Development of an efficient Construction Technique for Rammed Earth

N. Kamaladasa and C. Jayasinghe

Abstract: The increase in demand for building materials due to rapid reconstruction programme has given many opportunities for wider application of alternative building materials. Earth is gradually gaining popularity as a structural walling material due to the desirable properties that can be obtained with stabilization techniques. This paper describes construction aspects of rammed earth which can be successfully used as a walling material. Investigations were carried out on stabilization techniques, construction details with slip form methods and cost economics. This paper includes the details of rammed earth construction for rapid building of houses.

Keywords: rammed earth, slip forms, stabilization

1. Introduction

Rammed earth walls are formed by compacting damp soil between temporary forms. Since soil has poor strength characteristics and dimensional stability, cement can be used as a stabilizing agent. Rammed earth technology has been used in many countries with varying degrees of success [1], [2], [3]. Some of these buildings are still surviving which were built about 200 years ago in United Kingdom. Therefore, rammed earth could be considered as an alternative building material to be adopted in Sri Lanka.

Since rammed earth walls are made by compacting soil in between a suitable shuttering system, certain amount of time is spent erecting, aligning, checking, stripping, cleaning, moving and storing the formwork. It is reported by Walker and Maniatidis [4] that about 50% of the time is spent with the formwork related activities and only the rest for actually constructing the wall. In an environment where unskilled labour is less costly and where voluntary labour or family labour is available, the additional time consumption is not decisive as it could be easily compensated by the reduced cost of material. Hence especially in community and self help projects, this technology could be of valuable use.

However further reduction in labour would enhance its applicability. Most of the rammed earth structures around the world have used some type of formwork for centuries with only small variations. The traditional formwork comprises two timber shutters usually made out of soft wood planks of 19 mm thickness [5]. These are generally tied with steel bolts. Since the labor for formwork dominates, it will have a notable effect on the construction cost. Therefore, improving the formwork systems with suitable modifications could be the key for reducing the cost of construction of rammed earth. This paper explains the adoption of rammed earth in combination with cement stabilized soil block technology and slip forming for single storey houses.

Apart from the reduction in cost, it has other benefits such as thermal comfort, eco-friendliness, close-to-nature appearance (increasing valued by the urban dwellers), etc. However this technology will be of significant importance in the present context where traditional building material are in short supply and becoming expensive day by day, especially because of the gradual acceleration of tsunami reconstruction work. Thus, cost effective alternative building materials could play a key role in providing large number of houses for the Tsunami affected families in a short period of time with minimum impact on the environment.
2. Objectives and methodology

The main objective of this research was to minimize the labour component needed for the rammed earth technology used for single storey houses. The following methodology was adopted for this research:

1. The typical layouts suitable for basic single storey houses were reviewed.
2. These layouts were modified to suit the fixed length slip forms and cement stabilized soil blocks so that house could be constructed in two stages.
3. This technique was adopted in actual houses to check the viability.
4. A cost study was performed to determine the cost effectiveness of the developed technology.

3. The key features of a basic house

A basic house constructed in Sri Lanka should preferably have two bedrooms, a living area, and a kitchen, attached or detached toilet depending on the availability of water service.

It also should have sufficient head room and openings to create thermal comfort. Open verandah is also an essential element in the design given the social needs of most communities.

Wind loads are rarely a major concern for low rise earth buildings. Compliance with simple empirical guidelines for minimum wall thickness, maximum slenderness and provision of openings (windows, doors) is sufficient for most low rise buildings.

It is recommended by the Australian earth building hand book that the total combined horizontal length of all openings in a wall should not exceed one –third the total wall length [5]. Figure 1 explains the guidelines recommended for provision of openings.

If traditional rammed earth techniques are used for this type of houses, there can be time consuming operation to maintain the verticality and forming the corners. Therefore, it is important to make these operations more efficient.

4. The proposed system

One of the most difficult tasks of creating a rammed earth wall is maintaining the verticality. This is due to the possibility of shutters moving out of plumb when the wall is tamped.

