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Experimental Investigation and practical study on stabilized compacted earth block using local available material

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Abstract

Investigation is carried out mainly to find out a suitable mix proportion to blend locally available materials such as soil, sand, clay, grits, jute, etc. with cement for making compacted earth block for construction of affordable residential buildings. The local soil and clay in and around Jalpaiguri town of West Bengal was mixed with the local sand, and stone grits to make a composite good soil of gravel 15 percent, Sand 50 percent, Silt and Clay 35 percent, for compacted stabilized earth blocks (CSEB).1 Blocks of 254 mm x 127 mm x 76 mm size, were prepared with varying percent of Ordinary Portland Cement (5.0 percent, 7.5 percent, and 10.0 percent) and jute fibre of size 2.5 cm and compacting manually to the standard proctor density. Jute size of 2.5cm was chosen as it was found best option from earlier investigation by the same author 8 compared to other sizes from mixing and compressive strength point of view. The blocks were cured and tested for compressive strength, water absorption and density. Based on the results, it has been concluded that the compacted cement stabilized earth blocks both with or without jute fibre may be a cost effective and environment friendly alternative to the burnt clay bricks in lightly loaded building (rural areas) where stability is not a governing factor.

Keywords: Burnt clay-brick, Cement Stabilized, Earth Block, Compacted, Jute Fiber, Good soil, Compressive strength, Affordable housing.

Introduction

Providing affordable housing is a challenge around the world, especially in developing countries. The impediments to solving the housing problem are scarcity and high cost of building materials. Ideally, low-cost housing must rely on locally available raw materials. Furthermore, such materials must be abundantly available and be renewable in nature. Local soil has always been the most widely used material for earthen construction in India. Approximately, 55 percent of Indian homes still use raw earth for wall constructions.3 However, major limitations in using earth constructions are: i) Water penetration ii) Erosion of walls at the plinth level/ lower level by splashing of water from ground surfaces. iii) Attacks by termites and pests. ii) High maintenance requirements. iv) Low durability. Infact, the Stabilized Compacted Earth block (SCEB) technology could offer a cost effective, environmentally sound masonry system to over come these limitations. Therefore, the objective of this research was to evaluate local soils as a building material based on the following: (i) Technical needs (use of local soil, sand, clay and other resources, minimizes the need for importing buildings materials, reducing transportation cost and ensuring product availability) (ii) Social requirements (Application of existing or easily transferable skills, avoids costly training, minimizing displacement of labour and social-cultural disruptions) (iii) Economic requirements (reduced dependence on outside sources, ensuring low cost alternatives and requiring limited capital investment.) One of the main objectives was to promote CSEB building constructions as a tool for affordable housing and sustainable development.

2. Scope of work

The scope of this research project was limited to Jalpaiguri region. Representative materials collected were:

Soil: Mundabasti, Mohitnagar, Jalpaiguri collected from 2 feet to 4 feet depth soil in a landfill .

Stone chips/grits: North Bengal variety

Clay: Porapara, Jalpaiguri Sand : Panga River, Jalpaiguri

Thirteen to eighteen percent clay were added to the natural soil assuming there was no clay in the original soil to satisfy requirements of good soil for mix design. As there was no easy method to segregate clay from the silt some variation in silt and clay content in a particular design mix was expected. Therefore, while designing a particular mix, definition of good soil was not completely followed. This approach was needed for making the blending process simple and easy.

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3. Experimental programme

Testing of individual materials and design mix

Individual materials were first sieved and then blended in appropriate proportions to yield a good soil. Typically, the good soil consists of 15 percent gravel, 50 percent sand and 35 percent silt and clay together. Table 1 gives the results of sieve analysis of individual samples and blended soil. The mix design for 5 percent cement content, CM1 is given in Table 2 where as combination factors for others (CM2 & CM3) given in Table 3. The various physical properties of the blended soil used for investigation were:

Grain size distribution:- Gravel (stone chips) 14.23%, coarse sand 1.88%, medium sand 33.89%, fine sand 14.96% , silt & clay 35.04%

Atterberg limit – Liquid limit 41.3%, Plastic limit 25.7%, P.I =15.6 *Standard proctor test*: OMC 16.0%, MDD 1.85gm/cc.

Specific gravity - 2.67

Ordinary Portland cement is used and the full process is done in light compaction.

