Chapter 6

THE COST STUDY

6.1 GENERAL

When alternative building materials are introduced, it is important to ensure that the cost of such materials are either lower than or comparable with presently available materials. It has already been shown that cement stabilised soil blocks can be used as a loadbearing material with composite precast beam slab system in Chapter 5.

In Chapter 2, it was shown that cement stabilised soil blocks can be environmentally friendly than conventional bricks or cement sand blocks since laterite soils can be obtained locally with minimum damage to the environment.

It was shown in Chapter 4 that the precast composite slab system can be constructed with minimum use of formwork and falsework thus minimising the use of timber and bamboos; both are considered as depleting resources.

Therefore, the alternative building materials suggested in this research has a strong case even if the costs are not comparable. It will have a very strong case for wide spread use if the costs are lower. It should be noted that the cost of construction materials are changing seasonally and also subjected to general inflation remaining in the country. Therefore, any cost saving presented here is not absolute. However, these cost calculations would provide adequate guidance to carry out a similar study on the basis of prices remaining at the time of computations.

6.2 COST COMPARISON FOR CEMENT STABILISED SOIL BLOCK WALLS

The cost of construction of cement stabilised soil block walls are determined to compare it with the alternative loadbearing materials such as brickwork and cement sand blockwork. Cement stabilised soil blocks can be manufactured either on the basis of paid labour or self help basis. However, in these calculations only the paid labour case is considered since the workers of the self help schemes also would have an opportunity cost which could be equivalent to the paid labour cost.

Since soil can either be available at site or could be transported to the site from nearby laterite hills, two cases were considered for the cost analysis. Those were, soil available at site and soil bought for manufacturing of blocks.

If cement stabilised soil blocks are manufactured for sale, then a suitable mark-up should be added to the cost given in these calculations to cover overheads and profits.

6.2.1 Cost of cement stabilised soil blocks

The cost of cement stabilised soil blocks consist of the cost of soil, cement, labour and machine usage.

6.2.1.1 Cost of soil

The cost of cement stabilised soil blocks depends on the availability of soil at the site. For single storey houses, there may be a possibility for self help schemes, but such methods are unlikely for two storey buildings. Therefore, two options will be considered.

1. Soil is available at site, therefore the cost will only be the labour cost for preparing the soil which is considered as Rs 150/= per 3/4 cubes (1 cube = 2.83 m^3).

2. Soil is not available at site, therefore obtained from suppliers at Rs 400/= per 3/4 cube (a tractor load). This is the average price paid for a tractor load during the experimental programme.

It was found during the experimental programme that it would be possible to make 300 Nos of 290 mm x 140 mm x 90 mm blocks from a tractor load of 75 ft^3 (3/4 cube or 2.12 m^3 as described in Section 3.2.1). The corresponding number for 240 mm x 240 mm x 90 mm blocks is about 200. This is generally independent of the cement percentage. It was reported by Bryan (1988 a) that the density of a block is not affected by the cement percentage significantly. The cost figures calculated are given in Table 6.1.

Table 6.1: Cost of soil for different blocks sizes

Details soil	Cost of 290 x 140 x 90 mm blocks (Rs)	Cost of 240 x 240 x 90 mm blocks (Rs)
Soil is available at the site	0.50	0.75
Soil is transported to the site	1.33	2.00

6.2.1.2 Cost of cement

The cost of cement depends on the percentage of cement used for blocks. It was found during the experimental programme that the cement requirement is such that 300 Nos of 290 mm x 140 mm x 90 mm blocks of 2% cement can be cast per bag of cement of weight 50 kg as described in Section 3.2.1. The corresponding number for 240 mm x 240 mm x 90 mm blocks is 200 blocks. Thus, the figures given in Table 6.2 can be worked out. Cost of a bag of cement is considered as Rs 300/=, where the market prices vary from Rs 250/= to Rs 300/=.

Table 6.2: Number of blocks per bag of cement and cost of cement per block

Cement percentage	290 mm x 140 mm x 90 mm blocks		240 mm x 240 mm x 90 mm blocks	
	Number of blocks per bag	Cost Rs	Number of blocks per bag	Cost Rs
2%	300	1.00	200	1.50
4%	150	2.00	100	3.00
6%	100	3.00	67	4.50
8%	75	4.00	50	6.00

6.2.1.3 Cost of labour

It was found that a crew of four workers consisting of unskilled labourers will be able to make 400 blocks of size 290 mm x 140 mm x 90 mm per day. This was obtained from a construction site near Pannipitiya, where a two storey house was constructed using cement stabilised soil blocks with paid labour. This number is not very much affected by the size of the block. This could be attributed to the fact that the rate of operation of the machine, which is the same for both block sizes, determines the number of blocks. Thus, a total of 400 blocks per day was used as the rate of production of blocks for 240 mm x 240 mm x 90 mm blocks as well. Assuming that the wage of an unskilled labourer is Rs 200/= per day, the cost of production of a block is Rs 2.00/=.

6.2.1.4 Cost of machine usage

Auram Press 3000 machine used for this study can be used to manufacture about 500,000 blocks without much maintenance. Since a machine can cost about Rs 100,000/=, the machine cost per block is Rs 0.20/=.

6.2.1.5 Cost of blocks

On the basis of these costs, the data given in Table 6.3 can be obtained.

Table 6.3: Cost of cement stabilised soil blocks for different cement percentages

Cement percentage	290 mm x 140 mm x 90 mm blocks		240 mm x 240 mm x 90 mm blocks	
	Soil at site	Soil brought to the site	Soil at site	Soil brought to the site
2%	3.70	4.53	4.45	5.70
4%	4.70	5.53	5.95	7.20
6%	5.70	6.53	7.45	8.70
8%	6.70	7.53	8.95	10.20

6.2.2 Cost of 1:6 cement sand mortar for cement stabilised blockwork

The cost of mortar has to be calculated separately for 290 mm x 140 mm x 90 mm blocks and 240 mm x 240 mm x 90 mm blocks. The cost of material used for the calculations are the average values of those paid during the experimental study. The densities used for the calculations are obtained from Kong & Evans (1983).

