Instrumentation

ANNEXURE

to

Design of Concrete Pavements Overlying Foundations of Different Elasticities

By

N. K. VASWANI

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE [INDIA]
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CERTIFICATE

CERTIFIED that the thesis entitled '*Design of Concrete Pavements Overlying Foundations of Different Elasticities*' which is being submitted by Sri *N.K Vaswani* in fulfilment for the award of the Degree of Doctor of Philosophy in *Civil Engineering* of University of Roorkee, is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked part time for a period of more than four years, from *Sept. 1959* to *Jan. 1964* for preparing the thesis, at this University.

Dated January 30, 1964.

(Jai Krishna)
Professor and Director of Research &
Training in Earthquake Engineering,
University of Roorkee, Roorkee.

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CHAPTER I

DESIGN OF MOISTURE CELLS

CHAPTER NO. 1.

DESIGN OF MOISTURE CELLS.

1. INTRODUCTION:

The paper on "Measurement of subgrade Moisture in Situ" by the author, is published in Roorkee University Research Journal, 1962 and has been accepted for publication by the Institute of Engineers (India). This paper is given in Appendix IV. In this article various methods of measurement of moisture content in situ and the advantages and disadvantages of each method have been discussed. There in, it has been concluded that electrical resistance cell if properly designed, are best suited for measurement of moisture content under foundations.

In the proceeding paragraphs, attempt has been made to investigate each factor which affects the proper design of electrical resistance cells. This attempt has enabled design of suitable cells for this investigation.

2. ELEMENTS AFFECTING DESIGN.

In the design of electrical resistance cells the following elements affect the design.

(a) Electrodes : Their corrosive power, perforations for free flow of moisture through the electrodes and the area of the electrode.

(b) Insulating material: The moisture absorptive and release power of the insulating material and the resistance offered by it to the flow of electricity. The dielectric strength (i.e. the ability to with stand break down) of the insulating material does not affect the design, as the voltage applied is too low.

(c) Cover : The porosity of the material covering the electrode and the resistance offered by it to the flow of electricity.

The effect of these elements are discussed in the subsequent sub-paragraphs.

2.1. ELECTRODES :

2.1.1. MATERIALS FOR ELECTRODES : The materials for the electrode should be of low resistivity. Almost any metal will suit the purpose from this view point.

Since the electrodes are to be embedded in moist soil (may be with salt action) the metal so chosen should be non-corrosive. Various metals like copper, stainless steel and monel have been used. Copper is corrosive and hence is recommended for short durations only. Monel is an alloy containing about 3 parts of nickel to one part of copper. It is cheaper than nickel. It is tough, strong, non corrosive as pure nickel. Stainless steel is also non-corrosive.

2.1.2. FLOW OF MOISTURE THROUGH THE ELECTRODE : Since the variation in resistance in between the elecytrodes is only considered to be due to change in the moisture content between the electrodes, they should be of such pattern, as to in no way hinder the flow of moisture to or from the insulating material. In the first stage of development of electrical resistance cells, wire electrodes were used. They have now been replaced by mesh pattern. Any mesh pattern to serve the above mentioned need of free flow of moisture would be suitable.

2.1.3. AREA OF ELECTRODE : Since the resistance offered by electrodes is inversely proportional to the area of the conducting medium ($R = \rho \times \frac{\ell}{A}$ where R = resistance, ℓ = length, A = area and ρ = resistivity of the material) more the area, lesser the resistance offered and hence same measuring instruments may give more accurate results.

2.1.4. TYPE OF ELECTRODES INVESTIGATED : The following types of electrodes were adopted for this investigation :

(a) Circular , Stainless steel electrode with central hole.

(b) Circular and rectangular perforated brass mesh electrodes. They are shown in Fig. 1.

2.2. INSULATING MATERIAL :

2.2.1. CAPILLIARITY PERMEABILITY PROPERTY : It is claimed that the porous material of the cell wets and dries along with the moisture around it. Investigations carried by the author with plaster of paris cell as recommended by Bouyoucos, showed that this is not so and that the cell continued to remain wet in its interior (i.e. between the electrodes even though the soil surrounding it had dried.) This is naturally due to the difference in the capilliarity-permeability of the soil surrounding the cell and the capilliarity-permeability of the material in the cell. The author therefore concludes that with slight increase in moisture content of the surrounding soil the material in the cell gets saturated and no further change in electrical resistance is recorded even though the moisture content of the surrounding soil is increased. The same is true for nylon and fibre glass cells. It is therefore highly desirable that the capilliarity-permeability of the dielectric material in between the electrodes should be same or more than that of its surrounding soils. The capilliarity -permeability of plaster of paris is very low.

2.2.2. <u>RESISTIVITY OF MATERIAL</u> : - (a) When insulation consists of small sheets of material, in addition to the volume resistivity of specific resistance of material, surface resistivity is also to be accounted for. Surface resistivity can be defined as the resistance between opposite edge of a unit square area of the surface of the material. This quantity depends upon the general conditions of the surface and upon the humidity, and is not a constant (44)[*] - The surface resistivity is given by an equation

$$\frac{R \quad x \quad \Pi \quad d}{\ell}$$

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[*] Numbers in bracket indicate reference number at the end of this Chapter.

Value of resistivity at 30°C and ratio $\frac{\text{resistivity at } 20^\circ C}{\text{resistivity at } 30^\circ C}$ for a number of hard insulating materials have been determined. These ratios varies from 1 for mica to 16 for bee-wax.

2.2.3. TYPES OF INSULATING MATERIALS INVESTIGATED : The following types of insulating materials between the electrodes were tried:

(a) Rubber,
(b) Plaster of Paris with zero, 40 and 50 p.c. standard sand,
(c) Soil and
(d) Air.

(a) The object of providing rubber as an insulating material was to provide zero conductivity in between the electrodes and thus measure the conductivity due to the soil surrounding the cell. These cells were therefore not covered.

(b) Plaster of paris was adopted as it has been commonly used in one type of cells at present marketed. Since their capilliarity-permeability is very low and hence do not release moisture easily, Sand in 40 p.c. and 50 p.c. were added to plaster of paris to increase its capilliarity-permeability and thus reduce the moisture retaintive power of this materia

(c) Soil was adopted to provide the same capilliarity-permeability as that of the surrounding medium.

(d) Air was tried as it was assumed that the change in resistance would be proportional to air humidity which inturn will vary

Churcher (45) has shown the flow pattern of the current. This pattern is shown in Fig. 3 (The diagram is not intended to be a map of the various field forms but merely to show in an approximate way the nature of the effects tried). The flow through the surrounding medium has the effect of reducing the apparant impedance of the section of the specimen near the centre and at the same time reduce its power factor.

2.3.3. THICKNESS OF COVER : The disadvantages of providing usual cover over the electrodes in case of plaster of paris (which is highly impermeable) were observed during the preliminary investigations and has been discussed in Appendix IV. Thus in case of plaster of paris cells with or without sand, no cover or very little cover (as little as practically possible) was provided in later investigations. Plaster of paris and sand mix in the cover was the same as for the insulator between the electrodes. A thin cover was found necessary to prevent any air or moisture gap between the electrode and the insulator and also provide uniform electrode contact. However, some cells without cover have also been investigated.

All other cells having rubber or soil as an insulating material were not provided with cover because in case of soil, the surrounding soil is the same as the soil in between the electrodes, while in case of rubber, the object was to determine conductance through the surrounding soil.

3. DESIGN OF CELLS INVESTIGATED AND METHOD OF TESTING.

3.1. CELLS INVESTIGATED:

The elements in the design of cells have been discussed in para 2. The effect of different factors on these elements have been pointed out. Various combinations of these cells were tried. Their details are listed in Appendix No. 1, and shown in Fig. 7(b).

3.2. CALIBRATION:

The method of testing these cells is known as "Calibration". It can be divided in two parts (i) Embeddment of cells and measurement of moisture content by gravimetric method (ii) Measurement of resistance at different moisture content. They have been discussed below:

3.2.1. Two methods for embeddment of cells and measurement of moisture content by gravimetric method were adopted as explained below:

Method (a) : The cells were embedded in a soil in a big container having considerable area and depth, and moisture content of the soil at the level of the cells determined by taking soil samples, as explained later in this paragraph and shown in Fig.6.

Method (b): The cells were embedded in a shallow box (5 cm. depth) with top and bottom provided with perforated sheet of brass as shown in Fig. 7 (a) . The perforations in brass sheet were as shown in Fig. 4 a. Blotting paper on the inside of the perforated sheet was provided to prevent soil falling out through the perforations and also to provide uniformity of moisture over the whole area. The box was 30 cm. long and 15 cm. wide. The moisture content was determined by weighing the box as explained later in this paragraph.

The soil in both the methods was compacted for the same dry density as that obtained in the field.

Method No. (a) above had to be abondoned as two soil samples were taken for each reading of all the cells in the container and in all about 50 to 60 soil samples had to be taken within the limited area of the soil available. Each soil sample in method (a) was taken by driving a cork borer through the depth of the soil. The portion of the soil at the level at which the cell was embedded was then taken out of the borer. After the soil had been bored it was essential to fill the hole with the remaining soil from the borer and also some more additional soil to replace the quantity of soil removed for determination of moisture content. It was not possible to compact the soil in the bored hole to the same uniform density as that of the surrounding soil. All attempts were therefore made not to take the soil sample at the point where the boring had already been made. With the limited area of the soil available it was many a times not possible to take the samples at places other than the places where sample had already been taken

It may however be mentioned that two soil sample taken diametrically opposite but at the same depth and at the same time showed variation of moisture content not exceeding 1 p.c. of the average moisture content determined.

In method No. (b) above, all cells were placed at 2.5 cm. from the top and the bottom of the box (except cylindrical cells) and any two adjacement cells had a minimum clear gap of 2.5 cms. Cylindrical cells were placed in a vertical position i.e. perpendicular to the perforated top or bottom of the box. Each box contained about 16 cells or less. The weight of each box with dry weight of the soil, blotter and cells was determined. Thus the average moisture content of the soil in the box could be easily determined by just weighing the box. To provide uniformity of moisture throughout the area of the box, both its top and bottom were always kept exposed to air by keeping the box in flat position over the edges of an empty tray. Thus by this method moisture content could be determined without disturbing the soil.

In both the methods after the cells had been placed, the soil was wetted and dried for number of times, spread over a minimum period of six months. This was termed as a setting period. Calibration of the cells was then started usually for falling water content, under almost the same temperature of the soil. Three and sometimes four sets of readings for different falling moisture content were taken. The readings reported in this paper (by means of graphs) are the last readings taken as there is no appreciable difference between this set of reading and one taken immediately before it.

3.2.2. RESISTANCE MEASURING DEVICE :

The instrument for measurement of resistance have been mentioned under para 3. The forest service U.S.A. Department of Agriculture (30) have compared the utility of these instruments. For measurement of resistance, following four methods were tried:

i) Across Ohm-meter (AVO-8)
ii) Across D.C. Wet battery and Amp-meter (AVO-8)
iii) Across alternating current (10 Volts) and Amp-meter (AVO-8)
iv) Across volt tube voltmeter.
v) By Post Office Box method.

The circuit diagram of the first four methods above are shown in Fig. No. 5.

All the above methods were compared for number of times on dry (coil-resistance) as well as Wet (wet moisture cell) resistance. Sample readings are given in Appendix No. II and the results are reproduced below :

S.No	Type of resistance	Resistance in Ohms.			
		Across Ohm-meter	Across D.C.Wet battery	Across A.C. (10 V)	Across V.T.V.M. (10 V)
1.	Dry Coil resistance	1,950	1,865	1,820	1,825
2.	Wet, Saturated moisture Cell.	-	182	136	155

In case of measurement with Ohm-meter only, the needle fluctuates when measuring resistance along wet moisture cell and hence the readings are inconsistent.

From the above results we observe that the recorded resistance decreases in the following order :

(a) Across wet battery.

(b) Across V.T.V.M.

(c) Across A.C. Voltage.

The percentage decrease in resistance in these three methods is not appreciable.

Experiments carried out with A.C. Supply showed that when the terminal wires are embedded in soil with varying amount of moisture content, there is lot of variation in capacitance and inductance recorded. Since resistance in these three is almost same, D.C. Wet battery method was adopted.

4. DISCUSSION OF RESULTS.

4.1. PROPORTION OF THE DISSIPATION OF CURRENT THROUGH THE SURROUNDING SOIL AND THROUGH THE INSULATOR BETWEEN THE ELECTRODE.

To determine the amount of current dissipated through the surrounding soil as compared to that through the insulating medium inbetween the electrodes, cell No. 42 and 43 (Fig. No. 24) can be compared with cell No. 48 and 49 (Fig. No. 27). Cell No. 42 and 43 have rubber insulation between the electrodes. The dissipation of current through rubber will be almost zero. Moreover it being absolutely impermeable, the current if any passing through rubber will not get affected by the moisture content of the surrounding medium. Hence it can be assumed that the flow of current in cell No. 42 and 43 is only through its surrounding medium. Cell No. 48 and 49 is exactly identical to cell No. 42 and 43 except for its insulating material between the electrodes. This insulating agent is air, soil and the moisture contained therein. Thus the percentage of current passing through the insulator between the electrodes in case of cell No. 48 and 49 is given by :

$$\frac{\text{E/R of cell No. 48 and 49} - \text{E/R of cell No. 42 and 43.}}{\text{E/R of cell No. 48 and 49.}} \times 100$$

Where E is the voltage and R is the resistance.

Since E is constant, we have the percentage of current passing through the insulator of cell No. 48 and 49.

$$= 100 \times \frac{\text{Resistance of cell No. 42\&43} - \text{Resistance of cell No.48\&49}}{\text{Resistance of cell No. 42 and 43.}}$$

The values of resistance for these cells for different moisture content as obtained from Fig. No. 24 and 27 and the percentage current passing through the insulator are given in Table No. 1.

P.C. Moisture.	Resistance of cell Nos. 42 & 43.	Resistence of cell No. 48&49	Col.2 minus Col.3.	P.C. Current passing through insulator $\frac{\text{Col. 4.}}{\text{COL. 2.}} \times 100$
1	2	3	4	5
2	3.3×10^4	2.0×10^4	1.3×10^4	38.2
4	1.55×10^4	1.0×10^4	0.55×10^4	35.5
6	9.5×10^3	6.7×10^3	2.8×10^3	30.5
10	4.8×10^3	3.7×10^3	1.1×10^3	22.9
12	3.6×10^3	3.0×10^3	0.6×10^3	16.7
14	2.7×10^3	2.4×10^3	0.3×10^3	11.1
18	1.6×10^3	1.5×10^3	0.1×10^3	6.25

Table No. 1.

The graph of percentage moisture (Col. 2 Table No. 1) against percentage current passing through the insulator (Col. 5 Table 1) is shown in Fig. No. 8 From this graph following two things are evident.

(a) The dissipation of current through the soil and air insulation between the electrodes with relation to moisture content follow a straight line curve. Since cell No. 42 and 43 also show a straight line curve for resistance against moisture content, we conclude that the dissipation of current through the surrounding soil also follow a straight line curve.

(b) The percentage amount of total current passing through the soil and air insulation between the electrodes is about 28 p.c. at the lowest moisture content of 2 p.c. (Col. 5 Table 1) and decreases with increase in moisture content till it is 6.25 p.c. at 18 p.c. moisture content. This shows that most of the current is dissipated through the soil surrounding the cell.

Cell Nos. 44 and 45 with perforated rubber insulator (Fig. No. 25) have the same electrode area and other factors as those of cell No. 42 and 43, except that the area of insulation caused by air and soil through the perforations has decreased. Table No. 2 give the same type of percentage comparision as carried out in Table No. 1.

P.C. Moisture.	Resistance of Cell No. 42 & 43.	Resistance of Cell No. 44 & 45	Col. 2 minus Col. 3.	P.C. current passing through the insulator $\frac{\text{Col. 4}}{\text{Col. 2}} \times 100$
1	2	3	4	5
2	3.3×10^4	2.4×10^3	0.9×10^4	27.3
6	9.5×10^3	3.0×10^3	1.0×10^3	10.5
10	4.8×10^3	4.6×10^3	0.2×10^3	4.2
14	2.7×10^3	2.6×10^3	0.1×10^3	3.7
18	2.1×10^3	2.03×10^3	0.07×10^3	3.3

Table No. 2.

As the size of the perforated holes in cell No. 44 & 45 was of the order of 0.25 cm to 0.2 cm. dia. the soil could not get into the holes easily as in case of cell like Nos. 48 and 49. The conductivity as proportional to the area can therefore, be not judged from this comparis-ion. The only conclusion is that the insulation area has considerable effect. Theoretically it should be proportional to the area.

The above table proves that as the conductivity of the insulation is decreased the percentage current passing through the insulator also decreases. This is no doubt obvious from the theoretical stand point also.

4.2. COMPARISION OF INSULATORS :

With rubber insulation with or without perforations (cell No. 40, to 45 as shown in Fig. 23, 24 and 25) and with soil and air insulation (Cell No. 46 to 56 as shown in Fig. 26 to 31) there is almost a uniform rise in gradient from the lowest moisture content to the highest moisture content. It has also been shown (paragraph 4.1) that the dissipation of current through the cell or through the surrounding soil follow a straight line path from the lowest to the highest measurable moisture content.

In case of plaster of paris cells with or without sand (i.e. with variable capilliarity-permeability) the slope is flat upto a certain moisture content depending upon the capilliarity-permeability of the material and the cover provided . The slope beyond this moisture content steepens.

With rubber, soil and air insulator the steepest slopes are usually flatter than with plaster of paris insulator. However with suitable increase in capilliarity-permeability of plaster of paris (by addition of 40 to 50 p.c. sand) the steepest slope tends to be identical with the rubber or soil or Air insulator.

4.3. EFFECT OF AREA OF THE INSULATOR :

With increase in area from 3.75 cm^2 (2.5 x 1.5 cm) to 5.04 Cm^2(2.8 x 1.8 cm) or from 3.14 cm^2(2 cm. dia) to 6.6 cm^2(2.9 cm dia) the conductance of current increases. Comparing the percentage increase in different types of insulating materials (calculations not given) it is found that the percentage conductance of current decreases with increase in moisture content or remains almost uniform inspite of the increase in moisture content beyond its certain percentage. The percentage increase of conductance per unit area depends upon the type of insulator and increase in the following order of insulator : Plaster of paris, perforated rubber and unperforated rubber. For soil, this type of comparision was not made.

