ADAPTATION AND PERFORMANCE EVALUATION OF A VIBRO COMPACTION TECHNOLOGY FOR PRODUCTION OF STABILIZED-SOIL BLOCKS

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DEDICATION

I dedicate this thesis to my two sons and daughter: Peter, Paul and Anne and to all aspiring Engineers.

ACKNOWLEDGEMENT

I would like to thank The Almighty God, without whose grace this thesis would not have seen the light of the day. My sincere gratitude goes to my family, especially my wife Esther for being patient with my absence during the entire course of study.

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To my colleagues, your criticism made me a better person academically.

ABSTRACT

The need to address the shortage of housing in Kenya, led to the adaptation of the vibro technology used in sandcrete block making machine, for making stabilized-soil blocks. The adaptation envisaged to supplement the technologies used locally in producing stabilized-soil blocks which include the quasi-static and dynamic machines. The adaptation entailed determining the rotor shaft diameter, eccentric mass, the speed of the rotor, and selection of a close coiled helical compression spring and the static load where Non-stabilized sandy-clay-loam soil containing sand/fine gravel 51.1%, and silt/clay 48.8% as sample 'A' was compacted and the density of the formed soil blocks determined before curing. In the trial, different eccentric masses were clamped to the shaft and run at varied speeds. The centrifugal force from the rotor induced vibrations which were confined to the mould by the springs. Static-weight was applied vertically onto the soil mixture simultaneously with the vibrations. A batch of three non-stabilized-soil blocks was produced in each production where the mean density of the batch was determined. A total of 24 batches were produced and Analysis of Variance (ANOVA) was done to determine the speed and eccentric mass or a combination of both that resulted in a batch with the highest density, keeping the compactor weight and spring constant. A t-Test indicated no significant difference between non-stabilized-soil block density from the proctor test and the vibro compaction technology. An optimum speed of 1850rpm and eccentric mass of 4750gms based on Fisher's least significance difference was selected and applied to soil samples 'A', 'B' (sand/fine gravel 60.8%, silt/clay 33.4%) and 'C'(sand/fine gravel 53%, silt/clay 46.6%) mixed with varying cement contents by weight of soil. Soil sample 'C' was mixed with 6%, 8% and 10% cement content by weight where the mean values for bulk density, wet compressive strength, dry compressive strength and water absorption were,1513 Kg/m^3, 0.955 MN/m^2, 1.4 MN/m^2, and 16.7% respectively. It was observed that at 10% cement content, the bulk density was less by 5.4% from the minimum acceptable value of 1600 Kg/m^3, the water absorption was more by 1.7% from the minimum acceptable value of 15% and the ratio of mean dry compressive to wet compressive strengths was less than 2 which conformed to stabilized-soil block literature.Therefore, this study provides a baseline for further research in the adaptation of Vibro compaction technology for making soil blocks to supplement the Impact and Quasi static s oil block compaction methods.

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LIST OF SYMBOLS AND ABBREVIATIONS

A cross-section area (m^2)

b width (m)

C index

C_D dry compressive strength (N/m^2)

C_W wet compressive strength (N/m^2)

D diameter (m)

d_o diameter of rotor shaft (m)

d_t total thickness of material between the hole and the rotor shaft (m)

d_e equivalent pitch diameter

E young's modulus of elasticity (N/m^2)

E_{rotor} energy of the rotor

e eccentricity (m)

e_i impact energy J/sec

F force (N)

f_{ni} natural frequency of transverse vibration (Hz)

g acceleration due to gravity (m/s^2)

h height (m)

I 2^{nd} moment of area (m^4)

J polar second moment of area (m^4)

K stiffness of material (N/m)

K_d smaller diameter factor

K_{ts} stress concentration factor for bending

K_t stress concentration factor for torsion

K_w wahl stress correction factor

L length (m)

m mass (Kg)

M bending moment (N-M)

N speed (rpm)

N_a number of coils of spring

P power (Kw)

S correction factor

T torsion load (N-M)

V velocity in m/s

v_g volume of the soil block after ejection (m^3)

W weight (N)

w_A percentage water absorption

W_f circular frequency in radians per second

Y thickness of material from the outermost fiber to the neutral axis (m)

δ deflection (m)

σ_{en} ultimate stress (N/m^2)

σ_{yp} yield stress(N/m^2)

μ_i mean value

ρ density of soil block (Kg/m^3)

τ shear stress(N/m^2)

ψ limiting angle of friction or repose

CHAPTER ONE
INTRODUCTION

1.1 Background

The earliest building materials used to construct walls for houses included mud, timber and stones and existed prior to 8000 B.C (Venkatarama, 2004). According to Rees (2000), almost a third of the world's population live in unbaked earth housing and the technology used varies from country to country and from region to region. The advent of earth (soil) block making machine, Cinva-Ram press, by a Columbian inventor, Raul Ramirez at the Cinva center in Bogota, South America in the 1950s saw the revolution of the compressed soil blocks in the building industry. The machine was hand operated and its production rate was 200 to 300 blocks a day (Rigassi,1995).

The Cinva block making machine has been modified over the years to an automated machine for production of soil blocks. In the early 1970s, different machines were developed and tested along with construction techniques. Competition ensued and this resulted in innovative designs of block making machines which were factory installed, power operated and manually operated (Webb, 1988).The automatic soil block making machines in the market are out of reach for most people in developing countries especially Kenya where 46% of them live on less than a dollar a day (National Economics and Social Council, 2007). The production rate for the locally assembled, manually operated quasi-static and dynamic stabilized-soil block making machines is in the range of 400 to 500 blocks per eight hour working day (Makiga, 2011).

According to the Ministry of Housing (2010), there is a shortfall of 150,000 and 300,000 housing units annually in urban and rural areas respectively. A study done by Bahar (2004), found that conventional building materials such as cement, natural stones, and aggregates are getting rare and when found, they are expensive. To address this challenge, building blocks should be produced which are made of low cost materials such as soil that is in abundance on the earths crust. Research done by Adam and Agib (2001), Olotuah (2002), and Ministry of Housing (2010) showed that the unit cost of stabilized-soil blocks (ssb) is 20% to 70% lower than that of concrete blocks. The foregoing challenges served as a motivation to supplement the locally

available stabilized-soil block making technologies by adaptation of the Vibro compaction technology used in sandcrete block making to suit the soil regime.

1.2 Statement of the Problem

It is envisaged that all Kenyans will be adequately housed by the year 2030.This challenge can only be accomplished by supplying a deficit of 150,000 and 300,000 housing units annually in urban and rural areas respectively. This scenario is challenging because 46% of the Kenyan population live on less than a dollar a day and the cost of building materials such as natural stones, and cement continue to rise by the day. The cost of imported stabilized-soil block making machines which have high production rates is high and beyond the low income earners, while that of the locally assembled, manually operated stabilized-soil block making machine is low in cost and productivity which is in the range of 400-500 blocks per 8 hour working day. The challenge has necessitated the adaptation of a Vibro-compaction technique applied in sandcrete block making to supplement the locally available stabilized-soil block making technologies.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of the research was the adaptation of the technology used in sandcrete block making for making stabilized-soil blocks for housing with a view to supplement the locally available soil block making technologies.

1.3.2 Specific Objectives

The specific objectives of the research were to:

(i) determine the speed and eccentric mass of the rotor

(ii) determine the compactor weight required for compaction of the soil block

(iii) select the helical compression spring required to induce vibrations in the Vibro compaction soil block making machine and

(iv) test the density, water absorption, and compressive strength of the produced stabilized-soil blocks.

1.4 Research Hypothesis

H_{o_1}: The compactor weight would be equal to 225N, the total weight of the batch of three soil blocks

H_{a_1}: The speed and eccentric mass of the rotor in addition to the power transmission system would generate energy greater than 204 J/kg of soil block

H_{a_2}: The natural frequency of close coiled helical compression spring would be more than the rotor frequency

H_{a_3}: (i) The bulk density of the produced stabilized-soil block would be higher than the minimum specifications by the Kenyan standard

$H_a : \mu_1 > \mu_2$,

where μ_1 is the density of the soil block immediately after forming, and μ_2 is 1600 Kg/m^3

(ii) The water absorption of the produced stabilized-soil block would not exceed 15% of the original mass as specified by the Kenyan standard

(iii)Compressive strength;

(a) Dry compressive strength, of the produced stabilized-soil block would be higher than the minimum specifications by the Kenyan standard

$H_a : \mu_1 > \mu_2$, where μ_1 is the mean dry cmpressive strength,

and μ_2 is 2.5 MN/m^2, the minimum value given by the standard

(b) Wet compressive strength, of the produced soil block would be higher than the minimum specifications by the Kenyan standard.

$H_a : \mu_1 > \mu_2$, where μ_1 is the mean wet compressive strength and μ_2 is 1.5 MN/m^2, the minimum value given by the standard

1.5 Justification of the Study

Imported stabilized-soil block making machines' cost increase with the rate of their productivity while that of locally assembled, manually operated stabilized-soil block making machines is low, both in cost and productivity. This research was aimed at adaptation of the Vibro compaction technology applied in sandcrete blocks for making stabilized-soil blocks to supplement the already existing stabilized-soil block making technologies and address the housing demand. Since the sandcrete compaction regime is different from the soil compaction,

the adaptation would be achieved by determining the rotor parameters, compactor weight and to select close coiled helical compression spring suitable to soil-cement-water regime.

1.6 Scope and limitation

1.6.1 Scope

This study was limited to the determination of the:

(i) Speed and eccentric mass of the rotor

(ii) Compactor weight

(iii) Selection of close coiled helical compression spring

(iv) Density, water absorption and compressive strength of the produced stabilized-soil block

1.6.2 Limitation

The standard, KS 02 1070: 1993 which was used to evaluate the performance of the Vibro compaction method through the physical and mechanical properties of the soil blocks did not provide the procedure of making the stabilized-soil blocks. The water to add in order to achieve maximum density, was beyond the optimum water content in Vibro compaction method, while the literature in Vibro compaction of soil blocks is scarce and therefore, a trial and error method was applied to estimate the optimum water content for each of the soil sample.

CHAPTER TWO
LITERATURE REVIEW

2.0 Introduction

This section outlines the need for utilizing locally available materials and technologies for making stabilized-soil blocks (ssb), the major elements involved in ssb production, mechanical compaction of soil, current methods of ssb production, and development of standards.

2.1 Housing

A study done by Erguden (2001) and United Nations Housing Commission for Settlement-HABITAT (2007), reveals that about 95,000 housing units need to be completed daily in the urban areas of developing countries. The demand for 150,000 and 300,000 low cost housing units annually in urban and rural areas in Kenya respectively, far outstrips the capacity to supply, as 46% of Kenyans live on less than a dollar a day (Ministry of Housing, 2007). Without strategies for low cost housing materials it will not be possible to meet housing demands by the year 2030 as stated in vision 2030 (National Economics and Social Council, 2007). Research has identified soil as a low cost material abundantly found on the earth crust that can be used to make stabilized-soil blocks for housing (Montgomery, 2002).

2.2 Soil

According to Bengtsson and Whitaker (1986); Rigassi (1985); Malcolm (2000); Barnes (2000); Sutton (1986), there are several ways in which soil may be classified, and for the purpose of this research, classification of soil will be understood on the basis of particle size. The classification is determined by sieving to separate particles in the range between 60 mm and 60 microns for gravel and sand and by performing a sedimentation test to determine silt and clay particles. According to Dinachandra and Sarat (2007), a compressed earth block has high density which varies between 1800 and 2100 Kg/m^3. The compressed block of high density gives more load bearing capacity and improves water resistance, is low in cost, easy to manufacture locally by small groups of people, low in energy consumption because no fuel is burnt for block making or transportation, can use soil available at site and has smooth surfaces. The range of soil particle sizes suitable for cement stabilized-soil blocks has the following structure: Sand/fine gravel 40 -

75%, silt 10 - 30% and clay 15 - 30%. Different soils show different dry densities even for the same compaction energy (Fahey, 2006).

2.3 Linear Shrinkage Test

Linear shrinkage test is performed on the soil to assess the ratio of soil to cement and the number of blocks that can be made per 50Kg of cement, Table 2.1. The test is used to assess the ratio of cement required in the soil-cement-water mixture. The higher the amount of soil in the ratio, the higher is the number of soil blocks for the same 50 kilograms of cement. The linear shrinkage test indicates the suitability of the soil for construction purposes and the type and amount of stabilizer to be used. A linear shrinkage test gives the plastic properties of the soil (Adam and Agib, 2001; Bengtsson and Whitaker, 1986; Kerali, 2001; Madedor and Dirisu, 1990; Montgomery, 2002).

Table 2.1: Ratio of Cement to Soil for different percentages of Soil Shrinkage and the Number of Stabilized-soil Blocks per 50KG of Cement

Shrinkage	Cement: Soil ratio	No. of blocks per 50kg cement
0 – 2.5%	1:18	203
2.5 – 5%	1:16	167
5 – 7.5%	1:14	149
7.5 – 10%	1:12	131

Source: Bengtsson and Whitaker (1986)

2 .4 Soil Stabilizer

Soil stabilizers in common use include sand, clay, lime, bitumen, Pozolanic, Rice husk, fly ash, molasses, cow dung, gypsum, and Portland cement (Webb, 1988; Waswa, 1992). According to Rigassi (1985), ordinary Portland cement is one of the best soil stabilizers where clay content is not greater than thirty percent by weight and may reduce moisture movement, improving imperviousness and compressive strength, especially when used with sandy soils which would need between 5% to 6% cement for stabilization for impact and Quasi-static compaction

methods (Kerali, 2001; Montgomery, 2002). Jayasinghe and Kamaladasa (2006) found out that no deterioration has been observed in a comprehensive durability study for walls constructed with 5% cement soil blocks. As soon as the water is added, cement starts reacting and the mixture must therefore be used within 10 minutes (Adam, and Agib, 2001; Bengtsson and Whitaker, 1986; Rigassi, 1995). The use of stabilizing agents, cement in soils to produce a durable building material, has been recognized for quite a long time (Madedor and Dirisu, 1990) and for the purpose of this research, Ordinary Portland cement produced locally in Kenya, will be used for chemical stabilization of the soil blocks.

2.5 Water

Water lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement. The water content of a soil determines the compressibility of a soil for a given amount of compaction energy (Rigassi, 1985). The percentage of water used for a Dynamic and Quasi-static method of compaction for soil with 75% sand, 23% clay and 1% silt was 6% by weight as was determined by Kerali (2001) and Montgomery (2002). However, each soil has different requirements of optimum moisture content depending on the prevailing moisture content in the soil which is determined by a Proctor test. The amount of stabilizer used depends on the type of soil, density of the soil block required and the type of building (Bengtsson and Whitaker, 1986). Stabilized soil blocks with more water content than optimum moisture content, have very little initial strength, become unmanageable and the water does not permit sufficient cohesion between particles and the block regularly break during ejection and subsequent handling (Montigomery, 2002).

2.6 Mixing of Water and Soil Stabilizer

The amount of soil, cement and water for stabilized-soil blocks produced from Impact and Quasi-static technologies are determined from the formula applied by Waswa (1992);

$$\text{Soil (Kg)} = \frac{m}{(1 + x\,\%) + y\,\%\,(1 + x\,\%)} \qquad 2.10$$

Where x is the percentage of cement by weight of the soil block, y is the percentage of water by weight of the soil block and m is the mass of the soil block.

Two distinct stages are involved in the mixing and include dry and wet mixing.The quantity of cement and dry soil is measured by weight. It is manually mixed or mixed in a drum type mixture until the dry mixture has a uniform grayish colour. For wet mixing, clean water is added by sprinkling. The optimum duration for dry and wet mixing is 3 to 4 minutes respectively (Rigassi, 1995).

2.7 Mechanical Compaction of Soil during Road Construction

According to Montgomery (2002) and Zambrano, *et al.* (2006), there are three compaction methods in road making which include static, impact and vibratory compaction. Impact compaction method, Plate 2.1 gives a greater force on the surface than the static and vibratory method (Fahey, 2006). Road compaction is one of the areas that particularly focuses on dynamic compaction of soils with the application of vibrating rollers and vibrating sheep's foot rollers. According to Briaud and Seo (2003), the road making technology has evolved over the years and currently, Vario roller is used to adjust the amount of compaction effect for a given soil type. Rollers with static drums use the effective dead weight of the machine to apply pressure on the surface. Thus, soil particles are pressed together and the void content is reduced. Adequate compaction with static rollers is normally achieved only in the upper layers of the material because the effective depth of static compaction is limited.

Dynamic rollers make use of a vibrating or oscillating mechanism, which consists of one or more rotating eccentric weights. According to Briaud and Seo (2003), during dynamic compaction, a combination of dynamic and static load is applied. The dynamically excited drum delivers a rapid succession of impacts to the underlying surface where the particles are set in motion by the transmission of compressive and shear waves. These vibrations eliminate periodically the internal friction between particles and facilitate, in combination with the static load, the rearrangement of the particles into positions that result in a lower void ratio and a higher density.



Plate 2.1 Five sided Impact roller (Source: Geotechnical and Geoenvironmental Engineering CIVL4121)

According to Barnes (2000); Briaud and Seo (2003); Zambrano, *et al.* (2006), vibration energy assists compaction considerably by shaking the soil and reducing inter-particle friction while the pressure applied moves the particles together. Vibratory motion is caused by a rotating eccentric mass and the horizontal oscillatory motion shakes the soil in the horizontal direction inducing shear deformations in the soil mass. The drum of a vibratory roller, Plate 2.2, 2.3 (a), and (b) is excited by a rotating mass which is connected to the shaft of the drum axis. The rotating mass sets the drum in motion and the direction of the resultant force is tied to the position of the eccentric mass. Compaction is achieved mainly by the series of compression waves penetrating the soil in combination with the effective static weight of the drum and the frame. The resulting compaction force is almost vertical (Briaud and Seo, 2003).

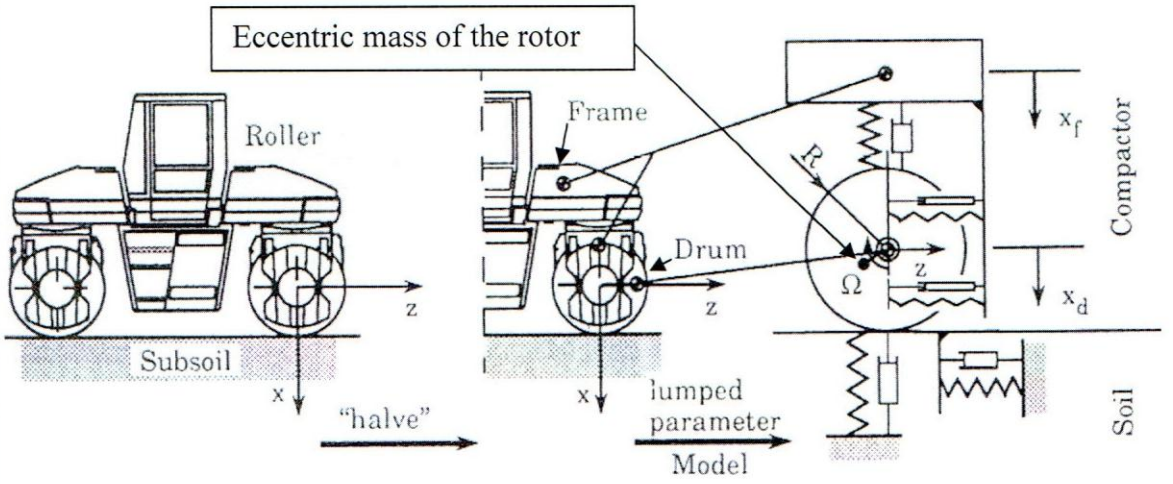


Plate 2.2 Model of vertical vibration of a single drum roller -circular excitation (Briaud and Seo, 2003)

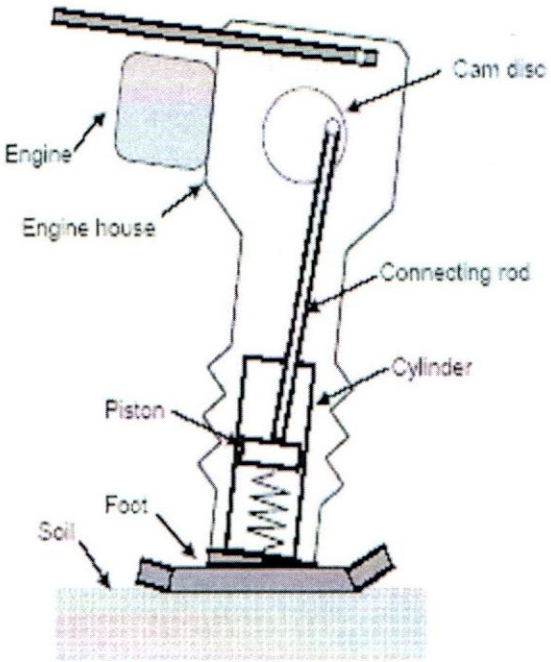


(a) Vibratory sheep-foot



(b) Vibratory double drum roller

Plate 2.3 Vibratory roller



(a) Vibro tampers



(b) Plate tamper

Plate 2.4 Vibro and Plate tamper: (Briaud and Seo, 2003))

The Vibro tamper also known as rammer compactor and Plate compactors in Plate 2.4, apply compaction by vibrations and are used in confined spaces (Jőnsson, 2001; Anders, 2001; Montgomery, 2002; Briaud and Seo, 2003; Anderegg, *et al.*, 2006; Fahey, 2006). According to Ogata, (1996); Mutambara, (1999); Goran and Anders, (2000); Jens and Anders, (1997);

Anderegg, *et al.* (2006); Broman and Jönsson (2000); Jönsson (2001); Debeleac and Oproescu (2009), Compaction in this method is made possible due to the periodic loss of contact between the vibrating foot of the tamper and the soil.

2.8 Technology in Earth Block Construction

According to Web (1988), Waswa (1992), Moor and Heathcote (2002), a wide variety of earth construction technologies are known to exist and include the following;

(i) Adobe earth blocks are soil blocks that are sun-baked. They are typically 250mm x 350 x 100 mm and are made by pouring a puddle mixture of clay and sand into forms. Once laid the blocks are left in the sun to dry.

(ii) Compressed earth blocks are a development of adobe, which surfaced in the second half of this century. In this method a dry soil is placed in a steel mould and compacted under high pressure. Typically densities of around 2000Kg/m^3 are achieved compared to around 1700Kg/m^3 for traditional adobe bricks.

(iii) Rammed earth or Pise was a technique of forming wall forms developed by the French in the latter half of 19th century, although it was centuries old. The name Pise is a shortening of the word Pise de terre. In this method a dry mixture of sandy soil is rammed into wall forms. The thicknesses of rammed earth walls is typically around 600mm but more recently walls built from earth stabilized with cement are being built with thicknesses around 300mm.

Research and Technological advancement has resulted in improved earth construction technologies and two types of stabilized-soil compaction machine designs have resulted according to Montgomery and Thomas (2000); Montgomery (2002). The two machine designs include;

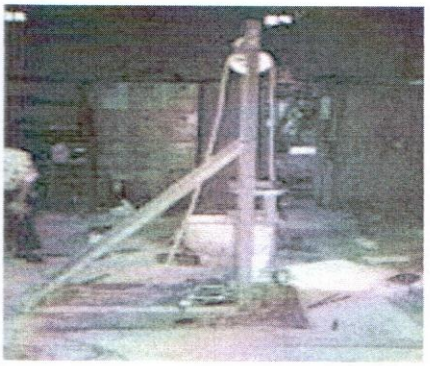
(a) Dynamic: impacterre compacting machine developed at Warwick University.

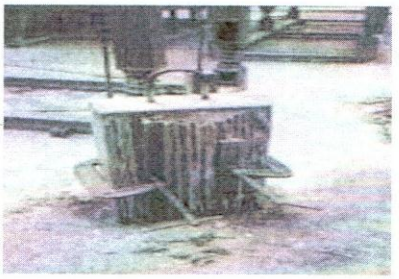
(b) Quasi-static: hydraform compacting machine was developed in South Africa and Balram developed in India through linkage with Warwick University

(c) Vibro-compaction: specimens were first vibrated on a laboratory-shaking table for one minute before being subjected to static compaction force, Bahar, *et al.* (2004).

2.8.1 Dynamic Compaction

Dynamic compaction uses the energy from a falling mass to compact the soil block, Plate.2.5, where the soil-cement-water mixture is confined in a mould chamber. The number of blows applied to the ssb can be varied within a predetermined optimum range of 8-32 where the impactor momentum, $mv = \sqrt{2gh}$, and the impact energy $e_i = mgh$, depends on the mass,m of the impactor and the height, h through which it is lifted and results in compaction energy of 204J/Kg (Montgomery and Thomas, 2000); (Montgomery, 2002).





(a) Impact ere compactor Prototype with a cast concrete compactor (Montgomery, 2002)



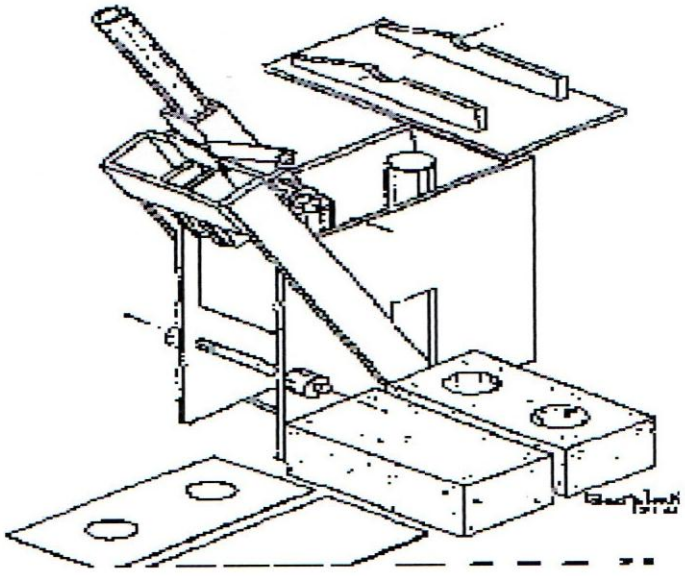
(b) An impact compactor manually operated

Plate 2.5 Impact compactor (Kenya: locally assembled in "Jua kali")

2.8.2 Quasi-static Compaction

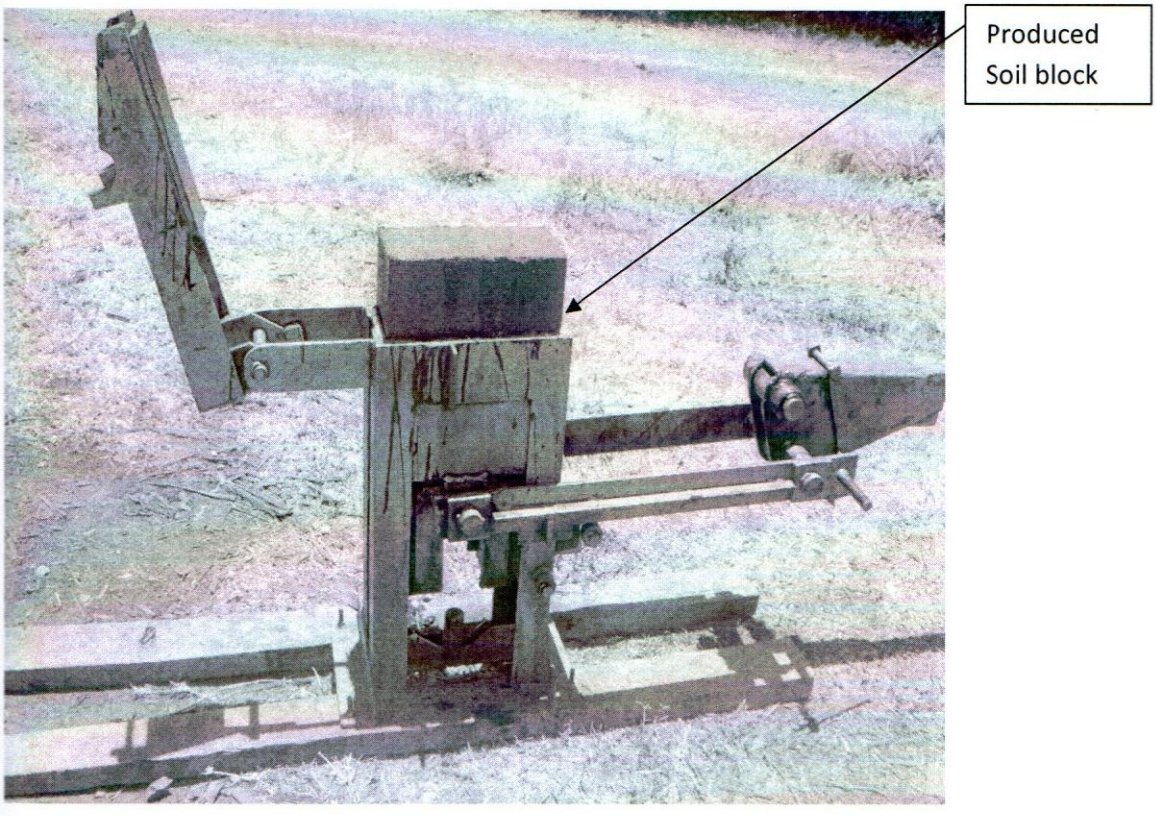
Quasi-static compaction involves a certain pressure being applied to the ends of the material confined in a mould, Plate 2.6 to 2.10. The pressure can be applied in one or more cycles and the speed of compression can also be varied between 5-100 mm/s. The applied pressure is between 8-12Mpa and for 10Mpa, the compaction effort applied was 279J/Kg, (Montgomery and Thomas, 2000; Montgomery, 2002 and Kerali, 2001).

The quasi-static machines for producing stabilized-soil blocks include mechanical press, Plate 2.6 and 2.7; manually operated hydraulic press, Plate 2.8 and motor or diesel driven hydraulic press, Plate 2.9 and 2.10.