It is stated that the specific gravity of the particles of cement is generally within the range of 3.1 to 3.2. Generally, it is taken as 3.15 for calculations. The unit weight of bulk cement depends on the degree of compaction. It is taken as about 1450 kg/m^3 (Kong & Evans, 1983).

The specific gravity of aggregate particles depends on the mineral contents of sand and aggregates. The specific gravity is generally taken as 2.60. The bulk density depends on the moisture content and the degree of compaction. It is generally taken as 1700 kg/m^3 for fine and coarse aggregates (Kong & Evans, 1983).

The following data was used:

1. Bulk density of cement = 1450 kg/m^3
2. Solid density of cement = 3150 kg/m^3
3. Bulk density of aggregates (fine or coarse) = 1700 kg/m^3
4. Solid density of aggregates (fine or coarse) = 2600 kg/m^3
5. Cost of 1 kg of cement = Rs 6.00/=
6. Cost of 1 m^3 of sand = Rs 400/=
8. Cost of 1 m^3 of water = Rs 20/=

6.2.2.1 Cost of mortar for 290 mm x 140 mm x 90 mm blocks

The effective size of a block with 10 mm mortar joints is 300 mm x 140 mm x 100 mm. The number of blocks per 1.0 m^2 is 33.33. The volume of mortar per 1.0 m^2 is 0.0182 m^3. The water cement ratio used is 1.2 as measured during the experimental programme. Thus, the quantities required with cement, sand and water can be calculated as follows per bag of cement.

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.0345	50/3150 = 0.0158
Sand	0.0345 x 6 = 0.207	0.207 x 1700/2600 = 0.135
Water		1.2 x 50/1000 = 0.06

Total solid volume = 0.0158 + 0.135 + 0.06 = 0.2108 m^3

The cost per 0.0182 m^3 of 1:6 cement sand mortar

= (50 x 6 + 0.207 x 400 + 0.06 x 20) x (0.0182/0.2108) =Rs 33.13/=

An allowance of 10% is made for variation of densities and wastage. The cost per 0.0182 m^3 of 1:6 cement sand mortar = 33.13 x 1.1 = Rs 36.44/=

6.2.2.2 Cost of mortar for 240 mm x 240 mm x 90 mm blocks

The effective size of a block with 10 mm mortar joints is 250 mm x 240 mm x 100 mm. The number of blocks per 1.0 m^2 is 40. The volume of mortar per 1.0 m^2 is 0.0326 m^3. The water cement ratio used is 1.2. Thus, the quantities required with cement, sand and water can be calculated as follows per bag of cement.

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.0345	50/3150 = 0.0158
Sand	0.0345 x 6 = 0.207	0.207 x 1700/2600 = 0.135
Water		1.2 x 50/1000 = 0.06

Total solid volume = 0.0158 + 0.135 + 0.06 = 0.2108 m^3

The cost per 0.0326 m^3 of 1:6 cement sand mortar

= (50 x 6 + 0.207 x 400 + 0.06 x 20) x (0.0326/0.2108) = Rs 59.35/=

An allowance of 10% is made for wastage as given in Building Schedule of Rates. The cost per 0.0326 m^3 of 1:6 cement sand mortar = 59.35 x 1.1 = Rs 65.29/=

6.2.3 Cost of labour for construction of cement stabilised block walls

One skilled labourer and one unskilled labourer can build 6.0 m^2 of cement stabilised soil block wall in one day. This was observed at a construction site at Pannipitiya where a two storey house was constructed with loadbearing cement stabilised soil block walls. It was the general observation of the masons that the cement stabilised soil blocks are easier to lay than cement sand blocks since the former is lower in unit weight, perfect in dimensions and the verticality can be maintained only from one face. The cost of labour per 1.0 m^2 can be calculated as Rs 83.33/= per day at Rs 300/= per day for the skilled labour and Rs 200/= per day for unskilled labour.

With the above data, the cost of cement sand mortar and labour for 290 mm x 140 mm x 90 mm block walls is Rs 36.44 + 83.33 = Rs 119.77/m^2.

With the above data, the cost of cement sand mortar and labour for 240 mm x 240 mm x 90 mm block walls is Rs 65.29 + 83.33 = Rs 148.62/m^2.

6.2.4 Total cost for construction of 1 m^2 area of blockwork

The overall costs per 1 m^2 of blockwork using 290 mm x 140 mm x 90 mm blocks are given in Table 6.4. The overall costs per 1 m^2 of blockwork using 240 mm x 240 mm x 90 mm blocks are given in Table 6.5.

Table 6.4: Cost per 1.0 m^2 of wall area with 290 mm x 140 mm x 90 mm blocks

Cement	Cost of blocks (Rs)		Cost of labour and mortar	Total cost (Rs/m^2)	
	soil at site	soil bought		soil at site	soil bought
2%	123.32	150.98	119.77	243.09	270.75
4%	156.65	189.31	119.77	276.42	304.08
6%	189.98	217.64	119.77	309.75	337.41
8%	223.31	250.97	119.77	343.08	370.74

Table 6.5: Cost per 1.0 m^2 of wall area with 240 mm x 240 mm x 90 mm blocks

Cement	Cost of blocks (Rs)		Cost of labour and mortar	Total cost (Rs/m^2)	
	soil at site	soil bought		soil at site	soil bought
2%	178.00	228.00	148.62	326.62	376.62
4%	238.00	288.00	148.62	386.62	436.62
6%	298.00	348.00	148.62	446.62	496.62
8%	358.00	408.00	148.62	506.62	556.62

6.2.5 Cost comparison with bricks

As an alternative to 240 mm x 240 mm x 90 mm cement stabilised soil blocks, brickwork can be used as a loadbearing material (Jayasinghe, 1998). Since the bricks manufactured in Sri Lanka are of non-standard size, the minimum size recommended for loadbearing construction is 200 mm in length, 100 mm in width and 50 mm in height. The quality controlling measures for brick selection and construction were also given by Jaysinghe (1998). Use of this brick size would give a wall thickness of 210 mm. For loadbearing walls, a cement, sand mortar of 1:6 should be used.

