STABILISED SOIL BLOCK TECHNOLOGY FOR SRI LANKA

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ABSTRACT

Due to the high cost and environmental problems associated with burnt bricks and cement blocks used as walling materials, cement stabilized compressed earth blocks have been introduced as a timely alternative. The design parameters which deal with aspects such as cement content, fines content, quality control at site and compaction ratio of the machine have been investigated in order to make this technology scientifically viable. It is shown that the wall strength and the block strength can be related so that it could be used in quality control at site. A summary of the cost analysis is also included in order to show the cost effectiveness of the compressed earth block technology.

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INTRODUCTION

The shortage of conventional construction materials and the associated environmental problems call for an urgent investigation into the possibility of using economical and environmentally friendly alternative materials that are available locally (Lim et al., 1984). One such material that is abundantly available is soil. Soil is a broad term used in engineering to include all deposits of loose materials in the earth crust.

With the advent of the Cinva ram compressed block press in 1952 by Raoul Ramirez at the Cinva Centre of Bogota, Colombia, stabilisation and compaction of soil has been used to produce blocks of sufficient strength (Guillaud et al., 1995). Presently, there are a number of manual and motorised machines in use. The compaction pressure of these machines varies between 2 N/mm^2 to 10 N/mm^2 (Bryan, 1988).

In Sri Lanka, laterite soil can be found a few centimetres below the ground level, beneath the organic top soil. Laterite soil is made up of inert materials (gravel, sand, silt) and active materials (clay). The former acts as a skeleton and the latter acts as a binding agent. The proportion in which each type of material present will determine the behaviour and the properties of different soils. There is a requirement for a small amount of fines (clay and silt), but an upper limit is also necessary to limit shrinkage to ensure effective stabilisation.

Stabilisation of soil means alteration of its properties in such a way that the soil does not lose strength on saturation. Stabilisation of soil is intended to reduce the volume of voids, fill the voids that cannot be eliminated and increase the bond between the grains. In stabilised laterite soil blocks, the stabilisation is achieved by three different means. Those are mechanical stabilisation, physical stabilisation and chemical stabilisation. Mechanical stabilisation, in the form of compaction, is used to change the structure of the soil, thus improving density and mechanical strength. It will also reduce the porosity and permeability. Physical stabilisation is used to change the composition and texture. For example, large particles are removed by sieving. When the fines content is too high, sand is added. Chemical stabilisation is used by adding products such as cement, lime etc. to modify the soil properties.

Since machines are used for making cement stabilised soil blocks, it would be possible to achieve good dimensional accuracy and quality by following a proper block making process. The process of block making includes; Soil preparation, measuring of quantities, mixing, compressing of blocks and curing. It is shown that properly manufactured cement stabilised soil blocks with adequate cement as the stabiliser can develop wall strength in excess of 0.9 N/mm^2 when the compaction ratio is more than 1.65. Such blocks can be successfully used for loadbearing walls of two storey houses that are properly planned. The guidelines that should be used for layout planning are also highlighted.

OBJECTIVES

The main objectives of this study are as follows:

1. To determine the strength characteristics of cement stabilised soil blocks for different types of laterite soils.

2. To highlight the potential uses of cement stabilised soil blocks.

3. To develop quality control measures that can be used with cement stabilised soil block and wall construction.

4. To determine the cost implications of adopting cement stabilised soil blocks for single storey and two storey loadbearing construction.

METHODOLOGY

In order to achieve the above objectives, the following methodology was adopted.

1. The strength characteristics of cement stabilised soil blocks and wall panels were determined experimentally.

2. The strength requirements for single storey and loadbearing construction was established with design studies.

3. The site tests that can be used for quality control measures were developed.

4. A detailed study was carried out to determine the cost implications of using cement stabilised soil blocks.

EXPERIMENTAL DETERMINATION OF STRENGTH CHARACTERISTICS

A large number of machines are available for manufacturing cement stabilised soil blocks. The properties of blocks vary with the compaction ratios that are achieved in these machines. Since highly sophisticated hydraulic or motor operated machines can be prohibitively expensive for developing countries like Sri Lanka, a simple economical manual operated machine giving sufficient compaction ratio should be selected.

