DESIGN AND MANUFACTURE OF MACHINERY FOR MASS PRODUCTION OF STABLIZIED SOIL BLOCKS FOR LOW COST HOUSES

By

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ABSTRACT

This paper explains the methods adopted for the local design and fabrication of machine for mass production of quality soil stabilized blocks for low cost house construction. The locally designed and fabricated machine is capable of producing two stabilized blocks per operation and has the capacity to produce up to 3150 blocks per 8-hour working day as against the imported and more expensive one that can produce only a maximum of 2500 blocks per 8-hours working day. The hydraulically operated machine powered with diesel engine was able to generate the required compaction pressure of 10Mpa. The produced soil blocks with 5% cement stabilization had average wet compressive strength of 1.2 Mpa and water absorption of 6.5%. In all cases, the average block density was within the range of 2060 kg/m^3. All these values are within the specified values for quality stabilized soil blocks used for low cost building construction.

1.0 INTRODUCTION

It is well documented that there is a massive and growing shortage of low cost housing for the urban and peri-urban poor in developing countries. The present housing shortage in Africa is already at alarming point. At least 52% of the total population in sub-Saharan Africa live in absolute poverty and cannot afford any form of decent shelter [1]. The majority of these city dwellers, who, in the face of exorbitant housing rents in cities, are forced to live in squatters' settlements or slums under appalling conditions. An average of 40 – 50% of Africa's population are living under such conditions.

More alarmingly, the continent will need vastly greater number of homes in the near future as a result of the twin effect of population expansion and rapid urbanization. This growing need for housing in Africa has been and will be matched by an equally growing need for building materials. Indeed, building materials play provision, constituting about two-third of the cost of home building. Any meaningful approach towards the alleviation of a continent's present shelter crises, particularly in regard to the low-income population, should, therefore, aim at making building materials available at affordable costs as a primary target.

Cement blocks were the major construction materials in both urban and peri-urban areas and are increasingly becoming the basic walling material in these areas. The block quality obtained for a given production cost is much below that which could be achieved. There are problems with raw material testing, cement optimization, mixing, batching, mould filling, compaction and curing. These problems could be reduced if producers were more informed, better skilled, equipped with production and testing equipment. Early studies [2] found that micro-enterprise production of soil-cement can offer cost savings over sandcrete walling.

A large sum of money in foreign exchange is being spent annually for the importation of machines used for the production of most crucial role in shelter quality stabilized soil blocks to meet demand for

low-cost house construction in Nigeria. The prices of these machines are not within the reach of most of the indigenous estate developers hence the need for their local design and fabrication.

In this work attempt will be made to explain the procedure adopted for the local Design and construction of machines for the mass production of quality cement stabilized soil blocks as a substitute for the imported ones.

2.0 CEMENT – STABILIZED SOIL BUILDING BLOCKS AND METHODS OF THEIR PRODUCTIONS

Regardless of the type of stabilizer used, the production process of stabilized soil blocks is similar. Firstly, the local area is surveyed to establish the location of a suitable soil type [3]. It has been widely accepted throughout the world that a soil with the following composition will be suitable for making soil blocks [4]: sand 25 – 40%; silt 40 – 45%; clay 20 – 30%. Having found a suitable Soil or modified a less suitable one, lumps in it are broken and the soil is sieved to remove any larger particles (greater than 6mm). It is thereafter laid out to dry. A suitable quantity of stabilizer (usually ordinary Portland cement) is mixed with the dry soil and a uniform mixture is produced. Suitable quantity of water is then added so that the resulting mix is at the Optimum Moisture Content (OMC). This mixture is transferred to the block mould for compaction. After compaction, the green block is ejected from the mould and transferred to a curing area which should be flat, level and protected from rain and direct sunshine. The block is left to cure for at least 7 days before in-corporation in a wall [5].