For partition walls or for the interior walls of upper floors of two storey dwellings, 110 mm thick brickwork is often used. A thickness of 110 mm is achieved by applying a filler mortar layer as shown in Figure 6.1. A thickness of 110 mm is preferred to 100 mm due to slenderness effects. For 110 mm thick brickwork, a cement sand mortar of 1:6 is generally used (Chandrakeerthy, 1987).

6.2.5.1 Cost of 210 mm thick walls

Since the bricks are of non-standard size, the material requirements given in Building Schedule of Rates cannot be used directly. Thus, material quantities are calculated using solid and bulk densities.

When bricks of 200 mm in length, 100 mm in width and 50 mm height are used, the effective height of a brick will be equal to 60 mm. Thus, the number of courses per 1 m height is 1000/60 = 16.67. The number of bricks per stretcher course is 2 x 1000/210 = 9.52. The number of bricks for the header course is 1000/110 = 9.09.

The volume of mortar in a stretcher brick is (210 x 105 x 60 - 200 x 100 x 50)x 10^{-9} = 0.000323 m^3. The volume of mortar in a header brick is (210 x 110 x 60 - 200 x 100 x 50) x 10^{-9} = 0.000386m^3.

The total volume of mortar for 1m^2 of brickwork

= (8.67 x 9.52 x 0.000323 + 8 x 9.09 x 0.000386) = 0.0547m^3

The number of bricks for 1 m^2 of brickwork with 5% wastage, as allowed in Building Schedule of Rates for breakage

= (8.67 x 9.52 + 8 x 9.09) x 1.05 = 163.01 bricks

Cost of bricks are subjected to seasonal variations. The cost of bricks of size and quality recommended for loadbearing construction varies between Rs 2000.00/= to Rs 2400/= for 1000 bricks, inclusive of transport and handling costs according to several brick suppliers. For the calculations, a cost of Rs 2/= per brick was used. Thus, the cost for 163.01 bricks is Rs 326.02/=

Cost of mortar from Section 6.2.2.2 = (65.29/0.0326) x 0.0547 = Rs 109.55/=

Work norms as given in Building Schedule of Rates (BSR) adopted by Buildings Department states that one square of brickwork, up to 1st floor level needs 2.25 days mason and 3.75 days labourer.

Labour cost for 1 square of brickwork = 2.25 x 300 + 3.75 x 200 = Rs 1425/=
Labour cost for 1 m^2 of brickwork = {1425 /(100/3.28^2)} = Rs 153.30/=

Total cost of brickwork for 1.0 m^2 = Rs 326.02 + 109.55 + 153.30 = Rs 588.87/=

6.2.5.2 Cost of 110 mm thick brick walls

When bricks of 200 mm in length, 100 mm in width and 50 mm height are used, the effective height of brick will be equal to 60 mm. Thus, the number of courses per 1 m height is 1000/60 = 16.67. Number of bricks for a length of 1000 mm is 1000/210 = 4.76. All the bricks will be used as stretcher bricks. The bond arrangement will be as shown in Figure 6.1.

The volume of mortar in a stretcher brick is (210 x 110 x 60 - 200 x 100 x 50)x 10^{-9} = 0.000386 m^3.

The total volume of mortar for 1m^2 of brickwork

= (16.67 x 4.76 x 0.000386) = 0.0306 m^3

The number of bricks for 1 m^2 of brickwork with 5% wastage as allowed in Building Schedule of Rates

= (16.67 x 4.76) x 1.05 = 83.31 bricks

Cost of bricks at Rs 2.00/= per unit = Rs 166.62/=

Cost of mortar from Section 6.2.2.2 = (65.29/0.0326) x 0.0306 = Rs 61.28/=

Work norms as given in Building Schedule of Rates (BSR) adopted by Buildings Department states that one square of brickwork, up to 1st floor level needs 1.5 days mason and 2.0 days labourer.

Labour cost for 1 square of brickwork = 1.5 x 300 + 2 x 200 = Rs 850/=
Labour cost for 1 m^2 of brickwork = {850 /(100/3.28^2)} = Rs 91.44/=

Total cost of brickwork for 1.0 m^2 = Rs 166.62 + 61.28 + 91.44 = Rs 319.34/=

6.2.5.3 Cost comparison of cement stabilised block walls with brickwork

On the basis of the costs presented in Sections 6.2.4 and 6.2.5, the following cost comparison can be carried out. When brickwork is used as a loadbearing material, for a wall thickness of 210 mm, the cost per 1 m^2 is Rs 588.87/=. When cement stabilised soil blocks of thickness 240 mm are used as an alternative material, 6% cement blocks should be used for the lower courses at the ground floor level. The cost of 6% cement blocks with soil available at site is Rs 446.62/= per m^2 (Table 6.5). This indicates a cost saving of Rs 142.25/= per m^2. If soil is bought, then the cost saving is Rs (588.87 - 496.62) = 92.25/= per m^2.

If it is decided to use 4% cement blocks for upper part of the ground floor, the cost saving with soil available at site is Rs (588.87 - 386.62) = 202.25/= per m^2. When soil is bought, the cost saving is Rs (588.87 - 436.62) = 152.25/= per m^2.

