

A Study on Stabilized Rammed Earth for Sustainable Construction

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ABSTRACT: From the ancient time onwards humans have adopted various building materials which comprises stones, wood, mud, soil, bricks, concrete, steel, glass etc. which have been changing with the developing technologies. In this modern world, where the conventional building techniques which causes immense environmental hazards, there is an urge for sustainable building technologies. Earthen buildings have proved to be suited for an economical, energy efficient, environmentally friendly and sustainable construction method.

This paper gives a review on stabilized rammed earth construction which gives an overview of the efficiency of rammed earth over earth block and other conventional building materials. The objective of this study is to explore the suitability of locally available soil for Rammed Earth construction and optimization of stabilizer and the mixing water. Compressive strength characteristics are assessed by rammed earth prism. Drying shrinkage and durability is also tested..

KEYWORDS: rammed earth construction, tests on soil, strength and durability, drying shrinkage

I. INTRODUCTION

Earth has been a tried and tested natural construction material for thousands of years, and in combination with modern methods can be used for modern ecological buildings. Rammed earth construction gives a strong and durable monolithic wall by dynamically compacting sub-soil. For a couple of year's earth building techniques have been growing in Iran, USA and all over Europe and Middle East. The reason for this increase is the interest in ecologically friendly construction. In many developing countries where the properties of earth construction are more widely appreciated, earth is utilized in the construction of floors and roofs, in addition to walls. Buildings made with earth are energy saving, environmental friendly, economical, and sustainable. Earth buildings include adobe, cob, and rammed earth blocks and walls [1]. Studies have shown that rammed earth blocks and walls gives a better performance than cob or adobe. For the construction of rammed earth buildings both stabilized soil and unstabilized soil methods are practiced. The compressive strength of unstabilized rammed earth wall ranges from 1.5 to 2 N/mm² whereas the compressive strength characteristics improves with stabilization of the soil. It is required to stabilize the soil to improve the properties of clay which acts as the binder in the rammed earth. On site construction is usually carried out with cement stabilization of 5-10%. Increasing the cement content increases the strength of the rammed earth construction.

II. LITERATURE REVIEW

A. TESTING FOR SUITABILITY OF SOIL

It is important to find out the consistency limits in the case of rammed earth construction as the soil properties determines the suitability of the soil for construction. The recommended values for these limits are suggested as the liquid limit below 35-40% and plasticity index below 10-30%, based on studies by Silva et.al [2]. For the rammed earth construction soil is mixed in the optimum moisture content (OMC) or wet of OMC which is found by standard proctor test [1][2][3][4]. Studies of Silva et.al [2], Venkatarama Reddy et.al [4] and Vasilios et.al [5] shows that OMC varies

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between 8 to 12% for different types of coarse grained soils and the maximum dry density (MDD) ranges in between 1700kg/m^3 and 2400kg/m^3 . In the studies done by Silva et.al [2], it is reported that limits for the particles content such as clay, silt, sand and gravel content are 5–20%, 10–30% and 45–75% respectively. So particle size distribution analysis is to be done for the soil under study to determine whether it satisfies the limits.

B. STABILIZATION OF EARTH

Stabilization is done on the soil to improve the strength properties of the clay which acts as the binder for the rammed earth construction. Materials such as cement, lime, activated fly ash etc. can be used for stabilization among which cement is found to be more effective [6]. Studies done by Jayasinghe et.al [6] shows that the cement content can be either 6% or more and higher cement contents can provide higher compressive strength. The experimental research on activated fly ash stabilization on rammed earth by Silva et. al [2] showed some improvement in the compressive strength characteristics. The relationship between cement content, OMC and MDD are investigated by Venkatarama et. al [4] in which it is found that the OMC and MDD are not sensitive to the variation in cement content. Apart from this lime and fiber stabilization is suggested by Vasilios et. al [5], but lime stabilized rammed earth elements needs curing period three times more than cement stabilized elements and fiber stabilization reduces the compressive strength.