4.4. EFFECT OF THE MATERIAL OF THE ELECTRODE :

Two types of electrodes i.e. Brass and stainless steel were tried. No change is marked due to the change in the metal of the electrode. The most important point is the perforations. From the [illegible] graph it is evident that stainless steel electrode with one central hole has some times given erratic results. Perforations uniformly spread over the area give more consistent readings.

From this it is concluded that mesh electrodes are the best. This is consistent with findings of Bouyoucos (10).

4.5. STUDY OF PLASTER OF PARIS CELLS.

The most important factor in this case is the permeability of the insulating material and the cover over the electrode. In the following sub-paras,cells with thin cover, without cover, effect of cover thickness and joint effects of these factors have been discussed :

4.5.1. PLASTER OF PARIS CELLS WITH THIN COVER : All cells with plaster of paris with or without sand but with thin cover of 0.2 cm. or less show a smooth uniformly rising curve upto 8 p.c. moisture content. Between 8 and 12 p.c. the rate of rise of the curve increases with increase in moisture content. Beyond 12 p.c. moisture content the curve obtains very steep but uniform slope. Since steep curves are most undesirable for proper determination of M.C. the steepness beyond 12 p.c. moisture content should be as less as possible. This varies with the percentage of sand added, and the area of the electrode as is evident from their respective graphs. The area of the electrodes and the slope of the curve above 12 p.c. moisture content for these cells is given in Table No. 3.

Cell No.	Sand percentage in plaster of paris.	Area of electrode in Cm^2	Slope of curve above 12 p.c. moisture content.
1	2	3	4
25 and 26	Nil	3.75	1 in 4.1
2	40	3.75	1 in 2.7
13,14, and 15	50	3.75	1 in 3.1
27 and 28	Nil	5.04	1 in 3.8
4,5 and 6	40	5.04	1 in 2.2
16,17 and 18	50	5.04	1 in 2.4

Table No. 3.

From Table No. 3 we observe that :

i) The slope steepens in the following order :

a) 40 p.c. sand.

b) 50 p.c. sand.

c) zero p.c. sand.

and that the difference in the steepness of the cells containing 40 or 50 p.c. sand is very little.

ii) The slope steepens with decrease in area of the electrode.

Thus we find that addition of standard sand to above 40 to 50 p.c. and increase in area of the electrode would provide flatter slopes.

4.5.2. PLASTER OF PARIS CELLS WITHOUT COVER :

All cells with plaster of paris with or without sand and without cover do not show such a smooth change in slope as in case of covered cells. This is probably due to non-uniform contact and interlocking of moisture between the electrode and the insulating material. The bond between the electrode and insulating material is not firm. However the curves for these cells indicate that the change in steepness is not as abrupt as has been noticed in covered plaster of paris cells. The steepest gradient in these cells also lie above 12 p.c. moisture content, as is observed in thin covered cells (See Appendix I.)

The steepness of the curve in case of these cells beyond 12 p.c. moisture varies with the percentage of sand added and the area of the electrode, as is evident from Table No. 4, prepared from data given in Appendix IV.

Cell No.	Sand percent in plaster of paris.	Area of electrode in Cm^2	Slope of curve above 12 p.c. moisture content.
1	2	3	4
30 and 31	Nil	3.75	1 in 3.3
7,8 and 9	40	3.75	1 in 2.0
19,20 and 21	50	4.75	1 in 2.2
32 and 33	Nil	5.04	1 in 2.9
10, 11 and 12	40	5.04	1 in 2.0
23 and 24	50	5.04	1 in 1.7

Table No. 4.

From the above we observe that :

i) The slope steepens in the following order :

a) 50 p.c. sand.

b) 40 p.c. sand.

c) zero p.c. sand.

and that the difference in the steepness of the cells containing 40 or 50 p.c. sand is very little.

ii) The slope steepens or remains same with the decrease in area of electrodes.

Thus we arrive at the same conclusion as that in para 4.5.1. that the addition of standard sand to about 40 to 50 p.c. and increase in area of the electrode would provide flatter slopes.

Now comparing the slopes given in this sub-para for cells uncovered with those given in para 4.5.1. with thin cover on cells, we find that in case of uncovered cells the slope is more flat. This is further discussed in the following sub-para.

4.5.3. EFFECT OF THICKNESS OF COVER IN PLASTER OF PARIS CELLS:

The effect of cover on plaster of paris cells with or withour sand has been pointed out at the bottom of para 4.5.2.

The effect of variation in thickness of cover was also tried with plaster of paris cells without sand. The following are the results:

In cell No. 78, 79 and 80 (Fig.No.32) with cover of 0.3 cm. the curve shows a smooth uniform rise upto 7 p.c. of moisture content as against 8 p.c. in case of plaster of paris cells with or without sand and with thin cover or even without cover.

Moreover the curve for cell No. 78,79 and 80 steepen sharply beyond 8 p.c. moisture content as against 12 p.c. in case of cells with or without sand and with thin cover or even without cover. This is evident from Table No. 5.

Cell No.	Area in Cm^2	Cover thickness	Steepest slope of curve beyond 9 p.c. moisture content.
78, 79 & 80	7.31	0.31	1 in 15.0
25 and 26	3.75	0.1	1 in 4.1
30 and 31	3.75	Nil	1 in 3.3
27 and 28	5.04	0.075 & 0.05	1 in 3.8
32 and 33	5.04	Nil	1 in 2.9

Table No. 5.

Thus we find that with decrease in thickness of cover the slope becomes flatter.

6.5.4.COMPARISION OF PLASTER OF PARIS CELLS: From the above discussions under paragraph 4.5 it is observed that the plaster of paris cells with 40 to 50 p.c. sand, with minimum possible thickness between the electrodes (say zero to 3 cm) and having bigger areas say (5 cm^2)would give better results.The cells without cover though give flatter slopes than with cover, but do not show a smooth change. The reason for this non uniform change has already been pointed out. A thinest possible cover to provide very good and uniform contact between the insulator and electrode will give the best results.

5. CONCLUSION.

i) Dissipation of current through the surrounding soil would give better results than through the insulating material between the electrodes. Cylindrical cells are therefore undesirable. Rubber insulation is the best. Soil and air insulation also give equally good results. Plaster of paris with improved capilliarity-permeability also would give good results.

ii) Meterials for the electrodes should be selected from the point of view of durability and corrosion; but all electrodes should have considerable perforations spread uniformly over the area of the electrode.

iii) The plaster of paris cells with 40 to 50 p.c. sand, with minimum possible thickness between the electrodes and having bigger area would give better results. The cells without cover though give flatter slopes than with cover; do not show a smooth change. The thinnest possible cover providing very good and uniform contact between the insulator and electrode will give the best results.

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S.No.	Cell No.	Insulation material	Thickness of insulation in cms.	Shape of electrode	Size in cms.	Cover Thickness in cms.	Type of electrode	Steepest slope and P.cent within which they lie.	Remarks
1	2	3	4	5	6	7	8	9	10
1.	78,79,80	Plaster of Paris	0.4 cm.	Rectangular	3.25 x 2.25	0.3	perforated brass electrode	1 in 15(9 to 20 pc)	Sometime the steepest slope (Col. 9) is vertical for types of cell given against S.No.1.
2.	25 & 26	-do-	0.2	-do-	2.5 x 1.5	0.1	-do-	1 in 4.1(12 to 19pc.)	
3.	27 & 28	-do-	0.25 & 0.1	-do-	2.8 x 1.8	0.075 & 0.05	-do-	1 in 3.8(-do-)	
4.	2	Plaster of Paris 60 pc. and standard sand 40 pc.	0.3	-do-	2.5 x 1.5	0.2	-do-	1 in 2.7(12 to 17 pc.)	
5.	4,5 & 6	-do-	0.3	-do-	2.8 x 1.8	0.2	-do-	1 in 2.2(12 to 19 pc.)	
6.	13, 14 & 15	Plaster of Paris 50 pc. and standard sand 50 pc.	0.3	-do-	2.5 x 1.5	0.2	-do-	1 in 3.1(-do-)	
7.	16, 17 & 18	-do-	0.3	-do-	2.8 x 1.8	0.2	-do-	1 in 2.4(-do-)	
8.	30 & 31	Plaster of Paris	0.3	-do-	2.5 x 1.5	Nil	-do-	1 in 3.3(12 to 16 pc.)	
9.	32 & 33	-do-	0.3	-do-	2.8 x 1.8	Nil	-do-	1 in 2.9(-do-)	
10.	7,8 & 9	Plaster of Paris 60 pc and standard sand 40 pc.	0.3	-do-	2.5 x 1.5	Nil	-do-	1 in 20 (-do-)	
11.	10, 11 & 12	-do-	0.3	-do-	2.8 x 1.8	Nil	-do-	1 in 2 (-do-)	
12.	19,20 & 21	Plaster of Paris 50 pc and standard sand 50 pc.	0.3	-do-	2.5 x 1.5	Nil	-do-	1 in 2.2(-do-)	
13.	23 & 24	-do-	0.3	-do-	2.8 x 1.8	Nil	-do-	1 in 1.7(-do-)	
14.	40	Rubber	0.075	Circular	dia = 2	Nil	-do-	1 in 2.6(8 to 18 pc)	A smooth risingcurve. The curve flattens with increase in moisture content.
15.	42 & 43	-do-	0.075	-do-	dia.=2	Nil	-do-	1 in 1.6(-do-)	-do-
16.	41	Perforated rubber	0.075	-do-	dia =2.9	Nil	-do-	1 in 2.2(-do-)	-do-
17.	44 & 45	-do-	0.075	-do-	dia = 2.9	Nil	-do-	1 in 1.6 (-do-)	-do-
18.	46 & 47	Soil & Air	0.15	-do-	dia = 2.9	Nil	-do-	1 in 1.8(4 to 18 pc)	Smooth rising curve. No change in resistance with increase in thickness of insulation.
19.	48 & 49	-do-	0.075	-do-	dia = 2.9	Nil	-do-	1 in 1.8 (6 to 18 pc.)	- do-
20.	50 & 51	Soil & Air	0.075	-do-	dia.= 2.4	Nil	Perforated stainless steel	1 in 6.7(14 to 19pc)	
21.	52 & 53	-do-	0.16	-do-	dia.= 2.4	Nil	-do-	1 in 1.8 (3 to 16pc)	Uniform slope. Straight line variation.
22.	54 & 55	-do-	2.3	-do-	dia.= 2.4	Nil	-do-	1 in 2 (2 to 19 pc.)	-do-
23.	56	Soil	3.2	-do-	dia.= 2.4	Nil	-do-	1 in 2 (2 to 18 pc.)	
24.	91 to 106	Soil & Air	0.45cm.	Cylindrical	dia.=0.9 0.64, 0.46, 0.33	Nil	Perforated brass electrode		Diameter of axial electrode = 0.07 cm.

APPENDIX II.

SAMPLE CALCULATIONS FOR COMPARISION OF FOUR METHODS OF MEASUREMENTS (REF. Para 11.2.) :

(a) With dry resistance coil :

i) Ohm meter (AVO-8) ------ 1950 Ohms, direct reading.

ii) D.C. Wet battery at 5.5 volts ------ reading = 2.95 M. A.

$$\therefore \text{ Resistance} = \frac{5.5}{0.00295} = 1{,}865 \text{ ohms.}$$

iii) A.C. Supply at 10Volts ---- Reading = 5.5 M . A.

$$\therefore \text{ Resistance} = \frac{10}{0.0055} = 1820 \text{ Ohms.}$$

iv) A.C. V.T.V.M. at 10 volts supply with a fixed resistance of 1,000 ohms ------ Reading = 5.45 volts.

$$\text{Hence resistance} = \frac{10}{5.45/1000} = 1{,}835 \text{ ohms.}$$

(b) With wet moisture cell :

i) Ohm-meter (AVO-8) ------ Needle fluctuates.

ii) D.C. wet battery at 5.55 volts ------ Reading 30.5 M. A.

$$\therefore \text{ Resistance} = \frac{5.55}{0.0305} = 182 \text{ ohms.}$$

iii) A.C. Supply at 10 volts ------ Reading = 73.5 M. A.

$$\therefore \text{ Resistance} = \frac{10}{0.0735} = 136 \text{ ohms.}$$

iv) A.C. V.T.V.M. at 10 Volts supply with a fixed resistance of 1,000 ohms ------ Reading = 66.5 volts.

$$\therefore \text{ Resistance} = \frac{10}{66.5/1000} = 155 \text{ ohms.}$$

Appendix II (2)

Results :

Type of resistance	Ohm meter	D.C.Wet Battery	A.C.	V.T.V.M.
i) Dry resistance coil	1950	1865	1820	1835
ii)Wet Moisture cell	-	182	136	155

-:0:-

APPENDIX III

PROPERTIES OF SOIL IN WHICH THE CELLS WERE CALIBRATED (ROORKEE SOIL)

1. Sieve Analysis.

Passing A.S.T.M.Sieve No.	Retained A.S.T.M. Sieve No.	Percentage retained
4	8	0.04
8	16	0.10
16	30	0.16
30	40	2.60
40	50	13.00
50	100	43.20
100	200	13.80

2. Optimum Moisture content = 10.6 p.c.

Plastic limit = 10.8 p.c.

Liquid Limit = 23.2 p.c.

Maximum dry density at O.M.C.= 126 lbs/c.ft.

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REFERENCES

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3. Croney D. and Coleman J.D. - "Soil moisture suction properties and their bearing on the moisture distribution in soils". Proc. 3rd Int. Conf. on soil Mechanics and Foundation Engg. Vol. I. P. 13 - 1953.

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5. Croney D., Coleman J.D. and Bridge P.M. " The suction of moisture held in soil and other porous material" Road Res. Tech. paper No. 24, H.M.SO.1952.

6. Schofield R.K. "The pF of water in soil" Transaction 3rd International Congress Soil-Science Vol. 2 page 37-48 - 1935.

7. Thilemmy N.B. - " An adjustment chart of use with the fibre glass moisture instrument" Soil Science Vol. 71-72 Page 377-380 - 1951

8. Witney M.A. - "Report of the chief of Division of Agricultural Soils". From the annual reports of the secretary of Agriculture - 1894.

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10. Bouyoucos G.J. " New type electrode for plaster of paris moisture blocks". Soil Science Vol.78 page 339-342 July-Dec.1954.

11. Colman E.A. - "The place of electrical soil moisture meters in hydrological research" Transactions Geophysics Union Vol. 27 page 847-853 - 1946.

12. Bouyoucos G.J. "Nylon electrical resistance unit for continuous measurement of soil moisture in field". Soil Science Vol.67; page 319 -330 - 1949.

13. Closs R.L. " A rapid method of calibrating soil moisture elements of the porous block type". Soil Science Vol. 78 page 333-338. July-Dec. 1954.

14. Rowland E.F., Fagan T.D. and Crabb G.A.Jr. "A slide rule for soil moisture determination" - Jour. Amer. Soc. Agr. Engin. Vol. 35 page 163-164 - 1954.

15. Tanner C.B. and Hanks R.J. "Moisture hysteresis in gypsum moisture blocks." Soil Science Amer. Proc. No. 16 48-51 - 1952.

16. Bourget S.J., Elrick D.E. and Tannes C.B. - "Electrical resistance units for moisture measurements, their moisture hysteresis, uniformity and sensitivity". Soil Science Vol. 86 page 298 July-Dec. 1958.

17. Kenneth Russam" An investigation into the soil moisture condition under roads in Trindad B.W.I. " Institute of Civil Engineers, London 1958.

18. Coleman J.D. and Farrar D.M. " The measurement of vapour pressure and surface area of soils" Road Res. Lab. note No. RN/2763/JDC.DMF - 1956.

19. Colman E.A. and Hendrix T.M. "Fibre glass electrical soil moisture instrument". Soil Science Vol. 67 Page 425-438 -1949.

20. Haise H.R. and Kelly O.J. "The relation of electrical and heat conductivity to moisture tension in plaster of paris blocks. Soil Science Vol. 61 - page 411-422-1946.

21. Youker R.E. and Dreibelbis F.R. " An improved soil moisture measuring unit for hydrologic studies". Trans. Am. Geophysics Union Vol. 32. Page 447-1951.

22. Croney D. -The electrical resistance method for measuring soil moisture. British Journal of Applied Physics Vol. 2 Page 85-91 - 1951.

23. Hendrix T.M. and Colman E.A. " Calibration of fibre-glass soil moisture unit". Soil Science Vol. 71-72. Page 419-427. 1951.

24. "Engineering testing equipment" Soil test incorporated.

25. "Field studies of movement of soil moisture" Road Res. Tech. paper 41.

26. Bouyoucos G.J. " A new type electrode for plaster of paris moisture blocks" Soil Science Vol. 78 Page 339-342 July-Dec. 1954.

27. Deplater C.V. " A portable capacitance type soil moisture meter -Soil Science Vol. 80 Page 391-395 July-Dec. 1955.

28. Carlton P.F., Belcher D.J., Cuykendall T.R. and Sack H.S.- "Mo Modification and tests of radio active probes for measuring soil moisture and density" C.A.A. Tech. Devel. Rpt. 194 -1953.

29. Anon."Soil moisture movement with the Fibre Glass Instrument" Occasional paper 128, Forest Service, U.S. Deptt. of Agricultu 1953.

30. Anon. "Some Field Laboratory and office procedure for Soil Moisture Movement". Occassional paper 135, U.S. Deptt. of Agriculture July 1954.

31. Robert Horonjeff and Irving Goldberg. "Field Measurement of Soil moisture and Density with Radio active materials". Proc. Highway Research Board, Vol. 32. Page 500-1953.

32. Coleman J.D. and Croney D. "The estimation of vertical moisture distribution with depth in unsaturated cohesive soils". Road Research Laboratory note No. RN/1709/JDC.D.C.(Unpublished)-1952.

33. Aldrous, Lawton and Mainfort - "The Measurement of Soil Moisture by heat diffusion" Civil Aeronautic Administration Devel. Rpt. No. 165 - 1952.

