to the forces of drying rain.

A spray test developed by Wolfskill (1970) was adapted by Jagadish and Reddy (1987) to test pressed soil blocks in India.

In 1960 Fitzmaurice carried out comprehensive study on the condition of existing wall buildings and concluded that only stabilized walls should be considered as permanent. In his detailed study of the properties of stabilized earth he used ASTM Standard D559-44 for testing stabilized earth.

In South Africa Webb et al (1950) carried out tests on stabilized pressed earth bricks and fired bricks using a modification of ASTM D559 and concluded that earth bricks made from suitable soils were equivalent to medium quality fired bricks.

In Australia a 'spray test' (Bulletin 5, 1987) has been developed which involves water being sprayed horizontally out of a special nozzle at a pressure of 50 kPa. The depth of erosion is compared to an allowable maximum.

Modifications made by Heathcote which are included in the N.Z. (New Zealand) Standard

NZS 4297: 1988 involves making the limiting erosion depth dependent on local environmental factors such as wind speed, annual rainfall and orientation of the wall with respect to the prevailing wind driven direction.

EXPERIMENTAL INVESTIGATIONS

The soil used for the investigations was obtained from Changanyikeni village close to the University of Dar es Salaam. Both field and laboratory tests were done. The field tests were the ribbon and the field settling tests. Sieve analysis and sedimentation tests were done in the

Table 3 Stabilizer Contents

Type of Stabilizer	Stabilizer content(%) by weight of dry soil		
Cement	7	8.5	10
Cement and lime	2	5	7

Structures and Building Materials Laboratory University of Dar es Salaam to determine the particle size distribution. The tests were done according to BS 1377(1975). Also determined were the plasticity properties of the soil i.e. the Atterberg limits. See Table 4.

The soil was sampled at a depth of 1.5 m from the surface to avoid any vegetable matter.

Soil stabilized bricks (size: 30 cm x 14 cm x 9cm)

were produced by a cinva ram press machine.

Two sets of stabilized soil bricks with varying stabilizer contents were produced. The first set was for bricks produced by using ordinary Portland cement alone as a stabilizer and the second set was for bricks produced by using ordinary Portland cement with lime (in equal proportions) as a stabilizer. The stabilizer contents were varied as shown on Table 3 following recommended ranges of stabilizer contents found in the literature survey.

Mixing was done by a pan mixer until the mixture had a uniform colour. The amount of water used for the mix was determined from the ball test. For each mix proportion bricks were cast for testing at 7 days and at 28 days. The ricks were kept moist for 7 days and later stacked as close as possible in a shade for curing.

The following tests were performed on the bricks in the laboratory at 28 days to ensure their functional capabilities in a wall and that quality was not compromised and any modification as to the production mixes or soil preparation made. The tests were:

- Visual inspection – blocks free of broken edges, honeycombing and other defects
- Shrinkage cracks – not more than 0.5 mm wide and not exceeding 50% the length of the dimension to which they are parallel
- Dry compressive strength – not less than 2.5 N/mm^2
- Wet compressive strength – not less than 1.5 N/mm^2
- Modulus of rapture – not less than 0.5 N/mm^2
- Water absorption – not more than 15% of original mass
- Density of blocks – not less than 1600 kg/m^3

Compressive strength tests were done according to BS 6070: Part 1:1981 and an average dry strength for 10 bricks obtained for each stabilizer content.

TEST RESULTS

The average properties of the soil used is shown on Table 4 and the particle size distribution on Fig 3. The soil was classified as clayey sand of low plasticity.

Table 4 Average properties of the soil used

British Standards Soil Classification	Average soil properties (%)
Fine gravel	0
Sand	72
Silt + clay	28
Liquid limit, w_l	25.2
Plasticity Index, w_p	8.5
Plasticity Index, I_p	17

The variation in compressive strength of the Soil Cement Bricks with stabilizer content is shown on Tables 5 and 6

Table 5. Average Compressive Strengths with Cement as a Stabilizer

Cement Content (%)	7	8.5	10
Average 7 days strength (N/mm^2)	1.09	1.62	2.02
Average 28days strength (N/mm^2)	2.93	3.88	6.07

The development in strength with age for the different stabilizers is shown on Figures 6 and 7.

Table 6. Average Compressive Strengths with Cement and Lime as a Stabilizer

Cement and Lime Content (%) each	2	5	7
Average 7 days strength (N/mm^2)	0.83	1.25	1.88
Average 28days strength (N/mm^2)	0.83	2.46	3.62