2.1 Methods of Forming Soil Stabilized Blocks

In all cases soil stabilized blocks are formed by the application of energy to a loose soil-cement-water mix in a mould that determines final block dimensions. The commonest forming processes are:

(i). **Hand-Tamping**

Hand tamping of a moist mix into a wooden mould with no top or bottom, placed on a flat surface, the mould is removed prior to curing the block in-situ on the surface.

(ii). **Pressing in a rigid steel mould with low pressure**

Pressing in a rigid steel mould with a force up to 10 tonnes (pressure up to 2 Mpa) onto bottom face of the block. This is obtained by using levers to amplify the pull (say 500N) of an operator. This process is mostly used for the production of soil-cement or unstabilized soil blocks in developing countries.

(iii). **Pressing with a force greater than 10 tonnes**

Pressing with a force greater than 10 tonnes (pressured typically between 2 Mpa and 10 Mpa) using hydraulic cylinders. This process is quite encouraging for mass production of soil-cement stabilized blocks.

(iv) **Dynamic compaction**

This is a method of using a fast impact to transfer the energy of a falling mass into the object being hit.

Among the forming methods enumerated above, method ii i.e Pressing in rigid steel mould with a low pressure of about 2 Mpa is commonly used in Nigeria and most of developing countries. The machine is manually operated with production capacity of between 300 and 500 bricks per 8-hour working day. The versions commonly in use include Cinva Ram Block press, Actionpak Block press, Brepak Block press and NBRRI Brick making machine. Method (iii), pressing with a and 10 Mpa using hydraulic cylinders, is a preferred option for mass production of quality Soil stabilized blocks for low cost house construction. In this work, compaction pressure of 10 Mpa was adopted as the design pressure.

2.2 Factors Affecting the Compaction of Stabilized Soil Blocks

The compaction pressure and the cement content used in the manufacture of stabilized soil blocks are, for a given soil, the prime determinants of the block's final cured strength. Compaction pressure and cement content may be traded against each other for a given final cured strength. Results of research conducted by M. C. Lunt [6] on two Ghanian soils revealed that improved performance can be achieved by increasing the compaction pressure, although the degree of improvement diminishes as the pressure is increased. It was suggested that presses operating in the range of 8 to 16 Mpa could give satisfactory and economical results.

2.2.1 Moisture Content

Any soil placed in the mould for compaction should contain a known quantity of water. There exist an Optimum Moisture Content pressure between 2 Mpa (OMC) at which the maximum density of the soil may be reached for a given compaction pressure. Usually the resulting cured dry density will be highest for block, which has been compacted at its OMC. OMC is not a parameter solely dependent on the soil, it varies considerably with the compaction pressure used to form the block. In general, as the compaction pressure increases so the OMC decreases. At higher compaction pressure the applied force is greater, the soil particles will move more readily and hence less lubricant (water) will be required [7]. This phenomenon is illustrated graphically [8] in figure 1 from where it can be seen, for soil stabilized with 4% cement, that with increase in compaction pressure from 1 Mpa to 6 Mpa, the Optimum Moisture Content reduces from 15% to 13.5%.

2.2.2 Delay in Compaction

As soon as moisture is added to the dry soil/cement mixture the cement will begin to react with the water. As the cement begins to hydrate the moisture levels in the soil available for lubrication becomes less, hindering the compaction process. Meanwhile the crystallization that is beginning to occur with the cement after the critical period, about 15 minutes, further hinders the compaction [5]. Following the mixture of a batch of material, some parts of the batch are made into blocks before other parts. The final strength of stabilized blocks depends, to a degree, on the length of time for which the cement is exposed to water prior to compaction in the mould.

3.0 DESIGN APPROACH FOR LOCALLYFABRICATED HYDRAULICALLY OPERATED SOIL STABILIZED BLOCK MAKING MACHINE.

Quasi-static or slowly applied compaction is the process adopted for majority of soil-block making machines. The loose soil mix is compressed by slowly applying large force. The magnitude of the pressure varies from machine to machine but generally within the range of 1 – 8 Mpa [7]. Brepack and Hydraform are examples of high-pressure machine that apply between 8 and 10 Mpa compaction pressure. These machines are imported into Nigeria at very high cost. An average imported hydraulically operated interlocking block making machine has a maximum production capacity of about 2500 blocks per 8 hours working day and costs about ₦4, 500,000 (Four Million five hundred thousand Naira). This high cost of the imported block making machine necessitated the local design of high pressure soil stabilized Block making machine capable of producing high quality blocks. The locally designed machine is to generate compaction pressure of 10 Mpa and capable of producing not less than 3000 quality stabilized blocks in 8-hour working day.

