STRENGTH AND DURABILITY CHARACTERISTICS OF EARTHCRETE BLOCKS

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THESIS DECLARATION

I hereby declare that this Thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous publication for higher degree.

All quotations are distinguished by quotation marks and the source of information are specifically acknowledged by means of reference.

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JUNE, 1989

CERTIFICATION

We hereby recommend that the Thesis prepared under our supervision by Mr. ADEBAYO ADEDOKUN ADEYEYE entitled "Strength and Durability Characteristics of Earthcrete Blocks" be accepted as partial fulfilment of the requirements for the award of Master of Science Degree (in Civil Engineering Construction Materials) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literacy presentation.

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D E D I C A T I O N

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A B S T R A C T

Different lateritic deposits in and around Kaduna were investigated to determine the variations in the physical/ chemical compositions of the laterites. These variations in the physical/chemical compositions affect the mechanical properties of the laterites in the production of earthcrete blocks. Cylindrical specimens were cast to investigate the basic parameters, compactive effort and moisture content, that affect the production of earthcrete blocks. The cylindrical specimens were crushed to determine the ultimate load of the specimens. The laboratory compaction tests were carried out using both the Standard B.S. Compaction and Modified AASHO. Durability test was performed on a 75 mm diameter cored sample from a sound block which was placed on a constantly water saturated porous surface for 24 hours.

Earthcrete blocks were hydraulically pressed out of Terra Block Machine using different lateritic deposits. A few compressive strength tests were performed on the earthcrete blocks. From the results of the above tests, relationships between the compactive efforts and compressive stresses were obtained. It was observed that the higher the compactive efforts, the higher the maximum dry densities and the lower the optimum moisture content.

The importance of soil investigations around construction sites and material design were stressed in the study as pre-requirements before the commencement of the production of earthcrete blocks using the Terra Block Machine. It was observed that external walls of the earthcrete blocks needed a coat of sealant before rendering the surfaces.

1. INTRODUCTION

1.1 The rapid rate of our population growth and the high drift of population from rural areas to urban centres have generated enormous problems including that of shelter, thereby causing housing shortage. Also, the present financial crunch in the country in addition to the high cost of imported building materials have continued to heighten the housing problems. There is therefore an apparent need to develop local building materials that will substantially reduce the cost of housing projects.

In recent years, efforts of researchers have been geared towards development of local building materials. One of such materials is laterite used in the production of "ADOBE" - sun dried brick of clay and straw - which is probably the simplest and most cost effective way to build houses. Adobes have been in use in the tropical countries and Nigeria in particular for over a century. This implies that both the load and the non-load bearing walls are made of unfired clay. (2)

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In the United State of America in recent times, the result of research work has produced TERRA BLOCK MACHINE which hydraulically compresses common lateritic soils into stable and dimensionally uniform blocks that can go directly into building a wall without any curing or drying time. This relatively new innovation aims at increasing the mechanical performances of the laterites and making their application easier while still conserving all the lateritic properties.

1.2 LATERITES

Laterite which is abundantly available in Nigeria, is hydrated ferric oxide, generally containing some alumina (Al_2O_3) and silica (SiO_2). Its composition varies according to the nature of the underlying rock and the amount of chemical breakdown that has occurred over time. This shows that laterites differ to some extent in physical/chemical compositions depending on the nature of the parent rock. The variations in the physical/chemical compositions also affect the mechanical properties of laterites, the main raw material in the production of earthcrete/soilcrete blocks.

1.3 DEFINITIONS OF BASIC PARAMETERS

A few terms are important to be defined as used within the context of this work.

a) EARTHCRETE BLOCKS:- are mansory units of compacted lateritic clay to which no admixtures such as cement or emulsified asphalt are added.

b) SOILCRETE BLOCKS:- are mansory units which are essentially cement, laterite and water.

c) STABILIZATION:- is the act of improving the properties of a given soil to fulfil specified requirements. There are two methods of stabilization viz. Mechanical and Chemical Stabilization.

d) MOISTURE CONTENT:- of a soil is the percentage weight of moisture the given soil contains.

e) COMPACTION:- is the process whereby soil particles are made to pack more closely together through a reduction in air voids thereby improving its mechanical properties.

f) DURABILITY:- is the ability of the produced blocks to withstand changing weather conditions.

From the above definitions it follows that soilcrete blocks are stabilized earthcrete blocks. Production of good, durable and sound earthcrete blocks are affected by a number of factors some of which include type of laterite, moisture content, compactive effort and method of application.

1.4 STUDY OBJECTIVES

The study objectives are:

1.4.1 Identification of the significance of different lateritic deposits on the production of earthcrete (lateritic) blocks.

1.4.2 Investigation of the strength and durability characteristics of earthcrete building units.

1.4.3 Detail investigation of the effect of moisture content on the physical characteristics and compressive strengths of the earthcrete blocks.

1.4.4 Investigation of the direct effect of 1.4.1 --> 1.4.3 above on large scale production of earthcrete building units in

the field.

1.4.5 To make recommendations on possible and/or manufacturing changes on the TERRA BLOCK MACHINE for large scale production of earthcrete blocks.

1.4.6 Investigation of the influence of sand and cement stabilization on the physical characteristics and appearance of earthcrete blocks produced by the Terra Block System.

1.4.7 Investigation of the bond stresses between the earthcrete blocks.

2. LITERATURE REVIEW

2.1 In compacting laterite, soil particles are made to pack more closely together through a reduction in air voids thereby improving its mechanical properties. In particular, compaction increases the strength and durability of soils, reduces its compressibility and decreases its ability to absorb water. Compaction is measured quantitatively in terms of dry density of the soil which is the weight of the soil solids per cubic meter. (11) The moisture content of the soil is the weight of moisture present expressed as a percentage of the weight of oven dried soil. Therefore the dry density of a soil is determined from the bulk density of the soil by deducting the weight of moisture present.

2.2 Important factors that affect the compaction of a soil are:-

(a) Soil type

(b) Moisture content

(c) Compactive effort

(d) Method of application of compactive effort

(e) Thickness of the compacted layer.

Compaction can be expressed as a function of the above parameters.

i.e. $C = f(S, W, E, M, T)$

where
- C = Compaction
- S = Soil type
- W = Moisture content
- E = Compactive effort
- M = Method of Application
- T = Thickness of compacted layer

This study concentrates on a fixed block mould and a particular method of application of compactive effort; which imply that the thickness of the compacted layer and the method of application of the compactive effort are not variables. The above argument reduces our basic parameters to moisture content and the amount of the compactive effort for a given soil.

2.3 When a soil is compacted by the same method but with different compactive efforts, families of compaction curves, i.e. dry densities against moisture contents, are obtained as illustrated in figure 1. (12) From the figure it will be observed that the higher the compactive effort, the higher is the maximum density and the lower the optimum moisture content. A line connecting the maximum points (maximum dry density at optimum moisture content) in such a family of moisture content against dry density curves, approximates to a straight line.

2.4 As earlier stated, compaction of a soil increases its strength, compressive strength being a measure of the strength. Ola (10) stated that compactive pressure is one of the most important basic parameters considered in soil compaction and further confirmed that reports from most of the Tropical soils so far investigated indicated that there is a general increase in compressive strength with increase in compaction pressure. He also showed that the rate of increase in compressive strength with compaction pressure increase has initial high values but for a higher compactive pressure, insignificant increase in compressive

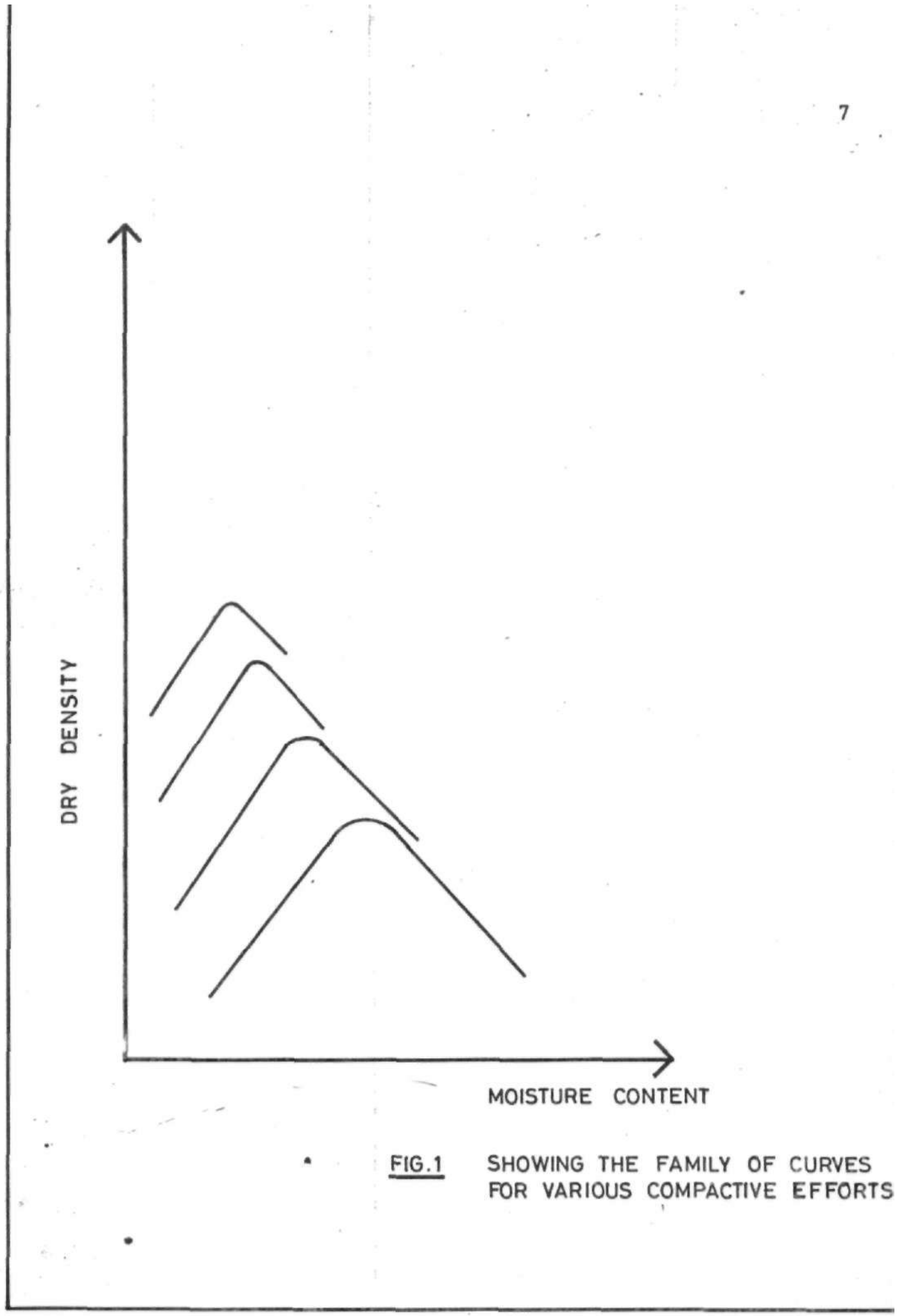


FIG.1 SHOWING THE FAMILY OF CURVES FOR VARIOUS COMPACTIVE EFFORTS

strengths are obtained. He then concluded that for both stabilized and unstabilized soils, at high compactive pressures, the compressive strength increases at a decreasing rate.

FLOREK, et, al, (8) identified the soil type which is widely used in the construction of houses in the tropics as 'Red Clay' laterite. The paper highlights some of the properties of such red clay as shown in Table 1.

TABLE 1

Some Physical Properties of 'Red Clay' Laterite

Percentage finer than B.S. sieve No. 7	98.75
Percentage finer than B.S. sieve No. 200	79.50
Percentage of sand	20.00
Percentage of silt	60.00
Percentage of clay	20.00

DIRISU, et, al, (5) in their research on how to achieve optimum compressive strength with a low cement content showed that a 4% cement content with a compactive effort of $3N/mm^2$ produced cement stabilized block of adequate strength and durability. The research was carried out using Bagauda clay soil from Kano having the physical properties as shown in Table 2.

TABLE 2

Physical Properties of Bagauda Clay Soil

1.	Specific Gravity	2.6
2.	Atterberg Limits	
	(i) Liquid Limit	32%
	(ii) Plastic Limit	19%
	(iii) Plasticity Index	13%
3.	Mechanical Composition	
	(i) Clay	28%
	(ii) Silt	26%
	(iii) Sand	46%
4.	Soluble Salt	Almost Nil
5.	PH Value	9.1

From the two tables above the following deductions are made:

2.4.1 Coarse aggregates are eliminated in the materials for the production of bricks and blocks. Table 1 only shows 1.25% retained on B.S. sieve No. 7, and this is negligible.

