

# Improving the traditional earth construction: a case study of Botswana

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The traditional societies developed earth as one of the most important construction materials by taking cognizance of the strength requirements, durability of resulting structures and the environmental concern in processing and using the material. Over the years, however, modern earth construction has replaced the traditional methods. Unfortunately, these methods are also accompanied by high energy consumption and environmental degradation. This paper examines the methods of improving earth construction in two major villages in Botswana. Tests with different stabilizers showed that only certain proportions were effective and it was concluded that the traditional earth construction may be improved by using certain ratios of

cement and lime as stabilizers.

**Keywords:** earth; stabilization; durability

## Introduction

After several centuries of trial and error, the traditional societies managed to develop earth as one of the most important building materials. Successful solutions in earth construction did not result from deliberate scientific reasoning, but grew out of countless experiments and accidents and the experience of builders who continued to use what worked and rejected what did not<sup>1</sup>. Given the variety of soil types, climatic conditions, cultural backgrounds and economic factors, several ways in which earth was used as a construction material evolved, amongst which were rammed earth, bricks moulded in raw earth and baked in sun, compressed bricks, etc.<sup>2</sup> Since the traditional societies could not expend large quantities of oil or coal to process earth, most people found that natural energy sources, e.g. the sun, wind, etc. could be relied upon<sup>3</sup>. This required a precise and detailed knowledge of local climatic conditions on the one hand, and on the other, a reasonable understanding of the performance characteristics of earth as a building material<sup>4</sup>.

Over the years, the use of earth as a building material has changed. This was necessitated partly by the needs for continuous maintenance and frequent repair or re-erection of the rammed earth structures and earth-brick buildings due to their low durability, and partly by the advent of new technologies which made processing of earth products possible. Unfortunately, the adoption of modern earth construction and contemporary building materials has resulted in the abandonment of development in the traditional earth construction. Modern earth construction materials entail the use of energy-intensive processes which result in large quantities of carbon dioxide and other emissions<sup>5</sup>. While it is important to acknowledge the

contribution of the modern clay-brick production and other modern earth construction materials in improving the overall properties of earth structures, it is equally important to consider the environmental effects caused by these methods.

Traditional earth construction uses low-energy materials that can be upgraded to improve their properties, e.g. strength, durability, etc. with little additional costs in terms of energy, and earth can also be reinforced with low-cost natural fibres such as sisal and bamboo<sup>6</sup>. Because of the familiarity with and low cost of earth as a building material, upgrading it for wide use would appear to be a strategy more likely to succeed than replacing it with new and unfamiliar materials, or by processing it using methods which are expensive and unsustainable. There is some evidence that building materials often constitute 70% of actual construction costs<sup>7,8</sup>. For any shelter programme to be successful, the cost of the materials should be as low as possible and also the materials should be as durable as possible. The energy content of earth, as a low-energy material, mainly consists of the energy spent in some primary crushing and transport. Hence, as earth can be produced locally, these costs can be almost negligible.

Against this background, the aim of this study was to assess the traditional use of earth as a construction material in Botswana and determine which methods can be adopted from the modern construction technologies to address these problems. Two villages which traditionally practice earth construction were selected and the problems faced by the earth structures were analysed to determine their main causes. It was found that although earth construction in these villages is characterised by both low strength and low durability, the latter is more critical.

## Requirements of earth as a construction material

According to Hammond<sup>9</sup>, the main causes of deterioration of earth buildings are shrinkage, cracking, erosion, under-scoring and mechanical damage, due directly or indirectly to water. However, by using suitable architectural designs, structural techniques, stabilization measures and care in siting, earth buildings can be successfully built in almost all types of climatic regions; and with proper care and maintenance, they should last for decades<sup>10</sup>.

