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Study of Compressed Earth Blocks as an Alternative Wall Building Material

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***Abstract*—This research reports on the investigation into the strength and durability in-terms of shrinkage of compressed earth blocks produced from natural site soil and modified or reconditioned soil types.**

The soils were stabilized chemically by cement and lime stabilizers with a mix proportion of 5 and 7% cement as well as 10 and 15% lime, the control treatment being with no stabilizer (un-stabilized) in both soil types. Hence, for each soil type five different treatments were considered for the study. Four blocks were produced for each treatment.

The engineering characteristics and classification of soil samples were determined by applying suitable tests. Furthermore, the compressive strength, dry block density and dimensional stability in-terms shrinkage (volume change) of the sample earth blocks were investigated after the elapse of their respective curing periods.

In general, significant improvements in dry compressive strength and dimensional stability characteristics were exhibited by the stabilized and compressed earth blocks. With regard to dry compressive strength of blocks, the result showed that the average compressive strength of cement stabilized blocks were found to be 1.42 and 1.53MPa in case of natural site soil and 2.73 and 2.90MPa in case of the modified soil with a mix proportion of 5 and 7% of cement by weight respectively. Similarly, the average compressive strength of lime stabilized blocks were found to be 1.45 and 2.20MPa in case of natural site soil and 1.38 and 1.45MPa in case of modified soil with a mix proportion of 10 and 15% of lime by weight respectively.

Accordingly, by considering a minimum dry compressive strength of 2MPa as an acceptable strength, the 15% lime stabilized earth blocks in the case of natural site soil as well as the 5 and 7% cement stabilized compressed earth blocks in the case of modified soil have shown a dry compressive strength value greater than 2MPa and hence can be conveniently used as an alternative durable and affordable wall building elements in Jimma area.

Keywords*— *Reconditioned soil; Stabilizer; Compressed earth block; Compressive strength; Shrinkage.

I. INTRODUCTION

Housing is one of the basic needs of mankind. It is a structure and an asset that an individual or a family aspires to acquire and own in the world. It is regarded as one of the most valuable and lasting human made capital asset for which most families ever make the largest investment. It should therefore be strong and durable and one that lasts for many years.

Housing still remains one of the important needs of man and its demand always is on the increase. However, in many parts of the world fulfilling housing requirement of the population remains a challenge. As a result, especially significant parts of the population of developing countries are found to be homeless, lives in slums and sub standard houses. The case of Ethiopia is not an exception. According to government estimates, Ethiopia's housing deficit is between 900,000 and 1,000,000 units in urban areas and that only 30% of the housing stock is in a fair condition with the remaining 70 percent in need of total replacement. The housing deficit is set to increase concurrently with the foreseen high population and urban growth. To accommodate the future growth, the Urban Sector Millennium Development Goals Needs Assessment held in 2004 predicted that to meet the Millennium Development Goals (MDGs) in 2015 requires a total of 2,250,831 units which equates to a considerable 225,500 houses per annum. To do away with urban poverty and to improve housing access to low and middle income residents of urban areas, government has since 2005 designed and implemented an ingenious urban housing development program called INTEGRATED HOUSING DEVELOPMENT PROGRAM (IHDP). One of its major development components of the program were the construction of 400,000 condominium units for housing low and middle income citizens. The program has been able to build 142,802 housing units between 2006 and 2010. In addition since the first growth and transformation plan (GTP) started in 2010 a total of 96,233 housing units and 1,720 housing blocks have been constructed [1].

As can be seen from the above data, there is a huge gap between the housing supply and demand. The provision of condominium housing units by the IHDP was suspended in regions because of low effective demand and weak ability to pay the down payment and monthly mortgage and lack of adequate financing from banks. The program was unable to meet its target [1].

Although condominiums are supposed to be provide low-cost and affordable housing for the poor and for middle-income households, they do not seem to be meeting their initial goals, as costs are so high that even many middle level-income earners cannot afford the payment [2].

As stated by [3] shelter problems are mainly related with low purchasing capacity of inhabitants and the ever-increasing cost of construction of housing. Hence, it stated that the costly walling materials need to be substituted with new local material and different construction technology apart from conventional one.

As evident in most developing counties, it is almost impossible to fulfill the immense requirements for shelter neither with conventional construction technique nor with conventional building materials i.e., concrete, aluminum and steel which are noted for their high energy consumption during production and associated negative environmental impacts [4]. Besides, these construction materials are becoming costly and are imported.

In Ethiopian, most buildings and houses are constructed with cement blocks, burnt clay-bricks, timber, wood and concrete. Those that are constructed from cement blocks, concrete, steel and burnt clay bricks are costly which could be afforded by relatively few households. The houses constructed from wood, timber and mud are not durable and have already contributed to deforestation and environmental damage and thus are unsustainable.

Hence, as a way of ensuring a sustainable environment and efficient use of resources, there has been the promotion of earth building inform of compressed earth block (CEB) technology which is based on locally available natural and renewable material [5].