34. Allyn. R.B. - " A Calibrated soil probe for measuring Field Soil Moisture" Soil Science Vol. 53 page 273-285-1942.

35. Engineering Test Equipment - Soil Test Incorporated U.S.A.-1960.

36. Soil Mechanics for Road Engineers - H.M. SO.

37. Aggarwal V.S. "In-situ measurement of moisture content" Indian and Eastern Engineer - Vol. 102 No. 6; June 1960-P 321-324.

38. Bouyoucous G.J. "More durable plaster of paris blocks". Soil Science Vol. 76 page 446-451 - 1953.

39. A.S.T.M. Specifications 1958.

40. Hatherly L.W. and Wood M. "Seasonal Variation in subgrade soil moisture content and temperature with depth in Baghdad, Iraq." 4th International Conference of Soil - Mechanics and Foundation Engg. - 1957.

41. Richarts L.A. "Porous plate apparatus for measuring moisture and transmission by Soil"-Soil Science Vol.66 Page105-110-1948.

42. Russam K. " A modified tensiometer for use under road or airfield pavements" Road Research (U.K.) Lab. note No. RN/3517/KP-1959 (Unpublished).

43. Physics. Zeits., Vol. VII. Page 570.

44. Golding E.W. - " Electrical measurement and measuring instruments" - Publisher Sir Issac Pitman & Sons Ltd., London.

45. Churcher B.G., Dannatt C. and Dalgleish J.W. " Contact effects between electrodes and dielectrics" Journal of the Institution of Electrical Engineers. Vol. 67 P. 271.

46. Pender H. and Del Mar W.A. - Electrical Engineers Hand Book. Jhon Willey and Sons.

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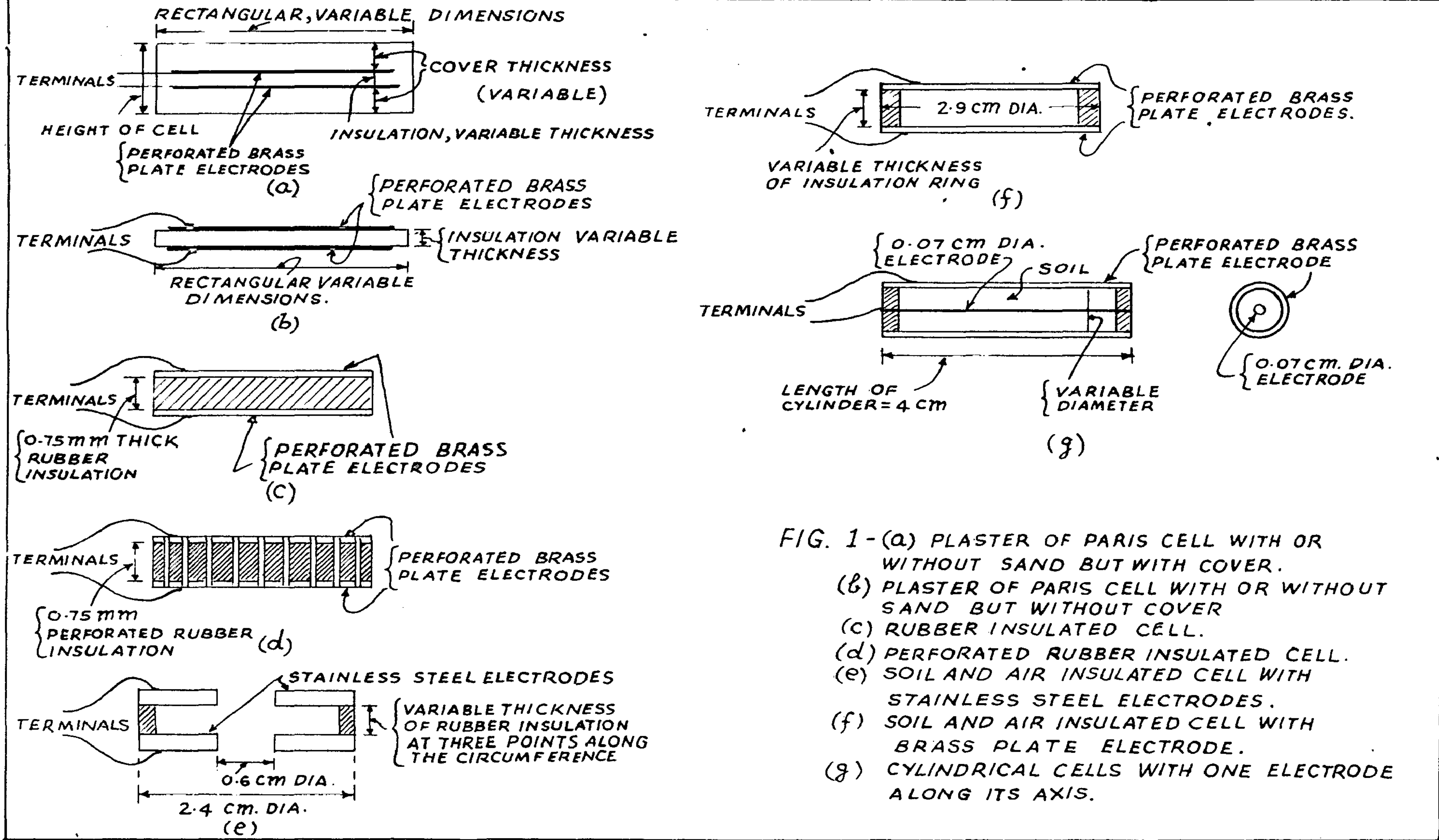
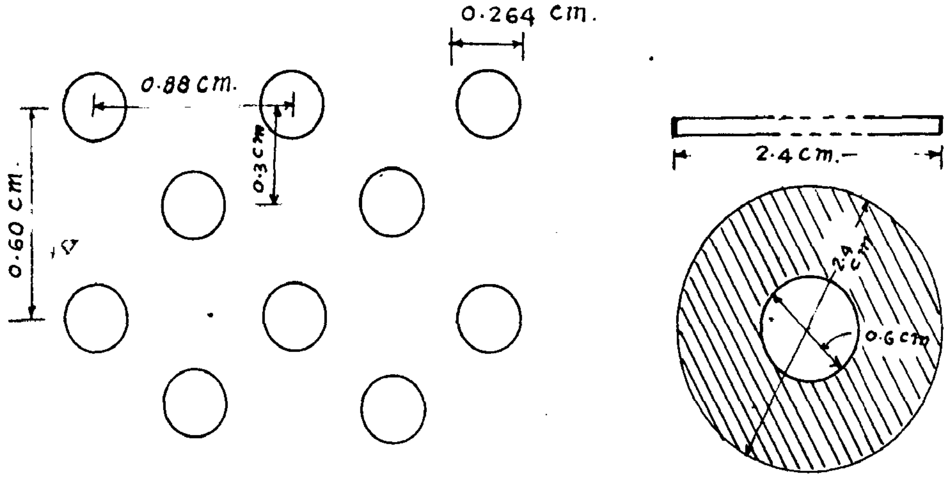
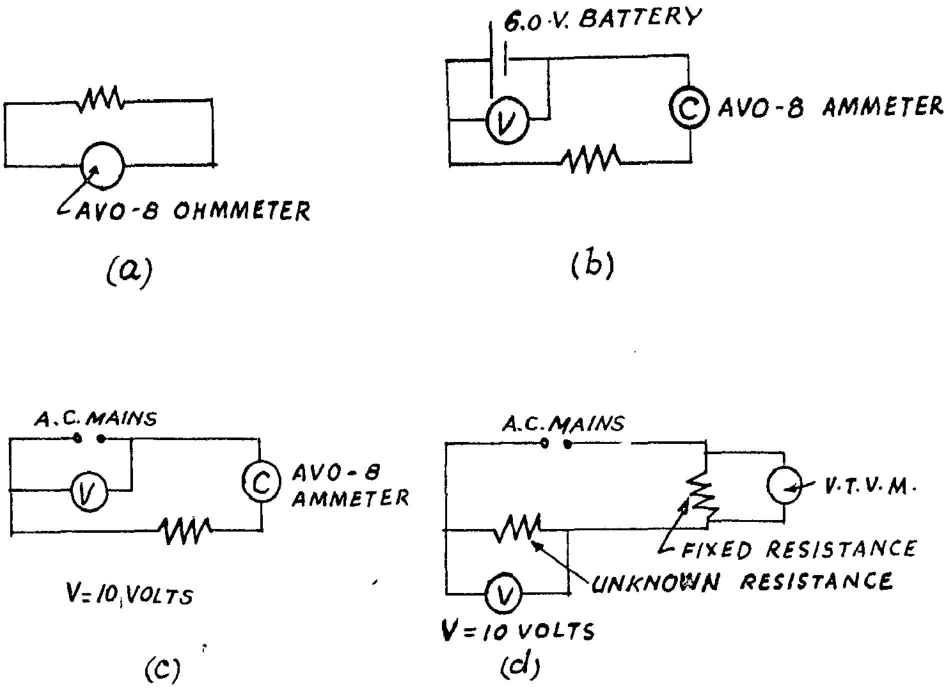


FIG. 1 - (a) PLASTER OF PARIS CELL WITH OR WITHOUT SAND BUT WITH COVER.
(b) PLASTER OF PARIS CELL WITH OR WITHOUT SAND BUT WITHOUT COVER
(c) RUBBER INSULATED CELL.
(d) PERFORATED RUBBER INSULATED CELL.
(e) SOIL AND AIR INSULATED CELL WITH STAINLESS STEEL ELECTRODES.
(f) SOIL AND AIR INSULATED CELL WITH BRASS PLATE ELECTRODE.
(g) CYLINDRICAL CELLS WITH ONE ELECTRODE ALONG ITS AXIS.



(a) (b)

FIG. 4 - (a) DETAILS OF PERFORATIONS IN BRASS ELECTRODE.
(b) PERFORATED STAINLESS STEEL ELECTRODE.



(a)- ACROSS AVO-
(b)- ACROSS WET BATTERY.
(C) - ACROSS A·C - 10 VOLTS
(d)- ACROSS V·T·V.M.(VACUUM TUBE VOLTMETER)

FIG. 5- CIRCUIT DIAGRAM OF MEASURING DEVICES.

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(iv) ~~Penetrometer method~~. In this method for a given soil the penetrometer has been calibrated with respect to the moisture content, (v) Soil point method. By this method a change of moisture of a porous block placed in soil is determined, (vi) Heat diffusion method. This method is based on the principle that the rate of heat diffusion increases with moisture content. The percentage moisture can be determined for those soils whose heat conductivity-moisture content relationship has already been determined.

From the above it is observed that the gravimetric method is not suitable to measure moisture content insitu and over a long period, and is very elaborate when spread over larger area and depth. The soil point and heat diffusivity methods are just attempts to remove the defects mentioned above.

2.2 Tensiometer method

By this method it is claimed that pressure upto one atmosphere above and below the atmospheric pressure can be determined in the soil moisture (2). The instrument consists essentially of a small water reservoir on one side of which is a porous plate. The other side of this reservoir is connected to a long glass capilliary tube, bent at the other end to form a manometer. It is protected by a brass cover from which the porous plate is arranged to protrude. A diagrammetic sketch is shown in Fig. 2. When the porous plate is brought in contact with the soil, the moisture is either sucked up or down the porous plate indicating pressure above or below one atmosphere respectively on the manometer The suction in the up or down direction stops when pressures on both sides of the porous plate balance. The instrument can be placed in soil tube holes upto reasonable working depth of say 3 meters.

Croney and Coleman (3) have recommended the following equation for determining the suction due to surface tension and adsorptive forces.

$$*U = \propto P - S$$

where *U = Pore Water pressure in the thin horizontal stratum of the soil, measured by means of tensiometer.

*S = Sunction due to surface tension and adsorptive force.

*P = Overburden pressure and can be deduced from the total weight of wet soil above the point under consideration with any surface load.

*∝ = The factor of the over burden pressure (or the fraction of the pressure) that affect the suction. It is greater than zero and less than 1. This factor has to be measured in the laboratory by loading test.

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*For explanation of the terms, see appendix I.

In saturated clay all normal pressure is carried by the soil since the absorbed water film surrounding the clay particles are continuous. α in this case is therefore equal to unity. In a material of rigid structure, e.g. incompressible soil, no part of normal pressure is transmited to water and $\alpha = 0$.

Black and croney (4) determined the following values of α for the soils used by them. For sandy clay it is $= 0.15$ and for silty clay $= 0.5$.

Having thus calculated the suction, the moisture content can be obtained after determining the relation between suction and moisture content in the laboratory for undisturbed condition. The method of measuring suction by plate technique is described by Croney, Coleman and Bridge (5). The relation between suction and moisture has been described by Schofield (6).

The tensiometer method can be applied only when a bore hole has been drilled. The moisture content at the bottom of the bore hole would not be the same as would have been otherwise after a certain interval due to the factors mentioned in the first paragraph of this paper. Laboratory tests on undisturbed samples are also likely to lead to error.

2.3 Nuclear method

Moisture measurement by Nuclear method depends upon (i) a source of fast neutrons (ii) slowing down and deflection of these neutrons by the water in the soil and (iii) a measure of the resulting slow neutrons. Carlton (7) has stated the theory behind this method and is mentioned below :

The measurement of soil moisture is based on the physical laws governing the scattering of neutrons in matter and, in particular, the scattering of neutrons in soil. When a fast neutron source is placed in soil, the emitted neutrons collide with the atoms comprising the soil. As a result of these collisions, the neutrons are scattered in all directions and some of them return to the vicinity of the source. However, in each collision the neutron loses part of its kinetic energy and is slowed down. The average energy loss is much greater in neutron collision with atoms of low atomic weight than with atoms of high atomic weight. As a result, the number of slow neutrons found near the source is a function of the number of atoms of low atomic weight present in the soil. If the number of these atoms in the soil is increased, a greater number of slow neutrons will be found near the source.

Hydrogen is the only element of low atomic weight found in ordinary soils in appreciable amount. Therefore, if a device for detecting slow neutrons is placed in the soil near fast neutron source, the number of slow neutrons counted per unit of time is a measure of the concentration of hydrogen atoms in the soil. Since hydrogen is largely contained in molecules of free water, the slow neutron count is a direct measurement of the moisture content of the soil.

measuring instrument. The electrodes can be embedded in a porous material, before placing them in the soil. The cell so formed is to be calibrated for moisture v/s electrical resistance between the electrodes.

Bouyoucos and Mick (9) prepared the first electrical resistance cell in 1940 by embedding the electrodes in plaster of paris block. This cell was further modified by Bouyoucos (10) in 1954, by providing stainless steel 20 U.S.A. mesh screen 2.4 cm. × 6.35 cm. wide and placed 0.5 cm. apart. Bouyoucos claimed that these blocks became sensitive to chang in moisture content at a tension range of 260 to 330 cm. of water.

In 1946 Colman (11) described a fibre glass cell and this cell was placed in market in 1947. Bouyoucos (12) brought out a fabric glass unit made of nylon and the electrodes.

At present three types of cells are available (i) Plaster of Paris or gypsum consisting of a pair of stainless or tinned copper screen electrodes embedded in plaster of paris. (ii) Nylon cells consisting of fine metal screen electrodes separated by a covering of nylon and enclosed in a perforated nickel case. The electrodes and casing may be of stainless steel (iii) Fibre glass cells consisting of two monel metal electrodes, separated by a processed fibre glass cloth. The whole assembly is enclosed in two or three layers of same material and then further enclosed in a monel metal case. Thus in the plaster of paris, nylon and fibre glass cells, the porous dielectric materials are plaster of paris, nylon and fibre glass respectively. In the fibre glass cell a small thermister is provided.

Further details of these cells are given in table below.

Item	Fibre glass	Nylon	Plaster of Paris
1. Outer dimensions cms.	3.8×2.5×0.3	3.8×3.2×0.3	4.3×3.2×1.8
2. Absorbent material between electrodes.	Two or three layers of fibre glass.	One layer of nylon.	Plaster of paris.
3. Distance between electrodes–cms.	0.08	0.08	0.5
4. Electrode area–sq. cm.	2.5	13.0	3.0
5. Mesh wires per cm.	24	38	8

3. Calibration methods of electrical resistance cells

The following methods can be used :

(i) *Field method*—In this method the cells can be embedded in the field, in the same type of soil where they are to be used and while recording the resistance, the most accurate method but it cannot be utilized for measuring moisture content in situ. Moreover, it is time consuming. The rest three methods i.e. tensiometer, electrical resistance and nuclear can be used for situ positions. In

Out of these three methods nuclear method is the only method of measuring moisture content without calibration. This is no doubt a big advantage, and as already discussed, will provide more accurate results than the other two methods. The calibration curve for nuclear equipment used at Vicksburg U. S. A. (1) show that the graph tends to level off at very high moisture content approaching saturation. Level or vertical graph means that there will be no change in reading, inspite of increase in moisture content. As regards time taken, each reading would take not more than 2 to 10 minutes from the setting of equipment to final reading.

With regard to tensiometer Lull (1) states that tensiometers are best available for the range of soil moisture from field capacity to saturation, and that they cannot determine low moisture content. They are more accurate at high moisture content. They frequently leak and hence give inaccurate results. Moreover, it takes 40 minutes to 6 hours to record a drop and hence may result into additional error.

Electrical resistance cells are more responsive to low moisture changes.

For measuring moisture content below ground level with tensiometer and nuclear method, the soil requires to be bored. Boring has to be done inorder that porous plate of the tensiometer or probe of the nuclear device should reach the source i.e. the point where moisture content is to be determined.

In case of structures, though having shallow foundations, it may many a time become difficult to reach certain points below the foundation by boring. In case of pavements, whether already existing or proposed to be built, boring will have to be made through the pavement if the moisture content is to be determined either by tensiometer or nuclear device. In case of tensiometer, the porous plate remains embedded while the manometer projects out. This will prevent the road to be used for traffic. In case of nuclear device it is impossible to obtain the actual moisture content because the bottom of the hole is exposed to atmosphere.

Further, in order to determine the moisture gradient through the depth of the soil for any place under the ground or pavement, the number of bore holes will be equal to the number of points at which the moisture content is to be determined. All these disadvantages are overcome in case of electrical resistance method. Moreover if the cells are required to be embedded before construction of pavement, no boring is required to be carried out in the pavement.