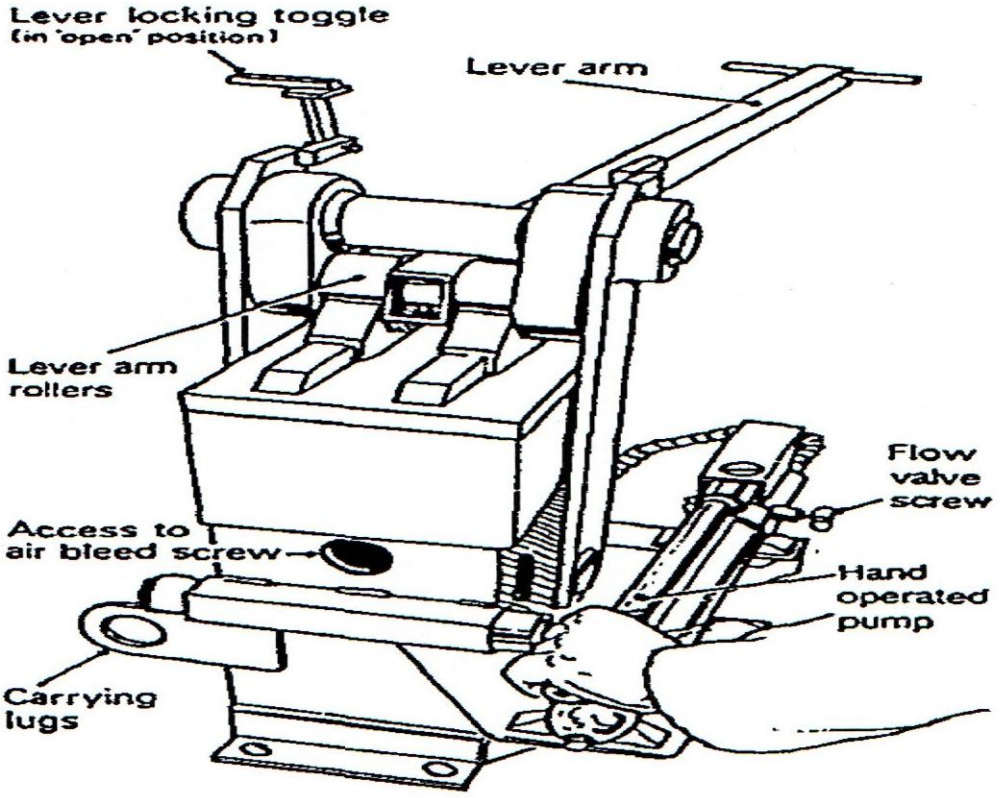
Manually operated; 40-60 solid/Hollow blocks/hr, 323x157x115mm

Plate 2.6: CETA RAM II: (Appropriate Building Materials (SKAT), 1988)



Compression force; 80-100KN; Weight 140 Kg; Production rate is 400-500 blocks/ 8Hr day

Plate 2.7: Ground breaker soil block press: (Makiga Engineering Services, 2012)



Hand operated hydraulic pump: 30-40 blocks/Hr; 290x140x100mm

Plate 2.8 (a) Brepak machine: (Appropriate Building Materials (SKAT), 1988)

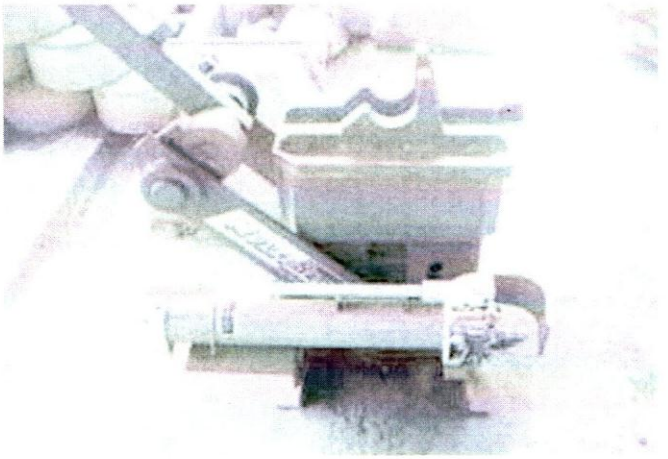


Plate 2.8 (b) The CINVA-Ram hydraulic machines: (Yasser Khalid, 2009)

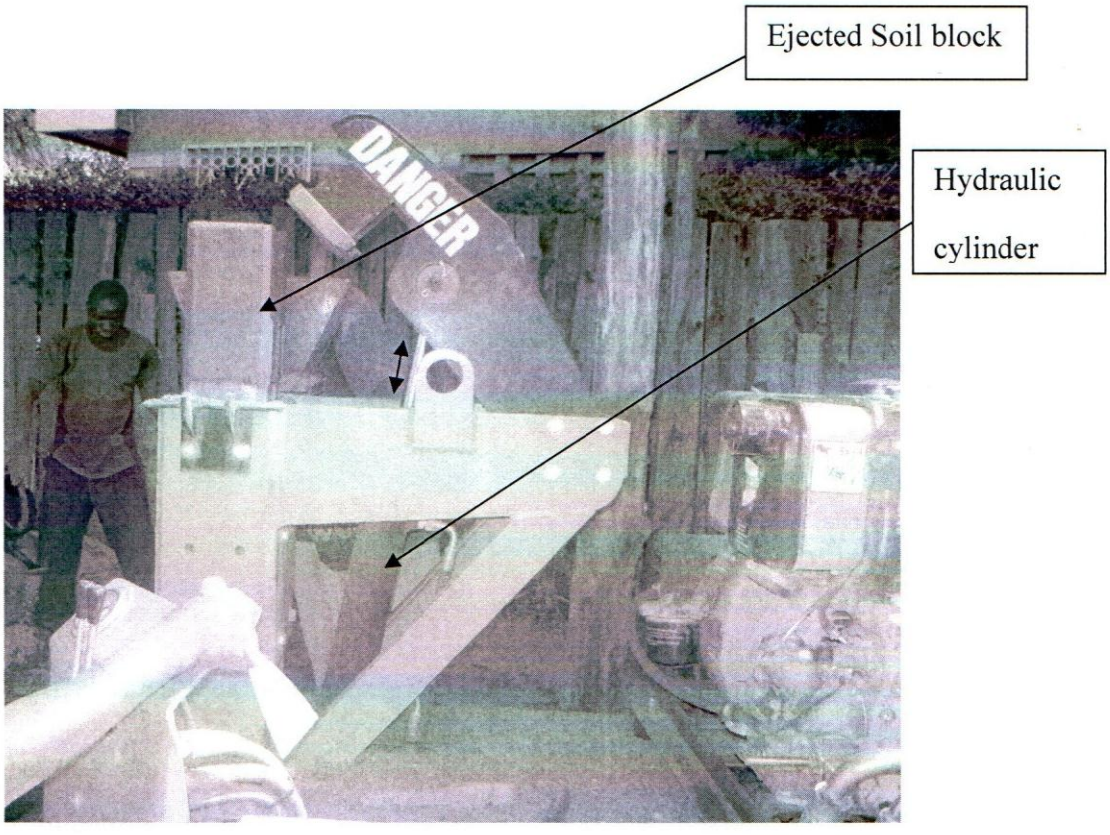


Plate 2.9 Hydraform soil block making machine: (Hydraform (India) PVT Ltd)

The building technology has evolved since the invention of the CinvaRam block making machine in 1950s, for making compressed earth blocks (Rigassi, 1995; Appropriate building materials-SKAT, 1988). Research and development work on soil-cement block making progressed in the 1970s and in the 1980s, there appeared new generations of manual, mechanical, motor, and diesel driven presses, as shown in Plate 2.7 to Plate 2.10

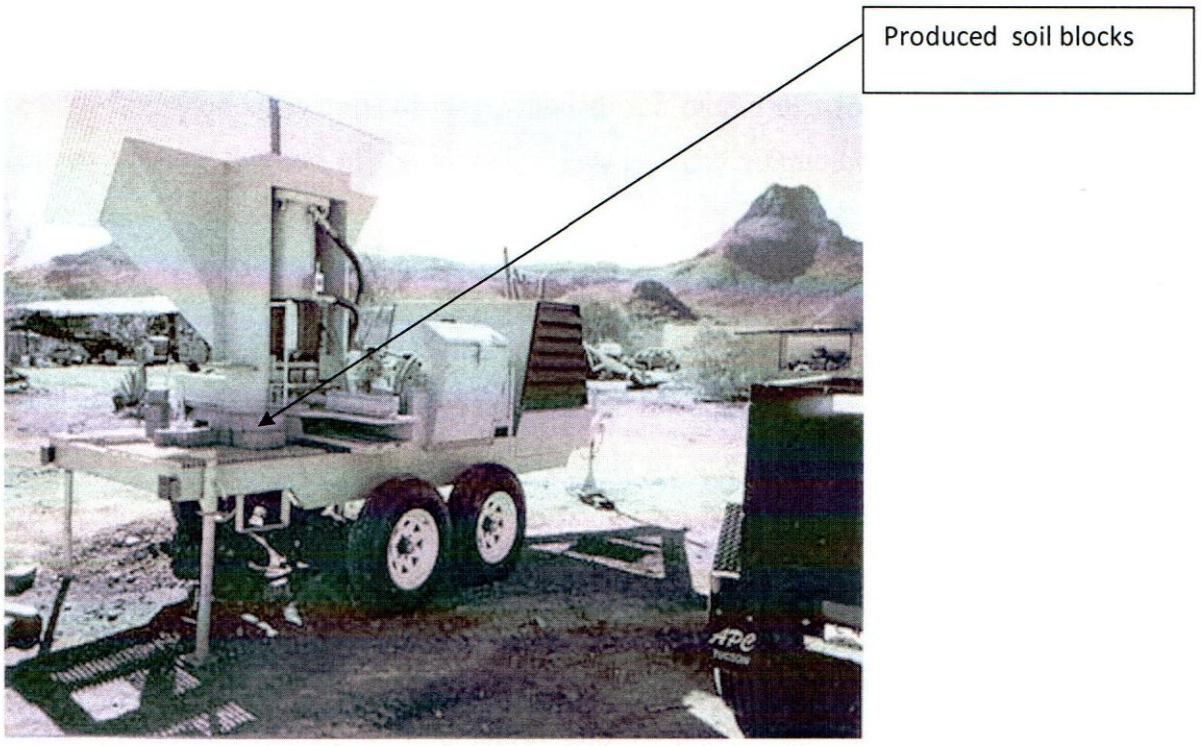


Plate 2.10 Vertical block making machine (Source: http//www.ferncometals.com/)

The progress of innovation of stabilized soil making machines was reported in India at the centre for Application of Science and Technology for Rural Areas (Astra) (Venkatarama, 2004); (Montgomery, 2000, 2002); Kerali, (2001) and in Nigeria building roads and research institute in the 1990s (Madedor and Dirisu, 1990). In Nigeria, a manually operated block making machine was designed and fabricated to facilitate formulation of Standards and production of stabilized-soil blocks. According to Webb (1988) a block press was developed in Kenya in mid 1970s by the Rural Industries Development Center that modeled the Cinva Ram and another advanced model, Bonner Block making machine was designed by the head of Action Aid, (Webb,1988).

2.8.1.3 Vibration Compaction Method

Kerali (2001) showed that the least stabilized soil-cement-water mixture is likely to be found at the middle of the block which was subjected to the least particle shear, when dynamic and quasi-static compaction methods are used. Water lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement (Badar, 2001).

Gooding and Thomas (1995) carried out research in nine African countries including Kenya and reported on a vibration method exclusively used in forming sandcrete blocks where sand-

cement-aggregate-water mixture was vibrated in a mould to which some modest pressure was applied towards the end of the vibration process. The vibrator was powered by a motor or a diesel engine.

Bahar, *et al.* (2004) in their study of soil blocks reported that for higher water content than the value that results in high dry density, Vibro-compaction seemed to be the best compaction method for soil blocks, probably because of the low friction forces. The specimens in the study were first vibrated on a laboratory-shaking table for one minute before being subjected to static compaction force. Water lubricates the soil grains so that they slide more easily over each other and can thus achieve a more densely packed arrangement (Badar, 2001). A little bit of water facilitates compaction, while too much water inhibits compaction as moisture cannot escape under impact of the hammer and instead, the entrapped air is energized and lifts the soil in the region around the hammer. Montigomery (2002) found out that soil blocks with very high water content than optimum have very little initial strength in impact compaction method, which makes them unmanageable because the excessive water does not permit sufficient cohesion between particles making them break during ejection and subsequent handling.

The suitable methods of compaction applied above the wet side of the optimum moisture content , Plate 2.11, are kneading, vibratory and the static (Bader, 2001), which is supported by a study done by Gitau, *et al.*, (2011) . The vibratory method is applied for coarse-grained soils in the laboratory while fine-grained soils are compacted by impact and quasi-static methods.

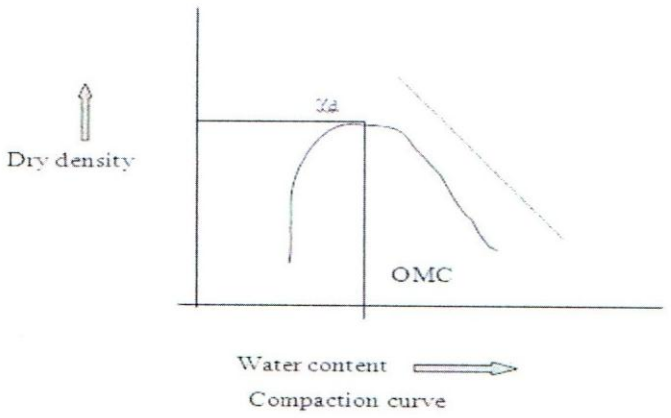


Plate 2.11 Moisture content versus dry density: (Badar, 2001)

2.9 Stabilized-soil Block Variables

Montgomery (2000, 2002), reported that the interaction between the independent variables, Fig.2.1, confined in a mould plus the energy transferred into the mixture of soil-cement-water resulted in a stabilized-soil block with the density, compressive strength and durability, as dependent variables. The permeability of the block decreases and the effect of water penetration is reduced with the increase of density, and if the block can be kept dry or made impermeable to moisture then it would survive for a much longer period (Barnes, 2000); (Montgomery, 2000); (Adam and Agib, 2001); (Kerali, 2001). As the green and bulk density of the block increases, so is the compressive strength which is at its maximum in 28 days when the hydration of cement has ceased (Montgomery, 2002). A block with high density provides both greater compressive strength and better resistance to the natural elements of rain and wind (Adam and Agib, 2001; Moor and Heathcote, 2002).

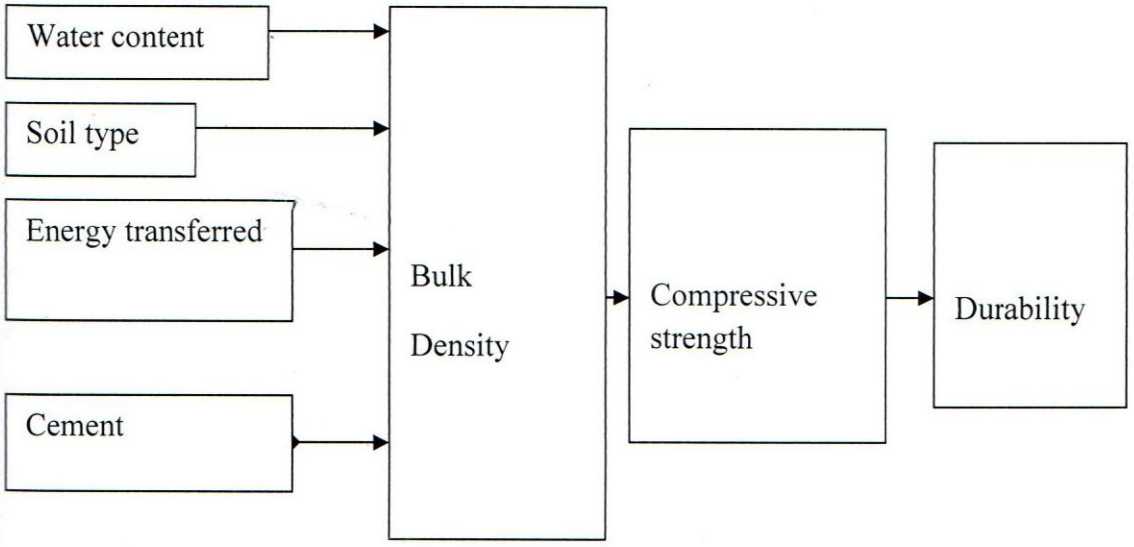


Figure 2.1 Model showing interrelationship between the stabilized-soil block variables: (Montgomery, 2000, 2002)

2.9.1 Green density

This is the density of the stabilized-soil block immediately after ejection. Green density is used to control the production process and to check whether the block meets the minimum standard prior to curing. Volume is calculated by measuring the block size after ejection. According to Montgomery (2000) and Barnes (2002), the green density depends on the particle size distribution or soil type, water content and level of compaction.

2.9.2 Bulk Density

According to Dinachandra and Sarat (2007), a suitable compressed earth block has high density which varies between 1800 Kg/m^3 to 2100 Kg/m^3.The high density gives more load bearing capacity and improved water resistance.

2.9.3 Compressive Strength

According to Montgomery (2000), low-cement stabilized soil blocks manufactured by low pressure compaction, 2MPa, have compressive strength adequate for the majority of low-rise buildings provided that water penetration is kept to a low level. If wet compressive strength is high, environment factors such as running water will not cause early failure to occur to the building material. The predominant factors that result in high wet compressive strength are cement content and level of compaction achieved during formation of the block. The durability of stabilized soil blocks is linked to the wet compressive strength and therefore, a stabilized-soil block with high wet compressive strength lasts longer (Barnes, 2000; Adam and Agib 2001); Kerali, 2001). According to Rigassi (1995), Modulus of rupture can be deduced from dry compressive strength by dividing by a factor often between 5 and 8 and vise versa.

2.9.4 Water Absorption

According to Kerali (2001), water deterioration in soil blocks is found to occur in various forms such as solvent action, abrasive action, swelling action, catalytic action and dampness. The deterioration mechanisms can be minimized by use of denser and more homogeneous soil blocks of low permeability and of low water absorption capacity of less than 15%, use of soil with clay content less than 30% when ordinary portland cement is used as the sole stabilizer and adequate curing of the soil block (Kerali, 2001).

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2.10 Compacted Stabilized- Soil Block Standards

In the 1980s, research in stabilized soil block standards progressed with earnest, with the formation of a technical committee on "Laterite based materials" with the objectives to produce an international draft building standard covering the use of stabilized soil building blocks (Webb, 1988). As a result of their recommendations, the Nigerian standard was developed in 1990 (Madedor, and Dirisu, 1990).

According to Pre-cast masonry technical committee (2003) and Housing and Building Research Institute (2003), the Kenyan Standard was developed in 1993 and code'95 was enacted in 1995 to enable housing standards and procedures acceptable to local authority and stakeholders. The stabilized-soil block standards relevant to this research include bulk density of not less than 1600Kg/m^3, dry compressive strength of not less than 2.5N/mm^2, wet compressive strength of not less than 1.5N/mm^2 and water absorption of not more than 15% of the original mass.For the purpose of this research, the working dimension and mass of the stabilized-soil block was taken as 290 x 140 x 115 mm and 7.5Kg respectively.

2.11 Compaction Energy in Impact and Quasi-static Technologies

Montgomery (2002) found out that the Quasi-static energy to compact a soil sample with 75% sand, 23% clay and 1% silt to 9.7 Mpa was 279J/kg and the energy for Impact compaction method for the same soil sample was 204J/kg. The compaction energy varied by 25% to 50% from quasi-static to impact method (Montgomery, 2002). The compaction energy for adaptation in Vibro compaction method to be used in this research for producing the stabilized-soil blocks is a combination of angular kinetic energy from the rotor and energy from power transmission system combined with energy from the compactor.

2.12 Vibro Compaction Technology

The rotor technology in plate 2.2 is used in compaction of unconfined soil mixtures in road making, where within each drum, an eccentric mass configuration rotating about the drum axle provide the eccentric force that induces vibrations (Briaud and Seo, 2003; Rinehart and Mooney, 2005). The Vibro compaction technology used in sandcrete block making, plate 2.13, for a confined mixture of sand, aggregate, cement and water is to vibrate the mixture in the

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mould using a rotor clamped to the mould externally. The technology incorporates rubber dampers to confine the vibrations in the mould hence densifying the soil mixture.

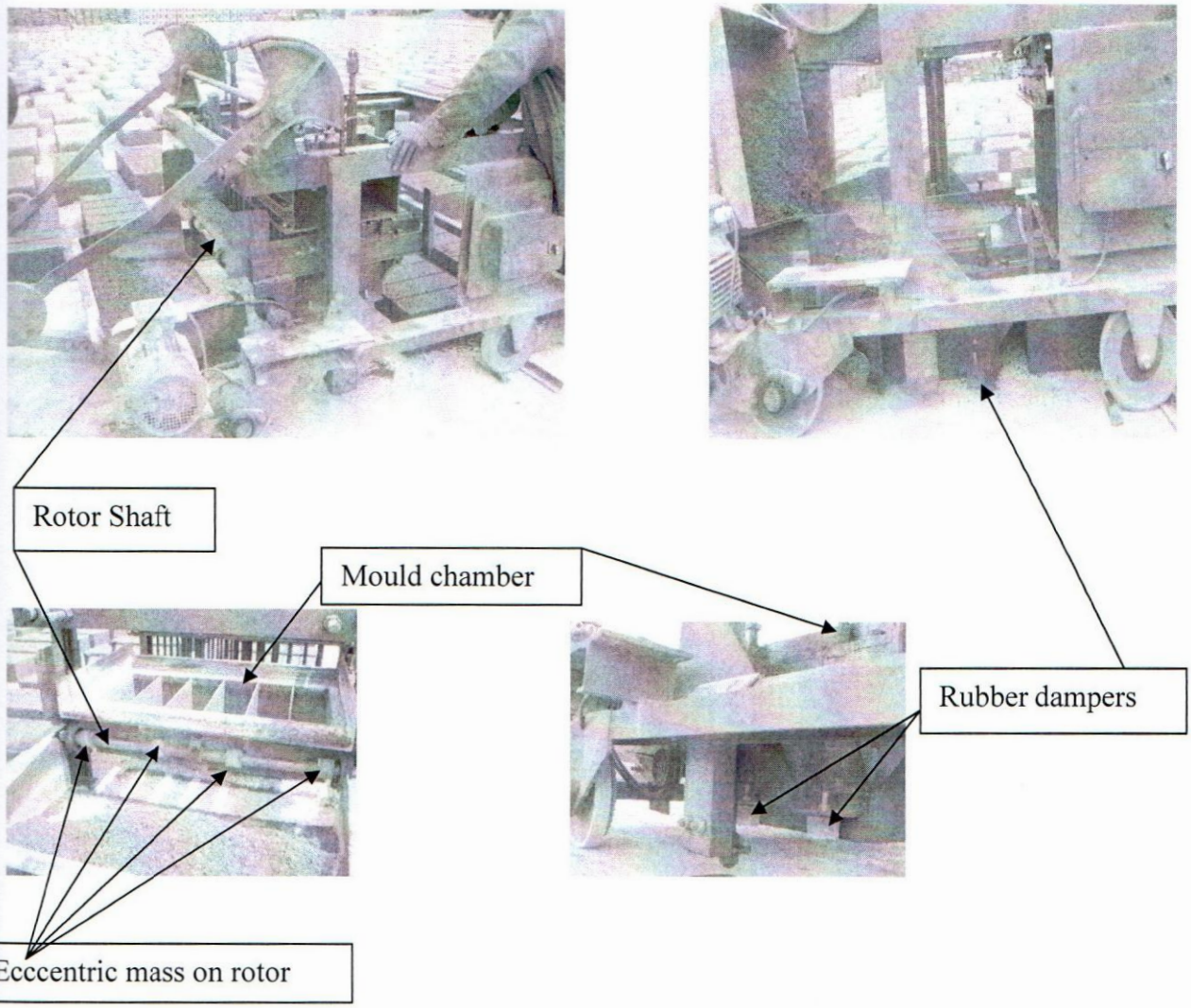


Plate 2.12 Vibro Compaction Sandcrete block machine (Wareng Ndovu enterprises (2005)

However, the sandcrete or concrete literature does not apply to the production of soil blocks (Montgomery, 2002). According to Anderson and Anderson (1987), the rubber dampers confine the vibrations to the mould vertically and horizontally. The generation of vibrations in this research entailed the integration of the speed and eccentric mass of the rotor and the use of close

coil helical compression Spring to confine vibrations of the mould horizontally and simultaneously applying a compacting weight onto the soil mixture.

2.12.1 The Rotor- eccentric Mass assembly

A rotor is a rotating element consisting of a shaft and an eccentric mass and is supported by bearings in the lateral direction (Ramesh, 2005). The dynamic force, F_c of the rotor, Fig.2.2, is given by the following expression (Ballaney, 1992); (Briaud and Seo, 2003); (Rinehart and Mooney, 2005); (Ramesh, 2005):

$$F_c = Mew^2 \sin wt \qquad 2.11$$

Where, w is the circular frequency in radians per second, M is the eccentric mass, e is the eccentricity, wt is the angular rotation of the rotor in radians per second. In this research, the maximum dynamic force, F_c , is used in selecting the close coiled helical compression spring. In equation 2.11, the centrifugal force is directly proportional to eccentricity and for the purpose of this research; therefore, the eccentric mass was arranged in a lateral direction, Fig.2.2, to increase eccentricity.

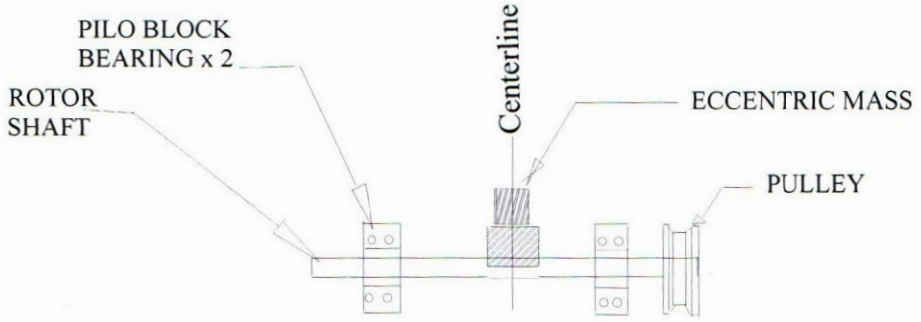


Figure 2.2 Rotor shaft eccentric-mass assembly

2.12.1.1 Eccentric Mass

The intensity of centrifugal force produced by the rotor depends on the eccentricity of the mass on the rotor shaft. Apostol and Mamikon (2000) found that, if the masses are on a

Line at points $x_1, \ldots, x_n$, the centre of total mass is the point,

$$\bar{x} = \frac{m_1 x_1 + \ldots + m_n x_n}{M} \qquad 2.12$$

Where, $\bar{x}$ is the weighted average of position of centre of mass or eccentricity, $m_{1,\ldots,} m_n$ is any finite number of masses, M is the total mass of m_i for $i = 1,2, \ldots,$ for $i \in N$. According to Ballaney (1992), the centre of mass through the polar axis for a circular solid shaft is given by:

$$\frac{d_o}{\sqrt{8}} \qquad 2.13$$

And the centre of mass about the diameter is given by:

$$\frac{d_o}{4} \qquad 2.14$$

2.12.1.2 Rotor Shaft Diameter

In this research, the rotor shaft has a transverse hole on the side through which the eccentric mass is clamped. The bolt experiences both a tensile force exerted by the mass and bending at the start and end of angular motion. The safety factor for steel shafts under tension and bending is taken as two (Tyler, 1987). The working stress in the bolt is given by the Equation used by Ballaney (1992):

$$\sigma = \frac{F_c}{A} \qquad 2.15$$

Where σ the working stress is experienced by the bolt, F_c is the centrifugal force due to the eccentric mass, A is the cross-section area of the bolt. The diameter of the bolt from Equation 2.15 is determined as follows:

$$d = \sqrt{\frac{4 \times F_c}{\text{Factor of safety} \times \text{working stress} \times \pi}} \qquad 2.16$$

According to American Institute of Physics (2011), for stress concentration in shafts with transverse circular holes, the ratio of diameter of shaft to that of the radius of the hole has a ratio equal to:

$$\frac{r}{d_t} \leq 0.5 \qquad 2.17(a)$$

And,

$$d_t = d_o - 2r \qquad 2.17(b)$$

Where, r is the radius of the transverse hole, d_o is the diameter of the rotor shaft, and d_t .is the total thickness of material between the hole and the rotor shaft diameter.

Mahadevan and Balaveera (1992) indicated that the diameter of a rotor shaft has to take into account such factors as suddenly applied load, heavy shocks and endurance factors especially at the start and end of power transmission. The diameter of a rotor shaft with a transverse hole for clamping the eccentric mass is given by the following expression (Mahadevan and Balaveera, 1992):

$$d_o = \left[\frac{16}{\pi\tau_{max}}\left(\sqrt{\left(M_m + \frac{K_t\sigma_{yp}}{\sigma_{en}} \times M_a\right)^2 + \left(T_m + \frac{K_{ts}\sigma_{yp}}{\sigma_{en}} \times T_a\right)^2}\right)\right]^{1/3} \qquad 2.18\ (a)$$

Where the stress concentration factors are K_t and K_{ts}, for bending moment and torsion moment respectively, σ_{yp} is yield stress in compression, M_a is alternating moment assumed to be equal to maximum moment, σ_{en} is assumed to be equal to ultimate stress and T_a is alternating torsion assumed to be equal to maximum torque T_m , and τ is the shear stress due to torsion.

$$M_m = \frac{\sigma I}{y} \qquad 2.18(b)$$

where M_m is the maximum bending moment acting on the shaft, I the second moment of area of a solid shaft, y is the distance of the outermost fiber of the solid shaft to the neutral axis of the shaft.

$$T_m = \frac{\tau J}{r} \qquad 2.18(c)$$

Where T_m is the maximum torque acting on the rotor shaft and,

$$\tau_{max} = \frac{16T}{\pi d_o^3} \qquad 2.18(d)$$

Where τ is the maximum torsion shear stress due to torsion load, d_o is the diameter of the rotor shaft. According to Mahadevan and Balaveera (1992), torsion load,

$$T = \frac{9.55 \times 10^6 \times P}{N} \qquad 2.19$$

Where N is the rotor speed in revolutions per minute and P in Kw is the power of the rotor.

2.12.1.3 Deflection of the Rotor Shaft

The general consideration in rotor shaft design is to minimize both deflection and stresses by keeping the shaft length as short as possible and overhangs minimized (Norton, 2000). The total deflection of the rotor shaft is the sum of the deflections caused by the concentrated load and the uniform load of the shaft. The general low carbon steel is just as good as higher strength steel since deflection is typically the design limiting factor (Norton, 2000). The design practice limits the transverse deflection of a shaft of any diameter to 0.83mm per meter of shaft length, (Tyler, 1987).