As a solution, the slip form technology introduced by Dr. A N S Kulasinghe and promoted by the NERD Center, for cement mortar dust walls, was to be adopted with the following modifications:

1. The forms were to slide along the cement stabilized soil block column instead of the pre-stressed concrete column adopted by the initial promoters to maintain verticality.
2. The forms were to be of different lengths to cater for different house plans (necessity arising out of the above because of the different shapes of the column – T and L shapes).

The reasons for modification were as follows:

1. The limited availability of pre-stressed columns (few manufacturers in and around Colombo).
2. The weight of the column that requires several people to handle in both transporting and erecting.
3. Difficulty of use it in gable walls that requires columns of different heights as it comes in pre set lengths.
4. Different thermal expansion properties that create stresses and separation in and around contact surfaces between the concrete column and rammed earth.

Unlike the pre-stressed column which is square, the soil block column proposed is of three different shapes (square, L or T) depending on the location of the column. Thus these columns also provide a braced structure. A lintel beam right round the house that could be tied down to these columns could enhance the lateral stability.
Figure 1: Guidelines for the provision of openings [5]

Figure 2: Rammed earth wall under construction
The block has other advantages. A hole available in the block provides space for a reinforcement bar to be embedded to the column (and anchored to the foundation) increasing its strength and stability and also providing a safe anchor to the roof at the top.

The appearance that the column gives and the feeling it creates as an eco-friendly element are also considered as added advantages.

Cement stabilized blocks can be manufactured using machines to various thicknesses. For example, a comprehensive study was carried out by Jayasinghe and Perera [6], [7] using blocks of 140 mm and 240 mm thickness manufactured using Auram Press 3000 machine. These blocks were subsequently used for two storey load bearing construction [8]. They can be manufactured using hand moulding as well as using steel moulds [9], and hence suitable for rural applications as well. Therefore, the use of cement stabilized blocks should not pose a disadvantage in terms of availability and strength.

This will allow creation of rammed earth walls as thin as 140 mm or as thick as 240 mm depending on the requirements.

The building regulations adopted in Sri Lanka indicates a minimum thickness of 125 mm for the external walls. Since it is preferable to have reveals of some thickness at doors and windows, a thickness of 160 mm was selected for the rammed earth walls. This could be done with a commercially available cement soil block which is hence used in the columns.

Since the form rises continuously the labour required to handle the formwork can be minimized. The wall system under construction can be seen in Figure 2.

5. **The expected strengths**

It was shown by an earlier study by Jayasinghe and Perera [6], [7] that the compaction ratio is an important parameter for the strength characteristics of block walls. A compaction ratio greater than 1.65 is recommended for obtaining a good strength. A cement content of 4% to 6% is found to be adequate with soils containing less than 30% fines (clay and silt) [7]. Therefore, soils satisfying above conditions were used with 6% or more cement for the initial trials. It was found that a compaction ration of more than 1.65 can be given with two compaction passes with a special rammer shown in Figure 2 made with steel. It was recommended to have a compaction ratio of 2 for the rammed earth walls.

The cement stabilized soil blocks with 6% cement can give block strength in excess of 2
N/mm². However, the characteristic wall strengths were in the range of 1.0 to 1.5 N/mm². This can be attributed to the mortar joints available at every 90 mm. This is similar to the brickwork where the strength of the walls is lower than the compressive strength of individual bricks as specified in BS 5628: Part 1: 1992 [10].