Soil stabilization measures deal directly with the behaviour of earth by addressing some of its weaknesses. For all types of earth construction, the important properties to be considered for improvement are the compressive strength, water absorption and weather resistance<sup>11</sup>. The compressive strength of earth, as a building material, enables an earth wall to sustain its load without failure or local crushing at points of high stress. Compressive strength is normally an indication of durability also, which, in this report, is defined after Sneek<sup>12</sup> as the resistance of a material to deterioration caused by exposure to the environment. The compressive strength of soil blocks and bricks is determined according to BS 3921: 1985<sup>13</sup>. The specimens are tested on a universal testing machine where the pressure is gradually increased until crushing occurs. The highest stress reached is recorded and averaged over a sample of five blocks/bricks<sup>14,15</sup>.

Water absorption of an earth construction material such as a brick is a measure of its porosity. Some porosity is desirable, but highly porous bricks may absorb and transmit too much water and thus may swell and shrink or may lack durability. The water absorption of an individual brick is most accurately measured by oven-drying the brick at 105°C for 24 h and then weighing it. It is then immersed in water for a further 24 h and re-weighed. The water absorption is the difference in weight expressed as a percentage of the dry weight, averaged over a sample of five blocks<sup>14,16</sup>.

Weathering resistance of an earth construction element is its ability to resist the erosion of material by rain, wind or other environmental agents. The weathering resistance of a pressed soil brick may be measured by water-spray test in which the brick is subjected to a specified water spray under pressure for a period of 2 h. The brick is then inspected for signs of deterioration<sup>15</sup>. It can also be measured by abrasion test whereby the brick is subjected to 12 cycles of wetting and drying for specified periods, followed by wire brushing to remove loose material. The weight loss is then determined and according to CRATERRE<sup>17</sup>, it should not exceed 10% by weight based on the initial oven-dry weight.

These requirements of earth as a construction material are supposed to be compared with established standards to determine their suitability for construction. Few countries have formulated specific standards for earth construction. Even those which have done so, there appears to be differences in the minimum criteria set for various standards; for example, IS: 1077-1986<sup>18</sup> specifies a minimum of 3.5 N/mm<sup>2</sup> for common bricks while BS 3921: 1985<sup>13</sup> specifies a minimum of 5 N/mm<sup>2</sup> for similar type of bricks.

## Soil improvement methods

Traditionally, the three main types of earth construction are mud brick, rammed earth and pressed earth blocks<sup>2</sup>. However, they are all characterised by low compressive strength and durability. They are also vulnerable to water absorption and other environmental agents. Several methods have been developed with the aim of alleviating these disadvantages. Among them are those given below.

### *Fired bricks*

Fired bricks require production temperature in the 700–1000°C range for strength and durability. As a result, large amounts of fuel are needed which depend on the kiln type, i.e. updraught or continuous kiln, on the type of fuel being used and the type of bricks produced. Production of fired bricks is accompanied by emissions of carbon dioxide to the atmosphere.

### *Soil stabilization*

Soil stabilization implies the modification of the properties of a soil-water-air system in order to obtain lasting properties which are compatible with a particular application. Stabilization is necessary when the material is exposed to moisture. If it is established that stabilization is absolutely essential and economic resources are available, the type and amount of stabilization have to be determined by experiment.

### *Stabilization using fibres*

Plant and vegetable fibres have been used extensively in traditional earth construction. These fibres act as a reinforcing material, in the same manner as fibres in fibre-reinforced concrete, and hinders cracking upon drying by distributing the tension arising from the shrinkage of clay throughout the bulk of the material<sup>19</sup>. With respect to dry compressive strength, the addition of fibres such as straw permits an increase in strength by at least 15% in relation to material without fibres. The fibres contained in the soil will be preserved without deterioration on the condition that the material is kept dry.

### *Stabilization using cow-dung*

Many traditional societies employed cow-dung and other animal excreta as stabilizing agents in earth construction. When cow-dung is introduced into a soil-mass in wet or flocculant form, an inert matrix is created in which the cohesion between the soil particles is increased. The cow-dung, in effect, surrounds the soil particles and glues them together on drying and maintains their stability as long as it is not subjected to excessive moisture. The presence of fibres in the cow-dung also reduces crack formation in the product. The current literature does not indicate the influence of cow-dung on the strength of the soil products, and so it was investigated in this study.

