THERMAL RESISTIVITY OF
KENYA SOILS

by

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This is to certify that this thesis has not been submitted for a degree of any other university, and that the contents of the thesis are my original work.

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I wish all the above named persons good health and success in the coming years.

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ABSTRACT

The object of the project is to investigate thermal resistivity of various Kenyan Soils, A discussion is given on the importance of the study for underground cables in terms of safety and economical choice.

Four main types of soils were tackled. An apparatus to measure the thermal resistivity of the soils in the laboratory was designed.

For each soil values of thermal resistivity were found for (1) a fixed dry density and varying moisture content and (2) a fixed moisture content and varying dry density. Dependence of thermal resistivity on moisture content and dry density are found from which the conditions for which thermal resistivity exceeds the nominal thermal resistivity of 1.2 °C m/W generally assumed for current rating of underground cables, are extracted. Also, the effect of moisture migration on various soils is studied briefly.

List of Symbols

Symbol	units	
g	°Cm/W	thermal resistivity
k	W/°Cm	thermal conductivity
H	W/m	i) rate,of heat dissipation per metre of cable
	,W	ii) rate of heat dissipation of the heater in the apparatus
A	m^2/m	i) crossectional area per metre length of the cable.
h	m	depth of cable below the ground surface
b	m	inside diameter of the outer cylinder of the apparatus.
a	m	i) outside diameter of the inner cylinder of the apparatus, ii) outside diameter of the cable.
L	m	Length of the inner and outer cylinder of the apparatus.
T^C	°C	cable conductor temperature.
T_a	°C	i) temperature of the inside of the outer cylinder, ii) Ground surface temperature.
T_0	°C	temperature of the outside of the inner cylinder
AT	°C	. temperature difference between outside of inside cylinder and inside of outer cylinder.

Symbol	units	
Gg	T/W/m	thermal resistance of the earth per metre length , of the cable,
G^	T/W/m	internal thermal resistance per unit metre of the cable,
G_t	T/W/m	total thermal resistance of the cable and earth per unit metre of the cab1eo
I	amps	cable current
	amps	cable current
	ohms/m	electrical resistance per metre of the cable
6 IllaX	°C	max, permissible temperature drop between ground surface and the cable conductor.
AV	mV	average thermocouple output
V	cc	total volume of soil
Vg	cc	volume of solids in a soil sample
V_y	cc	volume of voids in a " "
Vg	cc	volume of gas in a " "
W	g	total weight of water in a soil sample
W_g	g	weight of solids in a soil sample
W_w	g	weight of water in a soil sample,
Y_t	g/cc	total density of soil
Y(j	g/cc	dry density of soil
Y_s	g/cc	density of solids in a soil sample
v w	p ^{6}/cc	density of water in a soil sample
M	%	moisture content of the soil.

Symbol	units	
H^	watts	power flow through the bakelite base
U	watts	power flow through the styrofoam base
H_	watts	power flow through the top styrofoam
R **—AA<—**	fi	resistance
-		NPN Transistor
		Battery or DC supply
e_T	°C	error in temperature
e^	watts	error in rate of heat input

Diode as a thermometer

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Introduction

Electrical power engineers need knowledge about the electrical and thermal properties of the soil. The dissipation of heat in underground cables and transformer, and consequently their rating, is affected by the thermal resistivity of the soil. The electrical resistivity of the soil is important to a power engineer as it influences the design of the earth system of power systems.

In this thesis I am concerned with the thermal resistivity of Kenya soils. The four main types of Kenya soils have been investigated. An apparatus has been designed which is flexible in the sense that it provides a laboratory method of measuring thermal resistivity easily and conveniently, the moisture content and dry density can be systematically varied.

For each type of soil measurements of thermal resistivity has been made as function of moisture content, the dry density being constant. Also measurements have been made as function of dry density, with the moisture content constant®

CHAPTER I

Justification for the study of thermal resistivity of soils

1.1. The effect of thermal resistivity on underground cables.

The study of the thermal resistivity of soils under various natural and forced conditions of varying moisture, compaction, composition and type has become very important in connection with the rating and safe operation of cables, and lately underground transformers.

It will be noticed from the following analysis of a single cable some distance h below the ground surface that the rating of the cable is dependent on the thermal resistivity of the soil for a fixed ground temperature. T_a (Ref.l).

Assume the ground surface is a plane isothermal of ambient temperature Ta. All the heat generated is ultimately transmitted to the ground surface which remains at constant temperature. The ground surface can be replaced by a power sink of -H watts/metre at a distance h above the ground surface in analogy to an electrical conductor above a conducting plane.

We apply the equation of heat conduction given below to the case in question,

$$H = -kA \frac{d6}{35F}$$

where H = rate of heat dissipation per metre of the cable in watts/metre

k = thermal conductivity of the soil in watts/°C.m

d6

^ = temperature gradient across an element dx in °C/metre.

A = cross-sectional area, at a distance x, per metre of the cable: A = 2**TTX.**

The system is shown in Fig,1,1.1. Let the temperature of the cable surface be T_Q and the ground surface temperature T_a. Then $T_q - T_\&$ is fixed.

The contribution to temperature difference between the cable surface and the ground surface is due to both the underground cable 1 and its image 1',

Taking a circular element dx for cable 1, the heat equation, after rearrangement becomes

$$-de \quad = \quad 1C2tx^{dx}$$

Therefore contribution to temperature drop between the cable surface and the ground surface due to cable 1 is

$$-_{a}^{a} \; \overset{H}{F?ttx} \; dx' \; = \; \overset{H}{lik} \; \dot{®}e \; a^{h}$$

where a is the outer radius of the cable.

Taking a similar circular element dx at a distance x measured from 1', the contribution to the temperature drop between cable 1 and the ground surface is

$$f \; 2h-a$$

$$_{h} \quad \frac{Hdx}{FHx} \;\bar{'}\; \frac{H}{Tffk} \; \dot{} \; ^{10}S_{e} \; \frac{\overline{2h - a}}{K^{-}}$$

Usually 2h>>a, Therefore the expression becomes

$$\$FE \quad ^{log}e^{2}\,'$$

Therefore the total temperature drop due to the cable

Therefore the total temperature drop due to the cable

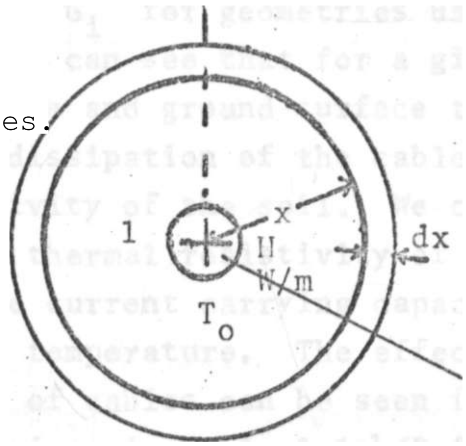

Fig.1.11 Diagram showing cable 1 below the ground with its image 1' at a distance h above ground

- 11 2h

From the expression, thermal resistivity g(°G.m/W) (= 1/k) is found to be

$$g = \frac{T_o - T_a}{2\pi H \log \frac{2h}{a}}$$

This can also be written as

$$G_g = \frac{T_o - T_a}{H} = \frac{g}{2\pi} \log_e \frac{2h}{a}$$

where Gg is defined as the thermal resistance of the soil.

To this must be added the internal thermal resistance of the dielectric, the armour and the sheath if the conductor temperature is specified. If T_c is the conductor temperature.

$$\begin{array}{llllllll} T & - T & & & & & & \\ & & i = & G. & + G_c & - & G_t & \qquad 1,1.1 \\ & H & & i & E & & T & \end{array}$$

where G^ is the internal resistance of the cable. G_t is the total thermal resistance from the conductor to the ground surface, both per meter cable length. G^ depends on the geometry of the dielectric and the dielectric, the armour and sheath materials used. G£ is far greater than G^ for geometries used in practice.

Therefore we can see that for a given maximum conductor temperature and ground surface temperature, the maximum power dissipation of the cable depends on the thermal resistivity of the soil. We can also conclude that the lower the thermal resistivity of the soil, the greater will be the current carrying capacity of the cable for a given ground temperature. The effect of g on the current rating of cables can be seen from rating factors of cables given in Table 1,1.1(Ref,2), Current rating for soil g • 1.20 °C m/u is taken as 1, and the table shows the ratings, relative to this, for other values of g.

Size of cable mm^2	Soil resistivity, °C m/w g = 0.8	g = 0.9	g = 1.0	g = 1,5
Single core cables				
upto 150	1.16	1,11	1,07	0,91
From 185 to 400	1.17	1.12	1,07	0,90
From 500 to 1200	1,18	1.13	1.08	0.90
Multicore cables				
upto 16	1.09	1.06	1,04	0.95
From 25 to 150	1.14	1.10	1,07	0.93
From 185 to 400	1,16	1,11	1,01	0.92

Table 1.1.1 Effect of soil g on the current rating of buried cables of various sizes, relative to the rating for g = 1.20°C m/w.

Thus before laying down cables involving large cable expenditure, it is desirable to survey the route, and at various points to determine the thermal resistivity of the ground in which the cable will be laid. Soils can vary enormously in their thermal resistivity-from as low as g = 0.30° Cm/W in certain water logged soils to very unfavourable ground which may approach g = 4°C m/W (Ref.3).

1.2 Effect of ground temperature on underground cables

Eqn. (1.1.1) gives for the rate of heat flow away from the cable:

$$\frac{T_c - T_a}{G_T}$$

$$\_ \quad \frac{\text{Total temperature drop}}{\text{Total thermal resistance.}}$$

where T_c is the maximum permissible temperature of the cable conductor and T_a is the soil temperature.

The rate of heat generated in a cable having n conductors is given by

$$H = {}^{nl2R}r_{(.C}$$

where R_{Tc} is the resistance of one metre length of each of the metallic conductors at the maximum operating temperature and ^ is the maximum current in each conductor (Ref.4).

Let us say the cable is rated at ground temperature T_a = 15°C.

$$^{Then}\ {}^{T}C \quad " \quad C^{6}max^{+\ 15})^{\circ C}-$$

where 6_{max} is the maximum permissible temperature drop.

At equilibrium,

$$"'ftc \quad - \quad \frac{T - T}{} \quad \bullet$$

where $\underset{l}{G_T} = G. + \underset{I}{\;}\underset{E}{G_c}$

$^{nR}T_{c}($

If the soil temperature $T* = 25$ C and 0^{1}_{max} $T_c - T_a'$ then the maximum current in each conductor is

$$V \qquad \sqrt{\frac{T_c - T_a\text{»}}{nR_{Tc}\ G_t}}$$

Then $$\frac{T_c - T_a\text{»}}{T_c - T_a'}$$

Thus $$I\text{»} \qquad I. \frac{T_c - T_a^{1}}{T_c - T_a}$$

If T 85 C for a certain cable

$$V \quad - \quad I_{1}. \frac{85° - 25°}{<85° - 15°}$$

$$0.926\ I.$$

0.926 is the current rating correction factor.
Table 1.2.1 gives the rating correction factors for various ground temperature (Ref,2).

Max. conductor temperature	Ground temperature				
°c	10°C	15°C	20°C	25°C	30°C
80	1.04	1.0	0.96	0.92	0.88
70	1.04	1.0	0.95	0.90	0.85
65	1.0	1.0	0.95	0.89	0.85

Table 1.2.1Effect of ground temperature on cable current rating correction factors for given maximum conductor temperatures.

The maximum ground temperatures in Kenya vary from place to place. From the Meteorological Department, East African Community, Nairobi the following data were supplied for the year 1973. The temperatures were measured at the depth of 2,5 cm (Ref.9),

Place	Max$_0$ ground temperature for 1973
Nairobi	35°C.
Kitale	30°C$_o$
Machakos	30°C,

1,3 Factors influencing thermal resistivity of the soil

a) Type of Soil and Composition

The thermal resistivity of the soil g, depends a lot on the type of soil and composition (Ref.5). Ref.5 indicates that from fine sand to coarse sand, g changes from 0.52°C m/W to 1.00°C m/W for a moisture content of 10$ and dry density (defined later) of 1.59 g/cc.

b) Moisture Content

For a soil of given compaction, g varies with the moisture content (Ref$_0$5). It has been observed that g increases with decreasing moisture content.

One of the reasons why a study of the dependence of a g on moisture content is important, is the effect of "drying out" of the soil in the vicinity of the cable because of moisture migration (Ref.6). Moisture migration is a process whereby liquid moisture vaporises in areas of higher temperature, passes as vapour through the air spaces between the soil particles, and eventually condenses in areas of lower temperature. The migration of moisture thus may cause a substantial increase in the thermal resistance of the soil (because dry soil has higher thermal resistance), thus the thermal resistance near the cable may get well above that assumed in the design of the cable. The resulting increase in the temperature gradient in the dried soil near the cable will cause further drying of the soil there and eventually the temperature of the cable may rise to a value far in excess of its safe operating level.

The danger of thermal "runaway" and final failure of high voltage underground cables, has long been recognized. In 1963 the Central Electricity Generating Board of Gt. Britain installed cooling pipes between cables of a 275 kV circuit to reduce the soil temperature and prevent moisture migration (Ref. 7). This installation was considered necessary to maintain a low thermal resistivity during prolonged periods of high cable loads. In North America, efforts have been concentrated largely on the use of special backfill materials of low thermal resistivity around cables (Ref. 7).

There is an increased possibility of moisture migration due to the advent of improved cable insulation materials with higher cable operating temperatures. The cable may operate continuously at temperature above 100°C and may eventually dry out the backfill to the extent that soil thermal resistivity will be increased five to tenfold near the cable (Ref. 7). This would result in a reduction in load capability below that possible with the cable operating at low temperatures,

e) Compaction

The thermal resistivity decreases with the increase in density of the soil for a given moisture content of the soil* Neither the variation of g with compaction for fixed moisture content for fixed density follow any general mathematical law (Ref. 5).

1.4 Economic aspect of lower g»

Data for the cost of various 3 Core Aluminium Paper Insulated Lead Covered Steel Wire Armoured Cables were supplied by East African Power & Lighting with rating for soil g = 1o20°C m/W. The figures are given below (Ref. 8 and Ref. 10):

Cable Size mm^2	Current rating Amps.	MVA rating	Cost per metre (1st July 1974) K. Shs./Cts.
70	160	3,02	41/=
185	260	5.33	60/=
300	365	6.94	85/=

(The prices quoted above are subject to fluctuations)

Table 1.4,1 Cost and rating for various sizes of 3 Core Ail PILC Cables

If we calculate the cost per MVA per 1000 metre of the cable, say for 185 mm^2 cable, we will see the economy obtained if it is possible to use soil g which is lower than the standard value i.e. g = 1,20 C m/W.

MVA rating for various g can be calculated by applying the relevant current rating factors from table 1.11 to the cost data of Table 1,4,1,

	g .8	g .9	g 1oO	g 1.2	g 1.5	°C m/W
MVA	6.27	6.00	5,75	5,33	4.78	MVA
Cost per MVA per 1000 metre	957/=	1000/=	1045/=	1125/=	1253/=	Shs.

(Prices are subject to fluctuations).

Table 1.4.2 Cost and rating relationships for varying soil £—of 3 Core AA PILC Cables

From the table we see, as an example, that under a condition where g = 0.90°C m/W instead of 1.2°C m/W Capital Saving of 13$ is possible.

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CHAPTER 2

Soil Classification and types of Kenya Soils

2.1. Some basic soil properties CRef.l).

A soil mass is commonly considered to consist of a network or skeleton of soil particles, enclosing voids of varying sizes. The voids may be filled with air, with water, or partly with air and partly with water.

The total volume of a given soil sample is designated V and consists of two essential parts, the volume of soil V_g and the volume of the voids V , The volume of voids in turn is subdivided into water volume V_w and gas volume V_o« These volumes are indicated in Fig. 2.1.1. This figure must be recognized as a diagrammatic representation since it is evident that all void and solid volumes cannot be segregated as shown.