It is possible to use 240 mm thick walls of 6% cement up to mid height and 4% cement above that in the ground floor loadbearing walls when those are not heavily loaded as explained in Section 5.5. Thus the above cost values indicate that when soil is available at site the average cost of saving of cement stabilised blocks per m^2 can be Rs (202.25 + 142.25)/2 = 172.25/=. This is a saving of (172.25/588.87) x 100 % = 29.25% with respect to 210 mm brickwork.

When soil is bought, the average saving of cement stabilised blocks per m^2 is Rs (92.25 + 152.25)/2 = 122.25/=. This is a saving of (122.25/588.87) x 100% = 20.76% with respect to 210 mm brickwork.

When 110 mm thick brick walls are used as a partition material or material carrying only light loads such as roof loads in single storey construction or in the upper floor of two storey construction, the cost per m^2 is Rs 319.34/=. As an alternative, 140 mm thick walls with either 2% cement or 4% cement can be used.

When 2% cement is used, the cost per m^2 of 140 mm thick wall is Rs 243.09/= when soil is available at site (Table 6.4). This is a saving of Rs (319.34 - 243.09) = 76.23/= per m^2 or a saving of 23.87% with respect to 110 mm brickwork. When soil is bought, the cost per m^2 is Rs 270.75/=. This is a saving of Rs (319.34 - 270.75) = 48.59/= per m^2 or a saving of 15.21% with respect to 110 mm brickwork.

When 4% cement is used, the cost per m^2 of 140 mm thick wall is Rs 276.42/= when soil is available at site. This is a saving of Rs (319.34 - 276.42) = 42.92/= per m^2 or a saving of 13.44% with respect to 110 mm brickwork. When soil is bought, the cost per m^2 is Rs 304.08/=. This is a saving of Rs 15.26/= per m^2 or a saving of 4.77% with respect to 110 mm brickwork.

These calculations show that the cost savings associated with cement stabilised soil blocks of 140 mm thickness can vary from 4.77% to 23.87% with respect to 110 mm thick brickwork. The cost savings associated with cement stabilised soil blocks of 240 mm thickness vary from 20.76% to 29.25% with respect to 210 mm thick brickwork.

One of the main advantages of cement stabilised soil blocks is that it may be possible to lay those accurately so that plasters could be replaced with a suitable water proofing coat such as 1:1:6 cement, lime and soil. This could lead to further cost savings.

It should be noted that the building regulations (1985) states that the thickness of exterior walls should be at least 125 mm. Thus, 140 mm thick cement stabilised soil block walls can be used even without plaster. However, when 110 mm thick brickwork is used, it must be provided with a plaster at least on one face, but preferably on both faces for aesthetic purposes.

6.2.6 Cost comparison with cement sand blocks

As an alternative to 240 mm x 240 mm x 90 mm cement stabilised blocks, cement sand hollow blockwork can be used as a loadbearing material. The size of the block used is 400 mm in length, 200 mm in width and 200 mm in height. This will give a wall thickness of 200 mm. The material requirement and the work norms could be obtained from a Building Schedule of Rates since these blocks are of standard size.

As an alternative to 290 mm x 140 mm x 90 mm blocks used for single storey construction or the upper floors of two storey construction, 100 mm thick cement sand hollow blockwork can be used. When used for external walls, these should be provided with a plaster to achieve a wall thickness of 125 mm as required by the building regulations.

6.2.6.1 Cost of 200 mm thick hollow cement sand blockwork

Material requirement for one square is given as follows:

112 hollow cement sand blocks and allow 5% wastage
37.5 kg of cement
0.06 cubes of sand

Work norms:

1.5 days mason
2.5 days of unskilled labourer

Cost of 200 mm cement sand hollow blocks manufactured with proper quality controlling will cost between Rs 34/= to Rs 37/= inclusive of transport cost as quoted by reputed block making companies. A cost of Rs 34/= per block is used for the calculations.

The material cost per square (100 ft^2)

= (112 x 34 x 1.05) + (37.5 x 6.00) + (0.06 x 1132) = Rs 4291.32/=

The material cost per 1 m^2 = Rs (4291.32/100) x 3.28^2 = Rs 461.67/=

The labour cost per square = 1.5 x 300 + 2.5 x 200 = Rs 950/=

The labour cost per 1 m^2 = Rs (950/100) x 3.28^2 = Rs 102.25/=

Total cost of cement sand hollow block work per 1.0 m^2

= Rs 461.67 + 102.25 = Rs 563.92/=

6.2.6.2 Cost of 100 mm thick hollow cement sand blockwork

Material requirement for one square is given as follows:

112 hollow cement sand blocks and allow 5% wastage
20.0 kg of cement
0.03 cubes of sand

Work norms:

1.5 days mason
2.0 days of unskilled labourer

Cost of 100 mm thick cement sand hollow blocks manufactured with proper quality controlling will cost about Rs 14/= per block inclusive of transport cost.

The material cost per square (100 ft^2)

= (112 x 14 x 1.05) + (20 x 6.00) + (0.03 x 1132) = Rs 1800 /=

The material cost per 1 m^2 = Rs (1800/100) x 3.28^2 = Rs 193.60/=

The labour cost per square = 1.5 x 300 + 2.0 x 200 = Rs 850/=

The labour cost per 1 m^2 = Rs (850/100) x 3.28^2 = Rs 91.40/=

Total cost of cement sand hollow block work per 1.0 m^2

= Rs 193.60 + 91.40 = Rs 285/=

6.2.6.3 Cost comparison of cement stabilised blocks with hollow blockwork

When hollow cement sand blocks are used as a loadbearing material, for a wall thickness of 200mm, the cost per 1 m^2 is Rs 563.92/=. When cement stabilised soil blocks of thickness 240 mm are used as an alternative material, 6% cement blocks should be used for the lower courses at the ground floor level and 4% cement blocks could be used for upper part of the ground floor.