Compressed earth blocks stabilized with different stabilizing agents has been found to be an excellent walling material that can replace the expensive cement blocks and burnt clay bricks and help to provide affordable housing for low and middle –income earners. There are sufficient scientific knowledge and experimental evidences that can prove and testify the suitability of compressed earth blocks as load bearing wall material comparable with the conventional ones. Furthermore, the strength and durability requirements that should be met by CEB have been set by building regulation of some counties.

Compression and stabilization of earth or soil is applied in order to improve the strength and durability of the resulting earth blocks as well as reduce the shrinkage and cracking of the blocks. Stabilization of soil is the process of modifying the soil properties in relation to its strength, texture, voids and water resisting properties, so as to obtain properties compatible with a particular application [5].

There are different types of stabilizers that can be mixed with soil or earth as stabilization material so as to improve its properties. These include cement, lime, bitumen, fibers, reins, natural products and synthetic products. The most widely researched and used stabilizers are cement and lime. Numerous studies have been conducted on compressed earth blocks stabilized with cement and to some extent with lime in different parts of the world. However, very few researches have been done on this area in Ethiopia in general and Jimma in particular. Therefore, the object of this study is to determine the compressive strength and durability properties of compressed earth blocks with different stabilization level using natural site soil and modified soils so as to provide locally based scientific evidence and proof as to the suitability of earth building.

II. MATERIALS AND METHODS

1. *Materials*

For this study various types of materials and equipment were used. The materials consist of natural site soil, modified (reconditioned) soil, cement, and lime as stabilizers and water. The type of cement used was ordinary portland cement (OPC) whereas the kind of lime used refers to the quick lime. Both stabilizers were manufactured by Mugger cement factory. The action pack block press machine which delivers a compaction pressure of 4MPa and manufactured by Selam Vocational Technical Centre was used for production of the compressed earth blocks.

2. *Methods*

In order to meet the objectives of the research, the following methods have been employed.

A. Experimental design

- Two types of soils were used for the experiment: the natural soil on the site and the modified or reconstituted soil.
- Compaction pressure was kept constant and it was 4MPa.
- The curing condition was also kept constant. Normal curing conditions were applied to all the blocks produced.
- The type and amount of stabilizer was varied.
  - Cement and lime were used as stabilizers.
  - The proportions of stabilizers applied were kept dependent on the type of stabilizer used and is based on the recommendations of earlier researches in the same area.

Generally, on the basis of soil type and the type and amount of stabilizer, ten different types of treatments were established and considered for the study. Table I shows the kind of treatments considered and investigated in the research work.

B. Soil and soil preparation

i. Natural site soil

The natural site soil refers to the soil sample obtained from the site that is selected as research area and is used in its natural state without any addition of other soil constituents or fractions.

TABLE I. EXPERIMENTAL DESIGN

Treatment type/block samples	Designation	Stabilization level
Natural soil with no stabilizer	NS	Un-stabilized
Natural soil with 10% lime stabilizer	NSLS 10	Stabilized
Natural soil with 15% lime stabilizer	NSLS 15	Stabilized
Natural soil with 5% cement stabilizer	NSCS 5	Stabilized
Natural soil with 7% cement stabilizer	NSCS 7	Stabilized
Modified soil with no stabilizer	MS	Un-stabilized
Modified soil with 10% lime stabilizer	MSLS 10	Stabilized
Modified soil with 15% lime stabilizer	MSLS 15	Stabilized
Modified soil with 5% cement stabilizer	MSCS 5	Stabilized
Modified soil with 7% cement stabilizer	MSCS7	Stabilized

The natural site soil for the study was obtained from the new Jimma Institute of Technology (JiT) campus at Kito-Furdisa site of Jimma University. The soil samples were excavated and collected from a depth of 150cm from the surface to avoid a mix with soil organic matter. The soil color was found to be reddish brown. As per the test carried out on the natural site soil sample, the soil is classified as A-5 using American Association of State Highways and Transportation Officials (AASHTO) soil classification and ML using United Soil Classification System (USCS).

The natural soil samples were air dried for ten days under roofed shed. Air drying was made to enhance the crushing and sieving of the soil. After drying, crushing of the soil was performed using a hammer to break the lumps present in the soil. Next, sieving of the dried sample was performed. This has been made in order to remove the oversized materials from the soil samples using a wire mesh screen with a diameter of 6mm. The soil samples that passed through the sieve were collected for use in the study.

ii. Modified soil

The modified or re-constituted soil in this study refers to the re-conditioned natural or local site soil. The modification of the local natural site soil was made in order to improve or increase the proportion of soil fractions that might be found deficient or below the recommended amount in the natural site soil. The main objective of re-constituting the natural site soil was to determine the performance of the modified site soil with and without stabilizers and hence arrive at what improvements need to be applied to make the natural site soil suitable for making strong and durable earth building blocks.

As per the test carried on the natural site soil showed, the soils were found to be deficient in coarse or sand fraction and may not fulfill the requirements as it lacks uniform grading. Thus, they may not be considered suitable for direct stabilization particularly with cement [6], [7].

The re-conditioning of the natural site soil was made by adding river sand and mixing thoroughly with the natural site soil. The river sand used in this work was obtained from Gilgel Gibe River. The sand was also thoroughly air-dried and screened like the soil before use. The mixing of the soil and sand were made after both materials were prepared and made ready for it. The proportion of sand added to the soil was 40%. This proportion of sand was found to raise the proportion of the coarse fraction of the natural site soil and meets the critical requirements. The modified or reconditioned soil was formed by mechanically dry mixing together, manually the prepared natural site soil and river sand. The property of the modified soil was also determined by performing the same types of soil tests made for natural site soil.