### *Stabilization using cement*

Hydrated cement reacts in two different ways in soil; first, it may react with itself or with the sandy skeleton to form

mortar, and second, it may undergo a three-phase reaction with the clay to form cement gel and clay aggregates which ultimately become intimately entwined. The required quantities of cement depend on the grain-size distribution and the structure of the soil, and the way it is used. Good results are obtained with cement content in the 3–12% range. Immediately above 3%, the cement gel starts to fill the voids in the soil<sup>20</sup>. While the product formed with cement, 3–6% in content, shows improved water resistance, the increase in strength is not appreciable<sup>21</sup>. Cement contents above 6% show both increased water resistance and increased strength<sup>22</sup>. Studies by Spence and Cook<sup>23</sup> showed that the cement ratio is also affected by the density of the soil; the denser the soil the lower the cement ratio which can give the same effect.

#### *Stabilization using lime*

Lime stabilization is the method commonly applied for soils which contain a significant clay fraction. Results of lime stabilization vary depending on the nature of clay minerals and are best with high contents of aluminosilicates, silicas and ferrous hydroxides<sup>24</sup>. The mixing must be very carefully carried out in order to ensure intimate mingling of the soil and lime. For very plastic soils, mixing should be done in two stages, with a break of one or two days in between, to allow the lime to loosen the lumps.

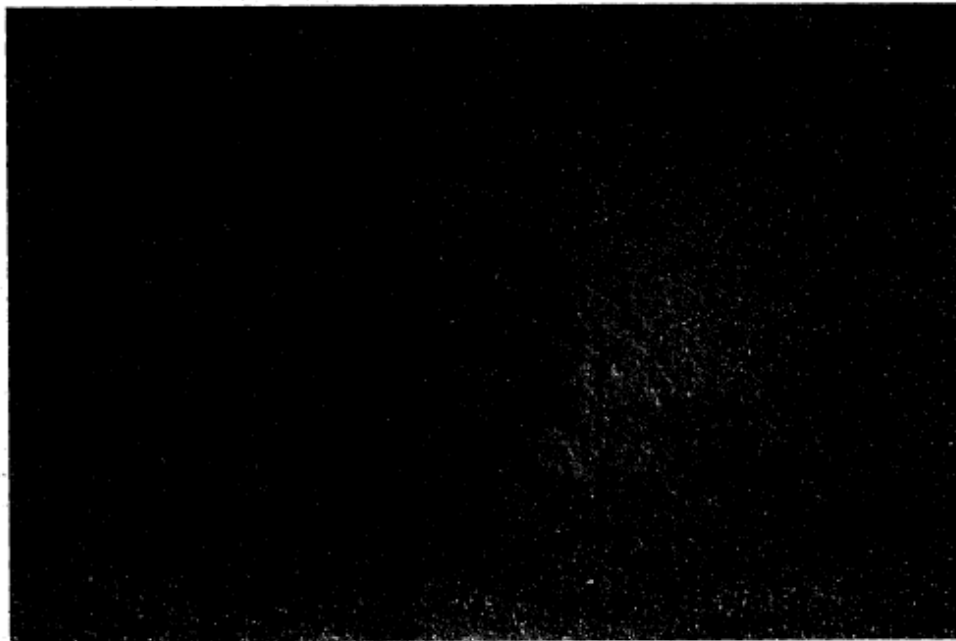
#### *Stabilizing using bitumen*

Bitumen, in this report, refers to a product consisting of at least 40% of heavy hydrocarbons and filler. To be used for stabilization, the bitumen must either be mixed with solvents resulting in 'cut-back,' or dispersed in water as

emulsion. As a general rule, soils which contain more than 50% sand require 4–6% emulsified bitumen by weight for effective stabilization, while soils which contain less than 50% sand require 7–12%<sup>23</sup>. The effectiveness of the bitumen stabilization depends very largely on mixing. Too much mixing can increase water absorption after drying because of the premature break-down of the emulsion.