The average cost of cement stabilised soil blocks of thickness 240 mm with 4% and 6 % can be calculated using the values given in Table 6.5. Generally, it is possible to use blocks with 6% cement for lower half and blocks with 4% cement for the upper half of the ground floor walls. When soil is available at site, the average cost is Rs (386.62 + 446.62)/2 = Rs 416.62/=. When soil is bought, the average cost is Rs (436.62 + 496.62)/2 = Rs 466.62/=.

These values indicate that when soil is available at site the average cost saving of cement stabilised soil blocks per m^2 is Rs (563.92 - 416.62) = 147.30/=. This is a saving of (147.30/563.92) x 100 % = 26.16% with respect to 200 mm hollow cement sand blockwork.

When soil is bought, the average cost saving of cement stabilised soil blocks per m^2 is Rs (563.92 - 466.62) = 97.30/=. This is a saving of (97.30/563.92) x 100% = 17.25% with respect to 200 mm hollow blockwork.

When 100 mm thick cement, sand hollow block walls are used as a partition material or material carrying only light loads such as roof loads in single storey construction or in the upper floor of two storey construction, the cost per m^2 is Rs 285/=. As an alternative, 140 mm thick walls with either 2% or 4% cement can be used.

When 140 mm thick blocks with 2% cement is used, the cost per m^2 is Rs 243.09/= when soil is available at site. This is a saving of Rs 41.91/= per m^2 or a saving of 14.70% with respect to 100 mm hollow cement sand blockwork. When soil is bought, the cost per m^2 is Rs 270.75/=. This is a saving of Rs 14.25/= per m^2 or a saving of 5.0% with respect to 100 mm hollow cement sand blockwork.

When 140 mm thick blocks with 4% cement is used, the cost per m^2 is Rs 276.42/= when soil is available at site. It is Rs 304.08/= per m^2 when soil is bought. Thus, the cost saving is either negligible or cement stabilised soil blocks can cost more in this particular case.

These calculations show that the cost savings associated with 140 mm thick cement stabilised soil blockwork with 2% cement can vary from 5.0% to 14.70% with respect to 100 mm thick hollow cement sand blockwork. It will vary from 17.25% to 26.16% for 240 mm thick cement stabilised soil blockwork with respect to 200 mm thick hollow cement sand blockwork.

It should be noted that the Building Regulations (1985) states that the thickness of exterior walls should be at least 125 mm. Thus, 140 mm thick cement stabilised soil block walls can be used even without plaster. However, when 100 mm thick blockwork is used, it must be provided with plaster on both sides. This indicates that the cost savings associated with cement stabilised soil blockwork of 140 mm thickness can be higher than those indicated above.

It should also be noted that the extensive usage of cement sand blocks should not be promoted in Sri Lanka since sand is in short supply (Dias et al, 1996).

6.3 COST COMPARISON FOR PROPOSED COMPOSITE SLAB SYSTEM

The cost of the proposed composite slab system includes the cost of precast panels, precast beams, insitu concrete and labour costs for erection of the composite system. The cost is calculated for the composite slab that was used for the load test described in Section 4.3.3. However, the labour requirement for constructing the composite slab system is based on actual field observations, since the laboratory conditions can be much favourable than the site conditions.

The densities of materials are based on those given in Kong & Evans (1983). The cost of construction materials are based on the average prices paid during the experimental study.

The following data is used:

1. Bulk density of cement = 1450 kg/m^3
2. Solid density of cement = 3150 kg/m^3
3. Bulk density of aggregates (fine or coarse) = 1700 kg/m^3
4. Solid density of aggregates (fine or coarse) = 2600 kg/m^3
5. Cost of 1 kg of cement = Rs 6.00/=
6. Cost of 1 m^3 of sand = Rs 400/=
7. Cost of 1 m^3 of 20 mm aggregates = Rs 1000/=
8. Cost of 1 m^3 of 8 mm chips = Rs 400/=
9. Cost of 1 m^3 of water = Rs 20/=
10. Cost of 6 m mild steel bar of 6 mm diameter = Rs 38/=
11. Cost of 6 m tor steel bar of 10 mm diameter = Rs 130/=
12. Cost of 6 m tor steel bar of 12 mm diameter = Rs 190/=

6.3.1 Cost of precast panels

The precast beam slab system consists of precast panels of the shape shown in Figure 6.2. Cost of precast panels consist of cost of 1:2:3:1 cement, sand, 20 mm aggregate and 8 mm chip concrete, cost of reinforcement, cost of labour and the cost of shuttering. The reinforcement arrangement used for precast panels is given in Figure 4.4.

6.3.1.1 Cost of concrete

Volume of concrete required for each panel is calculated with reference to Figure 6.2.

$$= (1500 \times 40 + 15 \times 300 \times 2/2 + 900 \times 15 + 900 \times 20) \times 300 \times 10^{-9} = 0.0288 \text{ m}^3$$

The material quantities required to produce this volume of concrete with 1:2:3:1 cement, sand, 20 mm aggregate and 8 mm chip concrete are calculated as follows.