2.4.2 The granular materials (sand) provide excellent mechanical stability for the block.

2.4.3 In the stable soil mixture, the granular fraction furnishes strength and hardness and can be compared to the function of aggregates in concrete.

2.4.4 The greater percentage of the laterite is in the fine soil region which include silt and clay. Table 1 has 80% while Table 2 has 54% in this region.

2.4.5 The fine soil fraction serves as a filler for the granular fraction and acts as a cementing medium to bind all the particles into a strong durable mass.

2.5 FOLA LASISI, et, al, (9) showed that the strength characteristics of stabilized and unstabilized lateritic soils are affected by the grain size range. A conclusion that the finer the grains the greater the compressive strength of the specimen tested was reached by Lasisi and Ogunjide (9) from their studies on the strength characteristics of Ifewara laterites.

2.6 The traditional problems associated with the use of clay soils for construction are poor durability and strength as highlighted in several papers. Research was therefore carried out to improve on the strength and durability properties of Nigerian lateritic clays for better performance.

DIRISU, et, al, (5) highlighted the need for the development of a block moulding machine that will bring about better performance of earthcrete blocks. The development of the machine became necessary from the fact that in the traditional production of blocks, sufficient compaction was never attained since the moulded blocks are at best tampered with hand.

The air voids are many as the soil particles are loosely packed and low compressive strength of the blocks so produced are observed.

2.7 The need for soil stabilization cannot be over-emphasised. One of the ways of achieving better compaction is by mechanical stabilization which is in the form of high compacting pressure to bring the soil particles much closer together thereby improving the compressive strength. When the material added to the given soil for stabilization is merely another type of soil in which the original soil is deficient, the process is termed Mechanical Stabilization, as no reaction takes place. Mechanical Stabilization gives rise to a more well-graded soil which has both cohesive and internal frictional properties, leading to better shear strength and stability.

Several other reports have appeared on soil stabilization using cementitious materials such as Portland Cement, Lime, Resins and Bitumen. In considering stabilized compressed tropical soils Ola (10) showed that the effects of compaction far outweighs the effect of cement content in a block. However, compaction pressures greater that $8MN/m^2$ will increase neither the tensile strength nor the compressive strength significantly.

The results of the research work carried out in the Department of Civil Engineering, Ahmadu Bello University by FLOREK A, et, al, (8) showed that high compactive pressure on soilcrete blocks are of no added advantage. The result showed that increase in cement content produced an increase in compressive

strength of the cubes tested up to 12.0 percent cement content. Similar increase in strength was seen with an increase in compaction pressure up to 4.0 N/mm^2. Results from FLOREK A, et, al, (6) showed that the compressive strength of soilcrete hollow blocks depend to a large extent on the method of curing adopted. They gave the standard method of curing to achieve a high strength as soaking the blocks produced in water after twenty four hours of age for two days. The blocks are then removed and allowed to cure for 28 days prior to testing under laboratory atmosphere.

2.8 FLOREK A, et, al, (8) investigated some properties of soilcrete including durability test. Some of the conclusions arrived at are :-

2.8.1 The elastic modulus of soilcrete tends to increase when compaction pressure of the specimen increases for a particular cement content. It also tends to increase for an increase in the cement content.

2.8.2 In describing or stating a particular soilcrete mix, both the cement content and the compaction pressure should be specified (not only one of them).

(f) Compression Tests on cylindrical specimens with varying moisture contents and compactive efforts.

(g) Shear Test on moulded blocks.

3.2 GRADING

The particle size analysis of a soil sample involve the determination of percentage by weight of particles within the different sizes. The particle size distribution of a coarse portion of each soil was determined by the method of sieving while that of the fine grained portion of the soil was determined by the method of sedimentation (wet analysis).

3.3 ATTERBERG LIMITS

3.3.1 LIQUID LIMIT of a soil is the moisture content at the boundary between the liquid and plastic states. The liquid limits of the four samples were determined using the standard liquid limit apparatus. The soil samples were seived through No. 40. The soil samples were then thoroughly mixed with water and was placed in the dish of the apparatus to a thickness of 25.0 mm at the bottom of the dish. A groove of 12.76 mm width was cut in the middle of each sample. The dish was then lifted and dropped by turning the crank. The number of drops required to close the 12.76 mm groove was recorded. The liquid limit was then read from the graph of moisture content against number of drops that closed the groove, as the moisture content at which 25 drops of the dish closed the 12.76 mm groove.

3.3.2 PLASTIC LIMIT of a soil is the moisture content at the boundary between the plastic and semi-solid states. The soil was mixed with water and rolled into threads of 3 mm in diameter without breaking into pieces.

The lowest moisture content at which the threads was achieved without breaking into pieces was determined.

PLASTICITY INDEX

Liquid limit minus plastic limit

= Plasticity Index.

3.4 NATURAL MOISTURE CONTENT

The natural moisture content of a soil is the weight of water it contains divided by the weight of an oven-dried soil expressed as a percentage. This was determined by weighing a quantity of soil containing moisture in a moisture content container, W_1. The soil sample was then left in the oven to dry for 24 hours. The weight of the oven dried soil was recorded after it was allowed to cool as W_2. Finally the moisture content container was weighed empty as W_3.

Moisture content of the soil is given as :

$$\frac{W_1 - W_2}{W_2 - W_3} \times 100$$

3.5 COMPACTION OF SOIL

Production of cylindrical specimens of the soils was carried out using the Universal Testing Machine. Soil was filled



PLATE 1 - A TYPICAL COMPACTION PROCESS



PLATE 2

A VIEW SHOWING EXTRUSION PROCESS

without shock and increased continuously at the rate of 10 KN/min until the ultimate load was reached.

3.7 LABORATORY COMPACTION TESTS

The laboratory compaction tests were carried out as a guide in the determination of the optimum moisture content and maximum dry density for a given soil sample. The results of both the Standard B.S. compaction and the Modified AASHO were compared with the results of compaction using the Universal Testing Machine. The author acknowledges the West African method of compaction as one of the laboratory methods of compaction that could be carried out. Suffice it to say that the B.S. Standard compaction and the modified AASHO methods are more universally adopted. As it was not the intention of the author to compare the results of various laboratory methods but to give a guide in the determination of the optimum moisture content and maximum dry density hence the restriction to the B.S. Standard compaction and Modified AASHO methods.

3.8 SHEAR TEST ON MOULDED BLOCK

The lateral force required to cause a slip of the loaded block over the bottom block was determined by the use of load cell shown in Plate 3. This was the force required to overcome the forces of static friction. As more blocks were placed on the block under test which increased the normal force, the lateral force for each incremental load was determined.

$$\frac{F}{N} = \mu$$

where F = Lateral force

N = Normal load

μ = Coefficient of static friction.

A graph of lateral force against normal load was plotted.



PLATE 3 - Typical arrangement of earthcrete blocks and load cell for Shear test.

3.9 DURABILITY TEST

Durability test enables us to study the ability of the produced blocks to withstand changing weather conditions such as wind and rain. A 75 mm diameter specimen was cored from a good (sound) block produced. The cored sample was placed on a constantly water saturated porous surface for 24 hours. The passage of water through the cored sample was observed.

4. TEST RESULTS AND DISCUSSIONS

4.1 GRADING:- The results of the grading (wet and dry - analysis) for the four samples are plotted on the semi logarithmic graph as shown in fig 2. Table 4 shows the percentages of clay content in each soil sample.

TABLE 4: PERCENTAGES OF CLAY IN THE SOIL SAMPLES

SAMPLE NUMBER	LOCATION OF BORROW PIT	PERCENTAGE CLAY
A	Along Kachia Road near NNPC Refinery	33.0
B	MALALI	1.0
C	NO. 8 GIWA ROAD	8.0
D	RIGASSA	42.0

The sample numbers indicated in the Table are used for identification in the subsequent discussions.

4.2 ATTERBERG LIMITS

The results of the Atterberg limits are shown in Table 5.

TABLE 5: ATTERBERG LIMITS FOR THE SOIL SAMPLES

SAMPLE NUMBER	LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX
A	39.5	17.6	21.9
B	37.5	NIL	N.P.
C	26.0	14.0	12
D	40.0	19.0	20.7

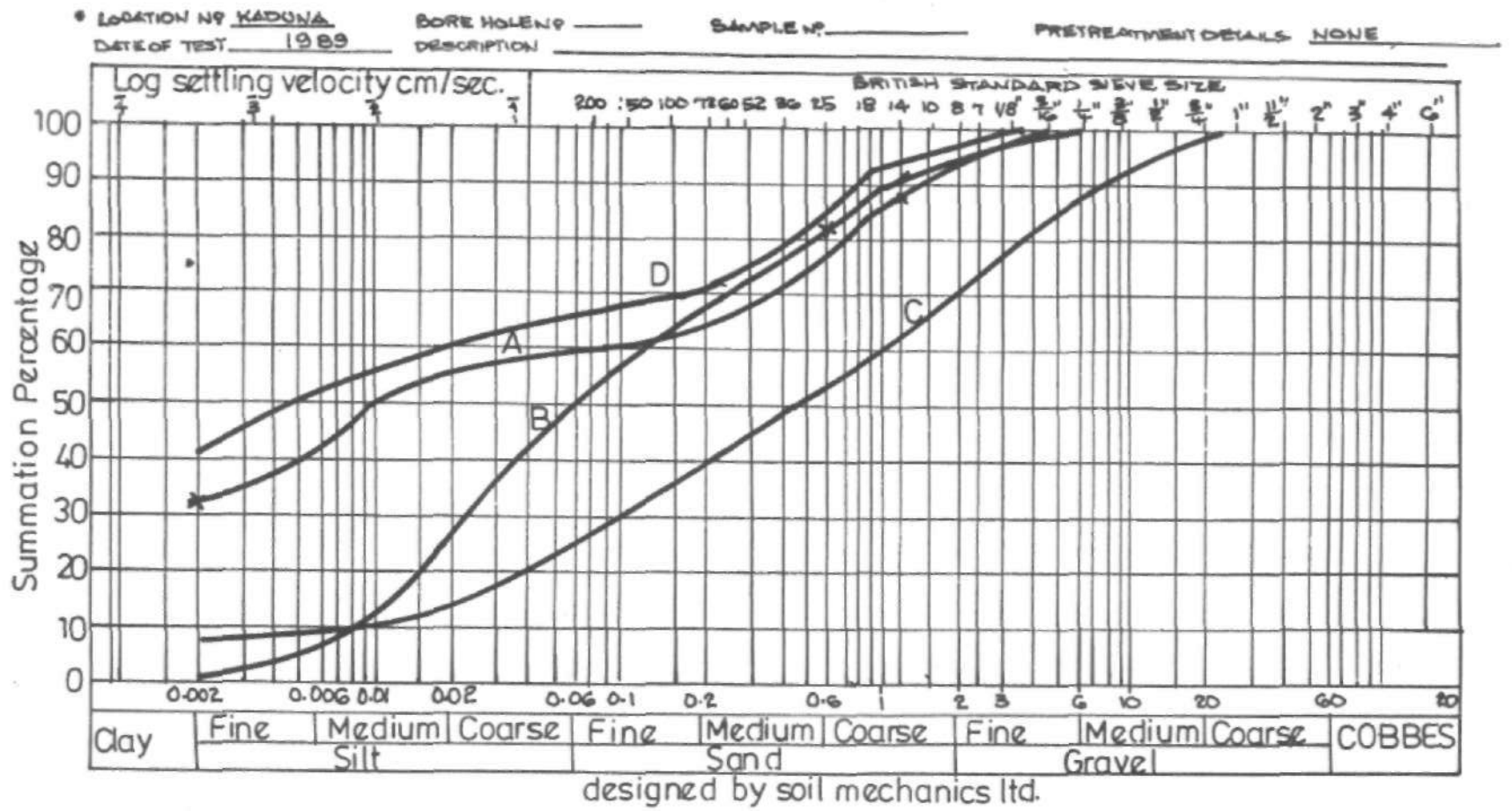


FIG. 2: PARTICLE SIZE DISTRIBUTION

From the results of the Mechanical analysis, liquid limit and Plasticity Index, the soil groupings based on the HRB or AASHO were obtained and these are given in Table 6.

TABLE 6: CLASSIFICATIONS FOR THE SOIL SAMPLES

SAMPLE NUMBER	SOIL CLASSIFICATION
A	A - 6 (6)
B	A - 4 (4)
C	A - 2 - 6 (1)
D	A - 7 - 6 (6)

4.3 NATURAL MOISTURE CONTENT

Table 7 shows the results of the natural moisture contents of the four samples.