### **The study on earth construction in Botswana**

The study on earth construction in Botswana resulted from a study on housing in the major villages of Botswana which was undertaken to examine the housing situation in these villages. The study found that the main mechanism of house delivery in these villages is by indigenous construction techniques which are based on earth as the main building material. It was then concluded that, for any proposed improvement to succeed, it has to be based on earth as the building material so that the construction skills, which the people inherited from the foregone generations, could be continued instead of replacing them with alien ones. Two major villages in Botswana, namely, Mahalapye and Tsabong were selected for a preliminary study. In Mahalapye, the walls of the houses are constructed using sun-dried soil bricks and rendered with soil/cow-dung mixture (*Figure 1*), while in Tsabong, the walls are constructed using vertical poles and the spaces between them are filled with soil/cow-dung mixture which is also used for plastering (*Figure 2*). The use of sun-dried soil brick for wall construction has started to make inroads in Tsabong recently.



**Figure 1** Wall showing a house constructed using sun-dried soil bricks and rendered with soil/cow-dung mixture (Mahalapye)

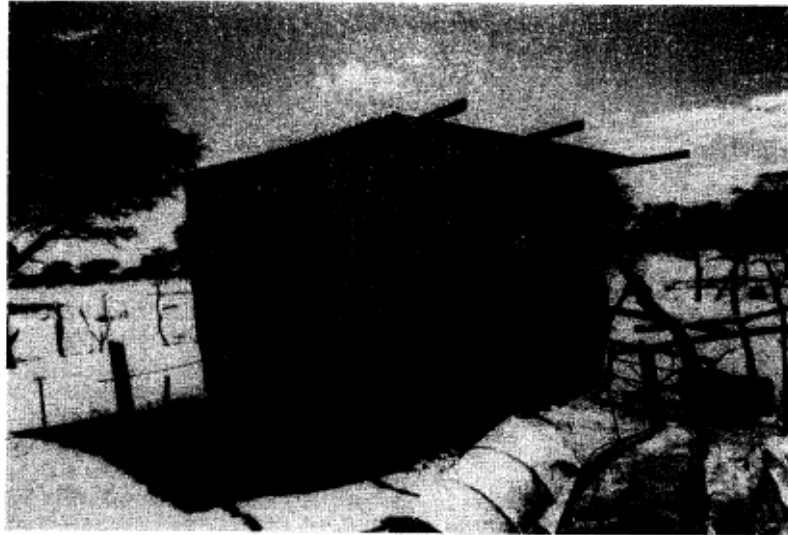


Figure 2 House constructed using vertical poles with the spaces between filled with soil/cow-dung mixture (Tsabong)

On inspecting the existing structures both in Mahalapye and Tsabong, the following were found to be the common problems:

1. Cracking of the walls and renderings.
2. Water absorption by the wall material when it rains, leading to increased weight and lowering of strength.
3. Erosion of the walls when subjected to driving rain.
4. Separation of the rendering in the form of large panels which eventually fall down.
5. Foul smell from the cow-dung when it is wet.

In general terms, the main problem is not about the strength of the walls. It is concerned with the low durability of the walls due to the effects of water, and this has resulted in high maintenance demands.

In order to determine an effective method for improving the wall material, soil samples from the two villages were collected and experimented with the soil improvement methods outlined earlier. The procedures adopted in collecting and testing the samples are outlined below.

#### Soil sample collection

It is common in the rural areas of Botswana for people to extract soil for construction purposes from the construction site or from the surrounding plots. However, in most cases, there are common pits from which this soil is extracted because it has proved suitable for construction. From each of the two villages, samples were collected from five such common sources.

The indigenous construction methods in both villages employ cow-dung to treat the soil. For this reason, the soil samples from these villages were treated with cow-dung and other available binding agents — lime, Portland cement and bitumen — to determine their effect on the behaviour of the soil.

#### Testing procedures

Laboratory tests included physical analysis of soil samples from the two villages and stabilization, curing and failure testing of bricks produced using soil from the two villages.