C. CONSTRUCTION ASPECTS

The soil for the rammed earth construction which satisfies the required consistency limits is mixed with wet of OMC and an optimum amount of cement content in the studies done by Jayasinghe et. al [6] and Vasilios et.al [5]. The literature of Jayasinghe et.al [6] also indicates the importance of moisture addition as it effects the stability during the construction. The construction method adopted for rammed earth wall by Quoc et. al [7] is by slip formwork in which the form work is raised after compaction of each layer which is being practiced in the site also. Generally a lift of 200mm is practiced in the site which is revealed in the studies done by Vasilios et.al [5]. Laboratory specimens prepared by manual compaction are kept for wet burlap curing for 28 days [1][3].

D. COMPRESSIVE STRENGTH

For a load bearing structural element compressive strength is the most important strength parameter. Small scale experiments using cylindrical specimens have been reported for assessment of compressive strength and determination of elastic properties by measuring the axial and lateral deformations [3][6].

BS 5628: Part 1 recommends tests on small panels to estimate wall strength when new masonry materials are used. Study of Jayasinghe et. al [6] on the strength characteristics of cement stabilized rammed earth walls adopted walls of height to thickness ratio (h/t) about 4 and observed that failure is of compressive crushing nature. It is also suggested to have an overall factor of safety of at least 5 in estimating the design stress. IS 1905-1987 [8] also recommends tests on prisms of h/t ratio not more than 5 and a factor of safety of 4 for and assessing the basic design compressive stress of masonry.

For a load bearing structural element compressive strength is the most important strength parameter. Compressive strength test using cylindrical specimens gives small scale experimental results along with the determination of young's modulus and the Poisson's ratio by measuring the longitudinal and lateral deflections [2][4].

E. DRYING SHRINKAGE AND WEATHERING TEST

Rammed earth walls can deteriorate due to cyclic weather conditions in which moisture ingress causes swelling or pits and moisture loss causes shrinking. In research studies of John [9] linear drying shrinkage is tested for 1, 3, 5, 7, 14 and 28 days. It is also mentioned that the for loadbearing and non-loadbearing applications limiting value of shrinkage is 0.5% and 1% respectively. In accordance with IS 1725-1982 [10] weathering test is done by spray test on cubical specimens. Durability is also tested by Geelong test as mentioned in studies of Silva et.al [2].

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III. OBJECTIVES

In this study, the following objectives are being carried out:

1. To study the viability of rammed earth construction with locally available soil, by optimizing the quantity of cement and water to be added for stabilizing the soil.
2. Determination of axial compressive strength characteristics of cement stabilized rammed earth.
3. Determination of drying shrinkage and durability by weathering test

IV. EXPERIMENTAL PROGRAMME

A. SOIL ASSESSMENT

The suitability of soil under test for rammed earth construction is determined using the following laboratory tests

1) Particle size distribution analysis

To quantify the proportion of clay, silt and sand content hydrometer analysis was done on the soil, see Fig.1. The proportion of clay, silt and sand obtained are 22, 17and 61% respectively.

A soil suitable for cement stabilized rammed earth construction sand content should be greater than 50% and clay and silt content should be less than 30% as reported by in the review by Vasilios et.al [5] based Australian earth building hand book. The result obtained from the particle size distribution analysis shows that the soil under test is suitable for cement stabilized rammed earth construction.

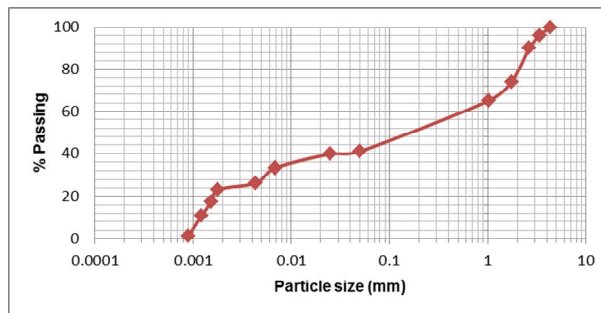


Fig 1. Particle size distribution curve of the soil

2) Consistency limits

Determination of consistency or atterberg’s limits are important for classifying the soil and to find the suitability for rammed earth construction. The recommended values for these limits mentioned in review of Vasilios et.al [5] are LL to be below 35-40% and Plasticity index to be below 10-30%. In the studies done by Silva et.al [2], it is said that shrinkage index should have a lower value as it affects the shrinkage/swelling characteristics of the soil. The limits obtained for the soil under test is as shown in Table.1

TABLE 1. CONSISTENCY LIMITS OF THE SOIL

LL (%)	PL (%)	SL (%)	PI (%)	SI (%)
29	22	20	8	9

3) Standard proctor test

The compressive strength and dry density of the soil depends on the compaction properties. Determination of optimum moisture content is required for the optimization of moisture for molding the rammed earth. Since there was only less than 50% of soil that retained on 4.75mm sieve light compaction was done on the soil as recommended by IS 2720 [11].

