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Economical stabilization of clay for earth buildings construction in rainy and flood prone areas

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HIGHLIGHTS

- This research is aimed at finding desirable and effective means of construction material.
- Cement, lime, gypsum etc. were used as stabilizers in this study.
- The samples were tested under compression and tension.
- It was found that using 4% cement with 1% straw would show excellent results.
- Construction using such stabilizers will be more resistant to weather and economical.

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ABSTRACT

About one half of the total world's population resides or works in buildings made of earth. It is a cheap and thus one of the oldest building materials known to mankind. Water is the worst enemy of raw earth buildings. To make it water resistant and durable, different stabilizers are added to the clay in building construction. Cement, lime, bitumen, fibers (natural and synthetic) and certain other chemicals are used worldwide. This research is aimed at finding desirable and effective means of construction material, which is economical as well as easy to handle. For this purpose, protecting earth buildings from the ill effects of rain and flood, cement, lime, gypsum and natural straw from wheat (all in different combinations) were used as stabilizers in this study. The samples produced were subjected to two different non-standard and relativity based tests in order to examine the durability of the materials used under rain and flood. The samples were also tested under compression and tension and the results obtained were compared with the published data. From the test results analysis and comparison, it was found that using 4% cement with 1% straw would show excellent results for construction in rain and flood prone areas and appeared economical as well. Therefore if a house is constructed with this combination of stabilizers in rainy and flood prone area, will be more resistant to weather and would be economical as well.

1. Introduction and background

Raw earth, as a construction material, is one of the oldest and very first building material man has ever used. Currently, in developed countries, like Western Australia and the south-west areas of the United States, rammed earth is widely used in buildings construction [1]. Though earth building construction has now been suppressed by the modern construction materials that show much better performance, in many countries where modern techniques are too costly to implement, it is still an important building construction practice [2]. It is estimated that one third of the total world's population reside in buildings made of earth [3]. There are about 500,000 earth buildings in the UK, mostly constructed before the 20th century and are still occupied [4]. In India, the walls of 55% of homes are still constructed from raw earth [5]. The earth building is strong when it is dry but become non-durable when exposed to moisture content. The main ill effect of raw earth is its affinity for water. Chemical additives like cement, bitumen and lime are added into the soil mix to protect the adobe brick from moisture decomposition and deterioration [5].

Additives such as cement, lime or bitumen, are added to raw and unfired earth to improve particular properties [6]. Cement is mostly used to improve the characteristics of unfired clays [7]. Compressive strengths ranging between 0.6 and 2.25 MPa were obtained by Jiménez Delgado and Cañas Guerrero for unstabilized

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soils [8]. Morel et al. [9] summarized the previous studies focusing on the mechanical properties of unstabilized earth construction in the light of Spanish standards [10], with a manual compressed earth blocks presenting a compressive strength in the range of 1.5–3 MPa. Higher strengths can be achieved using hydraulic presses and/or increased cement contents, but 2–3 MPa compressive strength is typical. Bui et al. [11] conducted a study in France to validate laboratory results of unstabilized blocks. A compressive strength of 1.65 MPa was obtained.

In Papua New Guinea Raw earth is stabilized with local materials such as volcanic ash, finely ground natural lime, cement and their various combinations. These are then evaluated and compressive strength in these cases ranges from 0.39 to 3.1 MPa [3]. In another study by Ngowi [12], the strengths of the cement stabilized bricks are 70% more than the lime stabilized bricks, because the strength of lime mortar is one third of the cement mortar.

Atzeni et al. [13] added stabilizers such as Portland cements, hydrated lime and polymers and found the increase in compression resistance from 0.9 MPa (in case of unstabilized sample) to 5.1 MPa (after stabilization). The same value was improved to 4.5 MPa with an addition of 10% of cement and further up to 6.5 MPa by adding 20% of cement as stabilizing agent by Bahar et al. [14].

Alginate (a natural polymer brown algae group) has been used as stabilizing agent by Marin et al. [15]. Sheep's wool was used as reinforcement in the same study. Results revealed that the addition of only alginate increases compression strength from 2.23 to 3.77 MPa and the addition of wool increase it up to a 37%. Better results were obtained with a lower quantity of wool by combinations of both stabilizer and wool fiber. Adding alginate as stabilizer and reinforcing it with wool fiber doubles the soil compression resistance.