2.13 Drive Speed for Production of Vibrations

The selection of the drive, motor or diesel engine depends on the natural frequency of free transverse vibration of the rotor system. The Dunkerley's empirical model ,Eqn. 2.19(a) to (c) ,used by Hannah, and Stephen, (1984); Ballaney, (2001), takes care of the mass effect of the rotor shaft and point load is used to evaluate the natural frequency of the rotor system:

$$f_n = \sqrt{\frac{f_{n_1} f_{n_2}}{f_{n_1} + f_{n_2}}} \qquad 2.20(a)$$

Where, f_n is the natural frequency of transverse vibrations of the system, and

$$f_{n_1} = \frac{0.5615}{\sqrt{\delta_1}}, \text{due to uniformly distributed load} \qquad 2.20(b)$$

$$f_{n_2} = \frac{0.4985}{\sqrt{\delta_2}}, \text{due to point load} \qquad 2.20(c)$$

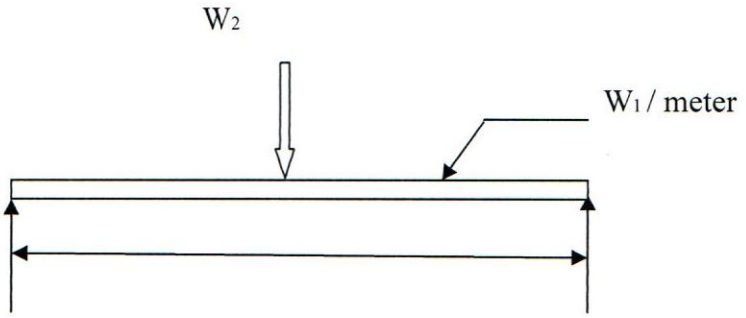


Figure 2.3: Shaft with distributed load and point load (eccentric load)

For the load system shown in Figure 2.3, W_2 is weight of the eccentric mass in Newton and W_1 is the distributed weight of the shaft in Newton's. For the rotor system on rigid support, the Lateral vibration is considered for the analysis of natural frequency of transverse vibrations (Ramesh, 2005). Robert (1992) and Mahadevan and Balaveera (1992) indicated that static deflection at each load point is evaluated as follows;

$$\delta_2 = \frac{W_2 L^3}{48EI}, \text{static deflection due to point load} \qquad 2.21(a)$$

$$\delta_1 = \frac{W_1 L^3}{384EI}, \text{static deflection due to distributed load} \qquad 2.21(b)$$

Where, E is young's modulus of the material of the shaft, and for the purpose of this research,

$E = 207\ GN/m^2$: (AISI 1018/1020, 2010; Insteel Ltd. Kenya, 2010), L is distance between the bearing supports I is the second moment of area of shaft is given by the following expression:

$$I = \frac{\pi d_o^4}{64} \qquad 2.22$$

Motors or diesel engines are available in specific horsepower, but usually the drive is purposefully oversized (Tyler, 1987). To avoid resonance the frequency of the external exciting force must not coincide with the natural frequency of the rotor system (Keith, 1998; Ballaney, 2001). It is therefore desirable to select the speed of the drive based on the natural frequency of the rotor system. The natural frequencies of transverse vibrations of the rotor system are below or above the drive speed by 25% to 30% in order to avoid resonance (Lees, *et al.,* 2004). Typically, machines are designed such that the critical speed is well below their operating speed (Ramesh, 2005).

2.13.1 Power of the Drive

The power of the rotor should be adequate to produce vibrations in the mould for densification of the soil-cement-water mixture. The drive should therefore be able to transmit the power to the rotor, given by the following expression (Tyler, 1987):

Design horse power of the drive = Horse power of driven device x service factor, 2.23

Where the service factor depends on the service conditions. Service factor, S_f is between 1.4 to 1.6, and for a drive of more than 700 rpm, the service factor is taken as 1.6 The Power of the driven shaft (rotor) is given by the following expression, (Tyler, 1987):

$$\frac{\text{Driver shaft horse power}}{\text{Service factor}} \qquad 2.24$$

2.13.2 Selection of Pulley

The pulley and belt combination is used to transmit power from the drive to the rotor

The selection of the pulley and belt was done according to Tyler (1987) and Mahadevan and Balaveera (1992):

(i) Selection of the v-pulley

The speed ratio of the shafts is the ratio of the speed of the high speed shaft to that of the low speed shaft and the sheave diameters have the same ratio. Therefore,

$$\frac{\text{High speed shaft}}{\text{Low speed shaft}} = \frac{\text{Pitch diameter of low speed shaft}}{\text{Pitch diameter of high speed shaft}} \quad 2.25$$

(ii) Selection of the v-belt

The number of belts for power transmission depends on the amount of power to be transmitted, which is derived from the following expressions (Tyler, 1987):

$$\text{Belt horse power rating} = \text{Design horse power} \times S_a \times S_l \quad 2.26$$

where S_a is the arc of contact correction factor and S_l is the belt length correction factor

$$\text{Number of belts} = \frac{\text{Design horse power}}{\text{Rated belt horse}} \quad 2.27$$

2.14 Selection of the Helical Coil Compression Spring

The closed coil helical compression spring is designed using empirical methods, (Tyler, 1987; Mahadevan and Balaveera, 1992; Rishovski and Villarreal, 2012). The following information is necessary for selection of the spring; service load, service movement, allowed space and installation method. Other design constraints for the spring include;

(i) Ratio of maximum to minimum force:

$$\frac{F_{max}}{F_{min}} < 3 \quad 2.28$$

Where F_{max} force at maximum operational state or solidity is limit less clash allowance, F_{min} is force at minimum operational state so that contact is not lost between spring and end support.

(ii) Clash allowance of 10% of the maximum working deflection;

$$\delta_s - \delta_{max} > 0.1\delta_{max} \quad 2.29$$

Where, δ_s is deflection at solid length, and δ_{max} is the deflection at solid length less the clash allowance.

(iii)Buckling or Slenderness ratio:

$$\frac{L_o}{D_{mean}} < 4 \qquad 2.30$$

Where L_o the free length of a compression spring, D_{mean} is the outside diameter of the spring less the wire diameter.

(iv) Spring index;

$$C = \frac{D}{d} \qquad 2.31(a)$$

The spring index C is in the range of;

$$4 < C < 12 \qquad 2.31(b)$$

Where, d is diameter of the wire, D is the mean diameter of the spring

According to spring-makers-resource.Net, the wire in the helical compression spring is stressed in torsion. The bending stresses can be ignored except when pitch angle is over 10 degrees. The Wahl stress correction factors are used to compensate for the stress concentration at the inner diameter of the coiled wire:

$$\text{Shear stress, } \tau = \frac{8DF_c}{\pi d^3} \times K_w \qquad 2.32$$

Where F_c is the centrifugal force, K_w is the Wahl stress correction factor.

For all set points of fatigue,

$$K_w = 1 + \frac{0.5}{C} \qquad 2.33$$

According to Shigley and Mischke (1990), to avoid resonance in dynamic loading of a close coiled helical compression spring; the natural frequency should be a minimum of thirteen times the operating frequency given by the equation:

$$f_{ns} = \frac{3.5(10^3)d}{D^2 N_a} \qquad 2.34$$

Where, f_{ns} is the natural frequency of the spring steel material, d is the diameter of the wire of the spring, D is the mean diameter of the spring coil.

2.15 The Compactor

The compactor or static weight is evaluated according to the model used by Ballaney (2001). In the limiting case, when the body or the mould, mixture and compactor is on the verge of sliding, the body is in equilibrium under the action of the following three forces,

(i) weight in the mould chamber, mg

(ii) applied force, F_c

(iii) reaction W_{nc} between the body and the Earth or concrete

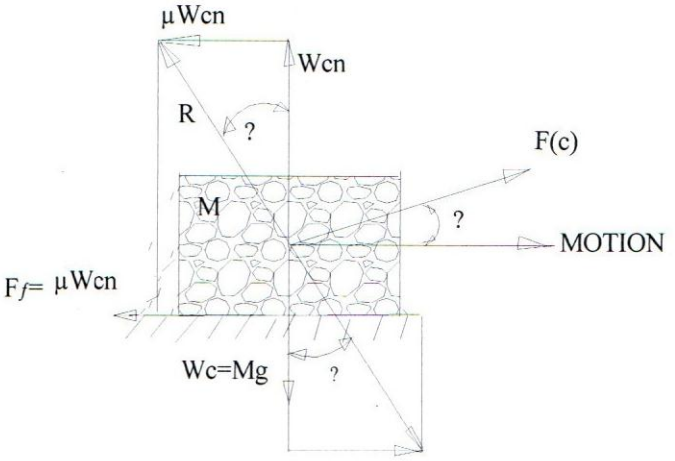


Figure 2.4 compactor weight force diagram

Where, ? = φ is the limiting angle of friction , m_c is the mass of mould chamber , W_{nc} is normal reaction of the weight in the mould chamber, F_f is force of friction in Newton.

The inclination of the resultant acting on the body is given by;

$$\tan\varphi = \frac{F_f}{W_{nc}} = \frac{\mu W_{nc}}{W_{nc}} = \mu = \text{constant} \qquad 2.35$$

If $\tan\varphi = \mu$ 2.36

then, the body and its contents was about to move over the surface irrespective of the magnitude of the force, F_c.

From fig. (2.4);

$$R = \sqrt{\{(\mu W_{nc})^2 + (W_{nc})^2\}} \quad 2.37$$

Where R is the resultant force between the frictional force μW_{nc} and the normal W_{nc}

The weight of the compacting unit or the resultant force: $W_c \geq R$

Where W_c total weight of the compactor.According to Ballaney, (1992), the minimum force that can be applied to pull the body is;

$F_c = mg \sin\varphi$ 2.38

2.16 The Mould Chamber

Bengston and Whitaker (1986) found out that the compaction ratio of soils in East Africa range between 1.33 and 1.65. A detailed study carried out by Jayasinghe and Kamaladasa (2006) on cement stabilized soil blocks produced by a manually operated machine gave a compaction ratio of 1.65. According to Webb (1988), the parameter to be considered in the design of the mould is whether the operation is constant volume or constant pressure. Rigassi (1985) specified a maximum dry mass of 7.434 Kg and a maximum of 8.177 Kg per freshly molded stabilized soil block ,while, Kerali (2001) recommended that the maximum mass of the stabilized soil block should not exceed 8.5Kg because of the challenge in laying and transportation.

2.17 Vibro Compaction Energy

According to Ballaney (1992), rotary energy for the rotor in Joules is given by the following equation:

$$E_{Rotor} = \frac{Iw^2}{2} \quad 2.39(a)$$

Where, $I = Me^2$ $2.39(b)$

M is the eccentric mass in Kg, e is eccentricity of the mass in meters.

Energy from power transmission, E_v in Kilowatt is given by the following expression used by Mahadevan and Balaveera (1992):

$$E_v = \left(0.61v^{-0.09} - \frac{26.68}{d_e} - 1.04 \times 10^{-4} \times v^2\right) \times 0.7355\, v \qquad 2.40(a)$$

Where the arc of contact for the belt is assumed to be 180^o, v is belt speed in m/s,

$d_e = d \times K_d$, equivalent pitch diameter, mm 2.40(b)

d is pitch diameter of the smaller pulley in mm, K_d is smaller diameter factor

Static weight compaction energy according to Montgomery (2002) is given by the following expression:

Energy, $E = mgh_i$ 2.41

Where m is mass of compactor and h_i was the height of free fall of the compactor, assumed to be the amplitude of vibration.

2.18 Stabilized-soil Block Test Specimens

Research done by Kerali (2001); Adam and Ajib (2001) justified the use of three soil block specimens from the same soil sample for compressive strength. The Kenyan Standard, (KS 02-1070:1993) however, recommends stabilized-soil block tests after twenty eight days curing as follows: five blocks for dry compressive strength, five blocks for wet compressive strength, three blocks for bulk density, and five blocks for water absorption test. For the purpose of this research, three soil blocks were used for each of the tests.

A Two-way analysis of variance technique is used when the data is classified on the basis of two factors (Kothari, 1990); (Moore and McCabe, 2003).The objective of analysis of variance is to determine which factor or factors are significant in achieving the desired results. For the purpose of this research the two factors to be investigated are the speed and the eccentric mass of the rotor. The mass or speed which was significant in compaction was determined from Fisher's least significant difference (LSD) model at 95% confidence level:

$$LSD = t_{\alpha/2}, d.f.e \sqrt{MSE\left(\frac{1}{n_i} + \frac{1}{n_j}\right)} \qquad 2.42$$

The anova table is set up as follows (Kothari, 1990);

Table 2.2 Analysis of Variance Table for Two-way Anova

Source of variation	Degrees of Freedom (d.f)	Sum of squares (SS)	Mean Square (MS)	F--ratio	F-critical (Table value)
Between Columns treatment	(c – 1)	$\sum \frac{(T_j)^2}{n_j} - \frac{(T)^2}{n}$	$\frac{\text{ss between columns}}{(c-r)}$	$\frac{\text{MS between columns}}{\text{MS residual}}$	
Between rows treatment	(r – 1)	$\sum \frac{(T_i)^2}{n_i} - \frac{(T)^2}{n}$	$\frac{\text{SS between rows}}{(r-1)}$	$\frac{\text{MS between rows}}{\text{MS residual}}$	
Residual or error	(c – 1) (r – 1)	Total SS – (SS between Columns + SS between Rows)	$\frac{\text{SS residual}}{(c-r)(r-1)}$		
Total	(c . r – 1)				

Where c is the number of columns, r is the number of rows; T is the total of the values of individual items in all the samples , $\frac{(T)^2}{n}$ is the correction factor, $\sum X_{ij}^2$

is the total of all squares of all item values, SS residual is total SS – (SS between column + SS between rows),

(c.r – 1) is degree of freedom for total variance, (c – 1) is degree of freedom between columns,

$(r - 1)$ is degree of freedom between rows, $(c - 1)(r - 1)$ is degree of freedom for residual variance, $ms = \frac{SS}{dfe}$ and n_i are the number of replications.

To compare the performance of the vibration static weight method of compaction with the laboratory test or proctor test on the same soil sample, a t-statistic is determined according to Kothari (1990), Moore and McCabe (2003):

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1 - 1)\sigma_{s_1}^2 + (n_2 - 1)\sigma_{s_2}^2}{n_1 + n_2 - 2}} \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \qquad 2.43$$

The t- Test statistic is applied where variance in the populations is not known but assumed to be equal. t-Test is used for difference in means, assuming population to be normal.

Where degrees of freedom, $d.f.e = n_1 + n_2 - 2$

CHAPTER THREE
MATERIALS AND METHODS

3.0 Introduction

This chapter describes the study area, materials and methods used to produce vibrations for compaction, the experimental procedure to select the optimum speed and the eccentric mass and the methods to determine the physical and mechanical properties of the produced stabilized-soil blocks.

3.1 Study Area

This research was on adaptation of a Vibro compaction technology and performance evaluation of stabilized-soil block. The determination of rotor parameters, compactor weight and selection of the springs, and Fabrication of the machine in addition to Stabilized-soil block tests have been carried out at the Eldoret Polytechnic Mechanical Engineering workshop and at Material testing laboratory, Ministry of Public Works, Eldoret, because of availability of equipments. The soil used in this research was collected from Eldoret Municipal council block 14/1465 and block 15/1819, in Wareng District, Rift valley Province, Kenya. The two sites were purposefully chosen because they were adjacent to Eldoret town and pron to slum settlement.

3.2 Materials and Equipments

The soil type from both sampled areas was Sandy-clay-loam and contained Gravel/sand 51.1% and Silt/clay 48.8% and was labeled sample "A"; The soil type from block 15/1819 was also Sandy-clay-loam (Gravel/sand 59.5%, Silt/clay 40.5%) and was labeled sample "B". The third soil sample "C" was modified by increasing the sand content, but was also found to be Sandy-clay-loam (Gravel/sand 53%, Silt/clay 46.6%). The following soil tests were carried out according to BS 1377:1975:

(i)The standard proctor test, 4.5Kg rammer method, was done on non-stabilized soil samples to establish the maximum dry density and the optimum moisture content, Appendix B (i).

(ii)Wet and dry sieve and Sedimentation tests were done to determine the particle size distribution in the respective soil sample, Appendix B (ii) - (iv) and B (v).

(iii)Linear shrinkage test was done to establish the suitability of the soils for making stabilized-soil blocks, Appendix B (vi)

The Materials and Equipment that were used to produce and assemble the Vibro compaction machine parts as indicated in the Drawings, Appendix G, can be found in Appendix F. The Equipment applied in testing the physical and mechanical properties of the produced soil blocks was described in each respective test and also included in Appendix F.

3.3 Sampling

Homogeneous sampling technique was applied in this study where all the soil blocks in a batch were assumed to exhibit similar characteristics and therefore enabled in-depth comparisons in dimensions, density, compressive strength and water absorption in order to gather information that aided in the determination of eccentric mass, the speed of the rotor, the compactor weight and the selection of the close coiled helical compression spring. The information obtained from each of the produced blocks was taken into account and determined the mechanical functioning of the assembled machine parts.

3.4 Experimental procedure

The adaptation of the Vibro compaction stabilized-soil block making machine required the determination and or selection and integration of the rotor shaft diameter, eccentric mass, drive and rotor speed, closed coil helical compression spring and the compactor or static-weight, figure 3.1. The Natural frequency of the rotor was determined taking into account the length of the rotor shaft, mass of the rotor shaft, static loading of eccentric mass on the rotor shaft, after which the speed of the driver was determined to avoid resonance. The centrifugal force of the rotor was determined for each variable speed and variable eccentric mass combinations. The eccentric mass was selected according to the arithmetic progression; $a_n = a_1 + (n-1)d$ (Brightstorm2, 1992), where a_1 was 3500gms, the inherent mass of the rotor shaft and d was 250gms, the common difference which was purposefully selected for faster convergence. The variable speed was determined from the different pulley size combinations according to the geo metric progression, Speed , $a_n = ar^{n-1}$, (Patrick, 2009), where a was the initial speed, and r was 1.1155, the common ratio. The centrifugal force was used to select the close coiled helical compression spring which was used to confine the vibrations to the mould and hence isolating it

from the machine structure. When the machine was assembled and connected to the drive, vibrations were produced and applied to the soil-water mixture in the mould, simultaneously with the compactor or static-weight. The different speed and eccentric mass combinations resulted in soil blocks of varying densities. The mean density was used to select the optimum speed and eccentric mass of the rotor. The optimum speed and eccentric mass selected were used to produce soil blocks mixed with cement of varying percentages, which were then subjected to physical and mechanical properties tests after curing for twenty eight days.

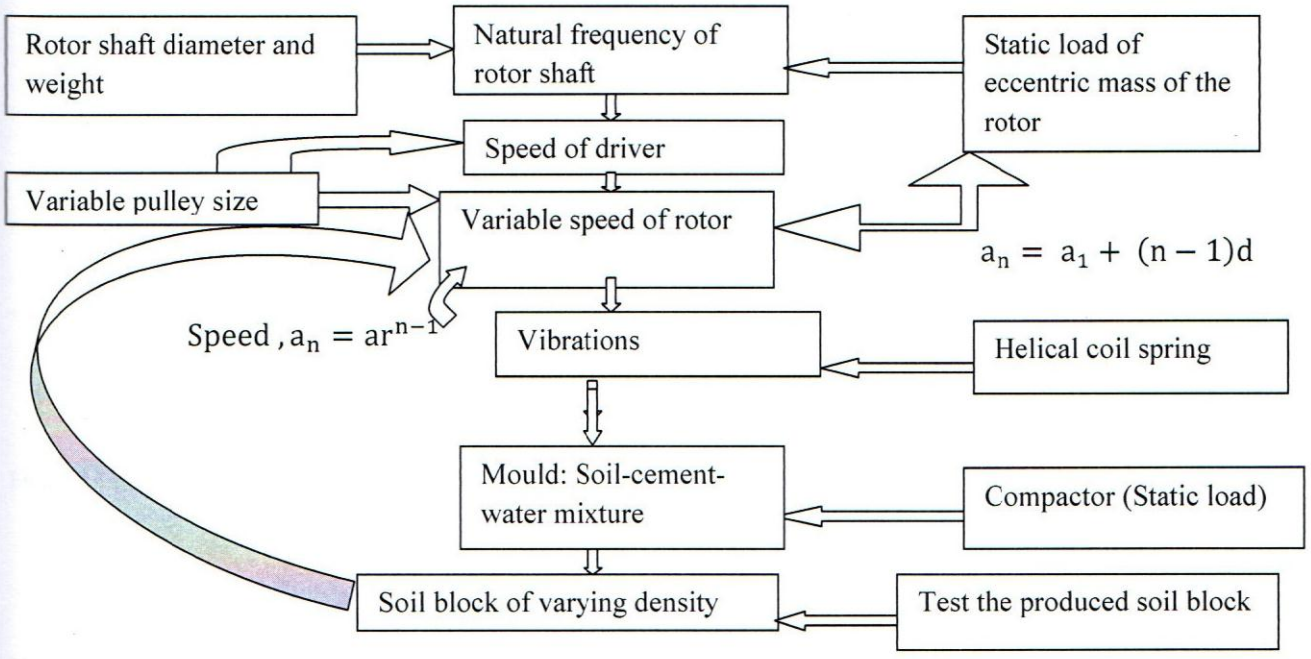


Figure 3.1 Flow diagram indicating the methodology applied in determination of rotor parameters, compactor weight and helical coil compression spring

3.4.1 Description of the Vibro Compaction Method

The six eccentric masses were made from the same material as the rotor shaft in order to maintain geometry and homogeneity of the material. These masses were clamped to the rotor shaft in turn during the experiment using a bolt. These masses were added to the inherent mass of the rotor shaft. There were four speeds used in the experiment and were obtained by using different pulley diameters.

Six different eccentric masses: 250gm, 500gm, 750gm, 1000gm, 1250gm and 1500gm together with the four different speeds: 1800 rpm, 1850 rpm, 1950 rpm and 2400 rpm, resulted in

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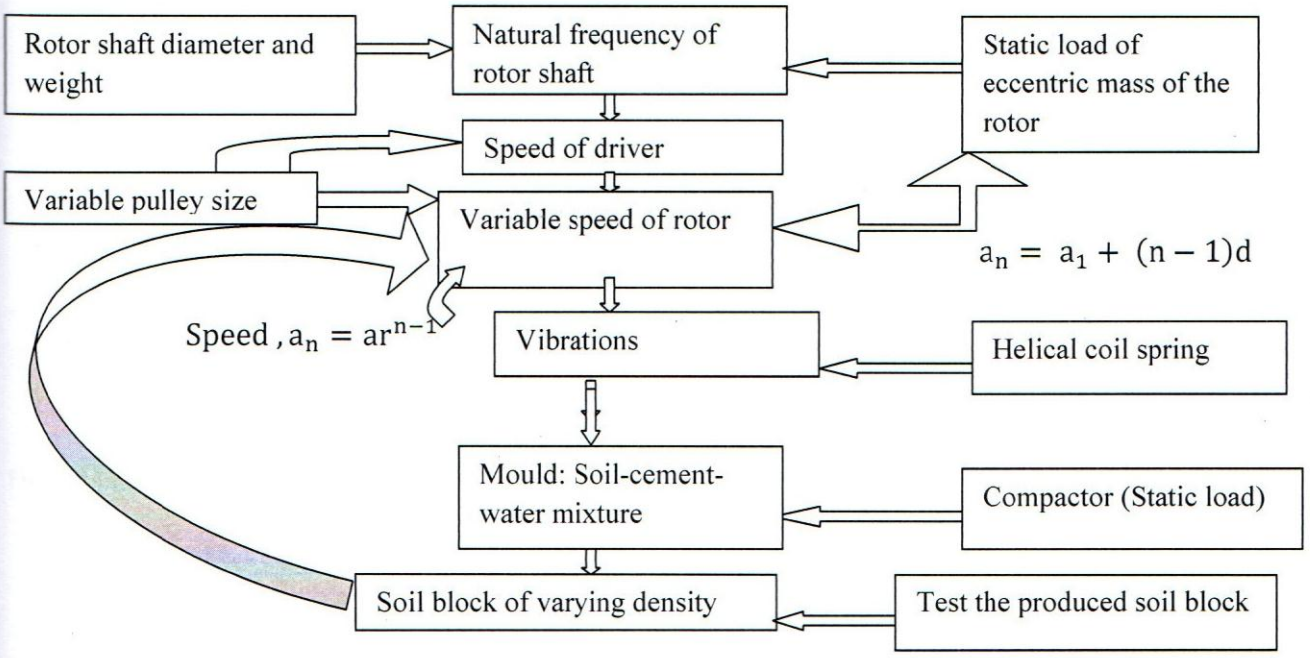


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Six different eccentric masses: 250gm, 500gm, 750gm, 1000gm, 1250gm and 1500gm together with the four different speeds: 1800 rpm, 1850 rpm, 1950 rpm and 2400 rpm, resulted in

varied compaction energy of the rotor which was applied to the soil mixture in the mould. A constant weight, compactor, on top of the mixture ensured vertical compaction through free fall of the compactor as the mould was vibrated.

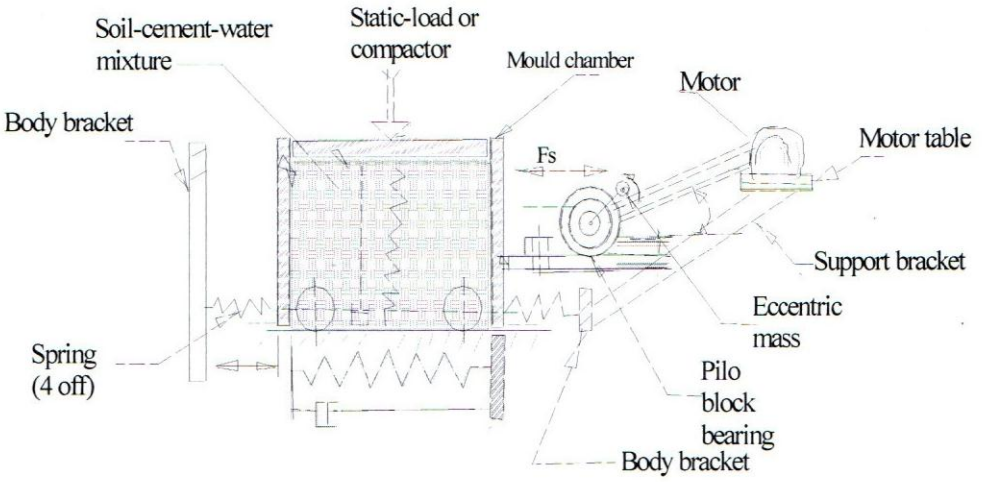


Figure 3.1 Rotor excitation model

In this Vibro compaction method, the mixture was loaded manually into the three mould chambers. The compactor unit was slid into the mould chamber and positioned onto the mixture. In operation the motor was switched on and through the pulley and the belt assembly rotated the rotor. The motor was switched off after 60 seconds (purposefully selected), after which the mould and the compactor were lifted off the formed blocks (a trial run for 90 seconds had been carried out but it was found out that the water meant for the mixture had been expelled by the compaction process. The whole machine was then moved forward, leaving the block behind on the ground, which served as a continuous pallet. The excitation model is a non-linear system due to the periodic loss of contact between the vibrating mould chamber and the soil-cement-water mixture, as the mould was vibrated to and fro. Vibrations were induced into the mould chamber, Figure3.1 to enhance slippage of soil particles and increased the density of the soil-cement-water mixture in the mould. Densification of the soil block was enhanced vertically by the compactor. The following assumptions were made in the rotor excitation model: vibration of the mould was

allowed in the horizontal direction, rotation was allowed for the rotor and motor shaft and the belt, all parts except the spring were rigid, and the steel wheels rolled without slipping.

Drawings of the Vibro compaction stabilized-soil block making machine assemblies, sub-assemblies and detail drawings in Appendix (G), have been done according to Jensen, (2002) and Autodesk Inventor Professional 2010 software. The fabrication and assembly of the machine parts, Plate 3.4, was done using the materials and equipment in appendix (F).

3.4.2 Determination of the Eccentric Mass and Speed of the Rotor

The rotor was composed of the shaft and the eccentric mass which had to be determined so that upon rotation, they produced a centrifugal force which induced vibrations in the mould when assembled together with the springs. The determination of the Rotor parameters started with the selection of Shaft diameter where the eccentric Mass would be clamped, followed by the determination of the eccentric Mass after which the deflection of the Rotor shaft was evaluated. The Rotor's Natural frequency was then determined and led to the selection of the drive Speed so as to avoid resonance.

(a) Shaft Diameter

The eccentric mass was attached to the rotor shaft by means of a bolt and a transverse hole therefore, was made at the side of the rotor shaft to clamp the eccentric mass. The diameter of the bolt to clamp the eccentric mass was determined from the Equations, 2.15 and 2.16:

$$d = \sqrt{\frac{\text{Factor of safety} \times 4 \times \text{centrifugal force}}{\text{working stress}}}$$

$$= \sqrt{\frac{2 \times 4 \times 2352.7}{55 \times 10^6 \times \pi}} = 0.1043 \text{ m}$$

The closest bolt diameter chosen since they are produced in series was Ø 12mm

(Mahadevan and Balaveera, 1992). Applying this diameter into Equations 2.17(a),

$$d_t = \frac{6}{0.5} = 12$$

. But in Equation 2.17 (b) , $d_t = d_o - 2r$. Therefore the rotor shaft diameter, $d_o = \emptyset 24$, where r was the radius of the bolt shaft.

From equations 2.16 (a) and 2.16(b), and using bending stress as 110 x 10^6 MN/m^2, shear stress as 55 x 10^6 MN/m^2, and diameter of the shaft as 24 mm, and using the maximum shear theory, the rotor shaft diameter d_o was determined . From equation 2.18 (a),

$$M_m = \frac{\sigma I}{y} = \frac{110 \times 10^6 \times \pi \times 0.024^4 \times 2}{64 \times 0.024} = 149.28$$

and equation 2.18 (b),

$$T_m = \frac{\tau J}{r} = \frac{55 \times 10^6 \times \pi \times 0.024^4 \times 2}{32 \times 0.024} = 149.28$$

Substituting these values into equation 2.16(a),

$$d_o = \left[\frac{16}{\pi \times 55 \times 10^6}\left\{\left(149.28 + \frac{1.9 \times 196 \times 10^5}{241 \times 10^6} \times 149.28\right)^2 + \left(149.28 + \frac{1.9 \times 196 \times 10^6}{241 \times 10^6}\right)^2\right\}^{1/2}\right]^{1/3}$$

$= 0.03677\text{m}$

However, the shafts are supplied in series, and the selection depended also on the size of bearing and its availability (Mahadevan and Balaveera, 1992). The selected shaft size to fit a self aligning Pillo block bearing was $\emptyset$ 38mm.The shaft diameter satisfied equation 2.17: $\frac{r}{d_t} = 0.23 \ll 0.5$

(b)Eccentric Mass of the Rotor

The eccentric mass in equation 2.11, $F_c = Mew^2 \sin(wt)$, was obtained from the following arithmetic sequence: $a_n = a_1 + (n-1)d$, (Brightstorm2, 2010) ,where a_1 was the first term, or the rotor shaft mass of 3500gms, d the common difference chosen purposely to be 250gms. The eccentricity was calculated from the equation 2.11.