3.1 Experimental procedure

The soil, sand, clay and stone grits were first air dried by spreading them in an open space and then, the required quantities of samples were weighed and mixed. Next, the blended soil was mixed with the required quantity of cement (5 percent; 7.5 percent, 10 percent by weight of dry soil) 9, 10 till the soil cement blend attained a uniform colour. The required quantity of water were weighed i.e. equal to the quantity of water corresponding to OMC of the soil by weight of blended soil plus the quantity of water corresponding to a water-cement ratio of 0.5. The total quantity of water to be added to the mix was decided through trials by varying

water content in the mix to attain maximum dry density (MDD) of blocks when compacted in a mould. The water was then gradually added by sprinkling it over the mix. The mixing was done manually and continued until a homogeneous mix was obtained. The soil-cement mix was then transferred to the block mould and compacted into three layers with the 2.6 kg Standard Proctor Density Hammer. The number of blows required was standardized by trial method to get above 95 percent compaction to it's maximum dry density

Table 1: Result of sieve analysis for individual samples and Design Mix

Sieve size	Percent finer				
	Sand sample	Soil sample	Stone chips	Clay soil	Blended Soil
80mm	100	100	100	100	100
40mm	100	100	100	100	100
20mm	100	100	100	100	100
10mm	100	100	89.50	100	82.32
4.75mm	99.59	100	12.21	100	85.7732
2.36mm	99.18	100	1.57	100	83.8904
1.18mm	89.71	99.46	0.07	100	79.354
600micron	47.53	98.38	0.07	100	60.5356
300micron	7.82	94.06	0.07	100	42.0264
150micron	1.03	87.03	0.07	99.0	21.3516
75micron	0.41	80.54	0.07	97.0	35.0412
Pan	0	0	0	0	0

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Table 2: Design mix-CM1 using 5.0% cement

Design Mix-CM1 **Cement 5%**

Sieve Size	Percent Finer						Remarks
	Type-1	Type-II	Type-III	Type-IV	Type-V	Combined	
C.F.	0.17	0.43	0.19	0.16	0.05	1	
80mm	100	100	100	100	100	100	
40mm	100	100	100	100	100	100	
20mm	100	100	100	100	100	100	Type-I stone chips
10mm	89.5	100	100	100	100	98.215	Type-II- sand
4.75mm	12.21	99.59	100	100	100	84.8994	Type-III-soil
2.36mm	1.57	99.18	100	100	100	82.9143	Type-IV-- clay
1.28mm	0.07	89.71	99.46	100	100	78.4856	Type V- cement
600m	0.07	47.53	98.38	100	100	60.142	
300m	0.07	7.82	94.06	100	100	42.2459	
150m	0.07	1.03	87.03	99	100	37.8305	
75m	0.07	0.41	80.54	97	95	35.7608	
Pan	0	0	0	0	0	0	

Table 3: Combination factor (C.F.) for CM2 and CM3

	Type-1	Type-II	Type-III	Type-V	Type-V
CM-2	0.17	0.435	0.17	0.15	0.075
CM-3	0.17	0.44	0.16	0.13	0.10

After 24 hours, the blocks were removed from the moulds and damp cured by covering them with wet gunny bags for 7 days and 28 days. The water requirement for complete hydration of cement was made available through curing. At the end of curing, the blocks were taken out and surface water if any was allowed to dry so that SDD (Saturated Surface Dry) condition was achieved. The blocks were then weighed separately at this condition to calculate the block density. Finally, the blocks were tested for their compressive strengths. In addition, they were tested for water absorption using standard procedure as laid down in IS: 3495 (part-2) 6. At least 3 specimens for each group were tested to calculate the average compressive strength and average water absorption. Since, the blocks were cast, cured and tested under controlled conditions; it was observed that the test result of the individual blocks were consistent. Considering this, it was decided to test only three specimens instead of five as stipulated in BIS code _IS: 5454 – 1974 5. A total of 84 blocks were tested out of which 72 were tested for compressive strength and 12 for water absorption. The details of the variables in the experimental program are given in Table 4.

4. Results and discussion

The results of sieve analysis, standard proctor density, block density, compressive strength, water absorption, are presented in Table 1, 4, 5, 6 and 7 respectively.

4.1 Optimum moisture content and maximum dry density

Table 4 summarises the test results of standard proctor density and shows no significant change in optimum moisture content due to increase in cement content.

