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Appropriate Design and Construction of Earth Buildings: Contesting Issues of Protection Against Cost

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Abstract: Stabilisation and adequate overhang are construction and architectural design requirements for unbaked earth walls for protective purposes. Adequate stabilisation is cost intensive; so is adequate overhang in the context of modern Architecture. The paper analysed the cost implications of the protective requirements of an unbaked earth walls with the intention of assessing its viability in the context of the existing earth technology. The factor of adequacy in stabilisation was determined by experimental research in a case study of Auchi, in Edo State of Nigeria. The research question was: Is the intended low construction cost of earth wall achievable within the framework of the existing design and construction requirements. The paper revealed that the overall cost of earth building in the modern context may not be cheaper than the sand-cement block building with simple roofs. A Composite Compressed Earth Block (CCEB) is proposed for further scientific analysis and study. This paper is part of an on-going research on the development of earth construction for improved utilization in urban areas.

Key words: Adobe % Cost % Compressed Earth % Durability % Rammed Earth % Sustainability

INTRODUCTION

Loam has to be sheltered against rain and frost, especially in its wet state. Earth walls can be protected by roof overhangs, cement, lime or bitumen stabilisation, damp proof courses, appropriate surface coatings etc. [1]. The impact of the micro-climate on the building envelope is a major concern in earth construction. Heathcote [2] explained that the mechanism causing removal of material from the surface of earth walls is the release of the kinetic energy associated with raindrops impacting on the surface. Erosion is further intensified when the earth wall surface absorbs moisture thereby weakening the binding strength of clay.

The design of earth building has to give due consideration to these requirements for good practise. It is therefore a common feature of modern earth buildings to see considerable overhangs. An appreciable overhang requires adequate structural support which if given a modern architectural approach could be cost involving. Typical example is the Primary School in Gando, Burkina Faso [3].

A communal effort led and arranged by Architect Diebedo Francis Kere and group of friends to build a school from locally sourced material [3]. The concept of high steel roof trusses on reinforced concrete beam was the architect's way of introducing protective overhang in modern architectural context. The walls and piers of the school were made of compressed earth blocks which were stabilised with small amount of cement. The open roof structure is, however, susceptible to wind damage in tropical environment and with the cement stabilised wall, it constitute a high cost element of the building.

Another example is the Arrillhjere Demostration House in Alice Spring, Australia [3]. Built of handmade mud bricks from the red soil found on site and stabilized with bitumen for water resistance of wall. The roof is of steel structure with appreciable overhang. The roof is gabble and structurally separated from the walls, supported by a metal frame.

In the above cases as most modern earth buildings, walls were given limited stabilization probably due to cost of adequately durable stabilization. Further protection was given by the roofs of elaborate steel or concrete structure

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Plate 1: Primary School, Gando, Burkina Faso, 2001 [3].

Plate 2: Arrillhjere Demonstration House 1997. [3]

capable of sustaining a reasonable cantilever; or simpler structures with isolated piers, columns or posts to support roof overhangs.

The planning of an adequate roof overhang to protect earth wall in Africa is very challenging. The micro climate of heavy driving rainfall in most parts of the continent and the low level of infrastructural development like irregular supply of electricity make such planning difficult. The Architect goes through the arduous task of balancing between creating internal spaces of adequate natural lighting and ventilation while avoiding an exposure of the external walls. Architects efforts at such planning always end up in a compromise of exposing few external walls. The planning becomes almost impossible when it comes to storey buildings which are most desirable in Africa for the factor of security, increased air-flow and social class factor.

This paper aimed at assessing the implications of constructing a truly durable earth building, economically, in a contemporary urban environment. The achievement of durability and modernity in a low cost housing setting may reverse the present trend of low utilization of unbaked earth in construction of building in most urban environment. The paper investigates through an experimental investigation, the amount of stabilization that is required to produce an adequately durable stabilised compressed earth wall, which is exposable to the micro climate of tropical rain forest. It goes further to investigate if such percentage stabilization is economically practicable. This investigation is expected to assist further research on the development of compressed earth for increased utilization in tropical urban environment.

MATERIAL AND METHODS

The materials used for this experiment were mainly soil and cement. Clay serves as the binder (physical) of silt, sand and gravel, just as cement (chemical) binds the concrete. Clay is soluble in water; its physical properties change with increase in moisture.