(c)Deflection of the Rotor Shaft

The total deflection of the rotor shaft was the sum of the deflections caused by the concentrated load and the uniform load of the shaft: The deflection of the point load in millimeters per meter length of rotor shaft was $6.8922 \times 10^{-4}/0.388 = 1.7763 \times 10^{-3}$ mm/ m

and the deflection due to uniformly distributed load in millimeter per meter length of rotor shaft was $4.8748 \times 10^{-4}/0.388 = 1.2563 \times 10^{-3}$ mmm. The total deflection, 3.0326×10^{-3}mm/m of the rotor shaft was 273 times the limit of 0.83mm/m length of shaft.

(d)Determination of Rotor Speed

According to equations 2.21(a) and 2.21(b), static deflection at each load point were determined as: δ_2 was 6.8922×10^{-07}m and δ_1 was 4.8748×10^{-07}m, where the distance between supports or bearings was taken to be 388mm. Therefore, from equation 2.21 (b) and 2.2 1 (c), f_{n_2} and f_{n_1} were evaluated as 600 Hz and 804.2 Hz respectively.

According to Dunkerley's empirical formula, the natural frequency of transverse vibration, f_n for the rotor system was18.54 cycles/sec and the Speed in revolutions per minute was therefore 18.54 x 60 =1112.6 rpm. According to lee, et al., (2004), the natural frequency of transverse vibration of the rotor system is below or above the drive speed by 25% to 30% in order to avoid resonance. The minimum speed required for a minimum separation of 25% was $1112.6\text{rpm} \times 125/100 = 1390.75$ rpm. The speed of the selected drive motor was

therefore 1420 rpm. A higher speed at the rotor was required and if the critical speed was taken as 1420 rpm then the minimum speed required at the rotor was $1420 \text{ rpm} \times 1.25 = 1775$ rpm. The pulley combination gave the closest speed of 1731rpm, which was selected as the minimum rotor speed. Subsequent speeds were obtained according to Geometric sequence: $a_n = ar^{n-1}$, (Patrick ,2009) .Where, a was the initial calculated speed of 1731rpm and r was 1.1155, the common ratio.

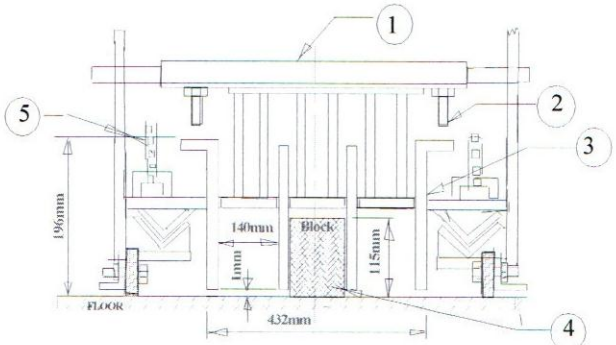
(e) Pulley Selection

After determining the speed of the driver and the initial speed of the rotor and from Equation 2.25, the speeds of drive pulley and rotor pulley were determined from the following expression:

$$\frac{\text{Rotor speed}}{\text{Drive speed}} = \frac{\text{Pitch diameter of drive pulley}}{\text{Pitch diameter of rotor pulley}}$$

The belt cross-section selected from a design horse power of 7.43 hp and a speed of 1850rpm was type 'A'. From Equation 2.26 and 2.27, and with the v-belt arc of contact assumed to be 180^0 at the smaller driven pulley, a nominal inside length of 1115 mm, the arc of contact and length factors were equal to 1 and 0.91 respectively, yielding to application of one belt in this research. However, the belts come in series and a belt of length 1120 mm was selected.

3.5 Determination of Compactor Static-weight



1.Compactor Assembly 2.Height gauge 3.Mould chamber

4.Formed block 5.Chain

Figure 3.3 Compactor and Mould assembly

From equation 2.35, $R = \sqrt{\{(\mu W_{nc})^2 + (W_{nc})^2\}}$, Where, R was the resultant force between the frictional force μW_{nc} and the normal, W_{nc}, $\mu = 0.4$, $W_{nc} = 75N$. The weight of the compacting unit, $W_C = R$ was determined to be 81N. For three soil blocks the total weight was $81N \times 3 = 243N$, where the total weight of the compactor was determined to be 260 N for a soil block of average mass of 8 Kg.From equation 2.36; $\tan\varphi = 0.4$, where $\varphi = 21.8^o$ and therefore, the least force to move the compactor, the mould chamber and the soil mixture, from equation 2.38 was:

$F_c = 60\ Kg \times 9.81 \times \sin 21.8^0 = 218.6N$, where 60 Kg was the mass of the compactor, the mould chamber and the soil mixture.

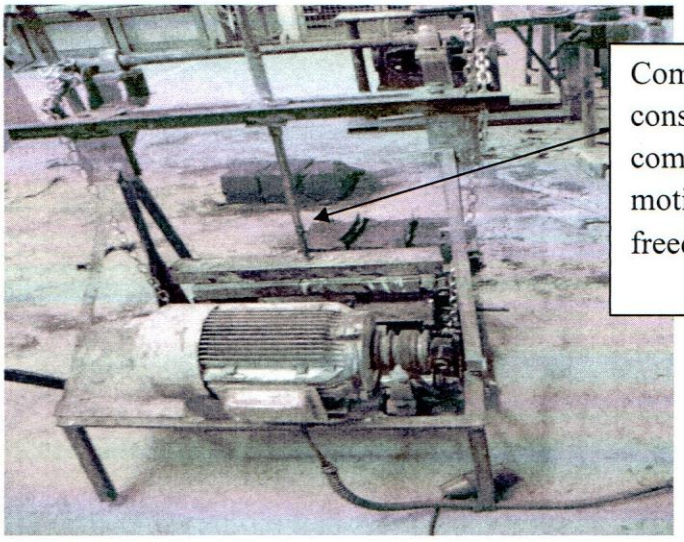


Plate 3.1 Compactor constrained to move in a vertical direction only

To investigate the optimum orientation of the compactor or static weight of 260N, it was constrained in the vertical direction so that the compaction would occur through free fall of the static weight or through one degree of freedom in one instance and also allowed to compact in the six degrees of freedom by removing the constraint.

3.6 Selection of Close Coiled Helical Compression Spring

The close coiled helical compression spring was used to transmit vibrations to the mould and also to isolate vibrations from the whole machine. According to Mahadevan (1992), the spring design stress for a wire of diameter 4 mm for severe service was determined as $380\ MN/m^2$. The selected spring had a free length of 60mm, outside diameter of 34mm and made of a wire of diameter 4 mother solid length of the spring was 33 mm and the maximum operational force was 5.7KN at the solid length. From equation 2.29, the clash allowance was equal to 0.1 x (60-33) and was less than (0.1 x 33) mm. The slenderness ratio of the spring from equation 2.30 was less than four. The fatigue factor was 1.06 while the spring index from equation 2.30 was 7.5. The spring was mounted on a cylinder whose outside diameter was 0.96 x internal diameter of the spring. From equation 2.33, the shear stress in service when the centrifugal force was 1101N,

and using two springs on either side of the mould was determined to be 387.8 MN/m^2. To avoid resonance the natural frequency of the selected close coiled helical compression spring was determined to be 7692 Hz which was 240 times the natural frequency of the rotor, 32 Hz, which was assumed to be the operating frequency.

3.7 Compaction Energy

For one stabilized-soil block weighing 7.5 Kg the total energy that would be required in Impact compaction method would be 204J/Kg x 7.5Kg =1530J. This energy was attributed to high friction forces between the soil mixture particles. Assuming an energy supply per second for a Vibro compaction method, the required energy for the block would be 1530/60 or 25.5J/s per 7.5Kg block. For production of three soil blocks the total energy requirement would be 4590J. A drive rated at 5.5 Kw and 1420 rpm produced 5500/1.6 or 3437.5J at the rotor. However, for higher water content than the optimum values, lesser energy would presumably be required because of the low friction values. The total compaction energy, according to Equations 2.39, 2.40 and 2.41, for this compaction method was generated by the rotor, V-belt transmission system combined with vertical compaction respectively.

3.8 Mould Chamber

The determination of the mould size took into account the minimum block parameters which included the minimum block density of 1600 Kg/m^3, block dimensions of 290 × 140 115 mm and the mass of the soil block as 7.5 Kg. For the block height of 115mm, the maximum height of the mould was determined to be 190 mm when a maximum compaction ratio of 1:1.65 was applied ,while the nominal length and width of the mould were determined to be 290 mm and 140 mm respectively. The mould height was increased to 196 mm by adding 6 mm, to permit the compactor to rest onto the mixture and inside the mould. The mould was made of mild steel plate, 4 mm thick and was stiffened by the V-guide ways welded to the mould sides, Fig.3.2 .The mould chamber slide on v-guide ways as it was vibrated. The vibrations had to be effected and isolated from the body of the machine by use of close coiled helical compression springs.

3.8.1 Rotor-Compactor-Helical Spring assembly

The Rotor-compactor-helical spring assembly, Plate 3.1, was used in the experiment to determine the optimum rotor speed, eccentric mass, the orientation of compactor and to select the

helical compression spring by confining the vibrations to the mould chamber for the production of soil blocks. The eccentric mass was aligned in the lateral direction in order to increase the eccentricity since compaction of stabilized-soil coiled block relied on the vibrations generated by the centrifugal force, which was confined to the mould chamber by the close coiled helical compression springs.

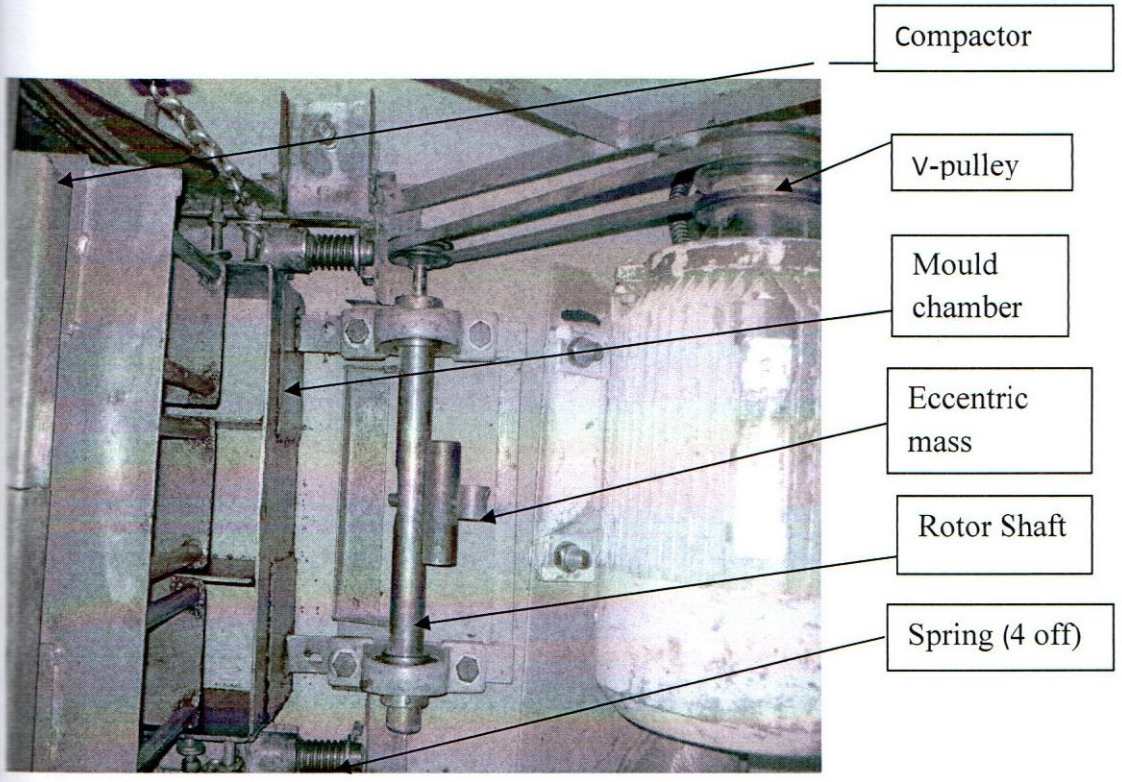


Plate 3.2 Rotor-compactor-helical spring assembly

The vibrations induced in the mould chamber were due to the centrifugal force induced by rotation of the eccentric mass clamped on the rotor shaft. These vibrations made the soil-water mixture to densify as a result of the particles moving closer together when air was expelled reducing the void ratio. A constant weight, compactor, on top of the mixture ensured vertical compaction through free fall. Different eccentric masses when combined together with different speeds resulted in varied compaction energy on the mixture. Hence there was need to investigate the optimum speed and eccentric mass combination that gave the highest soil block density. Three blocks were produced in each batch for each eccentric mass and speed combination and

the dimensions of each of the blocks were taken and average dimensions reported. The green density of each of the block was calculated and the average density for the batch of three blocks was determined.



Plate 3.3 Rotor speed measurement using an Electronic Tachometer

The drive and rotor speeds were ascertained using a feedback electronic tachometer: 0.2 mA/1000rpm: England. The experimental set up led to an 6 × 4 analysis of variance.

3.9 Procedure of Making a Stabilized-soil Block

For each of the six eccentric masses, four different speeds were applied by selecting different pulley size combinations. The soil and cement ratios for a standard block measuring

290 × 140 115 mm with a bulk density of 1600 Kg/m^3 were determined from the Equation 2.10, applied by Waswa, (1992) , after ascertaining the amount of water to apply through a trial method.

$$\text{Soil (Kg)} = \frac{\text{m}}{(1 + \text{x}\,\%) + \text{y}\,\%(1 + \text{x}\,\%)}$$

where x was the percentage of cement, y was the percentage of water, m was mass of a standard block measuring 290 × 140 115 mm with a bulk density of 1600 Kg/m^3. For the purpose of this experiment, the procedure for making the ssb, where x cement was not applied was as follows; Clean used oil was applied on the inside of the mould and in addition oiled damp

proof material was also applied on the inside surface of each of the moulds ensuring that they adhered to the surface. The oil was to minimize friction and adhesion between the soil-water mixture and the mould wall surface, (Agib and Adam, 2000). In addition, grease was applied between the upper and lower guide rails to reduce friction between the two surfaces. 6350gms of sampled soil was weighed and poured in a mixing container. 1150 ml of clean water was added to the soil by sprinkling and mixed well by rotating the mixing container as mixing got on by using a trowel until the same colour was attained. The soil-water mixture was poured into one of the three moulds. This preparation was repeated until all the three moulds were filled by equal amounts of this mixture. This was one batch of three blocks. The compactor was placed onto the soil-water mixture in the mould, ensuring it was well aligned vertically. The drive was switched on for duration of 60 seconds. The blocks were ejected by lifting the mould and compactor off the blocks simultaneously; the whole machine was pushed forward leaving the blocks on the ground to cure. The green density was determined by taking the dimensions of each of the blocks and the average density for the batch reported. Another combination of speed and eccentric mass was selected and the procedure repeated for a total of 24 trials.

The performance of the assembled Vibro compaction machine, Plate 3.4, was evaluated through the Physical and mechanical properties of the produced cement stabilized-soil blocks.

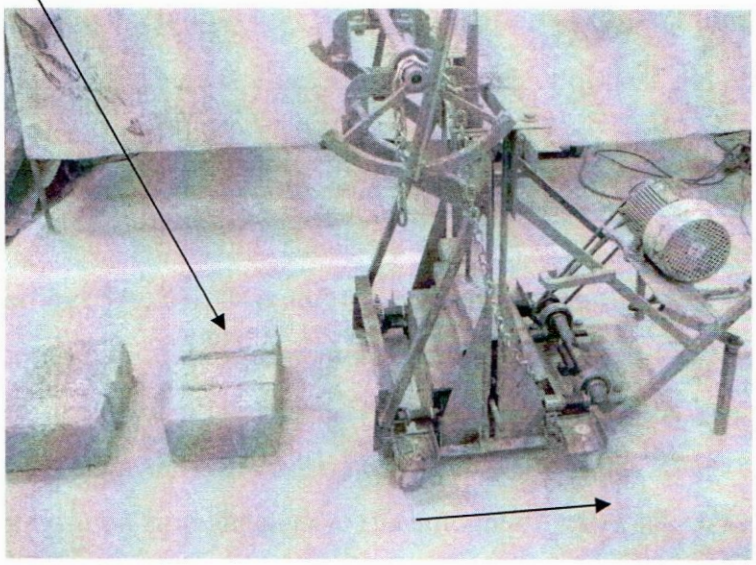


Plate 3.4 Rotor- compactor-spring assembly for making soil blocks

Size of the machine: 1542 x 880 x 1735 mm (l x w x h); Weight of machine: Approx. 120 kg

Size of block: 290 x 140 x 115 mm ; No. of blocks per production: 3 Nos.

Type: Portable; Manpower required: 5-8

Motor: 5.5 Kw: 1420 rpm; Rotor: Eccentric mass: 4750gms; Speed: 1850 rpm

Compactor: 260 Kg; Compaction method: vibration static-weight

Stabilization: Mechanical, chemical

A 6 x 4 analysis of variance was done at 95% confidence level to investigate whether the speed, eccentric mass or both were significant on compaction of the stabilized-soil block. The mass or speed which was significant in compaction was determined from Fisher's least significant difference (LSD) model at 95% confidence level , expression in Equation 2.42.

A t-Test on the sample soil 'A' was done to compare the performance of compaction by the Vibro compaction method and the laboratory compaction or the proctor test. According to Kothari, (1990), Moore and McCabe (2003), the t-Test statistic was given by the expression used in Equation 2.43.

3.10 Density, compressive strength and water absorption of the soil blocks

The performance of the machine was assessed through the Physical and mechanical properties of the produced stabilized-soil blocks. After determining the eccentric mass, speed, compactor and selecting the close coiled helical compression spring through experiment, further trial of the machine was carried out by producing stabilized-soil blocks from the mixture of different soil structures with water and 5%, 6%,8% and 10% cement content by weight. Two distinct stages were involved in the mixing of soil, cement and water and included dry and wet mixing. The mixing were done manually in a container. Dry mixing was stopped after a uniform grayish colour was attained between the soil and cement. For wet mixing, clean water was added by sprinkling as mixing went on simultaneously. The amount of water added which was beyond the optimum moisture content was obtained by trial and error after obtaining the optimum moisture content determined by the Proctor test on the same soil sample. The drop test was applied to a moist mixture shaped into a ball in the hand. The ball was dropped from a height of 1meter onto a hard surface. For the correct moisture content, the ball broke into two pieces with a tendency to flatten. Having established the required percentage of water, the amount of soil and cement content were then determined from equation 2.10.

The objective of determining the physical and mechanical properties of the soil blocks was to investigate whether the produced stabilized-soil blocks met the minimum soil block standards (Pre-cast masonry technical committee, 1993), and hence validating the machine. In this research, stabilized-soil blocks tests that were carried out included; dry and wet compressive strength, water absorption, bulk and green density.

(i) Green Density

Dimensional measurements were carried out for three stabilized-soil blocks noting the average length, width, and height of each block. The screw Vernier height gauge was used to measure the height and the tape measure to measure the length and the width of the block. The

volume was calculated and the density determined, where the mass in Kilograme was that of material including water in the block.

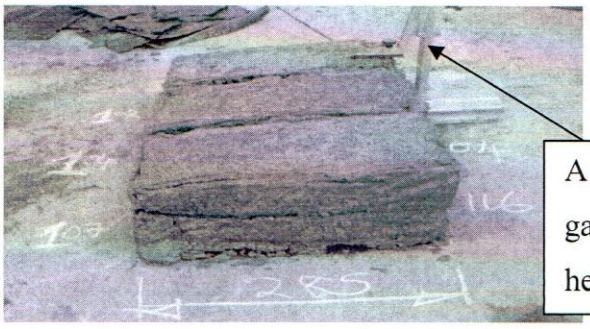


Plate 3.5, a batch of three stabilized-soil blocks

Green density,

$$\rho_g = \frac{m_g}{V_g} \qquad 3.1$$

Where, ρ_g was the green density; m_g was the mass of the mould content, including water; V_g was the volume of the stabilized-soil block after ejection. The green density was calculated immediately after ejection prior to any curing, drying or soaking.

(ii) Bulk Density

Dimensional measurements were taken for three stabilized-soil blocks noting the average length, width and height. A Vernier height gauge was used to measure the height, a tape measure was used to measure the length and the width of the three blocks. The bulk density was determined after 28 days curing by heating the blocks in a ventilated oven at 105 $\pm$ 5 ^{o}C for 24 h, after which the block is cooled to ambient temperature and weighed. The procedure is repeated until the mass lost does not exceed 0.05 Kg in one cycle. The bulk density is determined;

Bulk density,

$$\rho_b = \frac{m_b}{V_b} \qquad 3.2$$

Where ρ_b was the bulk density, m_b was the oven dry mass, V_b was the volume of the block after 28 days curing.

(iii) Determination of Compressive Strength

(a) Dry Compressive Strength

Three cured stabilized-soil blocks were picked from each batch of 5%, 6%, 8%, and 10% cement content and dimensional measurements taken noting the average length and width. A WP 310 Hydraulic universal material tester, 50 KN machine was used, Plate 3.2. In operation, the WP 310 Hydraulic universal material tester recorded all the data of force versus change in dimension of the specimen, and the values were read on the monitor. The PC- aided data-recording system enabled data recording and evaluation on the Scathe amplifier has a display unit of test force and elongation.

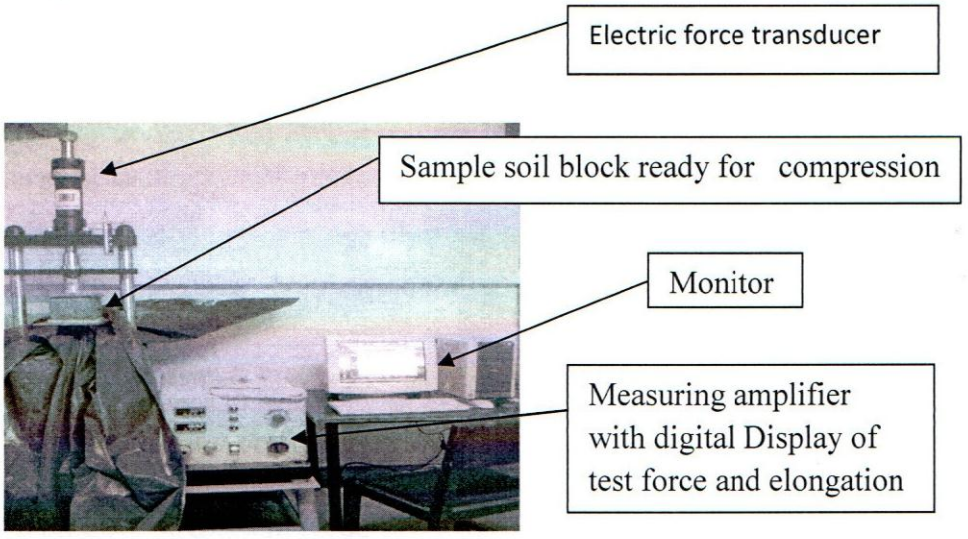


Plate 3.6 Compressive strength test set up: WP 310 Universal Material Tester 50 KN

The surface of each of the stabilized-soil block was wiped to remove all loose debris. In addition, the bearing surfaces of the 3 mm thin plywood platens to be placed between the specimen and steel plates were also cleaned. The stabilized-soil block was placed between two pieces of 3 mm thin plywood, the length and width of which exceeded the corresponding dimensions of the specimen but not less than 25mm. The specimen was placed in the testing machine such that the centre of the bed face coincided with the loading axis of the machine. The load was applied without shock and increased continuously at a uniform rate until failure

occurred. The compressive load was recorded by the integrated computer, up to the maximum load, W_D at failure. The values were saved and used to compute the compressive strength of the soil block.

Dry compressive strength for the soil sample was determined as follows:

$$\text{Dry compressive strength, } C_D = \frac{W_D}{A} \qquad 3.3$$

Where C_D was dry compressive strength in Newton per square millimeters; W_D was the load at which the dry specimen failed in Newton; A as the smaller bed face area in square millimeter.

(b) Wet Compressive Strength

Three cured stabilized-soil blocks were picked from each batch of 6%, 8%, and 10% cement content and dimensional measurements taken noting the average length and width. The specimens were then immersed in water bath at a temperature of between 15^0C to 30^0C for 24 h. They were then removed from the water bath and then wiped clean with a cloth. A WP 310 Hydraulic universal material tester, 50 KN machine Plate 3.2, was used for the wet compressive strength. Each specimen was placed between two plywood platens supported by steel plates and the test performed as in 3.3.10.2 (i). Wet compressive strength for the soil sample was determined as follows:

$$C_W = \frac{W_W}{A} \qquad 3.4$$

Where C_W was wet compressive strength in N/mm, W_W was load at which the wet specimen failed in Newton's, A the smaller bed face area in square millimeter, b x l taken for whichever of the two bed faces produces the smaller area. The average compressive strength was then reported.

(iv) Determination of Water Absorption

Three cured stabilized-soil blocks were picked from each batch of 6%, 8%, and 10% cement content after curing for 28 days. Each block was then weighed to the nearest gramme and the mass recorded as M_S the blocks were immersed in a water bath at 15^0C to 30^0C for not less than 24h after which they were removed from water and wiped with a cloth. Within 3 min. after

removing from water, the blocks were weighed to the nearest gramme and the mass recorded as M_2.

The blocks were then heated in a ventilated oven at 105 ± 5 °C for not less than 24H and until two consecutive weighing, at intervals of 2H showed an increment of loss not greater than 0.2 percent of the last previously determined weight of the block. The oven dried mass of each block was recorded as M_1.The water absorption for each block was determined and also reported as average for the batch.

$$w_A = \frac{M_2 - M_1}{M_1} \times 100$$

Where, w_A was percentage water absorption, M_1 was mass of oven dry block in grammes, M_2 was mass of saturated block after immersion in water in grammes.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.0 Introduction

This chapter reports on the effect of determined and or selected rotor parameters, the compactor, the Helical close coiled compression spring, proctor and assembled machine compaction test results for the non-stabilized-soil and the cement stabilized-soil Vibro-static load compaction test results.

4.1 Soil Types

Sieve wet/dry and sedimentation tests would not isolate fines of silt and clay and they were therefore reported together as a percentage of all the particles in the sample, Table 4.1 and Appendix B (ii) to (iv).

Table 4.1: Particle size distribution of soil types

Soil type	Fine gravel %	Sand content%	Clay & Silt% (wet sieve)	Clay & Silt% (Sedimentation)
Sandy clay loam (A)	6.3	44.8	48.8	47.4
Sandy clay loam (B)	20.7	44.1	33.4	32.6
Sandy clay loam (C)	4.5	48.5	46.6	45.8

The Linear shrinkage test for the respective Samples A, B and C were 11%, 12.1% and 12% respectively, which indicated that the soil was suitable for production of stabilized-soil blocks.

4.2 The Rotor-Compactor-Helical Compression Spring assembly

Different pulley sizes were combined to produce different speeds as indicated in Table 4.2, that were applied in the experiment to determine the optimum speed and eccentric mass for production of the soil blocks.

Table 4.2: Pulley size and speeds

	Pulley size			
	89/73	102/75	102/73	127/75
Calculated speed (rpm)	1731	1931	1984	2404
Measured speed (rpm)	1800	1850	1950	2400

The measured speeds used in determining the rotor speed were ascertained using a feedback electronic tachometer: 0.2mA/1000rpm: England.

Three stabilized-soil blocks were produced in each batch and measurements of length, width and height taken immediately and green density determined. The soil block was inspected and information gained was used to adjust other parameters such as orientation of the compactor. It was observed that wrong orientation of the compactor resulted in the soil block having a lesser height at the front face and back and also lengthwise, Plate 4.1.

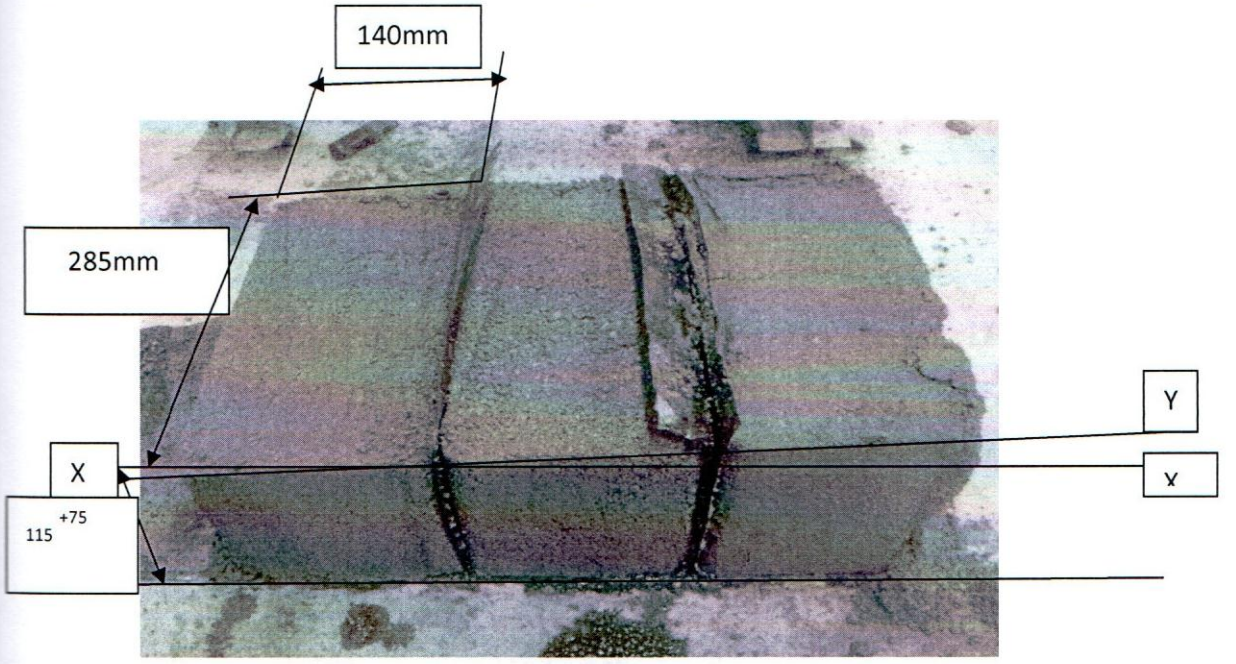


Plate 4.1: A batch of three non-stabilized-soil blocks

The nominal size of the non-stabilized-soil block was supposed to measure 290 x140 x 115 mm. However it was observed that the average length of the block reduced by about 5mm less and the range of the height by as much as 75 mm for the highest compaction. The width remained constant at 140mm, taking the width of the mould. The change in length was as a result of the vibrations being confined in the horizontal direction which resulted in compaction at the ends of the soil blocks because of loss of contact between the block and the ends of the mould. The height of the block depended solely on the interaction between the eccentric mass, the rotor speed and the compactor weight. Hence, the lesser the height the higher the density of the soil block. The density of the stabilized-soil block increased with increase of eccentric mass and speed, Table 4.3.

