

Structural Properties of Cement Stabilized Rammed Earth

C. Jayasinghe and N. Kamaladasa

Abstract: Earth is gradually gaining popularity as a structural material due to the desirable properties that can be obtained with various stabilization techniques. Cement stabilized rammed earth is one such application which can offer many advantages such as walls that will not need any mortar or plaster. The wider application of this material for walls of single and two storey houses will need strength and durability characteristics. The strength parameters relevant to compressive and flexural behaviours were found using a detailed experimental study using wall panels. The durability characteristics were tested with panels soaked in water for 24 hours. The applications of above parameters for single and two storey houses were highlighted.

Keywords: Rammed earth, Structural properties

1. Introduction

The prevailing scarcity of conventional building material based on natural resources indicates the importance of developing alternative building materials. The continuous use of burnt clay bricks or cement sand blocks as walling materials has led to the over exploitation of many natural resources with the associated environmental problems. The problems associated with excessive clay and sand mining can be highlighted as examples.

Due to the scarcity of conventional building materials, the awareness and interest on earth as a building material has grown very much all over the world [1], [2], [3], [4]. Already, cement stabilized soil blocks have become a viable alternative to bricks and cement sand blocks in Sri Lanka. Another alternative is cement stabilized rammed earth. This can offer many advantages in the light of the severe sand shortage prevailing in Sri Lanka since the walls will not have any mortar joints. Since it can be constructed to give a reasonably straight and smooth surface, the need to apply plaster can be minimised. Thus, the consideration of rammed earth as an alternative walling material is extremely worthwhile. The wider applications will need the strength characteristics so that proper engineering design methods can be used with various applications. This paper highlights the findings of a detailed research carried out using wall panels made with different soils and cement contents tested for compressive and flexural properties. Further, rammed earth construction requiring unskilled labor comes as a solution to

the scarcity and eventual high price of skilled masons, making it advantageous than any type of block construction.

2. Objectives

The main objective was to assess the following main design parameters.

- a. Compressive strengths and associated parameters
- b. Flexural strengths
- c. Wet strengths and durability aspects

3. Methodology

In order to achieve the objectives, a number of wall panels were cast with different types of soils which were tested under compression and flexure. Wall panels immersed in water for 24 hours were also tested under compression. These results were compared with results obtained in various other countries to determine the suitability of laterite soils available in Sri Lanka for rammed earth construction.

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4. Manufacturing process of rammed earth panels

Rammed earth walls are formed by compacting the prepared soil inside a set of temporary forms. The soil is mixed with the chemical stabilizing agent (cement) [4], [5], [6] and a very small amount of water if the soil is too dry. The size of the moulds used in the experimental programme are 2'-0" (0.6 m), 4'-0" (1.2 m) and 6'-0" (1.8 m) feet long which can form 12'-0" (3.6 m), 10'-0" (3.0 m), 8'-0" (2.4 m), 6'-0" (1.8 m), 4'-0" (1.2 m) and 2'-0" (0.6 m) long walls by combining two or three moulds. The soil is placed in layers of 100 mm to 150 mm thick and each layer is compacted with the manually operated hammer (Figure 1). Once the soil is compacted well, the formwork is moved upwards for the next lift of the wall.

The optimum water content is about 9.5 – 11.0% and the maximum dry density is about 20 kN/m³ for compaction levels. Mechanical stabilization by dynamic compaction seems to give better results as compared to static or vibro-static compaction [1]. The optimum moisture content (OMC) for rammed earth soils is critical in order to achieve maximum dry density through dynamic compaction, which will directly influence the strength and durability of the material [2].

The moisture content during the soil mixing stage was controlled by a simple test called drop test. A ball is made in the palm using a small sample of soil and then dropped on the floor from about 1.0 m height. If it breaks into 4 or 5 pieces, the moisture content is satisfactory. If it crumbles away, the soil is too dry or if it drops as one pat, it is too wet [7].