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.0345	50/3150 = 0.0158
Sand	0.0345 x 2 = 0.069	0.069 x 1700/2600 = 0.045
20 mm & 8 mm aggregates	0.0345 x 4 = 0.138	0.138 x 1700/2600 = 0.090
Water (W/C ratio = 0.5)	(50 x 0.5)/1000 = 0.025	0.025

Total solid volume = 0.0158 + 0.045 + 0.090 + 0.025 = 0.1758 m^3

The cost per 0.0288 m^3 of concrete
= (50 x 6 + 0.069 x 400 + 0.75 x 0.138 x 1000 + 0.25 x 0.138 x 400)x 0.0288/0.1758
=Rs 72.88/=

The cost with 10% wastage as given in Building Schedule of Rates

= 72.88 x 1.1 = Rs 80.17/=

6.3.1.2 Cost of steel per panel

Each panel is provided with three 6 mm bars of length 1.45 m each as longitudinal reinforcement. The transverse reinforcement consist of 10 Nos of 6mm bars of length 250 mm each. A wastage of 10% is allowed for reinforcement.

The length of 6 mm reinforcement = 1.45 x 3 + 10 x 0.25 = 6.85 m

Cost of reinforcement with 10% wastage = (6.85/6.0) x 38 x 1.1 = Rs 47.72/=

6.3.1.3 Cost of formwork

It is preferable to have five sets of reusable formwork in order to ensure continuous construction. The formwork can be easily removed two hours after casting a panel. These five sets of formwork will need about 2.4 m^2 of timber of 20 mm thickness which can be considered at Rs 325/= per m^2 for non-durable timber species such as Mango. A carpenter and a helper can make five sets in one day. The carpenter is paid at Rs 300/= and the helper at Rs 200/= per day. An additional cost of Rs 250/= is allocated for five formwork sets to meet the cost of nails, mould oil etc. It is also assumed that the formwork sets will be used for an area of 1000 square feet, which means a total of 200 panels will be cast.

The total cost for five formwork sets = Rs 2.4 x 325 + 300 + 200 + 250 = Rs 1530/=

The formwork cost per panel = 1530/200 = Rs 7.65/=

6.3.1.4 Cost of labour

Two unskilled labourers, who are given sufficient training in the casting of panels, would be able to make ten panels per day according to the work study carried out at Pannipitiya site. Thus, the cost per panel with unskilled labourers being paid at Rs 250/= per day is Rs (250 x 2)/10 = Rs 50/=.

6.3.1.5 Total cost per panel

The total cost per panel should include the cost of concrete, cost of mild steel, cost of formwork and cost of labour.

Total cost per panel = Rs 80.17 + 47.72 + 7.65 + 50.00 = Rs 185.54/=

6.3.2 Cost of precast beams

The total cost of precast beams consist of cost of 1:2:4 cement, sand, 20 mm aggregate concrete, cost of reinforcement, cost of labour and the cost of shuttering. The reinforcement arrangement used for a precast beam is given in Figure 4.5.

6.3.2.1 Cost of concrete

Volume of concrete required for each beam of cross section 200 mm deep x 125 mm wide x 3600 mm long = 0.125 x 0.2 x 3.6 = 0.09 m^3.

The material quantities required to produce this volume of concrete with 1:2:4 cement, sand, 20 mm aggregate concrete are calculated as follows.

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.0345	50/3150 = 0.0158
Sand	0.0345 x 2 = 0.069	0.069 x 1700/2600 = 0.045
20 mm aggregates	0.0345 x 4 = 0.138	0.138 x 1700/2600 = 0.090
Water (W/C ratio = 0.5)	(50 x 0.5)/1000 = 0.025	0.025

Total solid volume = 0.0158 + 0.045 + 0.090 + 0.025 = 0.1758 m^3

The cost per 0.09 m^3 of concrete required per beam

= (50 x 6 + 0.069 x 400 + 0.138 x 1000 + 0.025 x 20) x 0.09/0.1758 =Rs 238.61/=

Allow 10% for wastage as allowed in Building Schedule of Rates. Cost of concrete for 0.09 m^3 is Rs 238.61 x 1.1 = Rs 262.47/=

6.3.2.2 Cost of steel per beam

Each beam is provided with two 12 mm tor steel bars of length 3.8 m each as longitudinal reinforcement at bottom. The reinforcement requirement for shear links and the two 6 mm mild steel bars provided as top reinforcement in the precast beam to resist handling stresses is 5 Nos of 6 mm diameter mild steel bars of length 6.0 m. The cost of reinforcement is based on the prices paid during the experimental programme.

Cost of reinforcement = (3.8/6.0) x 2 x 190 + 5 x 38 = Rs 430.66/=

An allowance of 10% was made for wastage. Thus the cost of reinforcement used in a precast beam is Rs 430.66 x 1.1 = Rs 473.72 /=

6.3.2.3 Cost of formwork

Reinforced concrete beams can be precast on a cement rendered area using only the side shutters. The area of formwork required is (3.6 + 0.125) x 0.2 x 2 = 1.49 m^2. Formwork timber cost is calculated at Rs 325/= per m^2. A carpenter and a helper would have to work less than half a day to make a set of formwork. The carpenter is paid at Rs 300/= and the helper at Rs 200/= per day. It is also assumed that these formwork sets will be used for an area of 90 m^2. This means that the total number of beams would be about eight since each beam can represent a slab area of 3.0 m x 3.6 m. The formwork of a beam can be removed twelve hours after casting a beam. Thus, only one formwork set is required for all eight beams.

The cost of beam formwork = Rs 1.49 x 325 + 0.5 x (300 + 200) = Rs 734.25/=

The formwork cost per beam is calculated by considering that the total cost of formwork is Rs 800/= where there would be eight reuses.

The cost of formwork per beam = 800/8 = Rs 100/=

6.3.2.4 Cost of labour

One skilled labourer and one unskilled labourer can cast one beam per day attending to tasks like preparation of reinforcement, mixing of concrete, placing of concrete etc. Thus, the cost per beam with the skilled labourer being paid at Rs 300/= per day and the unskilled labourers being paid at Rs 200/= per day is Rs 300 + 200 = Rs 500/=.

6.3.2.5 Total cost per beam

The total cost per beam should include the cost of concrete, cost of tor steel, cost of mild steel, cost of formwork and cost of labour.