From light compaction test the obtained optimum moisture content is 12% and maximum dry density (MDD) is 2.02 g/cc.

B. UNCONFINED COMPRESSIVE STRENGTH TEST

To determine the unconfined compressive strength of the cement stabilized rammed earth and to obtain the optimum quantity of water and cement for molding the soil unconfined compressive strength test was carried out with 3%, 5%, 7% cement with varying water content of 11%, 13%, 15% (one percentage corresponding to dry of optimum and other two corresponding to wet of optimum). The selection of moisture and cement content for the test is done considering the stability during the construction and economical aspect of cement usage. UCC specimens of virgin soil (unstabilized) with the three moisture contents were also prepared for the test.

From the obtained result which is shown in Fig.2 of unconfined compressive strength better performance is shown by 7% cement and 13% water content. So for the further work the quantity of cement and water are taken as 7% and 13% respectively. UCC tests was also done with the measurement of vertical and horizontal deflections in order to find out the young's modulus and the Poisson's ratio, see Fig.3. An average value of 200 N/mm² and 0.192 is obtained for the young's modulus and Poisson's ratio respectively. The stress –strain curve and lateral strain – longitudinal strain curve obtained is shown in Fig.4 and Fig.5. The obtained values of young's modulus and poisons ratio are in the range obtained in the studies of Silva et. al [2] and Bui et. al [12].

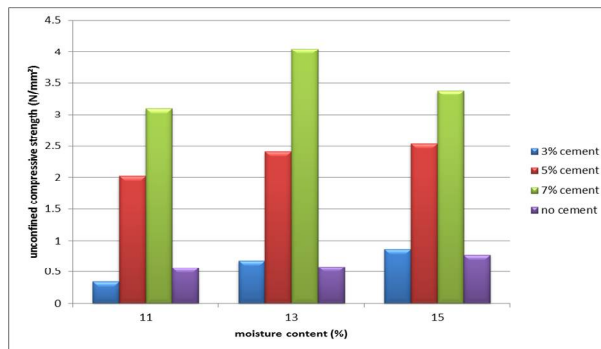


Fig.2 Variation of unconfined compressive strength with moisture and cement content



Fig.3 vertical and horizontal deflection measurement of ucc samples.

