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Cement stabilized rammed earth as a sustainable construction material

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HIGHLIGHTS

- Strength and durability properties of CSRE together with design requirements were established.
- Sandy laterite soil stabilized with 6% or more cement can be recommended for CSRE.
- Multipurpose applications of CSRE in buildings, roads and retaining walls are presented.
- CSRE is a sustainable construction material of desirable strength and durability together with lower life cycle cost.

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ABSTRACT

In a world where the exploitation of natural resources by the construction industry has become a severe problem, earth can represent an ideal building material that has the potential to reduce the carbon footprint when a cradle to grave life cycle approach is considered. This can also ensure minimum damage to the environment since one day in future, earth obtained can be returned, but could be in a slightly modified form. However, it is very important to consider ways to eliminate the undesirable properties of soil and convert it to a strong and durable building material that would be environmentally friendly. Stabilizing earth with cement and ramming at optimum moisture content forms cement stabilized rammed earth (CSRE), a building material with sufficient strength and durability but low in embodied energy. This paper covers a detailed research carried out on CSRE to establish strength and durability properties together with applications in the form of pilot projects. Sandy laterite soil available in the tropical regions has been identified as a preferable ingredient for CSRE construction which can offer adequate compressive and flexural strengths when cement content is in excess of 6%. Wet strength, erosion resistance and shrinkage properties were assessed and appropriate guidelines are proposed to ensure the durability of CSRE. Further, successful applications of CSRE are highlighted in different forms of construction including housing, roads and retaining walls.

1. Introduction

Ever increasing demand for housing and buildings all over the world has resulted in consumption of significant amounts of natural resources in the form of building materials. This over exploitation has gradually led to a situation of scarcities and higher prices to be paid for building construction materials. The realization of reasons for this has created a shift towards development of sustainable building materials which need less energy in manufacturing and also in the operational cycle of the building. Stabilized rammed earth has been identified as one such material which can optimize the resource usage while minimizing the carbon footprint.

The main ingredient of rammed earth is soil which comprises of a mixture of sand, gravel, silt and clay. This mixture is wetted to its optimum moisture content [1] before being rammed in-situ between formwork. As the material dries, rammed earth increases its strength significantly with time [2]. The properties of rammed earth can be improved by stabilizing it with physical, mechanical and chemical means [3–5]. Physical stabilization is achieved by selecting a better particle size distribution and having a proper mix of constituent materials of gravel, sand, silt and clay [6]. Mechanical stabilization is achieved by dynamic compaction using a manual or pneumatic rammer [7]. Mixing a chemical based agent such as cement, lime or any other additive to improve the properties of soil is termed as chemical stabilization. Cement stabilization has gained popularity due to higher and faster strength gain, durability, availability and ability to obtain acceptable properties with low percentage of cement, especially with laterite soils [8,9]. Laterite soil is often found in the countries with tropical climatic

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conditions and is readily available in many parts of Sri Lanka either as laterite hills or few meters of top soil. It has been found as one of the best suited ingredients for CSRE [10].

The selected soil is stabilized with required amount of cement and compacted either manually or mechanically at the moisture content close to the optimum [11]. The maximum dry density of CSRE can be achieved at the optimum moisture content which in turn gives favorable compressive strength [12]. Windstorm & Schmidt [13] highlighted the overall benefits and longer life cycle of rammed earth. This paper is focused on overall properties and applications of cement stabilized rammed earth (CSRE).

2. Objectives

Over exploitation of natural resources has placed a greater threat to the environment. Therefore, developing alternative materials has been considered a priority in sustainable design and construction. CSRE is one such alternative construction material which has a greater potential to be a part of sustainable development. Hence, this research has been aimed at assessing CSRE as an alternative construction material with following sub objectives:

a. To establish the strength properties of CSRE.
b. Identification of durability problems and remedial measures.
c. To assess the embodied energy and contribution to the operational energy.
d. To outline the applications of CSRE in pilot projects.