From the above discussion it is evident, that a suitable electrical resistance cell is an ideal method of determining the moisture content below foundation or pavements.

a given moisture tension is different for soil drying and soil wetting. Bourget determined the hysteresis over a tension range of 0 to 15 atmospheres and found that the accuracy of the unit is affected by (i) the magnitude of moisture hysteresis in the cell, (ii) uniformity of cells, unless they are calibrated individually, (iii) sensitivity and (iv) deterioration or aging of unit. A typical curve for gypsum cell with large electrodes placed in wet peat for 8 months as given by Bourget (16) is shown in Fig. 5.

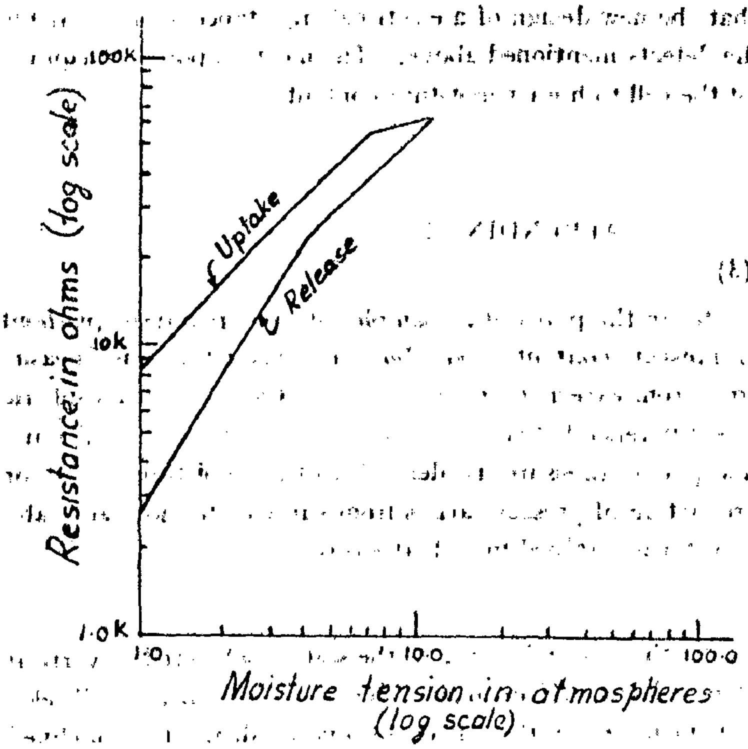

Fig. No. 5 — Electrical resistance of gypsum cells with large electrodes placed in wet peat for 8 months.

These experiments were conducted by them in the laboratory where the variation in moisture content was carried out during a very short interval. In case of soil below foundation, the moisture content is almost at equilibrium, and hence moisture tension will also remain in equilibrium inspite of very slow rate of falling or rising. The question arises about the calibration of moisture cells in the laboratory where the cells have to be calibrated during a short interval. The rise in moisture content is mostly due to rainfall or rise in the level of the water table.

energy of water in the soil is termed by a factor known as pF value introduced by Schofield (6). The pF value of soil water is defined as a common logarithm of the suction or tension, (expressed in cms. of water) under which water is held in the soil. A suction of 1 cm. of water has pF = 0 ; 10 cms. has pF = 1 ; 100 cms. has pF = 2 and so on.

References

1. Lull H. W. and Reinhart K. G.—"Soil moisture measurement" Occasional paper No. 140: Southern Forest Experimental Station, Forest Service U.S. Deptt. of Agriculture, 1955.
2. Jacobs J.C. and West G.—"A field tensiometer for soil moisture studies"—Road Research (U.K.) Lab. note RN/4085/JCJ. Nov. 1961.
3. Croney D. and Coleman J.D.—"Soil moisture suction properties and their bearing on the moisture distribution in soils". Proc. 3rd Int. Conf. on soil Mechanics and Foundation Engg. Vol. I. P. 13—1953.
4. Black W.P.M. and Croney D.—"Pore Water pressure and moisture content studies under experimental pavements" 4th International Conference of Soil Mechanics and Foundation Engineering—1957.
5. Croney D., Coleman J.D. and Bridge P.M.—"Suction of moisture held in soil and other porous material" Road Res. Tech. paper No. 24, H. M. S. O. 1952.
6. Schofield R.K.—"The pF of water in soil". Transaction 3rd International Congress Soil-Science Vol. 2 Page 37-48, 1935.
7. Thilammy N.B.—"An adjustment chart for use with the fibre glass moisture instrument" Soil Science Vol. 71-72 Page 377-380, 1951.
8. Witney M.A.—"Report of the chief of Division of Agricultural Soils" From the annual reports of the secretary of Agriculture—1894.
9. Bouyoucos G.J. and Mick A.H.—"An electrical resistance method for the continuous measurement of soil moisture under field conditions". Mich. U.S.A. Agr. Experiment Station Tech. Bulletin No. 172, 1940
10. Bouyoucos G.J.—"New type electrode for plaster of paris moisture blocks". Soil Science Vol. 78, Page 339-342, July, Dec. 1954.
11. Colman E.A.—The place of electrical soil moisture meters in hydrological research" Transactions Geophysics Union Vol. 27, Page 847-853, 1946.

REFERENCES

1. Lull H.W. and Reinhart K.G. - "Soil Moisture Measurement" Occasional paper No. 140. Southern Forest Experimental Station, Forest Service, U.S. Deptt. of Agriculture, 1955.

2. Jacobs J.C. and Host G. " A field tensiometer for soil moisture studies" - Road Research (U.K.) Lab. note RN/4085/JCJ. Nov. 1961.

3. Croney D. and Coleman J.D. - "Soil moisture suction properties and their bearing on the moisture distribution in soils". Proc. 3rd Int. Conf. on soil Mechanics and Foundation Engg. Vol. I. P. 13 - 1953.

4. Black W.P.M. and Croney D. - "Pore Water pressure and moisture content studies under experimental pavements" 4th International Conference of Soil Mechanics and Foundation Engineering - 1957.

5. Croney D., Coleman J.D. and Bridge P.M. " The suction of moisture held in soil and other porous material" Road Res. Tech. paper No. 24, H.M.SO.1952.

6. Schofield R.K. "The pF of water in soil" Transaction 3rd International Congress Soil-Science Vol. 2 page 37-48 - 1935.

7. Thilmany H.B. - "An adjustment chart of use with the fibro glas moisture instrument" Soil Science Vol. 71-72 Page 377-380 - 1951

8. Witney M.A. - "Report of the chief of Division of Agricultural Soils". From the annual reports of the secretary of Agriculture - 1894.

9. Bouyoucos G.J. and Mick A.H. - "An electrical resistance method for the continuous measurement of soil moisture under field conditions". Mich. U.S.A. Agr. Experiment Station Tech. Bulletin No. 172 - 1940.

10. Bouyoucos G.J. " New type electrode for plaster of paris moisture blocks". Soil Science Vol.78 page 339-342 July-Dec.1954.

11. Colman E.A. - "The place of electrical soil moisture meters in hydrological research" Transactions Geophysics Union Vol. 27 page 847-853 - 1946.

12. Bouyoucos G.J. "Nylon electrical resistance unit for continuous measurement of soil moisture in field". Soil Science Vol.67; page 319 -330 - 1949.

13. Closs R.L. " A rapid method of calibrating soil moisture elements of the porous block type". Soil Science Vol. 78 page 333-338. July-Dec. 1954.

14. Rowland E.F., Fagan T.D. and Crabb G.A. Jr. "A slide rule for soil moisture determination" - Jour. Amer. Soc. Agr. Engin. Vol. 35 page 163-164 - 1954.

15. Tanner C.B. and Hanks R.J. "Moisture hysteresis in gypsum moisture blocks." Soil Science Amer. Proc. No. 16 48-51 - 1952.

16. Bourget S.J., Elrick D.E. and Tanner C.B. - "Electrical resistance units for moisture measurements, their moisture hysteresis, uniformity and sensitivity". Soil Science Vol. 86 page 298 July-Dec. 1958.

17. Kenneth Russem" An investigation into the soil moisture condition under roads in Trindad B.W.I. " Institute of Civil Engineers, London 1958.

18. Coleman J.D. and Farrar D.M. " The measurement of vapour pressure and surface area of soils" Road Res. Lab. note No. RN/2763/JDC.DMF - 1956.

19. Colman E.A. and Hendrix T.M. "Fibre glass electrical soil moisture instrument". Soil Science Vol. 67 Page 425-438 -1949.

20. Haise H.R. and Kelly O.J. "The relation of electrical and heat conductivity to moisture tension in plaster of paris blocks. Soil Science Vol. 61 - page 411-422-1946.

21. Youker R.E. and Dreibelbis F.R. " An improved soil moisture measuring unit for hydrologic studies". Trans. Am. Geophysics Union Vol. 32. Page 447-1951.

22. Croney D. -The electrical resistance method for measuring soil moisture. British Journal of Applied Physics Vol. 2 Page 85-91 - 1951.

23. Hendrix T.M. and Colman E.A. " Calibration of fibre-glass soil moisture unit". Soil Science Vol. 71-72. Page 419-427. 1951.

24. "Engineering testing equipment" Soil test incorporated.

25. "Field studies of movement of soil moisture" Road Res. Tech. paper 41.

26. Bouyoucos G.J. " A new type electrode for plaster of paris moisture blocks" Soil Science Vol. 78 Page 339-342 July-Dec. 1954.

27. Deplater C.V. " A portable capacitance type soil moisture meter -Soil Science Vol. 80 Page 391-395 July-Dec. 1955.

28. Carlton P.F., Belcher D.J., Cuykendall T.R. and Sack H.S.- "Mo Modification and tests of radio active probes for measuring soil moisture and density" C.A.A. Tech. Devel. Rpt. 194 -1953.

29. Anon."Soil moisture movement with the Fibre Glass Instrument" Occasional paper 128, Forest Service, U.S. Deptt. of Agricultu 1953.

30. Anon. "Some Field Laboratory and office procedure for Soil Moisture Movement". Occassional paper 135, U.S. Deptt. of Agriculture July 1954.

31. Robert Horonjeff and Irving Goldberg. "Field Measurement of Soil moisture and Density with Radio active materials". Proc. Highway Research Board, Vol. 32. Page 500-1953.

32. Coleman J.D. and Croney D. "The estimation of vertical moisture distribution with depth in unsaturated cohesive soils". Road Research Laboratory note No. RN/1709/JDC.D.C.(Unpublished)-1952.

33. Aldrous, Lawton and Mainfort - "The Measurement of Soil Moisture by heat diffusion" Civil Aeronautic Administration Devel. Rpt. No. 165 - 1952.

34. Allyn. R.B. - " A Calibrated soil probe for measuring Field Soil Moisture" Soil Science Vol. 53 page 273-285-1942.

35. Engineering Test Equipment - Soil Test Incorporated U.S.A.-1960.

36. Soil Mechanics for Road Engineers - H.M. SO.

37. Aggarwal V.S. "In-situ measurement of moisture content" Indian and Eastern Engineer - Vol. 102 No. 6; June 1960-P 321-324.

38. Bouyoucous G.J. "More durable plaster of paris blocks". Soil Science Vol. 76 page 446-451 - 1953.

39. A.S.T.M. Specifications 1958.

40. Hatherly L.W. and Wood M. "Seasonal Variation in subgrade soil moisture content and temperature with depth in Baghdad, Iraq." 4th International Conference of Soil - Mechanics and Foundation Engg. - 1957.

41. Richarts L.A. "Porous plate apparatus for measuring moisture and transmission by Soil"-Soil Science Vol.66 Page105-110-1948.

42. Russam K. " A modified tensiometer for use under road or airfield pavements" Road Research (U.K.) Lab. note No. RN/3517/KP-1959 (Unpublished).

43. Physics. Zeits., Vol. VII. Page 570.

44. Golding E.W. - " Electrical measurement and measuring instruments" - Publisher Sir Issac Pitman & Sons Ltd., London.

45. Churcher B.G., Dannatt C. and Dalgleish J.W. " Contact effects between electrodes and dielectrics" Journal of the Institution of Electrical Engineers. Vol. 67 P. 271.

46. Pender H. and Del Mar W.A. - Electrical Engineers Hand Book. Jhon Willey and Sons.

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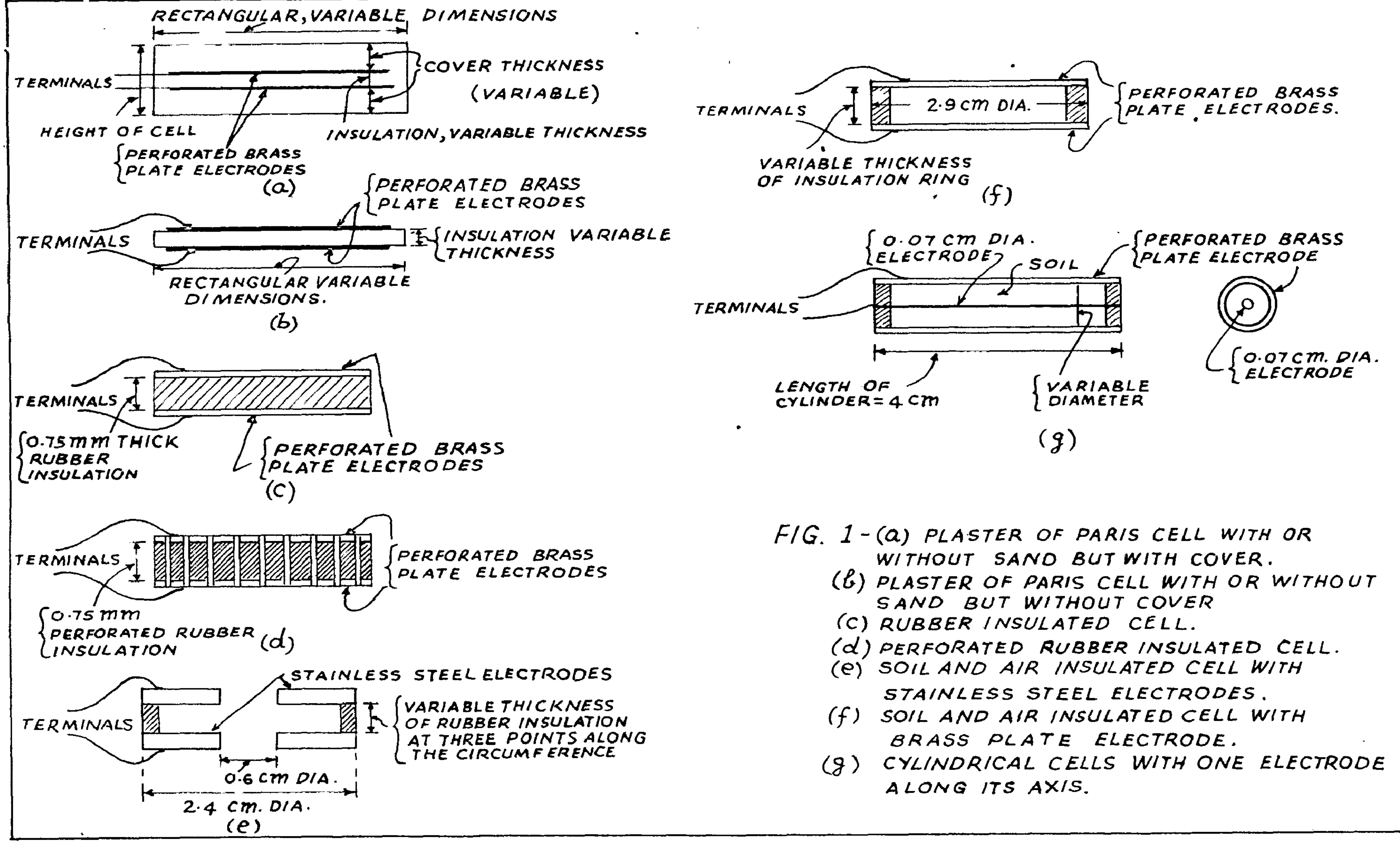


FIG. 1 - (a) PLASTER OF PARIS CELL WITH OR WITHOUT SAND BUT WITH COVER.
(b) PLASTER OF PARIS CELL WITH OR WITHOUT SAND BUT WITHOUT COVER
(c) RUBBER INSULATED CELL.
(d) PERFORATED RUBBER INSULATED CELL.
(e) SOIL AND AIR INSULATED CELL WITH STAINLESS STEEL ELECTRODES.
(f) SOIL AND AIR INSULATED CELL WITH BRASS PLATE ELECTRODE.
(g) CYLINDRICAL CELLS WITH ONE ELECTRODE ALONG ITS AXIS.

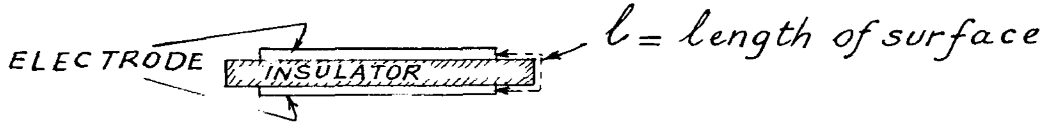


FIG_ 2. SURFACE RESISTIVITY IS INVERSELY PROPORTIONAL TO THE LENGTH OF SURFACE PATH.

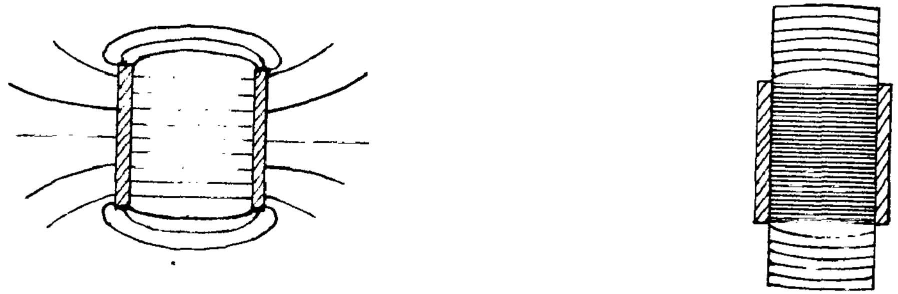


FIG_3. FLOW PATTERNS OF AIRRENT BETWEEN ELECTRODES.