Table 4: Standard Proctor Density Result

Mix	OMC	MDD gm/cc	Binder/Jute Fiber
CM1	13.0%	1.815	5% Cement
CM2	12.5%	1.819	7.5% Cement
CM3	12.5%	1.830	10.0% Cement
CM4J	15.5%	1.810	5% Cement + 0.25% Jute 2.5cm
CM5J	15.0%	1.807	5% Cement + 0.5% Jute 2.5cm
CM6J	15.0%	1.759	5% Cement + 1.0% Jute 2.5cm
CM7J	15.0%	1.800	7.5% Cement + 0.25% Jute 2.5cm
CM8J	15.0%	1.785	7.5% Cement + 0.5% Jute 2.5cm
CM9J	15.5%	1.780	7.5% Cement + 1.0% Jute 2.5cm
CM10J	14.5%	1.820	10.0% Cement + 0.25% Jute 2.5cm
CM11J	14.5%	1.810	10.0%Cement + 0.5% Jute 2.5cm
CM12J	15.0%	1.770	10.0% Cement + 1.0% Jute 2.5cm

Similar observation was made by Babushankar and Ch. Venkateswara Rao 2. However, maximum dry density increases with increasing cement content. Also, adding jute fibre decreases the maximum dry density and increases the optimum moisture content. The percentage of jute fibre in the range tested does not make any significant change to the optimum moisture content, however, the maximum dry density decreases with increase in percentage of jute fibre.

4.2 Block Density

From table 5, it is clear that block density varies between 2.09gm/cc to 2.22 gm/cc for the cement content range 5.0 percent to 10.0 percent. Blocks density is in the range of 1.90gm/cc to 1.96gm/cc with jute fibre content 0.25 % to 1.0 % when cement content is 5.0 percent. By increasing cement percentage, the block density increases and remains more or less constant with the maturity age. Adding jute fibre to the mix, decreases the block density (Table 5).

Table 5: Block density at 7days and 28 days maturity age

Mix	Proportion	Block Density 7 days maturity gm/cc		Block Density 28days maturity gm/cc	
		Individual	average	Individual	average
CM1	5.0%	2.07 2.10 2.06	2.08	2.09 2.10 2.08	2.09
CM2	7.5%	2.18 2.20 2.16	2.18	2.21 2.22 2.16	2.19
CM3	10.0%	2.21 2.19 2.21	2.20	2.21 2.20 2.25	2.22
CM4J	5.0% + 0.25% Jute 2.5cm length	1.94 1.95 1.98	1.956	2.000 1.950 1.930	1.960
CM5J	5.0% + 0.5% Jute 2.5cm length	1.90 1.94 1.91	1.916	1.920 1.950 1.920	1.930
CM6J	5.0% + 1% Jute 2.5cm length	1.88 1.89 1.90	1.890	1.90 1.90 1.88	1.896

4.3 Compressive strength

Compressive strengths of blocks for the maturity age of 7 days and 28 days for different mix are presented in Table 6 and graphically shown in Figures 1 to 4. As expected, the experimental results suggest that compressive strength increases with increasing cement content and maturity age (Figure 1) as approximately 80 percent of full strength was achieved at 7 days. This observation matches with Walker P. J 11. It is important to note that the specimen with 5 percent cement did not satisfy the BIS requirements (IS 1725) 4 of

maximum strength of 2.0 to 3.0 N/mm2 whereas those with 7.5 percent and 10.0 percent cement content did. Analysing the results, it appears that there is a scope for optimizing the cement content to 6.8 % to meet the minimum strength requirement (2.0 N/mm2). Adding jute fiber to the blended soil increased compressive strength as well as ductility. It was observed that adding with 2.5 cm long fibers increased the compressive strength. For 5 percent cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 78.45 percent, 134.87 percent and 253.76 percent respectively (Table 6, Figure-2). For 7.5 percent cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 69.40 percent, 90.95 percent and 121.95 percent respectively. (Table 6, Figure 3). Comparative results are shown graphically in Figure 5.