3. CSRE construction

3.1. Soil types for CSRE

The strength properties of CSRE made out of laterite soil can vary with the proportions of the constituent materials present such as gravel, sand, silt and clay. Therefore, three main types of laterite soil termed as sandy laterite, clayey laterite and gravelly laterite were tested to assess its suitability for CSRE construction. Soil selection was based on sieve analysis conducted in a laboratory and the jar test conducted at site which gives an approximate distribution of main constituents [1]. Wall panels were constructed out of the three types of lateritic soil and tested for compressive strength in 28 days after construction. The average compressive strength of each soil type was obtained from the duplicate wall panels loaded to the failure. Fig. 1 shows the strength of CSRE wall panels constructed with different laterite soil types. Sandy laterite contained about 60% sand, whereas gravelly laterite and clayey laterite contained 60% gravel and 40% fines respectively. However, Fines content (clay and silt) of soil should be in the range of 25–35% for better strengths of CSRE [10]. Moreover, Sandy laterite recorded the highest strength for CSRE out of the three types of soil. The wall panels were cast according to the dimensions specified in BS5628: Part 1:1992 [14] as indicated in Section 4.1 of the paper.

3.2. Construction of CSRE

The selected soil (preferably sandy laterite) is mixed with required amount of cement in the dry state. Then the mixture of soil, cement and water is placed inside the temporary formwork and compacted in layers as shown in Fig. 2.

Similar to the shutter for concrete, CSRE formwork should have sufficient strength, stiffness and stability to resist stresses exerted during erection, placing the soil, and dismantling. However, unlike concrete, CSRE formwork can be removed almost immediately after compaction, enabling a much faster reuse. As with in-situ concrete construction, efficient organization of formwork is essential for CSRE construction. The slip form mould (Fig. 2) and full scale formwork (Fig. 3) are the options available for CSRE construction out of which full scale formwork can offer better surface finish with higher productivity.

Loose soil and cement mixture is compacted in layers in the temporary forms with the moisture content close to the optimum, which was in the range of 12–14%. The optimum moisture content was maintained with the drop test carried out at field as recommended by SLS 1382 [1]. Ramming was done manually using a hand tamper of 2.5 kg weight as shown in Fig. 4. The depth of each loose soil layer was maintained at 300 mm and was compacted to 150 mm finished layer thickness. The compactive effort was standardized in all the wall panels by maintaining a compaction ratio of 2 [16] (height of the loose soil/height of the finished soil layer) and being consistent with the layer thicknesses.

4. Strength of CSRE

Strength being the most important parameter to assess CSRE as a structural material, a detailed experimental programme was carried out to determine the compressive and flexural strength of wall panels.

4.1. Compressive strength of CSRE

In order to determine the compressive strength of CSRE walls, two identical wall panels of size 1000 mm (length) × 160 mm (width) × 650 mm (height) were constructed and tested for three types of laterite soil stabilized with different cement contents of 6%, 8% and 10%. Wall panel dimensions were determined such that slenderness effects were not predominant. Slenderness ratio was maintained at 4 for all the wall panels. Three soil types selected were sandy, gravelly and clayey laterite. All the wall panels were tested for compressive strength in 28 days after casting. The average strength of the duplicate panels tested for each soil type is presented in Table 1. Eq. (1)was used to calculate the characteristic compressive strength (F_k) of CSRE, and the results are presented in Table 1. Sandy laterite soil has shown higher compressive strength than the other two types indicating its suitability for CSRE construction.

$$F_k = (F_m \Psi_u \Psi_m)/(1.2A)[14] \quad (1)$$

where F_m is the mean of the maximum loads carried by the two test panels; A is the cross-sectional area of each panel; ψ_m & ψ_u are the reduction factors for strength of mortar and sample structural units respectively. Both reduction factors were considered as 1.0 since this is a research study where wall panels were constructed and tested.

When the cement content was increased, the compressive strength of CSRE also has increased in all soil types as shown in Table 1. Moreover, Corbin & Augarde [17] have reported that adding cement increases the compressive strength while improving the fracture energy.

The compressive strength values indicated in Table 1 are found to be satisfactory according to the structural design performed for a typical two storied load-bearing house which accounts for a stress at plinth level of 0.9 N mm^{-2} with the factors of safety [18].

Since soil is a material which looses its strength when saturated, the wet compressive strength of the CSRE was found experimentally and this is further discussed in Section 5.2.

4.2. Load deformation characteristics of CSRE

According to several studies carried out by Jayasinghe and Kamaladasa [10], the load deformation characteristics of CSRE constructed with different types of soil have demonstrated a ductile behavior that indicates an adequate warning before the ultimate failure. Fig. 5 shows one such set of load deformation curves. Based