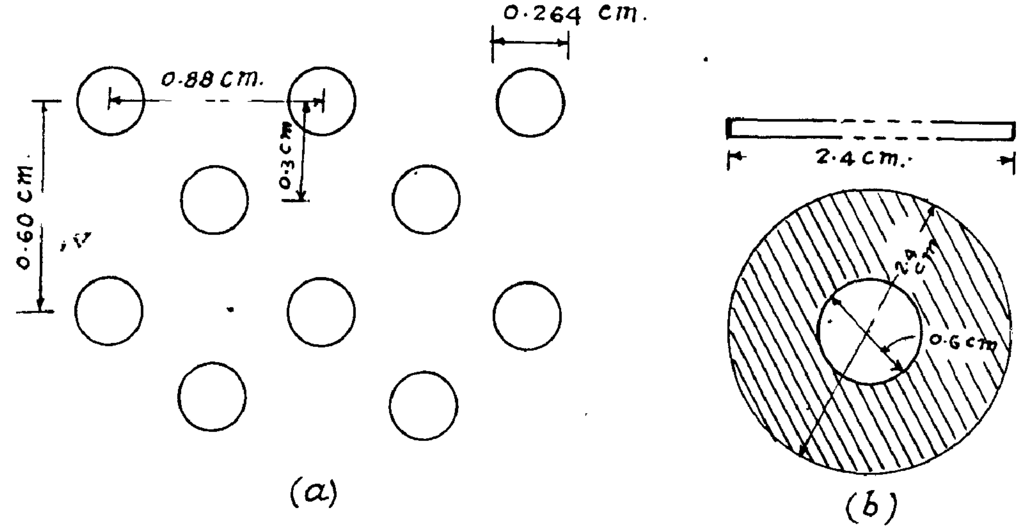
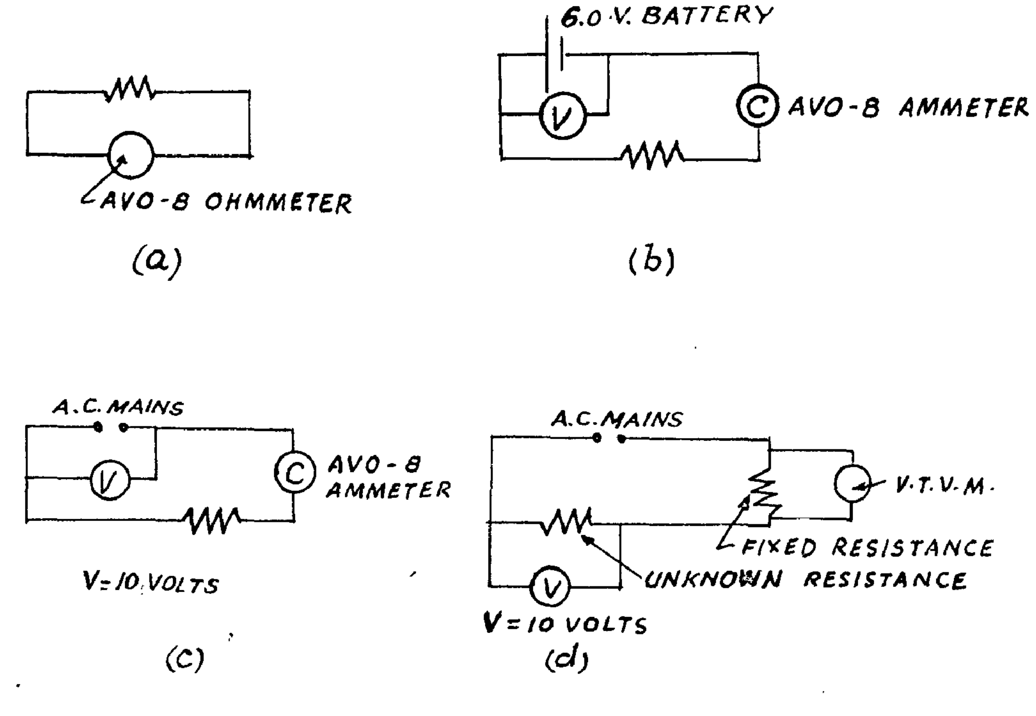


FIG. 4 - (a) DETAILS OF PERFORATIONS IN BRASS ELECTRODE.
(b) PERFORATED STAINLESS STEEL ELECTRODE.



(a) - ACROSS AVO-
(b) - ACROSS WET BATTERY.
(C) - ACROSS A.C - 10 VOLTS
(d) - ACROSS V.T.V.M.(VACUUM TUBE VOLTMETER)

FIG. 5 - CIRCUIT DIAGRAM OF MEASURING DEVICES.

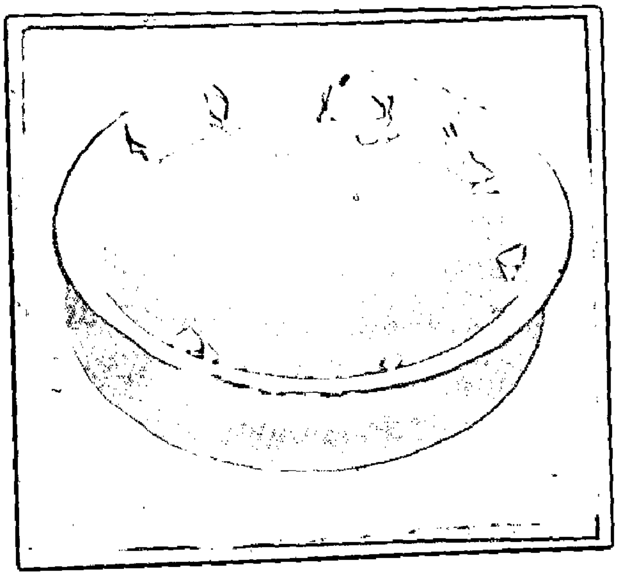
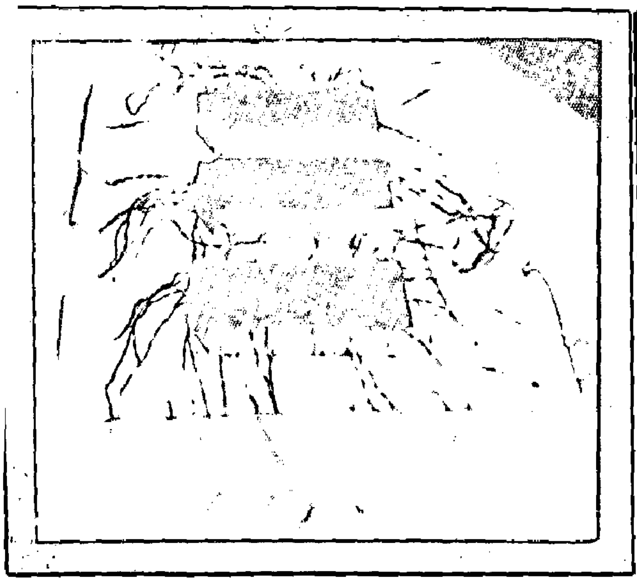


FIG- 6. CELLS EMBEDDED IN SOIL IN A BIG CONTAINER (LEAD WIPES PROJECTION [illegible]



IG-7(a). CELLS EMBEDDED IN SOIL CONTAINED IN A SHALLOW BOX.

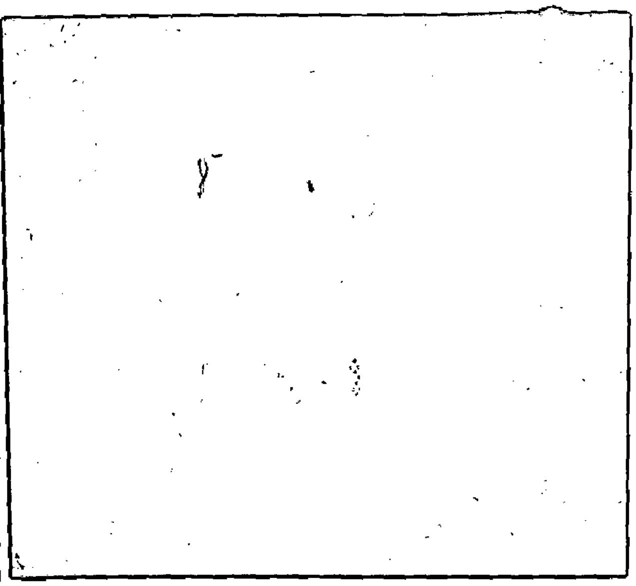
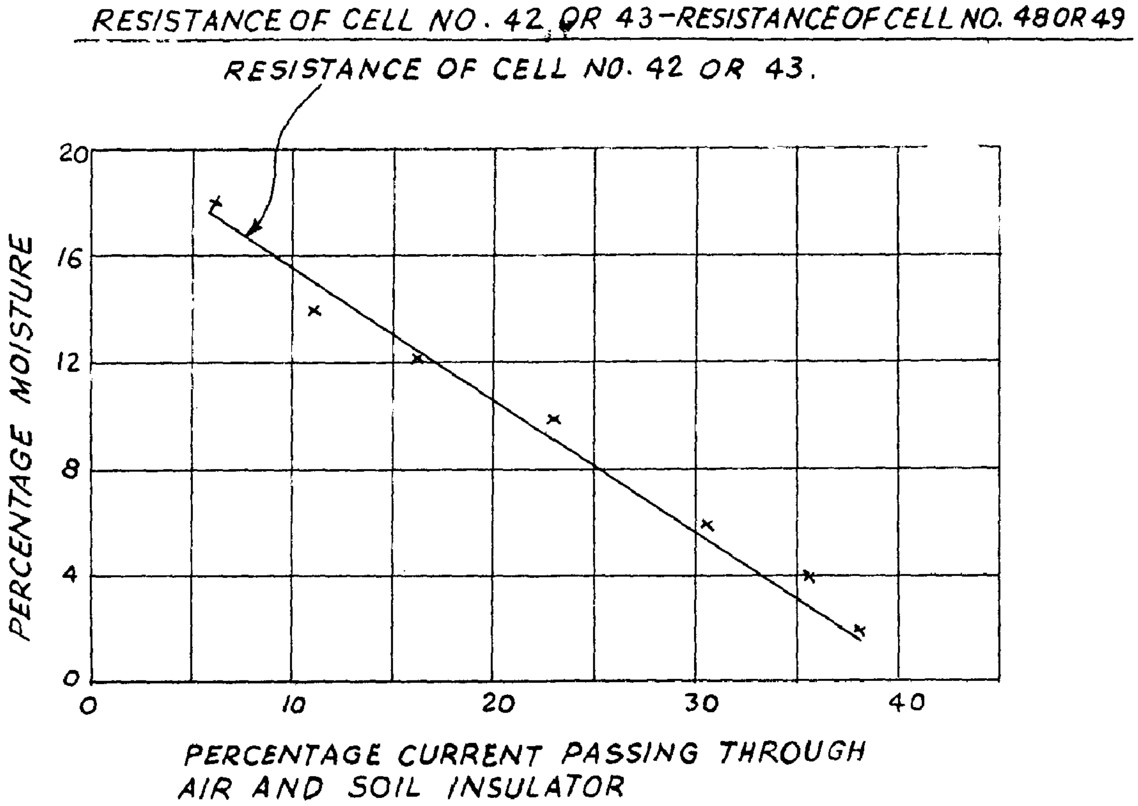
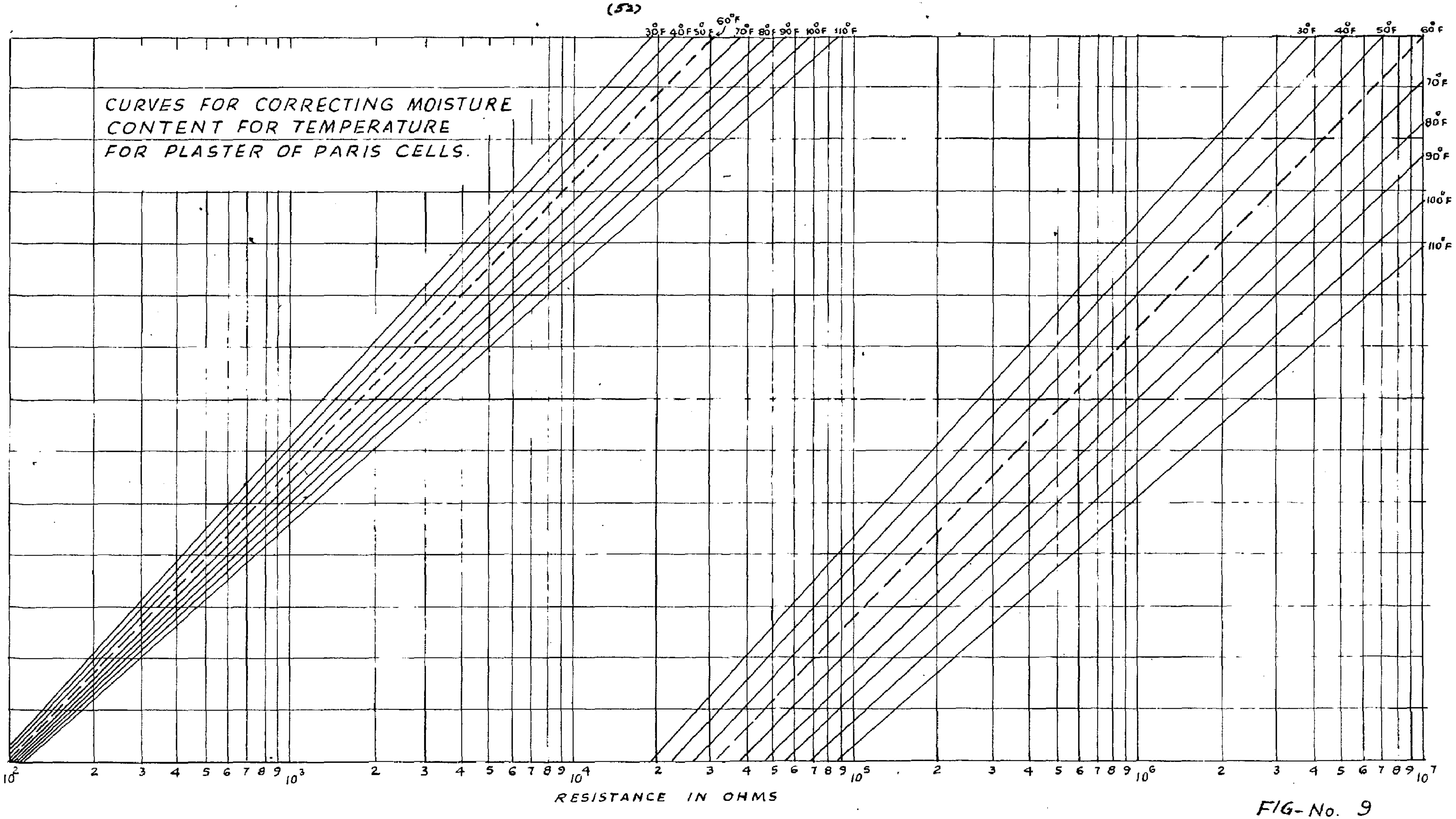


FIG 7(b) DIFFERENT TYPES OF CELLS TRIED.



$$\frac{\text{RESISTANCE OF CELL NO. 42 OR 43} - \text{RESISTANCE OF CELL NO. 48 OR 49}}{\text{RESISTANCE OF CELL NO. 42 OR 43.}}$$

FIG. No. 8



CURVES FOR CORRECTING MOISTURE CONTENT FOR TEMPERATURE FOR PLASTER OF PARIS CELLS.

FIG-No. 9

CELL NO. 2.

PLASTER OF PARIS WITH 40 p.c. SAND.
2·5 × 1·5 cm. (COVERED)

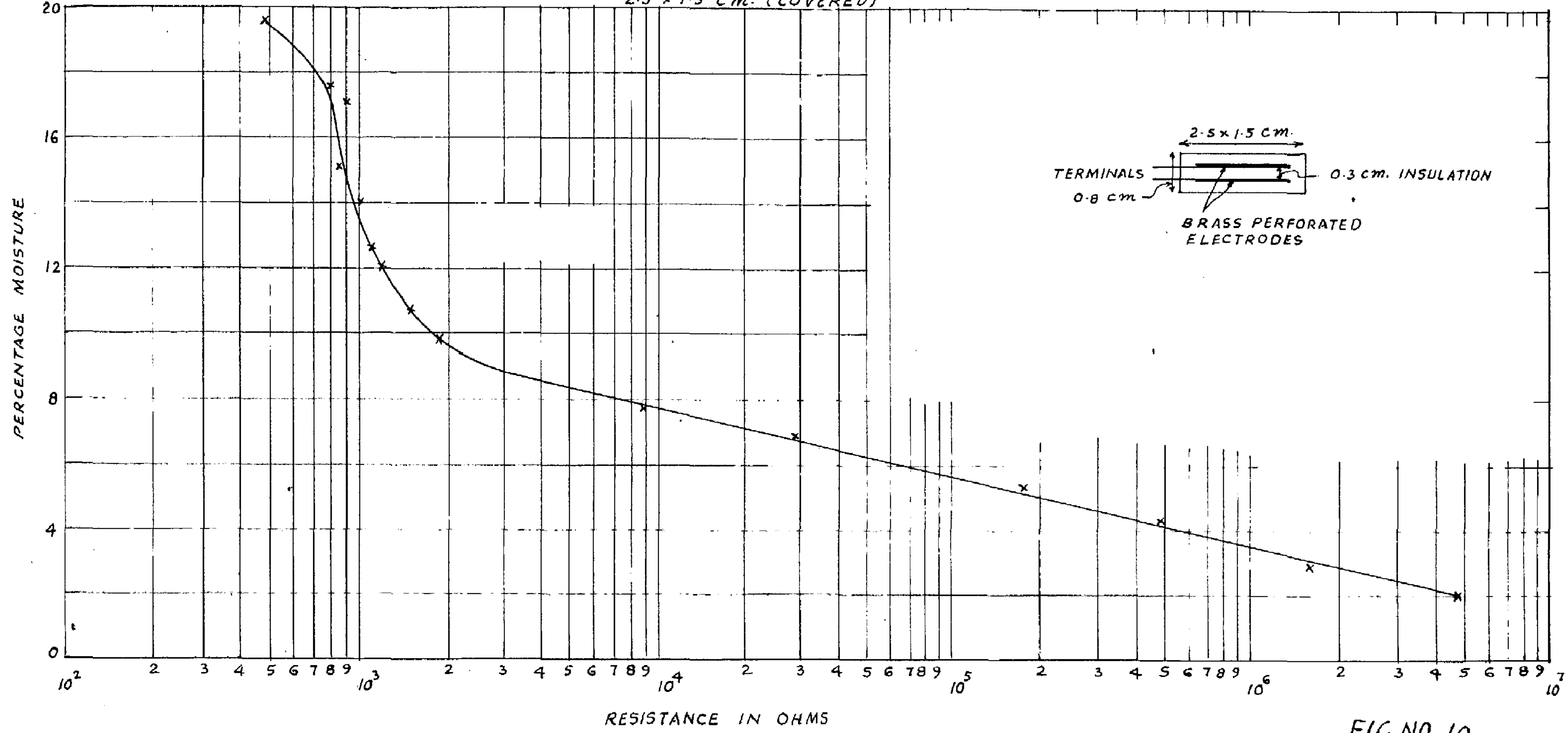


FIG. NO. 10.