C. Soil characterization test

Soil classification tests are performed in order to investigate and confirm the type and category of the soil in question among other soil types. Four kinds of soil tests has been considered in the study. These tests include the following.

- Particle size distribution test
- Sedimentation test
- Linear shrinkage test
- Atterberg limit test

D. Block production and curing

The description of block proportion is based on the four main stages of compressed earth block's production namely soil preparation, batching/measuring and mixing, molding, compacting and curing. The soil preparation is already discussed in the above section. Once the soils, stabilizer and water were prepared and made ready on the production platform the block production process was carried out.

i. Measuring

Measuring the quantities of the soil, sand and stabilizer according to the predetermined proportions was then performed in order to obtain the required samples for making the blocks as per the experimental design. The proportioning out of soil and stabilizer was made on weight basis using a weighing scale. Plastic bags carefully filled with samples, sealed and labeled were used for weighing of the materials.

Once the materials for each experimental setup were measured, mixing of the constituent materials was followed.

ii. Mixing

The mixing involves dry mixing and wet mixing. In all cases, initially dry mixing of the constituent materials was done.

The dry mixing process involves mixing of dried soil and stabilizers (cement or lime). It was done manually using a shovel. To achieve the dry mixing, the measured soil sample was spread using a shovel to a reasonably large surface area. Then, the stabilizers were spread evenly on top of the already spread soil and mixed thoroughly with the shovel. This dry mixing of the materials was done repeatedly for about four to five minutes. Once a uniform mix for each batch was achieved through dry mixing, then a wet mixing process followed. In order to make wet mixing, the dry mixture was spread again to receive the water, which was added gradually while mixing using shovel until the optimum moisture content of the mixture was attained. After a uniform wet mix was achieved, an optimum water content test was done for each mix by collecting a handful of the wet mix, compressing it firmly in the fist, and then allowing dropping on a hard and flat surface from a height of approximately 1.0meter. Any mix that passed the test was approved to be ready for molding and compaction.

iii. Molding and compaction

After the completion of wet mixing the molding and compaction of the damp mix was performed by using an Action Pack Block Press machine that delivers a compaction pressure of 4MPa. As the urgency of molding and compacting the wet mix depends on the type of stabilizer to be used, the required precautions were made accordingly. The molding and compression of the approved wet mix and de-molding of the resulting blocks has been made immediately after wet mixing, for earth blocks produced without stabilizers and for earth blocks produced with cement as stabilizer. However, for earth blocks produced with lime stabilization the wet mix has been allowed to remain on the mixing platform for 4hours [6]. This is called the reaction time.

Once the wet mix was made approved for molding, the required quantity of the mixture was taken from the wet mix by using a special trowel made for that purpose and it was filled in to the mould of the press. Then, the mould cover was turned in to position to cover the mix and the handle of the press was operated to deliver the required compaction force and compact the wet mix placed inside the mould up to the required compaction pressure. The procedures were repeated till the required numbers of sample blocks were produced.

iv. Curing

After the blocks were compacted and made demolding, handing and transporting them to the curing place or site were followed. This activity was done with great care as the new blocks were still weak and liable to damage. The blocks were then carefully labeled, and placed separately. This was done in order to identify each block by soil type, stabilizer type and content as well as date of manufacture. Finally, the newly produced blocks were allowed to cure for the required curing period. The curing period required depends on the type of stabilizer used in making the mix the blocks.

For blocks made without any stabilizer and using cement as a stabilizer, the curing period was fixed to be 28 days. However, for blocks produced with lime stabilizer, curing periods of 2 months were allowed before making the required tests on the blocks [7].

In order to achieve good results, the newly produced blocks were allowed to air dry for the required curing period under a shade. During the process of curing, water was lightly sprinkled on the blocks in the morning in order to prevent rapid drying of the blocks. This was performed each time turning the blocks to expose and water the different faces until they were ready for testing.

E. Block testing and measurement

There are several bulk properties that are believed to influence the strength and durability of earth blocks. In this study, the strength of each block has been investigated by making dry compressive strength tests. In addition the determination of the dry blocks density and the change on dry block density was carried out. With regard to durability of the blocks, the measurement of the size of the dry blocks after completing their curing period and the determination of shrinkage or volume change has been accomplished.

III. RESULTS AND DISCUSSION

1. Soil test results

As indicated on the methods part of the study, four kinds of soil tests has been performed on the natural and modified site soil types. The results obtained from each type of test performed on each type of soil will be outlined in tabular form in the following sections.

a) Soil test results on natural site soil

Table II below shows the result obtained from the four types of tests carried out on the natural site soil of the area.

