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Analysis and Assessment on Compressed Cement Stabilized Earth Blocks as an Alternative Wall making Materials

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ABSTRACT

This paper provides a detailed study on the technical and Economical information on the production of compressed cement stabilized soil blocks an alternative wall making material. With suitable soil types, stabilization and production techniques. The test results have shown that blocks produced using 6% (percent cement) as stabilser have equal compressive strength with hollow concrete blocks when tested at the age of 56days. In addition, increasing cement content results into the compressive strength and a decrease in the absorption capacity of the soil blocks; and increment of the compaction pressure has also improved the compressive strength of the soil cement blocks significantly. The influence of cement types on compressive strength development were also analyzed with the economical advantage of the blocks.

Keywords: ***Cement, compaction pressure, compressive strength soil cement Blocks, stabilization***

INTRODUCTION

The actual choice of Building material is one of the important criteria that determines the strength, aesthetic, quality, durability and Economy of any construction projects. In the past, stone, sand, earth, grasses, animal hides, etc were mainly used as building materials in their actual crude form. As Technology advanced, the crude as well as the partly refined materials were then replaced by others, especially made for different purposes such as dressed stones, bricks, cement, Reinforced and prestressed concrete, etc which later triggered the rapid development and advancement of construction Techniques. The aim of this study therefore centered on the following:-

(i) The optimum proportions between soil and cement as a stabilizing agent.
(ii) The effects of compaction pressure on the physical properties of the blocks
(iii) Establishing a reference for a future studies
(iv) Comparative costs with other wall making materials, such as hollow concrete blocks.

Historical understanding of Compressed Earth Blocks

The history of earth blocks is dated back to 1950s in the frame of a research programmes carried out on rural housing in Columbia. It is an improvement of the adobe production techniques. Instead of the earth blocks being moulded by hand in a wooden frame, the slightly moistened soils were formed by applying pressure in a steel press/mold. Compared to the hand-moulded blocks, compressed earth blocks are very regular in size and shape, and have better density. Using these blocks as wall making material, two-three storey marvelous residential and recreational buildings were built in different parts of the world. Unfortunately, its functional importance is little understood and used for only limited applications in Ethiopia. Typical compressed earth blocks are shown in fig 1

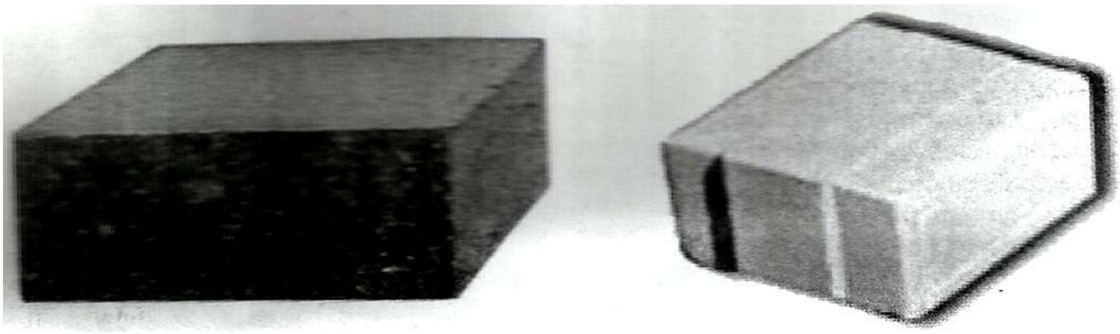

Fig. 1: Typical compressed earth blocks (3)

Today, there is a revival on the use of this traditional building material, not only in developing countries, but also in the developed western world for various reasons, among which cost effectiveness, natural aesthetic look. Environmental friendliness, energy conservation play a major role. The research centers in India Autryville, Cratered in France, and the Hydra form company in South Africa have made great progress on stabilized compressed earth blocks due to their intensive scientific research, experimentation, and architectural achievements which form the basis for a wide range of technical documents and academic and professional courses. A major effort is now being devoted to the question of norms and this should help to confer ultimate legitimacy upon the technique in the coming years.