TABLE 7: NATURAL MOISTURE CONTENTS OF THE SOIL SAMPLES

SAMPLE NUMBER	NATURAL MOISTURE CONTENT %
A	13.26
B	22.0
C	13.48
D	15.76

4.4 TESTS ON CYLINDRICAL SPECIMENS

The results of compaction tests on cylindrical specimens produced using the Universal Testing Machine are given in Tables 8 and 9. The tables give the results of the bulk densities, dry densities and moisture contents for given compactive efforts. Graphs of dry densities against moisture contents for given compactive efforts are plotted in figures 3 and 4. Giwa soil sample was used.

4.5 COMPRESSIVE STRENGTH TESTS

The results of the compressive strength tests on the cylindrical specimens are as given in Tables 10 and 11. The tables give the results of failure loads, compressive stresses and moisture contents for given compactive efforts. Graphs 5 and 6 show the compressive stresses against moisture contents.

The importance of the verticality of the cylindrical specimens when placed within the platens of the Universal Testing Machine cannot be over-emphasised. Plate 4 shows the typical view of a vertically well aligned cylindrical specimen when tested to failure. It is observed that the top cone is centrally placed and the crack pattern is symmetrical about the vertical axis of the cylinder. Plate 5 shows the view of an eccentrically loaded cylindrical specimen, load being applied at an eccentricity to the vertical axis of the specimen when placed within the platens of the Universal Testing Machine. Failure loads are much lower when loads are applied at an eccentricity to the vertical axis of the

TABLE 8 GIWA SAMPLE

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	140	1771.20	5.31	1681.89
2.		1811.38	7.51	1684.85
3.		1967.84	9.98	1789.27
4.		2093.27	11.95	1869.83
5.		2109.33	12.70	1871.63
6.		2126.49	14.53	1856.71
1.	155	1780.93	5.57	1686.97
2.		1816.53	7.63	1687.75
3.		1955.28	10.35	1771.89
4.		2050.54	11.78	1834.44
5.		2132.71	13.18	1884.35
6.		2129.61	15.73	1840.15
1.	170	1783.20	5.72	1686.72
2.		1863.38	7.69	1730.32
3.		2042.08	10.18	1853.40
4.		2150.80	13.05	1902.52
5.		2171.52	14.40	1898.18
6.		2174.93	14.65	1897.02
1.	185	1834.49	6.06	1729.67
2.		1871.25	7.90	1734.24
3.		2053.34	11.14	1847.53
4.		2141.25	12.38	1905.37
5.		2152.46	14.35	1882.34
6.		2185.04	14.95	1900.86

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	200	1854.10	6.33	1743.72
2.		1974.49	9.37	1805.33
3.		2113.12	11.39	1897.05
4.		2166.61	12.91	1918.88
5.		2195.99	14.43	1919.07
6.		2141.05	15.95	1846.53

TABLE 9

GIWA SAMPLE SIEVED THROUGH 2.4mm SIEVE

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	140	1752.00	6.31	1647.97
2.		1830.55	9.69	1668.81
3.		1930.87	10.72	1743.96
4.		2056.34	12.87	1821.94
5.		2122.98	14.41	1855.60
6.		2126.07	15.07	1847.71
1.	155	1800.69	7.67	1672.44
2.		1923.50	10.94	1733.69
3.		2094.26	12.72	1857.98
4.		2054.97	12.86	1820.81
5.		2178.31	14.74	1898.53
6.		-	-	-
1.	170	1778.74	5.16	1691.46
2.		1908.19	8.42	1760.00
3.		2113.01	10.48	1912.57
4.		2166.42	12.18	1931.20
5.		2171.25	13.22	1917.73
6.		2103.32	14.88	1830.88
1.	185	1790.10	5.89	1690.53
2.		1910.98	8.99	1753.35
3.		2111.38	10.78	1905.92
4.		2171.66	12.00	1938.98
5.		2169.13	13.57	1909.95
6.		2136.06	14.33	1868.33

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	200	1734.20	5.97	1636.50
2.		1921.18	9.70	1751.30
3.		2093.39	10.45	1895.33
4.		2182.00	12.48	1939.90
5.		2218.92	13.63	1952.76
6.		2194.07	14.88	1909.88

⊙-----1 - C/P = 140 KW

△-----2 - „ = 155 KW

⊡-----3 - „ = 170 KW

⊗-----4 - „ = 185 KW

⊞-----5 - „ = 200 KW.

C/P = COMPACTIVE PRESSURE

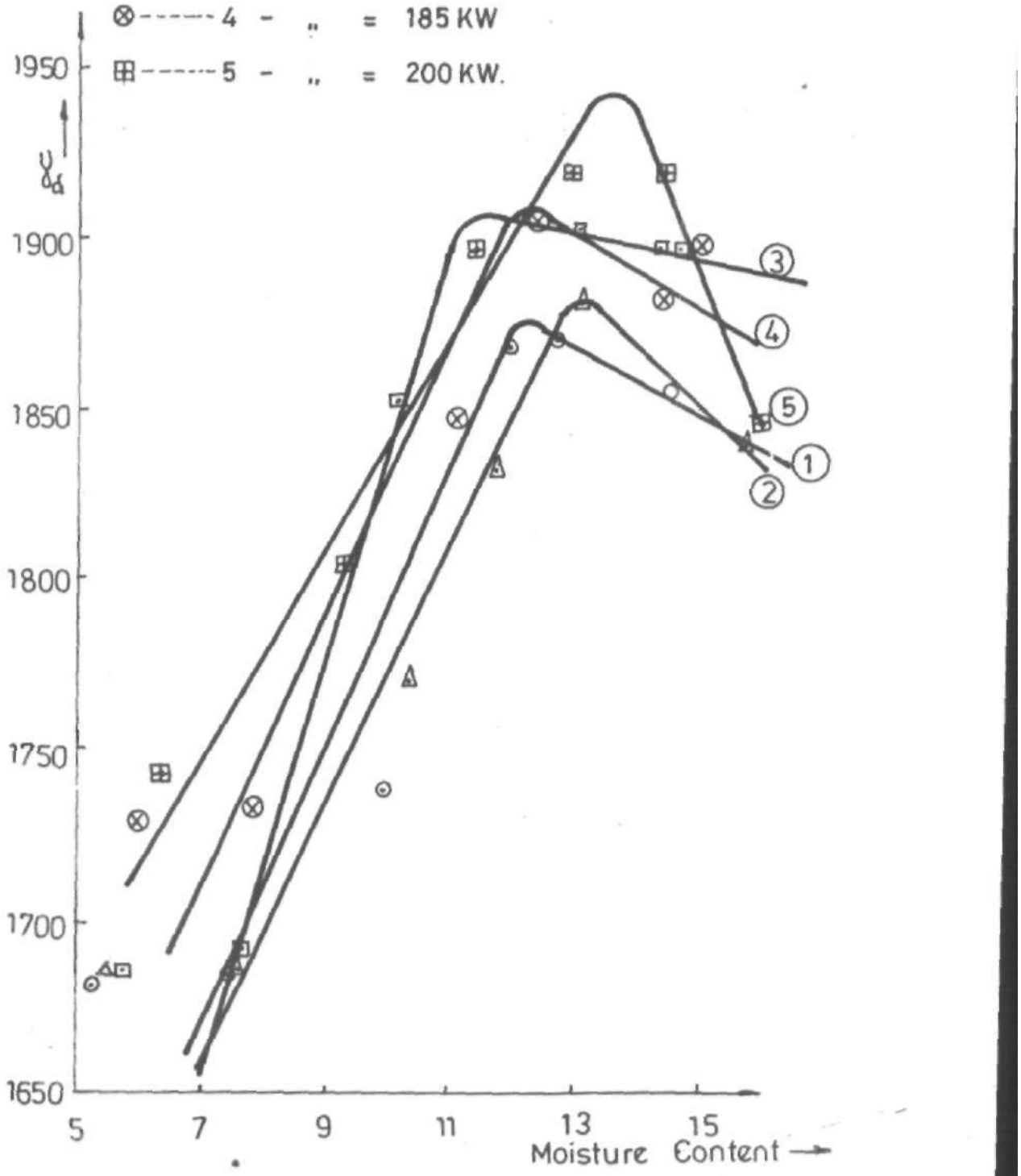


FIG. 3: GRAPH OF DRY DENSITY AGAINST MOISTURE CONTENT FOR GIWA SAMPLE SIEVED THROUGH 5.00mm SIEVE SIZE

⊙——— 1 - C/P. = 140 KW
A ——— 2 - „ = 155 KW
⊞——— 3 - „ = 170 KW
⊕——— 4 - „ = 185 KW
⊞——— 5 - „ = 200 KW.

C/P. = COMPACTIVE PRESSURE.

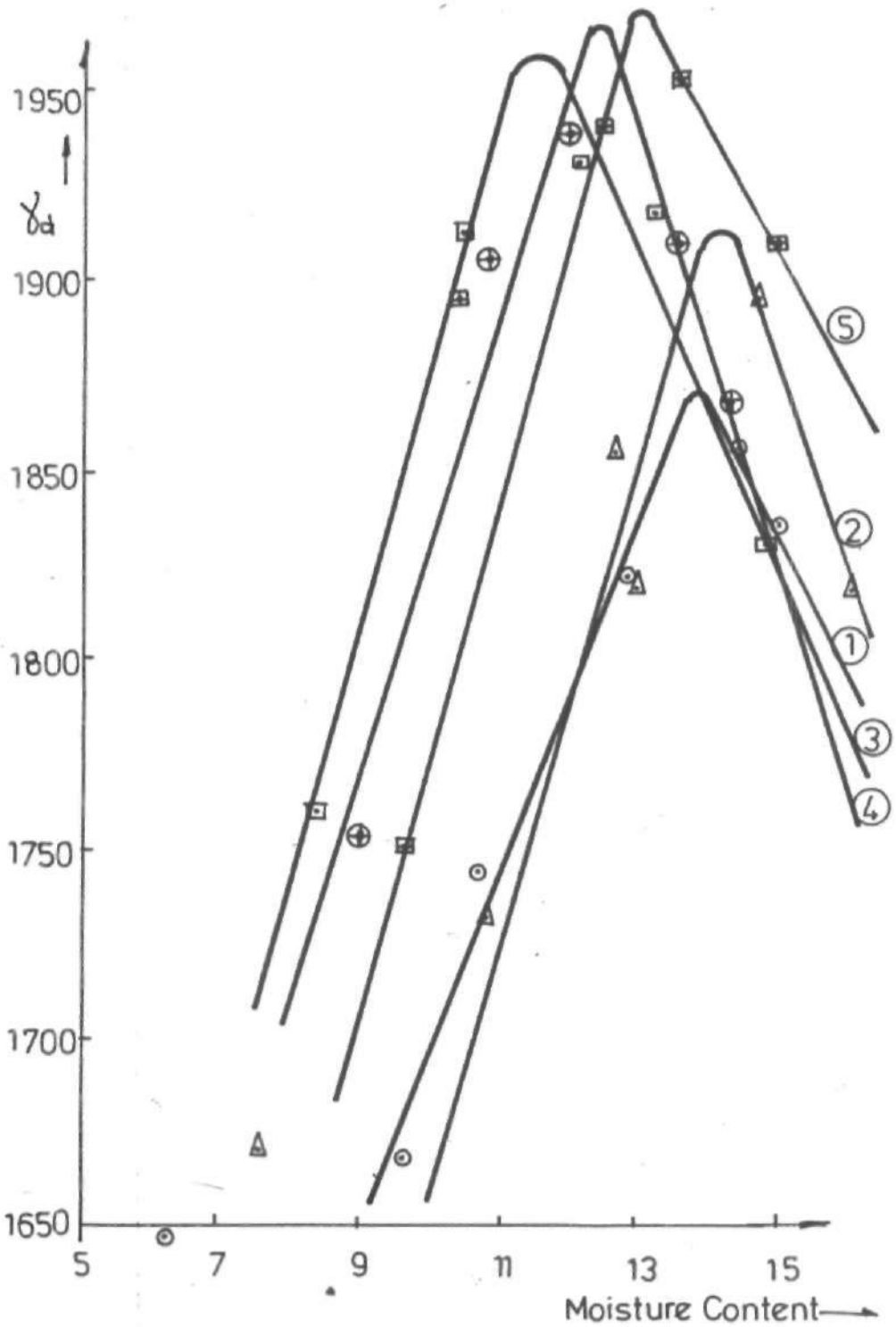


FIG. 4: GRAPH OF DRY DENSITY AGAINST MOISTURE CONTENT FOR GIWA SAMPLE SIEVED THROUGH 2.4mm SIEVE SIZE

TABLE 10

GIWA SAMPLE SIEVED THROUGH 5.0mm SIEVE

S/NO.	COMPACTIVE EFFORT KN	FAILURE LOAD KN	COMPRESSIVE STRESS (N/mm^2)	MOISTURE CONTENT %
1.	140	1.90	0.22	5.31
2.		3.77	0.44	7.51
3.		12.83	1.48	9.98
4.		13.50	1.56	11.95
5.		10.10	1.17	12.70
6.		8.93	1.03	14.53
1.	155	2.60	0.30	5.57
2.		5.10	0.59	7.63
3.		13.53	1.56	10.35
4.		14.63	1.69	12.08
5.		9.13	1.05	13.59
6.		6.70	0.77	15.73
1.	170	4.50	0.52	5.72
2.		5.60	0.66	7.69
3.		18.07	2.09	10.18
4.		11.17	1.29	13.05
5.		5.60	0.66	14.40
6.		3.80	0.44	14.65
1.	185	5.30	0.61	6.06
2.		7.30	0.84	7.90
3.		19.00	2.19	11.14
4.		14.90	1.72	12.38
5.		8.20	0.95	14.35
6		4.80	0.55	14.95