TABLE II. RESULTS OF SOIL TESTS ON THE NATURAL SITE SOIL

S.N	Type of test	Units	Test result
1	Particle size distribution		
	• Gravel	%	0
	• Sand	%	30
	• Silt	%	41
	• Clay	%	29
2	Sedimentation test		
	• Coarse fraction (Gravel & Sand)	%	32.7
	• Fine fraction (Silt and Clay)	%	67.3
3	Linear shrinkage test	%	13
4	Atterberg Limits test		
	• Liquid limit, LL	%	42
	• Plastic limit, PL	%	33
	• Plastic index, PI	%	9
5	Soil type: AASTHO	A-5	
6	Soil type :USSC	ML , Low plastic silt	

b) Soil tests results on modified soil

The results obtained after making the four kinds of soil tests on a modified soil types are outlined on Table III.

TABLE III. SOIL TEST RESULTS ON MODIFIED SOIL

S.N	Type of test	Units	Test result
1	Particle size distribution		
	• Gravel	%	0
	• Sand	%	69
	• Silt	%	20
	• Clay	%	11
2	Sedimentation test		
	• Coarse fraction (Gravel & Sand)	%	86
	• Fine fraction (Silt and Clay)	%	14
3	Linear shrinkage test	%	7
4	Atterberg Limits test		
	• Liquid limit, LL	%	32
	• Plastic limit, PL	%	26
	• Plastic index, PI	%	6
5	Soil type: AASTHO	A-2-5	
6	Soil type: USSC	SM, Silty sand	

2. Block measurement and testing results

As explained on the experimental design section, ten different kinds of treatments were considered. For each kind of treatment four representative blocks were manufactured and considered for the study. After the elapse of the recommended curing periods for each kind of treatment, the experimental blocks were tested, examined and the required measurements of sizes and weight, were taken and recorded.

a) Block size measurement results

The measurements of the size of the blocks were made after the blocks completed their respective recommended curing periods. The initial size of all the blocks is equal to the internal dimension of the earth block press machine mould i.e., 290mm*140mm*120mm.

The linear measurements made on the final cured blocks were length of blocks (L), width of blocks (W) and height or depth of blocks (H). Table IV and V shows the average values obtained from measurement of size of blocks and computation of important parameters for natural and modified site soils respectively.

TABLE IV. AVERAGE VALUES OBTAINED FROM MEASUREMENT OF SIZE OF BLOCKS AND COMPUTATION OF IMPORTANT PARAMETERS FOR NATURAL SITE SOIL

Treatments	Average Length, (mm)	Average Width, (mm)	Average Height, (mm)	Average Area, (mm^2)	Average Volume, (mm^3)
NS	286.75	136.50	117.25	39,141.75	4,589,448.75
NSLS10	288.25	138.50	118.75	39,922.50	4,740,769.50
NSLS15	289.75	139.50	119.75	40,420.25	4,840,280.00
NSCS5	287.00	137.75	118.50	39,534.50	4,684,802.50
NSCS7	288.25	138.25	118.25	39,850.50	4,712,295.00

TABLE V. AVERAGE VALUES OBTAINED FROM MEASUREMENT OF SIZE OF BLOCKS AND COMPUTATION OF IMPORTANT PARAMETERS FOR MODIFIED SITE SOIL

Treatments	Average Length, (mm)	Average Width, (mm)	Average Height, (mm)	Average Area, (mm^2)	Average Volume, (mm^3)
MS	288.75	138.75	118.75	40,064.25	4,757,747.50
MSLS10	289.50	139.50	119.25	40,385.00	4,815,892.50
MSLS15	289.50	139.75	119.50	40,457.50	4,834,672.50
MSCS5	290.00	139.75	119.75	40,527.50	4,853,150.00
MSCS7	290.00	139.75	120.00	40,527.50	4,863,300.00

b) Block test results

Once the sizes of the blocks were measured, the blocks were made ready for block testing. The weight of each block sample was measured before the blocks were placed on the compression testing machine. The investigations performed on the earth blocks were dry compressive strength test, dry block density and shrinkage or volume change. The average values obtained for each treatment with regard to compressive strength test and determination of dry block densities are indicated on Table VI and VII for natural site soil and modified soil respectively.

TABLE VI. AVERAGE VALUES OF COMPRESSIVE STRENGTH AND DRY BLOCK DENSITY FOR NATURAL SITE SOIL

Treatment	Average Volume, (mm^3)	Average Mass, (Kg)	Average Max. Load, (KN)	Dry Block Density, (Kg/m^3)	Dry Compressive Strength, (MPa)
NS	4,589,448.75	7.11	35.25	1,548.66	0.90
NSLS10	4,740,769.50	7.35	57.88	1,549.70	1.45
NSLS15	4,840,280.00	7.50	88.96	1,549.87	2.20
NSCS5	4,684,802.50	7.26	56.06	1,549.88	1.42
NSCS7	4,712,295.00	7.30	60.78	1,549.96	1.53

TABLE VII. AVERAGE VALUES OF COMPRESSIVE STRENGTH AND DRY BLOCK DENSITY FOR MODIFIED SITE SOIL

Treatment	Average Volume, (mm^3)	Average Mass, (Kg)	Average Max. Load, (KN)	Dry Block Density, (Kg/m^3)	Dry Compressive Strength, (MPa)
MS	4,757,747.50	7.90	50.09	1,660.55	1.25
MSLS10	4,815,892.50	8.00	55.54	1,661.46	1.38
MSLS15	4,834,672.50	8.03	58.65	1,661.63	1.45
MSCS5	4,853,150.00	8.06	110.47	1,661.69	2.73
MSCS7	4,863,300.00	8.08	117.52	1,661.75	2.90

i. Compressive strength test results

Compressive strength is one of the most important factors that determine the strength and durability of the earth blocks. The compressive strength of compressed earth blocks depends upon soil type, type and amount of stabilizer and the compaction pressure used to form the blocks [8].