Characteristics of Soil for Compressed Cement Stabilized Blocks

Identification of soil characteristics and study of ambient climatic conditions of an area are important before attempting to produce stabilized soil blocks. A soil in dry climate, for instance, may have different soil parameters from those in temperate, rainy or tropical climate areas. In all cases, however, the physical properties are of greater interest for making compressed stabilized soil block since they are useful to determine its ease of mixing, forming, de-moulding, porosity, permeability, shrinkage, dry strength and apparent bulk density. The basic materials, however, required to manufacture compressed stabilized earth building blocks is a soil containing a minimum quantity of silt and clay. An optimum fine content for making compressed stabilized soil block was more than 10% is clay (4). A more useful range of particle sizes suitable for building with earth block is given as: 40-75% sand / fine gravel, 10-30% sit and 15-30% clay (4).

Soil Stabilization

Several soil stabilization techniques are widely practiced worldwide for the purpose of improving soil properties that include: mechanical stabilization, cement stabilization, gypsum stabilization and pozzolana's stabilization. In this research work cement stabilization technique, which to moist soil sample and mechanically pressing, was employed. As it is widely understood, cement is mainly composed of lime (CaO) and silica ($SiO2$) which react with each other and the other components in the mix in the presence of water to form calcium-silicate-hydrtates. The chemical reactions eventually generate a matrix of interlocking crystals that cover any inert filler (eg. Sands) and provide a high compressive strength and stability (5). Due to its strong chemical binding capability, positive test results of prior studies, and availability in the market the selection of cement as a binding agent for the study has thus been justified. Lime and lime pozzolan stabilization are also growing in popularity sine they can be produced at a lesser cost using small scale batching kilns. The use of lime as a soil stabilizer is under investigation and will be reported later elsewhere.

Production of Compressed Earth Blocks

The process is started by dry mixing a suitable soil with a certain amount of cement and remixing the product with a specific quantity of water. The resulting damp soil is normally compressed in a mould, ejected and subsequently wet

$$2C_3S + 6H = C_3S_2H_3 + 3Ca(OH)_2 \text{----------------[Eq.1]}$$

$$2C_2S + 4H = C_3S_2H_3 + Ca(OH)_2 \text{-----------------[Eq.2]}$$

The free lime then reacts further with the clay fraction (pozzolanic reaction) by the removal of Silica from the clay minerals and subsequently forms more calcium silicate gel that also gradually crystallizes. These gels then slowly crystallize in to an insoluble interlocking matrix throughout the soil voids binding the soil particles together. As the matrix is insoluble it gives a strength mechanism that works to restrain the softening and swelling of the unaffected soil, thereby dramatically reducing the weakening effect of water. The interlocking calcium silicate fibers may be seen when a cured soil cement sample is examined under an electron microscope [6,7].

Materials used for investigation

The Soil

Curing for 3-4days followed by damp curing for twenty-eight days before used for building purpose. The minimum amount of cement required to stabilize a block depends on the type of soil, the degree of compression and the final application of the blocks. Generally the interest is to minimize the cement content to below 10%. Given suitable conditions, production of blocks with cements contents as low as 3% is possible. The exact mechanism by which a small content of cement may stabilize a large mass of soil is not yet fully understood. As mentioned above the major components of cements (C_3S and C_2S) form mono and declaim silicate hydrate gels (see the simplified equations below) in the presence of damp soil [5]. Making the logical assumption that $C_3S_2H_3$ (Calcium silicate hydrate) binding gel, is the final product of the hydration of both C_3S and C_2S, the reaction of hydration can be written according to the following reaction equations(as a guide, although not as exalt stoichiometeric equation) resulting in the release of free lime(CH)[5:].The physical properties and the chemical composition of the soil sample are given in table 1 and Table 2 below, respectively

Table1 Physical properties of the kara soil [3]

NO	PHSICAL PROPERTICS	VALUES
1	Specific gravity (gm/cc)	2.61
2	Natural moisture content (%)	14.87
3	Optimum moisture content (%)	19
4	Maximum dry density(kg/m^3)	1610
5	Silt content(%)	16.25
6	Clay content (%)	13.75
7	Sand content (%)	70
8	Linear shrinkage (%)	7.14
9	Liquid limit (%)	31.91
10	Plastic limit (%)	25.75
11	Plasticity index (%)	6.16