Not all soils are suitable for rammed earth construction. The Soil should be reasonably well graded between gravel to clay size particles. The main soil constituent for rammed earth is sand (40-70%). Clay content from 10-20% is generally sufficient for binding as higher clay contents may result in excessive shrinkage [8]. The research carried out at the Department of Civil Engineering, University of Moratuwa in 1999 by Jayasinghe & Perera [9] has shown that a clay content less than 30% is most suited for compressed earth blocks which are stabilized with cement. Therefore, in this study, three different laterite soil types were selected which can be identified as sandy, gravelly and clayey soils.

Unlike the other building materials, general suitability of soil composition for construction is not readily standardized because of its inherent natural variability. However, it is considered as an ideal replacement to reduce the environmental impacts, green house gas emissions and embodied energy [10]. Rammed earth technology is also suitable for soils with a high percentage of large grain size particles [1].

The three types of soils used for the experimental programme have material properties given in Table 1.

The results given in Table 1 were obtained from the sieve analysis. The silt and clay contents were considered together as this cannot be separated at the site conditions. At site, these proportions can be determined by conducting a jar test. As this technology will be popularized in the rural areas, where there can be difficulties in testing samples at laboratories, the jar test is an ideal measure to determine the soil type. In this simple test, a soil sample is placed in a bottle to about 1/3 the volume, the rest is filled up with water, shaken it well and left for about 24 hours. The composition of the soil sample can be seen as layers to approximately identify the constituent material [7].

Another important parameter that is of significant importance to strength and durability is cement. However, the cost of construction is very much affected by the cement content. Therefore, the optimum cement content should be determined to meet the strength requirements of single and two storey load bearing constructions.

Cement stabilization of soil increases the elastic modulus of the wall. It changed from 1.89 GPa for unstabilised soil to 2.51 GPa for 10% cement stabilized soil [1]. Since the wall has no joints, it can be adversely affected by shrinkage. The cement can control the shrinkage once the wall gains sufficient strength. It was found that shrinkage of cement stabilized soil increases rapidly during the first four days and at a later age the increase is very slow. Hence, curing during the first four days is very important in reducing drying shrinkage and cracking. Sand particles reduce the shrinkage as it opposes the shrinkage movement [1].



5. Wall panel testing for compressive strength

Wall panel dimensions were determined in such a way that the slenderness effects will not be predominant. The panels were constructed with three soil types mentioned in Section 4. A panel being tested is shown in Figure 2. In addition to the compressive strength characteristics, the load deformation curve was also obtained. The load versus deflection values were used to find out the load deformation behaviour of rammed earth panels.

Two panels were constructed and tested for each parameter as stated in BS 5628: Part 1:1992. The ultimate load given in Table 2 is the average of the two values obtained for the identical panels. The summary of the results are given in Table 2. The average strength of wall panels is given in Table 3.

The characteristic compressive strength, f_k of any masonry is determined by tests on wall specimens using the following equation (BS 5628: Part 1: 1992) [11]:

$$F_k = F_m / A \times \Psi_m \Psi_u / 1.2 \dots\dots\dots(1)$$

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 is the reduction factor for strength of mortar

Ψ_u is the unit reduction factor for sample structural strength

The factor 1.2 is introduced to relate the characteristic value to the mean value. Both Ψ_m and Ψ_u are taken as 1.0 since no mortar is used.

According to the results obtained for the three different soil types, sandy soil gave better results for the characteristic strength. This confirms the findings made at the University of Bath, United Kingdom [8].

These strengths indicate that a characteristic compressive strength of 1.5 N/mm^2 could be used for rammed earth walls. This is more than sufficient for single storey construction and hence economy can be achieved by using a wall thickness of about 140 – 160 mm. For two storey

load bearing wall houses, wall thickness of 240 mm may be a possibility as recommended by Perera and Jayasinghe (2003) [9], with cement stabilized soil blocks. However, it is advisable to have more testing on thicker walls prior to actual adoption of this for two storey houses.

The weight of a panel varies from 190 kg to 220 kg. The density of rammed earth is in the range of 1800 to 2000 kg/m^3 .