CELL Nos. 4, 5 AND 6

PLASTER OF PARIS WITH 40 pc. SAND

2·8 × 1·8 cm. (COVERED)

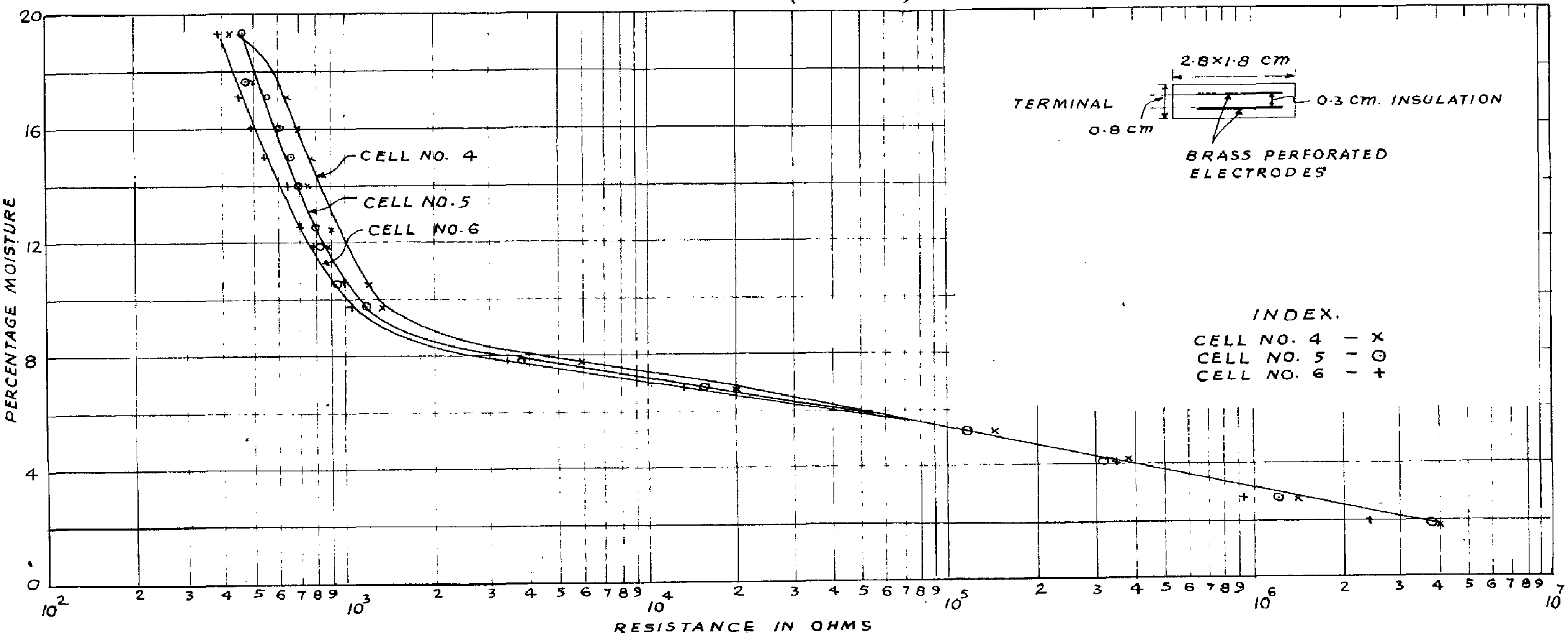


FIG. No. 11.

CELL No. 7, 8 AND 9

PLASTER OF PARIS WITH 40 p.c SAND
2.5 × 1.5 Cm. (UNCOVERED)

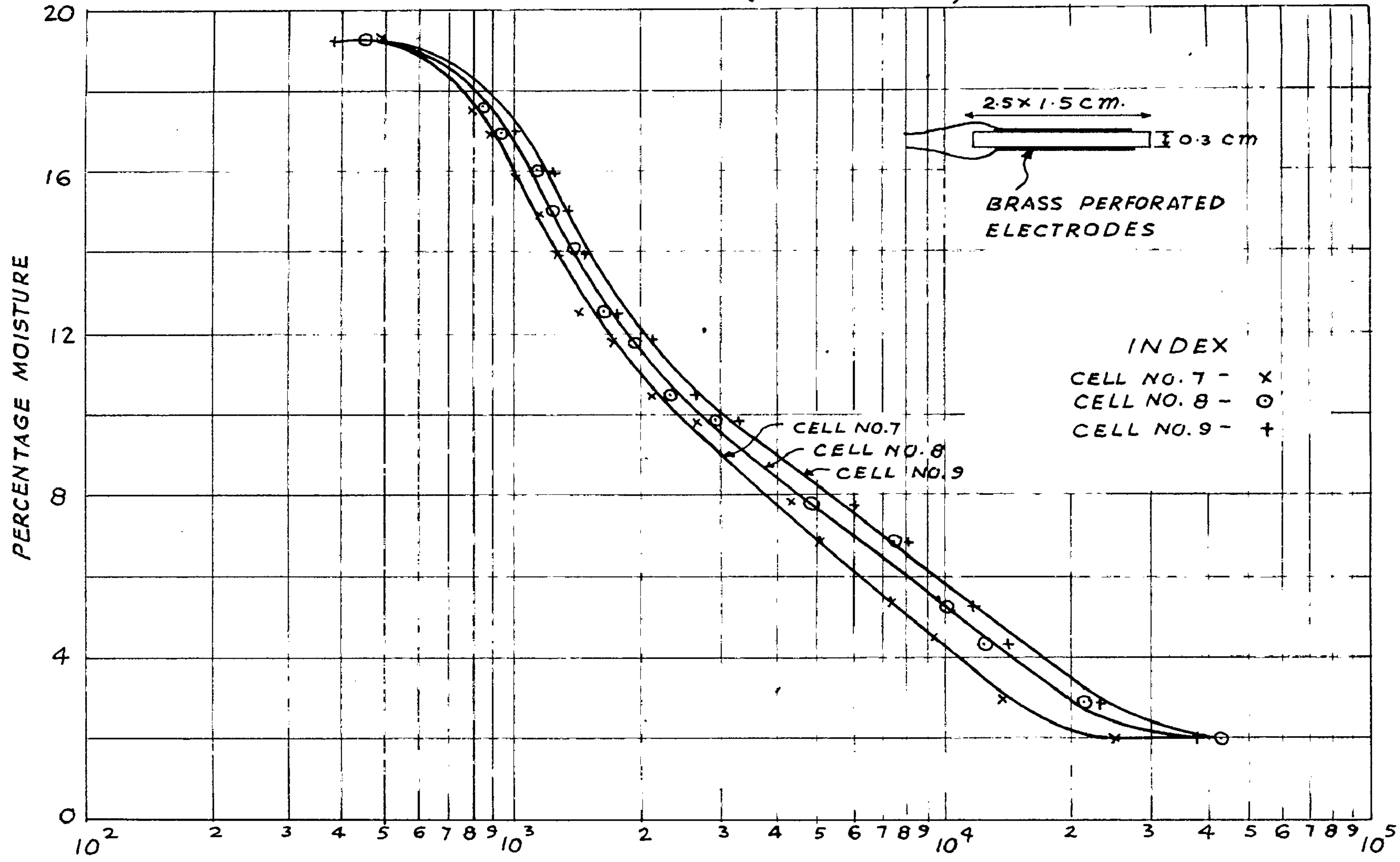


FIG No. 12

CELL Nos. 10, 11 AND 12.

PLASTER OF PARIS WITH 40 p.c. SAND.
2·8 × 1·8 cm. (UNCOVERED)

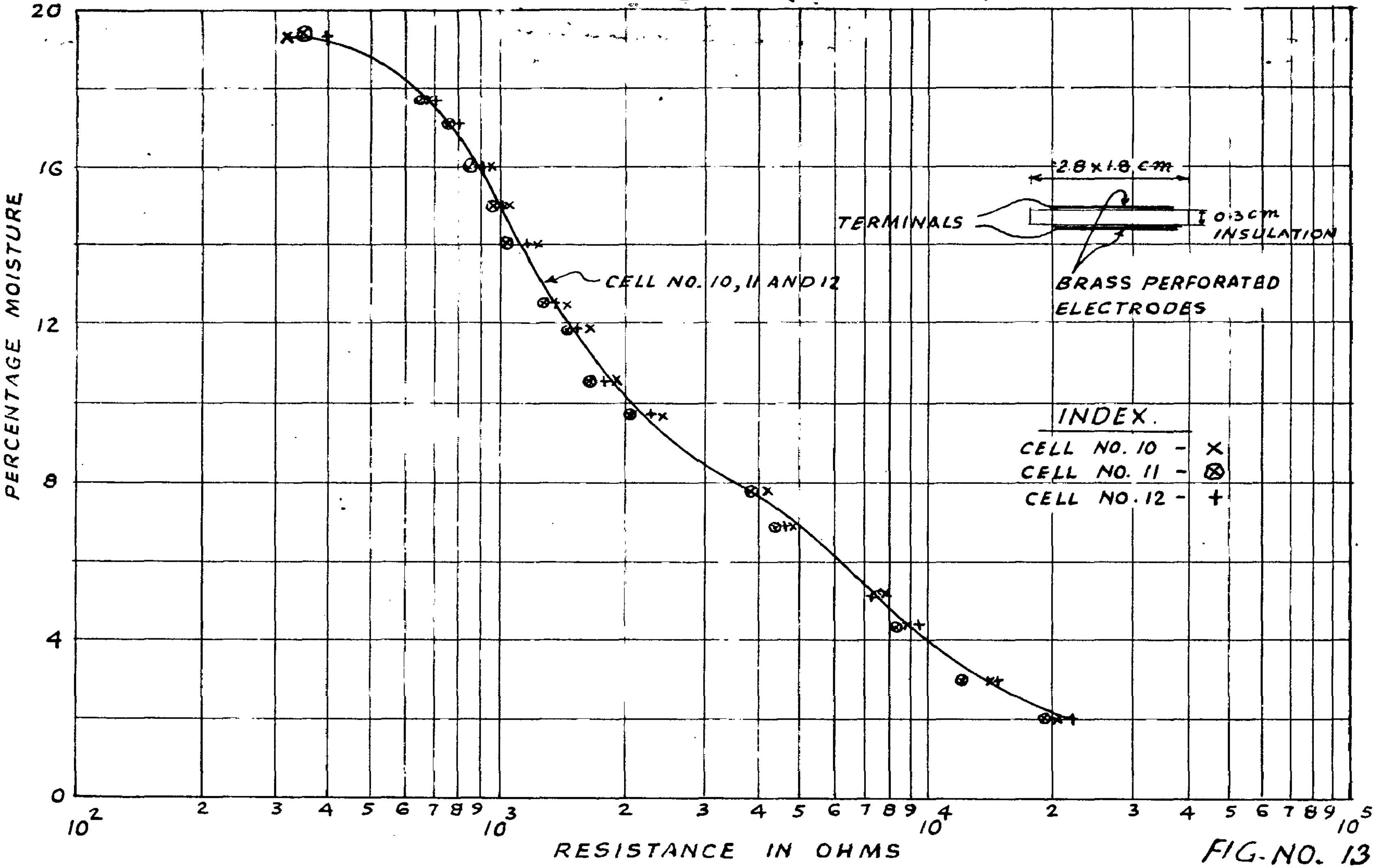


FIG. NO. 13

CELL Nos. 13, 14 AND 15.

PLASTER OF PARIS WITH 50 p.c. SAND
2·5 x 1·5 cm. (COVERED)

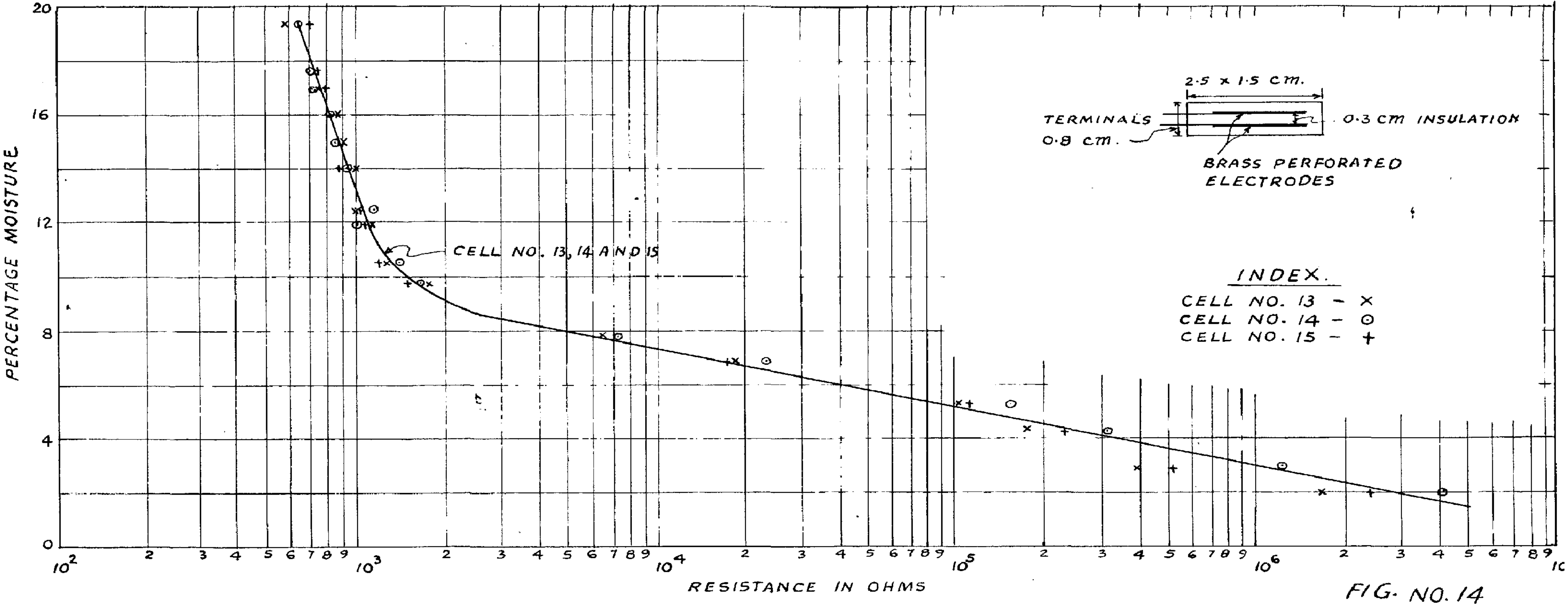


FIG. NO. 14

CELL Nos. 16, 17 AND 18.

PLASTER OF PARIS WITH 50 pc. SAND.

2·8 × 1·8 cm. (COVERED)

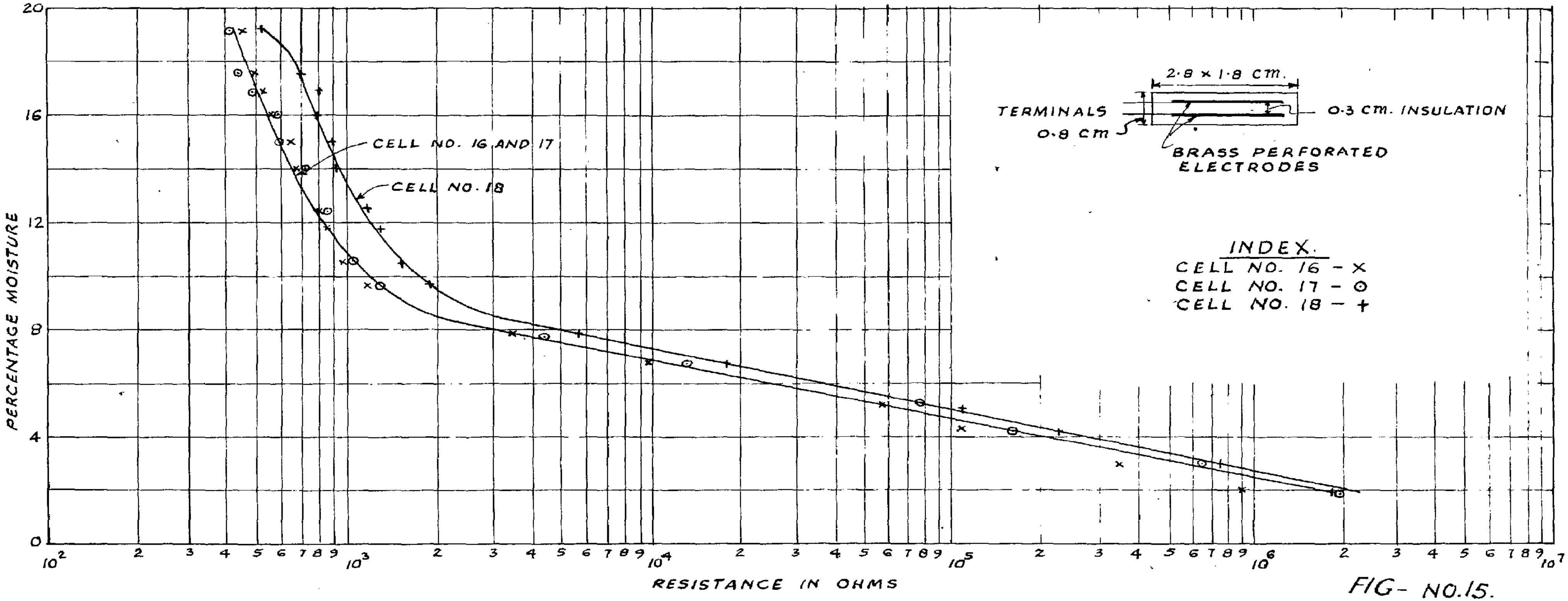


FIG- NO.15.