Table 2 chemical composition of the soil [3]

Chemical oxides of the soil and their chemical Composition														
SiO_2	AI_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K^2O	MnO	H_2O	LOI	TiO_2	P_2O_5	SO_3	CI-	pH
65.32	15.27	7.68	<0.01	0.18	1.59	5.07	0.19	4.06	4.06	0.4	<0.01	0.07	<0.01	6.75

Cement

In this reason work five mixes were prepared using Portland pozzolana cement and nine mixes are prepared using Portland pozzolana cement, of the cement are summarized elsewhere[8].

Water

Throughout the investigation tap water which is supplied by the water supply system in the laboratory was used.Table 3 Mix proportions for the first series

Mix Proportion

The following test programs were followed in the investigation based on available literature recommendations.

1. The first series of mixes (5 in number) were prepared to study the difference in compressive strength values with age of the blocks produced using Portland pozzolana cement. They are made with 24% of water and varying cement contents of 4, 6, 8, 10 and 12% by weight of the soil.

The mix proportions are summarized as shown in table4 below.

Mix code	Cement(kg)	Water (%)	Soil (kg)
MUG-4	4	24	100.45
MUG-6	6	24	100.45
MUG-8	8	24	100.45
MUG-10	10	24	100.45
MUG-12	12	24	100.45

2.

3. The second series of mixes (5 in number) were produced to compare the difference in compressive strength values with age of the blocks produced using Messebo Portland pozzolona cement. Similarity they were made with 24% water and varying cement of 4, 6, 8, 10 and 12% by weight of soil. The mix proportions are

Table 4 Mix proportions for the second series

Mix code	Cement (kg)	Water (%)	Soil (kg)
Mes-4	4	24	100.45
Mes-6	6	24	100.45
Mes-8	8	24	100.45
Mes-10	10	24	100.45
Mes-12	12	24	100.45

4. The third series of mixes (16 in number) were prepared using Messobo PPC to study the effects of mould pressure on t he compressive strength development of the samples and on the effectiveness of the cement stabilizer. They were produced with 4, 6, 8,and 10MPa mould pressure and cement contents of 6, 8, 10 and 12% by weight summarized below

Table 5 mix proportions for the third series

Mix code	Cement (%)	Mould pressure (MPa)
MES6-P4	6	4
MES6-P6	6	6
MES6-P8	6	8
MES6-10	6	10
MES8-P4	8	4
MES8-P6	8	6
MES8-P8	8	8
MES8-P10	8	10
MES10-P4	10	4
MES10-P6	10	6
MES10-P8	10	8
MES10-P10	10	10
MES 12-P4	12	4
MES12-P6	12	6
MES12-P8	12	8
MES12-P10	12	10

Specimen Preparation

A pre-installed M7 E380 machine designed on the quasi-static compression principal was for the entire samples to produce the blocks (see (fig 3). Before filling the mould for each compression, the mould lining was thinly lubricated with used engine oil. The soil was then carefully poured into the mould, all pre-weighed, packed and sealed in light transparent plastic bags. After each pouring, the soil was leveled in the mould. The use of the M7 E380 machine was applied strictly following the operational manual of the machine. The blocks were compressed by the pumping action of the side pump up to 10MPa. The hydraulic pressure was released using the flow value screw causing the hand pump to become slack. The mould cover (Top ram) was then moved upwards to expose the green block, which was, then demoulded. The green blocks were then carefully removed and put over base plates, and immediately placed in plastic bags and left to cure in the shade. The dimensions and the weights of the green blocks were recorded.