For the experimental programme, Auram Press 3000 machine was selected which gives a compaction ratio of 1.65 for blocks of height 90 mm. Once a suitable machine and a particular block size are selected, structural designers should be provided with information such as selection of suitable soils, determination of suitable cement contents, the block strengths and wall strengths that could be achieved with selected cement percentages and soil types. The principles and methods that can be used for structural design and the quality control measures that need to be followed should also be established. In this experimental programme, the following aspects were investigated:

1. The effect of fines content(clay and silt) of soil on compressive strength of blocks
2. The effect of cement content on compressive strength of blocks
3. The variation of flexural strength of blocks with fines and cement contents
4. The effect of fines content and cement content on wall strength
5. The effects of curing on compressive strength of blocks
6. Suitable mortars for wall construction

Testing of Cement Stabilised Soil Blocks

Cement stabilised soil blocks were tested to determine the compressive strength and flexural strength. These results were subsequently used to develop relationships between the block strengths and wall panel strengths.

Compression testing of cement stabilised soil blocks

The blocks manufactured with Auram press 3000 with a compaction ratio of 1.65 have minor indentations as shown in Figure 1 and hence were tested in a compression testing machine without capping the blocks. The blocks were tested 28 days after casting. In order to determine the effects of curing on the compressive strength of blocks, uncured blocks were also tested in a similar manner. The block strengths given in Table 1 represent the average values obtained by testing three blocks in a compression testing machine. It can be seen that most of the time cured blocks have given higher strengths than uncured blocks, which indicates that curing of blocks could be useful in improving the compressive strength of cement stabilised soil blocks. A moist environment could easily be achieved around the blocks by spraying the blocks with water and then completely covering them with polythene sheets. The blocks used for the experimental programme were all cured as described above.

When making the blocks, the water content to be mixed with soil can be determined by performing a simple test called "Drop test" at the site. It is possible to verify whether the correct moisture content is used for making the blocks by using the penetrometer test.

Penetrometer is a small equipment that is provided with the Auram Press 3000 machine to check the green blocks for water content.

According to Bryan (1988), for clayey soils, the compressive strengths increase with the increasing compaction pressure. Auram Press 3000 exerts a compacting pressure in the range of 2.7 N/mm^2 to 5.3 N/mm^2. Once a block size is selected, the compaction ratio is fixed and the associated compaction pressure is most likely to be constant. For a constant compaction pressure, it may be possible to have a considerable reduction in strength when the clay content increases. This could be attributed to the reduction in strength for fines contents of more than 40%.

In order to maximise the benefits of alternative building materials, it is necessary to ensure that this technology can be used even at remote locations. This can easily be achieved for cement stabilised soil blocks since the block making machine can be transported easily and laterite soil can be found in many parts of Sri Lanka.

However, it is absolutely necessary to ensure that some quality control measures can be exercised so that an acceptable strength will be achieved. Since laboratory testing of blocks for compressive strength may not be feasible specially when cement stabilised soil blocks are used at remote locations, an attempt was made to develop an alternative test by relating the average bending strength of blocks to characteristic compressive strength. The development of such a relationship can be supported on the basis that when a wall panel is loaded, a complex stress field occurs between block and mortar where the failure is likely to occur due to some tensile stresses causing the blocks to split.

Table 1 Strength details for different percentages of cement with 290 mm x 140 mm x 90 mm blocks

Fines %	Cement %	Average compressive strength of uncured blocks (N/mm^2)	Average compressive strength of cured blocks (N/mm^2)	Average bending strength of blocks (N/mm^2)
20	2	1.07	1.36	0.116
	4	1.57	2.49	0.184
	6	1.77	3.15	0.208
	8	3.49	4.30	0.327
25	2	1.20	1.84	0.109
	4	2.81	2.62	0.160
	6	2.62	2.94	0.184
	8	2.45	4.00	0.273
30	2	1.78	1.66	0.072
	4	2.03	3.32	0.191
	6	2.69	3.90	0.289
	8	2.40	3.97	0.257
40	2		1.13	0.084
	4		1.93	0.217
	6		2.70	0.287
	8		2.89	0.439
45	2		1.04	0.085
	4		1.79	0.187
	6		2.17	0.259
	8		3.33	0.244

Flexural testing of cement stabilised soil blocks

Flexural testing of blocks was done with the aid of a simple bend test machine of the form shown in Figure 2. Since cement stabilised blocks are strong in compression and weak in tension, the flexural failure occurs as soon as the flexural tensile strength is exceeded by the flexural tensile stress induced by the bend test machine. In this study, special attention was paid to the flexural test with the view of developing a relationship between the flexural tensile strength and the panel strength. Thus, this test could be used for quality control purposes when such relationships are available. Bend test results are given in Table 1.