The total weight of a soil sample is designated by W, the weight of solids by W_g, and the weight of water by W . The total weight and volume are related by W = y where y_L is the total density. Similarly, $W_W = y_W V_W$ and $W_g = Y_S V_S$. Also we define Dry Density in g./cc for the dried mass of a given volume of soil as: = ^JL

The water content of a soil is defined in soil mechanics as the ratio of weight of water to weight of solid matter. It is commonly expressed as a percentage and may be written

$$M \ ^{8} \ \overset{w}{\underset{s}{ir}} X \ 100 \ \% \ \backslash \quad . \qquad 2.1.1.$$

The idealised concept used herein assumes that the solid grains and water are two definite and separate phases of a soil. However, the actual situation is much more complex, since water may exist in a number of forms and mineral grains contain combined water. When a sample is heated to evaporate the pore water, certain amounts of combined water may also be driven off, the amount of loss

V_g i GAS

v

V_{to}1 WATER . W_w =

V . $V\,Y_{(0 to}$ •W = Vy,

V. SOL IDS MV_s =

$V_s Y_s$

Fig. 2.1.1c Diagrammatic representation of soil as a-three-phase system, showing weight and volume notation and relationships of combined water depending mainly on the temperature used. In order to give a fixed definition of what is to be considered as water, it is commonly stated that all weight loss in evaporation by heating to 105°C - 110°C for about 8 hours is water.

Therefore the diagram of Fig. 2.1.1 must be recognised as one based on simplified concepts but it is widely used and unless otherwise stated will be accepted for all consideration herein. This idealised concept also implies that the solids are stable. In many soils, such as those which in the past have been transported and worn by streams, this is essentially true and any loading or other action on the soil will cause no appreciable change in its properties, even over long periods of time. Some soils are very susceptible to chemical action, and their properties may change rapidly in certain environments.

Variations in the water content of a given soil change its characteristics to such a marked degree that the importance of this soil property cannot be overemphasized.

2.2, Homogeneity and variable nature of soil

There is variation of soil properties from place to place and also with depth below ground surface, A power engineer is mostly concerned with variations from place to place at a certain depth.

2.3. Simple soil tests and classification tests.

(1) Classification tests which can differentiate between different types of soil are:

- (a) Atterberg limits.
- (b) Grain size distribution,

(2) The following are some soil tests which are important for characterizing each different soil sample:

- (a) Water content,
- (b) Dry density,
- (c) Bulk density or wet density.

2.4. Atterberg Limit Considerations

A set of several physical limits for a soil type are defined as the Atterberg Limits. Those of relevance here are liquid limit and plastic limit.

The liquid limit w^ is the water content at which a clay is practically liquid but possesses a certain small shearing strength being presumably the smallest value that is feasible to measure by a standardised procedure.

The plastic limit w^ is the smallest water content at which a soil is plastic.

2.5. Grain size distribution

Soils are classified according to limits within which the grain sizes occur. They are classified as follows (Ref.6)

Type of Soil	
Gravel	Grain size between 2mm and 60mm.
Sand	Grain size between 0.06mm and 2mm.
Silt	Grain size between 0.002mm and 0,06mm.
Clay	Grain size between 0,0001mm and 0,002mm.

Various tests have been described in Ref.6 for sieve analysis,

2.6. Water Content Determination

The water content is found as follows:-

Let a specimen of soil be weighed in a container of weight $W_{\triangleright}$. If the dried sample is W_5, and the weight of water is W, then the moisture content is found from

(1) weighing the original specimen and container,

and (2) weighing specimen and container again after removing all moisture by drying.

The original weight of sample and container is

$$W_1 = W_c + W_s + V$$

The weight of dried sample and container is

$$W_2 = W_c + W_s$$

The water content is expressed as a percentage given by

$$M = \frac{W}{W_s} \times 100 = \frac{W - W_i}{W_2 - W_c} \times 100\%$$

2.7, Compaction

Compaction is the process of increasing the density of a sample by application of mechanical pressure. In the laboratory the applied pressure may be either static or dynamic, (In the latter case a weight is permitted to fall on the specimen a specified number of times, each time releasing a specified amount of energy).

Soil density increase is a function of both the compaction effort and the water content.

These relationships are well illustrated by curves of Fig, 2,9,1, and 2,9,2, for one type of Hawaiin Soil (Ref.2)

Another important property of the soil is that on remolding, i.e. taking from its natural state and molding it into an equipment, its properties change. This is because a reorientation of the grains takes place during the remolding. The effect of this on soil resistivity will be discussed later.

2.8. Compaction Curve

For a given soil there is a certain water content at which a given applied pressure gives the greatest dry density. This value is called the optimum water content.

15000,

Mean
pressure
(kg M

12000

(Density to which soil is
compacted is 1.529m/CC)

9000

6000

3000

0,

15 20 25 30 35

Moisture ®

Fip. 2.9.1 Variation of Mean Pressure vs. Moisture, to obtain a specified density (for one type of Hawaiin Soil, see ref.2)

6000

Mean
pressure
(k_g/m^2)

Moisture
content 24.51

3000

1.3 1.4 1.5 1.6 i: 7

Soil density (g/CC)

2»q.? Variation of Menn Pressure vs. soil density for a specified moisture content (for one type of Hawaiin Soil. Ref, (7^

A typical set of curves for a Kenya black cotton soil, for various types of compaction tests is shown in Fig.2.8.1. (Ref.10). Different curves are obtained as shown, by varying the energy imported to the soil i.e. the number of blows and the height from which the hammer falls on the soil.

2.9. Types of Kenya Soil (Ref.5)

In our experimental work, we cannot deal with all the Kenya soils. Broadly we will deal with four main types of Kenya soils. They are:

A. Red Coffee Soil.
B. Black Cotton Soil.
C_e Sand.
D. Murram,

A. Red Coffee Soil

The red coffee soil has low plastic limit (see Table 2.9.1), is reddish brown in colour, and has relatively good drainage properties (compared to black cotton soil). The colour is due to the presence of free aluminium and ferric oxide mixed with an equal or greater amount of aluminium silicate clay.

B. Black Cotton Soil

The black cotton soil is dark in colour and occurs in areas of well defined wet and dry seasons, poorly drained topography and in valley bottoms. It has poor drainage properties. The black colour is due to a particular type of iron oxide and/or titanium and not due to any organic matter.

C. Murram

Murram is a gravely soil which may contain various properties of the above two soils, its colour depending on the relative content of these soils, and other soils present, Murram is a hardened form of fine grained soils.

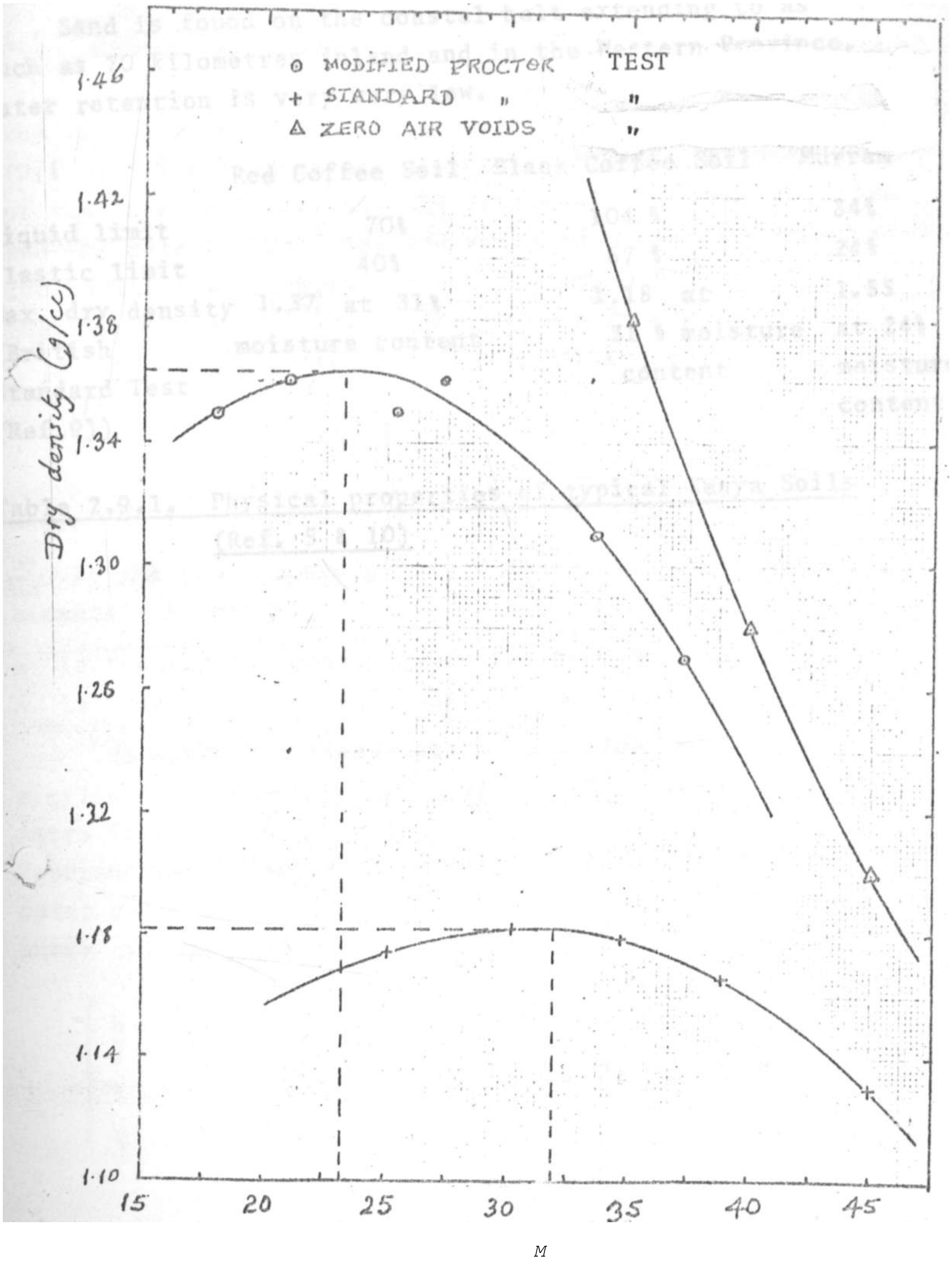


Fig. 2.8.1. Relation between dry density and moisture content (compaction curve) for a Kenyan Black Cotton Soil. (Details of various test methods can also be found in Ref.9)

D. Sand

Sand is found on the coastal belt extending to as much as 70 kilometres inland and in the Western Province. Water retention is very very low.

	Red Coffee Soil	Black Coffee Soil	Murrain
Liquid limit	70%	104.%	34%
Plastic limit	40%	67 %	24%
Max. dry density (British Standard Test (Ref.9))	1.37 at 31% moisture content	1.18 at 31 % moisture content	1.55 at 24% moisture content

Table 2.9.1. Physical properties of typical Kenya Soils CRef. 5 & 10)

CHAPTER 3

Design of the apparatus

3e1 Design Principle:

The design is based on a radial heat flow through the soil sample, which is between two concentric cylinders (Ref.l). The temperature difference between the outside of the inner cylinder and the inside of the outer cylinder and the rate of heat flow are measured. From the equation for radial flow of heat between two concentric cylinders, the thermal resistivity of the soil is found.

The steady state heat flow equation is

$$H = -kA$$

where H is the rate of heat flow in watts.

^ is the temperature gradient in °C/m„ across the element dx metre.

k is the thermal conductivity in W/°C m.

A is area in m^2 perpendicular to the heat flow.

We apply the steady state heat flow equation to a cylindrical element dx metre thick at a distance x metre from the centre and L metre long (Fig„3.1_0l). Rearranging and integrating between the inside of the outer cylinder (radius j metre) and outside of the inner cylinder (radius -j metre)

$$H \quad \overset{b}{\underset{\frac{a}{2}}{2}} \quad \frac{dx}{HFxL} = \text{"}^{k} \quad \overset{T_o}{\underset{T_a}{}} \quad de$$

where T_q is the temperature of inside of the outer cylinder in °C.

$T_\&$ is the temperature of the outside of the inner cylinder in ®C. .

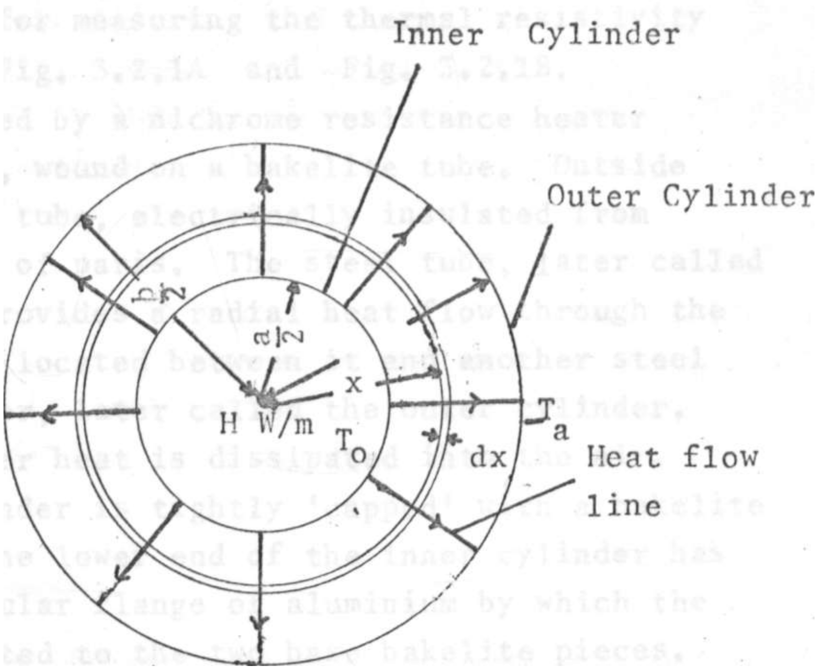


Fig. 3.1.1. Concentric cylinder with heat flow lines as indicated

$$\frac{H}{2\pi L} \log \frac{b}{a} = k(T_o - T_a)$$

$$g = \frac{1}{k} = \frac{2\pi L(T_0 - T_a)}{H \log_e \frac{b}{a}} \qquad 3.1.1$$

3.2 Description of the apparatus

The apparatus for measuring the thermal resistivity of soils is shown in Fig. 3.2.1A and Fig, 3.2,IB.

Heat is produced by a nichrome resistance heater element in the centre, wound on a bakelite tube. Outside the heater is a steel tube, electrically insulated from the heater by plaster of paris. The steel tube, later called the inner cylinder, provides a radial heat flow through the soil sample, which is located between it and another steel tube of bigger diameter, later called the outer cylinder. From the outer cylinder heat is dissipated into the air.

The inner cylinder is tightly 'capped' with a bakelite cylindrical piece. The lower end of the inner cylinder has a tightly fitted circular flange of aluminium by which the inner cylinder is bolted to the two base bakelite pieces. The heater supply wires come out to the outside via a hole and a groove in the bakelite base. Three grooves are machined in the inner cylinder as well as the outer cylinder. The two grooves directly opposite each other are shown in Fig.3.2,2, The third groove on each cylinder is next to the left hand groove on each cylinder. They accommodate 5 thermocouples on the inner and outer cylinder, and serve as paths for all the leads to the thermocouples. The thermocouples are located so as to give the temperature at representative locations, in case of non-homogeneous soil. Possible end effects can also be checked by comparing different pairs.

The 4 pairs are expected to give a good average for the whole soil sample. The fifth pair is used to measure absolute temperatures of the cylinders.

To prevent water from getting to the heater through the space between the bottom of the inner cylinder and the bakelite base a thin rubber gasket is used. At the top of the inner cylinder, araldite is used to fill any gaps between the 'cap' and the cylinder.

The outer cylinder is made of two halves, joined together by nuts and bolts along the flanges on the two halves, A rubber gasket is located between the flanges. The outer cylinder is fixed to the bakelite base by nuts and bolts on circular flanges welded at the base of two halves,

A polystyrene foam cover is used to cover the top of the complete assembly. Polystyrene is also used as a thick base on which the apparatus stands.

n

Fig, 3,2,1C shows the design of piston used for compaction of the specimen.

3,3 Design of the cylinders

The material chosen for the cylinders was steel (k = 71,9 W/^{U}C m) to provide isothermal surfaces. Copper would have been preferred but was considered expensive.

e

Dimensions chosen for the cylinder are as follows:-

Outside diameter of the inner cylinder = 4,2 cm.
Inside diameter of outer cylinder = 15,2 cm.
Length of the cylinders = 50 cm.

