SUSTAINABLE CONSTRUCTION FOR DISASTER RECOVERY

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ABSTRACT

Sri Lanka can be affected by a multitude of natural disasters such as cyclones, minor earthquakes, Tsunami, floods and landslides. Although it is relatively easier to avoid the sites prone to floods and landslides, the built environments must have sufficient robustness against cyclones and earthquakes. For houses constructed close to the coast, there is some risk of at least partial submergence in a tsunami since it is difficult to predict the distance of travel of waves inland. Therefore, partial or complete damage to houses is of common occurrence in a natural disaster as evident from cyclone of 1978 or tsunami of 2004.

When a rebuilding exercise is undertaken immediately after a natural disaster for resettlement of displaced families, a severe burden is placed in the supplies of building materials. Since majority of building materials used for houses have natural resources as the origin, certain adverse environmental impacts also could occur especially with over exploitation. Some examples are the recent sand crisis and environmental damage experienced due to excessive clay mining. Therefore, paying sufficient attention to sustainable construction will be of extreme importance during the disaster recovery phase. This paper critically evaluates the various alternative materials that could be used for minimizing the environmental impacts while improving the sustainability. Real examples are drawn from the tsunami reconstruction activities carried out in various parts of Sri Lanka where alternative materials such as Compressed Stabilized Earth bricks and blocks, rammed earth, chip concrete blocks and micro concrete tiles have been used.

Key words: Alternative building materials, disaster recovery

1. INTRODUCTION

The recent tsunami disaster that occurred in South and South East Asian region caused a severe devastation resulting in enormous loss of life and property. A key problem created was the loss of business that adversely affected the livelihood of many living in coastal regions. As a key measure to restore the normal life styles in the affected countries, a massive reconstruction programme has to be carried out. The provision of permanent shelter to the affected families is an essential requirement in such a programme followed by providing employment. However, there are many constraints such as limited funds, limited supply of traditional building materials, inadequate supply of skilled labour etc. Amidst these constraints, there is an urgent need to supply the permanent houses as early as possible to prevent the outbreak of various diseases among those confined to temporary shelter.

Mass scale housing will have considerable environmental impacts either due to large scale land preparation or due to increased use of building materials which are generally based on natural resources. Another important feature of permanent houses is the social acceptance. In the long run, the recipients are more likely to accept houses which were similar to those existed prior to the disaster. In the short term, any kind of permanent shelter will have willing recipients. This means that providing permanent shelter will need addressing many problems associated with social, environmental, labour and engineering aspects. This indicates that well thought engineering solution that encapsulate other aspects should be sought in this regard. This paper highlights such alternative solutions developed considering Sri Lanka as a case study. It addresses the cost effective housing solutions developed while considering the need for fast construction, alternative and environmentally friendly building materials and the use of unskilled or semi-skilled labourers as a short term solution to their unemployment problems.

2. OBJECTIVE AND METHODOLOGY

The main objective of this paper is to develop sustainable house construction solution that will have good social acceptance, strength, durability, minimum environmental impact and contribute towards short term employment generation. The following methodology was adopted:

1. The house plans were developed considering the local scenario with respect to immediate and long term social needs, and the availability of land.
2. The alternative building materials developed during the last decade in Sri Lanka were reviewed with the aim of adapting to the above layouts.
3. The possibility of using semi or unskilled labour for each alternative material was assessed.
4. The cost aspects were evaluated to check the economic feasibility.

3. CONCEPTUAL HOUSE PLANS

Since the construction of houses close to the coast is strongly discouraged with declaration of buffer zones, there is a need to find suitable alternative land for many of these houses. Since most of the Tsunami affected families lived in individual houses, multi-storey flat concept would also have lower acceptance. Thus, there is a considerable challenge and need to develop layouts that will facilitate providing detached houses within the constraints on land availability.

Two different scenarios can be identified.

1. Those who lived outside the buffer zone and hence land is available for the construction of houses.
2. Those who will need both land and houses.