The compressive strength test on the earth blocks were made by using Universal Testing Machine found in Civil Engineering Department of Jimma Institute of Technology.

The blocks were loaded, crushed and the corresponding maximum or failure load for each sample block was recorded. Then, the compressive strength of the blocks was calculated by dividing the maximum or failure load by load area of the sample blocks. In this analysis, the mean values of compressive strength of the sample blocks under different treatments were considered and are shown in Table VIII and IX for natural and modified soils respectively. The plot of the compressive strength against the type of treatments under each soil type is shown in Fig. 1 and 2.

TABLE VIII. MEAN DRY COMPRESSIVE STRENGTH OF COMPRESSED EARTH BLOCKS MANUFACTURED FROM NATURAL SOIL.

Sample blocks Treatments	Average Dry Compressive Strength, (MPa)
NS	0.90
NSLS10	1.45
NSLS15	2.20
NSCS5	1.42
NSCS7	1.53

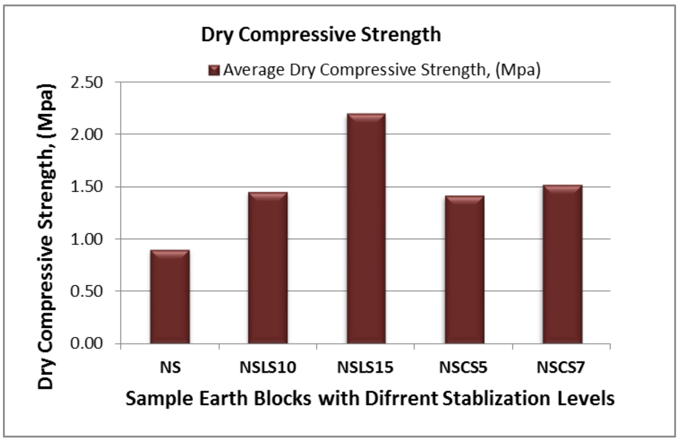

Fig. 1. Plot of mean dry compressive strength Vs treatment types (stabilization type and level) for blocks produced from natural site soil

In general the compressive strength of stabilized earth blocks was found to be greater than unstabilized blocks. Furthermore, the compressive strength values of the compressed earth blocks increased with increase in the stabilizer content. Moreover, there is a significant difference in compressive strength values of earth blocks stabilized with lime and cement for each type of soil considered in the study.

TABLE IX. MEAN DRY COMPRESSIVE STRENGTH OF COMPRESSED EARTH BLOCKS MANUFACTURED FROM MODIFIED SOIL.

Sample blocks Treatments	Average Dry Compressive Strength, (MPa)
MS	1.25
MSLS10	1.38
MSLS15	1.45
MSCS5	2.73
MSCS7	2.90

As can be seen from Table VIII and Fig. 1, the mean dry compressive strength of earth blocks manufactured with natural site soil varies from the minimum value of 0.9MPa to 2.2MPa. The minimum mean compressive strength value of 0.9MPa in the case of natural soil was obtained for the un-stabilized compressed earth block.

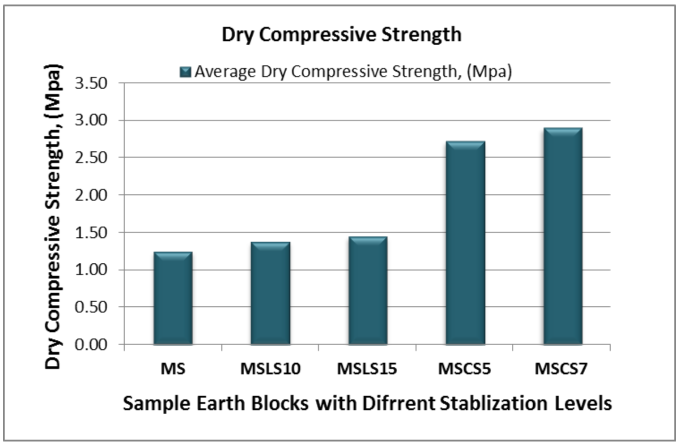

Fig. 2. Plot of mean dry compressive strength Vs treatment types (stabilization type and level) for blocks produced from modified soil

As the blocks were made of silty soil having low plasticity with no added stabilizer, the resulting minimum compressive strength value obtained is justifiable. The higher mean compressive strength value 2.2MPa in the case of natural soil corresponds to the natural soil sample stabilized with 15% lime.