3.1 Design and Fabrication Procedures

Procedure adopted for the local design and fabrication of high-pressure machine for the production of stabilized blocks is as follow:

(i). Establishment of basic design parameters;
(ii). Materials selection
(iii). Detailed Drawing
(iv) Fabrication of the Machine and
(v). Testing

3.1.1 Establishment of Basic Design Parameters

The machine was designed to produce two stabilized soil blocks per operation by compacting loose soil in two moulds. It was designed to generate the required pressure for the production of soil stabilized blocks with green density of about 2063 kg/m^3 as required. [9].

3.1.1.1 Compaction Ratio

Compaction ratio is one of the critical parameters required for the mould design. Compaction ratio can be determined as a ratio of density of molded block to the density of loose soil mix before compaction and can be expressed as

$$\eta = {}^{\rho 2}\!/_{\rho 1} \qquad (1)$$

Where $\rho_1 and\ \rho_2$ -the density before compaction and after compaction, respectively (kg/m^5).

The average values of $\rho_1 and\ \rho_2$ for 5% cement stabilization, which are the design conditions, are1240 and 2063 and kg/m^3 [9]. The compaction ratio of the designed machine was calculated to be 1.66, which was used for mould height determination.

3.1.1.2 Mould height Determination

The machine was designed to produce both interlocking blocks that do not require mortar for binding and regular soil stabilized bricks that require mortar for bonding. In the case of interlocking Blocks, the compaction of the soil in the mould is done longitudinally along the length of the blocks. This is done to ensure height consistency since the blocks are interlocked and stacked together to form building walls without mortar bonding. In the case of regular soil stabilized bricks, the compaction is done transversely to the length of the bricks and along the height. Mould height was determined from the following expression.

$$H_m = \eta\ L_B \qquad (2)$$

Where H_m – mould height, m

η – Compaction ratio

L_B – The length of interlocking blocks

3.1.1.3 Compaction Pressure

It was documented that high pressure press (10 Mpa) is capable of achieving sufficient densification to allow the quantity of cement used for stabilization to be reduced- to a low level (<6%) while still achieving adequate ~~block~~ properties [5]. This value coincided with the value obtained by Gooding [7]. Also, earlier, Ola, in 1983 established that value to be 8
Mpa [8].

3.1.2 Materials Selection

a. Moulds

In the case of interlocking block moulds, the working surface of the moulds has to be corrosion resistant and at the same time easy to machine. Machinability of metal is very important. The most machinable metal was defined as the one, which permits the removal of materials with satisfactory finish at lowest cost [10]. An industrial machining operation has many objectives such as rapid cutting, good surface finish and long tool life. These factors were considered in the selection of steel AISI 304 for the working medium of the mould. AISI 304 is an austenitic stainless steel with chemical composition of 18% Cr and 8% Ni. The thicknesses of the plates were determined to be 16mm for the sides, 25 mm for upper and down presser plates, respectively. Mild steel plate of 10 mm thickness was selected for the mould housing since it is not to be subjected to aggressive working medium. The upper arm presser support plate made from mild steel was also 10 mm thick.

b Frame

Various sizes of angle bars and U-channels were used for the construction of the machine frame. Plain carbon steel of 25 mm thickness was welded to the frame as base plate for the mould so also the base plate for the Diesel Engine.