Total cost per beam = Rs 262.47 + 473.72 + 100 + 500 = Rs 1336.19/=

6.3.3 Cost of constructing the composite slab

Cost of constructing the composite slab should include the cost of erecting the precast beam and slab panels, cost of fixing the reinforcement for crack controlling and cost of laying the insitu concrete.

6.3.3.1 Cost of insitu cast concrete

The volume of insitu cast concrete include that required for connecting the panels over the precast beam, that required over the walls and the insitu cast concrete required to connect two precast panels consisting of a strip of width 50 mm. The areas are illustrated in Figure 6.3. The concrete used consist of 1.5:2.5:3.5 cement, sand and 8 mm chips as described in Section 4.3.2.1.

Volume of concrete required for connecting two precast panels over an internal beam

$$= \{645 \times 75 - [(40 + 55)/2] \times 300 \times 2\} \times 3600 \times 10^{-9} = 0.0716 \text{ m}^3$$

The volume of insitu cast concrete on block wall is calculated with reference to the dimensions given in Figure 6.4.

Volume of concrete on walls = $[(35 + 20)/2] \times 300 \times 2 \times 3600 \times 10^{-9} = 0.0594 \text{ m}^3$

The gap between two precast panels is 50 mm and the thickness of insitu concrete is 20 mm. The length of it is 900 mm and over an area of 3.6 m x 3.0 m, there are 24 panels, so that the total volume of insitu concrete can be calculated.

Volume of insitu concrete between panels = $50 \times 900 \times 20 \times 24 \times 10^{-9} = 0.0216 \text{ m}^3$

Total insitu cast concrete volume for an area of 3.6 m x 3.0 m

$$= 0.0716 + 0.0594 + 0.0216 = 0.1526 \text{ m}^3$$

The material quantities required to produce this volume of concrete with 1.5:2.5:3.5 cement, sand and 8 mm chip concrete are calculated as follows.

	Bulk volume (m^3)	Solid volume (m^3)
Cement	50/1450 = 0.0345	50/3150 = 0.0158
Sand	0.0345 x 2.5/1.5 = 0.0575	0.0578 x 1700/2600 = 0.0375
20 mm aggregates	0.0345 x 3.5/1.5 = 0.0805	0.081 x 1700/2600 = 0.0526
Water (W/C ratio = 0.6)	(50 x 0.6)/1000 = 0.030	0.030

Total solid volume = 0.0158 + 0.0375 + 0.0526 + 0.030 = 0.1359 m^3

The cost per 0.1526 m^3 of concrete required for insitu cast concrete

= (50 x 6 + 0.0575 x 400 + 0.0805 x 400 + 0.030 x 20) x 0.1526/0.1359 =Rs 399.52/=

The total cost with an allowance of 10% is made for wastage = Rs 439.47/=

6.3.3.2 Cost of steel placed with insitu concrete

The insitu cast concrete should be provided with the reinforcement indicated in Figure 4.6 for effective flange action and for crack controlling. The number of bars required for this purpose is 7 Nos of 6 mm diameter mild steel bars of length 6.0 m.

Cost of 6 mm mild steel bars = 7 x 38 = Rs 266/=

The cost with an allowance of 10% = Rs 292.60/=

6.3.3.3 Cost of labour for the composite slab

The casting of composite slab requires one skilled labourer and five unskilled labourers for placing the precast beams and slab panels and laying of the insitu cast concrete for an area of 3.0 m x 4.5 m. This is based on some field observations at a construction site near Pannipitiya where a slab area of nearly 80 m^2 was constructed. It should be noted that the labour used for casting 3.0 m x 3.6 m area at the laboratory is much lower than this which could be attributed to much more favourable laboratory conditions.

The cost of labour for an area of 3.0 m x 3.6 m

= [(300 x 1 + 200 x 5)/(3.0 x 4.5)] x 3.0 x 3.6 = Rs 1040/=

6.3.3.4 Total cost of casting the composite slab

The total cost of casting the composite slab should include the cost of casting the precast elements (24 panels and one beam for an area of 3.0 m x 3.6m), cost of insitu concrete, cost of mild steel and cost of labour.

Total cost for an area of 3.0 m x 3.6 m

= Rs 185.54 x 24 + 1336.19 + 439.47 + 292.60 + 1040 = Rs 7561.22/=

Total cost for 1 m^2 = Rs 700.11/=

6.3.4 Cost comparison with solid slabs

When conventional two way slab system is used for the same purpose over an area of 3.0 m x 3.6 m, a slab of thickness 115 mm can be used. The reinforcement would consist of 10 mm diameter tor steel bars provided at 250 mm centres in the bottom reinforcement mat. This spacing is governed by the need to control cracking, thus, 3 x effective depth. The top reinforcement will include a mat of 10 mm bars provided at 250 centres extending 0.9 m from the face of the support.

The volume of concrete = 0.115 x 3.6 x 3.0 = 1.242 m^3
The quantity of tor steel = 31 bars of 10 mm diameter tor steel
The area of formwork including falsework = 3.6 m x 2.0 m = 10.8 m^2
The labour requirement:

The following are the approximate labour requirement calculated on the basis of values given in Building Schedule of Rates for an area of 3.0 m x 3.6 m.

For fixing steel = one day skilled and one day unskilled
For concreting = 1/3 skilled labour + 4 unskilled (with manual mixing)
For formwork = 2 days of skilled and 2 days of unskilled

Determination of total cost for an area of 3.0 m x 3.6 m:

The formwork and falsework cost comprising bamboo props and rubber wood framework and planks is estimated as Rs 450/m^2 considering the prevailing market prices.