From eqn. 3.1.1.

$$H = \frac{2ttL_v(T_{>} - T_o)}{g \log_e a^{1}}$$

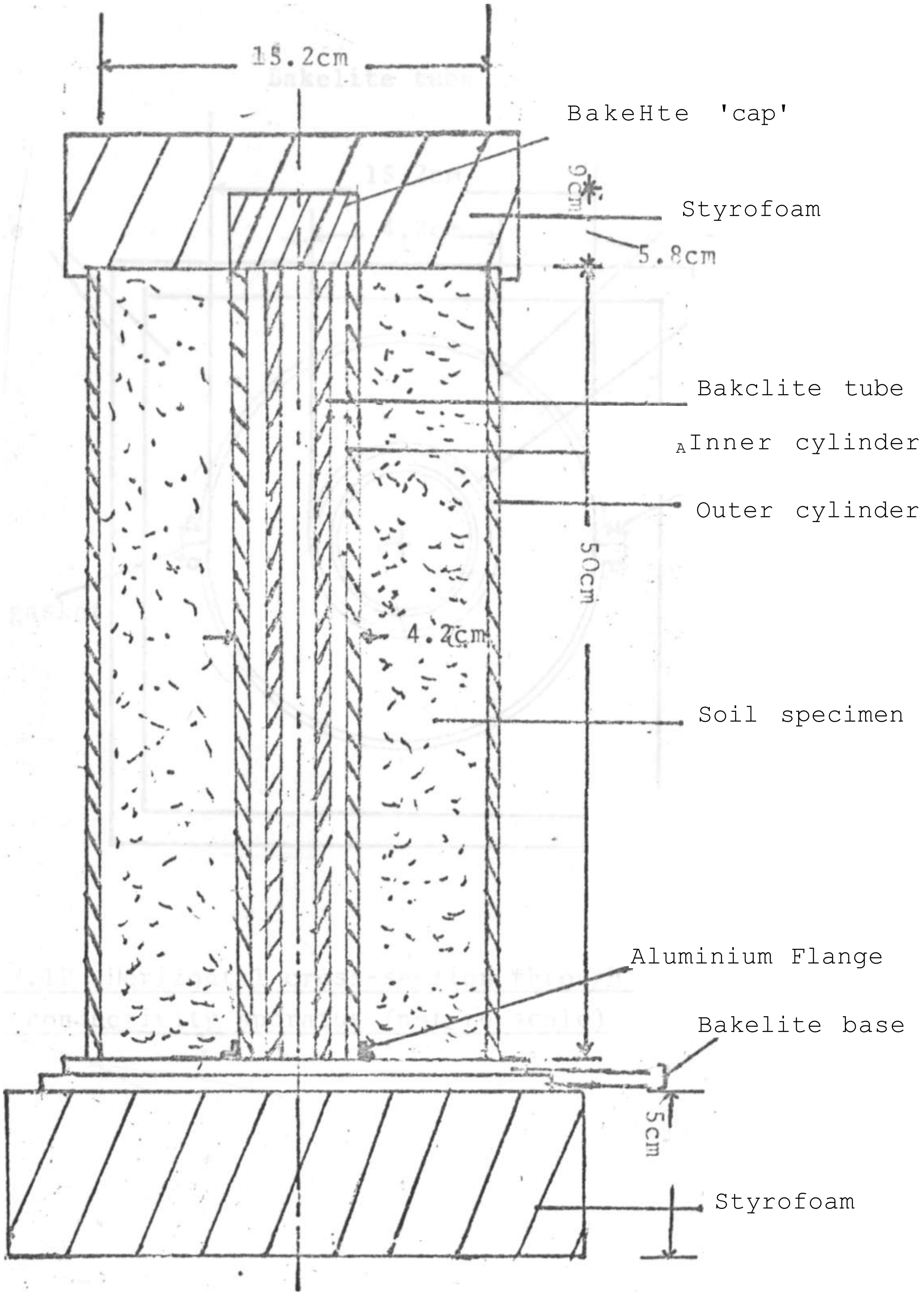


Fig. 3.2.1A Vertical cross-section through thermal conductivity, apparatus (not to scale)

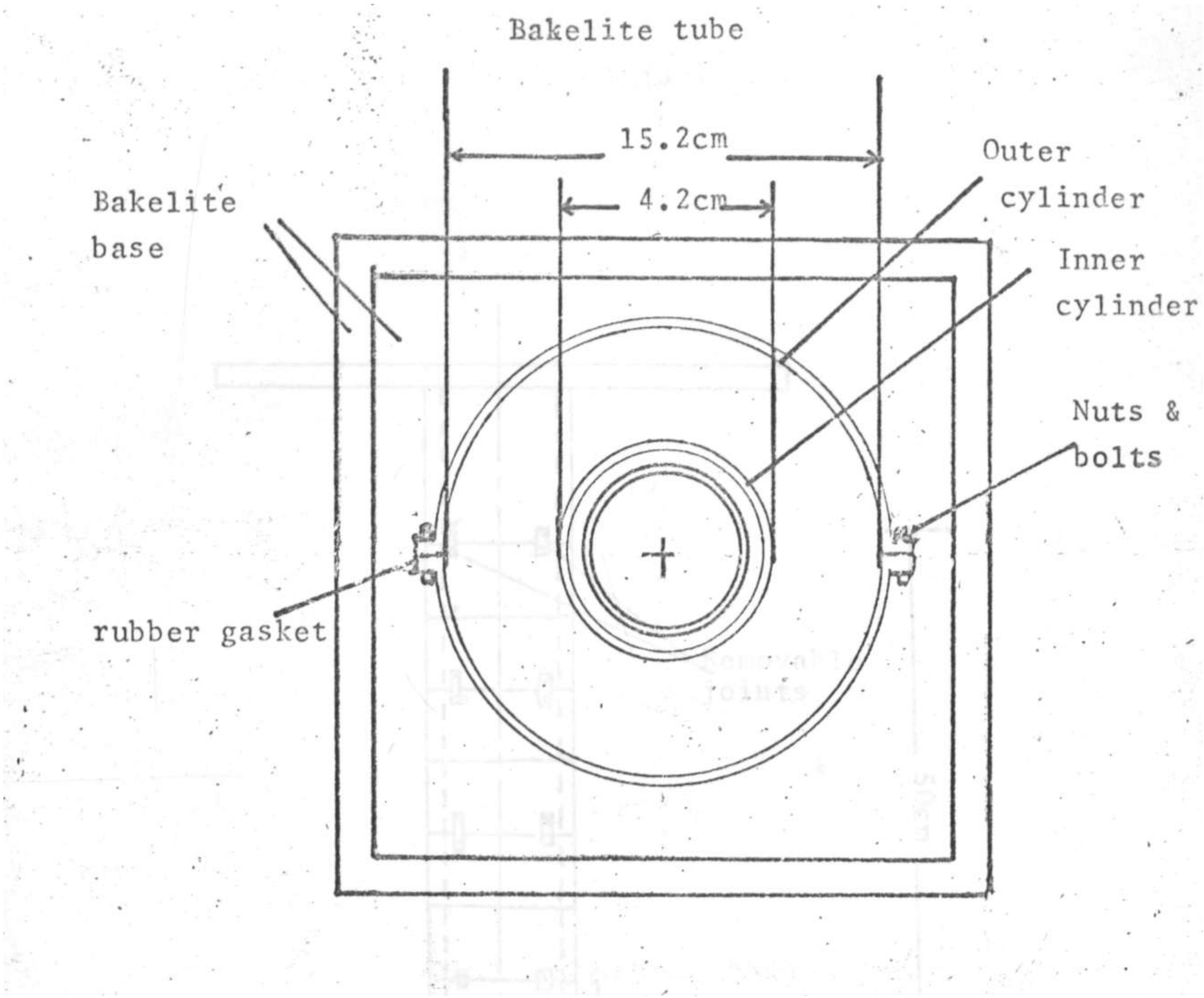
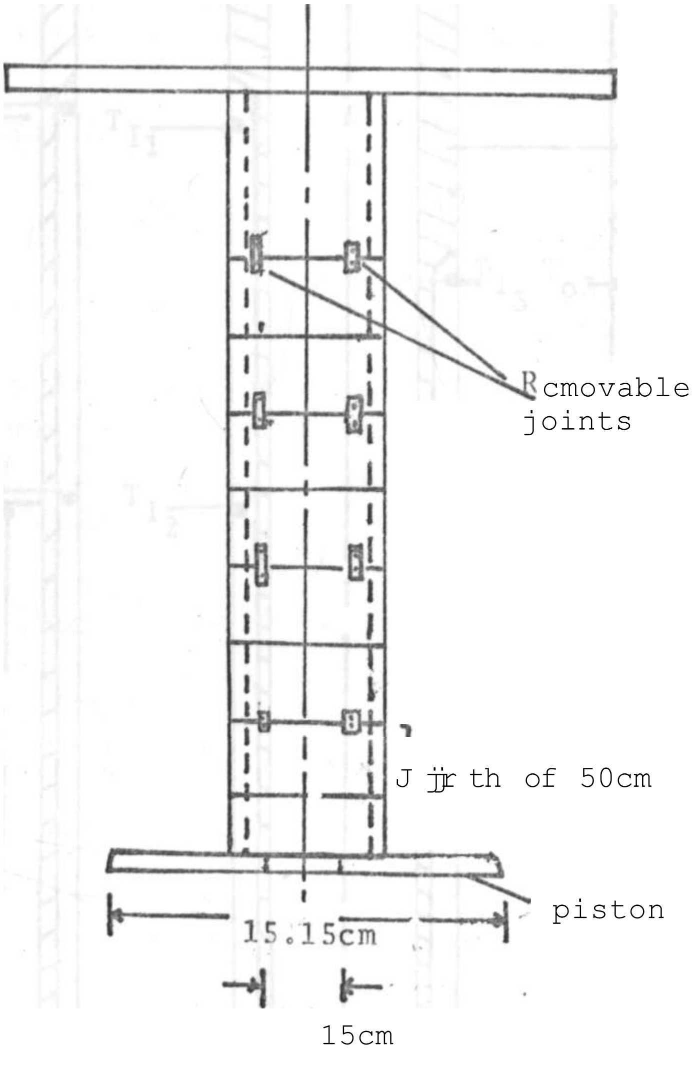


Fig. 3.2. IE Horizontal cross-section through the *
thermal conductivity appratus (not to scale)

o-



3.2.1C Piston for compressing soil in the specimen holder

T_{o1} - T_{o4} Outer thermocouples

II 14 Inner thermocouples.

Tji- and T thermocouples for measuring inner and outer cylinder temperatures.

H

/
/

/

_K Outer cylinder

If

A

→• Inner cylinder

5J I3 To, y

y

E
u

o
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o2

•TI4 To

Tfi-^Z..
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bake]ite
.5 base

Fig. 3.2.2. Position of thermometers through a vertical cross-section of the cylinder

Assuming minimum g - 0_o50 °C m/W and maximum H = 20 watts. Corresponding temperature difference

T_o " T_a = 4_10c,

For g » 3_000 °C m/W and maximum H - 20 watts corresponding T_0 " T_a = 24.6°C.

To keep T_Q - $T_\&$ less than 20°C, each experiment is started at a low H say 5 or 7 watts.

3.4 Heat loss from cylinders

Calculations show that for the geometry of the base plate used, most stray heat will be conducted radially (Fig.3.4.1). To find an upper limit to the stray heat through the base let us assume the temperature is the same as on inner cylinder all the down through the base, along an extension of the inner cylinder, radius a/2. Then, let us assume heat flows radially outwards in the base as well as in the soil. We calculate below the heat loss in bakelite plate, H^ and in the styrofoam, under these overly pessimistic assumptions.

Maximum temperature difference between the inner cylinder and the outside air can be assumed to be 20°C. The inside of the outer cylinder will be at a higher temperature than air temperature.

For bakelite,

1 i^T
e a

where k_1 = 5 x $10^{\sim 2}$ °C m/W

(thermal conductivity of bakelite)

H^ is the rate of heat flow through the bakelite.
b is the external diameter of the outer cylinder,

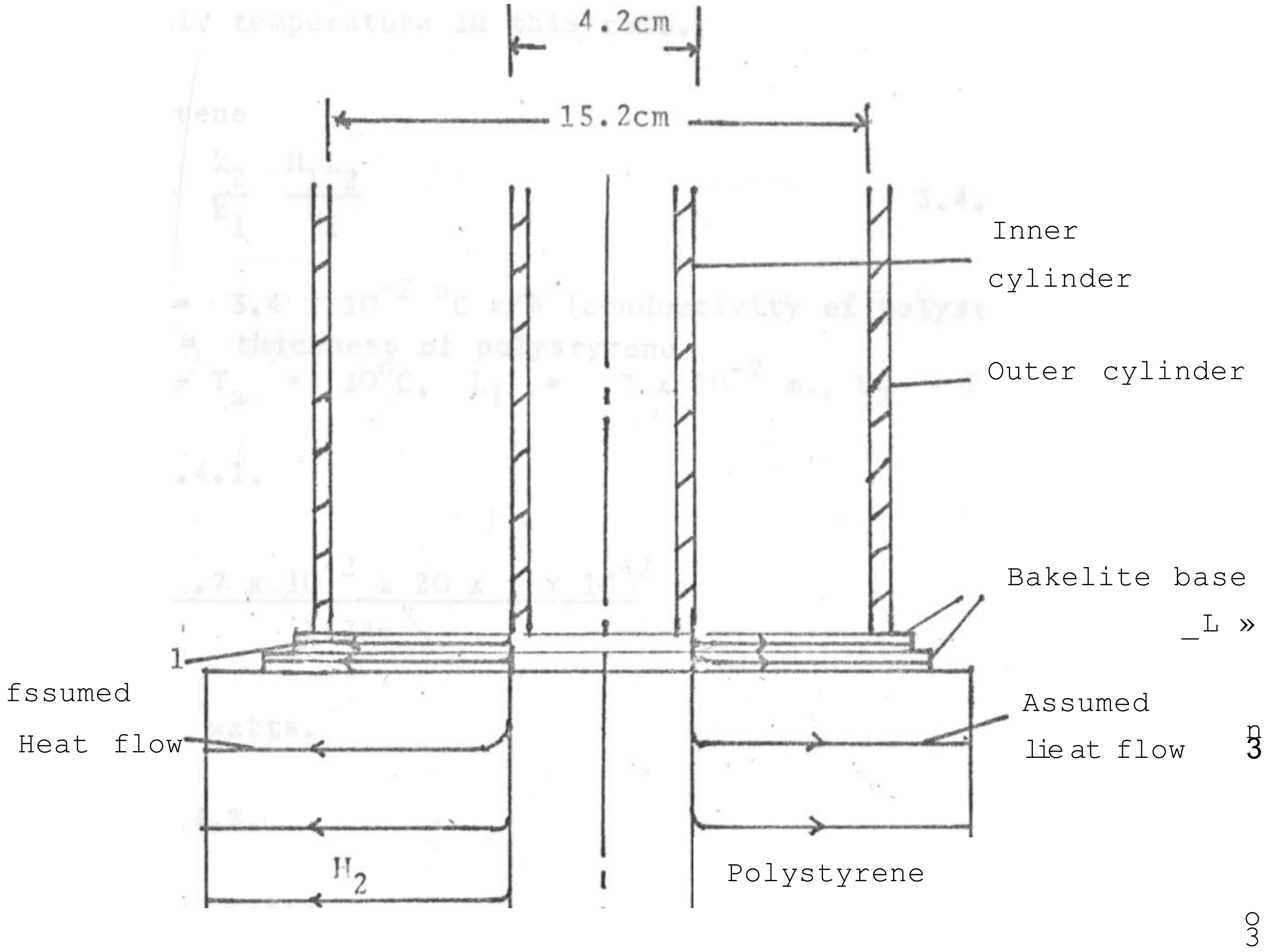


Fig. 3.4.1 Heat flow through <u>the base .,</u>

L is the thickness of the bakelite piece,

'a is the external diameter of the inner cylinder,

T_q is the temperature of the inside cylinder,

T_a is the air temperature in this case.

For polystyrene

$$K_2 \quad H \quad I$$

$$h_2 \; ' \; K7 \; -rf \qquad\qquad {}^{3}\_{}^{4}\_{}^{2}$$

where k_2 = 3.4 x 10~^{2} °C m/W (conductivity of polystyrene)

= thickness of polystyrene

Assume $T_0 - T_3$ 20°C, L_1 = ,7 x 10"^{2} m,, L^ = 5 x 10"

From eqn. 3.4,1.

$$H_X = \frac{2u \times .7 \times 10"^2 \cancel{\times 20 \times 5 \times 10"}^2}{1,286}$$

= .034 watts.

From eqn, 3.4.2.