Testing of Wall Panels

Determination of compressive strength of wall panels

In order to determine the strength properties of the walls, wall panels made with cement stabilised soil blocks were tested in compression. The load deformation behaviour of wall panels were recorded while applying the compressive load. The stresses at 1st crack and at failure were also noted.

It is recommended in BS 5628 : Part 1 : 1978 that the experimental determination of characteristic compressive strength of masonry should be done by obtaining the ultimate strength of panels tested to destruction. The panel size used for this experimental investigation was *3* blocks long and *6* courses high. The advantages of using this panel size is that height/thickness ratio is less than *8*. The slenderness effects will not be significant when this ratio is less than 8 for walls subjected to axial compressive loads (Table 7 of BS 5628 : Part 1 : 1978).

Results of panel testing

Table 2 gives the results of block and panel testing.. The variation of characteristic strength of panels with different fines and cement contents is given in Chart 1. The variation of characteristic strength of panels with compressive strength of blocks is presented graphically in Chart 2a and Chart 2b. The results obtained for panel testing are for a fines content of less than 30% and between 30% and 45%.

Table 2 Characteristic strength of wall panels

Cement percentage	Characteristic strength for fines <30% N/mm^2	Characteristic strength for fines>30% &<45% N/mm^2
2	0.86	0.41
4	0.94	0.66
6	1.00	0.79
8	1.30	0.88

All the above testing was carried out on 290 mm x 140 mm x 90 mm blocks. For loadbearing construction, a larger block size, 240 mm x 240 mm x 90 mm, is generally used. Thus, blocks were also made with 4%, 6% and 8% cement contents to determine the strength characteristics of 240 mm thick blocks. The soil contained about 25% fines. The test results obtained are given in Table 3.

Table 3 Strength details for different percentages of cement with cured 240 mm x 240 mm x 90 mm blocks made with laterite soil consisting of 25% clay

Cement percentage	Average compressive strength of blocks (N/mm^2)	Average bending strength (N/mm^2)	Average compressive strength of panels (N/mm^2)	Characteristic compressive strength of panels (N/mm^2)	Stress at 1st crack (N/mm^2)	
					panel 1	panel 2
4	2.58	0.108	1.03	0.85	0.423	0.427
6	2.85	0.147	1.09	0.91	0.403	0.617
8	3.23	0.199	1.11	0.92	0.403	0.423

Analysis of Block and Panel Test Results

The results of the comprehensive testing programme have been analysed to establish general trends and relationships that can be used in practice. The following general observations can be made with respect to these results:

1. It can be seen from Table 1 that in almost all instances the average compressive strength of blocks increases with the increase in cement percentage for a given fines content.

2. It can also be seen from Table 1 that in almost all instances, the cured blocks have given higher strengths than uncured blocks. Therefore, curing of blocks should always be carried out.

3. Table 1 indicates that the bending strength of blocks, which is a measure of the flexural tensile strength, increases with the cement percentage for a given fines content.

4. It can be seen from Table 1 that the fines percentage of the laterite soil used has some effect on the compressive strength of blocks. There is a considerable drop in strength when the fines content is above 40%. For a given fines content, the panel strength increases with the increase in cement percentage (Table 2).

5. Since there is a considerable drop in characteristic compressive strength when the fines content is more than 40%, it is advisable to use a fines content less than 30% for loadbearing wall construction (Table 2).

6. Table 1 and Table 2 give the characteristic compressive strengths of panels, average bending and compressive strengths of blocks for various clay percentages and cement percentages. Establishment of a relationship of the form given later in this paper between the flexural strength and the characteristic panel strength is extremely important since flexural strength can be obtained using a simple bend test apparatus that can be made available with the cement stabilised soil block machine.