Even for the second category, there can be two scenarios:

1. Alternative land can be found and land is not a major restriction.
2. Alternative land can be found but land is expensive and in short supply.

Thus, it is possible to identify two cases such as land is not a restriction and the other, where land usage has to be maximized.

After the tsunami disaster, many donors have come forward to assist with reconstruction of houses. Thus, there is a need to have a professional approach to maximize the number of houses that can be built with the available funds. One of the concepts that can be easily adopted (when land is not restricted) is a two staged house that will fulfill the immediate shelter needs with stage 1. Stage 2 can be constructed by the recipients at a later stage once they return to their normal life and secure a suitable employment. Figures 1 and 2 show two examples for the house plans developed to allow staged construction.

The other concept is for locations where land is restricted. The ideal option is to adopt multistoried concept where each family will receive a multi-story house with part of the land. This will minimize the land needed for each house while ensuring that each family will have access to a small plot of land. An example of this type of house is shown in Figure 3. This option will allow the creation of multiple unit semi detached houses in a given land. This is a concept permitted under the building regulations. It is also possible to replace the roof of these houses with an insulated concrete roof slab. This will allow regaining the land covered by the house.

4. ALTERNATIVE BUILDING MATERIALS

The present trend in the Sri Lankan housing industry is to use conventional building materials such as bricks, cement sand blocks, concrete and timber etc for permanent housing. These are manufactured using natural resources and hence with higher demand, there can be over exploitation of resources which cause environmental problems. For example, excessive clay mining for manufacturing of bricks has degraded many fertile lands suitable for various crops. Excessive river sand mining has deepened and widened the rivers and also allowed the intrusion of salt water along the river during high tide periods. Already the natural forest cover has reduced to about 23% of the total land extent [1]. These problems can be aggravated very much if the required 100,000 houses are constructed with the conventional building materials.

Therefore, the solution lies with alternative building materials that can provide a house with the same appearance as one built with conventional materials. However, the key parameters of alternative materials should be assessed in order to ensure quality of new houses at an affordable price. These include strength, durability, cost aspects, environmental impacts and social acceptability. A considerable amount of research and development has already been taken place with many alternative materials that can be used for walls, concrete slabs and roof. These materials are reviewed to highlight the methods of adopting them for urgent shelter needs with the proposed house layouts.

4.1 Compressed stabilized earth blocks (CSEB)

The tropical climatic conditions prevailing in Sri Lanka is responsible for the availability of laterite soil in many parts of the country. In some locations, they are available as laterite hills, and such lands are not suitable for house construction and hence offer ideal places to obtain soil in large quantities. The reducing the heights and leveling the land can also create very good buildable lands with high property value. Therefore, the environmental effects will not be as high as mining large pits for clay which can subsequently cause mosquitoe breeding if left without filling [2]. Laterite soils can be stabilized to provide blocks of adequate strength. The methods include physical stabilization by sieving to remove large particles, chemical stabilization with cement and mechanical stabilization with a compaction ratio of more than 1.65 (the ratio between the initial soil volume and final volume). A detailed study conducted in Sri Lanka indicated the possibility of obtaining characteristic wall strength in excess of 0.9 N/mm^2 with 4% and 6% cement as the stabilizing agent [3]. This strength is possible with machines operated manually. Such strengths are sufficient for single story houses where the design strengths required with suitable partial factors of safety is less than 0.5 N/mm^2. Cement sand mortar (1:6) or cement, soil and sand (1:6:6) mortar can be used to construct the walls. Strong mortars will have higher elastic modulus, which would reduce the shortening of the mortar under compressive stresses [4]. These blocks are now commercially manufactured and hence can be obtained without any restriction. However, greater demand may need setting up of more plants with automated machines. Another variation of this method is compacting the soil manually in steel moulds [5]. Although the hand moulded blocks may not be suitable for Stage I construction, it could be a good candidate for Stage 2 construction. A major advantage of these blocks is the wire cut brick appearance which allows obtaining an aesthetically pleasing appearance without any plastering thus reducing the burden on already depleted sand supply.