CELL Nos. 19, 20 AND 21.

PLASTER ~~OF~~ PARIS WITH 50 pc. SAND.
2.5 × 1.5 cm (UNCOVERED)

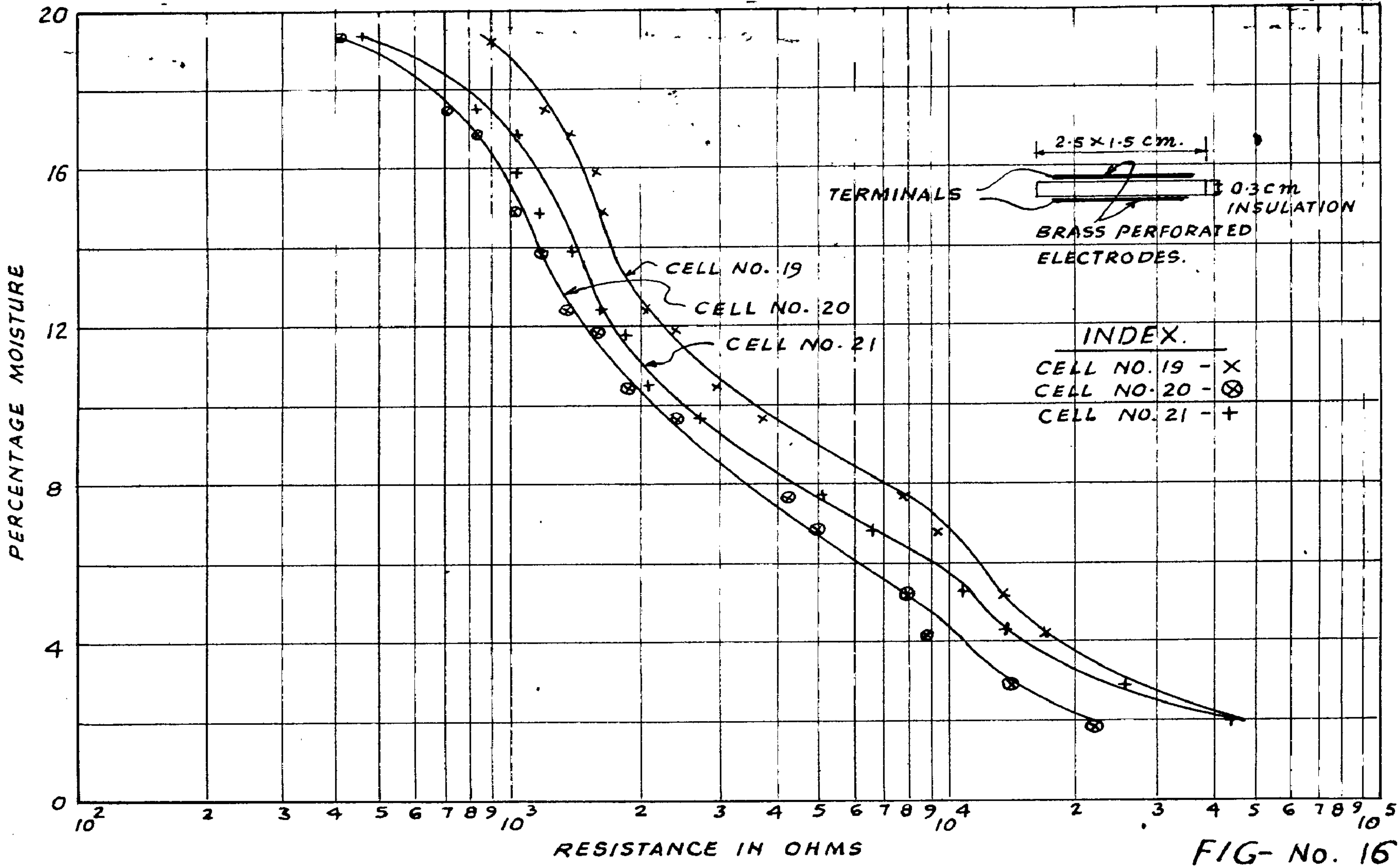


FIG- No. 16.

CELL No. 23 AND 24.

PLASTER OF PARIS WITH 50 p.c. SAND.
2·8 × 1·8 Cm.(UNCOVERED)

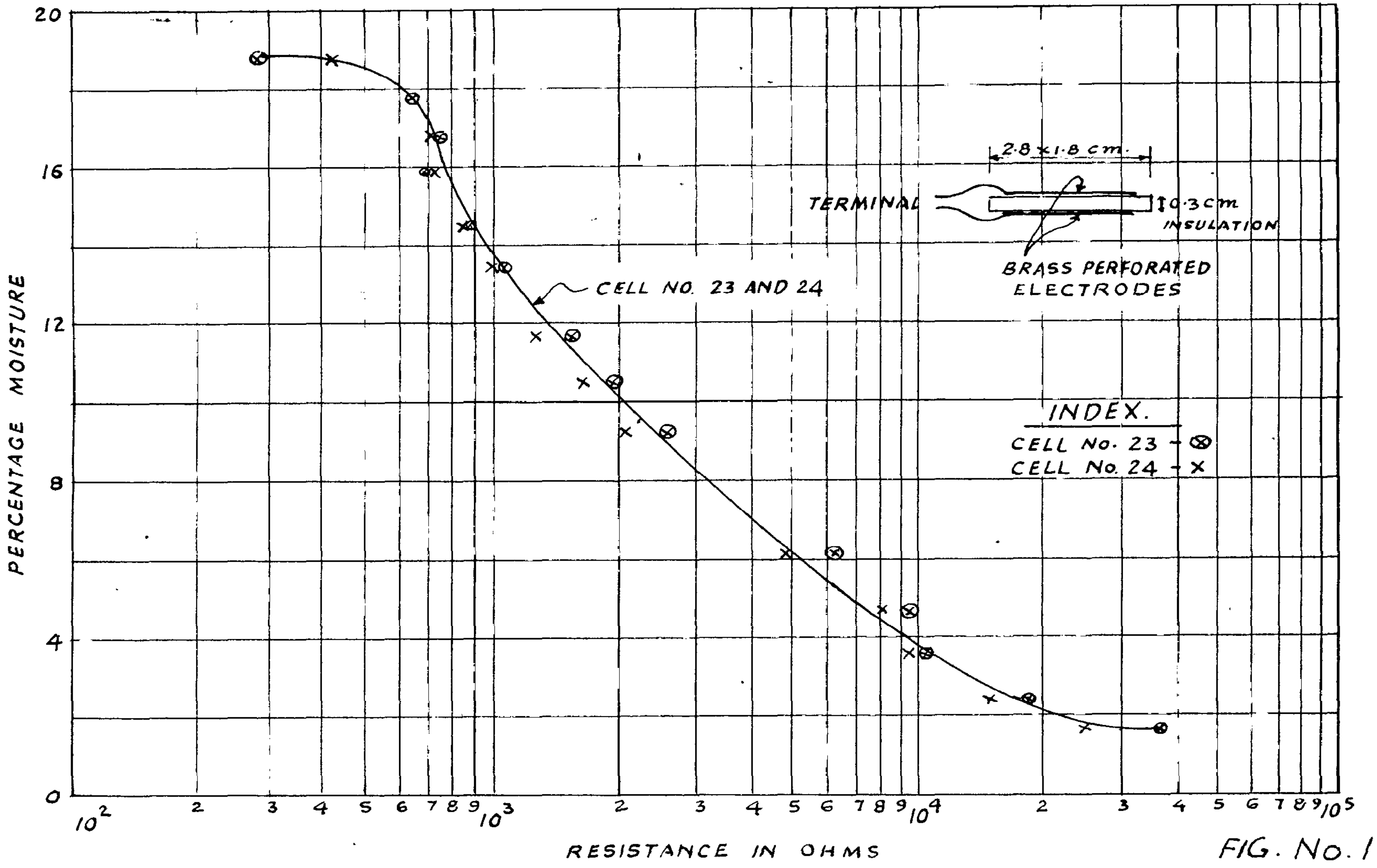
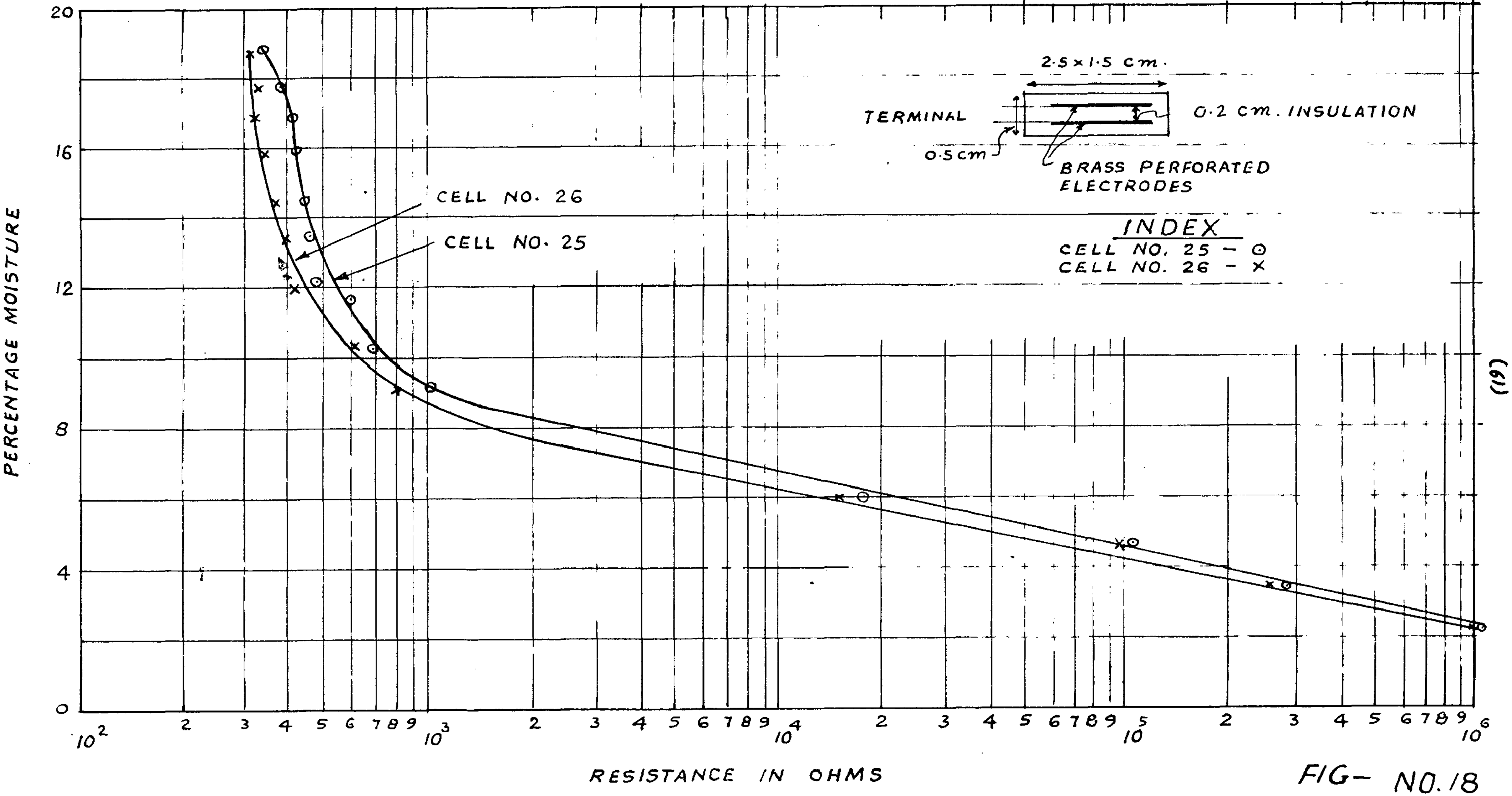


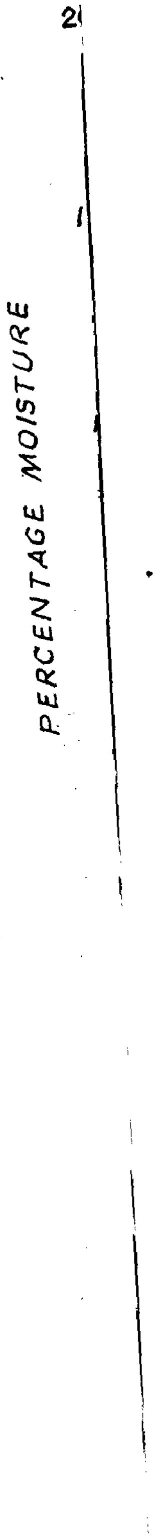
FIG. No. 17

CELL NOS. 25 AND 26.

PLASTER OF PARIS ONLY 2·5×1·5 cm.



FIG– NO. 18


2
1
PERCENTAGE MOISTURE

CELL Nos. 30 AND 31.

PLASTER OF PARIS ONLY.
2·5 × 1·5 C.m.

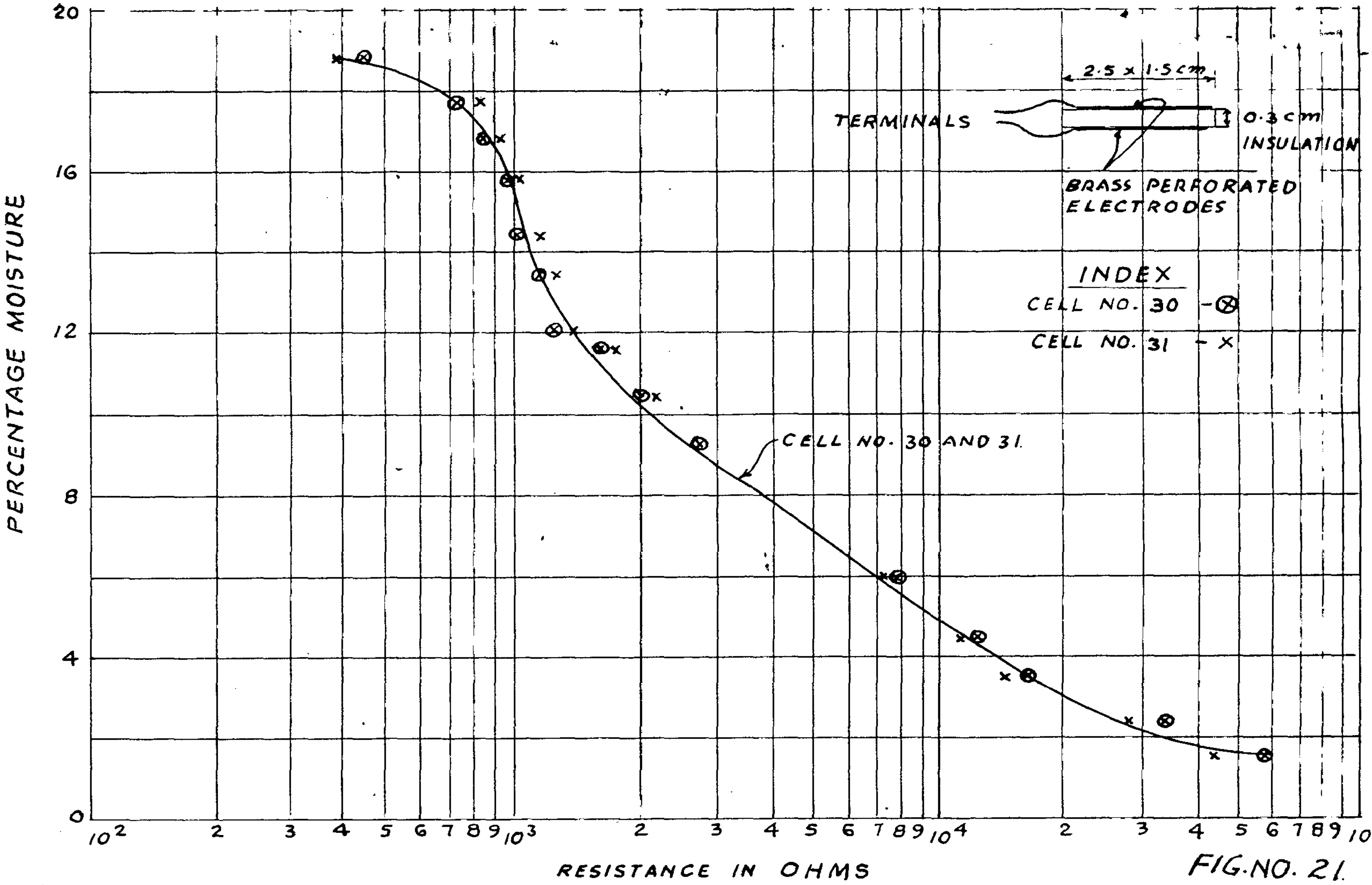


FIG. NO. 21.

CELL Nos. 32 AND 33

PLASTER OF PARIS ONLY.

2 8 × 1·8 cm.