Wet strength of wall panels was determined after soaking the panels in water for 24 hours. Wet strength results are given in Table 4. For this, the complete panel was immersed in a water bath for 24 hours. Due to the difficulties of doing an immersed test, only the panels with gravelly and clayey soils were used. These would be more susceptible to the strength decrease due to water.

Heathcote (1995) [3] has stated that the ratio of wet to dry strength be used as an indicator of the durability of earth wall components. The ratio of wet to dry strength of 0.33 – 0.5 may be regarded as suitable depending on the severity of rainfall.

Table 4 shows that panels made with even gravelly or clayey soils can give a ratio more than 0.33. Therefore, the strength of rammed earth walls under adverse conditions will be adequate.

According to the experimental results obtained for load deformation characteristics, rammed earth walls behave in a similar manner to the other masonry walls.

However, all three soil types gave load deformation characteristics with little warning before failure. As most of the panels did not show significant cracking before the ultimate crushing failure, a higher factor of safety is recommended in structural design of rammed earth walls. The availability of a compressive strength in excess of 1.5 N/mm^2 can give a very high factor of safety for single storey construction. New Zealand Standards [12] considers design strength of 0.5 N/mm^2 as adequate for single storey construction. This includes a factor of safety of about 5. Thus, rammed earth walls with commonly available laterite soils of low clay content can give a factor of safety close to 15 and hence can be used with confidence for single storey construction.



6. Flexural properties of rammed earth

Flexural properties are of less significance than compressive strengths for load bearing masonry construction. New Zealand Standard [12] takes the characteristic bending strength equal to 10% of the characteristic compressive strength or about 0.1 N/mm^2 when no other data is available. Australian earth building hand book recommends ignoring any material strength in bending in the absence of test data [6].

In order to determine the flexural strength of rammed earth, a special test method was adopted. A wall panel was constructed over a concrete lintel of 75 mm thick and 160 mm wide. A rammed earth panel was constructed with a 725mm height. On this, again a concrete lintel was placed. The length of the panel was 1900 mm and it was loaded to failure by applying loads as shown in Figure 3. A panel used for flexural testing is shown in Figure 4. The failure occurred with the formation of diagonal cracks which initiated at the supports. It should be noted that the concrete beams will be of very little influence to the failure load since the section predominately consists of cement stabilized rammed earth. Since the shear failure occurs due to direct tensile stresses induced in the wall, the failure stress can be used as an indication of tensile strength of the material. For the two panels tested, the shear stresses at first crack were 0.239 N/mm^2 and 0.31 N/mm^2 respectively. These give an average value of 0.275 N/mm^2 . Therefore a value of 0.1 N/mm^2 recommended in New Zealand Standard [12] can be used for walls made with cement stabilized rammed laterite soils. This can be used to check the lateral stability of the walls such as free standing or simply supported at the top.

Vertical bending moment capacity of the wall is given by [6]:

$$M_{cy} = (f_t + f_d) \times Z \dots\dots\dots(2)$$

Where, f_t - characteristic design bending strength of rammed earth which can be taken as 0.1 N/mm^2 .

f_d - design compressive stress at the cross section

Z - Section modulus of the cross section under consideration

7. The uses of the strength properties

The strength properties obtained from this detailed study can be used for a number of applications in the structural design of single and two storey houses. Some of them are highlighted below.

1. Design of load bearing walls subjected to vertical loads in single and two storey houses. This can be carried out using the design guidelines given in BS 5628: Part 1:1992, [11] and with a characteristic strength of 1.5 N/mm^2 .
2. The flexural properties can be used to predict the lateral load carrying capacity of free standing walls as presented in Cl. 36.4.3 of BS 5628: Part 1: 1992 [11].
3. The compressive strength can be used to determine the adequacy of internal return walls to carry both in-plane loads caused by lateral loads on outer walls and vertical loads that occur in two storey houses.
4. The shear capacity under flexural loads can be used to determine the reinforcement requirements for foundation strengthening needed in weak soil conditions [13].

It can be seen that the design parameters obtained on experimental basis will provide valuable design data that can be confidently used by design engineers for structural design purposes. This will assist in widening the applications of cement stabilized rammed earth and also making them safer.