Two samples of earth in Etsako West Local Government Areas in Edo State of Nigeria were selected for this experiment: Aviele laterite soil (TYPE 1) and the soil of Ubiane (TYPE 2). The choice of the two different soils was to investigate, first the percentage of stabilization that is durable and second, if the required percentage of stabilization changes with the composition of soil. A particle size distribution analysis and atterberg limit tests were conducted on the two soil samples.

Bricks of different percentages of stabilisation were moulded with a simple hydraulic press and a uniform pressure. Samples were cured for 7 days and air dried till the 14th day, before drying to constant mass in a ventilated oven. The dry weights before the simulated rain test were recorded against the dry weight after test.

Durability Assessment: Appropriate durability assessment has been a subject of many research works [4-6]. Most laboratory assessment methods for durability of earth wall are inconsistent with their field performance. A proper simulation of rainfall by drip test from a height of not less than two metres may give a better result [7]. In this work durability was assessed by subjecting the sample blocks of varying percentages of stabilisation to a laboratory simulation of the rain in tropical rain forest. Jets of water released with pressure from a height of 3 metres impacted on samples at vertical angle of 15 degrees for a period of 6 hours. The dry weight of eroded component was plotted against percentage of stabilisation.

RESULTS AND DISCUSSION

Soil Type 1 - Aviele Laterite Soil: Soil Type 1 is a laterite soil and the particle size distribution and atterberg limit tests results were as shown in Figures 1 and 2.

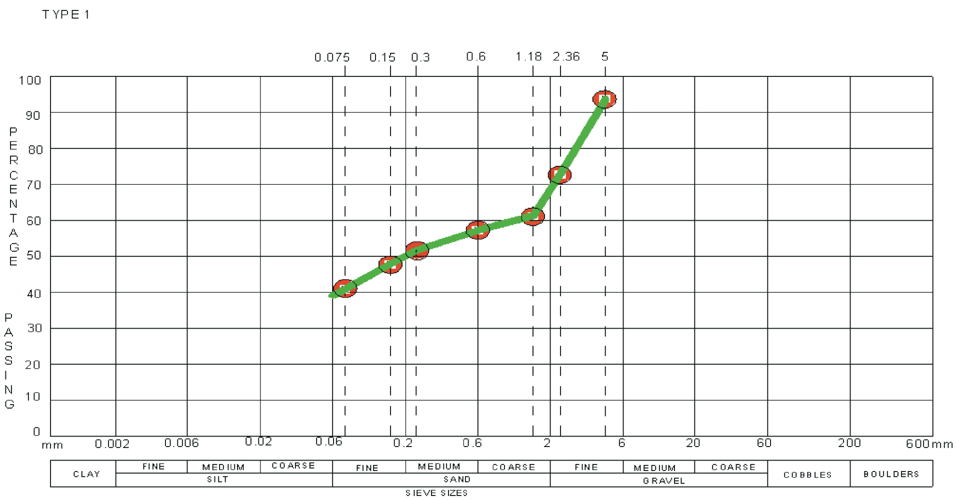

Fig. 1: Particle size distribution chart for Aviele laterite soil (Type 1).

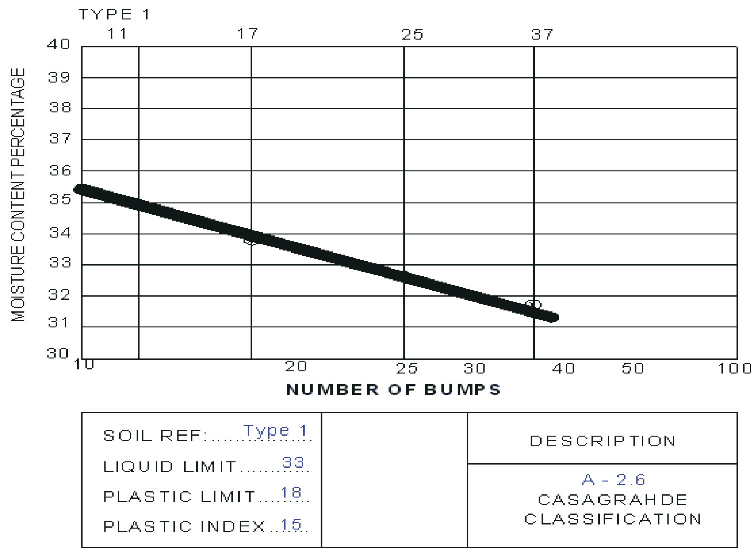

Fig. 2: Liquid and Plastic Limit of Aviele laterite soil (Type 1).