S/NO.	COMPACTIVE EFFORT KN	FAILURE LOAD KN	COMPRESSIVE STRESS (N/mm^2)	MOISTURE CONTENT %
1.	200	4.13	0.48	6.33
2.		11.23	1.30	9.37
3.		20.10	2.32	11.39
4.		15.00	1.73	12.91
5.		8.80	1.02	14.41
6.		4.50	0.52	15.95

TABLE 11

GIWA SAMPLE SIEVE THROUGH 2.4mm SIEVE

S/NO.	COMPACTIVE EFFORT KN	FAILURE LOAD KN	COMPRESSIVE STRESS (N/mm^3)	MOISTURE CONTENT %
1.	140	3.33	0.38	6.31
2.		6.73	0.78	9.69
3.		14.40	1.66	10.72
4.		18.33	2.12	12.87
5.		10.50	1.21	14.41
6.		9.70	1.12	15.07
1.	195	5.07	0.59	7.67
2.		11.20	1.29	10.94
3.		16.20	1.87	12.72
4.		15.93	1.84	12.86
5.		13.70	1.58	14.74
6.		-	-	-
1.	170	4.47	0.52	5.16
2.		8.57	0.99	8.42
3.		24.17	2.79	10.48
4.		19.70	2.27	12.18
5.		11.80	1.36	13.22
6.		8.50	0.98	14.88
1.	185	4.57	0.53	5.89
2.		7.60	0.88	8.99
3.		20.00	2.31	10.78
4.		16.43	1.90	12.00
5.		11.30	1.30	13.57
6.		8.33	0.96	14.33

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S/NO.	COMPACTIVE EFFORT KN	FAILURE LOAD KN	COMPRESSIVE STRESS (N/mm^2)	MOISTURE CONTENT %
1.	200	3.87	0.45	5.97
2.		9.93	1.15	9.70
3.		22.97	2.65	10.45
4.		21.90	2.53	12.48
5.		15.83	1.83	13.63
6.		16.50	1.90	14.88

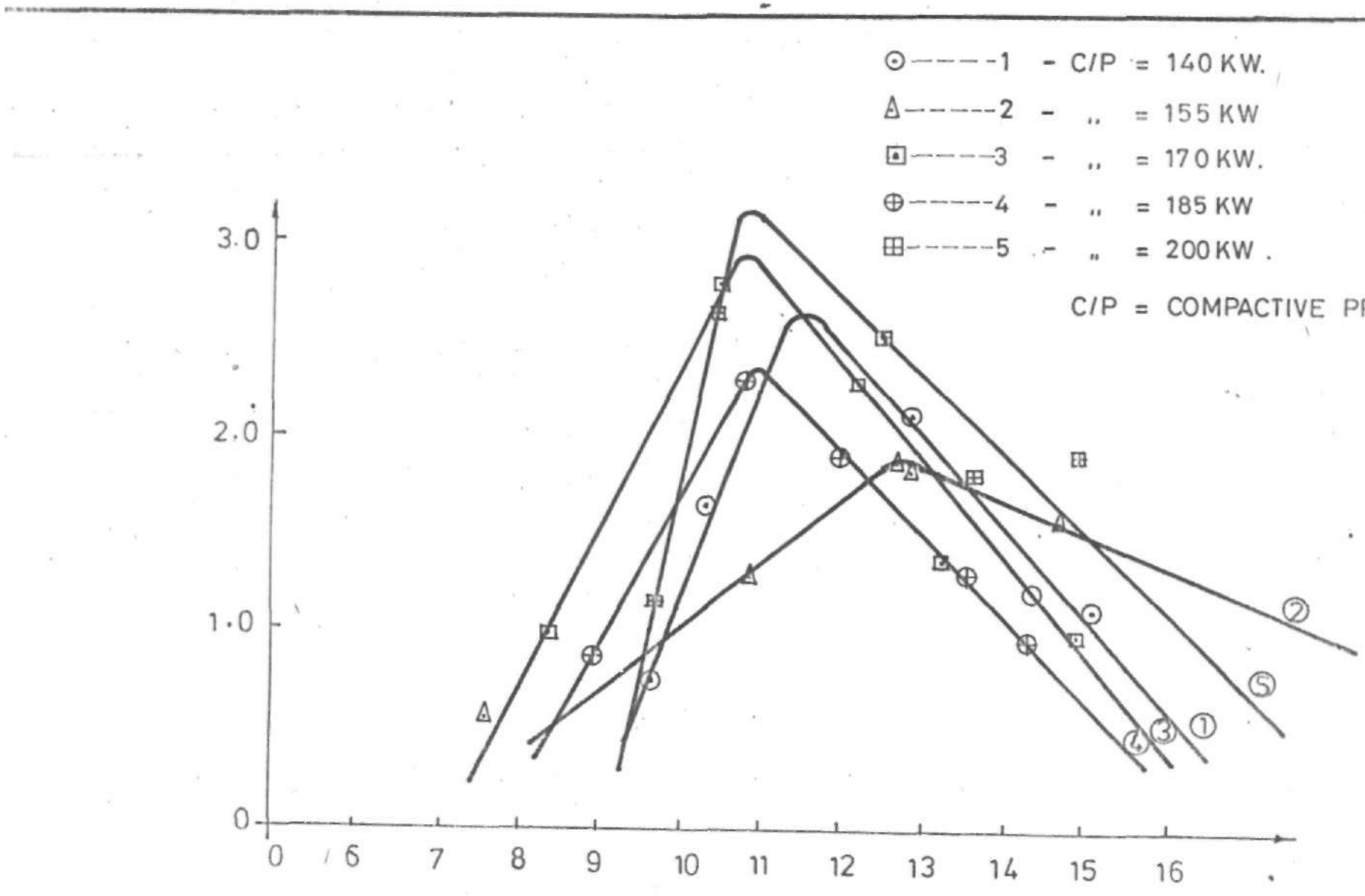


FIG. 6: GRAPH OF COMPRESSIVE STRESS AGAINST MOISTURE CONTENT FOR GIWA SAMPLE SIEVED THROUGH 2.4mm SIEVE SIZE

$$\frac{F}{N} = \mu$$

where F = Lateral force

N = Normal load

μ = Coefficient of static friction.

A graph of lateral force against normal load was plotted.



PLATE 3 - Typical arrangement of earthcrete blocks and load cell for Shear test.

test specimen.

It is worth noting that when compressive load is applied with a shock instead of uniform rate, an unduely high failure load is obtained. Hence rate of loading is usually specified.



PLATE 4 - showing the failure pattern of a well aligned cylindrical specimen within the platens of a Universal Testing Machine.



PLATE 5 - showing a typical view of the failure pattern of a cylindrical specimen eccentrically loaded.

TABLE 12:

COMPACTIVE EFFORTS AT VARIOUS OPTIMUM MOISTURE CONTENTS

Compactive Effort (KN)	Compressive Stress (N/mm^2)	Moisture Content %
(A)		
140	1.78	10.80
155	1.86	11.35
170	2.42	10.80
185	2.24	11.25
200	2.36	11.50
(B)		
140	2.64	11.50
155	1.88	12.40
170	2.94	10.80
185	2.36	10.95
200	3.18	10.80

(A) Material sieved through sieve 5.0 mm

(B) Material sieved through 2.4 mm sieve size.

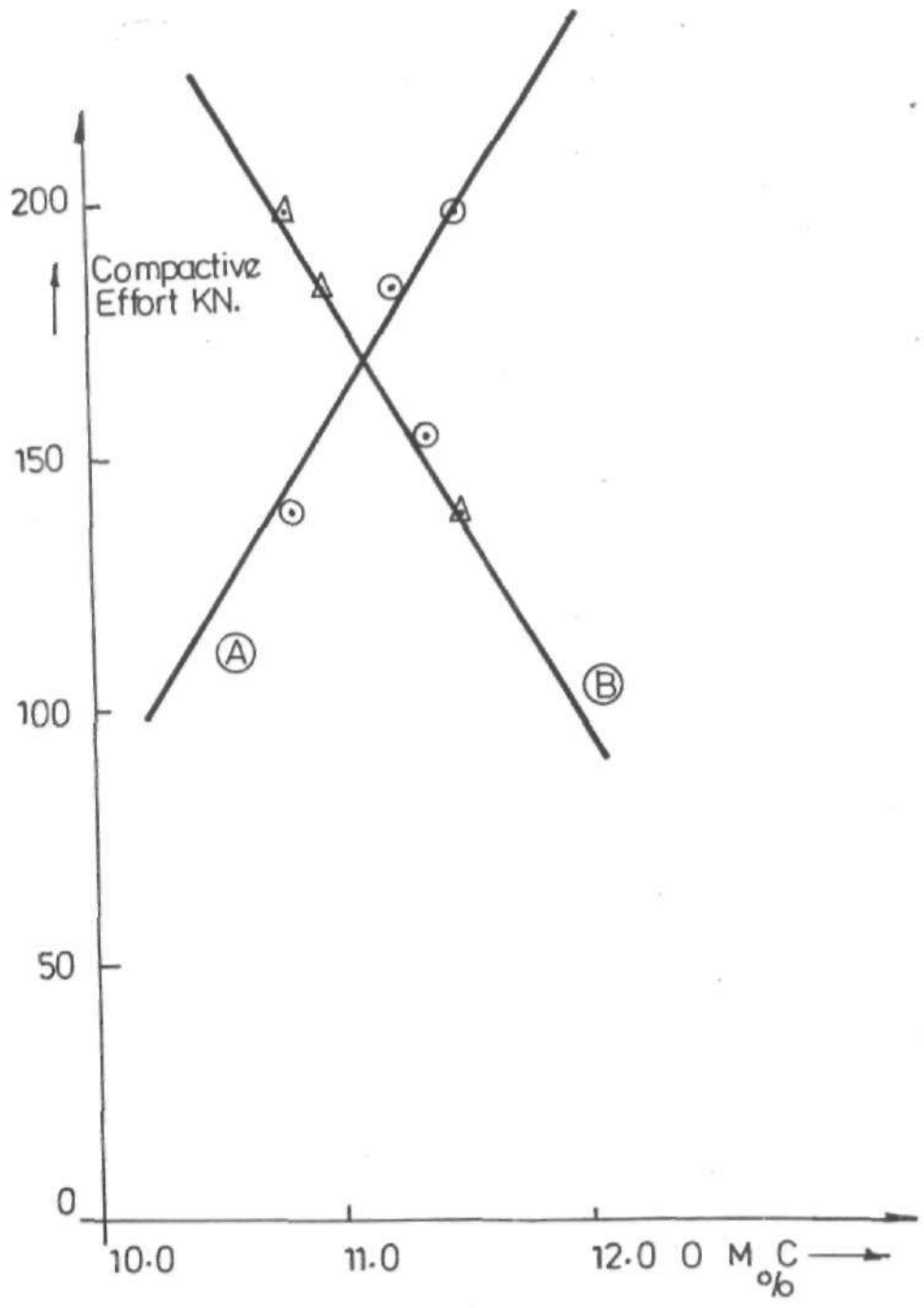


FIG. 7: GRAPH OF COMPACTIVE EFFORT AGAINST OPTIMUM MOISTURE CONTENT FOR GIWA SAMPLE

Ⓐ Material sieved through 5.0mm sieve size

Ⓑ Material sieved through 2·4mm sieve size

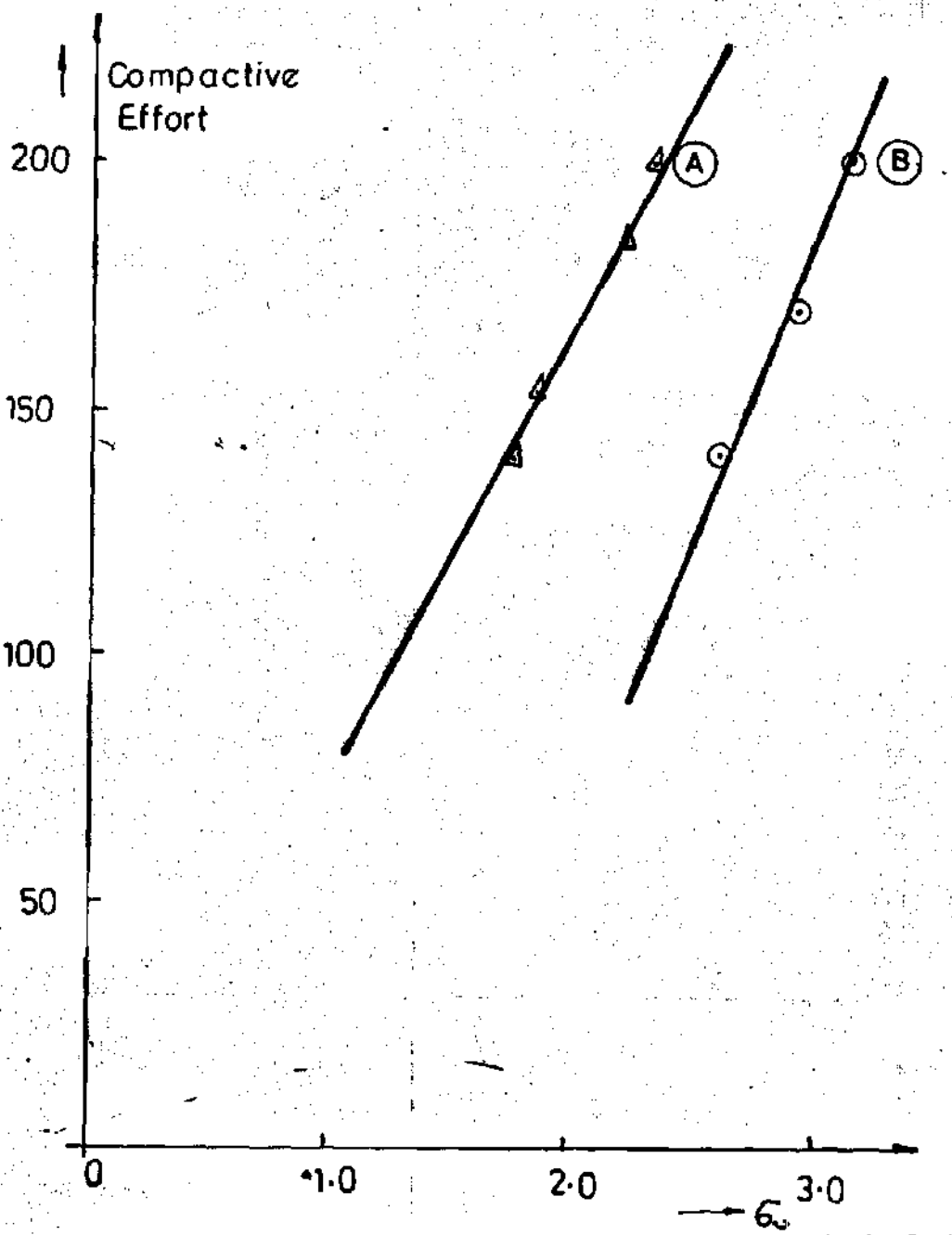


FIG. 8: GRAPHS SHOWING COMPACTIVE EFFORT AGAINST COMPRESSIVE STRESS FOR GIWA SAMPLE

Ⓐ Material sieved through 5.0mm sieve size
Ⓑ Material sieved through 2.4mm sieve size

TABLE 13 MALALI SAMPLE

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	140	1800.67	4.49	1723.29
2.		1846.72	7.42	1719.16
3.		1929.79	9.59	1760.92
4.		1994.82	12.45	1773.96
5.		2042.20	13.79	1794.71
6.		2023.75	15.52	1751.86
1.	155	1837.94	5.21	1746.93
2.		1903.80	7.33	1773.78
3.		2023.54	10.01	1839.41
4.		2083.16	12.21	1856.48
5.		2028.71	14.23	1775.99
6.		2030.51	15.72	1754.68
1.	170	1841.53	5.21	1750.34
2.		1920.70	7.41	1788.19
3.		2007.73	9.49	1833.71
4.				
5.				
6.				
1.	185	1853.86	5.40	1758.88
2.		1936.31	7.15	1807.10
3.		2024.06	10.34	1834.38
4.		2078.58	12.31	1850.75
5.		2055.44	14.02	1802.70
6.		2020.54	15.41	1750.75

S/NO.	COMPACTIVE EFFORT KN	BULK DENSITY Kg/m^3	MOISTURE CONTENT %	DRY DENSITY Kg/m^3
1.	200	1871.58	5.35	1776.54
2.		1949.54	7.62	1811.50
3.		2037.93	10.80	1839.29
4.		2044.69	13.12	1807.54
5.		2045.72	14.20	1791.35
6.		2025.65	15.39	1755.48

TABLE 14 MALALI SAMPLE

S/NO.	FAILURE LOAD KN	COMPRESSIVE STRESS N/mm^2	MOISTURE CONTENT %	COMPACTIVE EFFORT KN
1.	7.70	0.89	4.49	140
2.	9.93	1.15	7.42	
3.	15.20	1.75	9.59	
4.	15.67	1.81	12.45	
5.	13.67	1.58	13.79	
6.	6.30	0.73	15.52	
1.	8.03	0.93	5.21	155
2.	11.50	1.33	7.33	
3.	13.13	1.52	10.01	
4.	11.30	1.30	12.21	
5.	8.63	1.00	14.23	
6.	5.47	0.63	15.72	
1.	8.50	0.98	5.21	170
2.	12.47	1.44	7.41	
3.	13.37	1.54	9.49	
4.				
5.				
6.				
1.	9.33	1.08	5.40	185
2.	13.47	1.55	7.14	
3.	16.53	1.91	10.34	
4.	11.87	1.37	12.31	
5.	9.33	1.08	14.02	
6.	6.45	0.74	15.41	

S/NO.	FAILURE LOAD KN	COMPRESSIVE STRESS N/mm^2	MOISTURE CONTENT %	COMPACTIVE EFFORT KN
1.	10.37	1.20	5.35	200
2.	13.97	1.61	7.62	
3.	15.67	1.81	10.80	
4.	13.65	1.58	13.12	
5.	9.70	1.12	14.20	
6.	6.15	0.71	15.39	

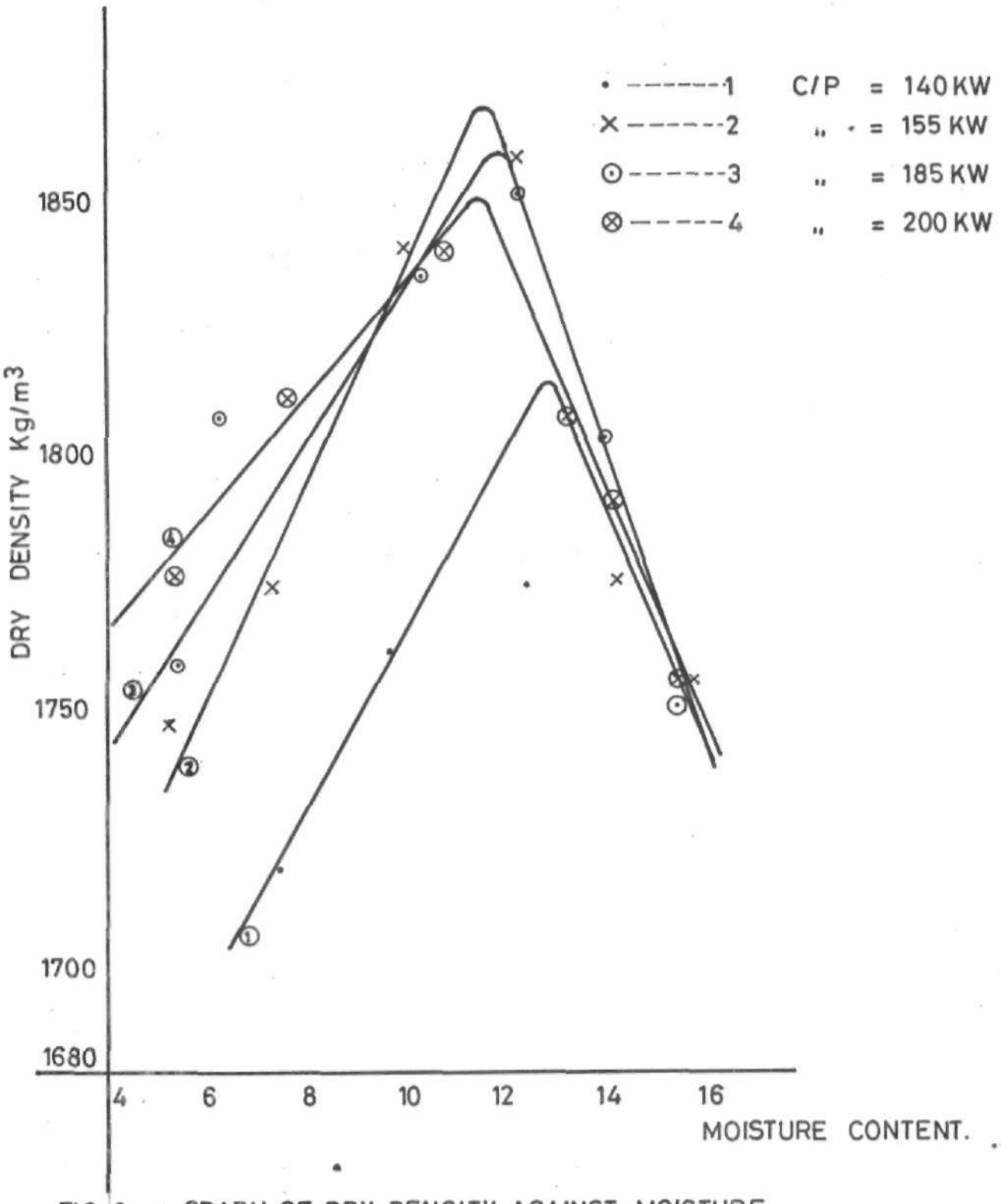


FIG. 9 GRAPH OF DRY DENSITY AGAINST MOISTURE CONTENT FOR MALALI SAMPLE.

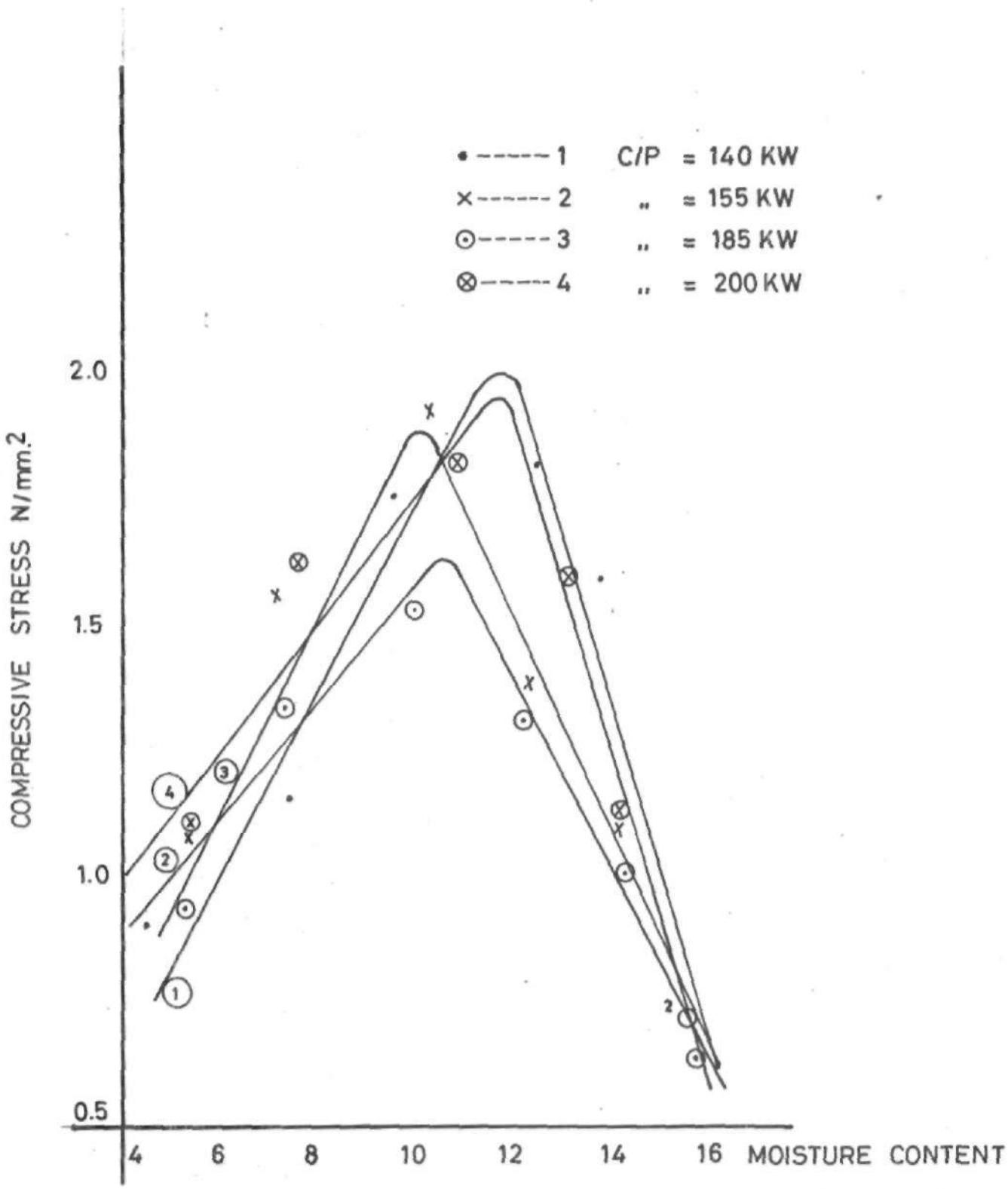


FIG.10 GRAPH OF COMPRESSIVE STRESS AGAINST MOISTURE CONTENT FOR MALALI SAMPLE.