Table 4.3: Mean green density of Non-stabilized-soil blocks for twenty four batches

	Speed rpm				
Eccentric mass (Gms)	**1800**	**1850**	**1950**	**2400**	**Average row means**
3750	1090	1133	1066	1045	**1084**
4000	1185	1178	1136	1111	**1153**
4250	1111	1161	1131	1238	**1160**
4500	1211	1322	1193	1278	**1251**
4750	1321	1407	1266	1437	**1356**
5000	1413	1411	1343	1479	**1412**
Average column means	**1222**	**1269**	**1189**	**1265**	

As the speed was held constant and the mass increased in all the columns, Table 4.3, the mean green density increased and was highest with the highest mass in each of the column. This could be explained by the fact that eccentricity increased with the increase of the mass, Table 4.4. When the eccentric mass was held constant and the speed varied in the rows, the change in mean green density was not as significant across the rows. Hence, the need to determine whether mass or speed or both were significant in achievement of the mean green densities and hence compaction.

Table 4.4 : Eccentricity of mass

Mass, Kg	3.75	4.00	4.25	4.50	4.75	5.00
Eccentricity, e m	0.0148	0.016	0.020	0.018	0.0215	0.0247

4.3 Analysis of Variance

From the results of compaction in Table 4.3 a 6 x 4 analysis of variance was done, at 95% confidence level to investigate the significance of speed and the eccentric mass on compaction of the stabilized-soil block.

Table 4.5: The analysis of variance

Source of variance	d.f.	SS	MS	F-ratio	F-critical
Between columns (variable speeds)	3	25700	8566.6	4.27	3.29
Between rows(variable eccentric mass)	5	327300	65460	32.65	2.9
Error	15	2004.6			
Totals	23	383070			

From Table 4.5, the variable speed was significant in compaction of soil block at 95% confidence level as the calculated F-ratio of 4.27 was greater than F-critical value of 3.29 and also, the variable eccentric mass was significant as the calculated F-ratio of 32.65 was more than its table value of 2.9. Since the F-ratio > F-critical for both speed and eccentric mass, this meant

that both speed and eccentric mass were significant in compaction of soil block. The mass or speed which was significant in compaction was determined from Fisher's least significant difference (LSD) model at 95% confidence level from Equation 3.4.

Where, LSD was least significant difference; $t_{\alpha/2}$ was the t-Test one tailed test statistics', d. f. e was the degree of freedom error,MSE was the mean square error; n^{ith} was the number of replications in each treatment.

(i) Speed

Speed or column means, $LSD = t_{0.025,15}\sqrt{2004\left(\frac{1}{4}+\frac{1}{4}\right)}$

$= 67.45$

Pair wise comparison of the column means or speed:

Hypothesis: $H_o: \mu_A = \mu_B = \mu_C = \mu_D$ at 0.05 level of significance. From the pair wise means, Appendix H (i), there was no significant difference between the rotor speeds of 1850rpm and 2400 rpm. They were however superior to the other speeds of 1800rpm and 1950rpm

(ii) Mass

Eccentric mass or row means, $LSD = t_{0.025,15}\sqrt{2004\left(\frac{1}{6}+\frac{1}{6}\right)}$

$= 55$

Pair wise comparison of the row means or eccentric mass:

Hypothesis:$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$

From Appendix H (ii), Pair wise comparison of the row means or eccentric mass, at 95% confidence level showed that there was no significant difference between the eccentric mass 4750 gms, 5000 gms and 4000 gms, 4250gms but 4750gms and 5000 gms were superior to the other eccentric masses in terms of compaction.

4.3.1 Estimated Marginal Means of Density

An observation from figure 4.1,the marginal means of green density, indicated that the speeds from column one , Sc1 and Sc2 two had a better performance than other speeds in terms of density.

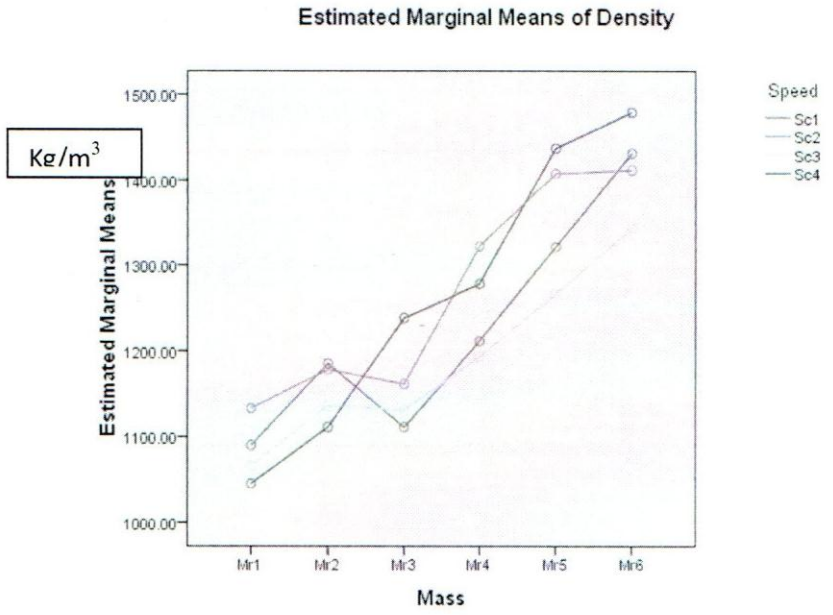


Figure 4.1 Estimated marginal means of density

The soil blocks produced from superior speed and mass were further subjected to physical inspection and the information gained was used to select the rotor parameters.

The soil blocks produced from the speed of 2400rpm and a mass of 5000gms had the highest green density of 1479 Kg/m^3, Table 4.6. However, water used for the mixture had been compacted out of the soil mixture which was viewed as over compaction. The blocks having the densities of 1411Kg/m^3 and 1437Kg/m^3 had the water used for mixing being compacted out also, which had the implication of carrying with it the cement used for chemical stabilization. The physical inspection of the block with a density of 1407Kg/m^3, produced from the speed of 1850rpm and eccentric mass of 4750Kg/m^3 had a smooth top surface and no water nor soil mixture was lost during compaction. A speed of 1850rpm, combined with eccentric mass of 4750gms was therefore selected for further production of stabilized-soil blocks.

4.4 Effect of Moisture content on Density for Nonstabilized-soil

Investigations were conducted to compare performance of two compaction methods: Proctor and Vibro compaction methods from the same soil sample with present moisture content of 19.9%. From Table 4.7, the maximum dry density, 1536 kg/m^3, obtained from the proctor method was lower than the minimum standard value of 1600kg/m^3.

Table 4.6: Mean green density for non-stabilized-soil for selected speed and eccentric mass

	Speed rpm	
	1850	2400
Mass (Gms)		
4750	1407	1437
5000	1411	1479

Table 4.7: Effect of Water content on Density for nonstabilized-soil for Proctor Method

	Water Content %			
	24.1	26.2	28.7	30.2
Dry density kg/m^3	1491	1536	1527	1475

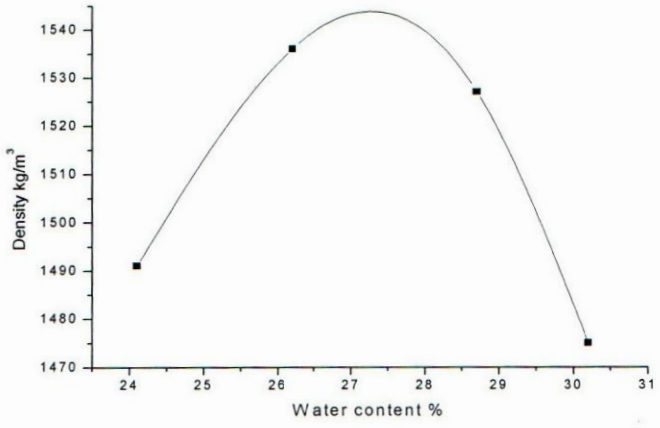


Figure 4.2: Effect of water content on density for non-stabilized Sandy clay loam soil (Fine/grave6.3%, Sand 44.8%, Silt/clay 48.8%)

The green density achieved by the Vibro compaction method, Table 4.8, was 1505Kg/m^3 compared to the density of 1536 Kg/m^3 from the proctor method for the soil sample 'A', which was still lower than the value from the standard, 1600Kg/m^3. It was observed that the amount of water added in Vibro-compaction to achieve the highest density of 1505Kg/m^3 was twice the amount used in the Proctor test to achieve a density of 1536 Kg/m^3 , for the same soil sample.

Table 4.8 :Effect of Water content on Density for Non-stabilized-soil for Vibro Compaction Method

	Water content %				
	9.3	10.5	11.6	13.4	13.9
Density kg/m^3	1273	1314	1385	1505	1478

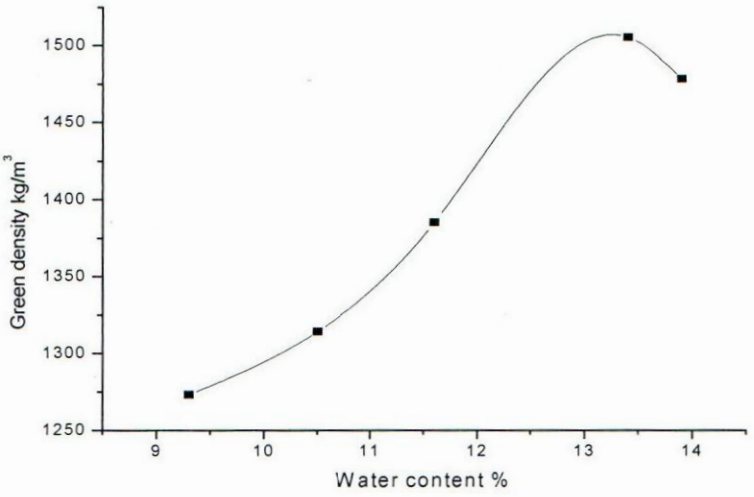


Figure 4.3. Effect of water content on density for non-stabilized Sandy-clay-loam soil (Fine gravel 6.3%, sand 44.8%, silt/clay 48.8%)

It was observed that the amount of water added in Vibro-compaction to achieve the highest density of 1505Kg/m^3 was twice the amount used in the Proctor test to achieve a density of 1536 Kg/m^3, for the same soil sample. A t-Test was done on the results of the two methods applied to the same soil sample 'A', and it was observed that the t-statistic, $|t| < 1.895$ (is less than the table value). It was concluded that there was no significant difference between the two compaction methods.

4.5 The Rotor

From Table 4.9, the eccentricity of the mass increased with the increase of eccentric mass, as the Natural frequency increased. It was observed that the higher the eccentric mass, the lower the natural frequency of the rotor and the higher the amplitude of vibration.

Table 4.9: Rotor Parameters at various Eccentric Masses

Effective eccentric mass (gms)	Weight (N)	Eccentricity(e) m	Natural Frequency of rotor system, f_n (Hz)	Rotor Speed (rpm)	Radian/Sec (ω/s)	Amplitude of Vibration (mm)
3750	37.5	0.01480	22.34	1340	140.36	0.98
4000	40.0	0.0160	20.76	1246	130.43	1.13
4250	42.5	0.0200	19.76	1185	124.15	1.01
4500	45.0	0.0180	19.00	1141	119.38	1.42
4750	47.5	0.02155	18.50	1112	116.23	1.75
5000	50.0	0.02475	17.90	1076	112.67	2.15

The rotor parameters in Table 4.9, were determined from a Motor speed of 1420 rpm with a Natural frequency of 23.6Hz. Other rotor parameters included the length of the rotor measuring 388mm with a distributed weight of 92N/m.

Table 4.10: Amplitude of Vibration for various Eccentric Masses and Speeds

					Rotor angular speed w_n , rads/ s			
					188.49	193.7	204.2	251.74
S/No	Eccentric Mass , mKg	ς	e	K	$X_A \times 10^{-3}$ m , amplitude			
1	3.75	0.0516	0.0148	0.0588	1.115	0.984	0.797	0.448
2	4.00	0.0500	0.0160	0.0625	1.282	1.130	0.916	0.460
3	4.25	0.0485	0.0200	0.0660	1.680	1.010	1.210	0.608
4	4.50	0.0470	0.0180	0.0697	1.600	1.420	1.150	0.577
5	4.75	0.0917	0.0215	0.0733	1.970	1.757	1.429	0.723
6	5.00	0.0447	0.0247	0.0769	2.420	2.150	1.740	0.873

$M = 60$ Kg ; $w = 141.37$ rads/s ; $c = 0.2$

$X_A \times 10^{-3}$ m , amplitude

4.5.1 Energy in Vibro Compaction Method

The combination of high eccentric mass, high eccentricity and high speed resulted in high rotary kinetic energy of 94.12J/sec, Table 4.10. The maximum power transmitted by the V-belt was 1.189Kw, and the potential power of the compactor was 2.27 J/sec., Table 4.10, 4.11 and 4.12. Therefore, the highest compaction energy in the vibration static-weight was estimated to be 1285.39J/sec.

Table 4.11: Results of Rotary Kinetic Energy

		Speed rpm			
		1800	1850	1950	2400
Eccentric Mass (Kg)	Eccentricity *e* (m)	Energy in J/sec			
3.75	0.0148	14.37	15.4	17.11	25.67
4.00	0.0160	18.15	19.17	21.33	32.33
4.25	0.0200	30.18	31.88	35.43	53.55
4.50	0.0180	25.88	27.33	30.38	46.03
4.75	0.0215	39.18	41.37	45.99	69.66
5.00	0.0247	54.40	57.45	63.84	94.12

Table 4.12: Power Transmitted by V- belt

Speed (rpm)	V (m/s)	Pitch Dia.(mm)	de (mm)	Power (Kw)
1800	6.88	73	78.11	0.841
1850	7.26	75	82.50	0.968
1950	7.45	73	80.30	0.937
2400	9.42	75	84.00	1.189

The total compaction power was determined from eccentric mass of 4750gms and a speed of 1850rpm, which was the rotor power, power from the transmission system, and potential power from the compactor, totaling to 1013.9J/s, Table 4.9, 4.10 and 4.11. Hence, the compaction power per Kilogramme of soil block per second was 44.86J. For a batch of three soil blocks

each weighing 7.5Kg, the power required for a production time of sixty seconds was 2691.65J/Kg.

4.6 The Compactor

The static weight of 260N was constrained in the vertical direction so that the compaction would occur through free fall of the static weight or through one degree of freedom. It was observed that after compaction, the density of the soil blocks made with the compactor having six degrees of freedom or with unconstrained compactor were higher than those made with the compactor constrained to one degree of freedom, Table 4.15 and 4.16. The compaction energy was estimated to be 4.57J/sec. where the height was taken as 1.78 mm.

4.7 Close Coiled Helical Compression Spring

The natural frequency of the close coiled helical compression spring was determined as 7692 Hz which was 18 times more than the minimum operating frequency of 416 Hz. The operating frequency was assumed to be the frequency of the rotor, which had been determined as 32Hz. It was observed that the vibrations were confined to the mould and there was minimal vibration of the machine structure.

4.8 The Physical and Mechanical Properties of the Cement Stabilized-soil Block

From Table 4.13, 4.14 and Figure 4.4(a), the values of compaction of soil block: green and bulk density, dry compressive strength, increased with increase of cement content, which agreed with the stabilized-soil block literature. The densification of the soil block was enhanced by the fact that the soil condition was non-uniform and the unconstrained compactor was asymmetrical and therefore experienced six degrees of freedom which resulted in the compactor rocking, yawing and pitching as it vibrated in the same amplitude of vibration as the rotor, and hence exacting compaction.

Table 4.13: Effect of Cement content on Dry Compressive Strength, Green and Bulk Density for Un-constrained Compactor for Soil Sample A:

Block No. in Batch	Cement Content (%)	Max. Load (KN)	Dry Compressive Strength (kN/m^2) (28 days)	Mean dry Compressive Strength (kN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3)	Mean Bulk Density (Kg/m^3)
1	5%	12	309		1428		1255	
2	Cement	11	289	296	1367	1376		1209
3		11.3	291		1333		1231	
							1222	
1	6%	23.5	537		1494		1394	
2	Cement	23.3	521	523	1383	1393		1298
3		23	511		1302		1379	
							1368	
1	8%	29.4	756		1483	1461	1445	1498
2	Cement	29			1455			
			749	753			1368	
3		29	753		1444		1373	

Table 4.14: Effect of Cement on Dry Compressive Strength, and Density of Cement Stabilized-soil Block for Soil Sample B

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (kN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3	Mean Bulk Density (Kg/m^3)
1	5 %	13	331		1698		1480	
2	Cement	11.7	298	308	1661	1672	1451	1458
3		11.6	295		1658		1444	
1	6 %	21	540		1690		1486	
2	Cement	18.7	548	543	1681	1683	1479	1480
3		19	541		1678		1475	
1	8 %	28.8	898		1720		1521	
2	Cement	28	714	769	1685	1688	1509	1502
3		27	695		1658		1476	

Table 4.15: Effect of Cement on Dry Compressive Strength, and Density of Cement Stabilized-soil Block for Soil Sample C

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (kN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3	Mean Bulk Density (Kg/m^3)
1	6 %	18.55	464.9		1660		1392	
2	Cement	26.87	673.4	588	1666	1659	1287	1326
3		24.97	625.8		1652		1298	
1	8 %	32.59	816.79		1666		1301	
2	Cement	34	852	815.3	1637	1676	1337	1339
3		31	777		1652		1380	
1	10 %	42.7	1070		1681		1516	
2	Cement	44.6	1117.79	1113.78	1681	1671	1438	1513
3		44.44	1113.78		1652		1584	

4.9 Density of cement stabilized-soil blocks

The bulk density increased as the cement content was increased in the same soil sample, Fig. 4.4 and 4.5.From Table 4.13 and 4.14, the bulk density for 5%, 6%, and 8% cement content was 1209 Kg/m^3, 1298 Kg/m^3,1498 Kg/m^3 for soil sample A and 1458 Kg/m^3, 1480 Kg/m^3, and 1502 Kg/m^3 for soil sample B respectively.The increase of bulk density with increase in green density was supported by observations in Table4.15 and conforms to stabilized-soil literature.

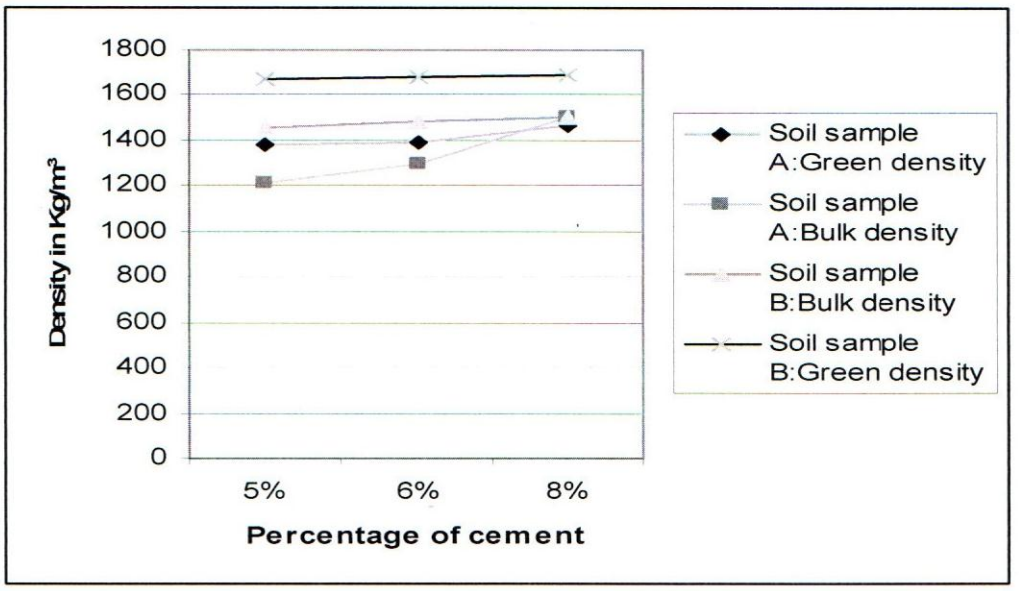


Figure 4.4 Effect of percentage of cement on the density of soil block, with unconstrained compactor

For a constrained compactor, the dry compressive strength was low for soil sample A with 5%, 6% , 8% cement content and for soil sample B with 6% cement content , Fig.4.5 . Hence, for a constrained compactor, compaction was lower than when the compactor was not constrained. One possible reason for low values in the constrained compaction was because the compactor was constrained to vibrate in one degree of freedom.

Table 4.16: Effect of Constrained Compactor on Dry Compressive Strength, Green Density, and Bulk Density for Soil Sample A:

Block No. in Batch 1;2	Cement Content (%)	Max. Load (KN)	Dry Compressive Strength (kN/M2) (28 days)	Mean dry Compressive Strength (kN/M2)	Green Density (Kg/m3)	Mean Green Density (Kg/m3)	Bulk Density (Kg/m3)	Mean Bulk Density (Kg/m3)
1	5%	5.65	140		1492		1252	
2	5%	2.25	57	79	1387	1396	1233	1209
3	5%	1.60	41		1308		1141	
1	6%	5.14	131		1395		1237	
2	6%	6.69	170	161	1491	1393	1312	1265
3	6%	7.19	183		1294		1245	
1	8%	5.16	132		1352		1566	
2		9.78	249	173	1386	1380	1619	1597
3		5.4	137		1401		1606	

Table 4.17: Effect of Constrained Compactor at 6% cement content on compressive strength and density of Cement Stabilized-soil Block for Soil Sample B.

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (KN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3	Mean Bulk Density (Kg/m^3)
1	5 %	11.45	290		1732		1438	
2	Cement	6.68	168	229	1659	1670	1411	1409
3		9.0	230		1621		1389	
1	6 % Cement	2.07	52.8		1602		1154	
2	(constrained	2.13	53.4	78	1257	1383	1228	1199
3	compaction)	5.13	128		1290		1215	
1	8 %	27.83	702		1720		1409	
2	Cement	30.86	770.7	697.7	1685	1687	1454	1418
3		24.85	620.6		1658		1390	

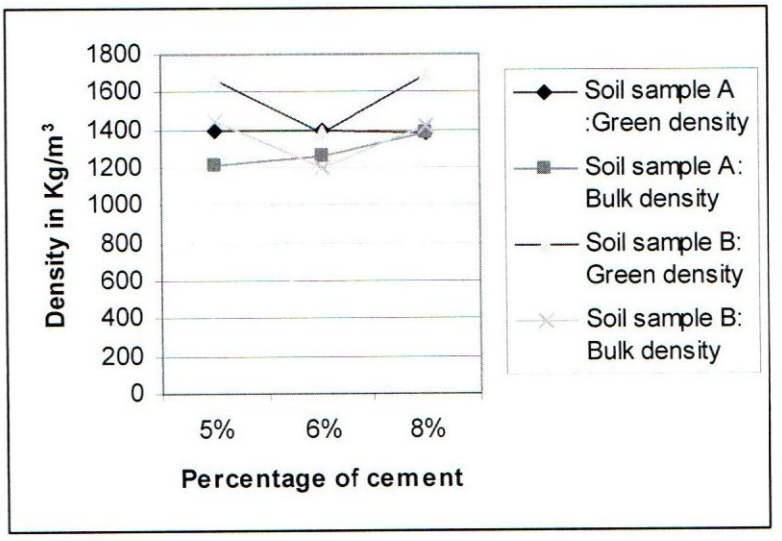


Figure 4.5 Effect of cement content on density of cement stabilized-soil block with constrained compactor at 6% cement content

From figure 4.4 and 4.5, the values of compressive strength, green and bulk density were highest for the 8% cement content whereas the values for 6% cement content were lower than those of 5% cement content. This occurrence could be explained by the orientation of the compactor. For the 6% cement content the compactor was constrained to one degree of freedom, vertical movement only. For the 5% and 8% cement content, the compactor had all the degrees of freedom and could exact the compaction onto the mixture.

4.8.1 Dry Compressive Strength of Cement Stabilized-soil Blocks

The difference in dry compressive strength for soil sample A and B varied from 4%, 20.7% and 2% for 5%, 6%, and 8% cement content respectively, for an unconstrained compaction, Fig.4.4 and the dry compressive strength increased with the increase in cement content to an average of 769 KN/m^2 and 753 KN/m^2 for soil sample A and B respectively.

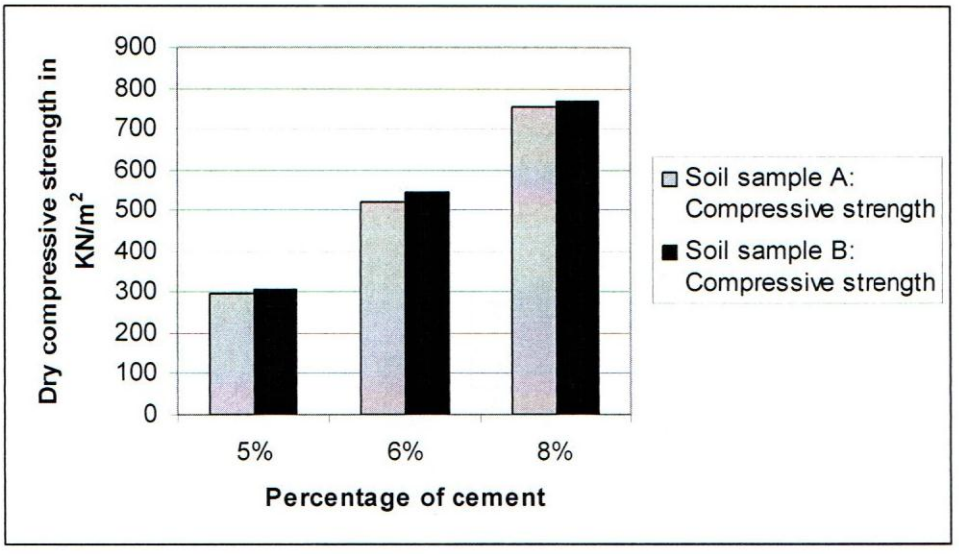


Figure 4.6 Effect of cement content on dry compressive strength of cement stabilized-soil blocks, with unconstrained compactor

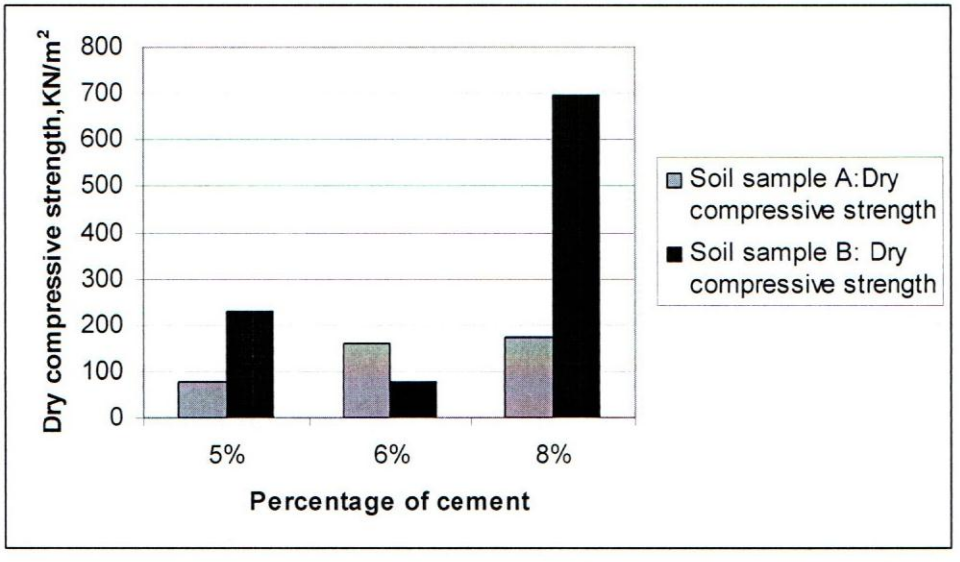


Figure 4.7 Effect of cement content on dry compressive strength for soil sample (A) and (B) with compactor constrained.

The dry compressive strength was highest with soil sample C, Figure 4.8 at 10 % cement content.

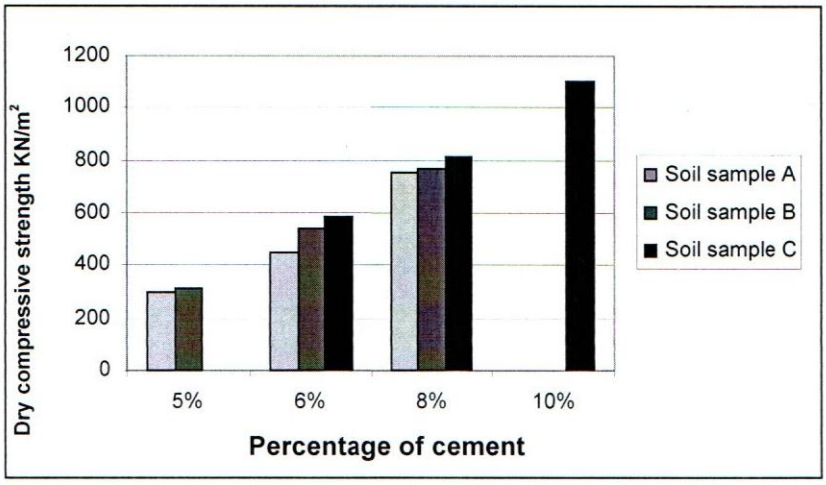


Figure 4.8 Effect of cement on dry compressive strength of cement stabilized-soil block

4.9 Wet Compressive Strength of cement stabilized-soil blocks

The higher the cement content, the higher the wet compressive strength of the soil block, Fig. 4.9. The values of the mean dry compressive strength increased from $588KN/m^2$,$815KN/m^2$, to $1100KN/m^2$ and the equivalent values of their wet compressive strength, Table 4.18, increased from $342KN/m^2$,$664KN/m^2$ to $952KN/m^2$ for 6%, 8% and 10% cement content , while the ratio of mean dry compressive to wet compressive strengths reduced as the cement content increased from 1.72, 1.22 and 1.17 respectively. The literature for stabilized-soil blocks recommends that the ratio of the mean dry to wet compressive strength in stabilized-soil blocks should not be greater than two, (2).The experimental results obtained in this research for 10% cement content fell within this limit. It was concluded that the increase in cement content was an effective method of increasing the dry and wet compressive strength when the compaction energy was held constant.