#### Physical analysis of the soil samples

Physical analyses performed on the soil samples were particle-size distribution to BS 1201: 1973, sedimentation and Atterberg limit tests. The result for the samples from each village differed slightly, but the average results are shown in Table 1.

#### Stabilized soil blocks

For the production of the bricks, the following types and contents of stabilizers were adopted:

- Pressed soil bricks with no stabilizer (unstabilized).
- Soil bricks, pressed and stabilized with lime in contents of 5, 7.5, 10 and 15%.
- Soil bricks, pressed and stabilized with Portland cement in contents of 5, 7.5, 10 and 15%.
- Soil bricks, pressed and stabilized with cow-dung in contents of 10 and 20%.
- Soil bricks, pressed and stabilized with bitumen in contents of 10 and 20%.

Table 1 Atterberg-limits and sedimentation results on soil samples from Mahalapye and Tsabong

	Mahalapye soil	Tsabong soil
Sand content (%)	27	63
Clay content (%)	48	14.5
Silt content (%)	25	22.5
Liquid limit (LL)	31	50
Plastic limit (PL)	19	24
Plasticity index (PI)	12	26

Hydrated lime and cement, in ratios by weight of dry soil, were added to the soil, mixed by hand in the dry state and then enough water was added to ensure adequate workability. Bituminous emulsion and cow-dung were mixed with the soil in wet state until a uniform mix was observed through the colour. The upper limits of cement, lime and emulsions described earlier in the review were selected from observations of previous researches<sup>22,25</sup>.

Moulding of the bricks was done by CINVA ram<sup>26</sup> which had undergone some modifications to suit the conditions of Botswana for production of bricks of the size 260 mm × 120 mm × 90 mm. The compaction speed depended on the strength of the workers, but the pressure was 2 N/mm<sup>2</sup>. As a control, unstabilized bricks were moulded to the same compacting pressure. The lime and the cement-stabilized bricks were stored under polythene sheets away from direct sunlight and cured by sprinkling with water daily for the first seven days and intermittently afterwards. The bitumen and the cow-dung-stabilized bricks were stored in the open and were not sprinkled with water.

#### Failure tests of the bricks

The tests carried on the specimens were basically directed to measure the parameters associated with durability, i.e. water absorption, loss of soil, and disintegration. However, compressive strength was also measured because it also indicates the durability of the material. The tests were carried out using the same testing equipment under similar environmental conditions.

#### Water absorption, soil erosion and disintegration

As water absorption is the main parameter for durability of an earth wall, the test was conducted to compare the unstabilized and the stabilized earth bricks in terms of water absorption, erosion from the brick surface by wetting and brushing after drying and disintegration. The tests were conducted according to ASTM D 559: Standard test method<sup>16</sup>. However, the tests were carried out in three cycles and only the averages of the results were recorded, to compare the produced bricks rather than to determine the soil loss, because the method is not very accurate in measuring the soil loss. Accordingly, the weight of the air-dried specimen ( $A_0$ ) was measured; then immersed into water for 24 h. The specimen was removed from the water, its surfaces were wiped dry and its weight ( $A_1$ ) was measured immediately. Then, the volume of the specimen was determined by re-weighing it in water to obtain  $A_2$ . From these measurements, the density of the brick was calculated as  $A_0/A_2$  while its water absorption was calculated as  $A_0/A_1 \times 100\%$ .

The specimens were then dried under the sun for three days, then all sides were brushed using a wire brush. The test results are presented in *Tables 2 and 3*.