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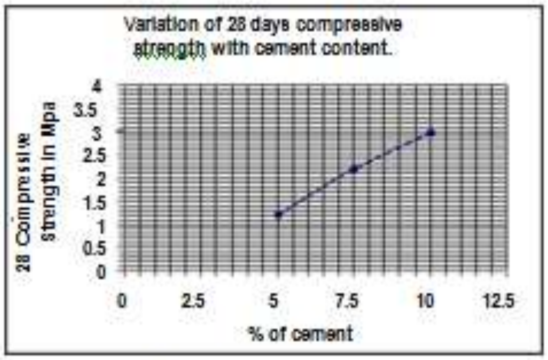

Figure 1: Variation of 28 days compressive strength with cement content

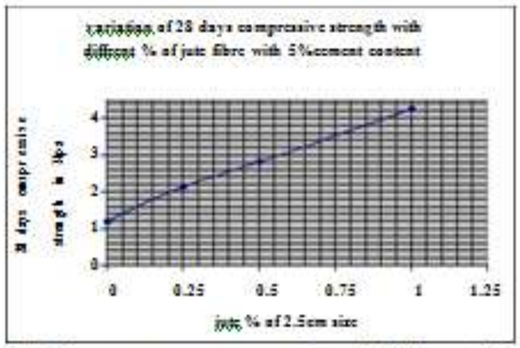

Figure 2: Variation of 28 days compressive strength with different % of jute fibre with 5 % cement content

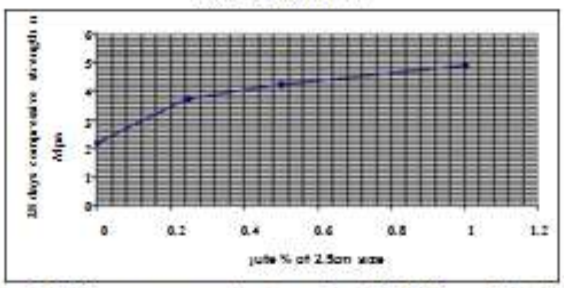

Figure 3: Variation of 28 days compressive strength with different % of jute fibre with 7.5% cement content

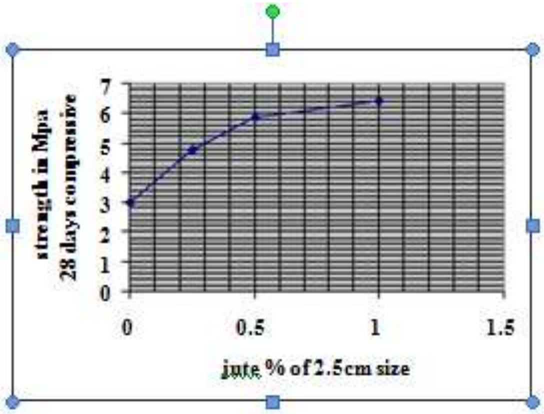

Figure 4: Variation of 28 days compressive strength with different % of jute fibre with 10.0% cement content

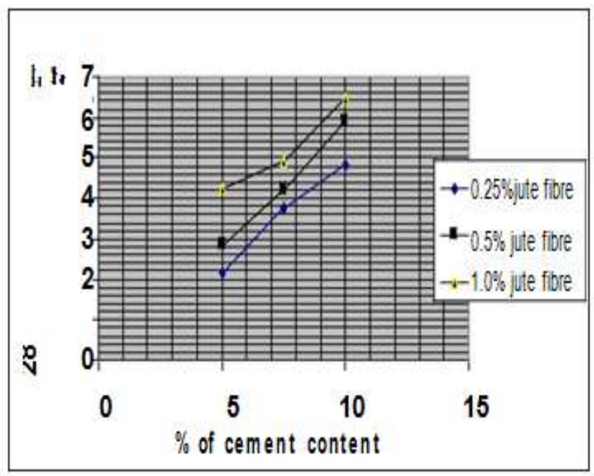

Figure 5: Comparison of compressive strength for different % of cement content

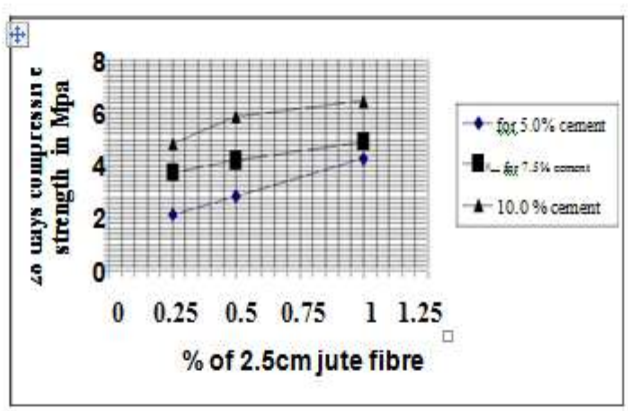

Figure 6: Comparison of compressive strength for different % of jute fibre content

For 10 percent cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 60.54 percent, 95.92 percent and 115.30 percent respectively. (Table 6, Figure 4). The 2.5cm length of the jute fibre was selected for preparing blocks as previous investigation by the same author 8, it was found the best size from strength point of view as well as mixing uniformity of jute fibre and workability of the mixture. Comparative results of compressive strength for all different cement contents are shown graphically in Figure 5. Also in Fig 6 comparative results of compressive strength for different % of jute fibre content are shown graphically .