7. It can be seen from Table 3 that for 240 mm x 240 mm x 90 mm blocks constructed with laterite soil containing 25% clay that the characteristic strengths are 0.85 N/mm^2 for 4% cement and about 0.9 N/mm^2 for 6% and 8% cement contents. The minimum value of stress at 1st crack is 0.403 N/mm^2.

On the basis of the results shown in Table 2, it could be stated that when the clay content is below 30% , it would be possible to obtain a characteristic strength of wall panels of 0.85 N/mm^2 for 2%, 0.9 N/mm^2 for 4% and 1.0 N/mm^2 for 6% cement contents with 290 mm x 140 mm x 90 mm blocks.

It can be seen from Table 3 that there is a drop in characteristic strengths for 240 mm x 240 mm x 90 mm blocks. For both blocks, the compaction ratio is fixed at 1.65 in the Auram Press 3000 machine. This drop in strength when the block size is made larger can be explained as follows.

In BS 5628 : 1978 : Part 1, the strength of solid block walls are given in Tables 2(b) and 2(d). For a block strength 2.8 N/mm^2, the characteristic compressive strength is 2.8 N/mm^2 for solid concrete blocks having a ratio of height to least horizontal dimension between 2.0 and 4.0. The characteristic compressive strength of walls drops to 1.4 N/mm^2 when the ratio of height to least horizontal dimension is reduced to 0.6. This indicates that for a given height of blocks, the wall strength drops with an increase in thickness of the blocks.

The following equations can be suggested to determine the panel strength when flexural strength and compressive strength of blocks are known. These equations are obtained by performing a linear regression analysis.

1. For soils with fines content between 20% - 30% , the characteristic compressive strength of walls is approximately given by $0.15\sigma_c + 0.55$ where σ_c is the average compressive strength of the blocks.

2. For soils with fines content above 30% and up to 45%, the characteristic compressive strength of walls is approximately given by $0.2\ \sigma_c + 0.2$ where σ_c is the average compressive strength of blocks.

3. For soils with fines content between 20% - 30%, the characteristic compressive strength of walls is given by $2\sigma_b + 0.6$ where σ_b is the flexural strength of the blocks.

4. For soils with fines content above 30% and up to 45%, the characteristic panel strength is given by $1.5\sigma_b + 0.35$ where σ_b is the flexural strength of the blocks.

Use of Recommended Strengths for Limit State Design

According to Hendry (1982), the basic aim of structural design is to ensure that a structure fulfils its intended function throughout its lifetime without excessive deflections, cracking or collapse.

In masonry design, the partial safety factors for loading (γ_f) are introduced to allow for (Hendry et al., 1981):

a. possible unusual increases in load beyond those considered in deriving characteristic loads,

b. inaccurate assessment of effects of load and unforeseen stress redistribution within the structure, and

c. variation of dimensional accuracy achieved in construction.

It should be noted that the values of γ_f recommended in BS 5628 : Part 1 : 1978 are quite similar to the values used for concrete construction although the effects allowed in (b) and (c) above may or may not be the same for masonry and reinforced concrete. In BS 5628 : Part 1 : 1978, such inaccuracies are taken into account by adjusting the partial safety factor for materials (γ_m), rather than γ_f (Hendry, 1982). Thus, the values allowed for γ_m are much higher than those for concrete and it takes account of rather approximate stress distributions assumed for load transfer and also somewhat brittle behaviour of masonry. The partial safety factors specified in BS 5628 : Part 1 : 1978 are given in Table 4.

Table 4: Partial safety factors recommended for material strength (γ_m) from BS 5628

		Category of construction control	
		Special	Normal
Category of manufacturing control of structural units	Special	2.5	3.1
	Normal	2.8	3.5

It is suggested that for structural design of cement stabilised soil block walls, a partial factor of safety for material strength, γ_m, of 3.5 should be used with the design strengths recommended.

For blocks of 6% cement with fines content less than 30%, the characteristic block strength is 0.9 N/mm^2. The corresponding working stress can thus be determined as follows. The partial factor of safety for loading, γ_f, is 1.4 for dead and superimposed dead loads and 1.6 for imposed loads. If an average value of 1.5 is assumed for γ_f, then the working stress can be calculated as $0.9/(3.5 \times 1.5) = 0.172$ N/mm^2.