4.6 LABORATORY COMPACTION

The results of both the Standard B.S. compaction and Modified AASHO are shown in Table 15.

TABLE 15:

RESULTS FROM STANDARD B.S. COMPACTION AND MODIFIED AASHO TESTS

MODE OF COMPACTION	SAMPLE NUMBER	OPTIMUM MOISTURE CONTENT %	DRY DENSITY Kg/m^3
B. S. COMPACTION	A	17.00	1813.89
	B	18.25	1721.59
	C	14.25	2070.73
	D	16.50	1789.81
MODIFIED AASHO	A	14.00	2046.65
	B	14.33	1958.36
	C	11.83	2167.04
	D	17.67	1910.21

Figures 11 and 12 show the results of the compactions using Giwa soil sample. It is important to note, however, that for a given method of compaction and compactive effort, a soil is compacted to a unique density at each moisture content. Figures 11 and 12 illustrate how dry density of a compacted soil increases with increasing moisture content until a "maximum dry density" is obtained at an "optimum moisture content". The dry density then falls as the moisture content increases. It therefore follows

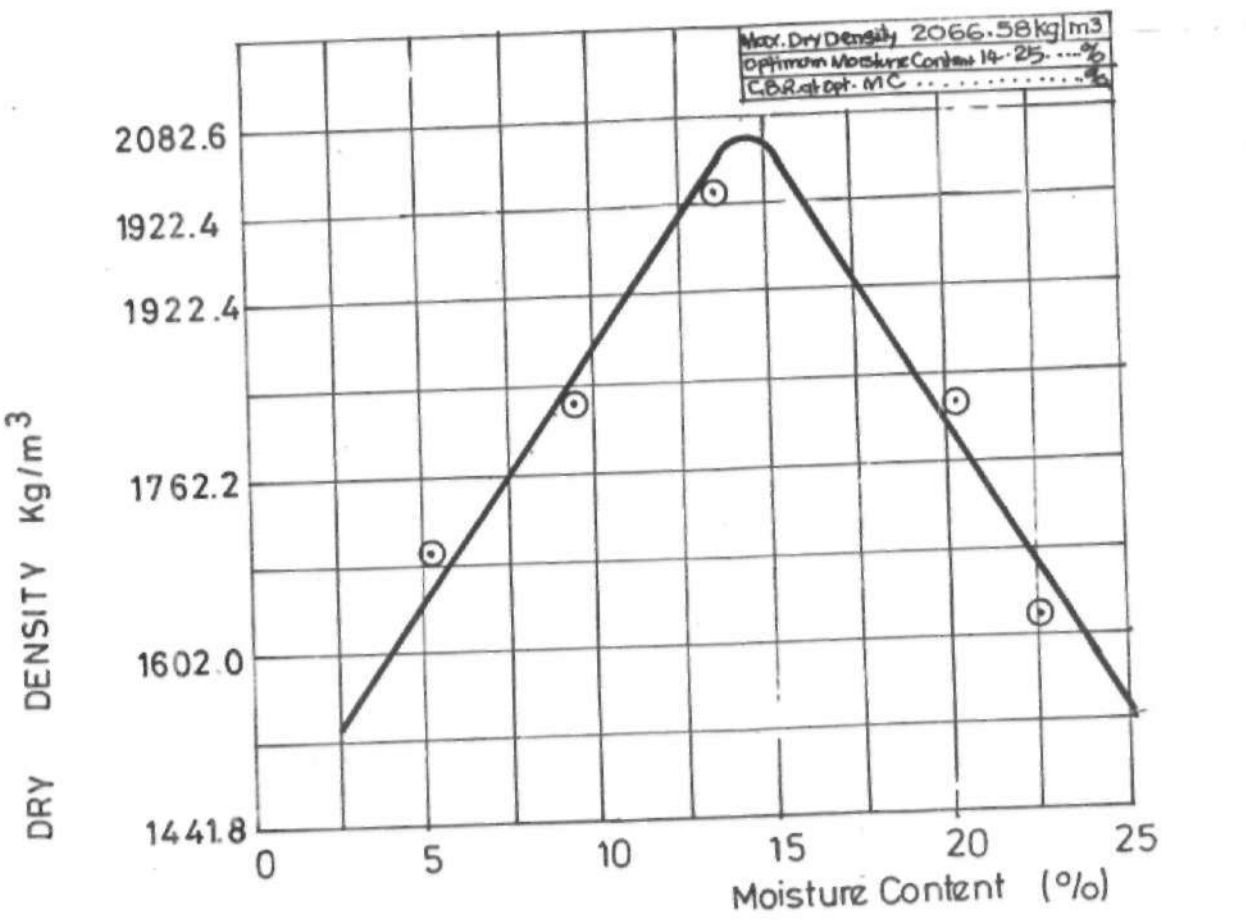


FIG. 11: B.S. STANDARD COMPACTION(GIWA SAMPLE)

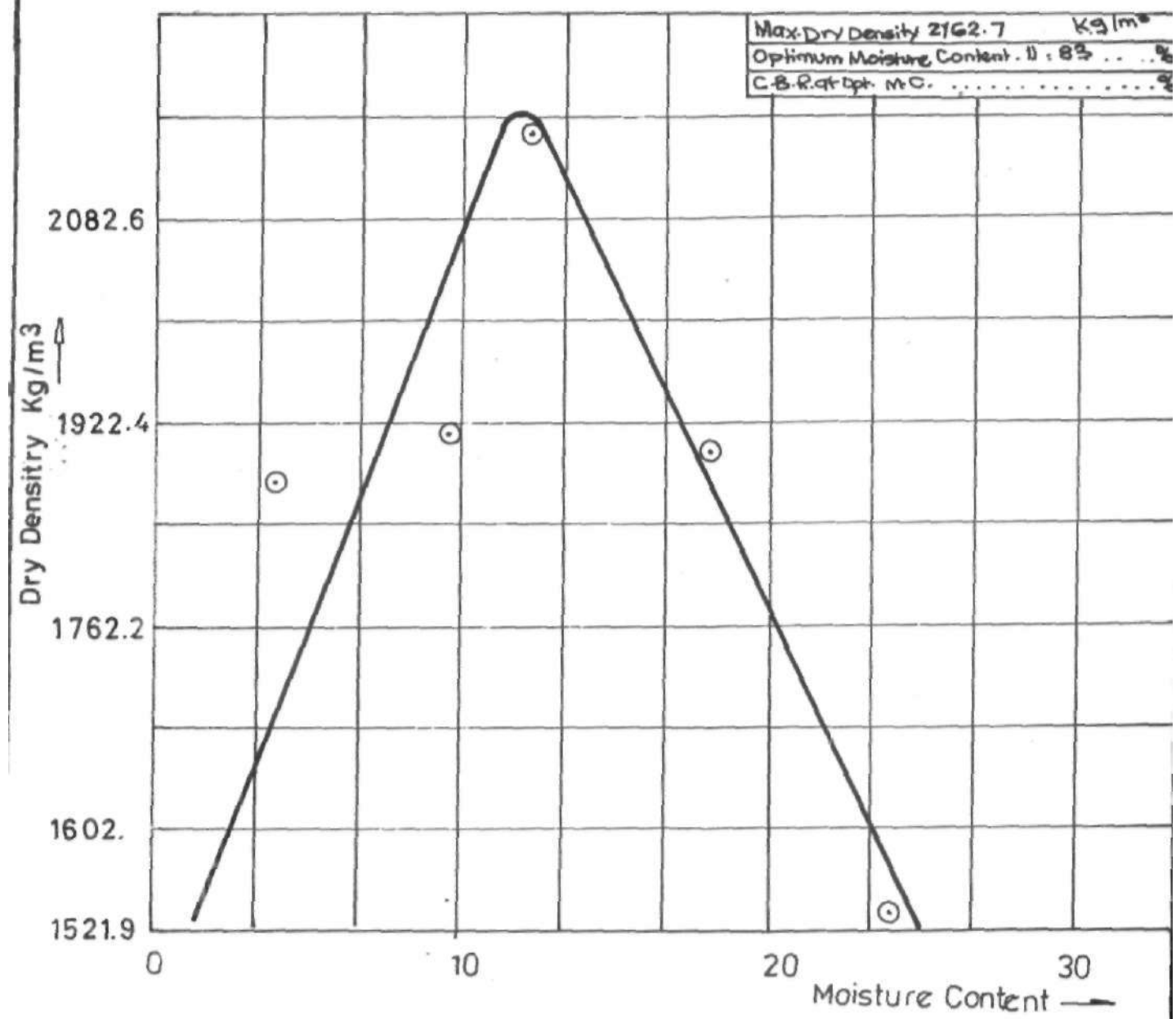


FIG. 12: MODIFIED AASHO COMPACTION TEST
(GIWA SAMPLE)

that for any given soil, the optimum moisture content, the maximum dry density and the shape of the curve vary considerably with different methods of compaction.

4.7 SHEAR TEST ON MOULDED BLOCKS

The results of the lateral force against the normal load are shown in Table 16. Figure 13 shows the graph of lateral force against normal load. From the figure, the coefficient of frictional force between two blocks can be calculated.

TABLE 16:

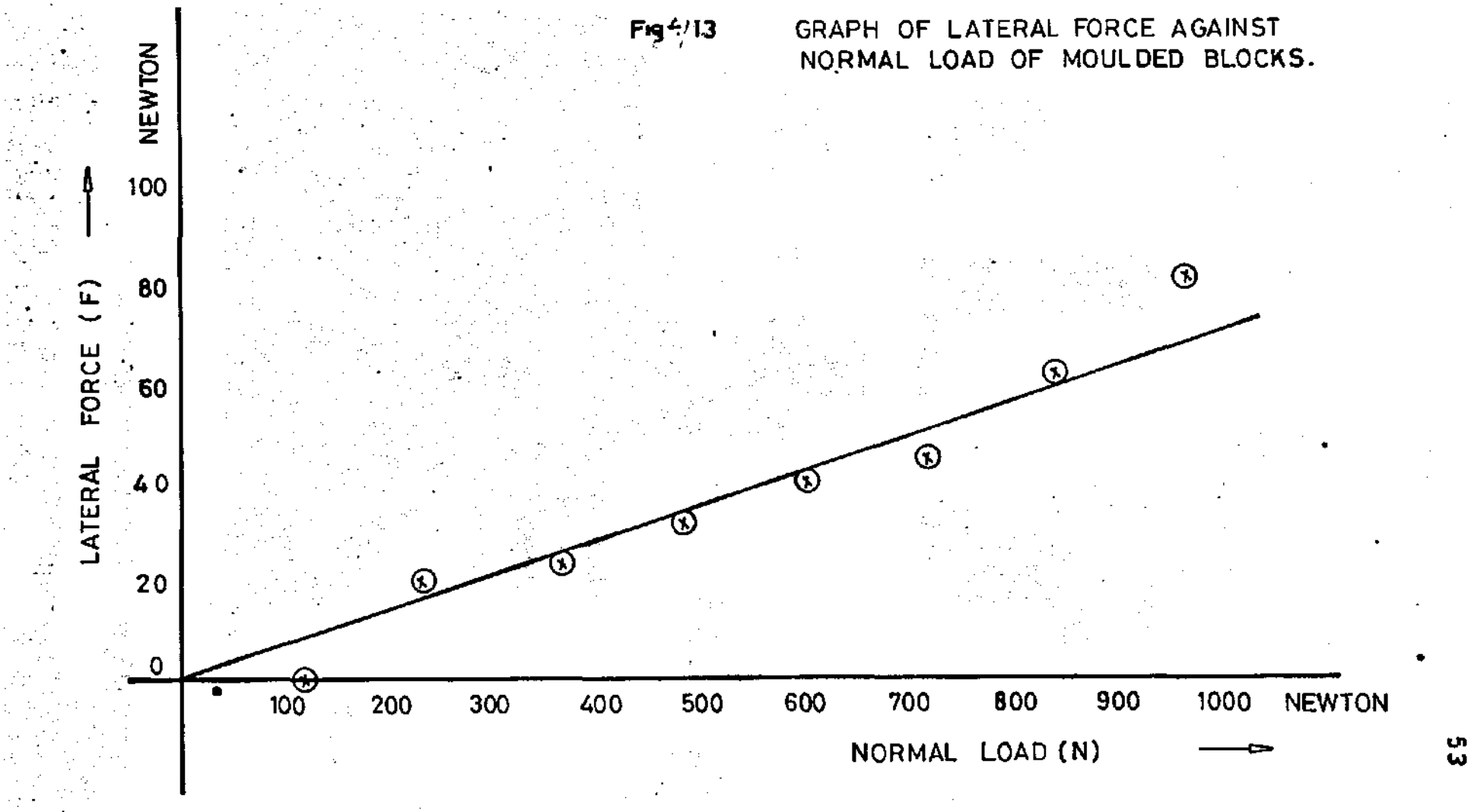
LATERAL FORCES AT VARIOUS NORMAL LOADS

NORMAL LOAD (N)	LATERAL LOAD (F)
120.0	0.0
237.7	20.0
371.7	24.0
486.7	32.0
609.3	40.0
728.5	44.0
851.6	60.0
978.6	80.0

4.8 DURABILITY TEST

The cored sample got swollen and large cracks were observed as the water travelled upwards by capillary action.