The strength 0.9 N/mm^2 is sufficient even for two storey load bearing construction if suitable thicknesses have been selected for the ground floor walls. The durability of unplastered walls can be enhanced by applying cement soil based paint of 1:1:6 cement: lime: soil ratio mixed with water. On this, any commercially available paint can be applied [6].

4.2. Rammed earth

Earth can be used for construction of walls in many ways. However, there are few undesirable properties such as loss of strength when saturated with water, erosion due to wind or driving rain and poor dimensional stability. These drawbacks can be eliminated significantly by stabilizing the soil with a chemical agent such as cement [7].

Although rammed earth without any stabilizing agent was widely used in Sri Lanka in the ancient times, a better load bearing behaviour can be achieved by cement stabilized rammed earth which was recently introduced. This reduces the amount of soil needed since the wall thickness can be reduced with thinner but strong and durable walls. Recent tests have indicated very promising characteristic compressive strengths such as 1.5 N/mm² with 6%, 8% and 10 % cement with soil, which is more than adequate for single story housing [8].

One of the major drawbacks of rammed earth is the labour required for mounting and dismantling the formwork. This problem is solved recently to a great extent by using cement stabilized block work corner column as guides and using continuously rising slip forms in between the columns as shown in Figure 4. At the moment, more research is undertaken to use this material for load bearing ground floor walls of a two storey house.

4.3. Chip concrete blocks

A by product of metal crushing industry of Sri Lanka is 6-8 mm chips. A detailed experimental program carried out by Jayasinghe (2002) [9] has revealed that blocks of adequate strength can be obtained with lean mixes such as 1:7:12 cement: sand: Chips. This can assist in reducing the quantity of sand needed for manufacturing cement sand blocks. This can also allow a good finish without the need for any plaster

4.4. Pre-cast beam slab system

Good quality timber has been a scarce and expensive material over the last three decades in Sri Lanka due to various controls over clearing of jungles for timber supply. Therefore, timber floors have been not very popular in the recent past. Thus floor slabs are usually constructed with reinforced concrete. However, the solid slabs are also not efficient in its usage of materials since at most of the sections, concrete below the natural axis is used only to provide adequate cover to reinforcing steel. Therefore, an efficient precast beam slab system was developed that would consume only 50% of steel, 60% of concrete and minimum formwork [10]. This can reduce the environmental damage by consuming less material. The structural performance was verified with load testing [11]. Figures 5 shows the details of the slab. This slab system is a potential candidate for floor and roof slabs of multi-storey houses. For the roof slab, a suitable thermal insulation system should be installed to enhance the thermal comfort. There are several other cost effective slab systems available locally such as NERD systems [12], SBS (Suspended Beam Slab System), Hollow core system manufactured by ICC (International Construction Consortium) etc. These are also potential floor slab systems for multi-storey houses.

4.5 Stabilized soil layer as the ground floor

Due to the tropical climatic condition, the ground floor is completed with a cement rendering and when affordable, ceramic tiles can be laid. In order to ensure durability, a 50-75 mm concrete is laid on well compacted soil prior to applying the cement rendering. The hard laterite lumps removed by sieving of soil for the soil block manufacturing can be used as an aggregate for this floor concrete after washing them to remove soil and dust. Alternatively, a cement and laterite soil mix of 1:10 also can be well compacted with 20 mm aggregate embedded at top and the rendering can be laid on it. This will provide a cost effective base for the ground floor preparation of houses.

4.6 Roofing material

Roofing material is not in short supply in Sri Lanka at present. However, rapid construction of many houses may arise the need for using alternative roofing material as well. In addition to calicut tiles and cement fiber sheets, chip concrete tiles and Micro Concrete Tiles (MCR) can be considered as alternatives. These are manufactured with cement sand/quarry dust and chip mix using small vibrating machines.