The unstabilized bricks produced using the soils of Mahalapye and Tsabong disintegrated a short time after immersing them into water. The cow-dung-stabilized bricks took a longer time to disintegrate in water. However, this occurred in the 12–24 h range after the commencement of the test. Also, these samples disintegrated into larger

**Table 2** Average density, soil erosion and water absorption of the cement and the lime-stabilized soil bricks produced from Mahalapye

Material	Ratio of stabilization (%)	Density (g/mm <sup>3</sup> )	Soil erosion (g)	Water absorption (%)
Cement	5.0	1.79	54.0	10.00
	7.5	1.81	19.0	7.11
	10.0	1.88	14.5	7.04
	15.0	2.00	5.7	6.85
Lime	5.0	1.87	78.9	8.52
	7.5	2.00	75.9	8.54
	10.0	2.02	57.0	8.56
	15.0	2.06	23.5	8.90

**Table 3** Average density, soil erosion and water absorption of the cement and the lime-stabilized soil bricks produced from Tsabong soil

Material	Ratio of stabilization (%)	Density (g/mm <sup>3</sup> )	Soil erosion (g)	Water absorption (%)
Cement	5.0	1.81	109.3	8.57
	7.5	1.89	49.4	7.20
	10.0	1.89	33.3	7.03
	15.0	2.03	19.0	6.65
Lime	5.0	1.81	190.0	10.99
	7.5	1.92	171.0	11.02
	10.0	1.95	161.5	11.26
	15.0	1.98	123.5	12.88

fragments than the unstabilized bricks. The bitumen-stabilized bricks did not disintegrate, but developed large cracks which rendered them unsuitable for use. All these bricks disintegrated into large fragments when dropped from a height of 300 mm. The unstabilized, the cow-dung and the bitumen-stabilized bricks were considered unacceptable in terms of water erosion.

The cement and the lime-stabilized bricks did not disintegrate. The cement-stabilized bricks with cement content of 5% absorbed more water than those with 15% cement content. Therefore, the increase in the cement decreased the water absorption of the bricks, with a maximum of 7% absorption for bricks with cement content of 7.5% produced from the soils of the two villages (*Tables 2 and 3*).

Water absorption of lime-stabilized bricks increased with increase in lime content. The results showed that the increase in lime content not only increased the strength, but also the water absorption of the bricks which in all cases was more than 7%. This is contrary to what was observed for cement stabilization. Therefore, the lime-stabilized bricks produced with the soils from both villages should not be considered as an effective material for walls subjected to extensive exposure to water.

Erosion of the bricks produced with soils from both villages and cement and lime stabilization decreased considerably when the amount of stabilization material increased in the mixes (*Tables 2 and 3*). The results also showed that the bricks produced from Tsabong soil lost four times more soil than the bricks produced from the Mahalapye soil. As it was established from the physical test of the soils, the Tsabong soil has a high sand content while

**Table 4** Mean compressive strengths of the pressed and the pressed and stabilized soil bricks from Mahalapye and Tsabong soils.

Type of brick and stabilizer ratio (%)	Compressive strength of soil bricks (N/mm <sup>2</sup> )				
	Unstabilized	Cement	Lime	Cow-dung	Bitumen
Mahalapye soil					
0.0	1.84				
5.0		4.55	2.65		
7.5		5.90	3.14		
1.0		6.80	3.85	1.80	1.79
15.0		8.50	5.00		
20.0				1.30	1.25
Tsabong soil					
0.0	1.80				
5.0		4.98	2.16		
7.5		6.02	3.10		
10.0		8.12	3.23	1.75	1.48
15.0		10.64	3.73		
20.0				1.43	1.39

the Mahalapye soil has a high clay content. Also, the lime-stabilized bricks from both the Tsabong and Mahalapye soils lost about six times more soil than the cement-stabilized ones.

#### Compressive strength

Besides indicating its ability to carry load, the compressive strength of an earth wall is also an indication of durability. The compressive strength test was done according to BS 5921 : 1985<sup>13</sup> to establish the crushing strength of the earth bricks. Five specimens were randomly taken from each type of brick and tested on a universal testing machine. The mean compressive strengths are given in *Table 4*. The test results were directly compared with the standard strength of 5 N/mm<sup>2</sup>. The strengths of the unstabilized and the cow-dung-stabilized Mahalapye soil were, respectively, 1.84 and 1.80 N/mm<sup>2</sup> showing that cow-dung did not increase the strength of the bricks. The strengths of the cement and the lime-stabilized Mahalapye soil rose with increased contents of the stabilization agents. The strength of the cement-stabilized bricks is ~ 70% higher than the bricks stabilized with lime, as the strength of lime mortar is only a third of the cement mortar. The strength of bitumen-stabilized Mahalapye soil decreased with increased content of the stabilizing agent and all bitumen-stabilized specimens displayed lower strength than the unstabilized soil brick.