The mean dry compressive strength values of earth blocks manufactured with natural site soil and stabilized with lime turns out to be 1.45 and 2.2MPa and that of earth blocks stabilized with cement turns out to be 1.42 and 1.53MPa. When the strength values of blocks obtained using the two stabilizers are compared, the 15% lime stabilized block developed the highest compressive strength of 2.2MPa. According to [9], considering the most conservative approaches, compressed earth blocks with a minimum dry compressive strength of 2.0MPa are acceptable by most building codes (Australia, New Mexico building code, CRATerre, ILO, UNESCO and African Regional standards for compressed earth blocks). This then implies that an earth block manufactured from natural site soil and stabilized with 15% lime can meet the minimum strength requirement set by codes and hence could be used as a wall building element.

Furthermore, as can be seen from Table IX and Fig. 2, the mean dry compressive strength of earth blocks manufacured with modified soil varies from the minimum vaue of 1.25 to 2.90 MPa. The minimum compressive strength value was obtained for un-stabilized blocks. This value turns out to be the minmum strength value in the group of treatments under the modified soil. This is due to the fact that the soil contains small clay proportion and hence low plasticity and no stabilizer was added that binds the soil particles together. However, the compressive strength value of the unstablized blocks manufactured from modifed soil appears to be greater than that of un-stabilized blocks manufactured from natural site soil. This is due to the fact that the modified soil is well graded as compared to the natural site soil and has more coarse fractions.

For the earth blocks produced from reconstituted soil, the compressive strength values of earth blocks stablized with lime appears to be 1.38 and 1.45MPa and for those stabilized with cement were found to 2.73 and 2.90 MPa. Accordinglly, cement stablized earth blocks have developed compressive strength values well above the minimum value of 2MPa set by most building codes. Hence, the most predominant type of site soil in the hill tops and sides of Jimma city could be modifed with the mixing of river sand (with a proportion ranging from 35-50% by weight) and stablized with 5 to 7% cement to manufacture a strong, durable and affordable wall building elements.

ii. Dry block density

In this part of the study, the effect of stabilization level and type towards the dry block density has been investigated. The results of the influence of stablizer level and type on dry block density are outlined in Table X and Fig. 3 for natural site soil while in Table XI and Fig. 4 for modified soil.

TABLE X. MEAN DRY BLOCK DENSITY OF BLOCKS PRODUCED FROM NATURAL SITE SOIL

Sample blocks /Treatments	Average Dry Block Density, (Kg/m^3)
NS	1548.66
NSLS10	1549.88
NSLS15	1549.96
NSCS5	1549.70
NSCS7	1549.87

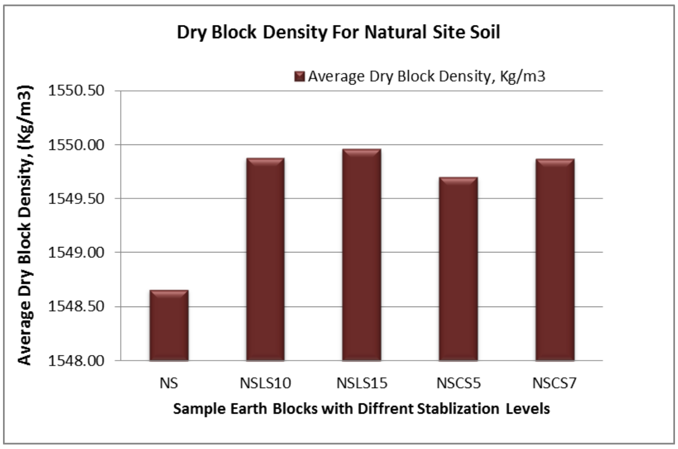

Fig. 3. Plot of mean dry block density Vs. treatment types for natural site soils

TABLE XI. MEAN DRY BLOCK DENSITY OF BLOCKS PRODUCED FROM MODIFIED SITE SOIL

Sample blocks /Treatments	Average Dry Block Density, (Kg/m^3)
MS	1660.55
MSLS10	1661.46
MSLS15	1661.63
MSCS5	1661.69
MSCS7	1661.75

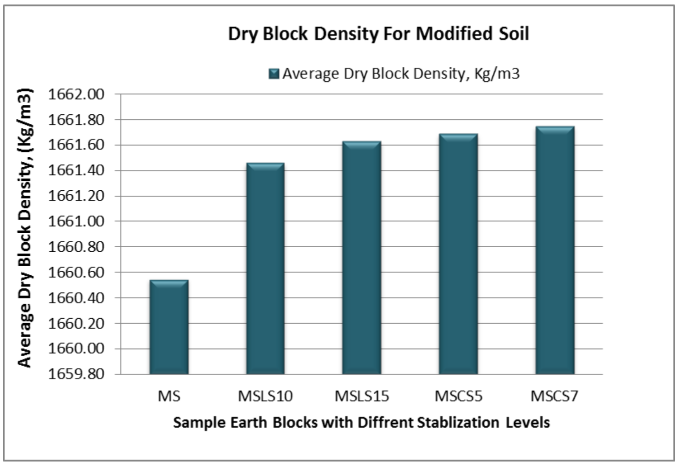

Fig. 4. Plot of mean dry block density Vs. treatment types for modified soils

The analysis of the data on Table X and Fig. 3 reveled that in case of natural site soil, when the lime content was increased from 0 to 15% there was an increase of 2.45 to 2.60% in dry block density and also when the cement content was increased from 0 to 7%, there was an increase of 2.09 to 2.43% in dry block density. Furthermore, in case of modified site soil as it is shown on Table XI and Fig. 4, when the lime content was increased from 0 to 15% there was an increase of 1.48 to 1.75% in dry block density and also when the cement content was increased from 0 to 7%, there was an increase of 1.84 to 1.94% in dry block density.From the results obtained, it is observed that the the stabilizer level has no noticeable and dramatic effect on dry block density. This is due to the fact that the stabilizers are added in minute quantities and they are not as such heavy and hence does not impart an increment in the weight of the block. The results obtained above are found to be consistent with [10].