TESTS ON BLOCKS

Compressive strength test

The main aim of the compressive strength test was to determine the wet compressive strength values of the blocks. It is the wet compressive strength value, which is normally lower than the dry compressive strength that is used in the structural design of the buildings. The compressive strength tests were done based on ASTM standards, volume 04.08, soil and rock, 1999[10]. After 7, 14, 28 and 56 days of wet curing durations the block dimensions were measured and weighed. The main compression equipment used was the concrete testing Machine with a maximum load of 100kn. The machine was certified and calibrated for the test duration by Hydra form Company, South Africa. Figure 4 shows a photographic record of the compressive strength test taken during the experiment. In all cases, three test samples were produced for each mix proportion and a mean of the three results are taken to represent the particular mix. The sample mould has a dimension of 22x22x11cm, and all samples were soaked in ordinary tap water for 24hours before testing. They were then removed and kept aside for 30 minutes to let extra surface water to drip off. The samples were then carefully placed within the set marking pins of the compression-testing machine and readied for loading. The crushing load was continuously applied without shock to the samples at a rate of 3.5 MPa per minute until failure. The wet compressive strength was then calculated in each case from the cross sectional area of the block

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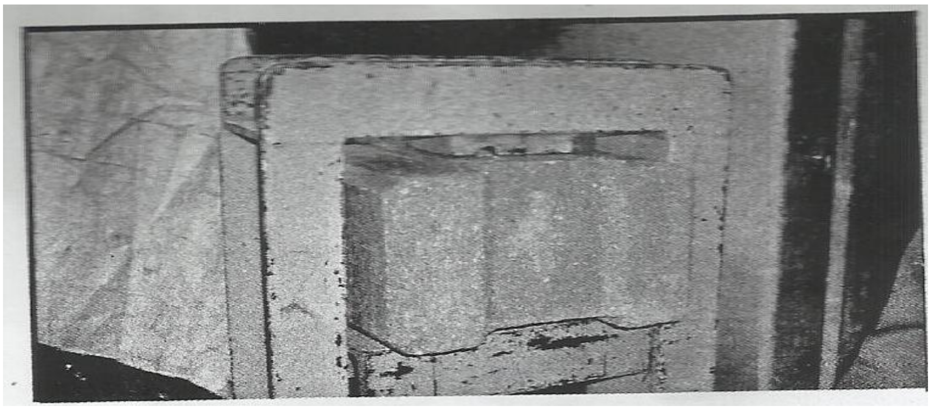

Fig.4 Compressive strength testing machine

Water absorption Test

The block samples were weighed in the laboratory dry condition (W_d) and, immersed in water for 24 hours, removed and weighed again (W_w). an accurate electronic weighing machine was used to an accuracy of 0.05g. The percentage moisture absorption by weight was calculated using the formula shown in Equation 3

Mc = <u>Ww – wd</u> x 100(%)………………………………… …….. (Eq. 3)

Where: Mc= percentage moisture absorption (%)

Ww = mass of wetted samples (g)

Wd = mass of dry sample (g)

The recommended maximum water absorption range values of blocks varied between 15 and a maximum value of 20%

RESULTS AND DISCUSSIONS

Compressive strength

The results of the compressive strength tests are tabulated and plotted on Table 6 and Figure 5 for PPC, respectively. As expected the compressive strength values are encouraging and increase with the cement content and test ages. For 6% and above cement additions, the 28 days compressive strength values are better than the minimum compressive strength requirement of Class C hollow concrete blocks. It is to be noted that Class C hollow concrete blocks required to have a mean of 2MPa according to ES C.D3.3010 [11]. Samples produced using 6% cement as a stabilizer and tested at the age of 56 days have also satisfied the class C hollow concrete requirement. Research made earlier on the quality of HCB in and around Addis Ababa reported that over 95% of the samples collected for compressive strength tests could not even satisfy class C requirements [12]. This indicates that if properly produced, compressed cement stabilized earth blocks can provide competitive advantage and in higher doeses of cement even better performance can be achieved over that of hollow concrete blocks which are usually available in local market without fulfilling standard requirements.