H_2 = 0,166 watts.

Max. total heat loss = ^ + H_2 * .20 watts.

(b) <u>Heat loss from top</u>

Calculations show that for the geometry of the top insulation, most stray heat will be conducted radially.

With assumptions similar to heat loss from the base, the stray heat through the top can be calculated,

$$H_3 = \frac{2ttL\ A0k}{1,286}$$

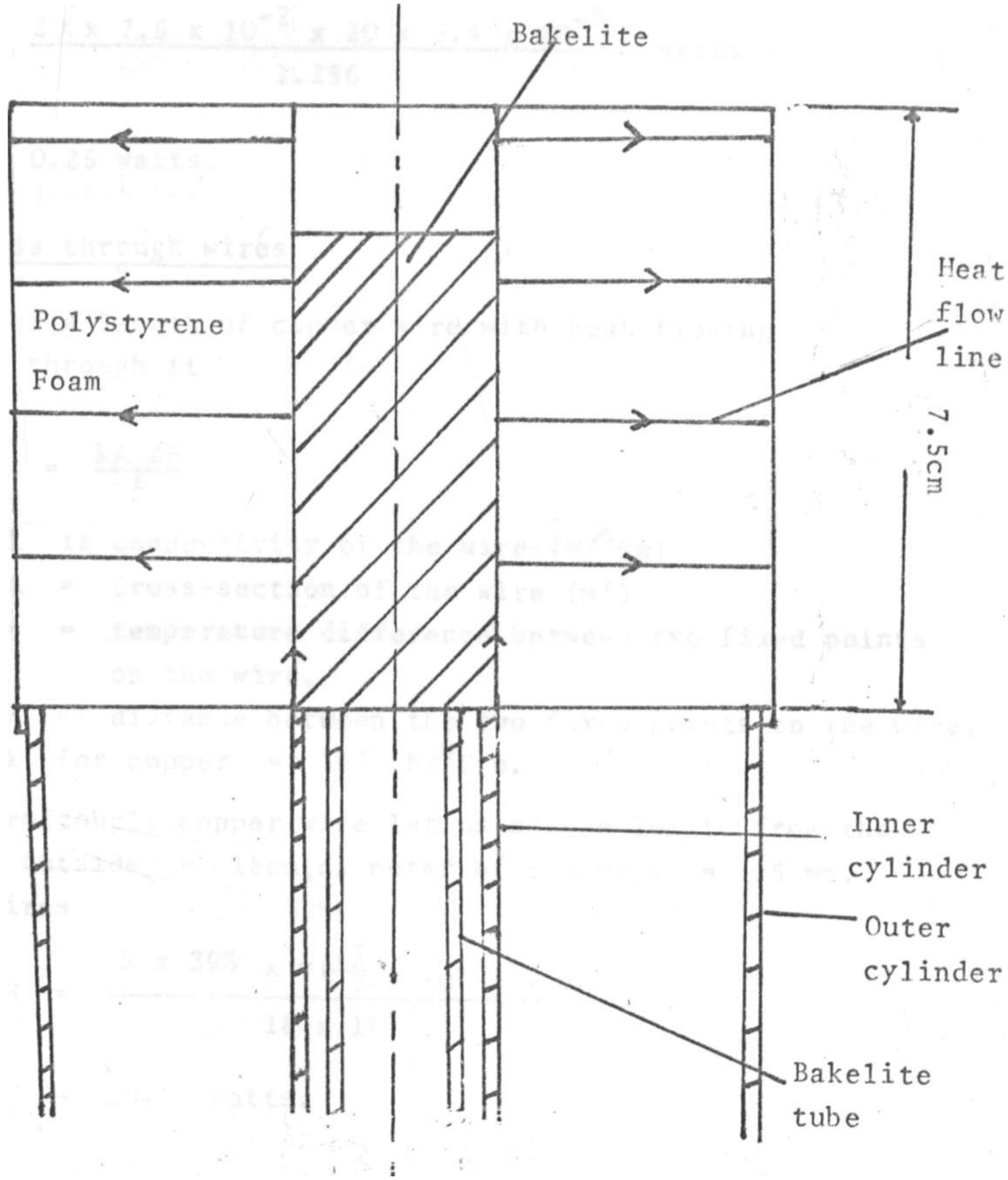


Fig. 3.4.2 Heat flow through top of the cylinder

where L = 7.5 x $10\sim^{2}$m. AT = 20°C.

k = 3.4 x $10^{-?}$ (conductivity of styrofoam).

H_3 = radial stray heat from the top.

$$H_3 = \frac{2\ tt \times 7.5 \times 10"^{2} \times 20 \times 3.4 \times 10"^{2}}{1{,}286} \text{ wattJ}\cdot$$

= 0.25 watts.

<u>Heat loss through wires</u>

For a length of copper wire with heat flowing axially through it

$$\overset{U}{H} = \frac{kA\ .A6}{j}$$

where k is conductivity of the wire (W/°Cm)

A = Cross-section of the wire (m^2)

A6 = temperature difference between two fixed points on the wire.

i = distance between the two fixed points on the wire,

k for copper • 393 W/°C m.

For thermocouple copper wire let us assume length from the base to outside = 18cm,diameter of the wire = .5 mm.
For 5 wires

$$\overset{''}{ri} = \frac{5 \star 395 \star '14 \times 10 - V,\ 20 \atop \star}{18 \times 10"\star}$$

= ,045 watts.

For 5 constantan wires of the thermocouples,

$$H = \frac{5 \times 22 \times 7r(^{e}|\wedge \times 1O^{-3})^{2}\ 20}{18 \times 10}$$

= ,001 watts

Heat loss from two heater supply wires of Area = 1.5 mm^2

$$» \frac{2 \times 393 \times 1.5 \times 10^{-6} \times 20}{18 \times 10^{-2}}$$

= 0.13 watts.

Total heat loss R ^ ^ = -$^{200\ +}$ -250 + .045 + .001 •O.IS

- .626 watts

Heat require^ for a temperature d/op of 15°C between outside of inside cylinder and inside of outside cylinder (for g • 2.00 °C m/W) will be assumed.

$$H = \frac{15 \times 2tt \times 0.5}{1.286 \times 2} \quad e \ 19 \text{ watts}$$

$$.\% \ \text{error is} \ H=100_{X} \ \frac{}{19} \ « \ {}_{3o5}«_{0} \ \text{say} \ n$$

Thus a pessimistic estimate of the error of the measured soil resistivity, for the unfavourable case of a high resistivity soil, is about 4'» which is quite acceptable.

3.5 Choice of Thermometers

There are many methods available for the measurement of temperature. Among the possible sensors that give electrical output are

1. Resistance thermometers, including thermisters
2. Thermocouples.
3. Semi-conductor diodes.
4. Transistors.

3.6 Resistance thermometers

Two lengths of thin copper wire could possibly be used as thermometer by coiling them up in grooves in the outer as well as inner cylinder. Some measurements on a sample of copper wire were done with this in mind, The result is indicated in table 3.10,l$_o$

The relationship used to determine temperature is

$$R_t = R_{to}\ O + \qquad -$$

where R_t resistance at temperature t°C
R_{to} » ii ii + o 8
a coefficient of increase of resistance (°C

(b) Thermistors

Thermistors were not used because of the non-linear relationship of its resistance to temperature change.

3.7 Thermocouples

Copper-constantan thermocouples were available. The output for different temperatures are tabulated in Ref,2. The output is about 41«6per ^ Q C rise of temperature.

To measure absolute temperature, the cold junction should be kept at ice-point. For difference measurement, two junctions are connected differentially. For amplified output more than one differential pair can be connected in series,

3.8 Diode as a thermometer

For a constant current through a semiconductor diode the voltage across it reduces linearly by about 2mV/°C rise of temperature, (Ref.3).

3,9 Transistor Thermometer

The variations of base emitter voltage with temperature are amplified by the transistor itself to give a much larger output (Ref.3). We made tests of transistor thermometer with the circuit shown in Fig. 3.9.1.

The voltage gain $(=\frac{{}^{3}V_{RL}}{{}^{3}e_T}$ where $e^{™}_{T}$ is the base emitter emf) as derived from an analysis similar to the one in Ref.2 is

$$VG = \frac{aR_T}{(R_x + R_2(1 - a)^{x})}$$

where $R_3 >> R_2$

The values of components used were

R_1 = 120fl

R_2 = 1,5 kf2

R_3 = 1Okfl

R_L = 3.9kfi

Assuming the sensitivity of base emitter emf $\frac{eT}{T}$ = 2mV/°C, this gives sensitivity of the transistor thermometer

$$\frac{{}^{3}V_{RL}}{{}^{3}T} = 47 \text{ mV/°C.}$$

Measured sensitivity: 51 mV/°C.

Measured drift over 10 hours period = +_ 7mV, corresponding to approx. 0.15°C.

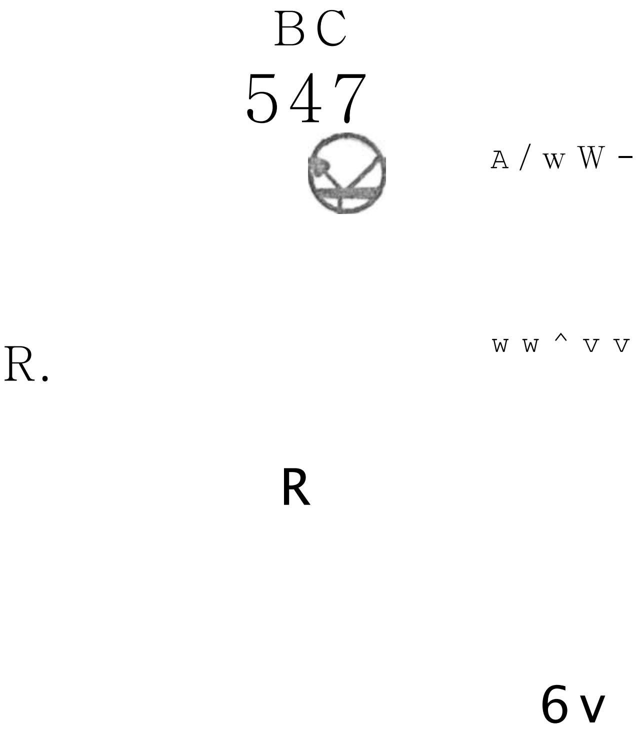


Fig. 3.9.1. Transistor Thermometer

3.10 Choice of Thermometer

Data for various thermomemters are summarised in table 3.10.1.

Type of thermometer	Sensitivity	Error in measurement
Copper thermometer	0.0955 Q/°C	+0.4 °C
Thermocouple (Cu - k)		
(Differential connection)	41.6yV/^{0}Ci	+0.8 °C
Diode	2mV/°C*	
Transistor	51mV/°C	+0.2°C (due to drift) in differential connection

(* Data taken from Ref.3)

Table 3.10.1. Data for various types of temperature sensors tested.

Transistor seems to be best choice because of high sensitivity and low error in measurement but constant failure of transistors led to abandonment of this method of measurement. Thermocouples were finally chosen for the ease in embedding them in the cylinders. The low output is amplified by "Philips" Voltmeter, Type PM2440 with amplification for various ranges as in table 3.10.1 with outputs to chart recorder for continuous monitoring over long periods of time. The chart recorder is a "Philips" Dual Channel Recorder, Type PM8221.

Range of input	Amplification
0 - 0.3 mV	326
0 - 1mV	102
0 - 3mV	34

Table 3.10.1 Gain of "Philips" Voltmeter. Type PM2440 for various ranges.

CHAPTER 4

Experimental Procedure, results and discussion

4,1 Experimental Procedure

Before compacting the soil to the dry density required, the dried sample of the soil (which has been left to dry in a drying furnace for at least 10 hours at temperature of about 125°C) is mixed thoroughly with the required amount of water. In case of red Coffee Soil and Black Cotton Soil a mixer is used. In case of Murram and Sand, mixing is done manually with a spade. In case of Black Cotton Soil, the mixture is left aside for 10 hours for the water to penetrate all parts of the soil sample before compaction is commenced. This work is all done in soils laboratory of Civil Engineering Department (Ref,4)

The soil is compacted into the apparatus by pressing it down with a piston, which fits closely in the specimen holder, the pressure being supplied by a hydraulic press. The amount of soil needed is weighed in advance, and divided into 8 parts. One part is put into specimen holder and compressed until it occupies exactly I of the volume. Then the next part is put in and compressed in the same manner. This procedure is used to get uniform compression in the whole sample.

For each type of soil, in one set of experiments, g is measured for various values moisture content (M), all at the same dry density (Yd.)® the other set, the moisture content (M) is fixed and the g is measured for various values of dry density (yd). For Murram, g is measured only for M variations for fixed

During g measurements the average of total output of all the (generally 4) differential thermocouple pairs connected in series gives the average difference of temperature (after conversion) between the cylinder.

The total output of the therocouples is amplified by the Philips Voltmeter PM 2440 and then fed to the Philips Chart Recorder for recording as a function of time.

For each experiment on a particular soil specimen, two runs are made (except for early experiments on red coffee soil and black cotton soil when this systematic technique had not yet been worked out). The heat inputs are chosen by varying a series resistance, re-adjustments are made from time to time to keep a constant heat input. The adjustments are needed because of fluctuations in the line voltage, and because of changes in the resistance of the heater element due to its temperature change.

4.2. Typical calculation of g

A typical thermocouple difference output vs. time of Black Cotton Soil of yd = 1.1 g/cc and M « 30% is shown on the recorder on Fig, 4.2.1. It is noted that output does not settle to a steady value after the transient period but increases linearly with time. This is because of moisture migration, as discussed in Chapter 1.

Although moisture migration is also of great importance in the soil around a cable, we are presently interested in g of soil with uniform moisture content. The following procedure is therefore used:-

An extrapolation of the linear part of the curve is carried out by a straight line shown on fig,4.2,1, to zero time when moisture migration is zero. For this value of heat input, the extrapolated temperature difference is found, and the resistivity is found as follows:-

We take 41,6 yV/°C (Ref.2) as thermocouple sensitivity for each constantant thermocouple. Then the temperature difference corresponding to zero moisture migration

$$\frac{AT}{A1} = \frac{2{,}05 \times 10"^{5} \; °C}{4 \times 41{,}6 \times 10"°} ,$$

$$= 12{,}5 \; °C$$

Thermal resistivity of the soil using eqn, 3,1,1 is

$$g = \frac{12{,}5 \times TTX \, ,50 \times 2}{1{,}286 \times 25}$$

$$= 1{,}21 \; °C \; m/W.$$

The g values of the soil specimens calculated from different heat inputs do not show any systematic departure on H, Since the average soil temperature will be higher for bigger H, we conclude from this that there is not strong T-dependance of the thermal resistivity of these soils,

4,3 Sources of error

a) Heat losses from top and bottom insulations

According to design calculations in Chapter 3 < 4% of heat input may be expected lost as strong heat when g = 2,00 °Cm/W. For lower g the error will be less. We therefore take 4% as a pessimistic estimate of error in g due to heat loss.