Furthermore, the improvements or drops in dry block density is analysed by taking the relative devation in dry block density of stablized blocks with respect to the dry block density of unstablized compressed earth blocks. The results so obtained are outlined in Table XII and Fig. 5 for natural site soil and in Table XIII and Fig. 6 for modified soil.

TABLE XII. IMPOROVEMENT IN DRY BLOCK DENSITY OF STABLIZED BLOKS IN COMPARISION WITH UNSTABLIZED BLOCK IN CASE OF BLOCKS MADE OF NATURAL SITE SOIL

Sample blocks /Treatments	Average Dry Block Density, (Kg/m3)	Change in Block Density,(%)
NS	1548.66	-
NSLS10	1549.88	0.079
NSLS15	1549.96	0.084
NSCS5	1549.70	0.067
NSCS7	1549.87	0.078

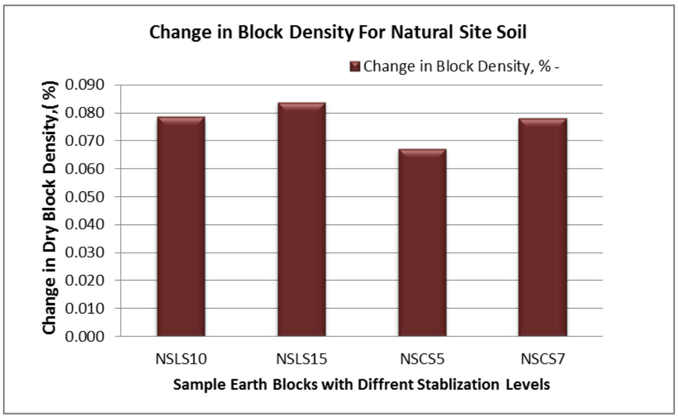

Fig. 5. Change in dry block density of blocks made of natural site soil

TABLE XIII. IMPOROVEMENT IN DRY BLOCK DENSITY OF STABLIZED BLOKS IN COMPARISION WITH UNSTABLIZED BLOCK IN CASE OF BLOCKS MADE OF MODIFIED SOIL.

Sample blocks /Treatments	Average Dry Block Density,(Kg/m^3)	Change in Block Density, (%)
MS	1660.55	-
MSLS10	1661.46	0.055
MSLS15	1661.63	0.065
MSCS5	1661.69	0.069
MSCS7	1661.75	0.072

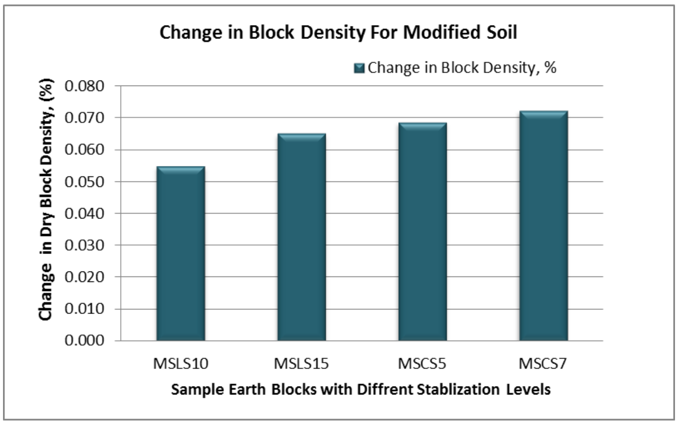

Fig. 6. Change in dry block density of blocks made of modified soil

As can be seen from Table XII and Fig. 5, the highest imporovements in block density has been observed in lime stablized earth blocks (0.079 and 0.084%) in the case of blocks made of natural site soil whereas for blocks made of modified soil, as depicted on Table XIII and Fig. 6, the highest improvement in dry block density has been observed in cement stablized earth blocks (0.069 and 0.072%) as compared to the un-stabilized blocks.

iii. Shrinkage or Volume change

The shrinkage here refers to the contraction of a given block sample during drying process. It gives an overall idea of the mixture behavior and suitability for construction. During drying process there is volume change or shrinkage. The shrinkage value varies from sample to sample depending on their composition [11] . In general, shrinkage has an effect on the final dimensions of earth blocks. The average shrinkage value in mm^3 and the corresponding mean shrinkage in percentage of each treatment are shown in Tables XIV and Fig. 7 for natural site soil and in Table XV and Fig. 8 for modified soil.