Table 6: Results of compressive strength

Mix	Cement content	Jute Fiber	Fiber Size	Compressive strength 7 days		Compressive strength 28 days		Strength ratio 7days/ 28days
				Individual N/mm2	Average N/mm2	Individual N/mm2	Average N/mm2	
CM1	5.0%	---	---	0.930 0.930 0.960	0.940	1.172 1.190 1.200	1.207	0.779
CM2	7.5%	---	---	1.900 1.850 2.000	1.916	2.211 2.312 2.109	2.210	0.865
CM3	10.0%	---	---	2.611 2.721 2.401	2.577	2.940 3.050 3.000	2.996	0.865
CM4J	5.0%	0.25%	2.5cm	1.575 1.472 1.575	1.540	2.010 2.132 2.320	2.154	0.714
CM5J	5.0%	0.5%	2.5cm	2.490 2.402 2.490	2.460	2.790 2.860 2.860	2.835	0.867
CM6J	5.0%	1.0%	2.5cm	3.410 3.720 3.720	3.616	4.195 4.350 4.270	4.270	0.84
CM7J	7.5%	0.25%	2.5cm	2.800 2.710 2.800	2.770	3.720 3.800 3.720	3.745	0.739
CM8J	7.5%	0.5%	2.5cm	3.410 3.400 3.620	3.470	4.150 4.310 4.200	4.220	0.822
CM9J	7.5%	1.0%	2.5cm	3.880 3.920 3.880	3.890	4.950 4.870 4.900	4.905	0.793

CM10J	10.0%	0.25%	2.5cm	3.910 3.920 3.810	3.880	4.750 4.880 4.810	4.810	0.805
CM11J	10.0%	0.5%	2.5cm	4.430 4.410 4.580	4.470	5.800 5.910 5.910	5.870	0.761
CM12J	10.0%	1.0%	2.5cm	4.950 5.070 5.120	5.045	6.500 6.350 6.500	6.450	0.782

4.4 Water absorption

Adding 5 percent cement failed to satisfy the water absorption criteria, but this level of cement addition can be useful for applications where stability is not a governing criteria such as in internal walls, partition walls, etc. and appears to be the most economical option. The cost analysis of blocks with 5 percent cement content suggests that they are about 47.50 percent cheaper than the burnt clay bricks. Average water absorption of the blocks having 7.5 percent and 10.0 percent cement were less than 15 percent satisfying the IS recommendation. The values of water absorption for different mixes are given in Table 7.

Blocks having 7.5 percent cement seemed to be the most acceptable alternative. They were satisfying the strength criteria, water absorption criteria and were 36.66 percent cheaper than the burnt clay bricks. Adding jute fibre to 7.5 percent cement content specimen may be a better option from strength and ductility point of view. However, it will increase the cost of block. From Figure 1, corresponding to 2.0Mpa (minimum requirement) percent of cement required is 6.8% and from Figure 7 corresponding to 6.8% cement interpolated water absorption is 14.9 percent.

Table 7: Water absorption at 28 days maturity age

Mix	Proportion	Water absorption (%)at 28 days maturity age	Average water absorption(%) at 28 days maturity age	Remarks
CM1	5.0% cement only	19.21 19.05 18.50	18.92	
CM2	7.5% cement only	14.27 13.86 13.45	13.86	
CM3	10.0% cement only	10.51 10.02 10.83	10.45	
CM5J	Cement 5.0% + 0.5% Jute fiber of 2.5cm	21.41 20.30 19.89	20.53	

Therefore Figure 1 and Figure 7 suggest a scope for reducing the cement content to 6.8 percent while satisfying both minimum strength requirement of 2.0N/mm2as well as maximum water absorption criteria as per BIS requirements.