In Jalpaiguri town of West Bengal the local soil and clay was mixed with the local sand and stone grits to make compacted stabilized earth blocks by Kabiraj [23]. They used various proportions of OPC and jute fibers as stabilizers in their study. They got the resulted compressive strength in the range of 2.01–5.09 MPa. They concluded that both the cement and jute fiber stabilized samples are cost effective and environment friendly comparing with the burnt clay bricks in buildings where stability is not considered as a governing factor.

For Earth buildings construction, soil blocks are usually formed. Two general types of these blocks are described here:

- Adobe block.
- Stabilized earth block.

Adobe blocks are made from prepared soil. They are made without pressure and then sun dried (cured). Stabilized earth blocks are made from soil mixed with stabilizing agents, formed into blocks with high pressure, and then cured in the shade [16].

In the current research, the effects of rain and flood are primarily taken into account. Additionally, durability against loadings and stresses is also investigated considered but was of secondary concern and used only for comparison purposes. The effects of rain are recorded on various samples using water jet tests. After rain, the flood tests are performed on samples by submersing these samples for a specific duration of time. The results of these tests for various combination of stabilizers are presented and compared to select the most appropriate, economical and durable mix for earthen buildings construction in rainy and flood prone areas.

2. Research significance

In the light of the previous literature, it is easy to find a durable stabilizer for earthen building construction. Numerous materials stated earlier could be used as potential stabilizers for the purpose. But economy and local availability are of great concern for people using such types of buildings. Additionally this study will focus on resistance to weather and its ill effects. This study will try to find out durable and economical solution to problems faced by earthen buildings in rain and flood prone areas.

3. Experimental program

3.1. Soil for sampling

Locally available soil was used in the study. It was taken from a nearby construction site – i.e., a deep excavated soil with index properties given in Table 1. These properties came from laboratory tests performed on collected samples. Soil was used from the same source throughout the course of this research. This soil was air dried and all the weight calculations and proportions were made based on the dry weight. The amount of water for sampling was also calculated according to the dry weight corresponding to OMC.

3.2. Stabilizers selection

Depending upon the availability, economy and ease of construction, stabilizers like cement, gypsum, lime and straw are selected. Different percentages of stabilizers alone as well as in combinations were used for study in this particular project. The main focus in selection was durability against rain and flood.

3.3. Preparing samples

The Standard Proctor test was performed to determine the moisture–density relationship under compaction and hence to obtain the optimum moisture content of the soil-stabilizer mixture for each sample. Based on these values, percentages of water were specified for each mix and compaction was done with respective moisture content. When stabilizers are used in raw earth, they must be thoroughly mixed with otherwise much of their benefits will be lost. Different combinations of stabilizers studied in this research are listed in Table 2.

All the percentages are by weight of dry soil. In case of cement and lime, minimum 5% and maximum 10% quantity was selected based on its strength and economy respectively. Decreasing quantity below 5% means no gain of strength, while increasing above 10% has good effect on strength but appears uneconomical. In case of straw, 1% and 2% were selected as limits. Since straw is lighter and is 2% by weight, contains huge quantity and therefore reducing the effect of clay in adobes. Standard 5 cm × 5 cm × 5 cm (2 inch cube) mold was used for compression test samples. The same dimension cubes are used in concrete for compression test. For flexure test samples a wooden mold was prepared with 30.5 cm × 15.25 cm × 7.62 cm (12″ × 6″ × 3″) clear dimensions (Fig. 1a). The selection of these dimensions was based on flexural test requirement in which we had to provide a 3 point load application area. Samples of the same dimensions from the same mold were used in water jet tests for consistency in data. Samples tested in water jet test were then used in submersion test. This was an actual simulation of rain followed by a flood event as

Table 1
Soil index properties.

Property	Value
Liquid limit	34%
Plastic limit	19%
Plasticity index	15%
OMC	16%
D_{15}	0.0065 mm
D_{60}	0.080 mm
Classification (USCS)	CL (low plasticity clay)

Table 2
Stabilizers percentages.

Stabilizer	Set 1	Set 2	Set 3
Cement	10%	5%	7%
Gypsum	10%	–	–
Lime	10%	5%	7%
Straw	1.5%	1%	2%
Combinations	1% straw + 2% cement (C2H1)	1% straw + 4% cement (C4H1)	Adobe (only soil)