For the Tsabong soil, the unstabilized and the cow-dung-stabilized bricks showed results similar to the Mahalapye soil. The compressive strengths of the cement-stabilized Tsabong soil bricks, on the other hand, rose with the increased cement content and were 20% higher than the corresponding cement-stabilized Mahalapye soil bricks. The lime-stabilized Tsabong soil bricks rose slightly with increased lime content, 2.16 to 3.73 for 5 and 15% lime content, respectively. The increase in the compressive strength of the cement-stabilized Tsabong soil brick was ~ 130% higher than the lime-stabilized one. As with the Mahalapye soil, the bitumen-stabilized Tsabong soil brick showed decreasing strength with the increasing ratio of the stabilizing agent. The strengths were also lower than those of unstabilized bricks.

#### Conclusions

The objective of the study was to examine ways to improve the durability of earth buildings by modifying the properties of earth so as to increase its strength and reduce its water absorption and other detrimental effects of water. In order to determine the quality of earth materials, strength, water absorption, soil loss and disintegration were considered the main criteria and were hence analyzed. Stabilization with additives and compaction was considered to be the most efficient means of modification of the earth. Several pressed and stabilized bricks were produced and tested for these criteria.

During the tests, the unstabilized bricks disintegrated within a short time after immersing in water, while the cow-dung-stabilized bricks took 12–24 h to break into larger fragments than the unstabilized bricks. The bitumen-stabilized bricks did not disintegrate within 24 h, but developed large unstable cracks which might be the result of insufficient hand mixing of the soil with bitumen. Mechanical mixing, which enables a uniform distribution of bitumen in the soil, may eliminate the weak points and stop the cracks, thus making the bricks more durable. However, this study reveals that the unstabilized, the cow-dung and the bitumen-stabilized bricks are inadequate in terms of soil loss and disintegration.

The cement-stabilized bricks did not disintegrate when they were immersed in water. The increase in the cement content decreased the water absorption of the bricks and bricks stabilized with more than 7.5% cement met the standard limit of 7% water absorption, which is acceptable for fired bricks used in damp-proof course.

For the lime-stabilized bricks, the increase in the lime content, unlike for the cement-stabilized bricks, increased the water absorption of the bricks. The lime-stabilized bricks did not meet the standard requirements for water absorption.

Soil erosion in both the cement and the lime-stabilized bricks decreased when the amount of stabilization material was increased in the mixes. The tests showed that the bricks produced from the soil with high sand content eroded three

to five times more than the bricks produced from soils with high clay content.

The test results revealed that the strengths of cement stabilized bricks are more than twice the strength of the bricks stabilized with lime.

The results verified that soil with high sand content and low clay content is more suitable for cement stabilization, while the soil with high clay content is better for lime stabilization in terms of strength. The lime-stabilized earth bricks produced with soil having high sand content should be stabilized with more than 15% lime, or moulded with higher pressure to meet the standard requirement.

The bricks produced from soil with high sand content satisfy the criteria in terms of strength, water absorption and soil erosion when stabilized with cement content of 5%. For soil with high clay content, in the 5–7.5% range, cement stabilization is required to produce satisfactory earth bricks. The lime-stabilized bricks meet the required strength if they are produced from soils with high clay content with at least 15% lime content. However, the increase in lime content increases the water absorption of the bricks.

Since both lime and cement are readily available in these two villages, the indigenous earth construction can be improved by stabilizing using them. However, as the study verified, the stabilizing agents should not be used indiscriminately as is presently done with cow-dung. Adequate experiments should be carried out to identify the most appropriate type of the stabilizing agent and the right contents.

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