Table 6. Mean compressive strength of soil cement block using Mugher PPc

Mix code	Mean compressive strength [MPa]			
	7 days	14 days	28 days	56 days
MUG -4	0.3	0.6	1	1.25
MUG – 6	0.6	1.3	1.5	2.23
MUG – 8	1.1	1.8	2.1	3.2
MUG –10	1.4	2.1	2.5	4.03
MUG-12	1.5	2.5	3.5	5.03

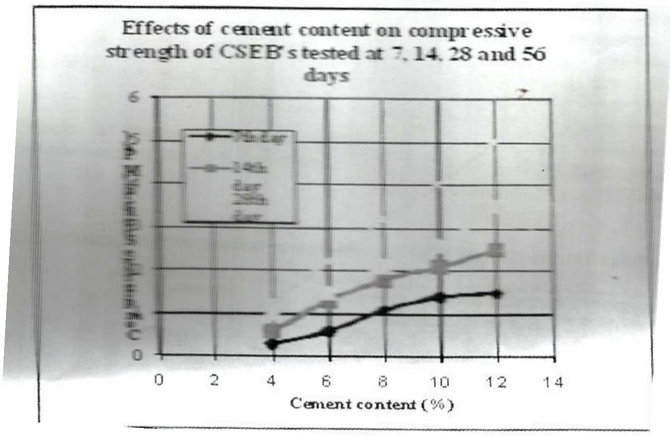

Fig 5: Effects of cement on the compressive strength development of stabilized soil blocks made using Mugher PPC.

Table 7: Mean compressive strength blocks using Messobo PPC

Mix code	Mean compressive strength [MPa]			
	7 days	14 days	28 day	56 days
MO4	0.15	0.7	0.8	1.0
MO6	0.4	1.0	1.6	1.85
MO8	1.0	1.3	2.3	2.9
MO10	1.3	1.7	3	3.2
MO12	1.7	1.8	3.4	4

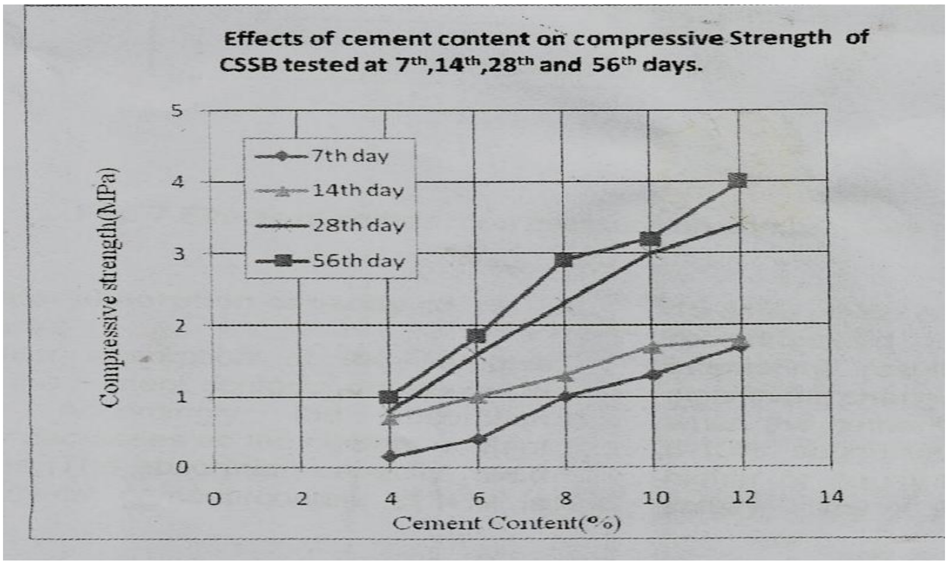

Fig. 6: Effects of cement on the compressive strength compressed stabilized soil blocks produced using PPC

Effects of mould pressure on the compressive strength development

The test results, as shown in Table 8 and fig. 7 indicate that increment of compressive strength of soil cement block significantly. For instance, increasing the mould pressure from 4 to 10MPa would double the compressive strength of the blocks. For better quality product, it is thus recommended to compact at a pressure of 8-10MPa.