8. Conclusions

The development of alternative building materials is of considerable importance in the context of various environmental problems associated with traditional building materials. Cement stabilized rammed earth is one such alternative. Whenever a new building material is introduced, determination of design parameters can enhance the range of applications.

As a result of the detailed experimental programme presented in this study, it is now possible to use rammed earth as a strong and durable material for wall construction. The design strength indicates that characteristic wall strengths in excess of 1.5 N/mm^2 can be obtained with cement stabilized rammed earth using



laterite soils. The sandy laterite soils have shown the best behaviour. Thus, it is ideal for single storey construction. It can become a potential building material even for the load bearing ground floor walls of two storey houses

Table 1: Particle size distribution of soil types

Soil type	Particle size > 19 mm	Gravel% content	Sand % content	Fines% content (clay and silt)
Sandy	4.3	32.2	59.4	8.4
Gravelly	17.9	56	29.6	14.4
Clayey	6.4	50.5	30.4	19.1

Table 2: Results for the compression testing of panels

Soil type	Cement %	Load at first crack (tonnes)	Dimensions (mmxmmxmm)	Average load (tonnes)
Sandy	6%	*	1045 x160 x633	41.65
	8%	*	1050 x 155x640	58.20
	10%	45.0	1050 x160 x645	61.25
Gravelly	6%	*	1040x160 x 650	33.70
	8%	*	1020 x160 x630	31.75
	10%	44.0	1035 x150 x640	67.45
Clayey	6%	*	1040 x163 x640	31.10
	8%	*	1030 x165 x630	34.50
	10%	30.0	1050 x160 x698	37.60

*- no cracks formed before failure

Table 3: Average strength of wall panels

Soil	Cement	Average strength (N/mm ²)	f _k (N/mm ²)
Sandy	6%	2.47	2.06
	8%	3.525	2.94
	10%	3.71	3.09
Gravelly	6%	2.03	1.69
	8%	1.97	1.64
	10%	4.34	3.62
Clayey	6%	1.82	1.52
	8%	2.06	1.72
	10%	2.30	1.92



Table 4: Wet strength results

Soil type	Cement %	Load at first crack	Ult.load (tonnes)	Dimensions (mmxmmxmm)	Weight (kg)	Strength (N/mm ²)
Gravelly	6%		22.5	1080 x160x630	218	1.30
Clay	6%	12	14	1030 x160 x640	216	0.85

Table 5: Ratio of wet/ dry strength of rammed earth panels

Soil type	Cement %	Dry strength	Wet strength	Ratio
Gravelly	6%	2.03	1.30	0.64
Clay	6%	1.82	0.85	0.46