Fig 4.13 GRAPH OF LATERAL FORCE AGAINST NORMAL LOAD OF MOULDED BLOCKS.



The cored sample finally crumbled within 24 hours. The result of the above experiment indicates that the exterior surface of earthcrete block walls must be protected from rain.

5. OBSERVATIONS ON LABORATORY TESTS

The following observations were made during the laboratory tests carried out on three of the four samples.

5.1 It was easier to dry a given soil sample if found too wet to a required moisture content and obtain a uniform consistency than to moisten a clayey soil. When water is added to a fairly dry clayey soil, lumps are formed which are found very difficult to break to obtain a uniform consistency.

5.2 It was observed that surface hairline cracks were seen on the surface of the cylindrical specimens. The cracks became finer as the moisture content increased.

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5.3 There was high frictional force between the cylindrical specimen and the wall of the mould during extrusion process. This high frictional force caused the scaling off of the lower part of the specimen as shown in Plate 6.

The frictional force decreased as moisture content of the soil sample increased. The scaling off was only observed with low moisture content. The surface of the specimens were fairly rough at low moisture content. As the moisture content increases, smoother surfaces were produced.



PLATE 6 - showing the scaling off of the cylindrical specimen.

5.4. During compaction process the metallic mould was filled. It was observed that as the moisture content increased the height of the produced specimen decreased as shown in Plate 7.



PLATE 6 - showing the scaling off of the cylindrical specimen.

5.4. During compaction process the metallic mould was filled. It was observed that as the moisture content increased the height of the produced specimen decreased as shown in Plate 7.



PLATE 7 - showing the variation of heights of the specimens with increased moisture content.

5.5 During compression test, the effect of barrelling became more apparent as the moisture content increased. This is illustrated in Plate 8.

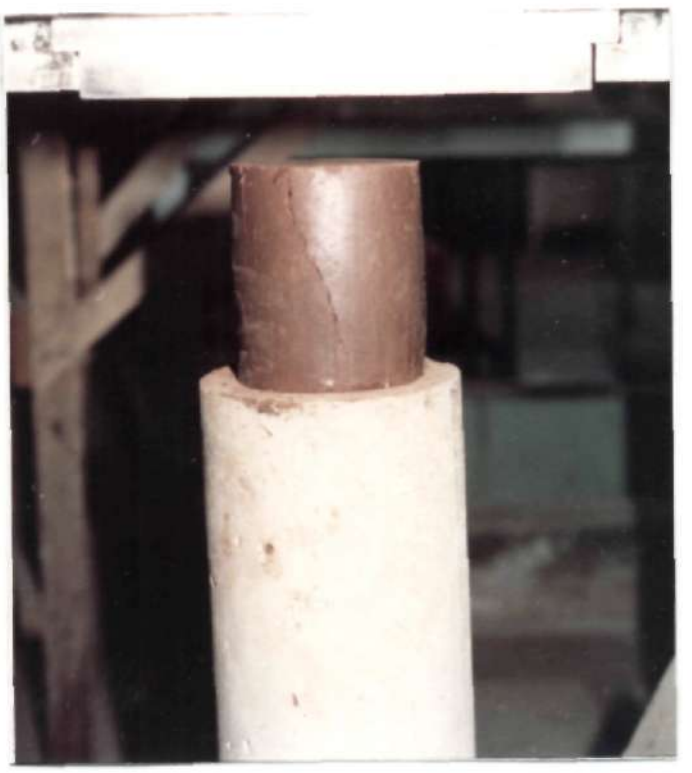


PLATE 8 - showing Barrel Effect.

5.7 When lateritic material was initially fed into the mould without sieving and compacted, it was observed that large grains of the soil were forced to the bottom of the mould as the compaction took place. This created honey combs where the compaction was left ineffective. The end close to the ram was observed to be well compacted and smooth all over.
Plate 9 shows the differential in the effectiveness of the compaction. Better results were achieved on sieving off the coarse aggregates.

5.7 As earlier stated in the last paragraph of section 3.5 that clayey soil sample mixed with water could not be brought to

a uniform consistency hence variations of moisture contents within the same mix. The non-uniform consistency and variation of moisture content within the same mix affected the results of the compaction and compressive strength tests as follows:-

(1) There were variations in the bulk densities due to variations in moisture contents. The dry densities calculated from bulk densities and moisture contents also vary. Three Number (3No) cylindrical specimens were cast for each mix. The mean (average) values of the bulk densities, moisture contents and dry densities were recorded as shown in Tables 8, 9 and 13. The mean dry densities were plotted against the mean moisture contents in figures 3, 4 and 9.

(2) There were variations in the compressive strengths of the cylindrical specimens tested. Tables 10, 11 and 14 show the mean values of the failure loads, compressive stresses and moisture contents, while Figures 5, 6 and 10 show the graphs of mean compressive stresses and moisture contents.

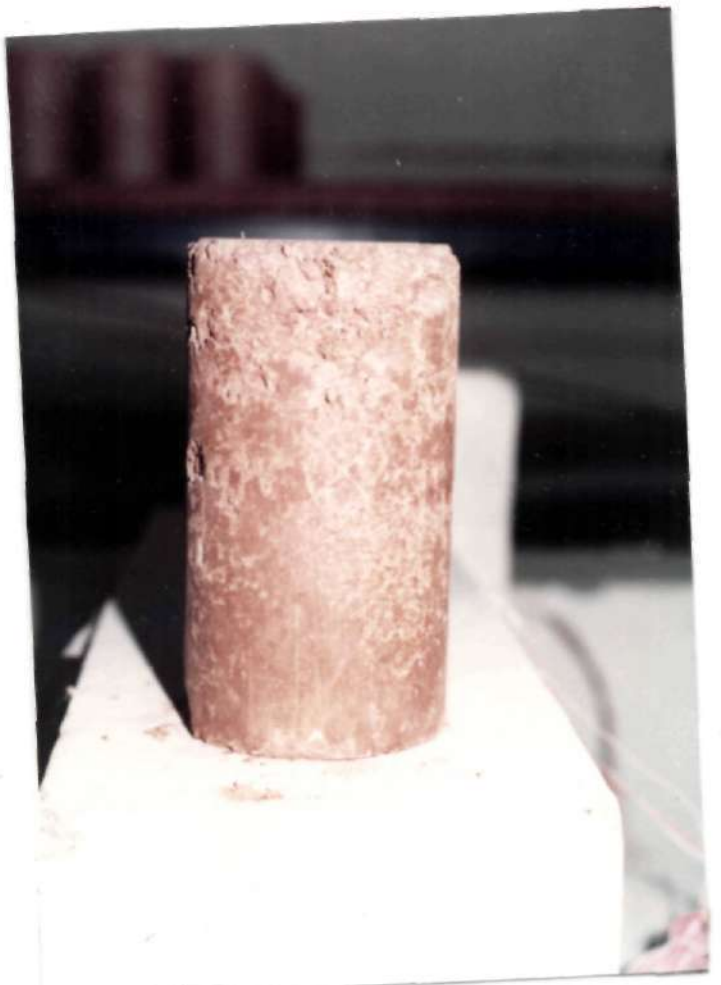


PLATE 9 - showing poor compaction at the top while the bottom is well compacted.

6. FIELD TEST

6.1 A Kaduna based firm purchased and commissioned the TERRA BLOCK MACHINE around mid 1988. The main aim of this machine is to produce earthcrete blocks with which to build substantial, structurally solid buildings cheaply and quickly using laterite excavated from the building site. On commissioning, blocks produced with the TERRA BLOCK SYSTEM had severe cracks. This called for research which was geared towards determining the causes of cracks, durability of the earthcrete blocks produced and the usefulness of the TERRA BLOCK MACHINE throughout the year.

Terra Block Machine which is described by the manufacturers as being compact, portable, uncomplicated, reliable, automatic and energy efficient has a duplex system whereby earthcrete blocks are produced from the two ends of the machine. Laterite which flows from the hopper into the block mould is compressed by hydraulically operated ram with a pressure between 15.18 N/mm^2 and 27.6 N/mm^2 to produce stable and dimensionally uniform earthcrete blocks that can often go directly into a wall without any curing or drying time. A view of the Terra Block Machine is shown in Plate 10.



PLATE 10 - A VIEW OF THE TERRA BLOCK MACHINE.

The machine has two forms of loading systems viz:-

(i) Manual system of loading

(ii) Automatic system of loading

Earthcrete blocks produced on manual system of loading showed permissible cracks in accordance with paragraph Q - 3.14 in Appendix A of the operation manual using lateritic materials from Giwa and NNPC borrow pits. However, blocks produced using laterite from Malali borrow pit had very deep cracks. Production was so difficult that nearly all blocks were split into two prior to ejection.

With the operation of the Terra Block Machine on automatic system of loading, slightly smaller size of block with

more and deeper cracks were produced with materials from Giwa and NNPC borrow pits. All blocks produced on automatic system of loading using laterite from Malali borrow pit broke into two halves.

Initial earthcrete blocks produced were with unsieved materials. The blocks produced were well trimmed at the edges close to the ram while the other half close to the gate showed very poor compaction. Plate 11 shows segregation of aggregates.

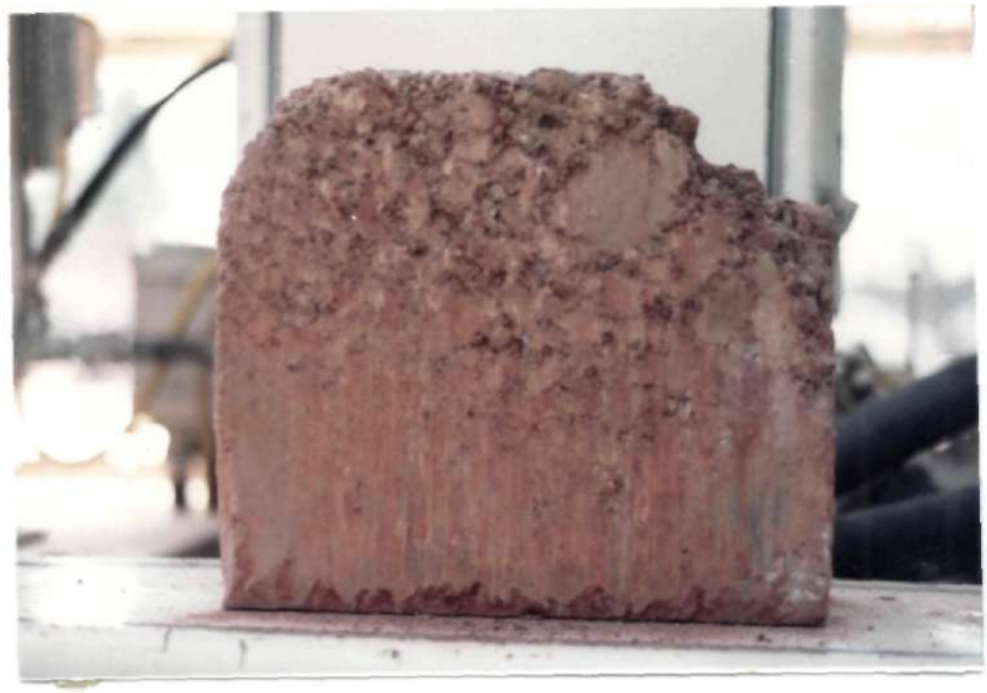


PLATE 11 - showing earthcrete block with unseived material from NNPC borrow pit.