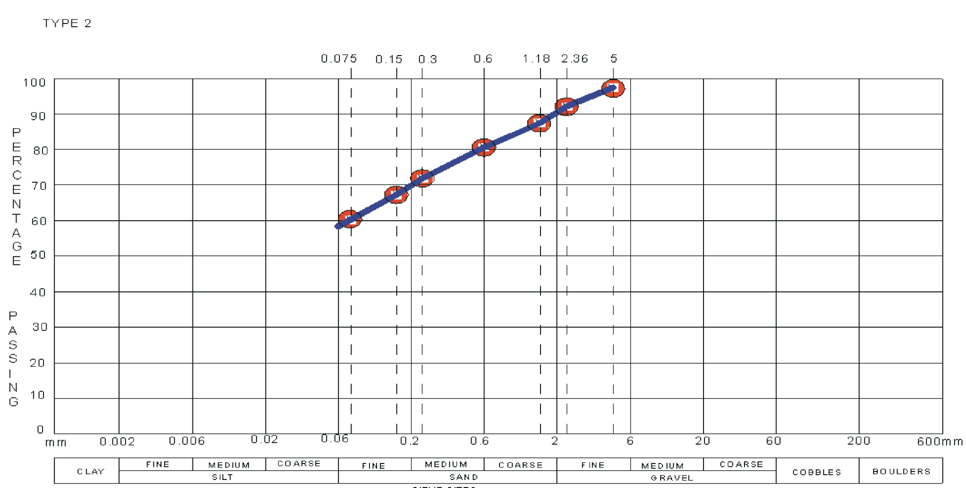

Fig. 3: Particle size distribution of Ubiane soil (Type 2).

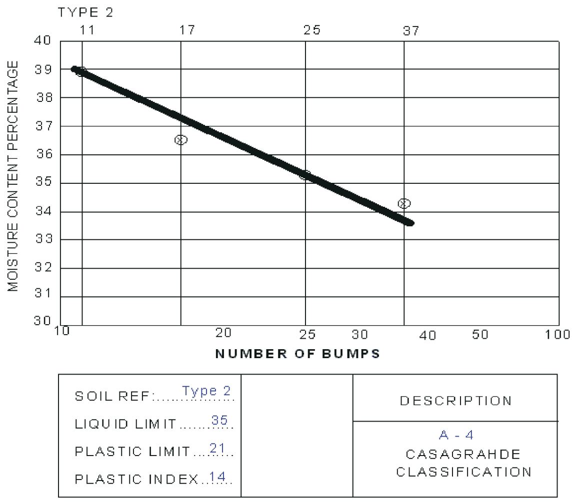

Fig. 4: Liquid and Plastic Limits of Ubiane soil (Type 2).

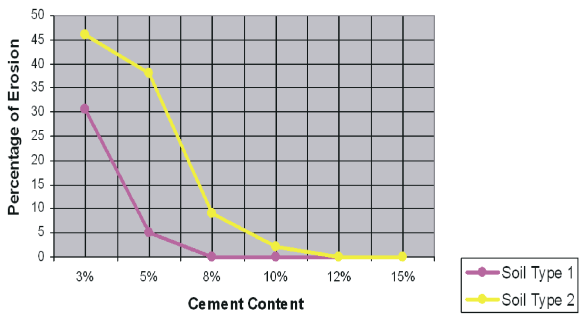

Fig. 5: Percentage of erosion of stabilised Compressed Earth blocks made from Aviele laterite soil (Type 1) and Ubiane soil (Type 2)

The Aviele laterite soil is cohesive and gravelly with Liquid limit of 33 and plastic limit of 18. The Plasticity index is 15.

Soil Type 2-Ubiane: The relevant properties of Soil type 2 were determined from the particle size distribution and atterberg limit tests as shown in Figures 3 and 4. The Ubiane soil has high clay content.

The Ubiane soil is more clayey and with Liquid limit of 35 and plastic limit of 21. The Plasticity index is 14.