Table 4.18:Effect of cement content on wet compressive strength for cement stabilized-soil block for soil sample C

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Wet Compressive Strength KN/m^2	Mean Wet Compressive Strength (kN/m^2)
1	6 %	13.56	340	
2	Cement	13.5	339	342
3		13.89	348	
1	8 %	23.9	599	
2	Cement	27.8	697	664
3		27.77	696	
1	10 %	37.54	941	
2	Cement	37.78	947	952
3		38.62	968	

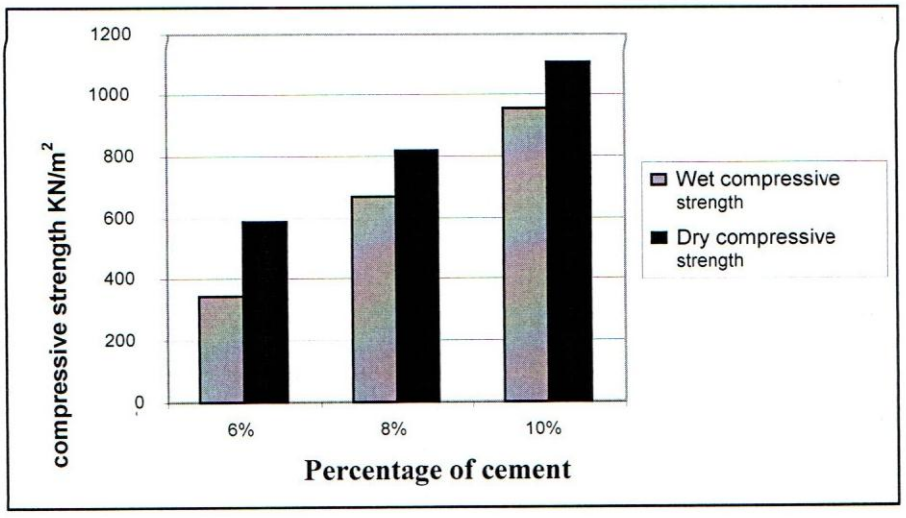


Figure 4.9 Effect of water on cement stabilized soil block for Soil sample "C"

4.10 Water Absorption of cement stabilized-soil blocks

A negative correlation exists between increase in cement content and water absorption, Figure 4.8. Stabilized-soil blocks of lower cement content were found to absorb more water than those with higher cement content. For the same compaction energy, high content of cement seemed to inhibit water absorption in cement stabilized-soil blocks. However the water absorption was more than 15% of the original mass of the soil block. The decrease in water absorption with increase in cement content from 6% to 10% was an average of 22.5% to 16.73% respectively.

Table 4.19: Effect of Cement on Water Absorption of Cement Stabilized-soil Blocks

	Percentage of cement in the soil block		
	6%	8%	10%
Water absorption	1. 23.33	19.64	15.52
	2. 23.21	19.30	16.36
	3. 21.05	19.33	18.33
Average	22.53	19.42	16.73
StdDev	1.28	0.19	1.17
StdError	0.74	0.11	0.68

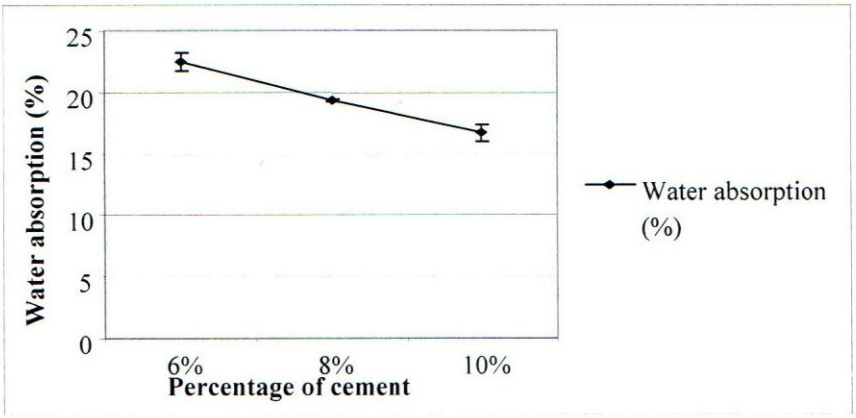


Figure 4.10 Effect of cement content on water absorption of a cement stabilized-soil block

The values of water absorption at 8% cement content, Fig. 4.10, indicated that the compactor was oriented uniformly resulting in uniform water absorption in the batch and hence the smaller y-Error bar. However, water absorption was lowest at 10% cement content in spite of non-uniformity of water absorption within the batch, indicated by the big size of the y-Error bar.It was deduced from Fig.4.11 that the more the water absorbed in the soil block, the lower its bulk density which was supported by the cement stabilized-soil block literature. It was inferred that increase in bulk density of 9.1% resulted in a decrease in water absorption of 25.74%

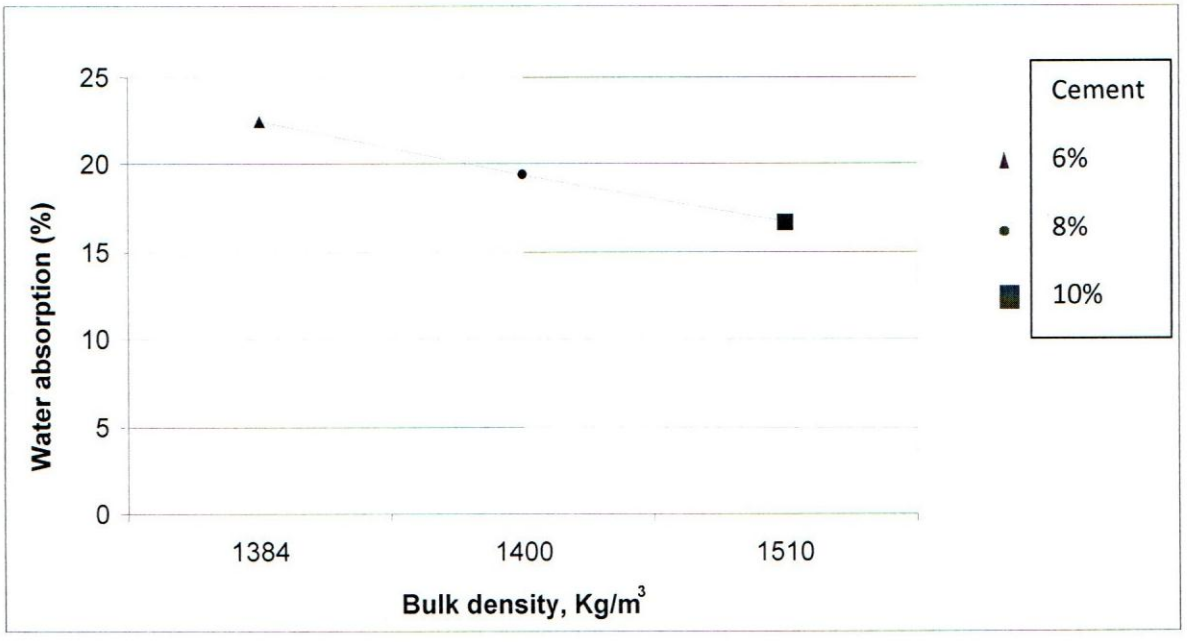


Figure 4.11Correlation between water absorption and density of cement stabilized-soil block

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Vibro compaction energy was provided by the rotor, power transmission system, and the compactor integrated together and was confined to the mould by the helical compression spring. The generated energy in this research was more than 204J/Kg of soil block leading to the acceptance of the alternative hypothesis, $H_{a1,}$ that stated that the rotor and the power transmission system would generate energy greater than 204J/Kg of soil block . The eccentric mass which was arranged in a lateral direction resulted in high amplitude of vibration and high energy values because of increased eccentricity and hence a high centrifugal force which resulted in high soil block density. A rotor speed of 1850rpm and eccentric mass of 4750gms was selected as optimum values and applied to produce soil blocks where the best performance was obtained with 10% cement contents by weight of soil.

The compactor weight was more than the total weight of the three soil blocks in the batch by15.5% , necessitating the rejection of the null hypothesis, H_{o1}, that the compactor weight would be equal to the total weight of the three soil blocks. It was observed that high values of physical and mechanical properties were obtained when the compactor was unconstrained during compaction, and hence this condition was maintained and has been recommended in soil block production.

The close coiled helical compression spring was assumed to operate at the operating frequency of the rotor but to avoid resonance, the minimum operating frequency of the spring was determined to be 416Hz . However, the natural frequency of the selected spring was 7692Hz which was more than the rotor frequency, and far beyond the resonance frequency, leading to the adoption of the spring for soil block production, and acceptance of the alternative hypothesis, H_{a2}, that stated that the natural frequency of close coiled helical compression spring would be more than the rotor frequency.

The performance of the Vibro compaction technology was evaluated from the results of tests on physical and mechanical properties of the soil block obtained as a result of application of

constant compaction energy from a rotor speed of 1850rpm and eccentric mass of 4750gms. The alternative hypothesis, H_{a3}, that the values for both Physical and Mechanical properties would be higher for the produced soil blocks was rejected because the Vibro compaction technology applied to the sandy-clay-loam soil did not achieve the minimum values as recommended by the Kenya standard, KS 02-1070:1993, even with up to 10% cement content, except for the ratios of dry and wet compressive strength, which is supported by the stabilized-soil literature. The bulk density, wet compressive strength, dry compressive strength and water absorption for 10% cement content were, $1513KG/m^3$, $0.955MN/m^2$, $1.114MN/m^2$, and 16.7% against the minimum values of $1600Kg/m^3$, $1.5MN/m^2$, $2.5MN/m^2$, and 15% respectively. It was observed that at 10% cement content, the highest bulk density obtained was less by 5.4% from the minimum acceptable value of $1600Kg/m^3$ and the water absorption was more than 1.7% from the minimum acceptable value of 15% . Furthermore, the ratio of mean dry to wet compressive strengths, 1.72 ,1.22 and 1.17 for 6% , 8% and 10% cement content respectively fell below the recommended value of 2, which is within the stabilized-soil block literature.

Therefore, this study provides a baseline for further research in the adaptation of Vibro compaction technology for making soil blocks to supplement the Impact and Quasi-static soil block compaction methods.

5.2 Recommendations

Literature on stabilized-soil block production shows that the use of cement content beyond 8% is not an economic way of achieving further dry and wet compressive strength in cement stabilized soil blocks. Therefore, further research is recommended in determining rotor parameters, compactor weight, and selection of the close coiled helical compression spring which may result in a Vibro compaction technology to produce a Sandy-clay-loam soil blocks with less than 8% cement content with acceptable mechanical and physical properties for the housing industry.

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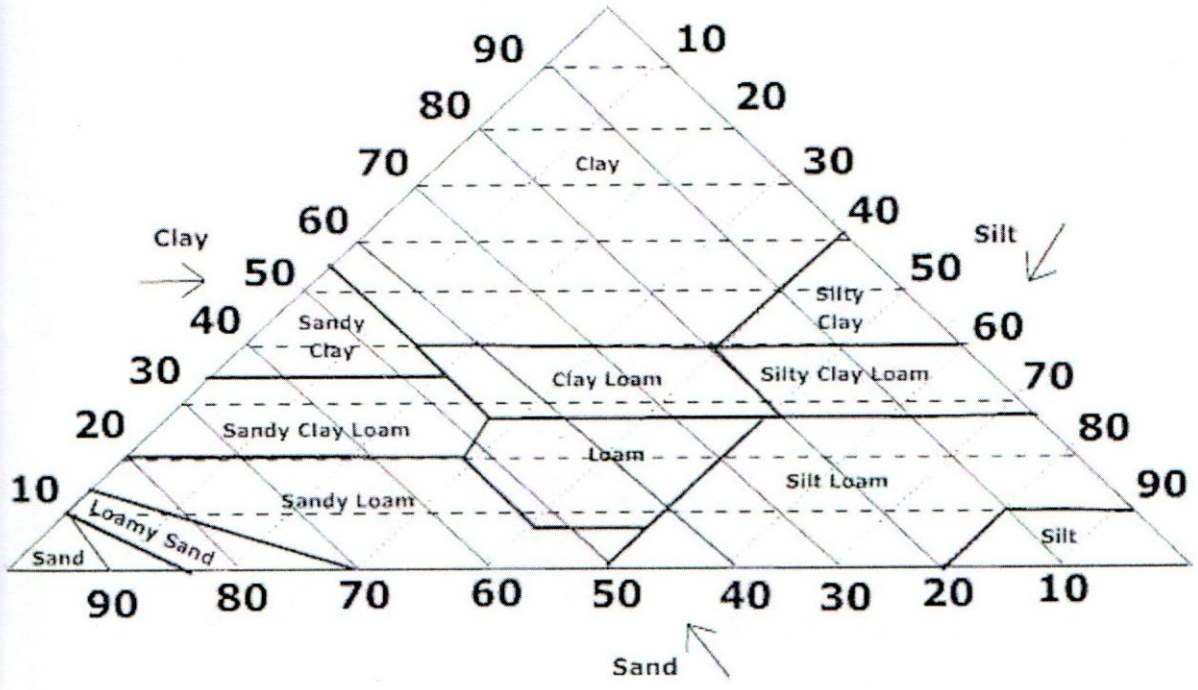
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APPENDICES

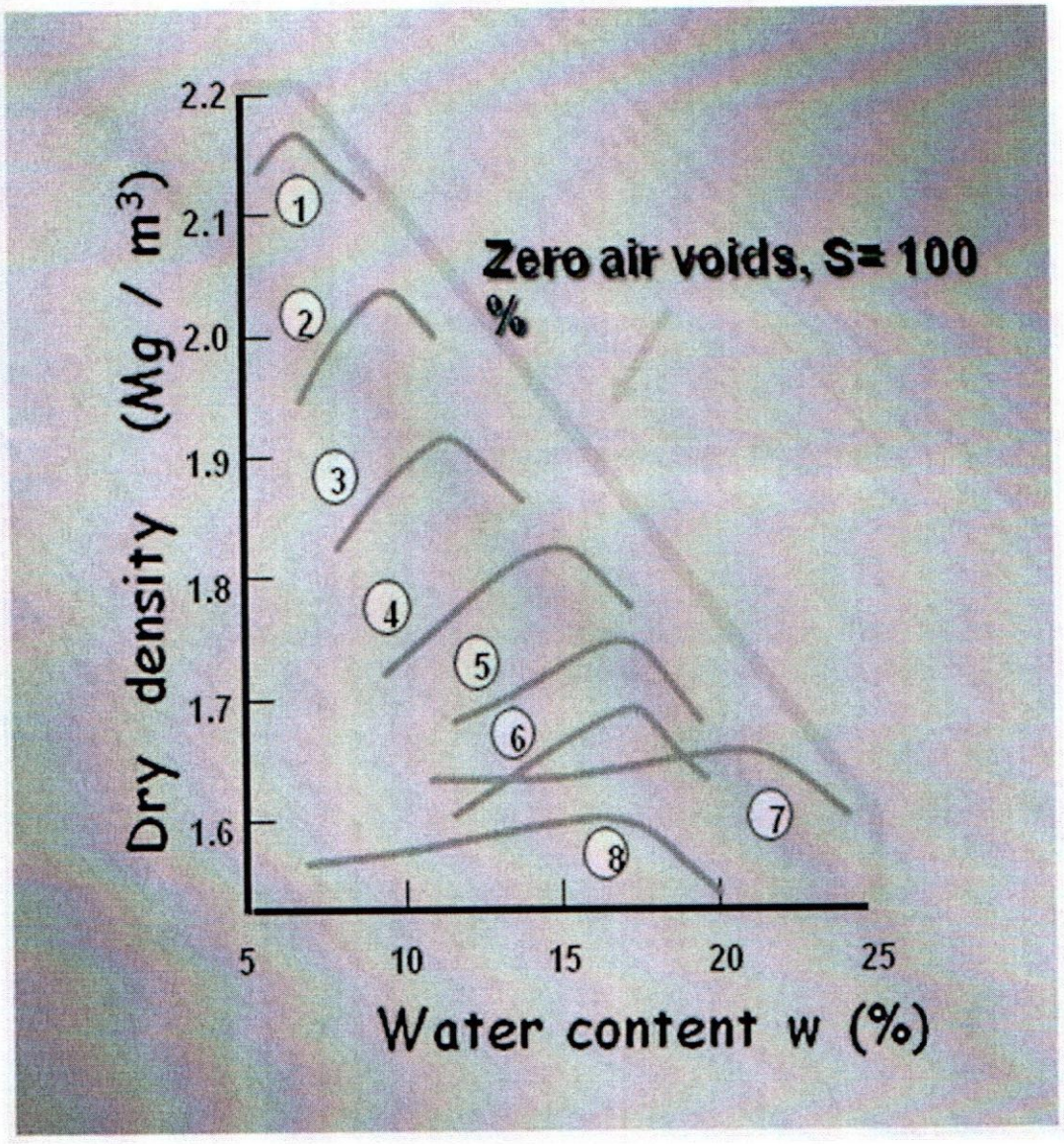
APPENDIX A

Appendix A(i) : Soil texture triangle



SOURCE: Soil texture triangle (source : Ritter Michael, 2006)

Appendix A (ii): Range of Optimum moisture content and Maximum Dry Density for various soils



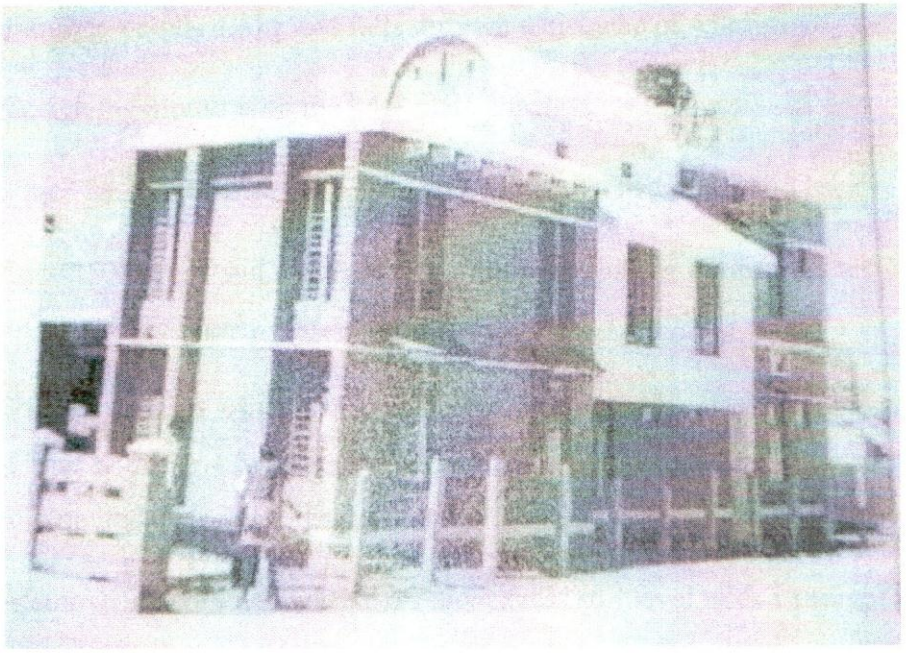
Appendix A (iii): Soil texture and plasticity data

Soil texture and Plasticity data

NO	Description	Sand	Silt	Clay	LL	PI
1	Well graded loamy sand	88	10	2	16	NP
2	Well graded sandy loam	72	15	13	16	NP
3	Med graded sandy loam	73	9	18	22	4
4	Lean sandy silty clay	32	33	35	28	9
5	Lean silty clay	5	64	31	36	15
6	Loessial silt	5	85	10	26	2
7	Heavy clay	6	22	72	67	40
8	Poorly graded sand	94	6	6	NP	NP

Source: *Geotechnical and Geoenvironmental Engineering CIVIL 4121,School of Civil and Resource Engineering*. The University of Western Australia.

Appendix A (iv): Stabilized-soil cement block residential house



Sources: Sustainable building technologies (2004)

APPENDIX B

Appendix B (i): Proctor test; 4.5 kg rammer method: BS 1377:1975

The rammer weighs 4.5kg and falls through a distance of 450mm.

i. Weigh the mould with the base plate attached

ii. Place the mould with base plate and collar attached on a solid base

iii. Mix 2500gm of soil obtained from material passing 6.3mm BS test sieve with a quantity of water thoroughly

iv. Place the moist soil into the mould in five equal layers and compact each layer with 27 blows with the 4.5kg rammer falling through a distance of 450mm, the blows being well distributed over the soil service

v. Remove the collar and strike off any excess soil level with a straight edge

vi. Weigh the specimen while the base plate is still attached

vii. Remove specimen from mould, mix it thoroughly and take two samples for moisture content determination

viii. The procedure is repeated at least five times with increasing amount of water to give a range of moisture contents which include the optimum moisture content at which the maximum dry density occurs.

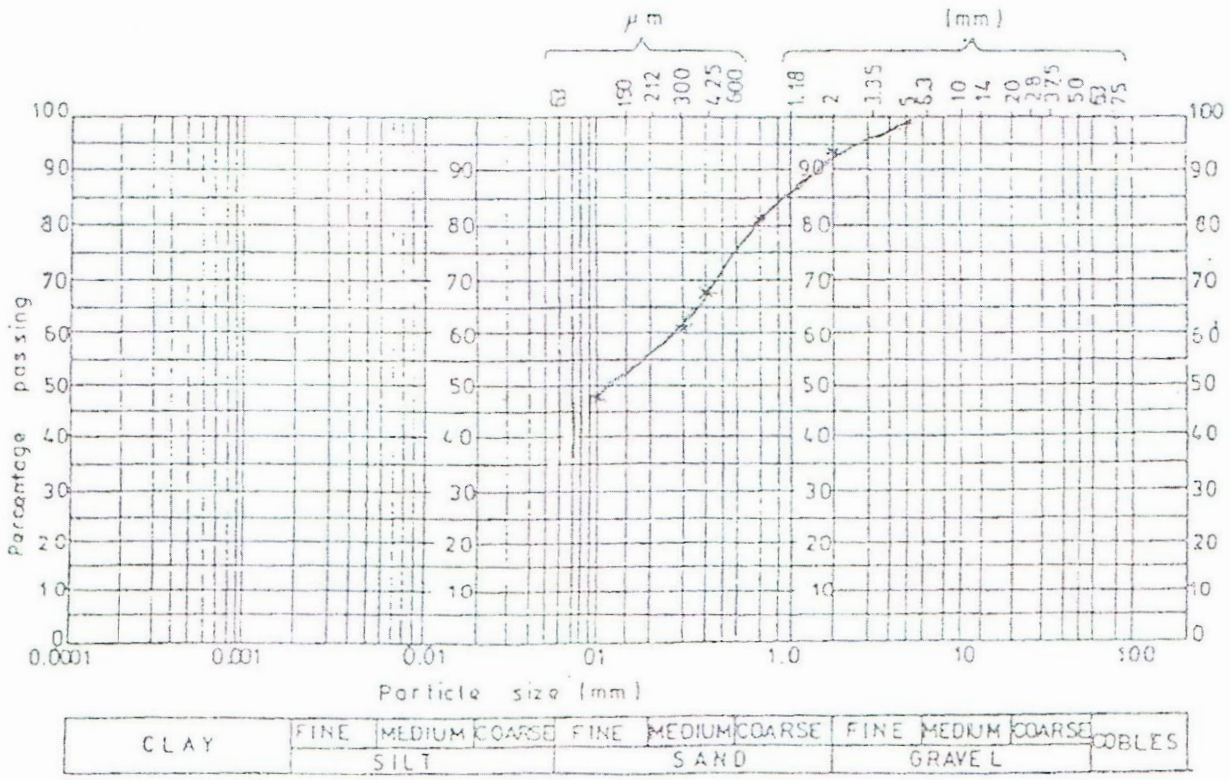
ix. Calculations and reporting the results

The calculations and reporting was done according to BS 1377:1975

$$\text{Dry density}, \rho = \frac{\text{specimen weight}}{\text{moisture} + 100} \times 100$$

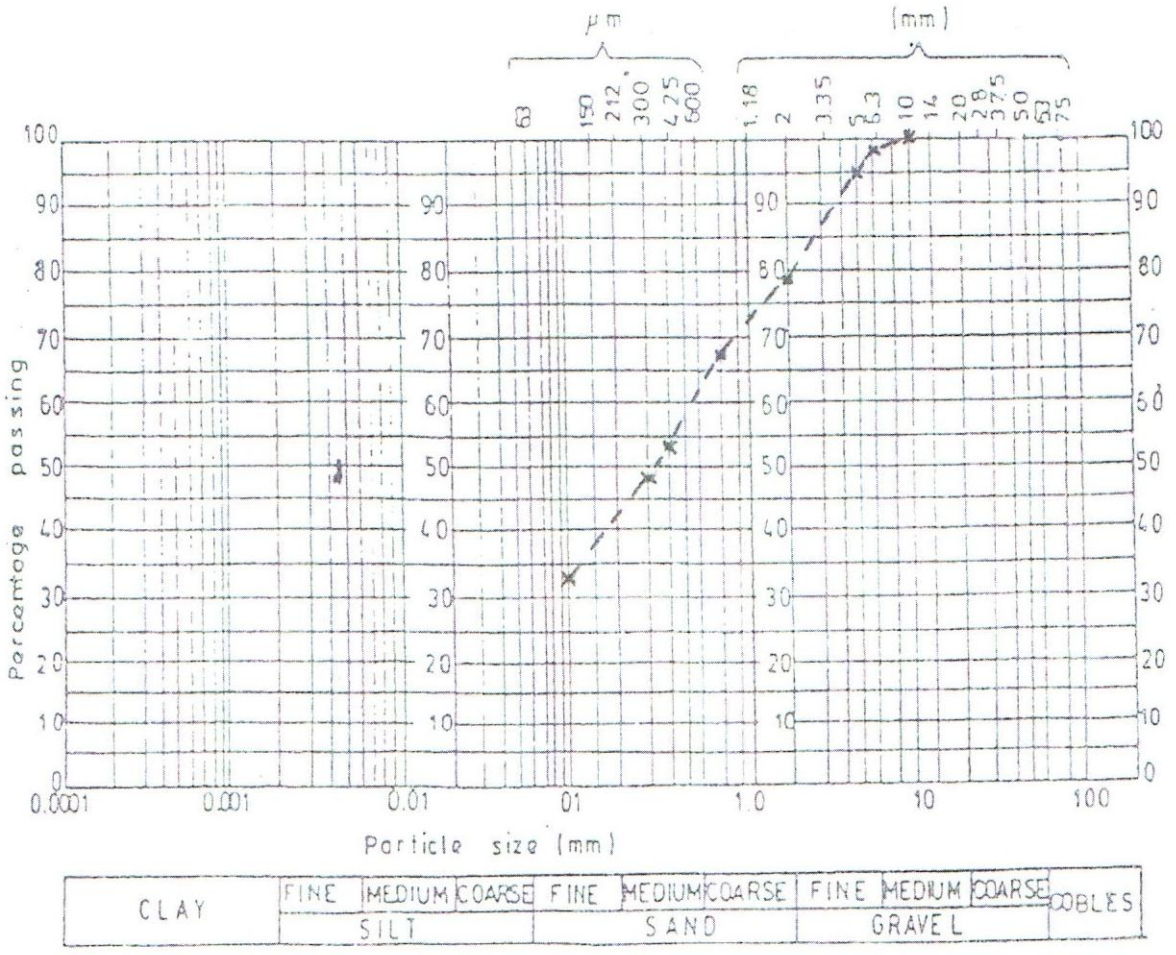
Appendix B(ii): Wet sieve analysis for soil sample (A)

Sandy clay loam: Gravel 6.3%; Sand 44.8%; Silt/ Clay 48.8%



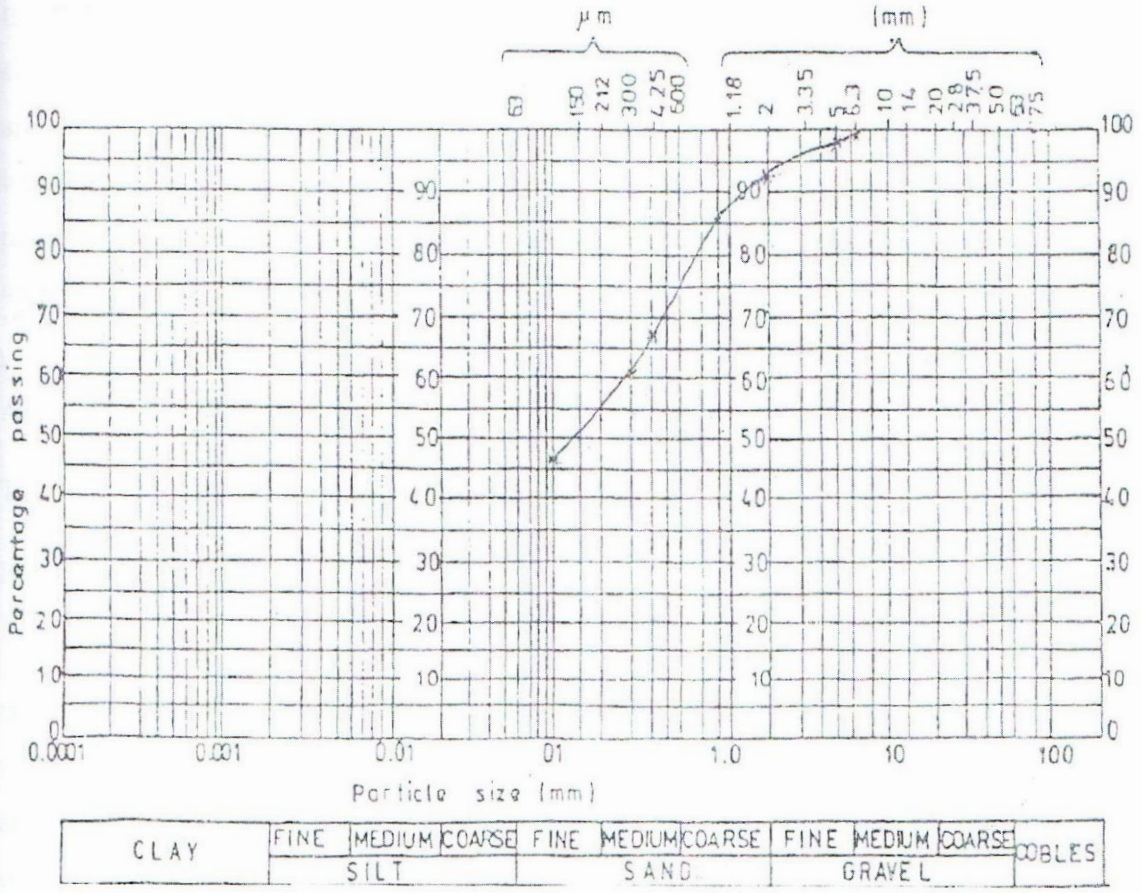
Appendix B (iii): Wet sieve analysis for soil sample (B)

Sandy-clay-loam: Fine gravel 20.7; Sand 44.1%; Silt/Clay 33.4%



Appendix B (iv): wet sieve analysis for soil sample C

Sandy-lay-loam: Fine gravel 4.5 % , Sand 48.5%, Silt/clay 46.65%



Appendix B (v): Sedimentation test

The Sedimentation test was done according to BS 1377: 1975 where a flat bottomed jar was selected and filled with a third full of soil from the sampled soil. water was added until two thirds full. Two spoonful of salt was added to the mixture and the bottle was rapidly closed and shook vigorously. The contents were allowed to settle for one hour. The bottle was shaken again and let to settle for at least 8 hours. The thickness of combined silt plus clay layer above the line was measured and calculated as a percentage of the total height of the soil sample. For the purpose of this thesis the combined thickness of silt and clay layer was 47.4%, 32.6%, and 45.8% for the soil sample A,B, and C respectively.