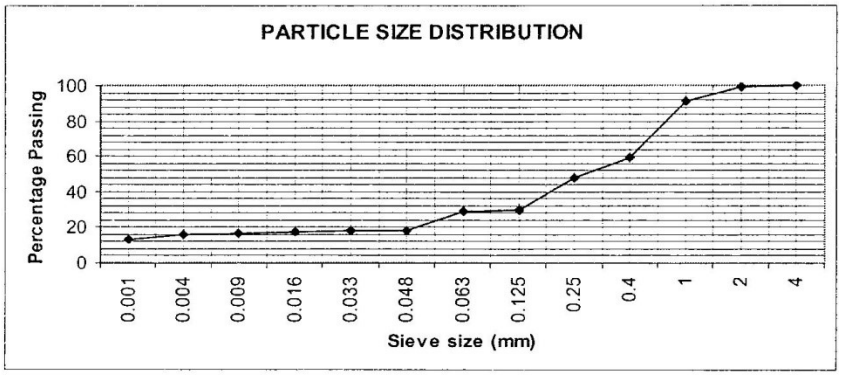

Figure 3: Particle Size Distribution

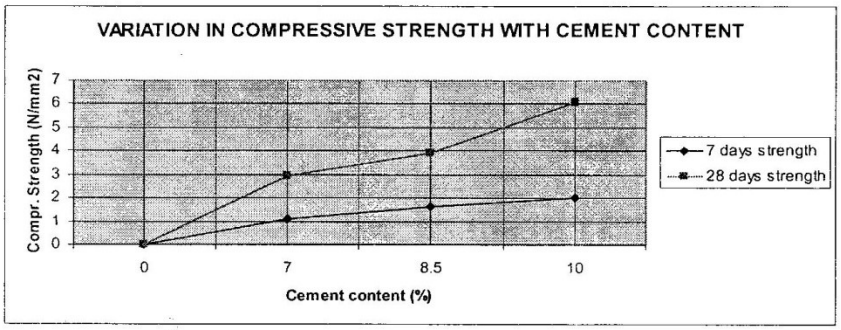

Figure 4: Variation in strength with cement content

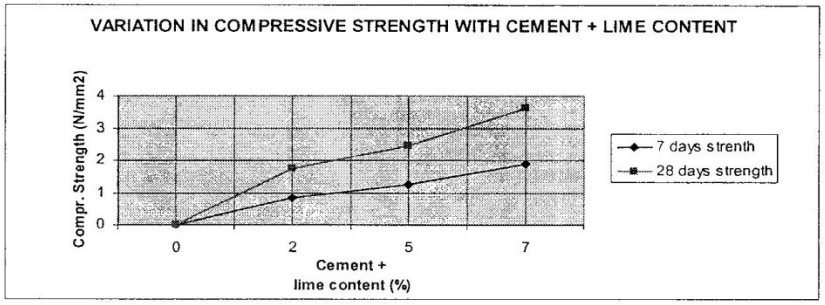

Figure 5: Variation in strength with cement plus lime content

DISCUSSION OF RESULTS

The results show that there is an increase in strength with an increase in stabilizer content and age as expected.

Considering the functional and quality requirements of the bricks it was found that with 7% cement content as a stabilizer the strength achieved at 28 days was 2.93 N/mm^2 well above the minimum of 2.5/mm^2 recommended for low cost housing (Low Cost Housing Technologies in Kenya, 1996). This result agrees fairly well with results obtained by Reddy (4) who noted that for sandy soils with 7% cement content we get blocks with compressive strengths of 3 – 4 MPa. Using a combination of lime and cement (5% each) as a stabilizer the minimum strength was also met (2.46N/mm^2 ~ 2.5N/mm^2). See Tables 5 and 6.

The Tanzania standard TZS 283: 1986 specifies for load bearing concrete bricks a minimum strength of 3.5 N/mm^2. From these investigations this strength requirement is met if we use 8.5% cement as a stabilizer or using 7% cement and lime (each) as a stabilizer. The strengths obtained were 3.88 N/mm^2 and 3.62 N/mm^2

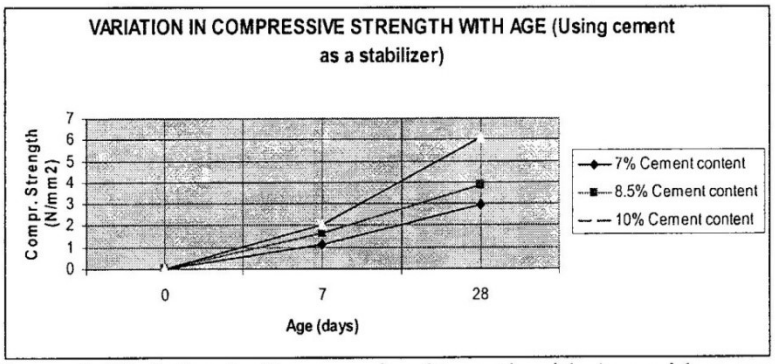

Figure 6: Variation in Compressive Strength with Age with cement as a binder

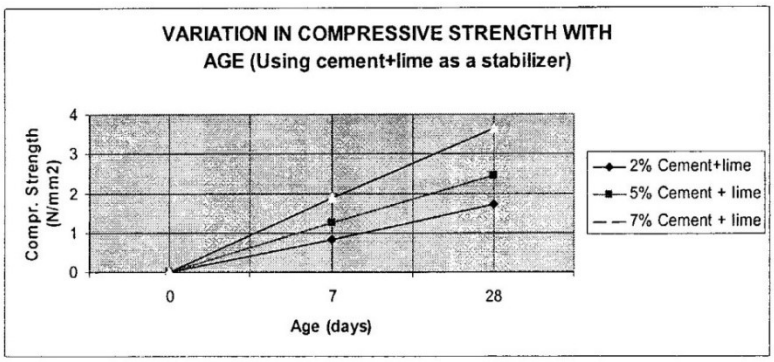

Figure 7: Variation in Compressive Strength with Age with cement and lime as a binder

respectively. Such earth bricks can therefore be used for load bearing walls for housing.

Since the hardening process of lime is by carbonation which is a slow process the strengths observed were mainly contributed by the cement component and we expect to achieve even higher later final strengths in case we use cement with lime as a stabilizer.

CONCLUSION AND RECOMMENDATIONS

From these investigations we can conclude the following:

a) The soil investigated can be used to make bricks and blocks for structural purposes by using 8.5% cement or 7% lime and cement each as a stabilizer.

b) For low income houses the binder content can be reduced to 7% cement and 5% lime and cement each as a stabilizer.

Further investigations are required on the effectiveness of different types of stabilizers and the mixing proportions which are appropriate for the different types of soils commonly found in the country. Appropriate stabilizers to investigate apart from cement and lime include bitumen, gypsum, ash/sand, murram soil, cow dung and fibrous type. The common soils to investigate are sandy loam, red coffee, murram, black cotton and clay soil.

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