Stabilisation: The weather resistant ability of earth walls is greatly improved when stabilised and compressed [8, 9]. The addition of cement, lime or bitumen to earth before compression changes the characteristic of earth from its unstable state of strength and volume with changing moisture conditions to a more suitable building material. The suitability of the above materials may be dependent on the composition of the Soil. Cement is more suitable for a soil with a higher percentage of sand, while lime is more appropriate with a clayey soil as it reacts, though slowly, with clay to form a stable pozzolanic material [4]. However the considerable amount of water required for lime and bitumen in process of production may restrict their use to adobe blocks and not compressed earth blocks that requires small amount of water for good compression [4]. The availability of these binders could also be a factor for a choice in local application. There have been recommendations, in the literature, that 5 per cent to 8 per cent cement is required for the satisfactory performance of compressed earth walls [10].

Durability in modern context should not be how long the earth wall stands without falling but also how well the integrity of the original texture of exposed surfaces lasts with little or no deterioration.

The result of the durability tests of compressed earth blocks produced from soil types 1 and 2 (Aviele and Ubiane) are shown in Figure 5. The percentage of cement stabilisation was plotted against the percentage or erosion.

Soil Type 1 with less clay content became very durable at 8 per cent stabilization. Soil Type 2 with higher clay content became adequately durable with 12 per cent stabilization.

Cost Analysis: A fairly modest single-storey dwelling needs around 120 tonnes to 150 tonnes of soil to build the external and some internal walls [11]. A physical measurement and calculation on a building site shows that an area of one square metre (1 m^2) of a 300mm thick compressed earth wall requires 0.686 m^3 of dry pulverised earth when a compressive pressure of 15 N/mm^2 is applied. This was deduced from a compressed earth brick mould of uncompressed volume of $0.0024m^3$ which produces a compressed brick of 0.00105 m^3 and a mass of 1.9 Kg.

The required cement for 8 per cent stabilisation was calculated as follows: One square metre ($1m^2$) area of 300mm thick wall has a compressed or brick volume of $0.3m^3$ which requires 0.686 m^3 of dry pulverised earth, based on a measured relationship.

Weight of required dry pulverised earth for $1m^2$ of wall

$$= \frac{0.686 \times 1900}{0.0024} = 543\text{Kg}$$

Required cement for 8% stabilisation: 543 x 0.08 = 43.5 Kg

Comparison with Sand-Cement Blocks in Nigeria: A 50kg bag of cement produces 25 units of 450x225x225mm hollow blocks which is capable of covering 2.5 m^2 of wall excluding plaster. This places the cost of cement for 8 per cent stabilization of earth higher than production of sand-cement blocks.

The above assessment was based solely on the quantity of cement required. Other cost elements like the cost of sand for sand-cement blocks may compare favourably with the labour cost of digging and pulverising earth.

Though the self-help factor of earth construction works in rural communities where all hands come on deck to assist in a housing project, it is hardly workable in urban environment where neighbours are busy and will not want to get muddy or dirty in assistance.

Durability at a Lower Cost: Following the issues relating to adequacy and durability of earth walls and the corresponding cost implications, the concept of a Composite Compressed Earth Block (CCEB) may be worth the efforts of further research work. The Composite Compressed Earth Masonry Unit is an earth block of two layers of different percentages of stabilisation. The inner layer/core shall constitutes of about 60 per cent of the block's volume shall be of less stabilised earth and the outer layer/shell, which constitutes about 40 per cent of block is of highly stabilised earth - all compressed mechanically into a single solid block.

The concept was evolved with the intention of giving adequate stabilisation to the exposed part of compressed earth block with less overall cost of wall.

CONCLUSIONS

These results indicate that different soils may require different percentages of stabilization which may go as high as 12 per cent before adequate durability can be achieved. Buildings are expected to function at a high level of quality and reliability and all materials and components in the building envelope are required to perform their functions and maintain their integrity with minimum maintenance.

Efforts towards achieving a durable earth wall in the context of modern architecture are usually expensive. Inadequate stabilisation is commonly inevitable, as the cost of adequate stabilisation of the entire masonry unit is high. The complementary overhang is a major cost element which makes the low cost factor associated with earth wall, contestable.

A Composite Compressed Earth Block (CCEB) is proposed for adequate stabilisation with less overall cost of wall and elimination of overhang. The development of the composite compressed earth block by scientific study, test and analysis of performance is a subject of an on-going research.

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