Appendix B (vi): linear shrinkage test

This test gave an indication of the plasticity index of the soil.

Procedure

A wooden or metal box without a top and with a square cross-section of 30 to 40 mm per side and a length of 500 to 600 mm was filled with soil from the sample. The soil was first mixed with water to slightly more than the liquid limit. The box was filled with the soil-water mixture and then compacted well. The surface of the mixture was smoothed by scrapping off the excess soil mixture. The box with its contents was placed in the room for seven days. The linear shrinkage ratio was measured by pushing the dried samples to one end of the box and the length was measured and calculated as a percentage of the length of the box as follows:

$$\text{Linear shrinkage ratio} = \frac{(\text{Length of wet bar}) - (\text{Length of dried bar})}{\text{Length of wet bar}} \times 100$$

The linear shrinkage ratio was 11%, 12.1% and 12% for soil samples A, B, and C respectively.

Table B(i): Data on effect of water content on Green density of Nonstabilized Soil sample A:Proctor method

Test No.	1	2	3	4
Water added(mls)	100	150	200	250
weight (gms)	1850	1940	1965	1920
Moisture content (%)	24.1	26.2	28.7	30.2
Dry density Kg/m^3	1491	1536	1527	1475

Maximum dry density is 1555 kg/m^3 ;

Optimum moisture content is 27.6%

Table B(ii): Data on effect of water content on Green density of Nonstabilized Soil sample A: Vibro compaction method

Test No.	1	2	3	4	5
Water added %	9.3	10.5	11.6	13.4	13.9
Water added(mls)	700	800	900	1050	1100
weight (gms)	7500	7600	7700	7850	7950
Green density Kg/m^3	1273	1314	1385	1505	1478

Present moisture content 19.9%

Maximum density is 1505 kg/m^3

APPENDIX C

Appendix C (i): Eccentricity of mass

Eccentricity of the mass;

$$e = \frac{m_1 x_1 \ldots + m_n x_n}{M}$$

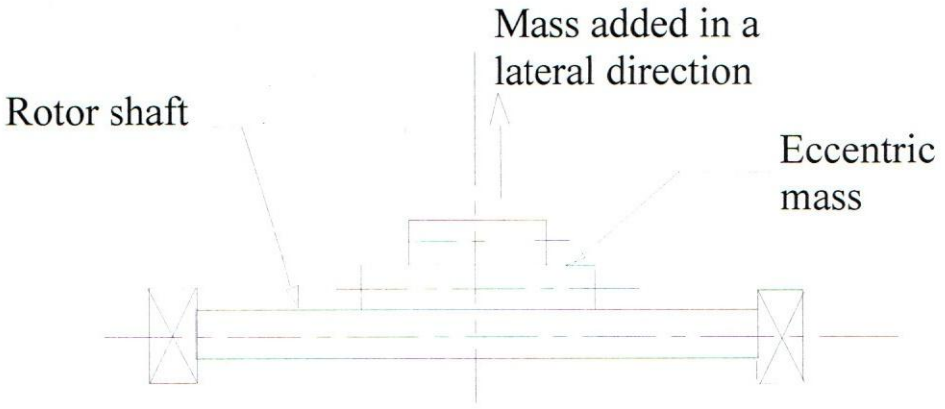


Table C (i): Eccentricity of mass

Mass, Kg	3.75	4.00	4.25	4.50	4.75	5.00
Eccentricity, e (m)	0.0148	0.016	0.020	0.018	0.0215	0.0247

Table C (ii): Dynamic rotor parameters

Eccentric mass (kg)	e (m)	Speed(rpm)	w^2 rad/s	mew^{2}N) (For measured speed)
3.75	0.0148	1731*/1800	32858	121.53
		1931*/1850	40890	151.27
		1984*/1950	43165	161.84
		2404*/2400	63376	233.71
4.0	0.0160	1731*/1800	32858	525.7
		1931*/1850	40890	654.21
		1984*/1950	43165	690.52
		2404*/2400	63376	1013.89
4.25	0.0200	1731*/1800	32858	657.15
		1931*/1850	40890	817.78
		1984*/1950	43165	863.28
		2404*/2400	63376	1267.51
4.50	0.0180	1731*/1800	32858	591.39
		1931*/1850	40890	736.01
		1984*/1950	43165	776.96
		2404*/2400	63376	1138.86
4.75	0.02155	1731*/1800	32858	885.11
		1931*/1850	40890	1101.47
		1984*/1950	43165	1178.06
		2404*/2400	63376	1707.12
5.00	0.02475	1731*/1800	32858	1203.3
		1931*/1850	40890	1498
		1984*/1950	43165	1624.7
		2404*/2400	63376	2352.71

*Calculated speed

APPENDIX D

AMPLITUDE OF VIBRATION

The amplitude is approximated at the instance the mould chamber is in contact with the Soil-cement-water mixture:

$$X_A = \frac{Ke\ {}^{w^2}/_{w_n^2}}{\left\{\left(1 - \frac{w^2}{w_n^2}\right)^2 + \left(2\varsigma\frac{w^2}{w_n^2}\right)^2\right\}^{1/2}}$$

Where w is the angular speed of the driver or motor = 141.37 rads/sec.

w_n is the natural frequency of the rotor = 193.73 rads/sec

e = 0.0215 m, the eccentricity

$$K = \frac{m}{M + m}$$

= 0.0733, the ratio of offset mass to total mass

$$\varsigma = \frac{c}{2\sqrt{K(M + m)}}$$

= 0.0917 ,the damping factor of the system ,where c is the damping coefficient of the system

Therefore, X_A = 1.757mm

Table D: Amplitude of vibration for various eccentric masses and speeds

					Rotor angular speed w_n, rads/ s		
					188.49	193.7	204.2	251.74
S/No	Eccentric Mass ,m Kg	ς	e	K	$X_A \times 10^{-3}$ m , amplitude			
1	3.75	0.0516	0.0148	0.0588	1.115	0.984	0.797	0.448
2	4.0	0.05	0.016	0.0625	1.282	1.13	0.916	0.46
3	4.25	0.0485	0.02	0.066	1.68	1.01	1.21	0.608
4	4.5	0.047	0.018	0.0697	1.6	1.42	1.15	0.577
5	4.75	0.0917	0.0215	0.0733	1.97	1.757	1.429	0.723
6	5.0	0.0447	0.0247	0.0769	2.42	2.15	1.74	0.873

$M = 60$ Kg ; $w = 141.37$ rads/s ; $c = 0.2$

APPENDIX E

Table E (i): Data on the amount of soil, water and cement used in each soil sample

Soil sample (Sand-clay-loam) and their constituents	Mass of Soil (Kg)	Cement Content (%)	Mass of Cement (Gms)	Water Content (Gms)	Present water content in the soil (%)
A: Gravel 6.3%; Sand 44.8%; Silt/ Clay 48.8%	6158	5%	308	1200	19.9
	6050	6%	365	1300	
	5820	8%	470	1450	
B : Fine gravel 20.7; Sand 44.1%; Silt/Clay 33.4%	6055	5%	305	1350	18.8
	5961	6%	358	1400	
	5840	8%	470	1450	
C: Fine gravel 4.5 % , Sand 48.5%, Silt/clay 46.65%	5996	6%	360	1350	11.30
	5840	8%	470	1450	
	5682	10%	570	1500	

Table E (ii): Data on linear measurement for stabilized-soil blocks after production for Sample soil (A):

Cement content	BLOCK No.	L (mm)	W (mm)	H (mm)		BLOCK NO.	L (mm)	W (mm)	H (mm)
		Batch 1					Batch 2		
5 % cement	1	281	140	128		1	280	140	128
	2	282	140	131		2	281	140	131
	3	283	140	134		3	281	140	137
6 % cement (Constrained Compactor)	**1**	280	140	136	(Un-constrained Compactor)	1	281	140	127
	2	280	140	145		2	282	140	128
	3	281	140	151		3	282	140	131
8% cement	**1**	281	140	125		1	282	140	126
	2	281	140	127		2	283	140	128
	3	282	140	130		3	283	140	132

Table E (iii) Data on Bulk density of soil sample A after 28 days curing for constrained compactor

Batch No. 2	L (mm)	W (mm)	H (mm)	Mass (KG)	Bulk Density KG/m^3	Mean Bulk Density KG/m^3
	280	139	136	6.1	1141	
5%	280	139	130	6.2	1233	1209
cement	279	139	127	6.1	1252	
	280	139	136	6.6	1237	
6%	281	139	136	7.0	1312	1298
cement	281	139	147	6.7	1345	
	280	139	127	7.2	1476	
8%	280	139	129	7.3	1452	1498
cement	280	139	135	7.3	1566	

Table E (iv): Data on linear measurement ,mass and bulk density after 28 days for sample soil (A)

	L (mm)	W (mm)	H (mm)	Mass (Kg)	Bulk Density Kg/m^3
Constrained Batch					
5% cement	280	139	129	6.3	1255
	281	139	131	6.3	1231
	281	139	132	6.3	1222
6% cement	280	139	129	7.0	1394
	281	139	130	7.0	1379
	281	139	131	7.0	1368
8% cement	280	139	128	7.2	1445
	281	139	131	7.0	1368
	282	139	132	7.1	1372

Table E (v): Data on Linear measurements of stabilized-soil blocks after production for Sample soil (B)

Cement content	Batch 1 Compactor Constrained At 6% cement content			Batch 2 Not constrained At 6% cement content		
	L (mm)	W (mm)	H (mm)	L (mm)	W (mm)	H (mm)
	283	140	110	284	140	113
5%	285	140	114	285	140	111
cement	287	140	124	286	140	113
	283	140	130	283	140	112
6%	284	140	140	284	140	113
cement	286	140	143	285	140	114
	282	140	115	282	140	112
8%	285	140	117	284	140	111
cement	287	140	120	285	140	113

Table E (vi): Data on Linear measurements after 28 days curing for sample soil (B)

	Batch 1			Batch 2				
Cement content	L (mm)	W (mm)	H (mm)	L (mm)	W (mm)	H (mm)	Mass (Kg)	Bulk Density Kg/m^3
	Constrained compactor			Unconstrained compactor				
	282	139	109	283	139	111	6.3	1467
5%	284	139	113	284	139	113	6.2	1438
cement	285	139	119	284	139	114	6.1	1411
	280	139	130	281	139	111	5.4	1154
6%	283	139	139	282	139	115	6.7	1228
cement	285	139	135	283	139	116	6.8	1215
	281	139	114	280	139	110	6.0	1409
8%	284	139	116	282	139	110	6.2	1454
cement	286	139	119	283	139	112	6.1	1390

Table E (vii): Data on Linear measurements and Green density after production :sample soil (C)

	L (mm)	W (mm)	H (mm)			L (mm)	W (mm)	H (mm)		
		Batch 1		Green density	Mean Density	Batch 2			Green density	Mean density
6%	288	140	112	1661	1656	287	140	112	1660	1659
cement	288	140	112	1661		287	140	112	1666	
	288	140	113	1646		287	140	113	1652	
8%	288	140	112	1661	1636	287	140	112	1666	1676
cement	288	140	114	1631		287	140	114	1637	
	288	140	115	1617		287	140	115	1725	
10%	288	140	119	1563	1600	287	140	111	1681	1671
cement	288	140	119	1563		287	140	111	1681	
	288	140	111	1676		287	140	113	1652	

Table E (viii): Data on Linear measurements (mm) and Bulk density Kg/m^3 after 28 days curing for soil sample (C)

Cement content (Percentage)	Linear Measurement (mm)			Mass (Kg)	Bulk Density (Kg/m^3)	Mean bulk Density (Kg/m^3)
6%	284	138	110	6.0	1392	
cement	284	138	111	5.6	1287	1326
	284	138	112	5.7	1298	
8%	283	137	111	5.6	1301	
Cement	283	137	110	5.7	1337	1339
	283	137	99	5.3	1380	
10%	282	137	99	5.8	1516	
cement	282	137	99	5.5	1438	1513
	282	137	98	6.0	1584	

Table E (ix):Data on cement content on dry compressive strength, green density, and bulk density for soil sample A:

Block No. in Batch	Cement Content (%)	Max. Load (KN)	Dry Compressive Strength (kN/M2) (28 days)	Mean dry Compressive Strength (kN/M2)	Green Density (Kg/m3)	Mean Green Density (Kg/m3)	Bulk Density (Kg/m3)	Mean Bulk Density (Kg/m3)
1	5%	12	309	296	1428		1255	
2	Cement	11	289		1367	1376		1209
3		11.3	291		1333		1231	
							1222	
1	6%	23.5	604	600	1494		1394	
2	Cement	23.3	599		1383	1393		1298
3		23	597		1302		1379	
							1368	
1	8%	29.4	756	753	1483	1461	1445	1498
2	Cement	29	749		1455		1368	
3		29	753		1444		1373	

Table E (x): Data on dry compressive tests, green density, and bulk density with constrained compactor for soil sample A:

Block No. in Batch 1;2	Cement Content (%)	Max. Load (KN)	Dry Compressive Strength (kN/M2) (28 days)	Mean dry Compressive Strength (kN/M2)	Green Density (Kg/m3)	Mean Green Density (Kg/m3)	Bulk Density (Kg/m3)	Mean Bulk Density (Kg/m3)
1	5%	5.65	140	79	1492		1252	
2	5%	2.25	57		1387	1396	1233	1209
3	5%	1.60	41		1308		1141	
1	6%	5.14	131		1395		1237	
2	6%	6.69	170	161	1491	1393	1312	1265
3	6%	7.19	183		1294		1245	
1	8%	5.16	132		1352		1566	
2		9.78	249	173	1386	1380	1619	1597
3		5.4	137		1401		1606	

Table E (xi): Data on effect of cement on compressive strength, and density of cement stabilized-soil block: soil sample B

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (kN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3	Mean Bulk Density (Kg/m^3)
1	5 %	11.5	290		1732		1467	
2	Cement	6.7	168	229	1659	1670	1438	1439
3		9.0	230		1621		1411	
1	6 %	2.1	53		1602		1154	
2	Cement	2.1	53	78	1257	1383	1228	1199
3		5.1	128		1290		1215	
1	8 %	28	702		1720		1409	
2	Cement	31	771	698	1685	1687	1454	1418
3		25	621		1658		1390	

Table E (xii): Data on content of cement on dry compressive strength, green and bulk density of cement stabilized-soil blocks: soil sample B:

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Green Density (Kg/m^3)	Bulk Density (Kg/m^3
1	5 %	13.0	331	1698	1480
2	5 %	11.7	298	1661	1451
3	5 %	11.6	295	1658	1444
AVERAGE			308	1672	1458
STDEV			16.30	18.20	15.50
STDERROR			9.40	10.50	9.00

1	6 %	21	540	1690	1486
2	6 %	18.7	548	1681	1479
3	6 %	19	541	1678	1475
AVERAGE			543	1683	1480
STDEV.			26.70	5.10	4.50
STDERROR			15.40	2.90	2.60
1	8 %	28.8	898	1720	1521
2	8 %	28	714	1685	1509
3	8%	27	695	1658	1476
AVERAGE			769	1687	1502
STDEV.			16.80	25.40	19.0
STDERROR			9.70	14.70	11.0

Table E (xiii): Data on effect of cement on compressive strength, and density of cement stabilized-soil block: soil sample B

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (kN/m^2)	Green Density (Kg/m^3)	Mean Green Density (Kg/m^3)	Bulk Density (Kg/m^3	Mean Bulk Density (Kg/m^3)
1	5 %	13	331		1698		1480	
2	Cement	11.7	298		1661		1451	1458
3		11.6	295		1658		1444	
1	6 %	21	540		1690		1486	
2	Cement	18.7	548		1681		1479	1480
3		19	541		1678		1475	
1	8 %	28.8	898		1720		1521	
2	Cement	28	714		1685		1509	1502
3		27	695		1658		1476	

Table E (xiv): Data of cement content on water absorption of cement stabilized-soil blocks: Soil sample C

Cement content (%)	Mass of block After 28 days curing	Mass after Immersion In water (24h)	Mass after Oven drying 100^0c for (24h)	$W_A = \left(\frac{M_2 - M_1}{M_1}\right) \times 100$ Water absorption (%)
6%	6.0	7.4	6.0	23.33
	5.6	6.9	5.6	23.21
	5.7	6.9	5.7	21.05
AVERAGE				22.53
STDDEV				1.283
STDERROR				0.740
8%	5.6	6.6	5.6	19.64
	5.7	6.8	5.7	19.30
	5.3	6.2	5.2	19.33
AVERAGE				19.42
STDDEV				0.188
STDERROR				0.108
10%	5.8	6.7	5.8	15.52
	5.5	6.4	5.5	16.36
	6.0	7.1	6.0	18.33
AVERAGE				16.736
STDDEV				1.177
STDERROR				0.679

Table E (xv): Data of cement content on dry compressive strength for cement stabilized-soil block for soil sample C

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Dry Compressive Strength KN/m^2	Mean dry Compressive Strength (kN/m^2)
1	6 %	18.55	464.9	
2	Cement	26.87	673.4	588
3		24.97	625.8	
1	8 %	32.59	816.79	
2	Cement	34	852	815.3
3		31	777	
1	10 %	42.7	1070	
2	Cement	44.6	1117.79	1113.78
3		44.44	1113.78	

Table E (xvi) Data of cement content on wet compressive strength for cement stabilized-soil block for soil sample C

Block No. in batch	Cement Content (%)	Maximum Load (KN)	Wet Compressive Strength KN/m^2	Mean Wet Compressive Strength (kN/m^2)
1	6 %	13.56	340	
2	Cement	13.5	339	342
3		13.89	348	
1	8 %	23.9	599	
2	Cement	27.8	697	664
3		27.77	696	
1	10 %	37.54	941	
2	Cement	37.78	947	952
3		38.62	968	

APPENDIX F

MATERIALS AND EQUIPMENT

1. Motor: 3 phase;5.5 kw;1420 rpm
2. V-Pulley: Ø127/ Ø102/ Ø 89/Ø75/ Ø73 (mm)
3. V- belt: A5460 17 x 1120 L1
4. Shaft: Ø38 mm x 20 kg x 390 mm: Cold drawn (Bright steel)
5. Pillo block bearings; Bore Ø 38 mm x 2 off
6. Mass: 1.5kg,1.25kg,1kg,0.75kg,0.5kg,0.25kg
7. Angle iron: 30 x 30 x 4 x 40 mm x 2 off
8. Plate:2400 x 1200 x 4 mm Shaft: Ø 15 mm x 200 mm x 20 off
9. Shaft: Ø 15 mm x 200 mm x 20 off
10. Soil: Sandy-clay-loam
11. Water: clean water
12. Cement: pozolanic cement: Ks EAS 18-1:2001
13. Compactor: to weigh 26 kg after assembly
14. Spring: Helical compression spring ;60mm x 25mm x 3mm x 4 off
15. Lathe machine: Harrison 600
16. Shaper: ELLIOT 18 M
17. Drilling machine: PILLAR-STARTRITE EFI-PM 401011;BENCH 126
18. The WP 310 Hydraulic universal material tester
19. Oven:

20. Proctor testing equipment and accessories:

21. Welding machine: OXFORD WELDER,OIL IMMERSED: 25A-250A

22. Angle grinder

23. Vernier height gauge

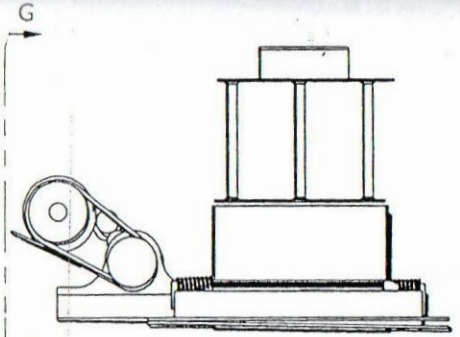
24. Tape Measure

APPENDIX G

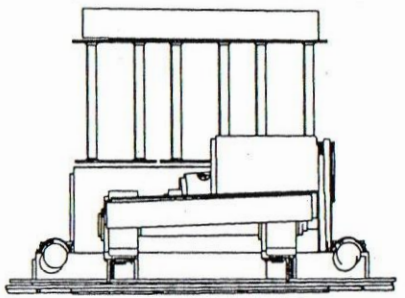
DRAWINGS

The drawings in this appendix include the following:

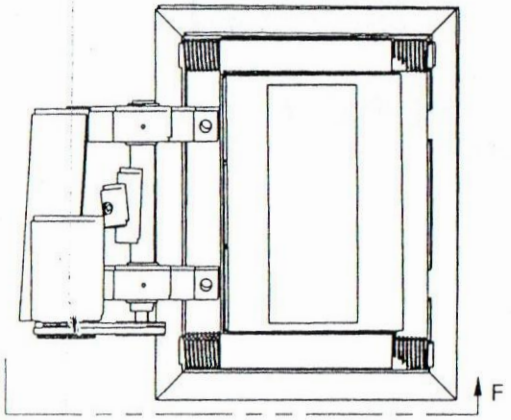
1. Rotor-mould-compactor assembly
2. Mould-rotor assembly
3. Machine base assembly
4. Eccentric masses
5. Exploded view of the helical compression spring
6. Compactor assembly

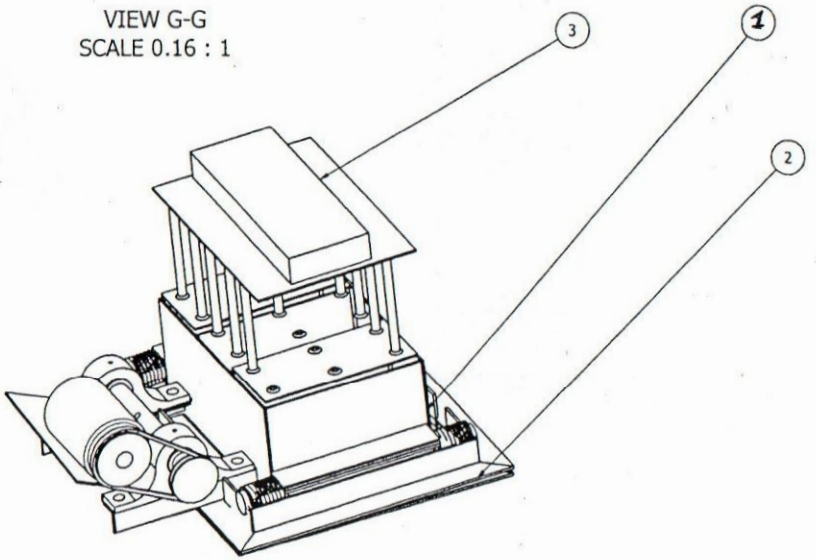


SECTION F-F
SCALE 0.16 : 1



VIEW G-G
SCALE 0.16 : 1



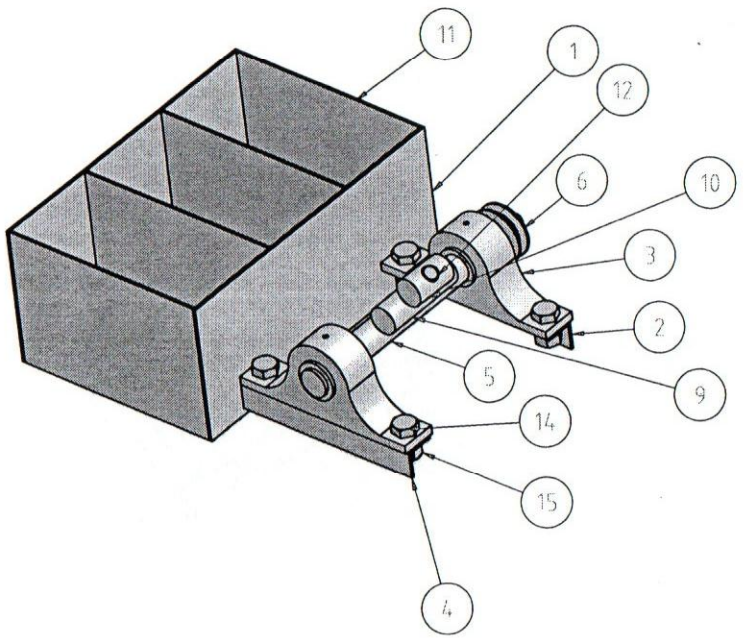


PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
2	1	3	Compactor assembly
3	1	2	Machine base assembly
1	1	1	Rotor-mould assembly

DRAWN JOGI	6/18/~~2017~~	
CHECKED		
QA		TITLE VIBRO COMPACTOR ASSEMBLY
MFG		
APPROVED		
		SIZE C | DWG NO 1 | REV
		SCALE | SHEET 1 OF 1

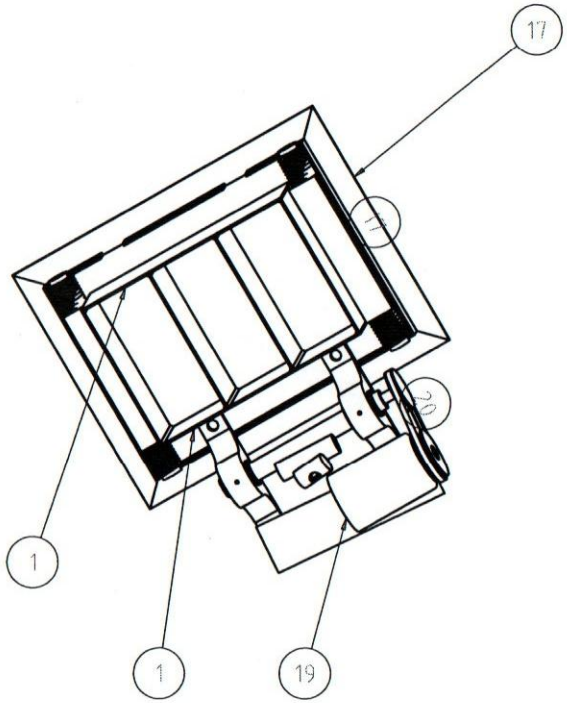
4 3 2 1

C B A



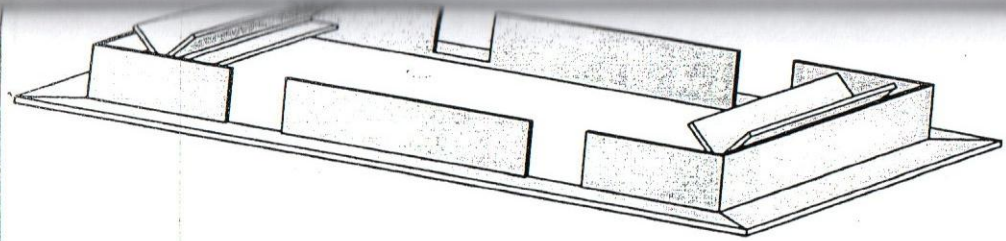
Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
15	4	ISO 4033 - M20	Hexagon nuts, style2 - Product grades A and B
14	4	ISO 8676 - M20 x 1.5 x 40 - A	Hexagon head screws with metric fine pitch thread
13	1	ISO 7413 - M12	Hexagon nuts for structural bolting, style 1, hot-dip galvanized (oversize tapped) - Product grades A and B - Property classes 5, 6 and 8
12	1	ISO 8676 - M12 x 1.25 x 110 - A	Hexagon head screws with metric fine pitch thread
11	4	side plate	
10	1	Weight 2	DRG. NO. 4
9	1	Weight 1	DRG. NO. 4
8	1	ISO 4035 - M20	Hexagon thin nuts (chamfered) - Product grades A and B
7	1	ANSI B18.22M - 20 R	Metric Plain Washers
6	1	Pulley	O/D 75
5	1	Rotor shaft	Ø38 x 400
4	1	angleline 2	40 x 40 x 5
3	2	pilo block bearing	Ø38
2	1	angle plate	40 x 40 x 5
1	2	front	428 x 196 x 4

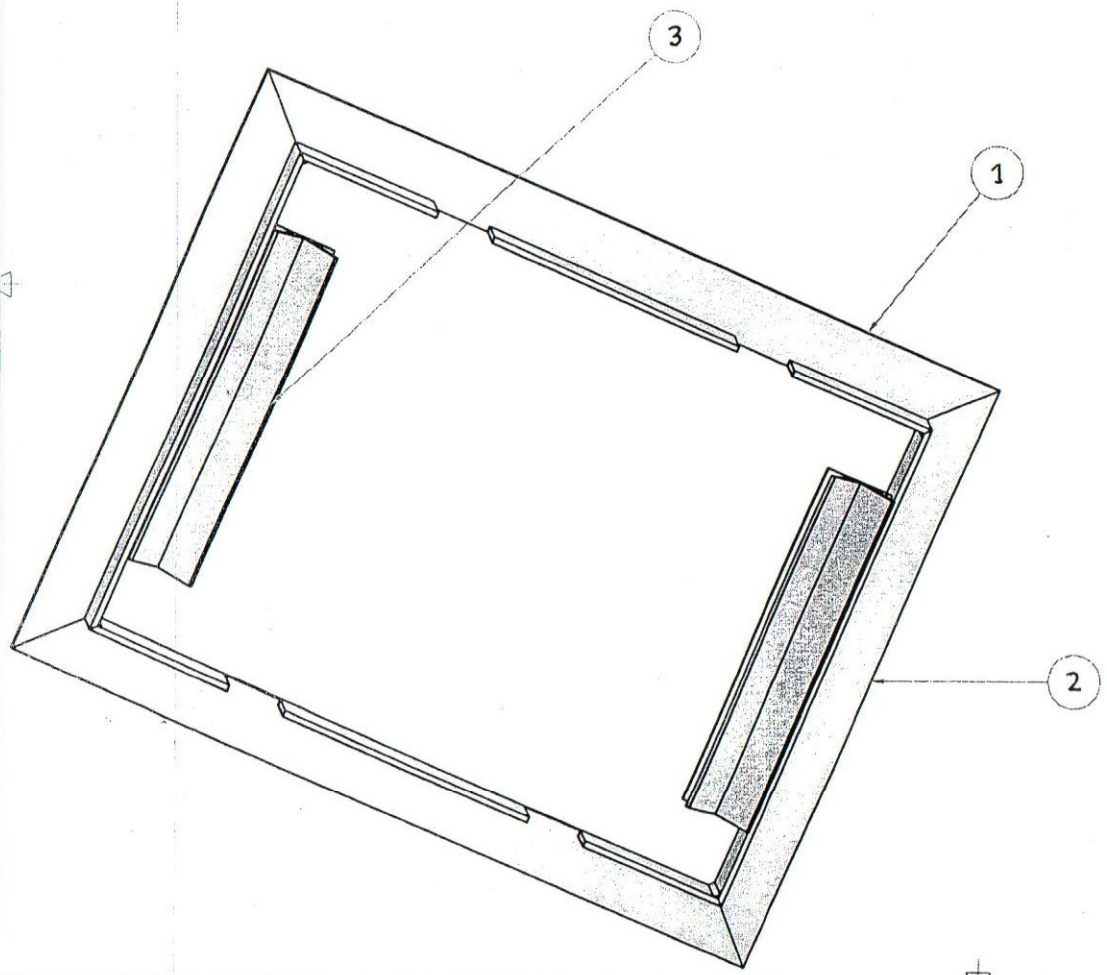
FILE NAME Stabilized Soil Block Mak	FSCM NO ng Machine	SHEET	SCALE 1:1
SIZE			
DRAWN Sept 2011 John Gitau			
CHECK		Mould Chamber and Rotor Assembly	
APPR.			
ISSUED			
REV		DWG NO -2A	(MM)
CONTRACT NO			



Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
22	4	Spring Support Assembly5	Drg.No. 4
21	1	Grooved Pulley1	Dia. 102 mm
20	1	V-Belt	Fenner A SP A 1120 L!
19	1	Motor Assembly1	5.5 Kw; 1420 rpm
17	1	Machine base Assembly	Drg. No. 3
16	2	Top rail Assembly1	Drg.No. 2
11	4	side plate	ms 290 x 196 x 4 mm
10	1	Weight 2	Drg.No. 4
9	1	Weight 1	Drg.No.4
5	1	Rotor shaft	Dia.38 x 400 mm
4	1	angleline 2	Drg.No.2
3	2	pilo block bearing	Dia. 38 mm
2	1	angle plate	Drg.No.2
1	2	front and back plate	ms 428 x 196 x 4 mm

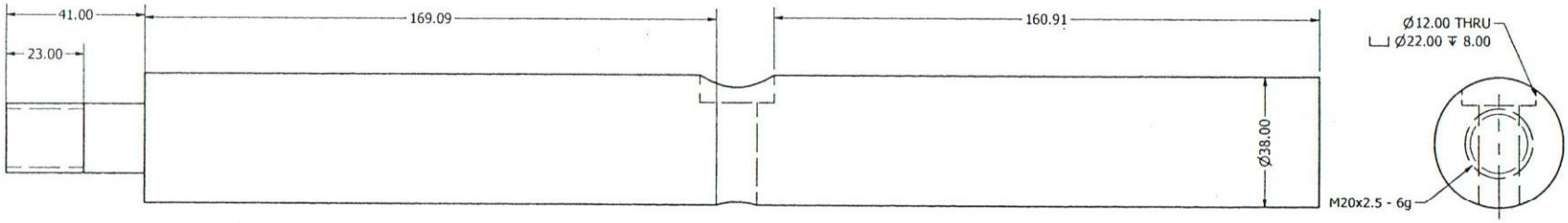
FILE NAME Vibration Static weight S	FSCM NO tabilized-soil Block	SHEET making machine	SCALE 1:1
SIZE			
DRAWN Sept.2011 J.GITAU			
CHECK			
APPR.		Rotor-Mould assembly	
ISSUED			
REV		DWG NO -02B	
CONTRACT NO			



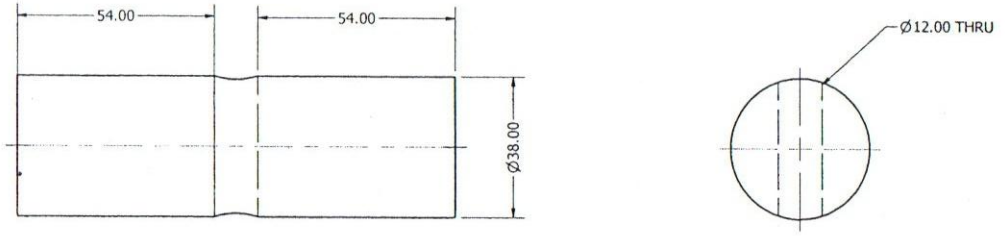


Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Front angle base	ms
2	2	Left angle base	ms
3	2	Rotor bottom rail	ms

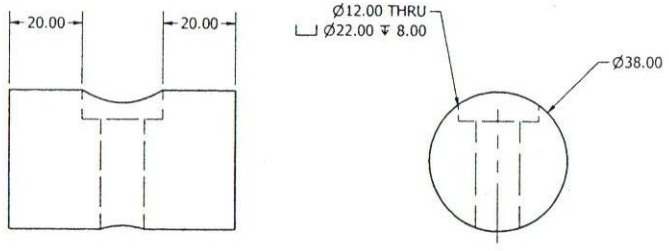
FILE NAME Vibration Static weight block making machine	FSCM NO	SHEET	SCALE
SIZE			
DRAWN 17.09.2012 J. Gitau			
CHECK		Machine base assembly	
APPR.			
ISSUED			
REV		DWG NO -3	
CONTRACT NO			



Part No.5 Rotor shaft



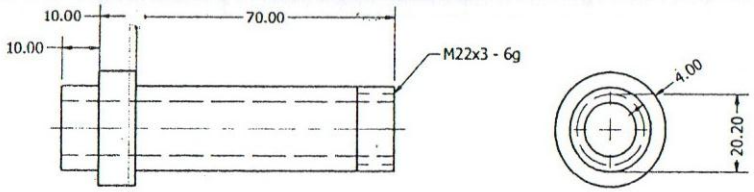
Part No. 9 weight 1



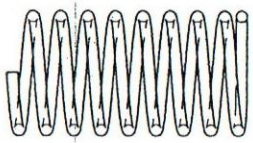
Part No. 10 Weight 2

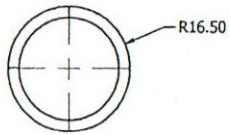
PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
3	1	10	Weight 2
2	1	9	Weight 1
1	1	5	Rotor Shaft

DRAWN JOGI	1/14/2012		
CHECKED		TITLE	Eccentric weights
QA			
MFG			
APPROVED			
		SIZE C	DWG NO Eccentric weights4 REV 1
		SCALE 1:2	SHEET 1 OF 1

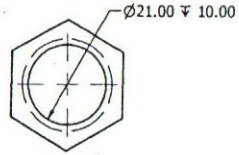


PT . No. 2

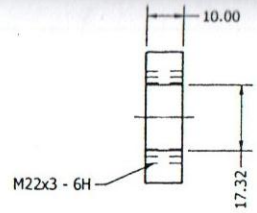


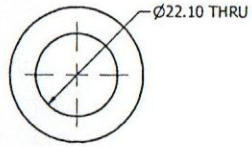


PT. No. 1

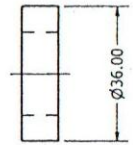


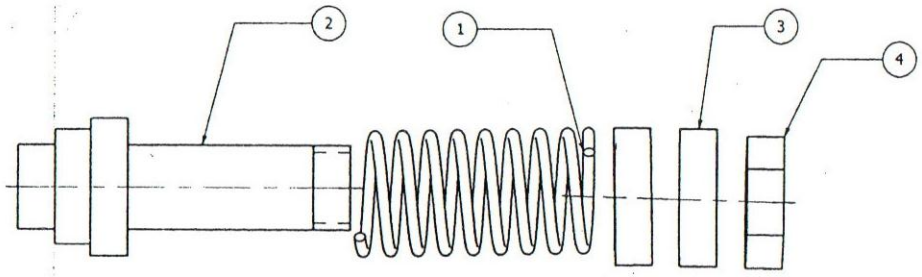
PT.No. 4





PT.No. 3



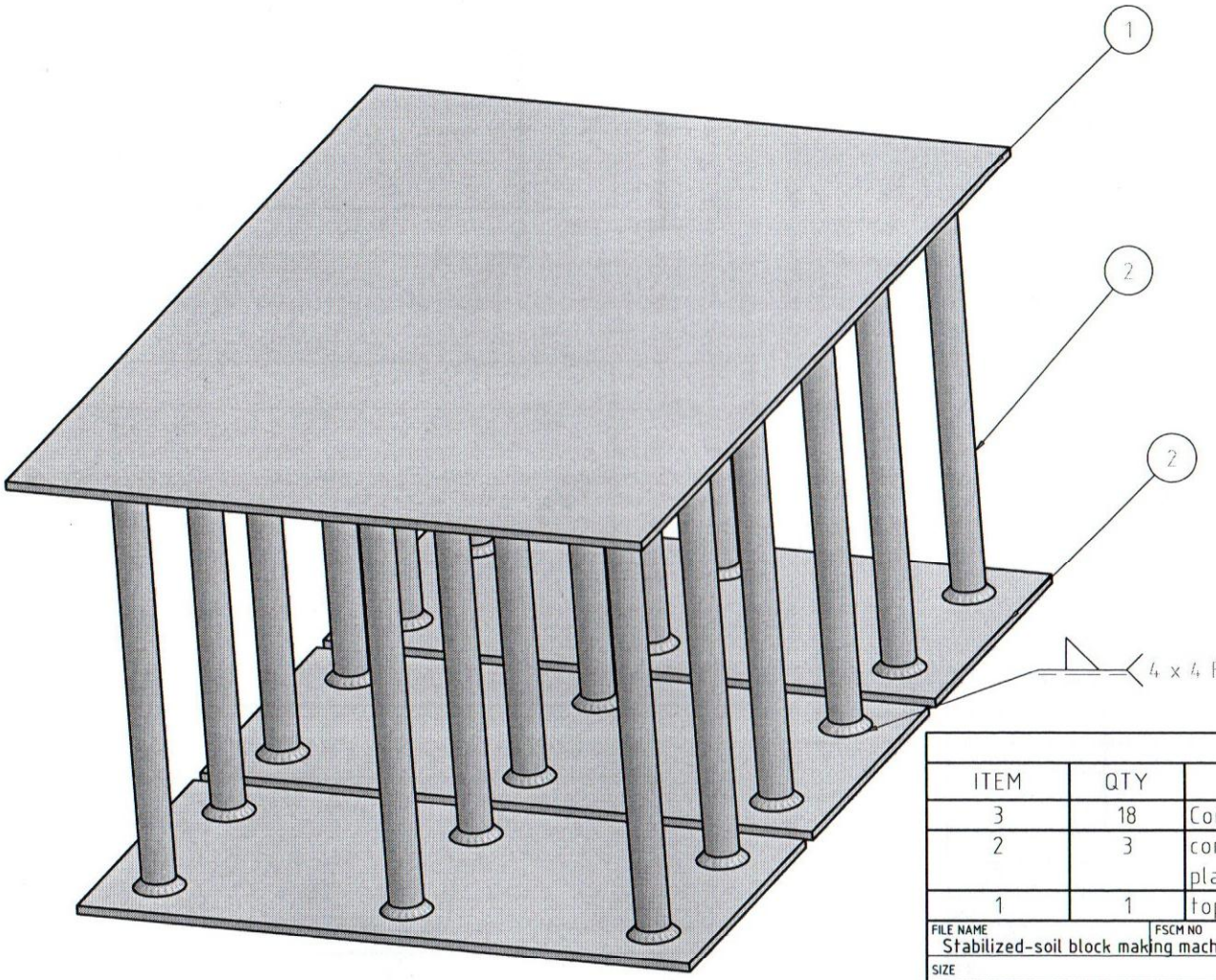


Exploded view of helical closed coil compression spring assembly

PARTS LIST

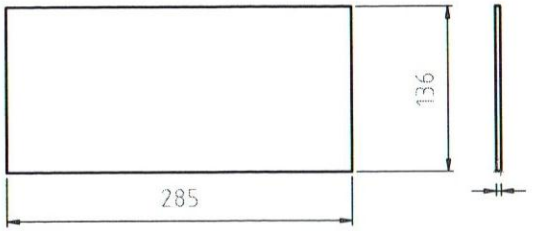
ITEM	QTY	PART NUMBER	DESCRIPTION
4	4	4	Lock Nut
3	12	3	Washer
2	4	2	Helical spring support
1	4	1	Helical closed coil spring 62 x 25 x 3 mm

DRAWN JOGI	1/12/2012	
CHECKED		TITLE: Helical closed coil compression spring assembly
QA		
MFG		
APPROVED		
		SIZE C; DWG NO: Helical coil spring.; REV
		SCALE; SHEET 1 OF 1

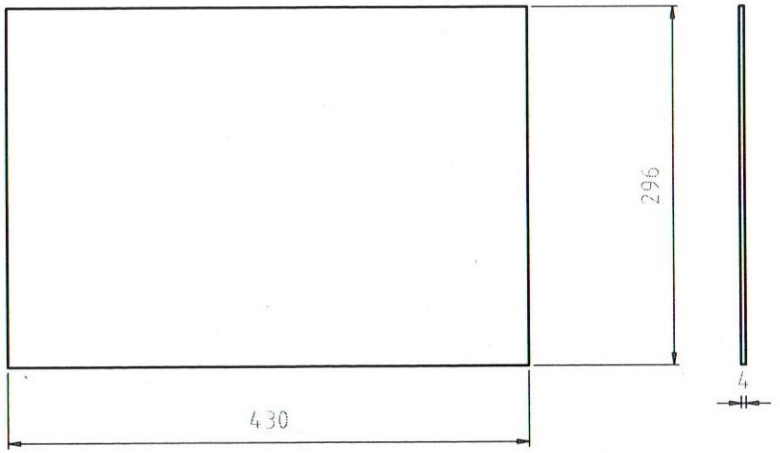


Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
3	18	Compactor spacer	ms Dia. 24 x 200 mm
2	3	compactor bottom plate	ms 285 x 135 x 4 mm
1	1	top plate	ms 430 x 296 x 4 mm

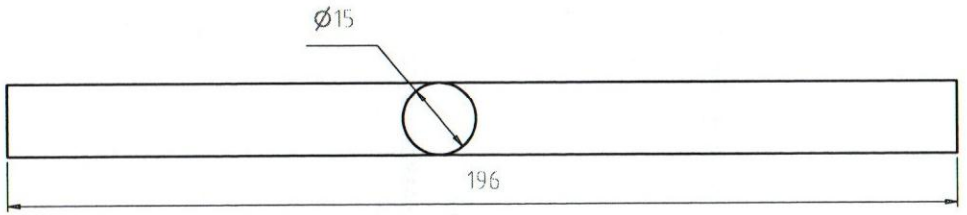
FILE NAME Stabilized-soil block making machine	FSCM NO	SHEET	SCALE 1:1
SIZE			
DRAWN October 2011 John Gitau BM12/1796/06			
CHECK		Compactor Assembly	
APPR.			
ISSUED			
REV		DWG NO -06	
CONTRACT NO			



PART 3



PART 2



PART 3

Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
3	18	Compactor separator	Dia. 15 x 200 mm
2	3	Compactor bottom plate	ms 285 x 135 x 4 mm
1	1	Top plater	ms 430 x 296 x 4 mm

FILE NAME Vibration static weight S	FSCM NO tabilizing-soil block	SHEET making machine	SCALE 1:1
SIZE			
DRAWN October 2011 John Gitau BM/1794/06		Compactor parts	
CHECK			
APPR.			
ISSUED			
REV		DWG NO -6	
CONTRACT NO			

APPENDIX H

Appendix H: Pair wise comparison of the column means (speed):

$$LSD = t_{0.025,15}\sqrt{2004\left(\frac{1}{4}+\frac{1}{4}\right)}$$

$$= 67$$

Hypothesis : $H_o : \mu_1 = \mu_2 = \mu_3 = \mu_4$

Where, average column mean densities are denoted by

$\bar{\rho}_{c1} = 1221$; $\bar{\rho}_{c2} = 1268$; $\bar{\rho}_{c3} = 1189$; $\bar{\rho}_{c4} = 1264$

And μ_i is the Speed rpm

$|\bar{\rho}_{c2} - \bar{\rho}_{c4}| = 4 < 67$, do not reject $H_o : \mu_{c2} = \mu_{c4}$

$|\bar{\rho}_{c2} - \bar{\rho}_{c1}| = 47 < 67$, *do not reject* $H_o : \mu_{c2} = \mu_{c1}$

$|\bar{\rho}_{c2} - \bar{\rho}_{c3}| = 79 > 67$, *reject* $H_o : \mu_{c2} = \mu_{c3}$

$|\bar{\rho}_{c4} - \bar{\rho}_{c1}| = 43 < 67$, do not reject $H_o : \mu_{c4} = \mu_{c1}$

$|\bar{\rho}_{c4} - \bar{\rho}_{c3}| = 75 > 67$, reject $H_o : \mu_{c4} = \mu_{c3}$

$|\bar{\rho}_{c1} - \bar{\rho}_{c3}| = 32 < 67$, do not reject $H_o : \mu_{c1} = \mu_{c3}$

Appendix H (ii).Pair wise comparison of the row means (eccentric mass):

Eccentric mass or row means, $LSD = t_{0.025,15}\sqrt{2004\left(\frac{1}{6}+\frac{1}{6}\right)}$

$= 55.077$

Hypothesis : $H_o : \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$

Where, $\bar{\rho}_{r1} = 1083$, $\bar{\rho}_{r2} = 1152$; $\bar{\rho}_{r3} = 1160$; $\bar{\rho}_{r4} = 1251$; $\bar{\rho}_{r5} = 1357$; $\bar{\rho}_{r6} = 1411$

And μ_i is the eccentric mass

$\lvert\bar{\rho}_{r6} - \bar{\rho}_{r5}\rvert = 54 > 55$;	*do not reject*	$H_o : \mu_{r6} = \mu_{r5}$
$\lvert\bar{\rho}_{r6} - \bar{\rho}_{r4}\rvert = 149 > 55$;	*reject*	$H_o : \mu_{r6} = \mu_{r4}$
$\lvert\bar{\rho}_{r6} - \bar{\rho}_{r3}\rvert = 251 > 55$;	reject	$H_o : \mu_{r6} = \mu_{r3}$
$\lvert\bar{\rho}_{r6} - \bar{\rho}_{r2}\rvert = 259 > 55$;	*reject*	$H_o : \mu_{r6} = \mu_{r2}$
$\lvert\bar{\rho}_{r6} - \bar{\rho}_{r1}\rvert = 328 > 55$;	reject	$H_o : \mu_{r6} = \mu_{r1}$
$\lvert\bar{\rho}_{r5} - \bar{\rho}_{r4}\rvert = 106 > 55$;	reject	$H_o : \mu_{r5} = \mu_{r4}$
$\lvert\bar{\rho}_{r5} - \bar{\rho}_{r3}\rvert = 197 > 55$;	*reject*	$H_o : \mu_{r5} = \mu_{r3}$
$\lvert\bar{\rho}_{r5} - \bar{\rho}_{r2}\rvert = 205 > 55$;	*reject*	$H_o : \mu_{r5} = \mu_{r2}$
$\lvert\bar{\rho}_{r5} - \bar{\rho}_{r1}\rvert = 274 > 55$;	*reject*	$H_o : \mu_{r5} = \mu_{r1}$
$\lvert\bar{\rho}_{r4} - \bar{\rho}_{r3}\rvert = 91 > 55$;	*reject*	$H_o : \mu_{r4} = \mu_{r3}$
$\lvert\bar{\rho}_{r4} - \bar{\rho}_{r2}\rvert = 99 > 55$;	*reject*	$H_o : \mu_{r4} = \mu_{r2}$
$\lvert\bar{\rho}_{r4} - \bar{\rho}_{r1}\rvert = 168 > 55$;	reject	$H_o : \mu_{r4} = \mu_{r1}$
$\lvert\bar{\rho}_{r3} - \bar{\rho}_{r2}\rvert = 8 > 55$;	do not reject	$H_o : \mu_{r3} = \mu_{r2}$
$\lvert\bar{\rho}_{r3} - \bar{\rho}_{r1}\rvert = 77 > 55$;	reject	$H_o : \mu_{r3} = \mu_{r1}$
$\lvert\bar{\rho}_{r2} - \bar{\rho}_{r1}\rvert = 69 > 55$;	reject	$H_o : \mu_{r2} = \mu_{r1}$

Table H: t-Test computation

Sample 1: $\rho_1 = 1470\ Kg/m^3$				Sample 2: $\rho_2 = 1250\ Kg/m^3$			
s/no.	X_{1i}	$X_{1i} - \rho_1$	$(X_{1i} - \rho_1)^2$	s/no.	X_{2i}	X_{2i}- ρ_2	$(X_{2i} -$ *ρ22*
1	1491	21	441	1	1273	23	529
2	1536	66	4356	2	1314	64	4096
3	1527	57	3249	3	1385	135	18225
4	1475	5	25	4	1505	255	65025
Totals		**149**	**8071**	5	1478	228	51984
Totals						**705**	**139859**

$$\overline{X}_1 = \rho_1 + \frac{\sum(X_{1i} - \rho_1)}{n_1} = 1507.25\ Kg/m^3$$

$$\overline{X}_2 = \rho_2 + \frac{\sum(X_{2i} - \rho_2)}{n_2} = 1391\ Kg/m^3$$

$$\sigma_{s_1}^2 = \frac{\sum(X_{1i} - \rho_1)^2 - [\sum(X_{1i} - \rho_1)]^2/n_1}{n_1 - 1} = 840.25\ Kg/m^3$$

$$\sigma_{s_2}^2 = \frac{\sum(X_{2i} - \rho_2)^2 - [\sum(X_{2i} - \rho_2)]^2/n_2}{n_1 - 1} = 10113.5 \text{ Kg/m}^3$$

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{(n_1 - 1)\sigma_{s_1}^2 + (n_2 - 1)\sigma_{s_2}^2}{n_1 + n_2 - 2} \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}} = 1.8114$$

APPENDIX J

Appendix J: Two-way 6 x 4 Anova – SPSS Statistics

```
GET
  FILE='D:\Documents and Settings\JOGI\My Documents\Two-way 6 x 4 Anova
Data.sav'.
UNIANOVA Density BY Mass Speed
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PLOT=PROFILE(Mass*Speed)
  /EMMEANS=TABLES(Mass) COMPARE ADJ(BONFERRONI)
  /EMMEANS=TABLES(Speed) COMPARE ADJ(BONFERRONI)
  /EMMEANS=TABLES(Mass*Speed)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=Mass Speed Mass*Speed.
GET
  FILE='D:\Documents and Settings\JOGI\My Documents\Two-way 6 x 4 Anova
Data.sav'.
UNIANOVA Density BY Mass Speed
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /PLOT=PROFILE(Mass*Speed)
  /EMMEANS=TABLES(Mass) COMPARE ADJ(BONFERRONI)
  /EMMEANS=TABLES(Speed) COMPARE ADJ(BONFERRONI)
  /EMMEANS=TABLES(Mass*Speed)
  /PRINT=ETASQ HOMOGENEITY DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=Mass Speed Mass*Speed.
```

Univariate Analysis of Variance

Between-Subjects Factors

		N
Mass	Mr1	4
	Mr2	4
	Mr3	4
	Mr4	4
	Mr5	4
	Mr6	4
Speed	Sc1	6
	Sc2	6
	Sc3	6
	Sc4	6

Descriptive Statistics

Dependent Variable Density

Mass	Speed	Mean	Std. Deviation	N
Mr1	Sc1	1090.0000	.	1
	Sc2	1133.0000	.	1
	Sc3	1066.0000	.	1
	Sc4	1045.0000	.	1
	Total	1083.5000	37.77565	4
Mr2	Sc1	1185.0000	.	1
	Sc2	1178.0000	.	1
	Sc3	1136.0000	.	1
	Sc4	1111.0000	.	1
	Total	1152.5000	35.12359	4
Mr3	Sc1	1111.0000	.	1
	Sc2	1161.0000	.	1
	Sc3	1131.0000	.	1
	Sc4	1238.0000	.	1
	Total	1160.2500	55.75766	4
Mr4	Sc1	1211.0000	.	1
	Sc2	1322.0000	.	1
	Sc3	1193.0000	.	1
	Sc4	1278.0000	.	1
	Total	1251.0000	59.81639	4
Mr5	Sc1	1321.0000	.	1
	Sc2	1407.0000	.	1
	Sc3	1266.0000	.	1
	Sc4	1437.0000	.	1
	Total	1357.7500	78.47452	4
Mr6	Sc1	1431.0000	.	1
	Sc2	1411.0000	.	1
	Sc3	1343.0000	.	1

	Sc4	1479.0000	.	1
	Total	1416.0000	56.41513	4
Total	Sc1	1224.8333	130.12981	6
	Sc2	1268.6667	126.85214	6
	Sc3	1189.1667	100.95824	6
	Sc4	1264.6667	172.27497	6
	Total	1236.8333	130.16834	24

Levene's Test of Equality of Error Variances[a]

Dependent Variable Density

F	df1	df2	Sig.
.	23	0	.

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Mass + Speed + Mass * Speed

Tests of Between-Subjects Effects

Dependent Variable Density

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	389707.333[a]	23	16943.797	.	.	1.000
Intercept	3.671E7	1	3.671E7	.	.	1.000
Mass	333641.833	5	66728.367	.	.	1.000
Speed	25225.000	3	8408.333	.	.	1.000
Mass * Speed	30840.500	15	2056.033	.	.	1.000
Error	.000	0	.			
Total	3.710E7	24				
Corrected Total	389707.333	23				

a. R Squared = 1.000 (Adjusted R Squared = .)

Estimates

Dependent Variable Density

Mass	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Mr1	1083.500	.	.	.
Mr2	1152.500	.	.	.
Mr3	1160.250	.	.	.
Mr4	1251.000	.	.	.
Mr5	1357.750	.	.	.
Mr6	1416.000	.	.	.

Pairwise Comparisons

Dependent Variable Density

(I) Mass	(J) Mass	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Mr1	Mr2	-69.000	.	.	.	.
	Mr3	-76.750	.	.	.	.
	Mr4	-167.500	.	.	.	.
	Mr5	-274.250	.	.	.	.
	Mr6	-332.500	.	.	.	.
Mr2	Mr1	69.000	.	.	.	.
	Mr3	-7.750	.	.	.	.
	Mr4	-98.500	.	.	.	.
	Mr5	-205.250	.	.	.	.
	Mr6	-263.500	.	.	.	.
Mr3	Mr1	76.750	.	.	.	.
	Mr2	7.750	.	.	.	.
	Mr4	-90.750	.	.	.	.
	Mr5	-197.500	.	.	.	.
	Mr6	-255.750	.	.	.	.
Mr4	Mr1	167.500	.	.	.	.
	Mr2	98.500	.	.	.	.
	Mr3	90.750	.	.	.	.
	Mr5	-106.750	.	.	.	.

	Mr6	-165.000	.	.	.	.
Mr5	Mr1	274.250	.	.	.	.
	Mr2	205.250	.	.	.	.
	Mr3	197.500	.	.	.	.
	Mr4	106.750	.	.	.	.
	Mr6	-58.250	.	.	.	.
Mr6	Mr1	332.500	.	.	.	.
	Mr2	263.500	.	.	.	.
	Mr3	255.750	.	.	.	.
	Mr4	165.000	.	.	.	.
	Mr5	58.250	.	.	.	.

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable:Density

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	333641.833	5	66728.367	.	.	1.000
Error	.000	0	.			

The F tests the effect of Mass. This test is based on the linearly independent pair wise comparisons among the estimated marginal means.

Estimates

Dependent Variable:Density

Speed	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Sc1	1224.833	.	.	.
Sc2	1268.667	.	.	.
Sc3	1189.167	.	.	.
Sc4	1264.667	.	.	.

Pairwise Comparisons

Dependent Variable:Density

(I) Speed	(J) Speed	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
Sc1	Sc2	-43.833	.	.	.	.
	Sc3	35.667	.	.	.	.
	Sc4	-39.833	.	.	.	.
Sc2	Sc1	43.833	.	.	.	.
	Sc3	79.500	.	.	.	.
	Sc4	4.000	.	.	.	.
Sc3	Sc1	-35.667	.	.	.	.
	Sc2	-79.500	.	.	.	.
	Sc4	-75.500	.	.	.	.
Sc4	Sc1	39.833	.	.	.	.
	Sc2	-4.000	.	.	.	.
	Sc3	75.500	.	.	.	.

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Univariate Tests

Dependent Variable:Density

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	25225.000	3	8408.333	.	.	1.000
Error	.000	0	.			

The F tests the effect of Speed. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

3. Mass * Speed

Dependent Variable:Density

Mass	Speed	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Mr1	Sc1	1090.000	.	.	.
	Sc2	1133.000	.	.	.
	Sc3	1066.000	.	.	.
	Sc4	1045.000	.	.	.
Mr2	Sc1	1185.000	.	.	.
	Sc2	1178.000	.	.	.
	Sc3	1136.000	.	.	.
	Sc4	1111.000	.	.	.
Mr3	Sc1	1111.000	.	.	.
	Sc2	1161.000	.	.	.
	Sc3	1131.000	.	.	.
	Sc4	1238.000	.	.	.
Mr4	Sc1	1211.000	.	.	.
	Sc2	1322.000	.	.	.
	Sc3	1193.000	.	.	.
	Sc4	1278.000	.	.	.
Mr5	Sc1	1321.000	.	.	.
	Sc2	1407.000	.	.	.
	Sc3	1266.000	.	.	.
	Sc4	1437.000	.	.	.

Mr6	Sc1	1431.000	.	.	.
	Sc2	1411.000	.	.	.
	Sc3	1343.000	.	.	.
	Sc4	1479.000	.	.	.

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RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Design of a semi-automatic machine for producing stabilized soil blocks and testing of the blocks"*** I am pleased to inform you that you have been authorized to undertake your research in ***Wareng District*** for a period ending ***30th June 2010.***

You are advised to report to **The District Commissioner, Wareng District, The District Education Officer Wareng District, The District Works Officer Wareng District and The Regional Officer, Kenya Bureau of Standards** before embarking on your research project.

Upon completion of your research project, you are expected to submit two copies of your research report/thesis to our office.

PROF. S. A. ABDULRAZAK Ph.D, MBS
SECRETARY

Copy to: