A Study on Soil Sample to Evaluate the Suitability for Rammed Earth Construction

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ABSTRACT

As man has realized sustainable practices to be followed for his sustenance on the planet Earth, alternatives to conventional practices are in research in every field. Global Status Report 2021 by the UNEP reported that 37% of global carbon emissions are from the construction sector. Here, the study focuses on the earthen construction method, particularly on Rammed Earth, which has been practiced worldwide since time immemorial. It is an energy-efficient, low-carbon embedded, and sustainable approach that is being researched and practiced worldwide to meet emission targets. Earthen building construction is not well practiced in many countries, India being a part, more studies have to be made on prevailing conditions of socioeconomic as well as engineering factors. The paper presents a comprehensive study on materials used for rammed earth construction, Tests to be done for both material and rammed earth specimens, Construction aspects, and a study on locally available soil to assess its viability for rammed earth construction. It also discusses the studies to be made to popularize the same to society as a sustainable alternative construction method and practice the same.

Keywords: Rammed earth, Soil test, Strength and durability

1 Introduction

As a natural construction material soil was being used since time immemorial which can be again revived andcan be used as a modern building material with a traditional and sustainable approach. Construction with soil by dynamically compacting sub-soil is termed as rammed earth construction which gives monolithic, strong, and durable wallings even though different techniques are identified such as wattle, cob, adobe, etc. [1] for construction with soil. Construction methods with earth are rejuvenating in different parts of the world mainly in European countries as carbon emissions target has been allocated to each and every country in due consideration to climatic change. In developing countries like India, there are more possibilities of utilizing the earthas a construction material and being studied by various researchers, and efforts are made to create proper guidelines for the design and construction of the same. Buildings made with earth are energy-efficient, low- carbon embedded, and sustainable. Rammed earth construction with stabilization and unstabilization is practiced, cement being a chief stabilizer whereas lime, some organic materials, alkali-activated fly ash, etc are found to be effective stabilizers. Unstabilized rammed earth wall gives compressive strength suitable for low-riseconstructions whereas the stabilization of the soil improves the compressive strength characteristics. Studies are being carried out with construction demolition waste, alkali- activated fly ash, M-sand, and mine sand for material substitution.

2 Literature Review

2.1 Soil Properties

Consistency limits are important to check whether a soilsample suits for rammed-earth construction. and Plasticity index ranging between 10- 30% and Liquid limit between 35-40%, are recommended by Silva *et al.* [2]. The amount of water to prepare the soil for the construction of rammed walls is taken as the optimum moisture content (OMC) or wet of OMC [1], [3], [4] and research by Venkatarama Reddy *et al.* [4], Silva *et*

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al. [2] and Walker *et al.* [5] show that the maximum dry density (MDD) ranges in between 1700 kg/m^3 and 2400 kg/m^3 and OMC varies between 8% to 12% for various types of soils. Particle size distribution recommended in HB195 [13] and Walker *et al.* [5] are, silt,clay, sand, and gravel content are 10–30%, 5–20%, and 45– 75% respectively.

2.2 Stabilization of soil

Stabilization improves the strength properties and durability when the rammed earth walls come in contact with water. Lime, cement, activated fly ash, some organic materials, etc. can be used for stabilization. Jayasinghe *et al.* [6] studied the quantity of stabilization required and found that cement content can be either 6% or more and compressive strength increases with a more quantity of cement. when Silva *et al.* [2] studied activated fly ash stabilization on rammed earth there was an enhancement in the strength properties of rammed earth samples. Lime, as well as stabilization using fiber, is proposed by Walker *et al.* [5], where rammed earth specimens with lime as a stabilizer need a period of curing three times more than cement-stabilized rammed earth samples and it is found that compressive strength reduces while using fiber stabilizers.

2.3 Preparation of mix and construction

The mixture of soil and stabilizer (cement) for the rammed earth specimens is mixed with wet of OMC and with a limiting cement content [5], [6]. Moisture addition is of much importance as it affects the durability and shrinkage of rammed earth construction [6]. The construction method suggested for the walls by Bao *et al.* [7] is after mixing the soil in the required proportion it is put in a slip formwork which is raised vertically after compaction of each lift which is generally taken as 200mm and is being practiced on the site as well. Wet burlap curing for 28 days is provided for laboratory specimens prepared by manual compaction [1], [3].

2.4 Compressive strength test

The strength of the wall is to be assessed when there is a change in the material used for construction. BS 5628: Part 1guide with the test on small prisms with an h/t ratio of 4 to 5 to assess the wall strength by applying the slenderness effect.The strength in compression of stabilized rammed earth wallsis studied by Jayasinghe *et al.* [6] in which prisms of height- to-thickness ratio (h/t) 4 is tested and compressive crushing nature is noticed in failure. In estimating the design stress a factor of safety of at least 5 is also recommended. IS 1905- 1987 [8] also recommends the same for evaluating the basic design compressive strength of masonry.

2.5 Durability test

Cyclic weather conditions make rammed earth elements deteriorate where moisture reduction causes shrinkage and moisture addition causes swelling in the same. John Thuysbaert [9] tested cylindrical rammed earth specimens for linear drying shrinkage in 1, 3, 5, 7, 14, and 28 days. The recommended shrinkage value is 0.5 and 1% for the loadbearing and non-loadbearing applications respectively [9]. To study the effects of weathering spray test is done on cube specimens of rammed earth cast as specified in IS 1725-1982 [10]. In studies of Silva *et al.*, durability is tested by the Geelong test [2].

3 Objectives

1. To study the properties of a soil sample to check whether it suits rammed earth construction.
2. To study the strength properties of cement-stabilized rammed earth prism.
3. To study the effect of weathering action by drying shrinkage and spray test.

4. To review the tests to be done on a particular soil sample to evaluate its suitability for the rammed earth method of construction.

4 Experimental Programme

4.1 Test on Soil

4.1.1 Particle size distribution analysis

Hydrometer analysis has been carried out to determine the percentage of silt, clay, and sand content which is obtained to be 17, 20, and 60% respectively [Fig.1]. Particle size distribution recommended in HB195 [13] and Walker *et al.* [5] are silt, clay, sand, and gravel content are 10–30%, 5–20%, and 45–75% respectively. From theanalysis of the soil for particle size, it can be seen that the result conforms to the recommendations of the particles to be present in the soil by various researchers. The same isto be analyzed while selecting soil and proper additions and reductions to be made to make it to be suitable for the same for use in rammed earth construction.

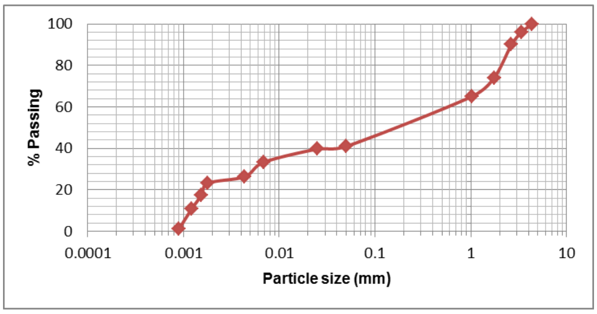

Figure 1: *PSD curve of the soil sample*

4.1.2 Atterberg's limits

To classify the sample of soil and find whether it suits for rammed earth construction, the determination of consistency or Atterberg's limits is carried out. In the review of Vasilios *et al.* [5], it is recommended that the Plasticity index to be below 10-30% and Liquid limit to be below 35-40%. The shrinkage index affects the swelling or shrinkage characteristics of the soil, therefore, it should have a lower value [2]. Improper particle distribution affects the consistency limits also which should be taken care of while selecting a soil. The consistency limits for the soil that is tested are LL -29%, PL – 20%, PI- 8%, and SI – 9%.

4.1.3 Standard proctor test

Optimum moisture content (OMC) is determined for finding the amount of water to mold the rammed earth. Soil has to bemixed with optimum moisture or wet of OMC [1]- [4]. When the soil sample is sieved through a 4.75 mm sieve,only less than 50% is retained in the sieve hence light compaction is carried out with the soil sample [11]. Otherwise, heavy compaction is to be done and OMC and MDD are to be found out. From the compaction test, 12%and 2.02 g/cc are obtained as OMC and maximum dry density (MDD). In actual construction at the site, the mould is filled with soil and rammed to its half height.

4.2 Compressive strength test on rammed earth prism

Rammed earth prisms of 450mm in height, 300mm in width, and 150mm in thickness stabilized with 6% of cement and compacted in 3 layers are used to evaluate the compressive strength properties of rammed earth walls. The earthen prisms are tested in the UTM (Fig.2) after 28 days of wet burlap curing. Adopting a FOS of 4 for the slenderness effect and applying it to the obtained average compressive strength of 2.4 N/mm^2, the allowable compressive stress calculated is 0.6N/mm^2. For domestic construction up to two

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stories, this stress is safe. Proper stabilization and compaction improve the compressive strength properties of rammed earth. The obtained results can be compared with numerical analysis. If compatible results are obtained walls of larger dimensions can be assessed.

Figure 2: *Compression test on rammed earth prism*

4.3 Test for durability

IS: 1725 -1982 [10] recommends a spray test on cubes of 150x150 mm to study the durability of rammed earth specimens. By adjusting pressure intensity to different levels water is sprayed through a shower for 2 hours on any of the exposed surfaces of the block as shown in Fig.3. To pass the weathering test, the depth of pit formed on the surface after exposing to the water spray tobe limited within 10 mm. The surface exposed to the spray of the rammed earth specimen before & after the test is shown in Fig.4. Here in the experiment, a pitting depth of 2mm is obtained which was well within the value and it suits to be turned into a rammed earth wall. The same test can be done on a large scale [12] with a prism and walls with a large spray nozzle with average impact intensity of rain in a particular region and pitting depth can be determined to study the durability of rammed earth elements.

Figure 3: *Spray test with shower on cube specimen*

Figure 4: *Surface of cube specimens before & after the durability test*

4.4 Drying shrinkage test

Shrinkage measurements are taken after wet burlap curing of rammed earth cylinder specimens of 200mm in height and 100 mm in diameter. It is reported in the studies of John Thuysbaert [9], that for load-bearing application, shrinkage (change in length to original datum length) should be within 0.5%. The same was obtained in the shrinkage studies of the rammed earth specimens under test. The variation of drying shrinkage obtained on 1, 3, 5, 7, 14, 28, and 56 days is shown in Figure 5. Shrinkage characteristics mainly depend upon the nature and amount of clay that is present in the soil. It is important to limit the clay content well within the specified limits to counteract the damages caused due to the shrinkage and swelling of rammed earth elements.

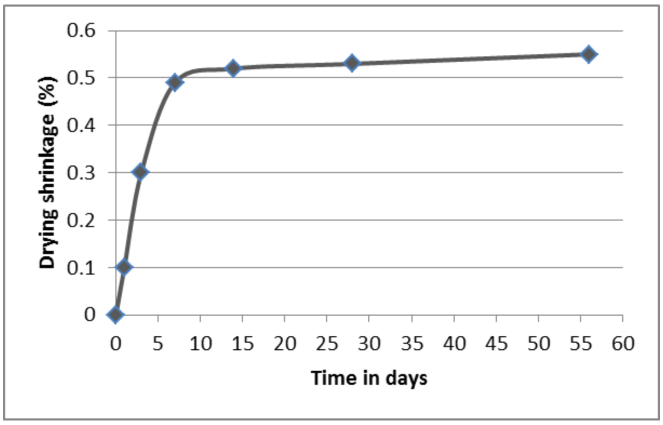

Figure 5: *Variation of Drying Shrinkage with Time*

5 Conclusion

(1) For rammed earth construction, the soil should have a particle size distribution and consistency limits well within the limits. Proper modifications have to be made to the soil if it goes out of limits.

(2) The addition of stabilizers improves the strength properties of the rammed earth, but more sustainable stabilizers have to be identified and their quantity to be optimized.

(3) Compressive strength studies on rammed earth prism resulted in an acceptable value for load-bearing walls &can be studied on a larger scale experimentally or with numerical analysis

(4) Drying shrinkage and durability tests are two important tests to be passed by the rammed earth samples to verify its acceptance in varying climatic conditions.

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