Micro concrete roofing tile is an alternative option for roof covering material. This is produced with cement, sand or quarry dust and chips (6 mm). The cement, aggregate ratio varies from 1:2 to 1:3. The tile has been made stronger by adding 4 - 6mm chips to the mix. This will give a chip concrete tile with the mix of 1 cement, 1 $^1/_2$ sand or quarry dust and 1 chips. These tiles have given very good load carrying capacity when tested in the laboratory. This in another alternative material which would be ideal for a developing country [13].

For the low income housing these tiles can be hand molded. This option has also been tried and tested as a viable alternative [14],[15]. This is an ideal option for the house owners who have little capital funding and a considerable free time during the day after their daily work schedule.

5. COST OF ALTERNATIVE SOLUTIONS

In order to investigate economic feasibility of alternative material and systems, a detailed cost analysis was conducted for several walling and roofing materials. This includes the production cost, construction cost and the finishing cost. Several building material manufacturers were interviewed and the necessary information was collected for the detailed cost studies. This analysis will be useful to compare different alternatives in terms of overall cost.

Although basic material costs will shed light on various cost components associated with production, a more useful tool in practice is the overall costs. For these materials, the overall costs include the cost of basic units, finishes, frame work where applicable etc. For example, it is the usual practice to plaster the brick walls in Sri Lanka. Block work can be a good candidate for un-plastered walls. However, even block walls are generally given a plastered finish. Cement stabilized soil blocks can give a very pleasing finish externally without a plaster and the interior could be plastered. Rammed earth also could give a high quality finish without plaster both internally and externally, if necessary. These examples indicate that different materials could lead to different overall costs not only due to basic cost variations, but also due to the way they are completed.

5.1 The overall cost of walling materials

The overall cost of walling materials to complete one square (100 ft^2 or $10.8m^2$) is presented. Table 3 presents the comparison of walling material in terms of overall cost. Cost of each item has been evaluated based on the standard work norms and Building Schedule of Rates [16]. For example cost of one square of 9”brick work includes 1090 bricks with 5% wastage, 3 bags of cement, 0.2 cubes of sand, 115 gallons of water with 2.25 days of skilled labour, 3.75 days of unskilled labour and allowing 3% for the scaffolding. This has been worked out to Rs. 12,500/= according to the current prices.

The cost study based on overall cost (basic units and finishes) shed light on the economic feasibility of alternative walling materials. It can be seen that slip formed stabilized rammed earth will cost least. Cement stabilized soil blocks also can be competitive. When the environmental cost is also considered, these options can be given more prominence.

5.2 The overall cost of roofing materials

The overall cost to complete a square (100 ft^2 or $10.8m^2$) is presented in Table 4. The following assumptions were made.

Ridged roof is selected. Workmanship is for frame work and roof covering. Cost for applying wood preservatives is not included. These rates are calculated according to the current market prices of the all building materials [16].

Cement fiber roofing gives the least cost for the roof. However, other materials are also competitive when the overall cost is considered. Therefore the selection should be done according to the overall cost and the other concerns such as environmental cost, thermal comfort etc.

5.3 Cost of floor slabs

The item has been separated from the rest as this element is only used in multi sotrey building construction. Reinforced concrete is the most commonly used slab system in residential buildings. The cost of conventional concrete slab system varies from Rs. 250/= to 300/= per Sqft, whereas the alternative pre-cast systems will offer 20 – 40 % cost reduction in the overall cost of floor slab system since they use only 50% - 60% concrete, about 50% steel and very little formwork and false work. By using alternative slab system, material and labour components can be optimized and sometimes unskilled labour could be given special training on precasting operation. This will not only result in overall reduction of cost of the slab but will save on the environment cost as well.

6. SOCIAL ACCEPTANCE

Social acceptance is a very important feature of introducing a new technology. There are many ways that alternative building materials proposed offer an ideal solution to this. The cement stabilized soil blocks, rammed earth, MCR tiles, precast slab system are all suitable for manufacturing at local level with a combination of semi-skilled and unskilled labour. This means that the people who lost the employment due to the disaster could be invited to participate in their own house construction activities as paid labor. This will solve the unemployment problem to a certain extent in short term while creating a better social acceptance for the technology. This is because, it will take some time to build the confidence on any new technology and the workers will be able to test the suitability of the materials in their own ways when they use them for construction. This will act as a confidence building exercise and could assist in popularizing the technology when building second phase of the houses as well.