The stress at 1st crack in the panels have a minimum value of 0.32 N/mm^2 for any cement or fines content covered in the study (Jayasinghe C., 1999). This means that it is unlikely for any cement stabilised soil block wall to develop cracks at working stresses. Thus, the use of γ_m as 3.5 will be adequate to ensure that no cracks will appear in the cement stabilised soil block walls when subjected to working loads.

The use of a partial factor of safety of 3.5 is also advisable from the following point of view. BS 5628 : Part 1 : 1978 recommends that a partial factor of safety of 2.5 can be used with special manufacturing and construction control. This means that the factor of safety allowed for the uncertain load transfer and the statistical variation of strength is 2.5. Thus, the factor of safety allowed for the variation of strength of materials due to average quality controlling is 3.5/2.5 = 1.4.

Hence, when a structural design is carried out with a design strength of 0.9 N/mm^2, the strength that should be assured in the wall is 0.9/1.4 = 0.64 N/mm^2. It can be seen from Table 2 that this characteristic strength can be obtained even with 2% cement when the fines content is less than 30%. It can also be seen that with a cement content of 6% and above, this strength can be obtained even with higher fines contents such as 45%. This means that, when proper block making practices are followed, any localised variations in the block manufacturing process are extremely unlikely to affect the performance of a loadbearing wall.

This gives a lot of confidence for the design engineers to recommend cement stabilised soil blocks made with a compaction ratio of 1.65 as a loadbearing material for walls. When such recommendations are made, it is desirable to follow good block manufacturing practices and block work construction practices.

DESIGN STUDY

Design Strengths Required

Since the characteristic compressive strengths that can be obtained with cement stabilised soil blocks are in the range of 0.9 N/mm^2, careful planning will be required for two storey residential buildings or houses in order to keep the maximum stresses sufficiently low. This will need attention to minimise the loads acting due to upper floor and also to reduce the stress concentrations due to openings.

It is shown with a detailed design study for two internal and external walls that the compressive strength required at the ground floor level of a carefully planned two storey loadbearing wall house is less than 0.9 N/mm^2 (Jayasinghe, 1999). A characteristic strength of 0.9 N/mm^2 can be achieved with cement stabilised soil blocks of 6% cement and where the soil has less than 30% fines. The mortar recommended is 1:6 cement sand.

When the stress at 0.4 x wall height below the top of the wall was checked, it was found that the compressive strength required is generally less than 0.85 N/mm^2 (Jayasinghe, 1999). This strength can be achieved with cement stabilised soil blocks of 4% cement. Thus, it would be possible to use these blocks for the upper part of the ground floor loadbearing wall and reduce the cost of construction. It may be safe to use 4% blocks above the mid height of the ground floor.

Guidelines for the Layout Selection

On the basis of the design study, the following guidelines can be suggested for the design and construction of loadbearing cement stabilised soil block houses and residential buildings.

1. The ground floor walls should be at least 240 mm thick. The ground floor openings should be carefully planned so that they are well separated and the maximum size is limited to 1.25 m.

2. The openings in the ground floor external walls should preferably be located in walls carrying lesser loads. If window openings are required in walls supporting concentrated loads, the openings should be located between the loads. It is not advisable to locate the centre of an opening below a concentrated load.

3. The internal walls should be provided with a minimum number of openings since those can be loaded heavily due to loads acting from both sides. When there are openings in the ground floor internal walls, it is preferable to have similar openings in the upper floor too, thus reducing the load on the ground floor walls.

4. The upper floor walls should be constructed with 140 mm thick blocks, thus reducing the load on ground floor. The maximum height of internal walls should preferably be maintained below 4.0 m. This height would be satisfactory when asbestos is used as the roof covering since the slopes required for drainage is low.

5. The upper floor openings also should be located preferably over the ground floor openings. Since openings of length 1.2 m can provide adequate lighting and ventilation when suitable heights are selected, the maximum length of an upper floor opening can be maintained at 1.2 m.

6. When partition walls are required not coinciding with the ground floor walls, the weight of partition walls can be minimised by using timber partition walls.