_ HW

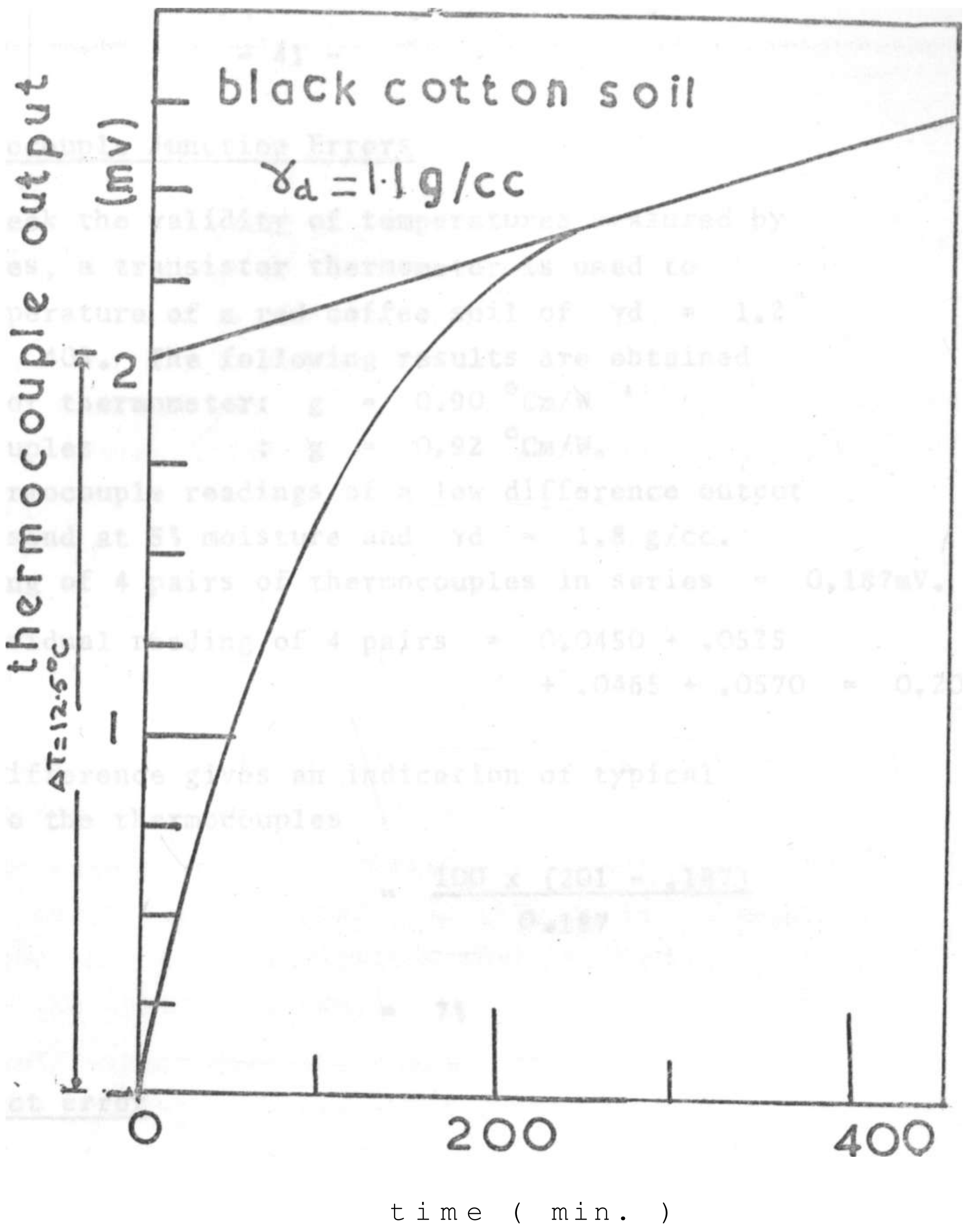


Fig. 4.2,1. Thermocouple output vs. time for Black Cotton Soil.

(b) Thermocouple Junction Errors

To check the validity of temperatures measured by thermocouples, a transistor thermometer is used to measure temperature of a red coffee soil of yd = 1,2 g/cc, M = 40$, The following results are obtained
By transistor thermometer: g « 0.90 °Cm/W *
By thermocouples : g = 0.92 °Cm/W.
Typical thermocouple readings of a low difference output is that of sand at 5°& moisture and yd = 1.8 g/cc.
Total reading of 4 pairs of thermocouples in series = 0.187mV.

Sum of individual reading of 4 pairs = 0.0450 + .0525
+ .0465 + .0570 = 0.201 IPV

The difference gives an indication of typical error due to the thermocouples

$$\frac{100 \times (201 - .187)}{0.187}$$

$$= 7\%$$

(c) Contact error

Poor thermal contact between the soil and each of the two metal cylinders will give error in the measurement of g, since in general our thermometers are located in grooves in the metal, and measure the temperature of the metal. Thus we measure a temperature difference which includes the temperature drop across the soil, but also a possible temperature drop between the inner cylinder and the soil surface and a temperature drop between the soil surface and the outer cylinder.

A check of the magnitude of each temperature drop across the metal-soil interface was made in one experiment by introducing an extra thermocouple junction in the soil.

---

* The soil was from a different area.

This junction was connected to the junction in the groove of the inner cylinder close by, to form a differential thermocouple. A voltage of 8yV (corresponding to the thermocouple junction in the soil being 0.2 °C colder than the junction in the metal) was measured. The check was made for sand of yd = 1.8 g/cc, M = 13$, H = 5.33 watts for which AT extrapolated®2»22 °C. Thus the error is

^ x 100 = 9 %
2.22

A similar arrangement was set up on the soil-metal interface on the outer cylinder. A voltage of 12yV (corresponding to thermocouple junction in the soil being 0.3°C colder than the junction in the metal) was measured.

Thus we note that the measurement of a voltage « 12yV is itself very uncertain, so this error estimate must be taken only as an indication that the temperature drop across the contact is small.

One would expect that the thermal contact resistance, and therefore the error caused by it, would be bigger for low than for high moisture content, and bigger for low than for high compaction,

(d) <u>Error due to remolding of soil</u>

According to Ref.l remolding into the apparatus of sensitive clays can result in a change by as much as 10$ in g of the specimen measured in laboratory compared to the same soil when measured directly. Another source of error is the non-uniformity of soil which is caused by difficulty in making a completely homogeneous mixture of soil and added water. An example of unusually big variation in thermocouple readings can be seen from following individual reading of the 4 differential thermocouples located at different heights in the specimen holder, which is holding

Black Cotton Soil$_f$ yd = 1.1 g/cc and M = *1S%*

AV = 0.232mV, 0.226mV, 0.242mV, 0.206mV.

Typical variations of thermocouple outputs for a more homogeneous mixture of Black Cotton Soil of yd = 1.1 g/cc

M = 30% are as follows:-

AV = 0.160mV, 0.161mV, 0.155mV, 0.164mV.

4.4 Total error

From eqn. 3.1.1. we see that soil g with error can be written as

$$g + Ag = \frac{2ttL\ C\ T + {}^{e}T)_{L}}{1.286\ (H + e\hat{}\ )}$$

where e_T is the error in AT = T_Q - T_a

h $\qquad$ ^{H},

From this we get to 1st order, for the worse case when errors add up:

$$\frac{A£}{g} \qquad \frac{T}{If} \qquad \frac{{}^{e}h}{TT}$$

The heater power is found by measuring voltage and current separately, so

$$\left|\frac{{}^{e}h}{H}\right| - \left|\frac{AV}{V}\right| + \left|\frac{AI}{I}\right| + \left|\frac{fh}{H}\right|$$

where $\underline{AV}$ $\frac{\text{error in heater voltage}}{\text{Heater Voltage}}$

$\frac{M}{I}$ $\frac{\text{error in heater current}}{\text{Heater current}}$

$\frac{^{c}h}{IT}$ = error due to stray heat (see sec.4.3)

From section 4.3

$\frac{T}{AT}$ n, TT 4%

$\frac{AV}{V}$ • 21, & + 8% C^{sin}ce f.s.d. error is +_ IV-
and I of the scale is used)

Total % error = (7 + 4 + 2 + 8) %

« 20%

Since these errors, except the stray heat, must be considered random errors, it is not likely that they will all have the same sign. It may therefore be more reasonable to use the root mean square error.

Root Mean Square errors

$$= 100 \times \left|\frac{^{e}T}{AT}\right| + \left|\frac{^{e}h}{"FT}\right| + \left|\frac{AI}{\sim T}\right|^{2} + \left|\frac{AV}{T\sim}\right|$$

$$100 \times |.0049 + .0016 + .0004 + .0064$$

12%

Thus: It is expected that the overall error in the result of a given measurement is about *12%* or less. This estimate should be compared to the error bar for each sample on the graphs which follow, and the spread of the data around the smooth curve drawn for each set of experiment. The error bars represent the difference in g calculated from the runs of different heat input for a given sample. From the graphs it appears that the above estimate of error is realistic.

4,5 Experimental Results

In Fig. 4.5.1A to 4.5,4., our experimentally obtained values of soil resistivity for different soils and for different conditions, are presented in form of graphs. (The detailed data are also tabulated, with additional relevant information, and details of soil, in Appendix A1 to A4)«

For each of the soils: red coffee soil, black cotton soil, sand, murram, only one or two batches of soil were used. After measurement at one yd, M, the soil was dried and re-used after water had been added to give a different M, In general a graph is given of g(M) at a constant yd, and one graph for g(yd) for constant M. (For murram it was not possible to change yd significantly by compaction, so g (yd) is not given).

It was attempted to cover the widest range of M possible. However, a natural limit was, on the low side, a value of M below which completely homogeneous mixture (generally about the M of plastic limit) was not possible. In some cases it was also attempted to measure M = 0% but the yd required was not achieved.

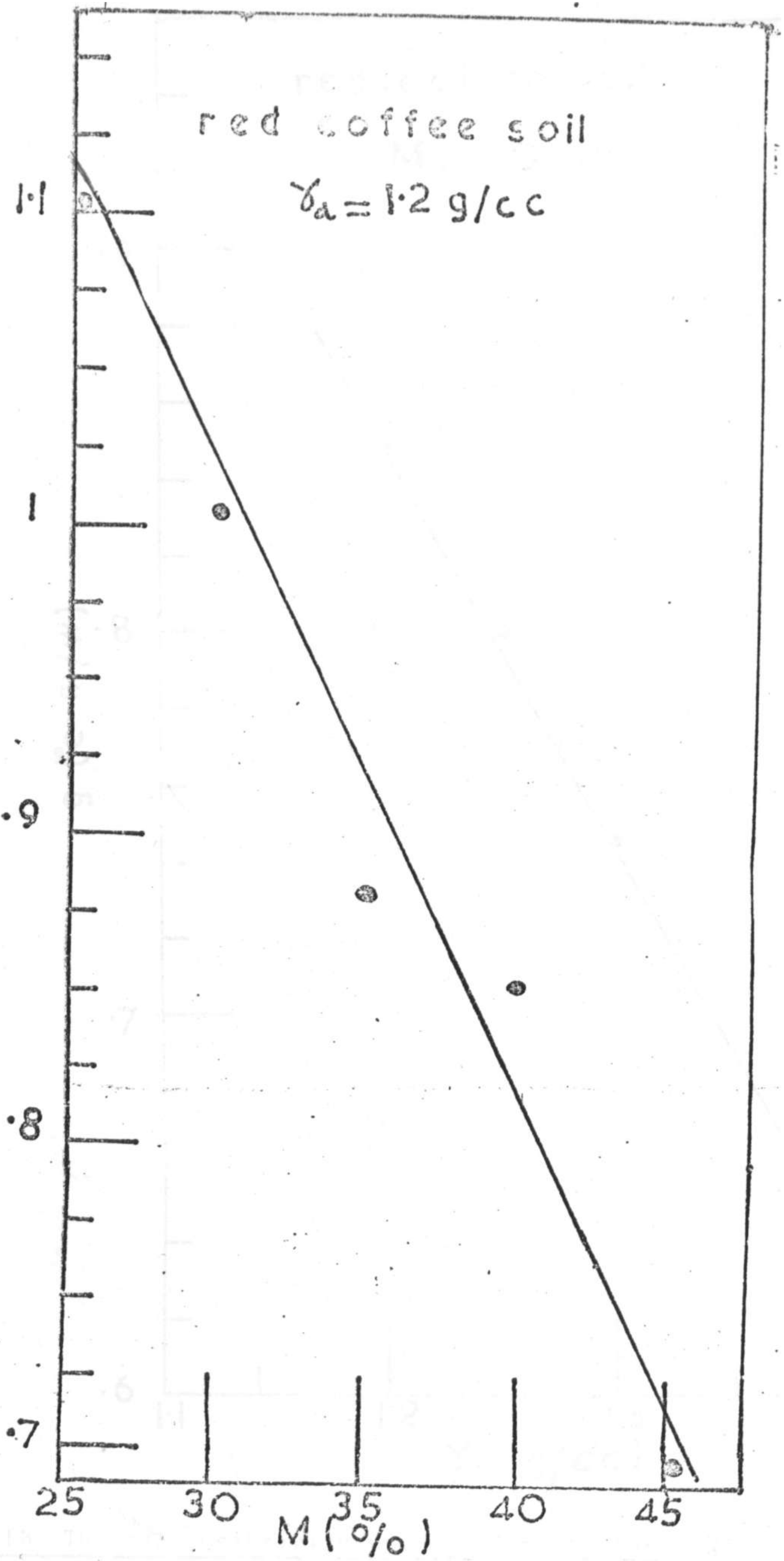


Fig.4.5.1A Variation of thermal resistivity vs. moisture content for Red Coffee Soil.

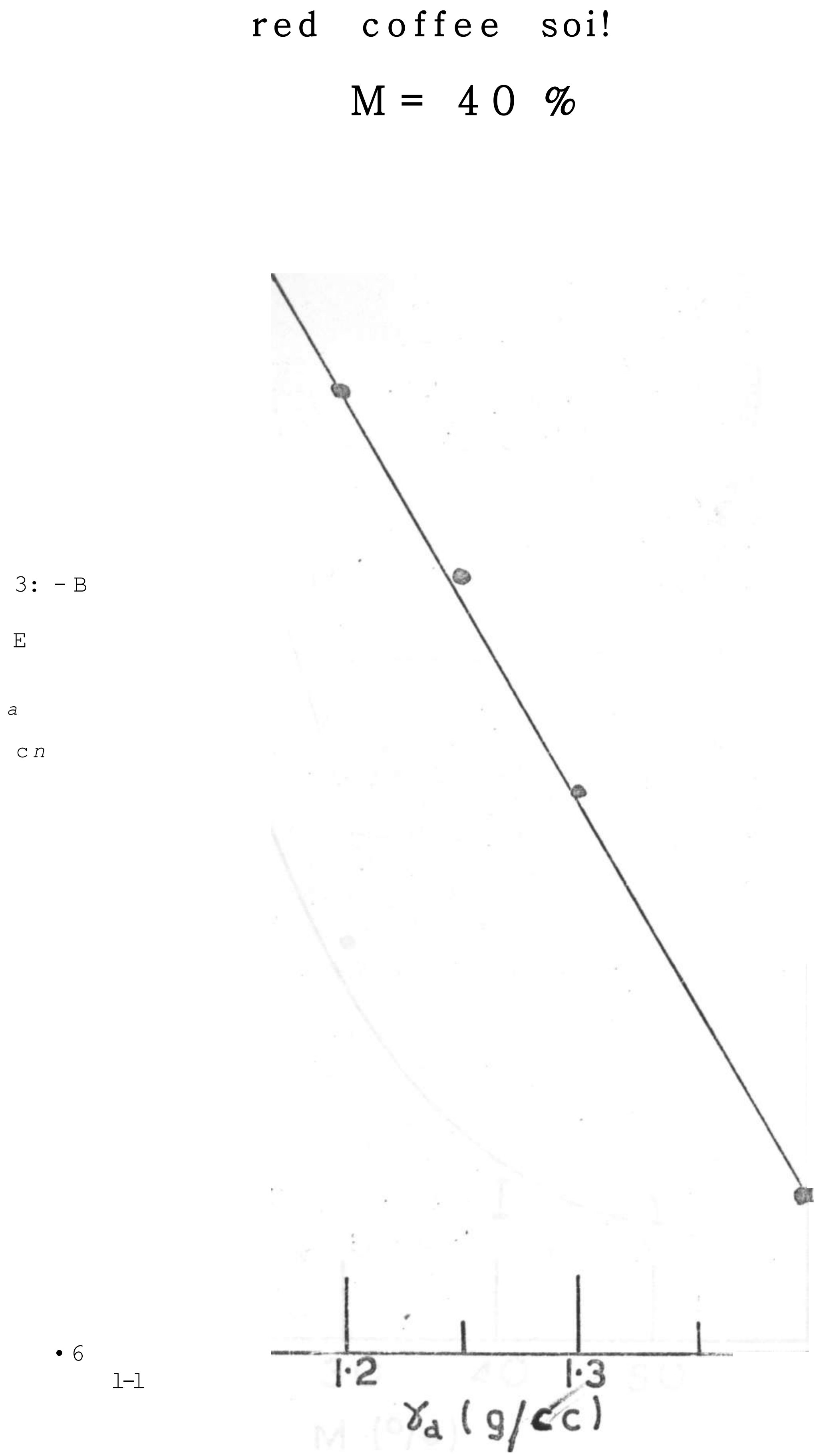


Fig. 4.5.1R Thermal resistivity ys. dry density for Red Coffee Soil.