7. CONCLUSIONS

The vast amount of resources required to provide quality housing for the families affected by the recent tsunami disaster has necessitated a fresh approach. In this context, many alternative building materials developed in last two decades in Sri Lanka can offer a viable option to reduce the environmental impacts of needing a large number of new houses in a short period of time. A very important aspect is proposing alternative solution for the different constraints imposed by the type of land available. The various building materials reviewed indicated that they can be as strong and durable as the conventional building materials. However, the better finish of these materials can reduce the cost of finishes and hence assist in reducing the overall cost of a house. The manufacture of alternative materials at local level can assist in improving the social acceptance for those new materials and methods. It can also provide a short term solution to the employment problem while creating a sense of ownership.

ACKNOWLEDGEMENTS:

The author wishes to thank the National Science Foundation (NSF) Sri Lanka for providing funds to study more about the topic covered in this paper. The author also wishes to gratefully acknowledge the support given by all the material manufacturers in the data collection stage. Special thanks should go to the Technical staff, Mr.SP Madnayake, Mr. SLKapuruge, Mr. HP Nandaweera of Stucutural Engineering Laboratories who supported the experimental programne on alternative building materials.

REFERENCES:

1. Abeykoon, A T P L, “Population Profile”, in *Natural Resources of Sri Lanka – 2000,* The National Science Foundation, Sri Lanka, pp 9-29, 2000.
2. Ranasinghe, M, Clay mining for building materials: Future land use”, Engineer, Journal of Institution of Engineers, Sri Lanka, Vol. xxvi, No.2, pp42-49.
3. Perera AADAJ, Jayasinghe C. Strength characteristics and structural design methods for compressed earth block walls, Masonry International, 2003; 16(1): 34-38.

4. Reddy BV, Jagadish JS. Properties of soil–cement block masonry, Masonry International, 1989; 3(.2): .80 -84
5. Jayasinghe C., Perera AADAJ, West S., "The application of hand moulded stabilized earth blocks for rural houses in Sri Lanka", *EarthBuild 2005*, International Earth Building Conference, University of Technology, Sydney, 19th – 21st January, 2005.
6. Jayasinghe, C., Perera, A. A. D. A. J., "Alternative Building materials and structural systems for the housing and building sectors", 2003, SASBE 2003 International conference, Brisbane, Australia, Nov. 2003.
7. Standards Australia, The Australian Building handbook, Standards Australia, Sydney, Australia, 2002.
8. Jayasinghe C, Compressive strength results of rammed earth panels, Report submitted to Center for Housing Planning and Building, Sri Lanka by Department of Civil Engineering, University of Moratuwa, 2005.
9. Jayasinghe, M.T.R., "Suitability of hand moulded chip concrete blocks for single storey houses", *Engineer, Journal of Institution of Engineers, Sri Lanka*, and Vol: 35, No: 3, September 2002, pp 24-30.
10. Jayasinghe, C., Perera, A. A. D. A. J., "Alternative concrete floor slab system for residential buildings", *Engineer, Journal of Institution of Engineers*, Sri Lanka, Vol:XXXIII, No: 02, September 2000, pp 54 -65
11. Jayasinghe, C., Perera, A. A. D. A. J., "Load testing on reinforced precast slab system for residential buildings", *Transactions – 2000*, Institution of Engineers, Sri Lanka, pp 96 –106.
12. Kulasinghe, A. N. S. (1998), "Building research and development", Newsletter of National Building Research Organisation of Sri Lanka, March/June, Vol. 8, Number 1-2, pp 1-4.
13. Twist, F. J. and Brys, G., "Technico-Economic report on micro-concrete tile technology in Sri Lanka", International labour organization
14. Jayasinghe C., Jayasinghe MTR, Illangakoon DHS, Gunawardane PK, Edirisinghe ENS., Hand moulded chip concrete tiles, *Transactions - 2004*, Institution of Engineers, Sri Lanka.
15. C. Jayasinghe, MHPJ De. Silva, DMMP Dissanayake, CTKI. Fernando, "Engineering Properties of Micro Concrete Roofing Tiles", *Engineer*, Vol. 39 No 3, 2006.
16. Building Schedule of Rates (2004), Western Provincial Engineering Organization, Sri Lanka.