4.5 Cost analysis for production at Jalpaiguri

Cost analysis is based on the rates of materials at Jalpaiguri and production of per unit brick comes around Rs.7 which is based on the following calculation :

Cost of stone grit per truck (180 cft) :Rs. 4400/-
Cost of local sand from Panga River, per truck (180 cft) :Rs. 2000/-
Cost of labor and transportation for soil per truck (180 cft) :Rs. 1000/-
Cost for clay per truck (180 cft) :Rs. 3200/-
Cost of cement (as available in the market) per bag (50.0 kg) :Rs. 360/-
Cost of Jute including cutting in size per kg :Rs. 30/-

Calculated Dry wt of components for different mixes and estimated rate per kg of material are given in Table 8. Also comparative cost analysis of different design mix against fire clay bricks is given in Table 9.

Table 8: Calculated dry weight and cost per kg of component s for different mixes

Component	Calculated dry weight of component per block in kg						
	Design mix – CM1	Design mix CM2	Design mix CM3	Design mix CM4	Design mix CM5	Design mix – CM6	Cost per kg in Rupee
stone grit	0.765	0.765	0.765	0.765	0.765	0.765	0.7
sand	1.935	1.958	1.980	1.935	1.958	1.980	0.3
soil	0.855	0.765	0.720	0.855	0.765	0.720	0.2
clay	0.720	0.675	0.585	0.720	0.675	0.585	0.5
cement	0.225	0.337	0.450	0.225	0.337	0.450	7.2
Jute	----------	-----------	------	0.01125	0.0225	0.0450	30.0

5. Conclusions

The following conclusions can be drawn from the results:

1. Maximum dry density of blended soil increases with increasing cement content.
2. With the increase in cement content, the block density increases and remains more or less constant with age.
3. As expected the compressive strength increases with increasing cement content and age; 80 percent of full strength was achieved at 7 days
4. A significant increase in compressive strength as well as ductile behaviour was observed when jute fibre was added to the blended soil; though it decreased the block density.
5. For 5 % cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 78.45 percent, 134.87 percent and 253.76 percent respectively.
6. For 7.5 % cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 69.40 percent, 90.95 percent and 121.95 percent respectively.
7. For 10 % cement content and jute content of 0.25 percent, 0.5 percent and 1.0 percent increased the compressive strength by 60.54 percent, 95.92 percent and 115.30 percent respectively.
8. Specimens with 5 percent cement content did not satisfy the water absorption criteria of BIS (IS 1725) but were considered suitable for applications where stability is not a governing criteria such as internal walls, partition walls, etc. It was the most economical alternative.
9. The average water absorption for the blocks having cement content of 7.5 percent and 10.0 percent were less than 15 percent, satisfying the IS recommendation

10. The cost analysis of blocks with 5 percent cement content suggests that they are about 47.50 percent cheaper than the burnt clay bricks.

Table 9: Comparative cost analysis of per unit block at JALPAIGURI, West Bengal as on February 2012

Item	CM1 Block	CM2 block	CM3 Block	CM4 Block	CM5 block	CM6 block	Burnt clay bricks
Cost of stone grit (Rs)	0.55	0.55	0.55	0.55	0.55	0.55	7.2
Cost of local soil (Rs)	0.17	0.15	0.15	0.17	0.15	0.15	
Cost of clay soil (rs.)	0.36	0.34	0.3	0.36	0.36	0.36	
Cost of local sand (Rs)	0.58	0.59	0.60	0.58	0.58	0.58	
Cost of Jute fiber (Rs)	--	---	---	0.34	0.68	1.36	
Cost of cement (Rs)	1.62	2.43	3.25	1.62	1.62	1.62	
Cost of Labor (Rs)	0.50	0.50	0.50	0.50	0.50	0.50	
Total cost of one unit (Rs)	3.78	4.56	5.35	4.12	4.46	4.97	7.2
Price index	0.54	0.65	0.764	0.590	0.637	0.71	1.0
28daysCompressive strength in Mpa	1.207	2.21	2.996	2.154	2.835	4.27	
Savings in cost compared with the burnt clay bricks in %	47.5	36.66	25.69	42.78	38.05	30.97	

Blocks having 7.5 percent cement seemed to be the most acceptable alternative as they were satisfying the strength criteria, water absorption criteria and were cheaper than the burnt clay bricks by 36.66%. The experiments suggest a scope for optimising the cement content at 6.8 percent while satisfying both minimum strength requirement of 2.0 N/mm2 as well as maximum water absorption criteria as per BIS requirements.]

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