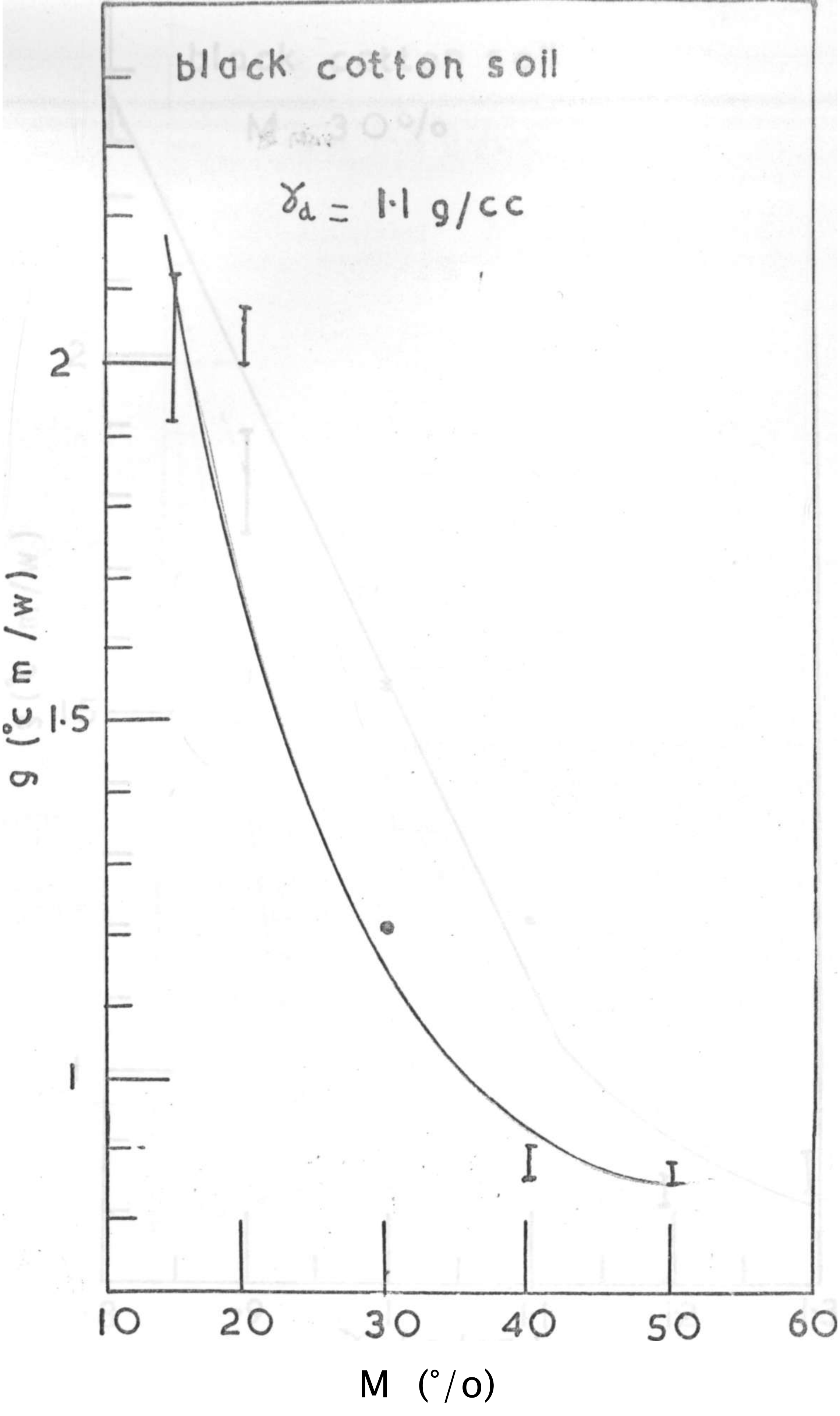


Fig. 4.5.sA Thermal resistivity us. "oistnre content for
Black Cotton Soil;

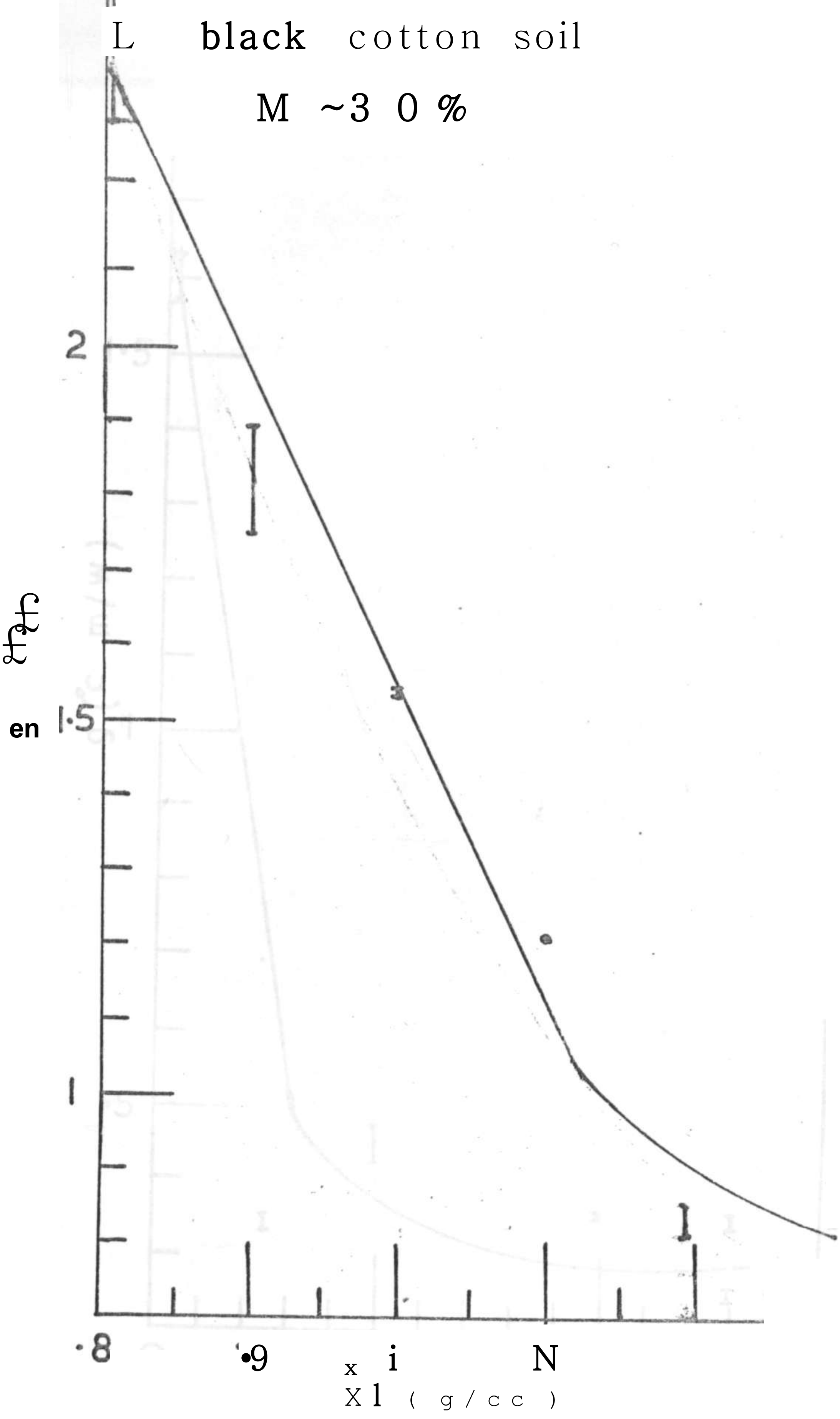


Fig. 4.5. 2B Thermal resistivity vs. density for Black Cotton Soil.

sand

Xs. = I • 3 g /cc

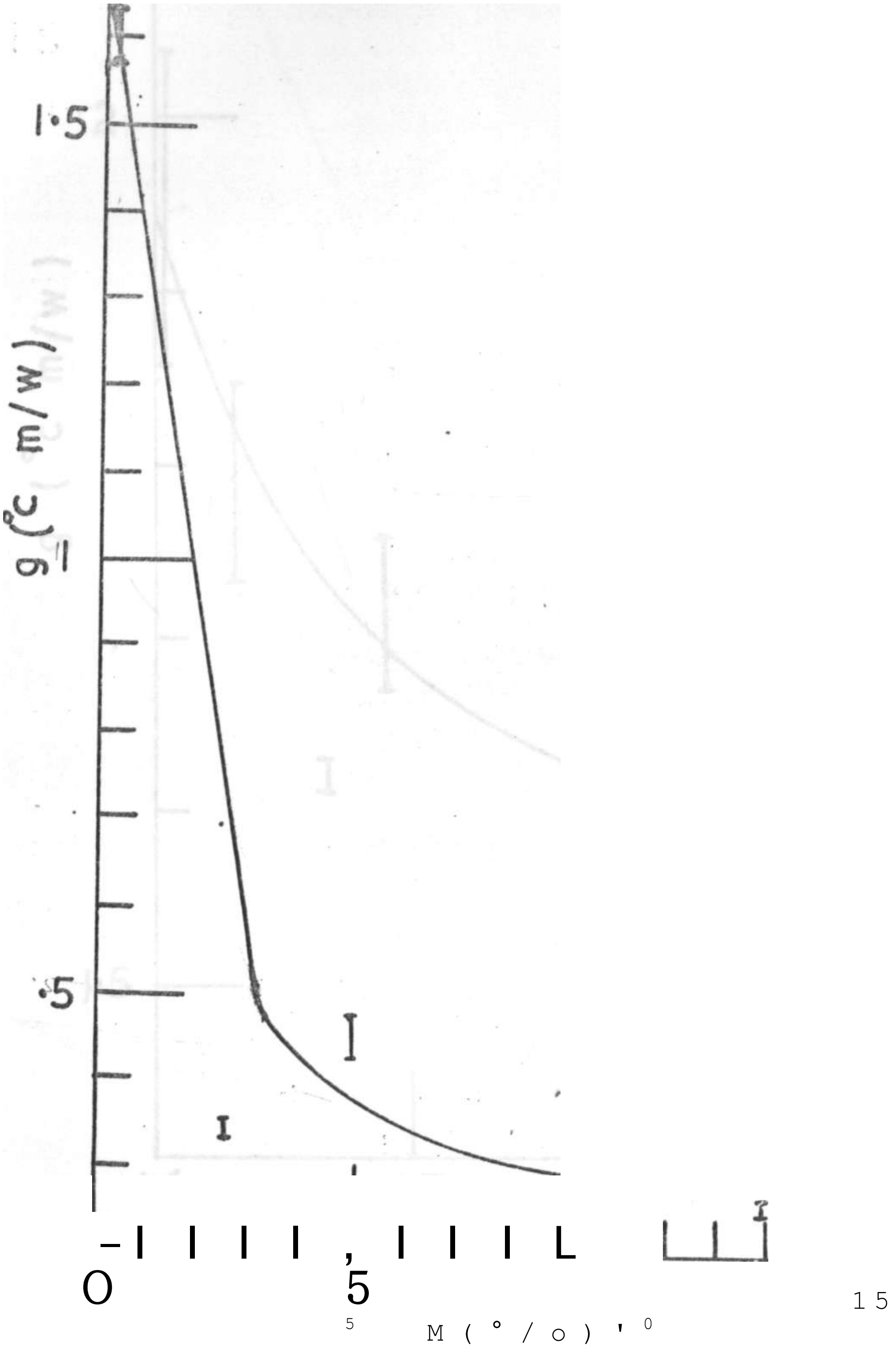


Fig. 4.5.3A Themal. resistivity vs. moisture content for San'^{1}.

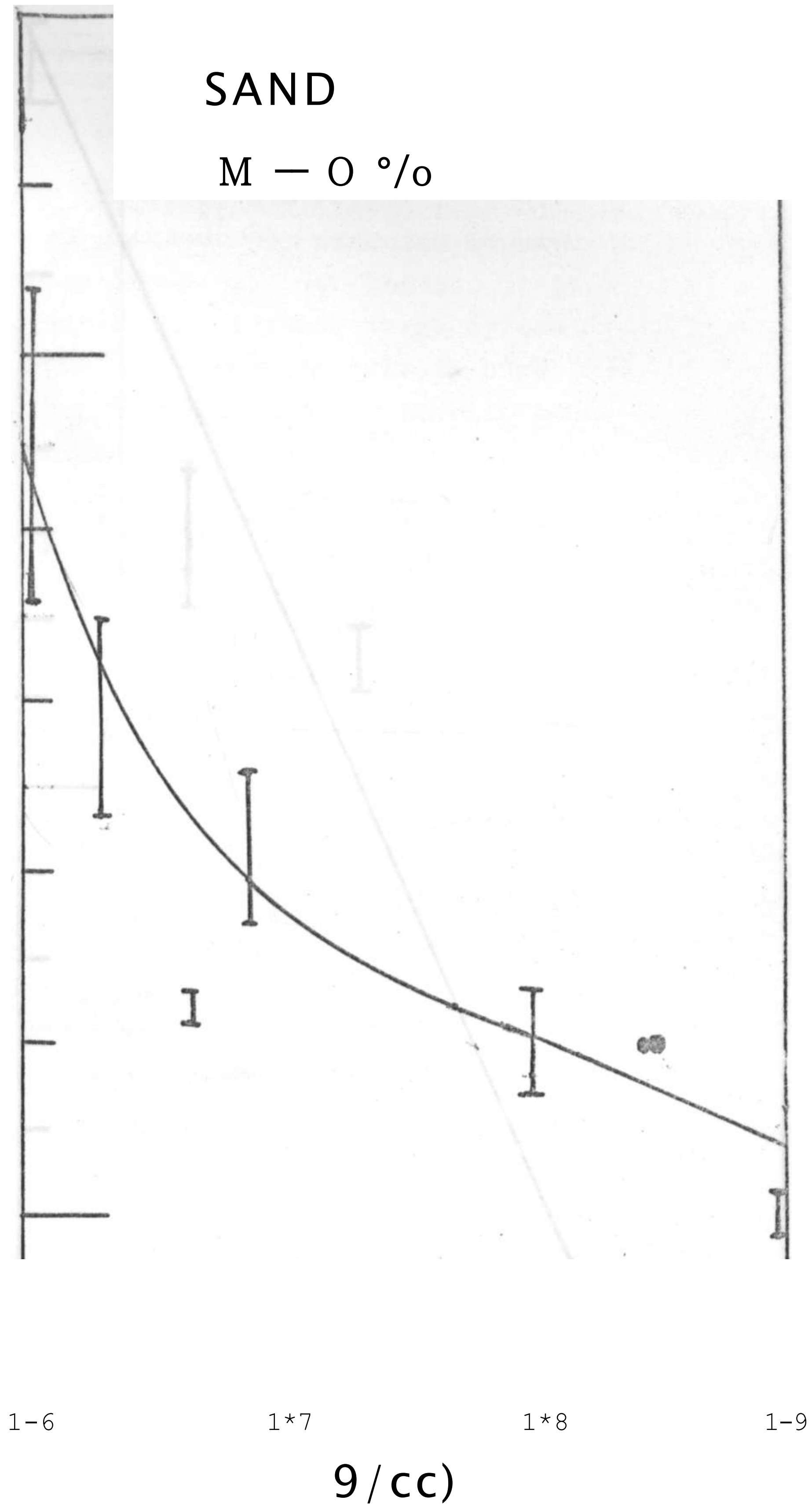


Fig. 4.5.SB Thermal resistivity vs. dry drnsity for Sand.