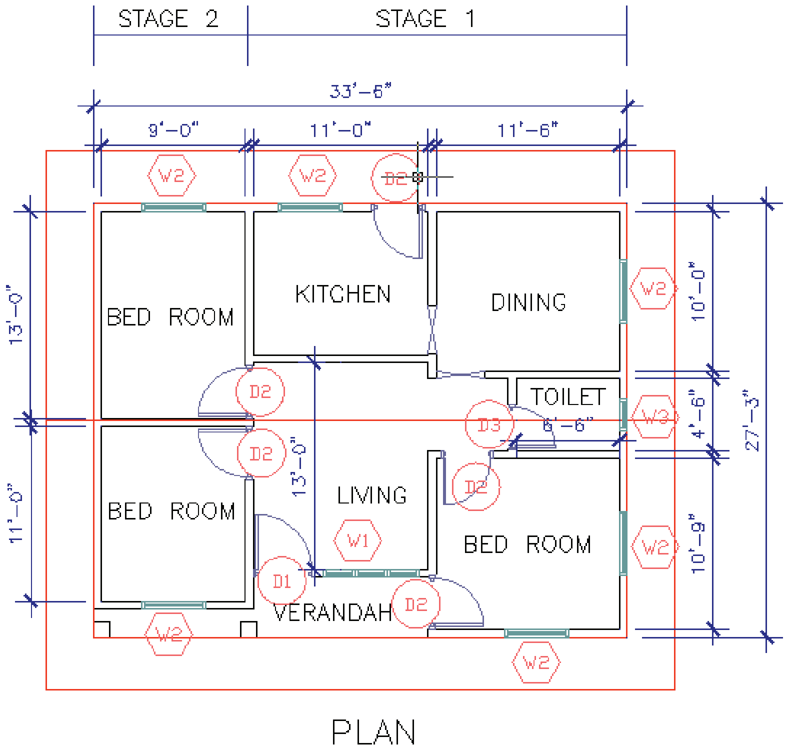

Figure 1: Single storey house plan 1 for two stage construction

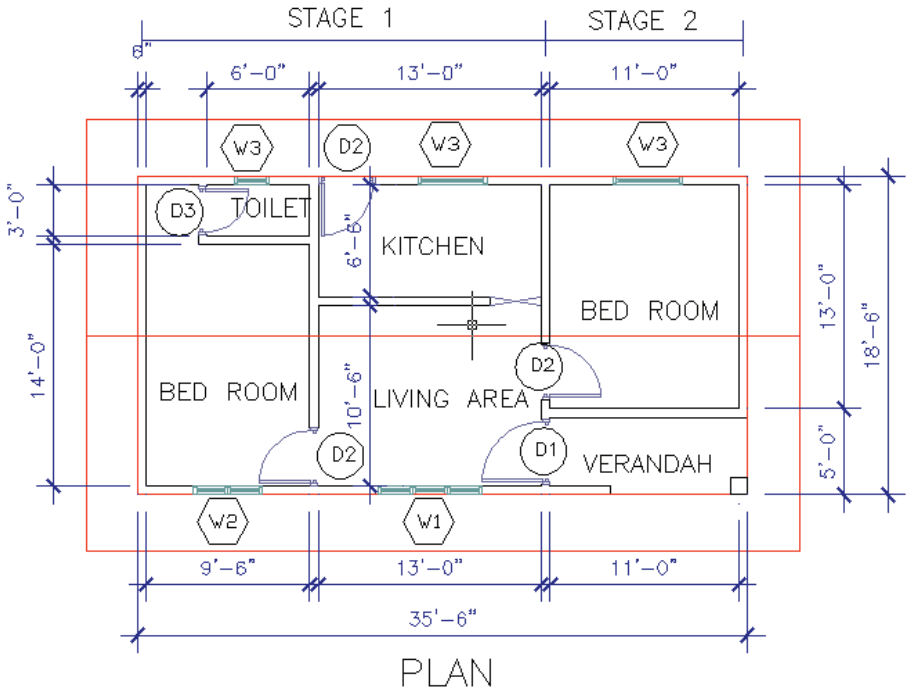

Figure 2: Single storey house plan 2 for two stage construction

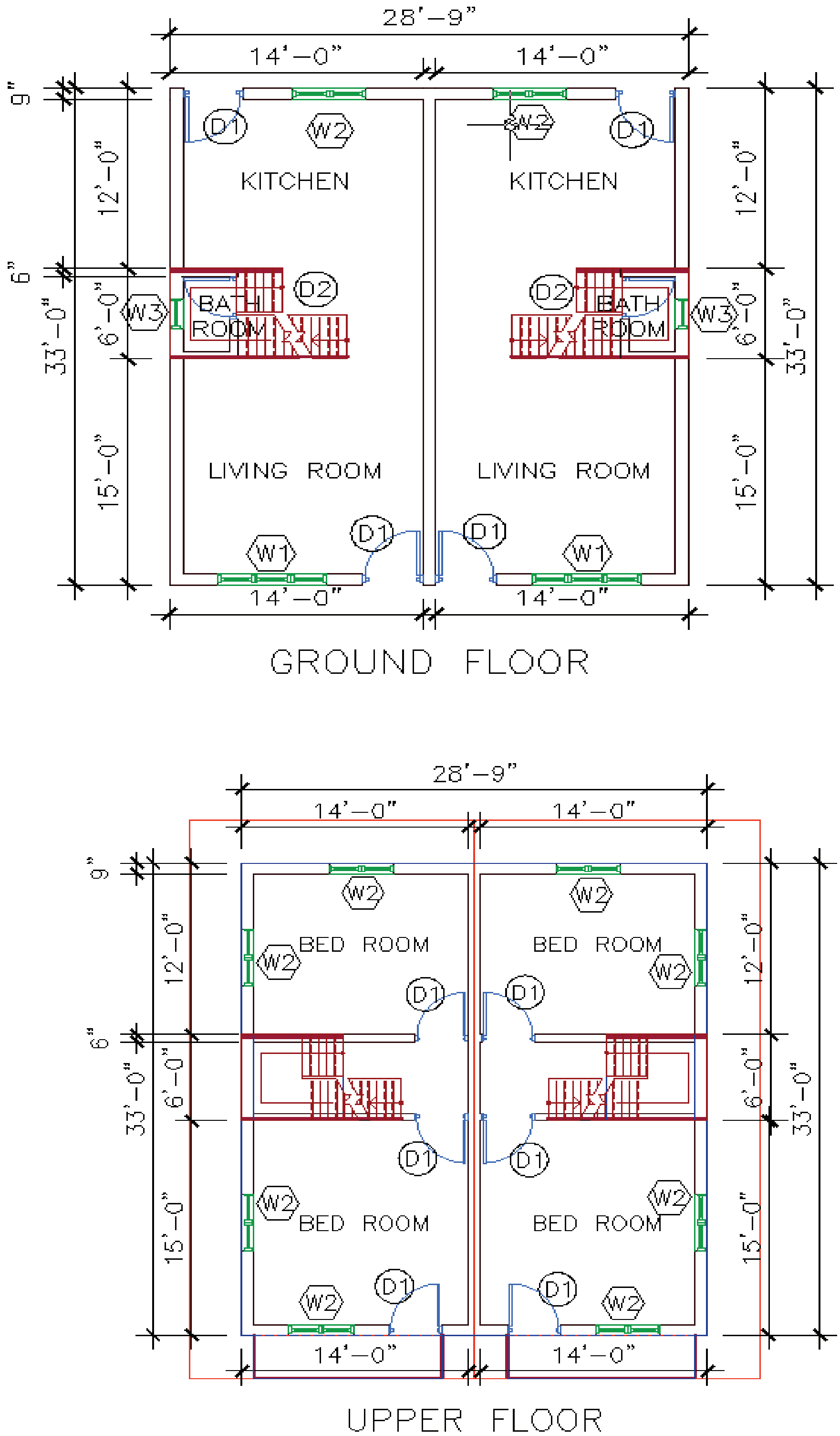

Figure 3: Two storey house plan

Figure 4: Rammed earth construction

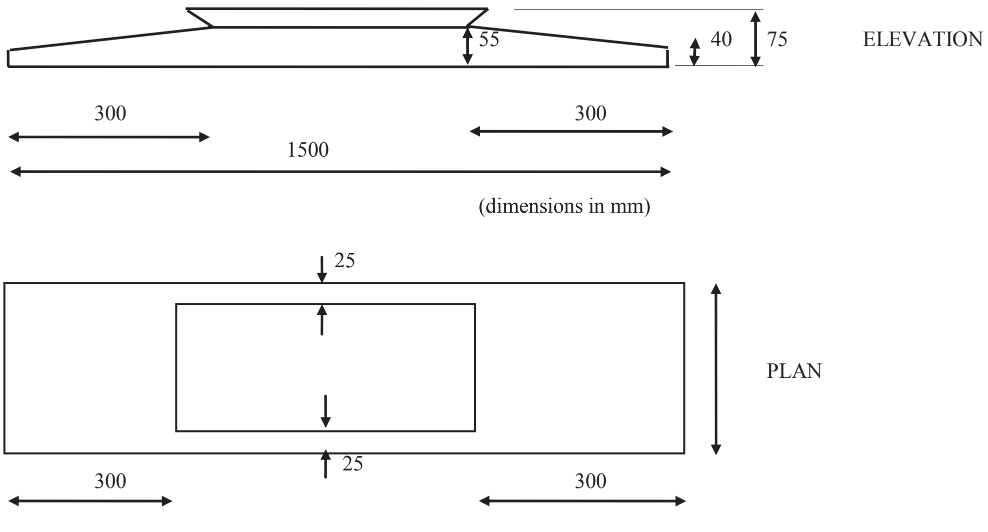

Figure 5 Pre-cast slab panel used for the reinforced concrete composite slab system

Table 1: Cost of walling materials

Description	**Total cost/sqr**
9″ thick brick walls using clay bricks bonded with 1:5 cement/sand mortar mix and finished with 1:1:5 plaster	23,254.00
4.5″ thick brick walls using clay bricks bonded with 1:5 cement/sand mortar mix and finished with 1:1:5 plaster	17,385.00
4″ thick walls using cement blocks bonded with 1:5 cement/sand mortar mix and finished with 1:1:5 plaster	16,100.00
5.75″ thick walls using Compressed Stabilized Earth blocks (CSEB) bonded with 1:4:8 cement/sand/soil mortar mix and finished with a 1:1:5 plaster on the internal surface	13,000.00
5” thick slip formed walls using cement stabilized soil and finished with 1:1:5 plaster on the internal surface	12,000.00

Note: Since the paint cost is common to all the walling material it is not included in the comparison.

Table 2: Cost of roofing materials

Description	**Total Cost / sqr**
Roof covering and ridging with **clay tiles** on a timber frame	13,100.33
Roof covering and ridging with **Micro concrete roofing tiles** on a timber frame	12,542.33
Roof covering & ridging with **Cement tiles** on a timber frame	15,451.03
Roof covering and ridging with **Cement fiber roofing sheets** on a timber frame	9,952.22

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