Cost of concrete from Section 6.3.2.1 = Rs (262.47 / 0.09) x 1.242 = Rs 3622.09/=
Cost of steel with 10% wastage = Rs 31 x 130 x 1.1 = Rs 4433.00/=
Cost of formwork and falsework at Rs 450/m^2 = 10.8 x 450 = Rs 4860.00/=
Cost of labour = Rs (3.33 x 300 + 7 x 200) = 2399.00/=

Total cost for 3.0 m x 3.6 m area = Rs 3622.09 + 4433.00 + 4860.00 + 2399.90
= Rs 15314.09/=

Total cost per 1.0 m^2 = Rs 1417.97/=

The cost of composite slab system is Rs 700.11/= per m^2 whereas a solid slab reinforced in a conventional manner would cost Rs 1417.97/= per m^2. Thus, the proposed composite slab system can save Rs 717.860/= per m^2. This is a saving of 50.6% with respect to solid slab systems.

Thus, it can be stated that the proposed composite slab system is quite cost effective in addition to its other benefits such as much reduced usage of formwork and falsework. It also allows a better and reduced usage of traditional construction materials such as concrete and steel. It should be noted that these cost saving can vary from one slab to another and also due to seasonal variations of the cost of construction materials.

6.4 SUMMARY

It is shown with a detailed cost study that cement stabilised soil blocks can be a cost effective alternative building material when compared with both brickwork and hollow cement sand blockwork. In this cost study, it is shown that when 240 mm cement stabilised soil blocks are used as a loadbearing material, the cost savings can vary between 29.25% to 20.76% depending on whether soil is available at site or bought, when compared with brickwork. The corresponding cost savings are 26.16% to 17.25% when compared with hollow cement sand blockwork.

Cement stabilised soil blocks of thickness 140 mm can be used for single storey houses or the upper floor of two storey houses. This can be used as an alternative material to 110 mm thick brickwork or 100 mm cement sand blockwork. It was shown that the cost savings for blocks of 2% and 4% cement can vary between 23.87% to 4.77% with respect to 110 mm brickwork. When blocks with 2% cement is used, the cost savings with respect to 100 mm hollow block work is 14.70% and 5.0%. When cement stabilised blocks of 4% cement is used for 140 mm walls, it may cost more than 100 mm thick cement sand blockwork. It should be noted that 100 mm cement sand blockwork and 110 mm brickwork should be provided with plaster in external walls to achieve a minimum thickness of 125 mm as required in Building Regulations of 1985. Thus, these cost savings can be higher than those indicated.

Thus, on the basis of this cost study, it can be stated that cement stabilised soil blocks could be a cost effective alternative to traditional building materials such as bricks and hollow cement sand blocks. This will be in addition to other advantages such as lesser environmental damage associated with cement stabilised soil blocks.

It is also shown that the composite slab system introduced in Chapter 4 of this thesis is quite cost effective when compared with solid slab systems that are usually used in multi-storey houses where the cost saving is in the range of 50.6%. These will be in addition to the other advantages such as optimised usage of traditional construction materials and minimum usage of depleting sources of building materials.

Thus, it would now be possible to introduce cement stabilised soil blocks and the composite slab systems as structurally sound and cost effective alternative building materials for the building industry of Sri Lanka.

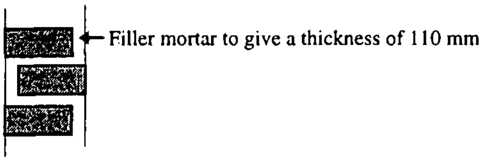

Figure 6.1: Bond arrangement for 110 mm thick brick walls

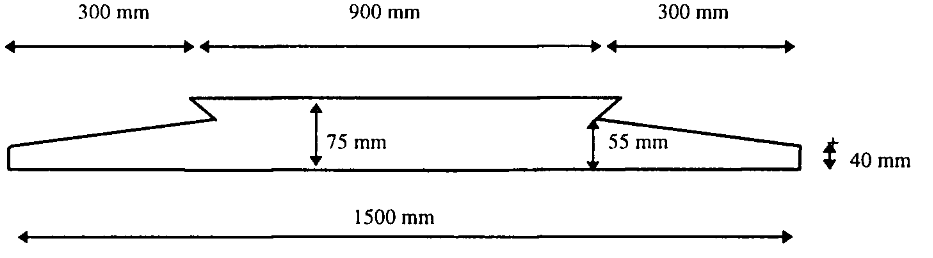

Figure 6.2: Dimensions of the precast panel of width 300 mm

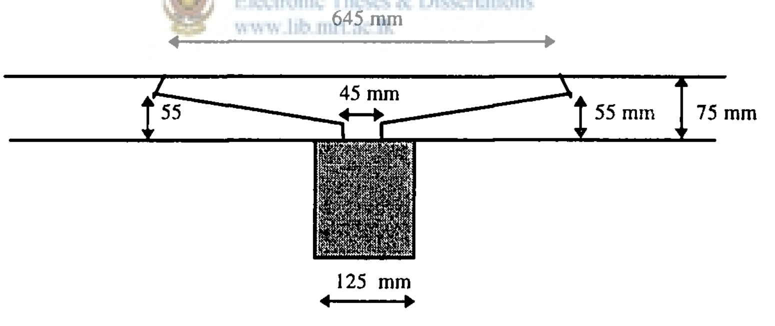

Figure 6.3: Insitu cast concrete above the precast beam

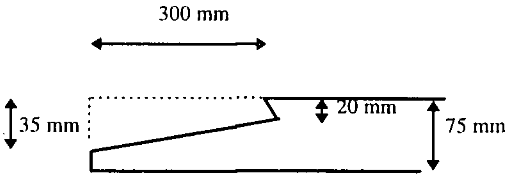

Figure 6.4: Dimensions to calculate the volume of insitu cast concrete over block walls