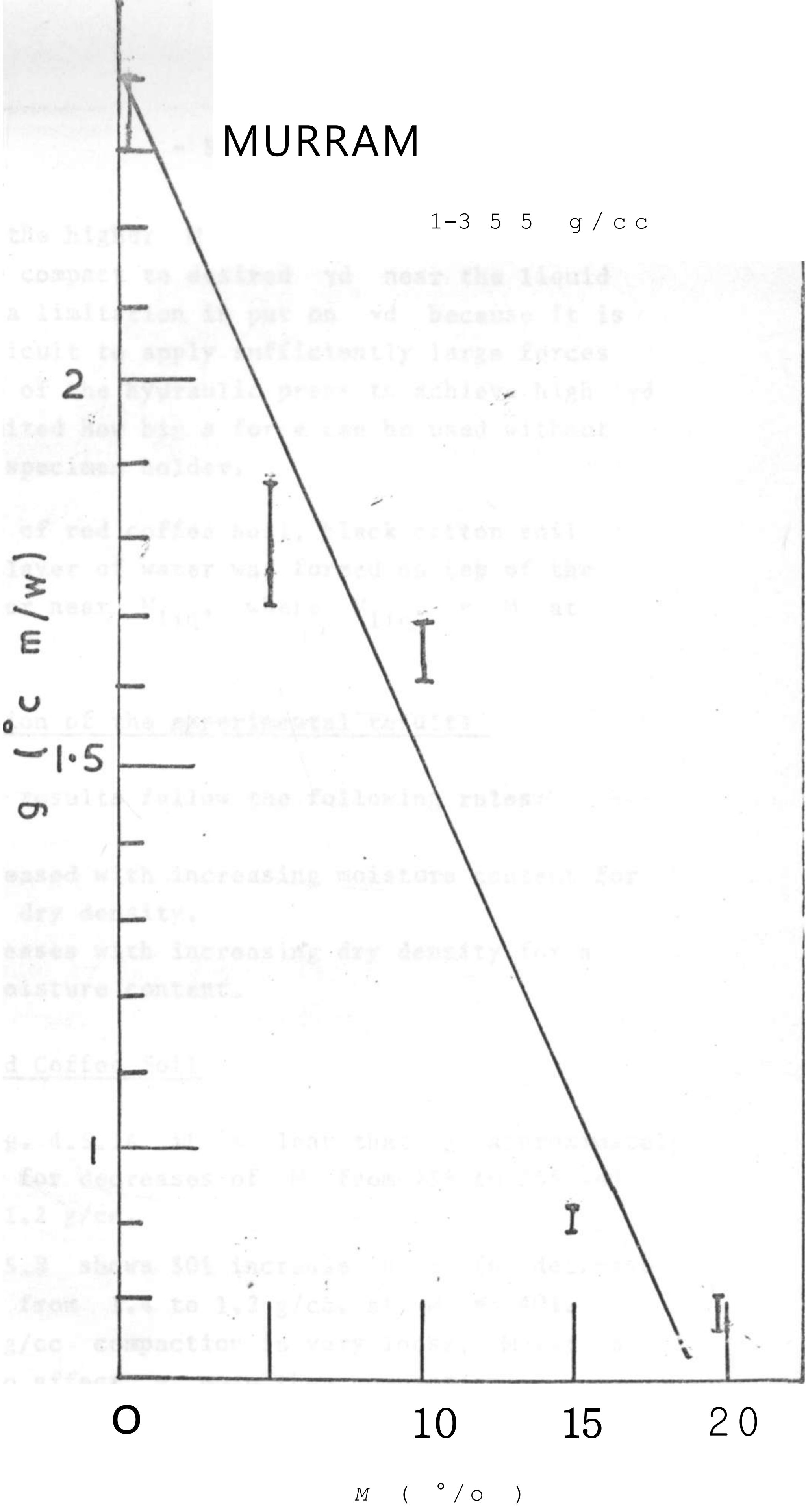


Fig. '.5.4. Thermal res.istiytt.v_ys. roisturc content for Murram.

Similarly on the higher M side, the soil sample was impossible to compact to desired yd near the liquid limit. Also a limitation is put on yd because it is manually difficult to apply sufficiently large forces on the handle of the hydraulic press to achieve high yd and it is limited how big a force can be used without damaging the specimen holder.

In case of red coffee soil, black cotton soil and murram a layer of water was formed on top of the specimen holder near where M^iq* = M at liquid limit,

4,6, Discussion of the experimental results

All the results follow the following rules:

(1) g decreased with increasing moisture content for a given dry density,
(2) g decreases with increasing dry density for a given moisture content,

a) Red Coffee Soil

From Fig, 4,5,1A it is clear that g approximately doubles for decreases of M from 45% to 251 and yd = 1,2 g/cc.

Fig, 4.5.B shows 50% increase in g for decrease of yd from 1.4 to 1.2 g/cc. at M - 401, At 1.1 g/cc compaction is very loose. Moisture seems to affect g more than compaction.

(b) Black Cotton Soil

From Fig. 4,5.2A it is seen that there is 155% increase in g for decrease of M from 60S to 151 for yd = 1.1 g/cc.
Fig, 4.5.2B shows a decrease of 75% for change of yd from 0.8 to 1.3 g/cc at M = 30*。

Above 1.2 g/cc there is little change in g. This may be because compaction to this dry density is sufficient to remove all air voids from the soil.

(c) Sand

Sand shows the largest quantitative change of g of all the soils as M from no moisture at all to only a few %. Fig. 4.5.3A shows g drops by 70% for an increase from 0% to 2J% in M. Then there is practically no change with further increase in M.

Sand changes by 40% for a change of yd from 1.9 to 1.6 g/cc, at M = 0%. It is hardly a big change compared with change with M,

(d) Murram

yd of murram does not change significantly when the sample is compacted and there g vs. yd was not measured, g drops by 70% for a change of moisture content from 0 to 20%.

4,7 Effect of Moisture Migration on Soil Specimens

Appendix A5 to A8 show the average temperature output vs. time recordings for some cases of moisture migration. The results have been summarised in Table 4.7.1.

Type of	yd (g/cc)	M (I)	Fig,No.	H (watts)	Slope of the linear part (°C/h_r)	AT (extrapolated) C°c)
Red Coffee	1.2	40	A5	15	33	
			A5	30'	.95	11.3
Black Cotton	1.1	40	A6	14.6	.28	
			A6	7.9	.18	2.2
Sand	1.8		A7	14.2	.05	2.1
			A7	19	.06	2.55
Murram	1.355	•ZJO W	A8	9.4	.076	2.6
			A8	5.2	.046	1.7

* In case of red coffee H was increased from 15 to 30 watts.

Table 4.7.1, Comparison of moisture migration of various soils

We see from Table 4.7.1. that sand has the least rise in temperature per hour after the transient period, and consequently the least moisture migration'.

4.8. Comments:

It seems sand has thermal properties good in two respects. Firstly g is lower for sand with lot of water and fairly good compaction than any other soil. Secondly it is much easier to compact sand than any other soil. It is also seen from table 4.7.1. that moisture migration is the least in case of sand, - Two disadvantages are that g is very big at zero moisture content, and that it retains very little water.

Red Coffee Soil retains water but when it has a high moisture content it may be physically difficult to compact, if improvement of g by compaction is desireable, because the soil gets slippery or sticky. Same comment applies to black cotton soil.

g of Murram cannot be changed significantly by compaction. g of .83 °Cm/W at 20% moisture content is fairly low. Murram is easy to handle.

The tests carried out show that in case of black cotton soil in unfavourable conditions g exceeds the' nominal g of 1.2 °Cm/W, which has been used till today by East African Power & Lighting for design of underground systems, g for this i soil is >1.2 °Cm/W for moisture content less than 30$ for Y_d = 1.1 g/cc, and for Y_d <1.1 g/cc for M = 30%.

g >1.20 °Cm/W is also observed for sand at l\<2\% at Y_d - 1.8 g/cc, and for M = 0% at any Y^, and murram with M<12$.

The seriousness has been realised by the fact that E. A. P. & L. (Ref.3) requested me to carry out tests for two samples, one from Nairohi area and one from Mombasa, the results of which are in Appendix A9.

CHAPTER 5

Conclusion and Recommendations

5 o1 Conclusion

The four main soils of Kenya namely, red coffee soil, black cotton soil, sand and murram were experimented upon for finding thermal resistivities.

It was found that for a fixed dry density g decreases with moisture content for all the soils. Also for a fixed moisture content, g decreases with increase of dry density.

It was also concluded that the experimental error in the measurement was some 12% or less in the values of g. This error is not high compared with the in situ methods of measurement where the error is about 10%.

The results of the four soils are very important because they show g for some soils and conditions gets very high. All the soils, except red coffee soil show that for certain ^{Y}d and M g can exceed the nominal g of 1.2 °Cm/W used by electrical engineers. Following is the summary of conditions of soils for which appropriate derating of the cables should be considered:

Red Coffee Soil« No derating required to M upto 25% and

Yd = 1.2 g/cc

No derating required to M = 40% and yd upto

1.2 g/cc

Black Cotton Soil g>l,2 for yd = 1.1 g/cc

and M <30%.

g>l.2 for Y<1.1 g/cc and M = 30%

Sand $g>1.2$ for $M = 0\%$ and all *yd.*

Murrain $g>1.2$ for $M< 12\%$ and *yd* = 1,355 g/cc.

It was also found that sand has the least moisture migration so is less likely to suffer thermal instability,

g was also investigated for two soils namely black cotton soil and sand from location of an underground cable in Nairobi and Mombasa respectively supplied by E.A. Power and Lighting Co, Ltd,, Nairobi, the results of which are in Appendix 9.

5,2,Recommendation

In my opinion, a further study can be carried out on the same type of soil from different areas and their g compared for the same conditions of moisture content and dry density. Also further investigation on moisture migration in soils and temperature dependence of g can be carried out.

Further research into three dimensional analysis i.e. variation g when both M and yd are varied can be carried in the future.

APPENDIX

Red Coffee Soil

Area:- Kabete near Nairobi

Max. dry density = 1.37 g/cc.

Plastic Limit:- 381

Liquid Limit:- 701

(1) y_d = 1.2 g/cc

M(»$_0$)	H(watts)	g(°C m/W)	T_{av}(°C)
25	15	1.10	25
30	15	1.04	25
35	15	.880	25
40	15	.853	26
45	30	.695	26

(2) M = 40%.

Y_d(g/cc)	H(watts)	g(°Cm/W)	T_{av}(°C)
1.2	15	,850	26
1.25	15	,800	25
1.3	15	.742	25
1.4	15	.640	21.6

A1 Experimental data for Red Coffee Soil.

Black Cotton Soil

Area:- LANGATA near NAIROBI

Maxo Dry Density:- 1,385 g/cc at M = 29%

Plastic Limit:- 33%

Liquid Limit:- 83?

CD 1.1 g/cc

M(V)	H(watts)	g(°C m/W)	T_{av}(°C)
15	7.8	1.92	21.6
	3.94	2.12	22.8
20	17.2	2.08	29.0
30	25	1.21	no data
40	7.9	0.860	no data
	14.6	0.905	
50	20	0.815	19.0
60	10	0.85	24.4

(2) M = *30%*

Y_d(g/cc)	H(W)	g	T_{av}C°C)
.8	3.08	2.30	17
.	7.38	2.53	19
.9	5.67	1.89	no data
	9.95	1.75	
1.0	6.63	1.53	22
	9.55	1.54	19
1.1	25	1.21	(not reco
1.2	7.71	0.80	18
	14.7	0.86	20
1.3	11.35	0.88	18
	7.45	0.83	17.4

A2 Experimental Data for Black Cotton Soil

Sand

Area: Athi River.

CD Y, 1.8 g/cc.

M(l)	H(Watts)	g(°Cm/W)	T_{av}(°C)
0	5.67	1.620	21.9
	20	1,570	22.6
21	4.97	0.346	no data
	9.55	0.327	
5	5.67	0.422	19.9
	20	0.472	21.43
10	14.65	0.356	21
	20	0.346	20.6
13	9.93	0.240	18
	19	0.260	21.1
13	14.4	0.356	20.7
	19	0.328	18.7

(2) M = 0%

^d	H(Watts)	g(°Cm/W)	
1.61	5.20	2.04	20.1
	9.95	**1.86**	21
1.63	5.34	1.85	21.9
	14.9	1.73	22.0
1,67	$4_{r}75$	**1.61**	20.5
o	9.45	**1.63**	21.7
1.69	4,70	1.76	18.3
	9.20	1.67	25.9
1.8	5.07	1.63	18.5
	9.35	1.57	22,3

Contd.

(2) Contdo

^{Y}d	H(Watts)	g (°Cm/W)	$T_{av}{}^{v}$(°G)
1,85	5.87	1.54	19.82
	8.85	1.54	22.62
1.9	5.18	1.48	17.25
	13.4	1.51	21.25

A3 Experimental data for Sand,

Murram

Area:- WILSON AIRPORT, NAIROBI.

Max. Dry Density:- 1.56 g/cc at M = 26.5*

Plastic Limit:- 26.4%

Liquid Limit:- 40%

Y_d = 1.355 g/cc.

M(%)	H(Watts)	g(°Cm/W)	T_{av} (°C)
0	9.4	2.4	20.6
	4.85	2.3	19.4
5	9.45	1.71	18.3
	5.2	1.87	22,3
10	9.45	1.69	19,2
	6.5	1.61	16,7
15	5.15	.885	17,0
	9.45	.920	18
20	9.4	.760	17,9
	5.2	.810	17

A4 Experimental data for Murram,

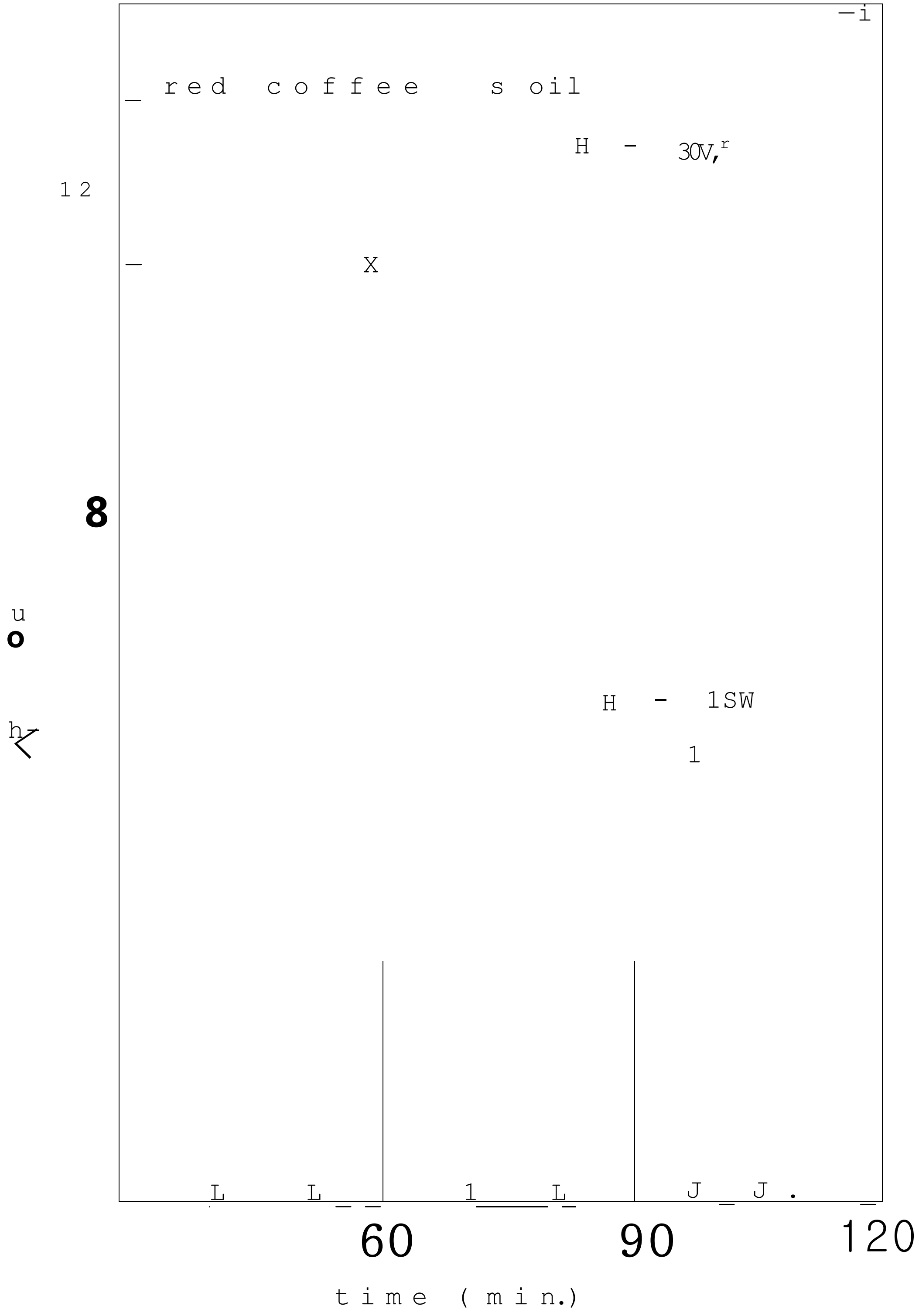


Fig. AS Average Temperature difference vs. tine for 'ted Coffee Foil.