3.1.3. Fabrication

a. Frame and mould construction

On completion of detailed drawing, fabrication was carried out in a private fabrication shop at Ota, Ogun State. The frame was constructed with steel channels 100 x 40 x 5 and 250 x 75 x 5 mm. The dimension of the frame was 1,300 x 915 x 920 mm. The dimension of the mould base plate welded to the frame was 710 x 365 x 25 mm. The assembly Drawing of the machine is presented in figure 2

3.1.4. Hydraulic system assembly

The following were installed for the control of the hydraulic system: direction control and pressure relief valves. Two hydraulic cylinders were flanged and bolted to mould base plate welded to the frame. One cylinder was mounted to control the movement of the two upper arm pressers. The required pressure for compaction was generated with the help of hydraulic pump that sucks the required hydraulic fluid from the Hydraulic Tank through the connected high-pressure hoses. Diesel engine of 7.5 KW and 1500 rpm was installed to power the system. The hydraulic system circuit is shown schematically in figure 3.

3.1.5 Testing

Testing of the machine to ascertain its workability was carried out. The hydraulic system was inspected to ensure there were no leakages. The mould supports were thoroughly inspected. The required pressure of 10 Mpa was attained and the machine was successfully subjected to 8 hours continuous working. The production capacity of the machine was established to be between 2850 and 3150 blocks per 8-hour working day. The molded blocks were subjected to compressive strength and water absorption tests. The average results obtained, after the testing of the produced soil stabilized blocks of 5% cement stabilization, were as follows: wet compressive strength of 1.2 Mpa and water absorption of 6.5%. The results obtained were within the accepted range for soil stabilized blocks. In all cases average density of 2060 kg/m^3 was obtained. This value is close to the one obtained from a similar machine with 10 Mpa compaction pressure [8].

4.0 LABOUR REQUIREMENT FOR OPTIMUM USAGE OF LOCALLY DESIGNED MACHINE

The labour requirement for the optimum use of the locally designed and fabricated high-pressure soil stabilized block-making machine is as follows:

Operator	1
Display block	2
Batching gang	2
Curing	1
Mixer	4
Total	10

Ten (10) persons are required for optimal performance of the machine.

Conclusion

Methods of molding stabilized soil blocks were identified in this work to include (i) hand-tamping, (ii) pressing in the steel mould with low pressure of below 2 Mpa, iii) pressing with high pressure of between 2 and 10 Mpa and iv) dynamic compaction by using fast impact to transfer energy of a falling mass into the object being hit.

Among all the compaction methods enumerated above, pressing with high pressure of between 2 and 10 Mpa was considered suitable for mass production of quality Soil stabilized blocks for low cost house construction.

Procedure adopted in the local design and fabrication of hydraulically operated machine for mass production of quality Soil stabilized blocks include; establishment of basic design parameters; materials selection, detailed drawing, fabrication of the machine and finally, testing of the machine to ascertain it's functionality.

The locally fabricated machine is capable of producing two stabilized blocks per operation and has the capacity to produce 2850 – 3150 quality stabilized blocks per 8-hour working day. This is an improvement over the imported and more expensive version that can produce only 2000 – 2500 blocks per 8-hour working day. The locally fabricated machine can be powered with diesel engine of 7.5 kw and could generate a compaction pressure of 10 Mpa. The produced Soils-cement blocks with 5% cement stabilization, had average wet compressive strength of 1.2 Mpa and water absorption of 6.5%. In all cases, the average block density was within the range of 2060 kg/m^3. All the obtained test results are within the specified values for quality soil stabilized blocks used as walling materials in low-cost house construction.

The Design of the machine has contributed greatly to capacity building in equipment design and its fabrication shall create jobs for indigenous fabricators. Its usage shall enhance the production of quality Soil stabilized blocks required for low cost house construction nationwide.