The NNPC, Giwa and Malali Materials were sieved through 12.76 mm sieve size eliminating coarser aggregates. The materials were then exposed to the harsh harmattan weather to reduce the moisture contents. The results showed that the soil sample from Malali could still not produce any acceptable blocks. The soil samples from Giwa and NNPC borrow pits had some good results.

Subsequently, further sievings were carried out using 5.00 mm and 2.4 mm sieve sizes using as reference FOLA LASISI et, al (9). The moisture contents were low as the materials were left exposed for several days. Good earthcrete blocks were produced but the edges of the blocks from Giwa borrow pit broke off easily as the percentage of clay content in the material was low. Blocks produced from the NNPC sample were good.

Soil samples from Rigassa village was used in the production of earthcrete blocks, initially without sieving. The blocks cracked. The soil sample was then sieved through 5.00 mm sieve size. The soil sample still produced cracked blocks. Plate 12 shows the pattern of cracks on the blocks, which are not acceptable as per paragraph Q - 3.14 in Appendix A of the operation manual.



PLATE 12 - showing crack patterns of earthcrete blocks with the Rigassa soil sample.

6.2 MECHANICAL STABILIZATION

As earlier stated Mechanical Stabilization is the provision of some grade of soil to which the original soil is deficient to produce a well graded soil which has both cohesive and internal frictional propertiies. The cracks in the earthcrete blocks led to stabilizing soil from Rigassa borrow pit with some sharp fine sand. The sieved material was mixed with sharp fine sand in the proportion of 3:1.

Three parts by volume of Rigassa lateritic clay sieved through 2.4 mm sieve size mixed with one part by volume of fine sharp sand. This mix produced very sound, strong and durable earth-crete blocks without cracks with very strong edges as shown in Plate 13. The compactive effort applied was 16.56 N/mm^2.



PLATE 13 - showing strong sound and durable earthcrete block without cracks.

6.3 CEMENT STABILIZATION

The possibility of cement stabilization was investigated. Five (5%) percent cement content was added to lateritic sample from Malali with no additional water as the natural moisture content was high (22.0%). The soilcrete blocks

broke off into several fragments as the compactive effort was too high (5, 10). They were difficult to lift off the conveyor tray. Similarly cement stabilization was carried out with sieved samples from Giwa and NNPC borrow pits. 5% cement content was added at a very dry state. The results were not positive as many deep cracks similar to that of Malali sample were observed.

Increasing the water / cement ratio gave no better result. It was difficult to mix to obtain a uniform consistency.

7. ANALYSIS OF TEST RESULTS

7.1 COMPCATIVE EFFORT

As earlier stated the higher the compactive effort, the higher is the maximum dry density and the lower the optimum moisture content. The results of the laboratory compactions, Standard B.S. Compaction and Modified AASHO, as given in Table 15 show higher values for the maximum dry densities with the Modified AASHO over the figures obtained with Standard B.S. Compaction. The differences in the dry densities as obtained from the two methods of compaction are tabulated in Table 17. Also Table 17 gives the differences in the values of the optimum moisture content.

TABLE 17:

COMPARISON OF RESULTS FROM MODIFIED AASHO AND STANDARD B.S. COMPACTION TESTS

SAMPLE NUMBER	Δ = M (AASHO) - B.S.	Differences in Optimum Moisture Content %
A	232.76	3.00
B	236.77	3.92
C	96.31	2.42
D	120.40	1.17

The compactions of lateritic materials into cylindrical specimens at various compactive efforts using the Universal Testing Machine show a great departure from the foregoing.

system which is a hydraulic press.

7.2 MOISTURE CONTENT

When a soil sample is dry the intergranular friction between the soil particles resists compaction, hence only a limited degree of compaciton is attained and the voids are not completely filled as against an ideal situation when voids are completely or nearly completely eliminated. The effect of poor compaction or the weakness in strength is illustrated in Plate 14 which shows the failure of a cylindrical specimen.



PLATE 14 - showing the failure of a poorly compacted cylindrical specimen due to low moisture content.

The specimen failed under its own weight when lifted up and held at a point one quarter distance of its length from the top.

As the moisture in the soil sample increased, the intergranular friction between the soil particles is reduced and a higher degree of compaction is attained. At optimum moisture content maximum degree of compaction is attained.

As earlier stated the higher the compactive effort the lower the optimum moisture content for a given soil.
In figure 7, the graph of compactive effort against optimum moisture content for Giwa sample sieved through 2.4 mm sieve size conforms to the rule. The same Giwa sample sieved through 5.00 mm sieve size shows a marked departure. The cause of departure can be linked to more soil grains being crushed when sieved through 5.00 mm sieve size thereby increasing the surface area of the material. Hence, the moisture content that will be required to produce sound, good and durable earthcrete blocks using the Terra Block Machine which is designed to function best at very high compactive effort would depend on the grain sizes present in the soil matrix at the time of hydraulic press. If moisture present within the soil matrix is more than the required optimum moisture content, the amount of pore pressure developed within the soil matrix as the compactive effort is applied will be high. As soon as the compactive effort is removed and the block is ejected out of the mould, the internal stresses within the soil matrix can no longer be maintained and this leads to the cracking of the blocks to release the stored pressure. Hence, moisture

content is one of the main factors that cause cracking of the earthcrete blocks.

7.3 MATERIAL DESIGN

The results of Particle Size Distribution for the four samples show that the lateritic materials contain the properties tabulated in Table 18.

TABLE 18

MATERIAL COMPONENTS OF THE DIFFERENT SOIL SAMPLES

SAMPLE NUMBER	A	B	C	D
Percentage of Sand	36.0	44.0	42.0	31.0
Percentage of Silt	25.0	51.0	18.0	24.0
Percentage of Clay	33.0	1.0	8.0	42.0
Percentage of Coarse Aggregate	6.0	4.0	32.0	3.0

The Malali soil sample which is mainly sandy silty, labelled as Sample B, could not produce good earthcrete blocks at all as the clay content which is the cementitous material is negligible. If however, the clay - binder material - is provided to stabilize the sandy silty material so as to obtain about the same soil sample with properties close to that specified in Table 1 or that contained in Table 2 (Mechanical Composiition), good, durable and strong earthcrete blocks will be obtained. Similarly it is important to increase the clay - binder content - in sample C from

the Giwa borrow pit and reduce the coarse aggregates. If the 32% coarse aggregate is sieved off, the resulting material will then have the following properties.

$$\text{Percentage of Sand} = \frac{42}{68} \times 100$$

$$= \underline{61.76\%}$$

$$\text{Percentage of Silt} = \frac{18}{68} \times 100$$

$$= \underline{26.47\%}$$

$$\text{Percentage of Clay} = \frac{8}{68} \times 100$$

$$= \underline{11.76\%}$$

Since the clay content is only 11.76%, blocks produced still lacked enough binder content hence the edges of the block broke off easily.

The results of gradings for NNPC (A) and Regassa (D) borrow pits show that the clay contents in the sampes are higher than those in Tables 1 and 2. But clay has two objectionable properties that make it the most troublesome of all the materials to be dealt with. It swells when subjected to wetting and shrinks with drying. When clay swells, the individual soil particles are pushed apart and the internal friction between the grains is reduced. During drying period, some of the water in the clay evaporates and this is accompanied by shrinkage process which tends to pull the clay particles away from the granular material which it is supposed to bind together.

For maximum compaction to be achieved therefore, the percentage of clay - binder content - in the soil sample must not be in excess.

Soil sample from Rigassa borrow pit after sieving through 2.4 mm sieve size was then mixed with sharp fine sand in the ratio of 3:1 to produce good, durable and strong earthcrete blocks with no cracks.

If the 3% coarse aggregate is removed by sieving the soil sample through 2.4 mm sieve size, the fractions of sand, silt and clay will increase.

From Table 18 -

Percentage of sand = 31.0

Percentage of silt = 24.0

Percentage of clay = 42.0

The sieved material will now contain the following -

$$\text{Percentage of sand} = \frac{31}{97} \times 100 = \underline{32.0\%}$$

$$\text{Percentage of silt} = \frac{24}{97} \times 100 = \underline{24.7\%}$$

$$\text{Percentage of clay} = \frac{42}{97} \times 100 = \underline{43.3\%}$$

If the sieved material is now stabilized by mixing it with sharp sand in the proportion of 3:1 by volume, the total volume of sand in the new mix becomes

$$= \frac{32}{100} \times 3 + 1$$

$$= \underline{1.96}$$

Volume of silt $= \frac{24.7}{100} \times 3$

$$= \underline{0.74}$$

Volume of clay $= \frac{43.3}{100} \times 3$

$$= \underline{1.3}$$

$\therefore$ Percentage of sand $= \frac{1.96}{4} \times 100$

$$= \underline{49\%}$$

Percentage of silt $= \frac{0.74}{4} \times 100$

$$= 18.5\%$$

Percentage of clay $= \frac{1.3}{4} \times 100$

$$= \underline{32.5\%}$$

The result of this sand stabilization is comparable to the figures given by DIRISU et, al (5) in Table 2.

Mechanical composition as :-

Percentage of sand = 46.0

Percentage of silt = 26%

Percentage of clay = 28%

From the above, it therefore follows that material design is an important factor for the successful operations of TERRA BLOCK MACHINE.

7.4 FRICTIONAL FORCE

The coefficient of static friction between the earthcrete blocks is 0.08. This result indicates that a small force can easily push down an uncompleted wall.

The LAW ENGINEERING TESTING COMPANY OF ATLANTA GEORGIA carried out shear test of small earthcrete blocks and came up with a result of an average of 79 lb/in^2 (0.55 N/mm^2).

The manufacturers of the TERRA BLOCK MACHINE has therefore recommended a ring beam at every height of 3.0 m of earthcrete block wall. This allows the walls of the house to act as a rigid unit.

8. CONCLUSIONS

8.1 Material design is an essential ingredient for the successful use of the TERRA BLOCK MACHINE. Material required is to possess the following properties if it is to be used for the production of strong and durable earthcrete blocks without cracks:

Percentage of sand - 48.0%

Percentage of silt - 20.0%

Percentage of clay - 32.0%

The silt and clay contents which account for 52 percent can be varied but the percentage of silt should not be more than the percentage of clay content.

8.2 Other materials with less percentage of clay content with some gravel content will still produce blocks that meet the requirements of Appendix Q - 3.11 which stipulates a compressive stress of 2.1 N/mm^2 but would show less compaction (segregation of the aggregates) at one end or broken edges.

8.3 The importance of moisture content in the production of good and durable earthcrete blocks without cracks cannot be over-emphasised.

8.4 The use of the Terra Block Machine presently limited to the relatively short very dry season of the year, except materials are stockpiled during the very dry season for use in the wet season.

8.5 Soil investigation are necessary around the construction sites to determine soil properties around the site and locate adequate borrow pits before construction commences.

8.6 Mechanical stabilization is often necessary. Cement stabilization is not feasible as the compactive effort is too high.

8.7 Application of sealant to the external wall surface is necessary before rendering to prevent rain from washing away the wall.

8.8 Mortar recommended for rendering is lateritic clay mixed with cement and not sand and cement.

9. RECOMMENDATIONS

9.1 Since Terra Block Machine functions best at very high compactive efforts which means at very low moisture content (about 4 percent), and in Nigeria the equilibrium moisture content is over 10 percent beneath the top soil, at the very dry season of the year, the Terra Block Machine might be considered not too efficient for use in this country. It is therefore recommended that further research work be undertaken to modify the machine to accommodate less compactive effort and higher moisture content.

9.2 The percentage of soil grains crushed during the compaction of cylindrical specimen using the Universal Testing Machine or that at the production of earthcrete blocks, at high compactive pressure, was not determined in the course of this study. It is therefore recommended that further research work be carried out to determine the extent of crushing of soil grains that takes place.

9.3 The cost of a building depends on the requirements of the client and the amount of money that is available to execute the project. Earthcrete block buildings can be as expensive as one wishes, in which case sieving of the lateritic clay material to meet the specifications as contained in paragraph 1 of the conclusions of this report would be necessary. But for low cost building which is the main aim of the manufacturers of the Terra

Block Machine, lateritic clays containing less than 20% clay content and having about 5 percent gravel content with broken edges which meets the requirements of Appendix Q - 3.11 is considered satisfactory.

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