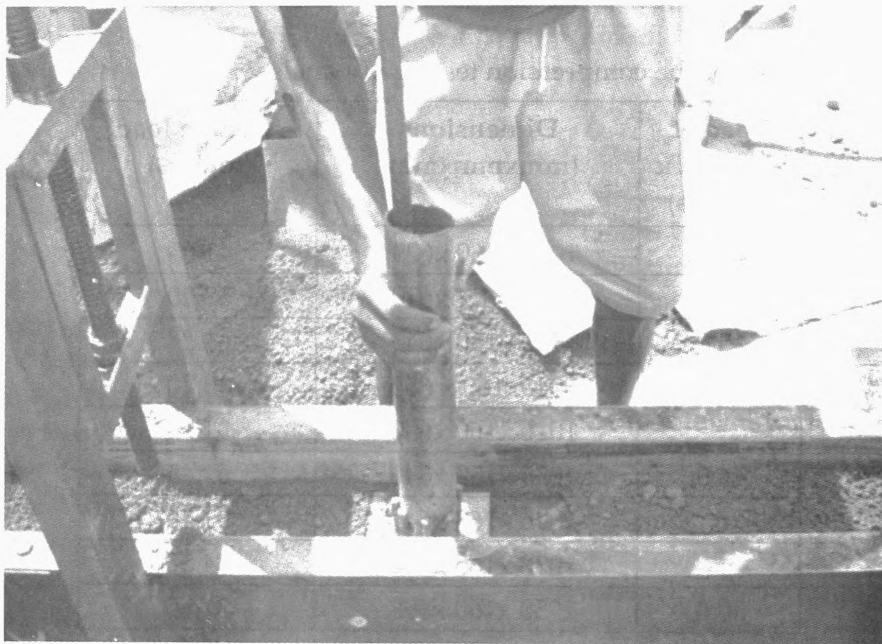


Figure 1: Moulds and hammer used to construct the rammed earth walls

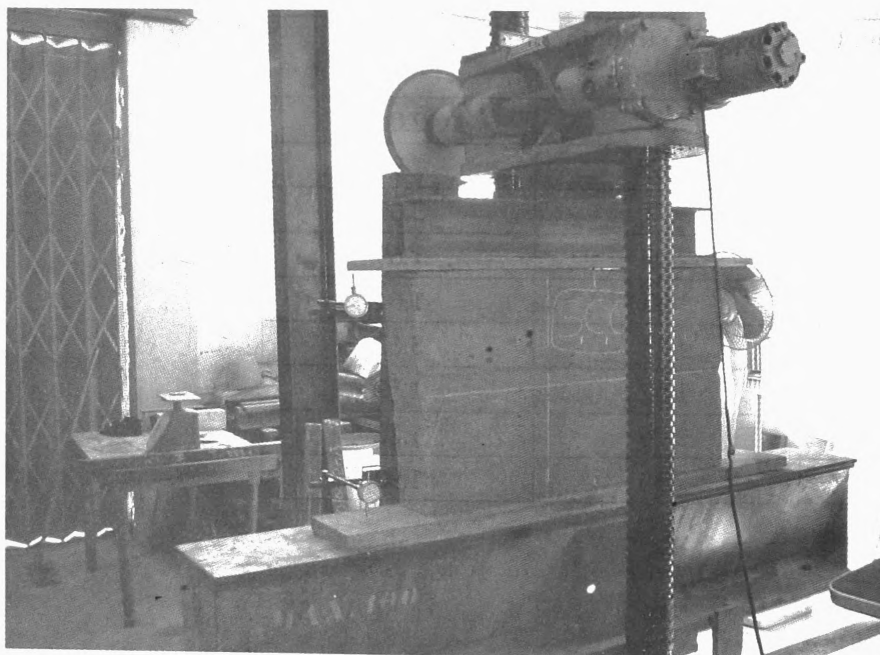


Figure 2: Panel being tested in the compression testing machine

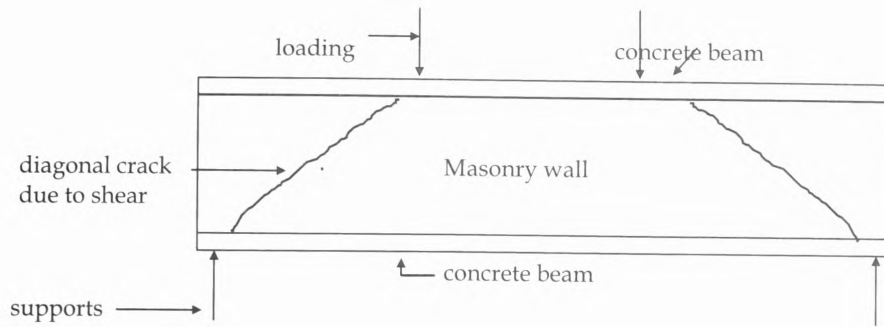


Figure 3: Testing of reinforced masonry beams in two point loading



Figure 4: Wall panel used for flexural testing

which should be further investigated with additional laboratory experiments on the structural behaviour. The characteristic flexural strength obtained is more than 0.1 N/mm^2 . Although it appears as a low value, this can give a significant lateral load carrying capacity for a thick wall. Since the weight of the structure will act as an advantage, it is possible to obtain suitable housing layouts that will have adequate vertical and lateral load resistances. Thus, rammed earth could be considered as a material of comparable strength to good quality bricks available in Sri Lanka.

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