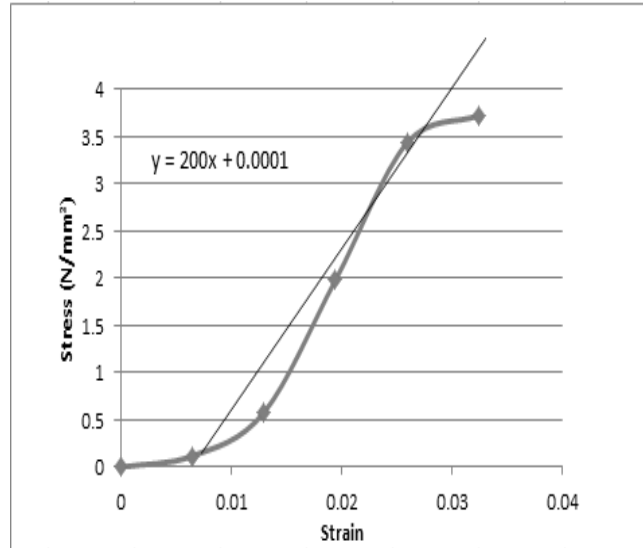


Fig.4 stress v/s longitudinal strain curve of ucc specimen

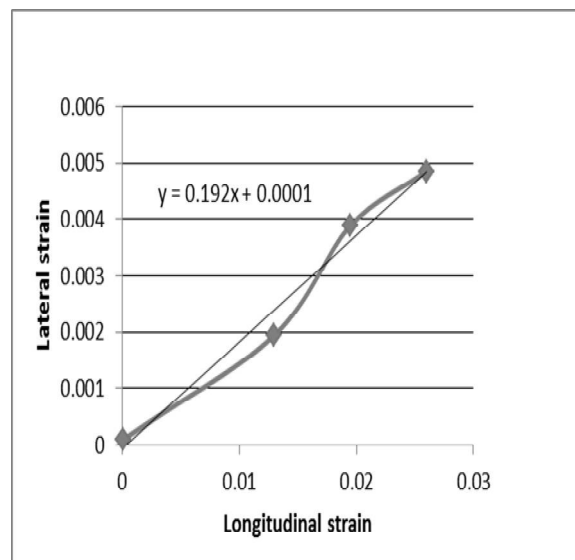


Fig.5 lateral strain v/s longitudinal strain curve of ucc specimen

C. COMPRESSION TEST ON RAMMED EARTH PRISM

The compressive strength of rammed earth was assessed with rammed earth prisms of 450mm height, 300mm width and 150mm thickness prepared in layers with a lift of 150mm. After curing it was tested in the universal testing machine with the top surface properly capped and uniform load distributed through thick steel plate (Fig.6). The average of compressive strength obtained in the prism tests was 2.4 N/mm². Assuming a factor of safety of 4, the allowable compressive stress is 0.6N/mm². In low to medium rise constructions when the load is due to the self-weight of the walls and a portion of supported roof, the stresses can be limited to well within this value.



Fig.6 Compression testing of rammed earth prism

D. DRYING SHRINKAGE TEST

Linear drying shrinkage is tested on cylindrical specimen of 100 mm diameter and 200mm height. Shrinkage measurements were taken on 1, 3, 5, 7, 14, 28 and 56 days after curing. Linear shrinkage is expressed as the ratio of change in length to original datum length. The variation of drying shrinkage obtained is as shown in Fig.7. The shrinkage value obtained after 56 days is in the range of the limiting value (0.5%) for load bearing application as reported in the research studies of John [9].

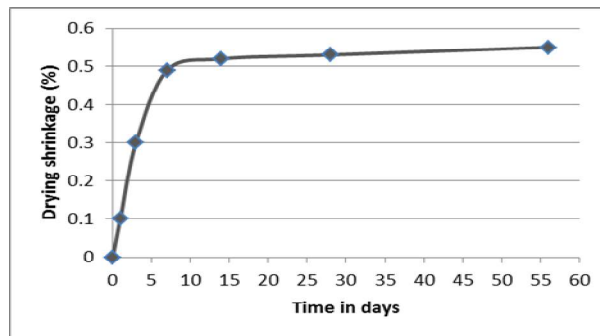


Fig.7 Relationship between Drying Shrinkage and time

E. DURABILITY TEST

Durability test is done by spray test as recommended by IS: 1725-1982 [10] on cubes of 150mmx150mm. One face of the block is exposed to a shower for 2 hours as shown in Fig.8 and then the exposed surfaces are examined for possible pitting Fig.9. The limiting diameter of the pit formed is to be within 10 mm for passing this weathering as per IS 1725-1982[10].



Fig. 8 Spray test on cube specimen

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Fig. 9 Exposed face of the cube before and after the spray test

The pitting depth formed on the cube specimen after 2 hours exposure is 2 mm. Since the result is within the limit, the durability aspect is good for the investigated cement stabilized earth for rammed wall construction.

V. CONCLUSION

The following conclusions have been derived from this study:

- The soil under the study is suitable for rammed earth construction in the aspect of particle size distribution and consistency limits.
- Through unconfined compressive strength test 7% cement and 13% water has been selected as the optimum quantity for the soil
- An average value of 0.192 is obtained as the Poisson's ratio and young's modulus of 200 N/mm² is obtained from UCC test.
- The design compressive stress for the rammed earth construction experimentally obtained is suited for walls of moderate intensity loading
- Drying shrinkage of the stabilized soil was found to be in the range recommended for load bearing application.
- The pitting depth obtained for weathering test is 2mm which is less than 10mm as per the recommendations for durability.

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