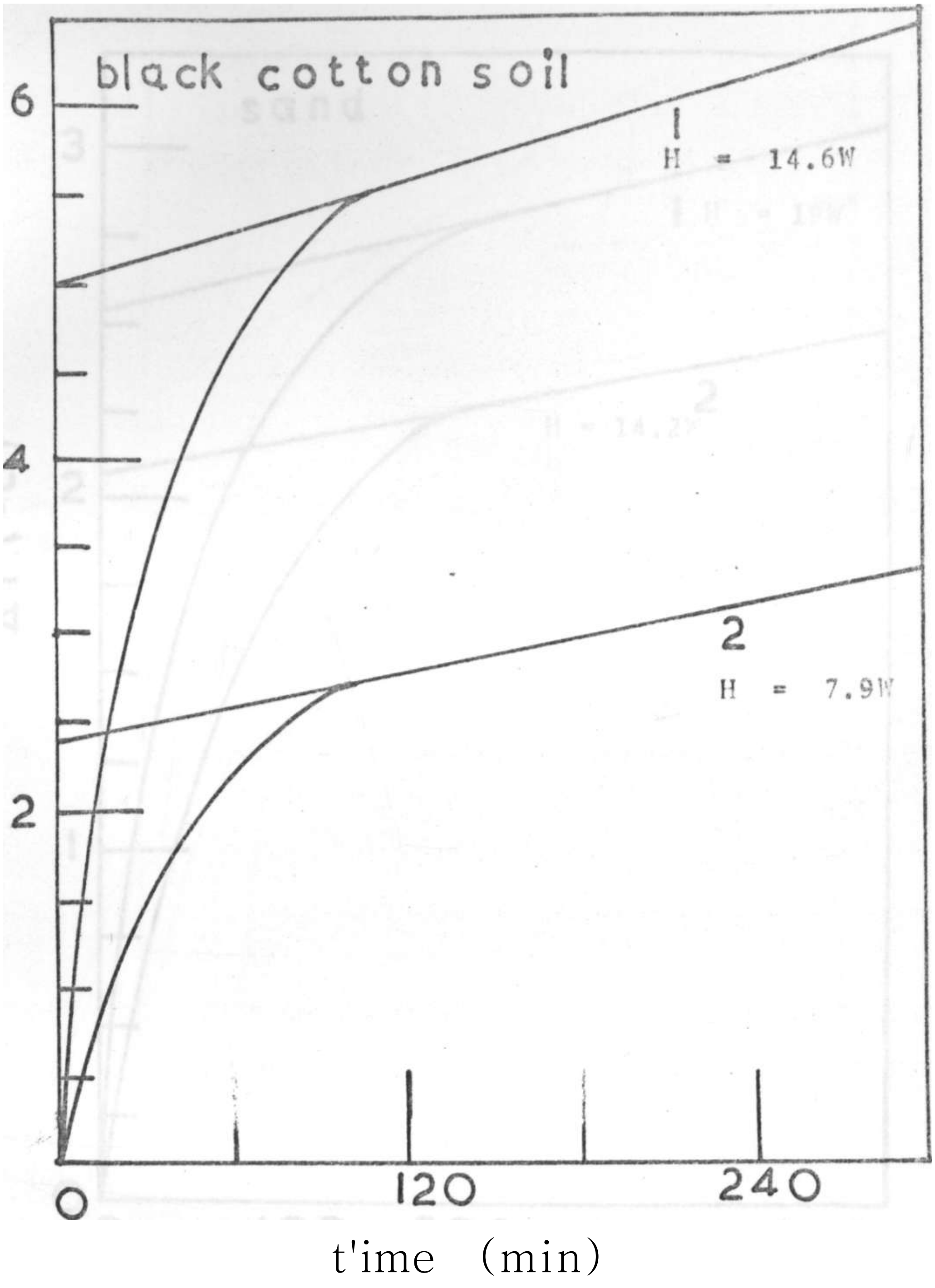
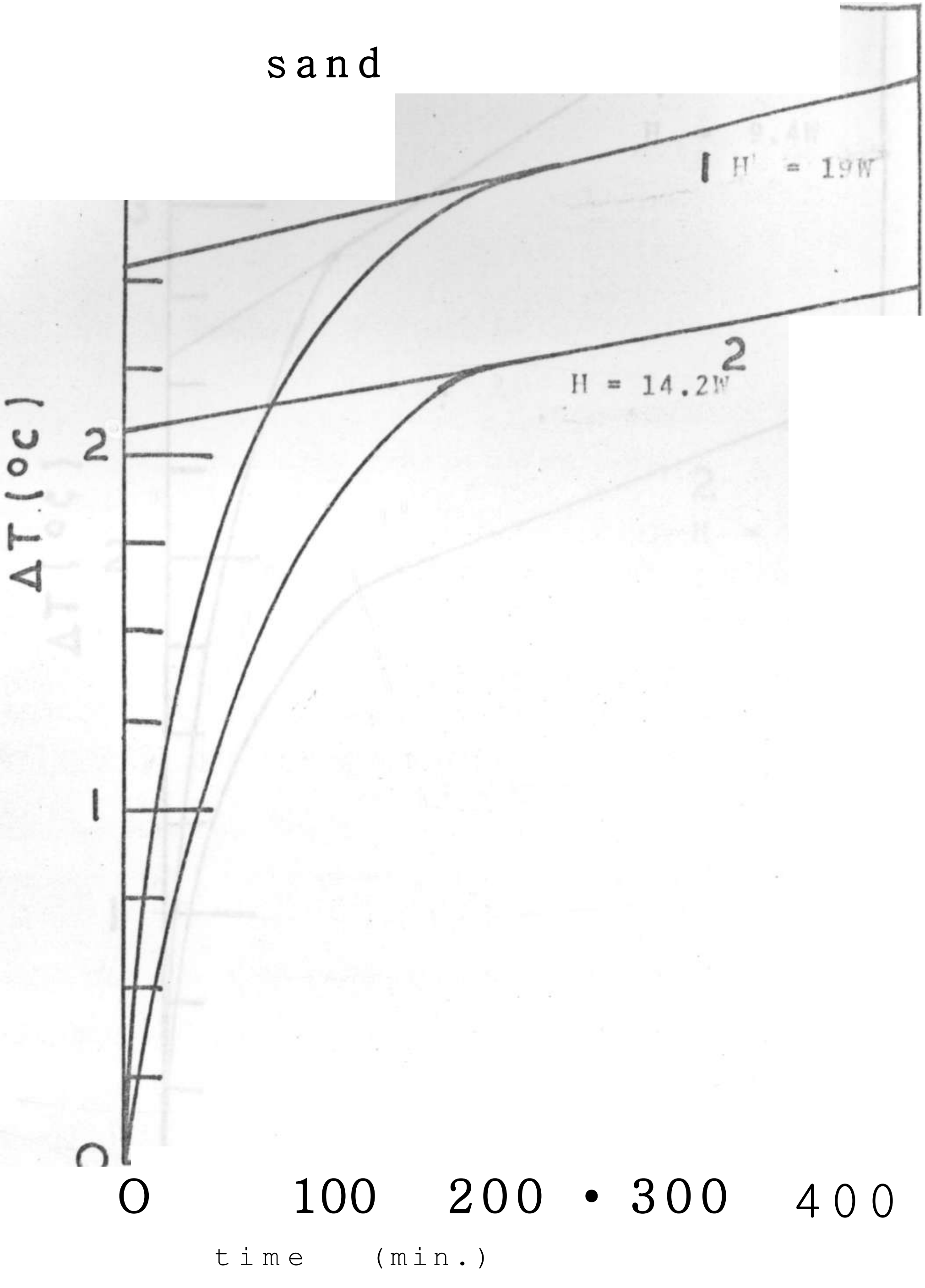


Fig. A6 Average teFvn^rature difference vs. tine for Black Cotton foil.



Fir. A7 Average tcmooraturc diffcrcnce vs. time for Sand.

An -

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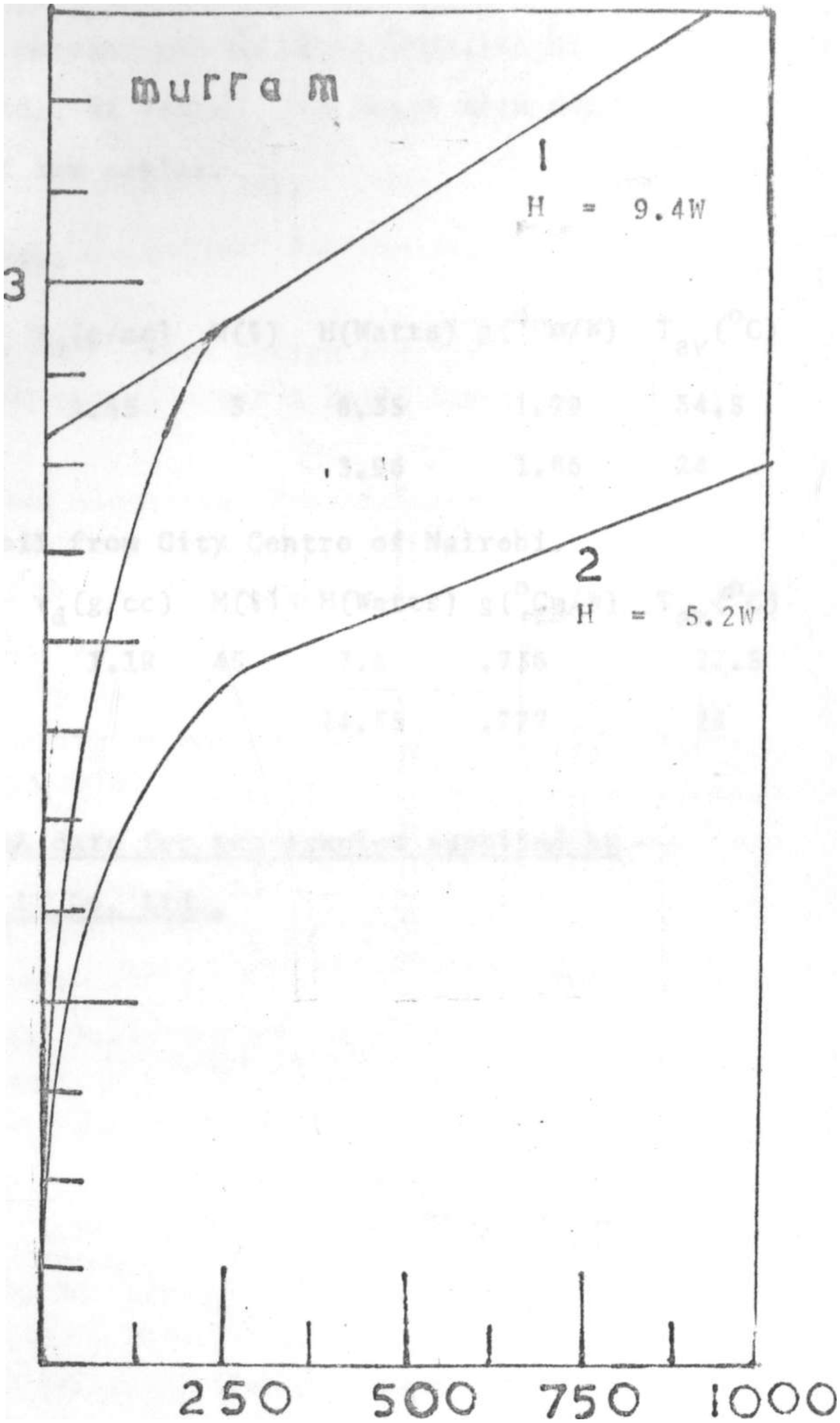

time (snin.)

Data for tests carried out on soils supplied by E. A. P. & L. Co. Ltd., of Kenya. The Soils were dug from the vicinity of the cables.

(1) Sand from Mombasa,

Density (g/cc)	Y_d(g/cc)	M(t)	H(Watts)	g(°Cm/W)	T_{av}(°C)
1.595	1.55	3	8.35	1.79	34.5
			3,96	1.86	24

(2) Black Cotton Soil from City Centre of Nairobi.

Density (g/cc)	Y_d(g/cc)	M(»)	H(Watts)	g(°Cm/W)	T_{av}(°C)
1.73	1.19	45	7.6	.736	22.5
			14.55	.777	24

<u>A9 Experimental data for two samples supplied by E. A. P. & L. Co. Ltd.,</u>

References (Chapter I")

Ref.1 Electrical Power Systems Vol. 1 by Guile and Peterson (Oliver & Boyd) 1969. Chapter 5 Pages 176 - 178.

Ref.2 "Paper Insulated Cables" Publication No. 597 by BICC Page 24.

Ref.3 "Power Cables: Their Design and Installation" by C. C. Barnes (Chapman & Hall) 1966. Page 102.

Ref.4 "Thermal and Electrical Properties of Hong Kong Soils" by Halfter & King. (Hong Kong University Press). 1970.

Ref.5 Soil Thermal Resistivity Measured Simply and Accurately by John Stolpe. I.E.E.E. Transactions on Power Apparatus and Systems, Page 300 Vol.PAS-89, No. 2, Feb. 1970.

Ref.6 "Thermal and Electrical Properties of Hong Kong Soils" by Halfter & King. (Hong Kong University Press 1970). Chapter 4 Page 25-27.

Ref.7 "The Thermal Behaviour of Cable Backfill Materials" by John Adams. I.E.E.E. Transactions No,4, April 1968. Page 1149,

Ref.8 "Paper Insulated Cables" BICC Publication No.597, Page 31. Table 40.

Ref.9 Data on ground temperatures obtained from Department of Climatology, Meteorological Department, E.A, Community, Dagoretti Corner, Nairobi, Personal discussion,

Ref,10 Mr, S. M, Kirika, Stores Superintendent, E. A. Power & Lighting, Nairobi,

References ("Chapter 2)

Ref.l Fundamentals of Soil Mechanics by D. W. Taylor. (John Wiley 1948). Pages 12-18 and 23-54.

Ref.2 Soil Physics by L. D. Baver, W. R. Gardner and W. H. Gardner. Fourth Edition (John Wiley 1972). Chapter 3 Pages 107-109.

Ref.3 "Thermal Resistivity Simply and Accurately Measured" by John Stolpe. I. E. E. E. Transactions on Power Apparatus and Systems, Vol. PAS-89, No.2 Feb., 1970.

Ref«4 Fundamentals of Soil Mechanics by D. W. Taylor. (John Wiley 1948). Chapter 18, Page 532,

Ref.5 "Shear Strength of Red Coffee Soil and Black Cotton Soil" by F. K. Moledina. B.Sc, Project, Civil Engineering Department, University of Nairobi, 1970.

Ref.6 Lab. Experiments on Sieve Analysis for 2nd year students, Civil Engineering Department, University of Nairobi, 1973.

Ref.7 "A Glossary of definition of common world soils and their occurance in Kenya"by N.N. Nyandat. Soil Survey Unit, National Agricultural Laboratories, Ministry of Agriculture. Report No.S26/JK/NN dated 2/8/74.

Ref.8 Mr. E. A. Charania, Lecturer, Soils Department, University of Nairobi.

Ref.9 "Methods of Testing Soils for Civil Engineering Purposes". British Standard 1377: 1967. British Standard Institution.

Ref.10 F. Mwithiga and P. C. Karanja.Test on Ulu Soil 1972, Civil Engineering Department, University of Nairobi.

References (Chapter 31

Ref.1 "Soil Thermal Resistivity Measured Simply and accurately" by John Stolpe,
I.E.E.E. Transactions on Power Apparatus and Systems, Vol. PAS-89, No.2, Feb. 1970.

Ref.2 Tahle 4a-16. Section 4-20.
American Institute of Physics Handbook.
McGraw-Hill 2nd Edition (1963).

Ref.3 "Semiconductor Diodes and Transistors as Electrical Thermometers" by A. G. Mc Namara. The Review of Scientific Instruments. Vol.33. Number 3.
March 1962.

References fChapter 41

Ref.l "Soil Thermal Resistivity Measured Simply and accurately"
by John Stolpe.
I. E, E, E. Transactions on Power and Systems,
Vol. PAS-89, No.2, Feb. 1970.

Ref.2 Table 4a-16 Section 4-20
American Institute of Physics Handbook,
McGraw-Hill 2nd Edition 1963.

Ref,3 Mr. Ferrar, Distribution Engineer, E. A, P. & L,
NAIROBI, Private Communication,

Ref,4 Standard procedure before compaction tests.
Information obtained from Mr, Charania lecturer,
Civil Engineering Department, University of
Nairobi,