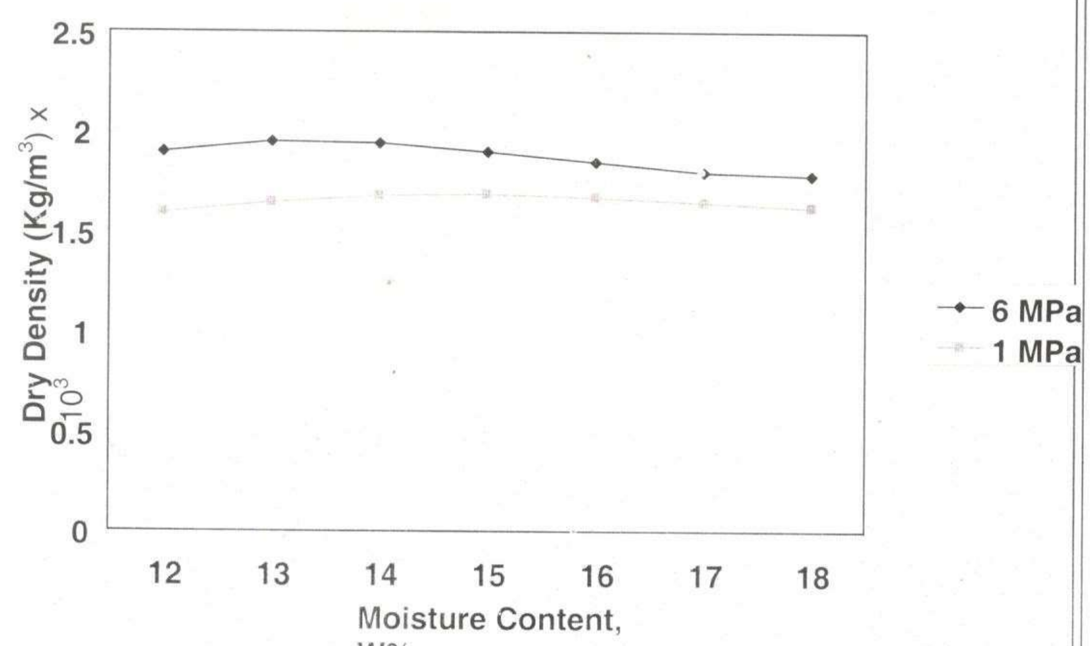


Fig. 1: Static Compaction Curves for Soil **Stabilized with 4% Cement [8]**

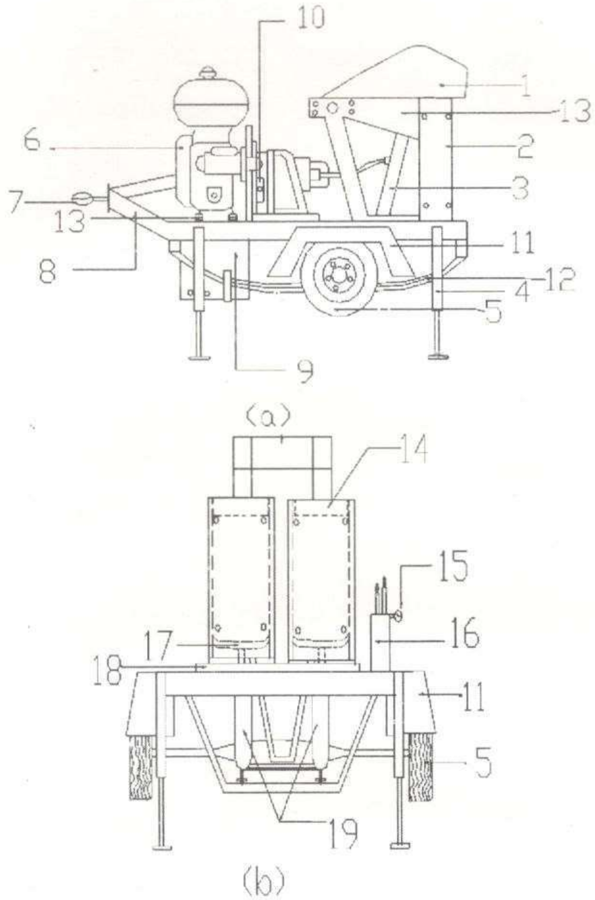
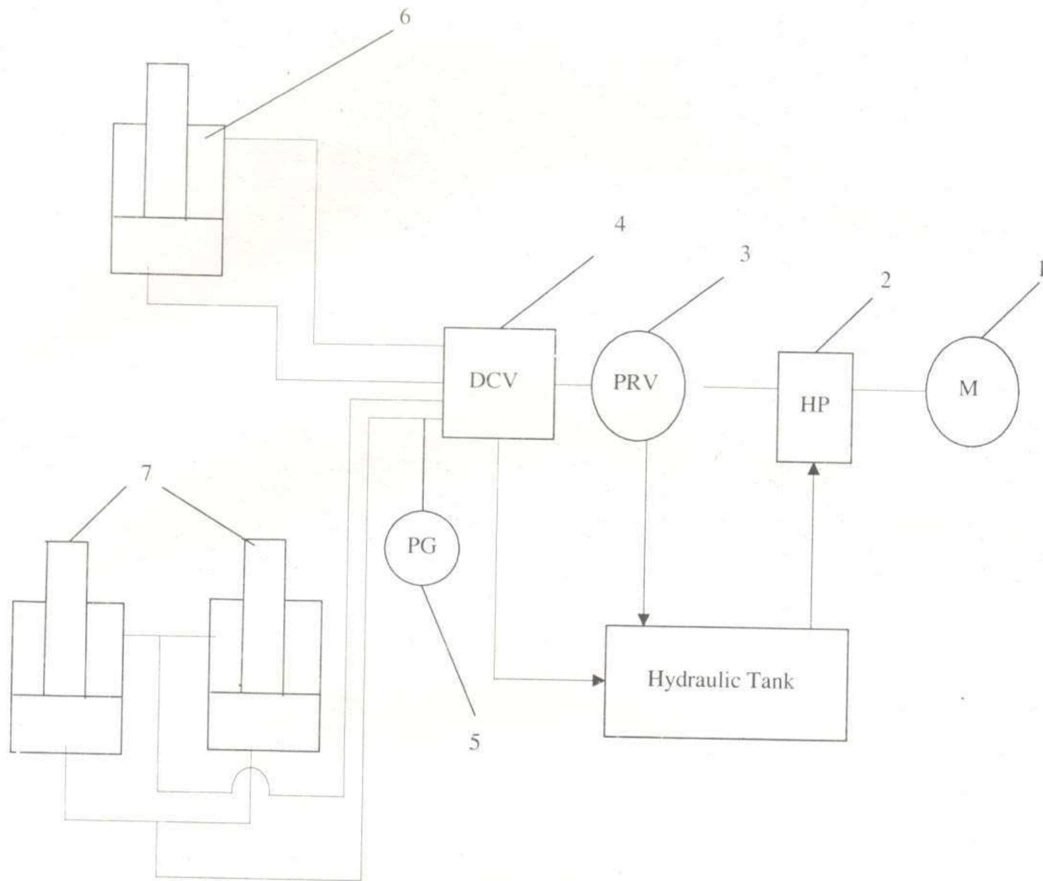


Fig 2: Assembly Drawing of the Hydraulically Operated Stabilized Block Making Machine (a) Side View (b) Front View

1. Upper Presser Arm
2. Mould
3. Upper Hydraulic Cylinder
4. Adjustable Stand
5. Tyre
6. Prime Mover
7. Towing Switch
8. Frame
9. Hydraulic Tank
10. Hydraulic Pump
11. Mud Guard
12. Suspension Spring
13. Dampers
14. Upper Presser Plate
15. Pressure Gauge
16. Direction Control Valve (4 ways, 2 – Position)
17. Lower Presser Plate
18. Base Plate
19. Lower Hydraulic Cylinders for Compaction and Ejection of Blocks



1 -Prime mover
2 – Pump
3 – Pressure relief valve
4 – Direction Control Valve (4 – way, 2 position)
5 – Pressure Gauge
6 – Cylinderto control the movement of upper arm
7 – Cylinder for compaction

Fig. 3: Hydraulic Circuit

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