Table 8 Effects of compaction pressure on the 28 days compressive strength of concrete

Cement content	Compaction pressure and compressive			
	4	**6**	**8**	**10**
6	0.1	0.9	1.2	1.7
8	1.3	1.65	2.1	2.6
10	1.4	2.2	2.6	2.75
12	1.8	2.4	2.95	3.4

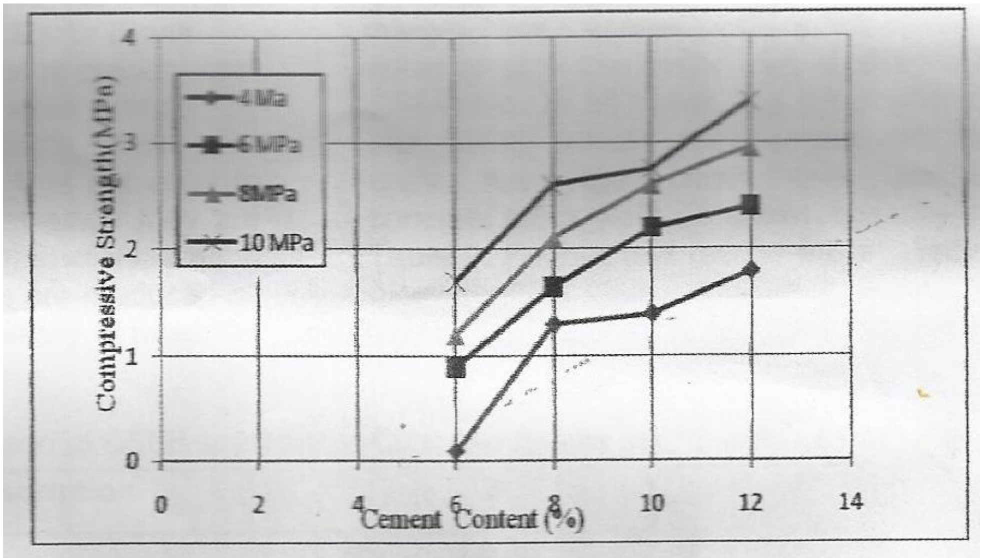

Fig.7: Effect of compaction pressure on compressive strength of CSSB

Water absorption capacity of block

The water absorption of the samples against the cement contents are shown in fig. 8. According, the absorption capacity decreases as the cement content increase. The absorption capacity, even at the lowest cement content of 4%, is 15.81%, which is within the allowable limit recommended by literature. The other interesting result is that there is no significant change in absorption capacity when the cement content varies between 6-10% suggesting that cement content higher or equal to 6% would sufficiently satisfy the sorptivity requirement. Effects of cement on the absorption capacity of CSEB

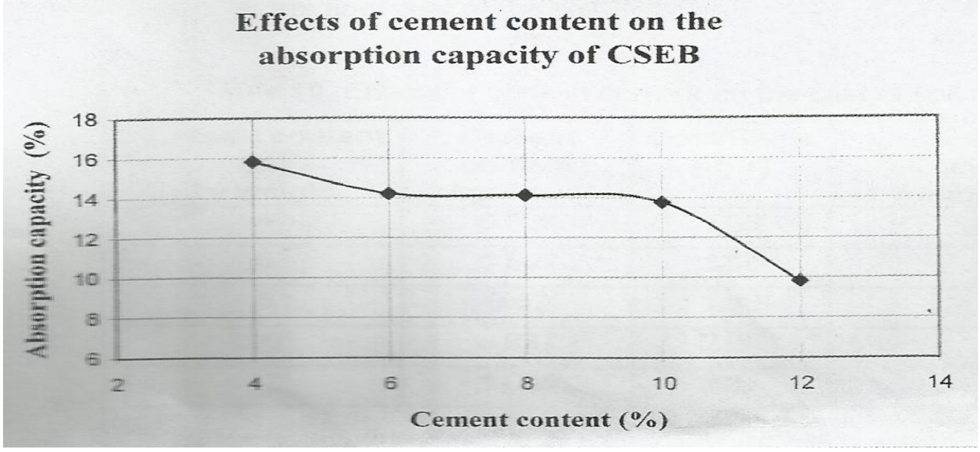

Fig. 8 Effects of cement on the absorption capacity of soil cement block.

Economic Analysis of Cement Stabilized Compressed Earth Block

Attempts have been made to prepare cost comparison between walls made by compressed stabilized earth blocks with hollow concrete blocks. It is not easy to exactly compare the cost since, they are influenced by various parameters, among which whether the blocks are produced on site or block yards, efficiency of machine, investment and variable costs, profit margin and accessibility to the raw material play the major part in the cost differences. In all cases, the result shows that CSEB provide cheaper solution for walls than the conventional hollow concrete block walls as shown typically in Table 9. Further test results are available elsewhere [3].