7. Since the wet strength of cement stabilised soil blocks is low, it is advisable to use it as a loadbearing material only for buildings where there is no threat of floods. To improve the durability of these walls, some coatings and paints have been successfully used. A paint of 1:1:6 cement, lime and soil is one of such paints which is reasonably water resistant. There are some plasters such as 1:4:8 cement, soil and sand that can be used economically for protecting the cement stabilised soil block walls.

When large openings are required at few locations in the ground floor, it may be possible to use reinforced concrete framework at those locations and to use cement stabilised soil block loadbearing walls elsewhere.

COST ANALYSIS

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 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 in the country. Therefore, any cost saving presented here is not absolute.

The cost of cement stabilised soil block walls depends on the cost of cement, soil, labour required for block making and wall construction. Since laterite soil can be available at site, two cases are considered, namely soil at site and soil bought. The details of the cost study can be found in Jayasinghe (1999).

Total Cost for Construction of 1 m² Area of Blockwork

The overall costs per 1 m² of blockwork using 290 mm x 140 mm x 90 mm blocks are given in Table 5. The overall costs per 1 m² of blockwork using 240 mm x 240 mm x 90 mm blocks are given in Table 6.

Table 5: Cost per 1.0 m² 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/m²)	
	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: Cost per 1.0 m² of wall area with 240 mm x 240 mm x 90 mm block

Cement	Cost of blocks (Rs)		Cost of labour and mortar	Total cost (Rs/m²)	
	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

Cost of Brickwork and Blockwork

The cost of brickwork depends on the cost of bricks, cement, sand and labour. The following costs have been determined on the basis of prevailing market prices.

The cost of brickwork for 1.0 m² was calculated as Rs. 319.34/= for 110 mm thick walls. The cost of brickwork for 1.0 m² was calculated as Rs. 588.87/= for 210 mm thick walls.

The size of blocks can be either 200mm x 200mm x 400mm or 100 mm x 200mmx 400 mm. The cost of cement sand block work for 200 mm thick blocks was calculated as Rs . 563.92/== per m². The cost of cement sand blockwork for 100 mm thick blocks is Rs. 285/= per m². These prices are calculated on the basis of prevailing market prices. On the basis of above cost data, the cost savings can be determined.

SUMMARY

A detailed experimental programme has been carried out for the cement stabilised soil blocks manufactured with AURAM Press 3000 machine giving a compaction ratio of 1.65.

It has been shown that characteristic design strengths of 0.9 N/mm^2 and 1.0 N/mm^2 can be obtained for 240 mm and 140 mm thick walls respectively, with certain cement percentages and certain fines percentages. The relationships between the panel strengths and flexural strength of blocks also have been developed. With these findings, now it would be possible to use cement stabilised soil blocks for the construction of two storey houses with proper scientific background and also with a lot of confidence. It is also possible to maintain the quality control that is required for a design method based on limit state design philosophy by using the bending test that can be carried out at the construction site itself.

It is shown that cement stabilised soil blocks can be used for loadbearing construction since the compressive strengths required are less than the characteristic strengths that can be achieved for blocks with 6% cement. It is also shown that blocks with 4% cement also could be used at the ground floor above the mid height. However, it should be noted that this technology can be used only with carefully planned houses since it is absolutely necessary not to overload the loadbearing walls. Thus, a set of guidelines also has been given which can be used at the initial design stage of planning layouts. 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.

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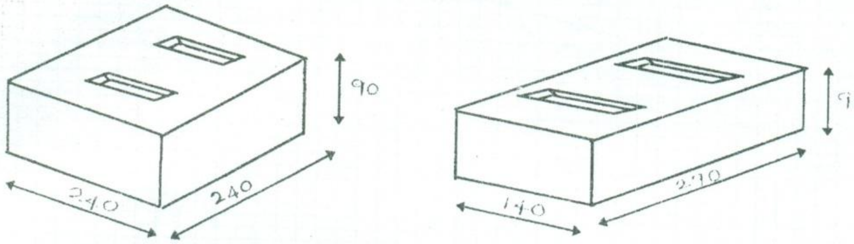

Figure 1: Shape of blocks manufactured by using Aurum Press 3000 machine

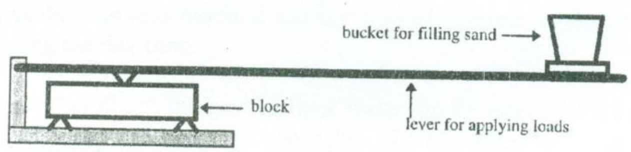

Figure 2: Bend test machine

Chart 1 : Variation of characteristic compressive strength of panels with fines and cement contents