The percentage of shrinkage (SP) of earth block samples was calculated using the following equation [11]

$$Sp = \frac{(V_m - V_b)}{V_m} * 100 \qquad (1)$$

Where, S = Percentage of shrinkage

V_b = Volume of the block sample (mm^3)

V_m = Volume of the mould(mm^3)

= 290mm x 140 mm x120mm= 487200 mm^3

TABLE XIV. AVERAGE SHRINKAGE VALUE OF EARTH BLOCKS PRODUCED FROM NATURAL SITE SOIL

Sample blocks or Treatments	Average Shrinkage, (mm^3)	Mean Shrinkage/Volume Change, (%)
NS	282551.25	4.86
NSLS10	131230.5	2.69
NSLS15	31720	0.97
NSCS5	187197.5	2.71
NSCS7	159705	2.74

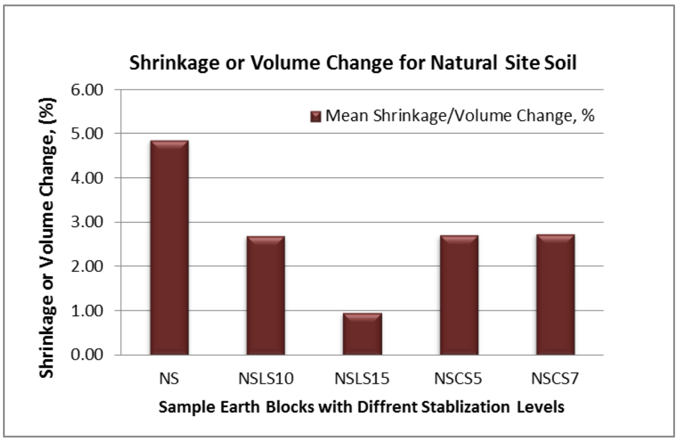

Fig. 7. Plot of average shrinkage value Vs. treatment type for natural soil

TABLE XV. PLOT OF AVERAGE SHRINKAGE VALUE VS. TREATMENT TYPE FOR MODIFIED SOIL

Sample blocks or Treatments	Average Shrinkage, (mm^3)	Mean Shrinkage or Volume Change, (%)
MS	114252.5	2.35
MSLS10	56107.5	1.15
MSLS15	37327.5	0.93
MSCS5	18850	0.39
MSCS7	8700	0.18

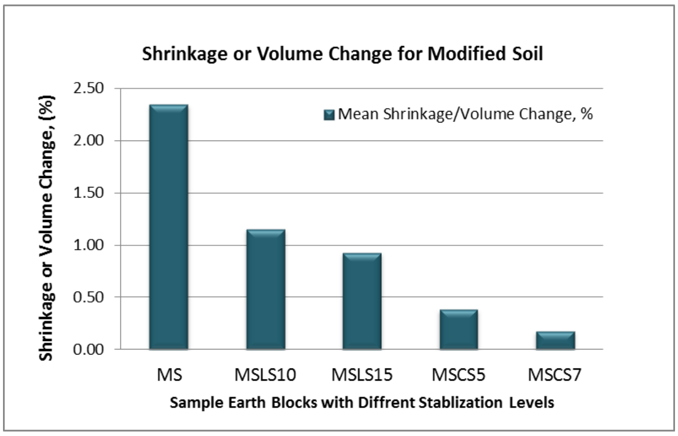

Fig. 8. Plot of average shrinkage value Vs. treatment type for modfied soil

As can be seen from Tables XIV and Fig. 7, in case of natural site soil, the lowest block shrinkage value was exhibited by lime stabilized blocks (2.69 and 0.97%). In case of modified site soil, as it is shown on Table XV and Fig. 8, the lowest block shrinkage value was exhibited by cement stabilized blocks (0.39 and 0.18%). Furthermore, in general it was observed that stabilized blocks have shown the lowest shrinkage value as compared to un-stabilized blocks.

IV. CONCLUSION

From the findings of this research work the following conclusions can be drawn.

- Stabilized earth blocks have shown a higher dry compressive strength than un-stabilized earth blocks.
- Lime stabilization is observed to be more effective in improving the dry compressive strength of fine textured soils.
- Cement stabilization in turn is found to be more effective in improving the dry compressive strength of coarse textured soils.
- The addition of 15% lime in case of blocks made of natural site soil and 7% cement in case of blocks made of modified soil have developed the highest dry compressive strength.
- Considering a minimum dry compressive strength value of 2.0MPa recommended by building standard codes, the earth blocks manufactured from natural site soil with 15% lime stabilizer (2.2MPa) as well as those earth blocks produced from modified soil with 5% and 7% cement stabilizer (2.73 and 2.90MPa respectively) fulfills the requirements and hence can be conveniently used as appropriate wall building materials.
- Cement and lime contents as stabilizers have little effect on the dry block density. Furthermore, in case of natural site soil (fine grained soil) the slight improvement observed in dry block density was found to be highest for lime stabilized blocks where as in case of modified site soil(coarse grained soil) it was found to be highest for cement stabilized blocks.
- Considering shrinkage characteristics of blocks, the 15% lime stabilized blocks has shown the lowest shrinkage or volume change in the case of blocks made of natural site soil. Similarly, in case of earth blocks made of modified soil, the blocks produced with 7% cement stabilizer has shown the lowest shrinkage value.

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