However, rammed earth has no joints and hence of the same material over the full height. For cement sand blocks with height to width ratio of 2.0, BS 5628: Part 1: 1992 specifies wall strengths similar to the block strengths. All these evidence indicates that the rammed earth walls can be expected to have compressive strengths approximately equal to the individual block strengths and hence should be above 1.0 N/mm² as expected for cement stabilized block walls. A detailed experimental programme for the determination of strength characteristics is in progress and the findings have already been included in another publication. These results have indicated wall strengths are well above 0.9 N/mm². For single storey houses, the compressive stresses are primarily due to the self weight of the wall and the roof. It is generally in the range of 0.1 N/mm². With a partial factor of safety of 3.5 for material strength (γm) and 1.4 for partial safety factors for dead loading (γd) an overall factor of safety of about 5.0 is applicable for masonry construction. Thus, the required strength will be about 0.5 N/mm². This is the value recommended in New Zealand Standards [11] for rammed earth construction. Such strength can be easily expected with rammed earth since the compaction ratio is more than 1.65 and also there are no mortar joints.

5. The layouts required for rammed earth

The slip form shutters are made to lengths of 0.6, 1.2 and 1.8 m. By combining them the lengths can be increased to 2.4, 3.0 and 3.6. Thus, wall lengths should be in special values as shown in the Figure 3 which is a picture of the model house done at Pellawatta. Once the desirable plan is selected, the dimensions should be adjusted to suit the rammed earth moulds.

There is also another alternative to overcome this limitation. That is done through extending the corner column constructed to take up any additional length required for the wall, provided that the dimensions of the column are aesthetically acceptable.

7. Cost study

A detailed cost analysis was done to see whether this material is comparable with the conventional walling materials such as burnt bricks and cement blocks. The cost study was done for the model house constructed at Pellawatta, Battaramulla. The wall thickness is 160 mm and the cement percentage used is 10% (1:10 cement and soil). Table 1 gives the detail cost of the rammed earth wall construction. However in actual house construction there can be further cost reductions such as soil available at site and using local labour for the construction etc. At the time of model house construction the laborers were in the learning phase and this will improve with experience and the time spent for the construction will be much less than that spent for the model house construction.

8. Conclusions

The demand for alternative building materials is becoming higher as the commonly used materials would cause environmental problems. This detail study was conducted on cement stabilized rammed earth as a walling material. Investigations were carried out on appearance, construction aspects, structural properties, durability and the cost. From this comprehensive study it has been proven that cement stabilized rammed earth is having comparable performance as a walling material.

The slip form moulds can be used successfully to form the walls with stabilized soil block columns. The construction time can be optimized with slip forming and interlocking stabilized soil block columns. Stabilized soil block and the stabilized rammed earth will behave in a similar manner and form a uniform walling system for the house.

The testing programme conducted on structural strength has given much confidence to the structural engineers to design the stabilized rammed earth walls according to the Masonry code BS 5628: Part 1: 1992.

With all these findings cement stabilized rammed earth can be recommended as a good alternative which could be used in Sri Lanka for single storey and carefully planned two storey houses.
Table 1: Cost of cement stabilized rammed earth walls (per 100 Sq ft)

<table>
<thead>
<tr>
<th>NO</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>QTY</th>
<th>RATE</th>
<th>COST</th>
</tr>
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<tr>
<td>1</td>
<td>Main raw materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Cost of soil - extraction, loading and transporting to the site</td>
<td>cube</td>
<td>0.67</td>
<td>750.00</td>
<td>502.50</td>
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<tr>
<td>2</td>
<td>Cost of cement</td>
<td>bags</td>
<td>4.00</td>
<td>500.00</td>
<td>2,000.00</td>
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<tr>
<td>3</td>
<td>Other materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stabilized soil block columns</td>
<td>l.ft</td>
<td>20.00</td>
<td>145.00</td>
<td>2,900.00</td>
</tr>
<tr>
<td>4</td>
<td>Labour</td>
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<td>550.00</td>
<td>550.00</td>
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<td>5</td>
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<td>4</td>
<td>350.00</td>
<td>1,400.00</td>
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<tr>
<td>6</td>
<td>Add for scaffolding</td>
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<tr>
<td></td>
<td>Total</td>
<td></td>
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<td>7402.50</td>
</tr>
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</table>

Total cost per Square of slip form walling out of stabilized laterite soil is Rs. 7,402.50

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References