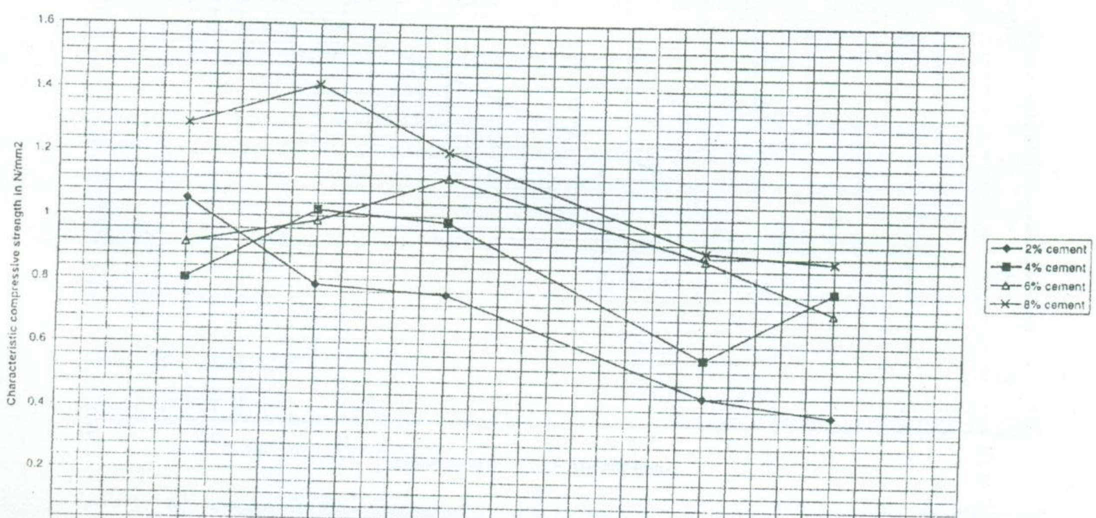

Chart 2a: Variation of characteristic compressive strength of panels with average compressive strength of blocks (Fines content < 30%)

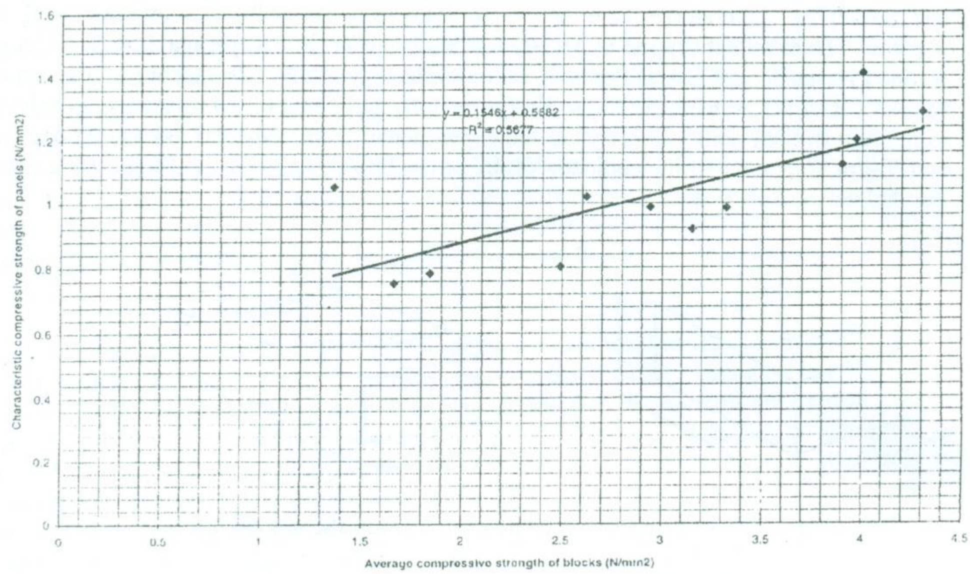

Chart 2b: Variation of characteristic compressive strength of panels with average compressive strength of blocks (Fines content 40% - 45%)