Table 9: Comparison of CSEB with Hollow Concrete Blocks per m^2 area of wall

No	Description	1^A	2^B	3^C	4^D
1	Block	74.36	74.36	62.40	62.40
2	Mortar for fixing	21.70	21.70	-----	----
3	Plastering	50.00	-----	25	----
4	Pointing	-----	20.00	----	----
5	Painting	24.00	-----	12.00	-----
6	Varnish	-----	-----	7.00	14.00
7	Labor	34.00	22.00	23.00	15.00
8	Total walling cost (Birr)	204.06	138.06	129.40	91.40
	Percentage difference	0	-32.35	-36.59	-55.2

1^A Hollow concrete blocks (HCB) Birr per m^2 plastered and painted, both outside and inside

2^B Hollow concrete blocks (HCB) per m^2 pointed, both, outside and inside

3^c Dry stack CSEB, plastered only internally, Birr per m^2

4^D Dry stack CSEB, without plaster on both sides, Birr per m^2

Sensitivity Analysis

Sensitivity analysis is used to evaluate the effects of change in the variable and fixed costs on the final cost o the soil block This prevents one being caught unaware if costs increase or if productivity falls. Table 10 and Fig 9 below shows the effects of cement content on final cost of the soil cement block

Cement content (%) by weight	Cement Content kg/Block	Cost/Blok (Birr)	56 days wet Compressive Strength (MPa)
4	0.335	1.33	1.25
6	0.502	1.56	2.23
8	0.67	1.83	3.2
10	0.837	2.08	4.03
12	1.005	2.33	5.03

Effect of cement content on soil cement cost

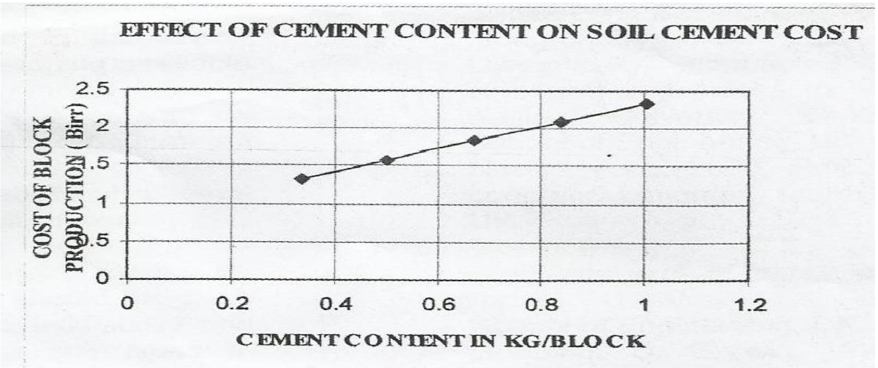

Figure 9 sensitivity test chart

CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory investigation made on CSEB's the following conclusions and recommendations stated

1. Stabilization of soil block using Portland pozzolana cement fulfills a number of objectives that are necessary to achieve a durable wall making material from locally available soil resulting in competitive compressive strength, better cohesion between particles reducing porosity that in turn reduces changes in volume due to moisture fluctuations.
2. Increase in stabilizing cement content results in an increase in the compressive strength value of blocks made at the same constant compaction pressure.
3. Increase in the cement content of CSEB's result in a reduction of its water absorption capacity, which

could contribute to improvement of durability.

4. Assessing the financial and technical performance comparison between compressed stabilized soil block and hollow concrete block, it was found out that the CSEB's are affordable to low income community and user friendly in production. It has further advantage by using only suitable one raw material stabilized with cement, reducing the transport of sand, scoria and pumice like in that of hollow concrete blocks. CCSEB's can therefore be used as an alternative wall making material competitive to the conventional ones in the community.
5. Political decision makers as well as public and private institutions have important roes to play in propagating the appropriate technology so that it is adopted by the community at large.

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