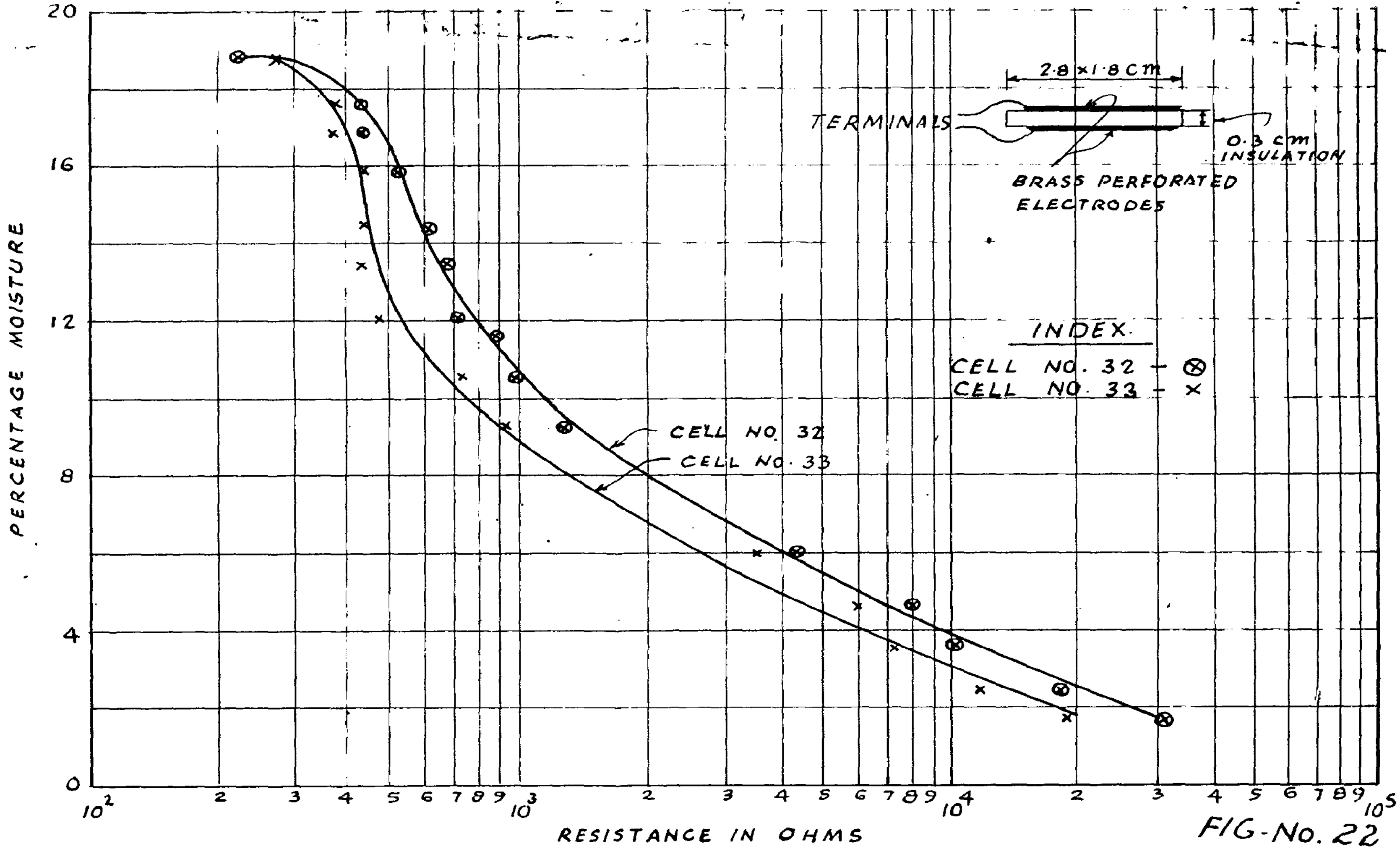


FIG-No. 22

CELL No. 40 AND 41

B-TYPE - 0·75 m m. AND 2 cm. DIA.

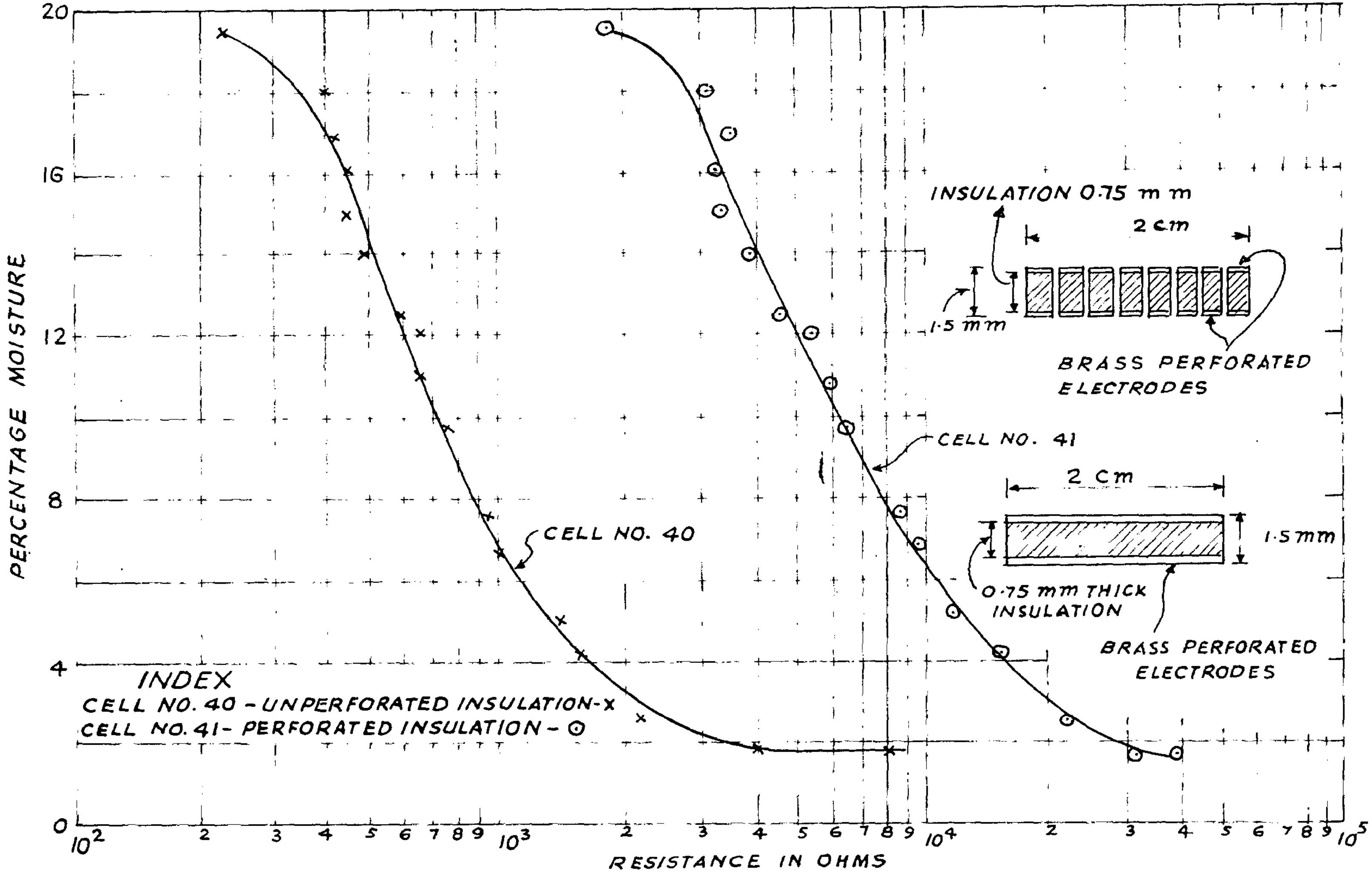


FIG. No. 23

CELL No.- 40, 42 AND 43
A-TYPE-0·75 mm. INSULATION
2·0 AND 2·9 cm. DIA.

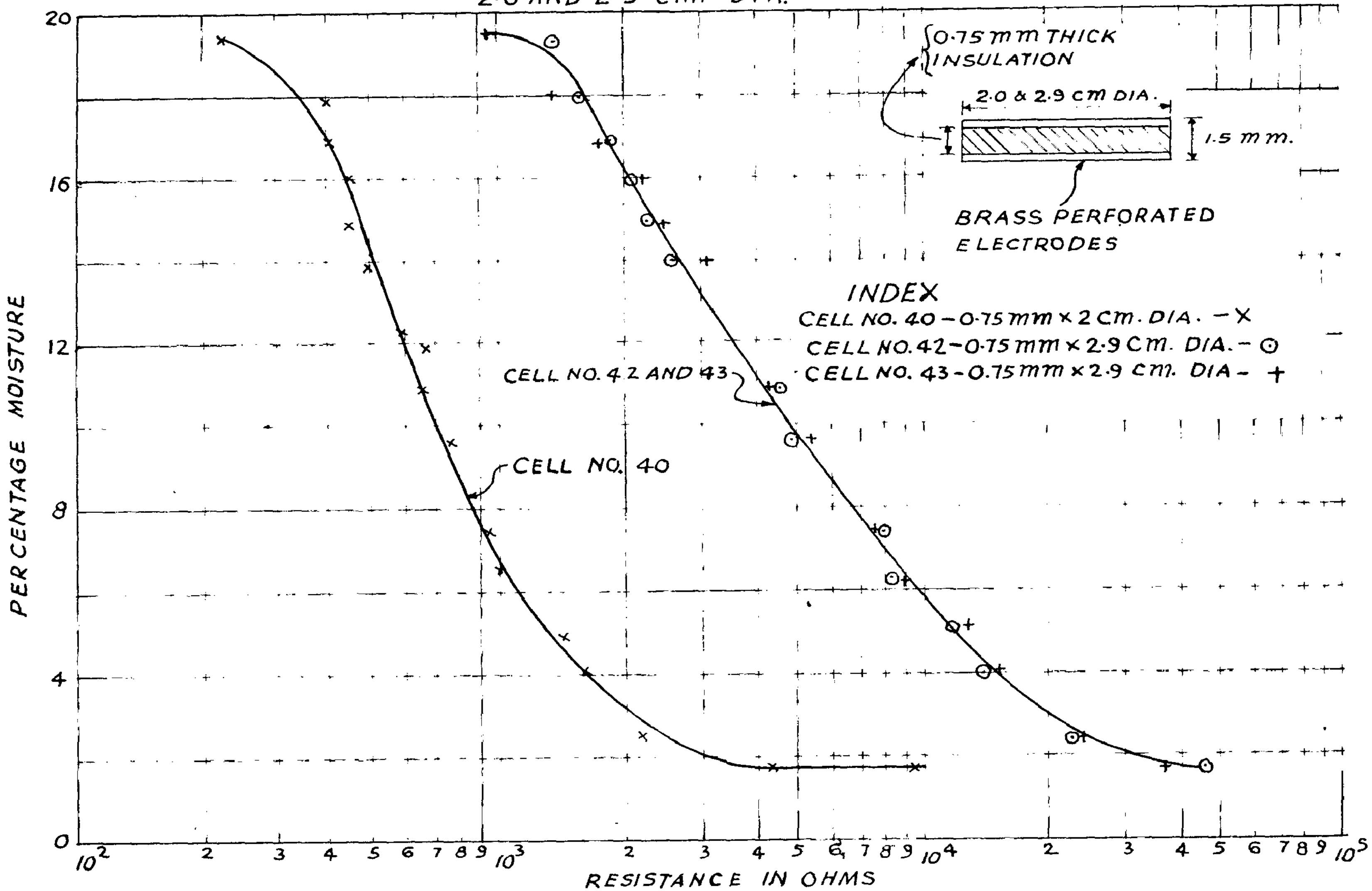


FIG. No. 24

CELL No. 44 AND 45

B-TYPE 0·75 mm & 2·9 cm. DIA.

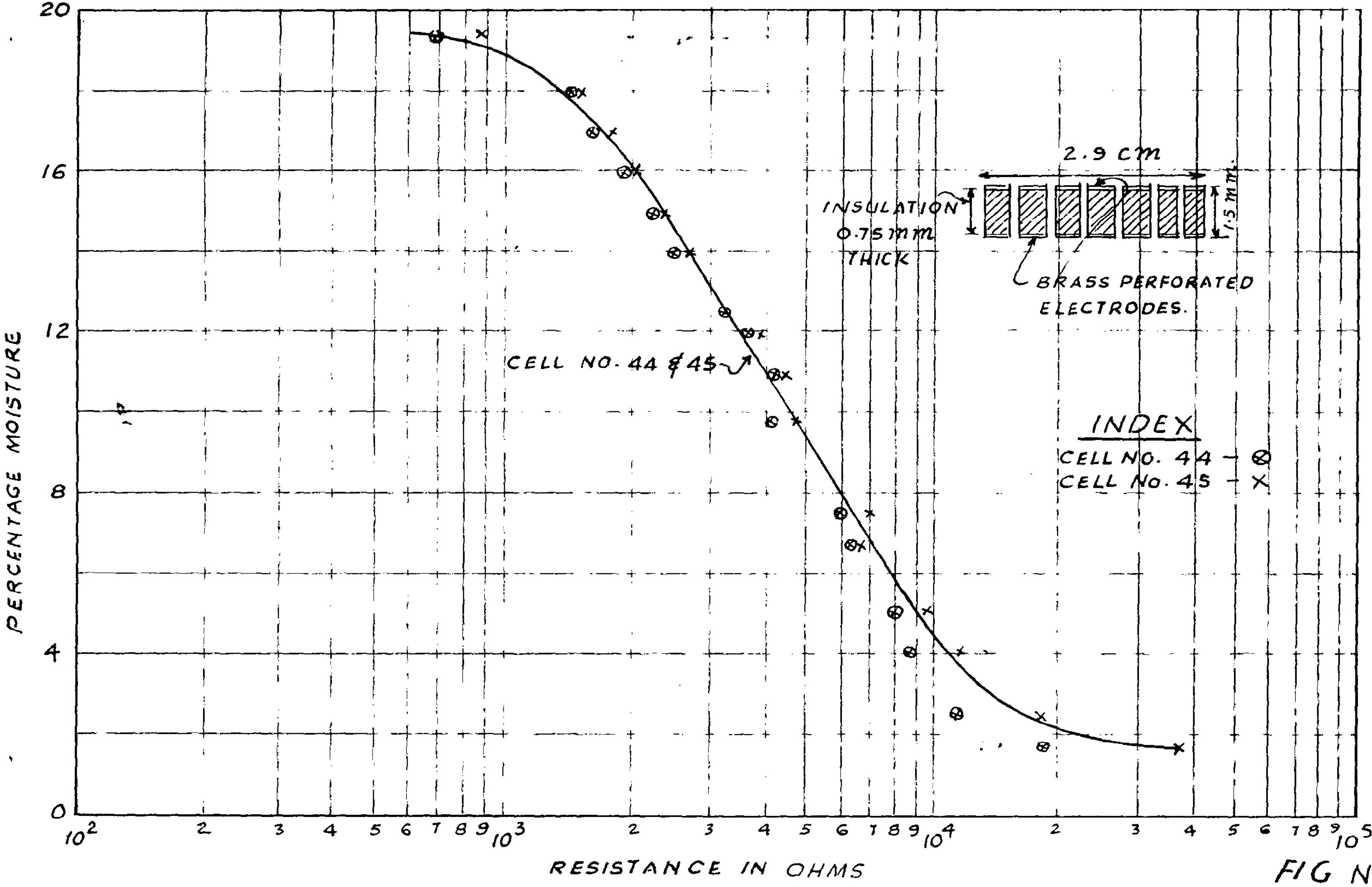


FIG No 25

CELL No. 48 AND 49

C-TYPE - 0·75 mm GAP.

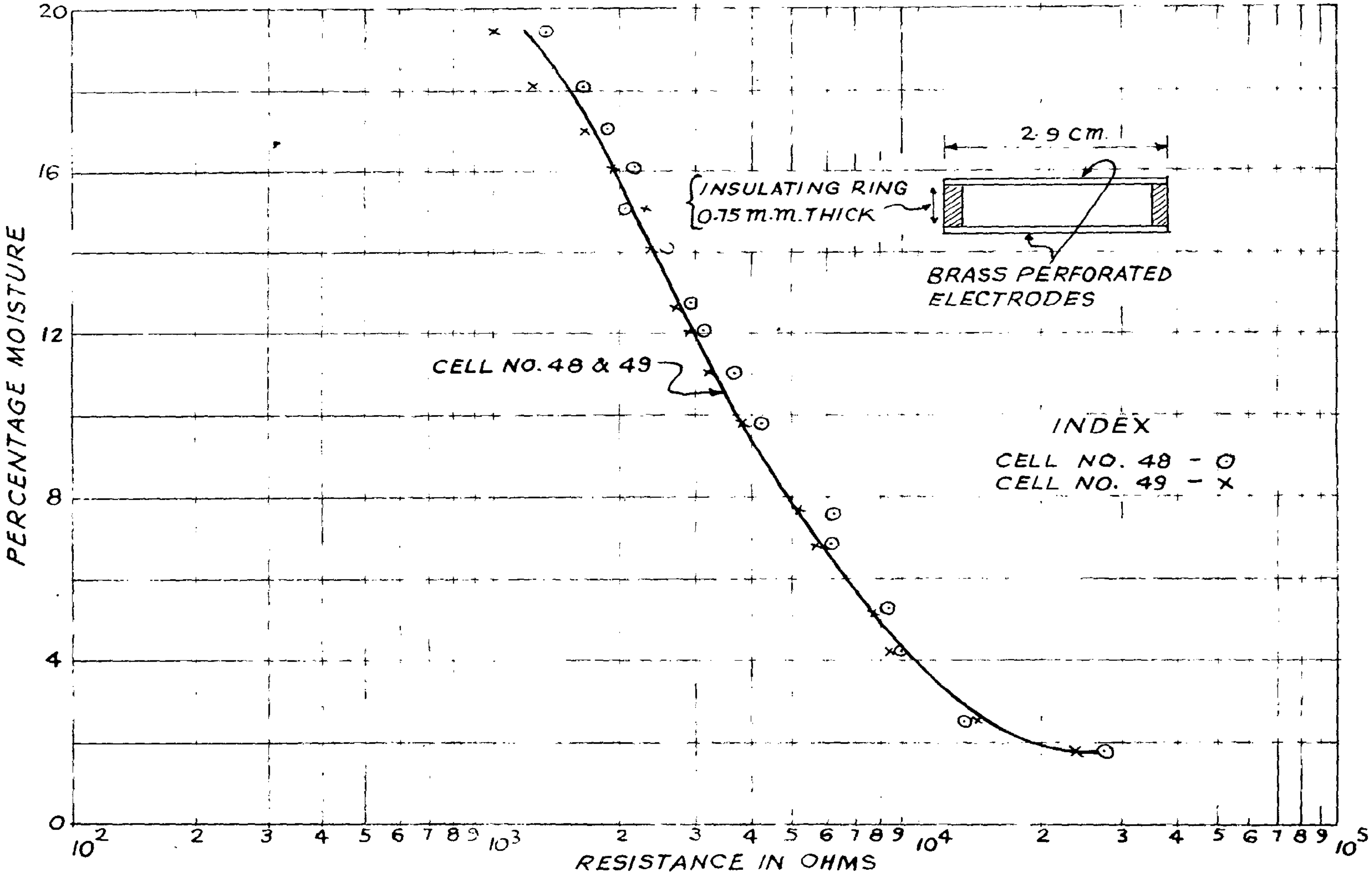
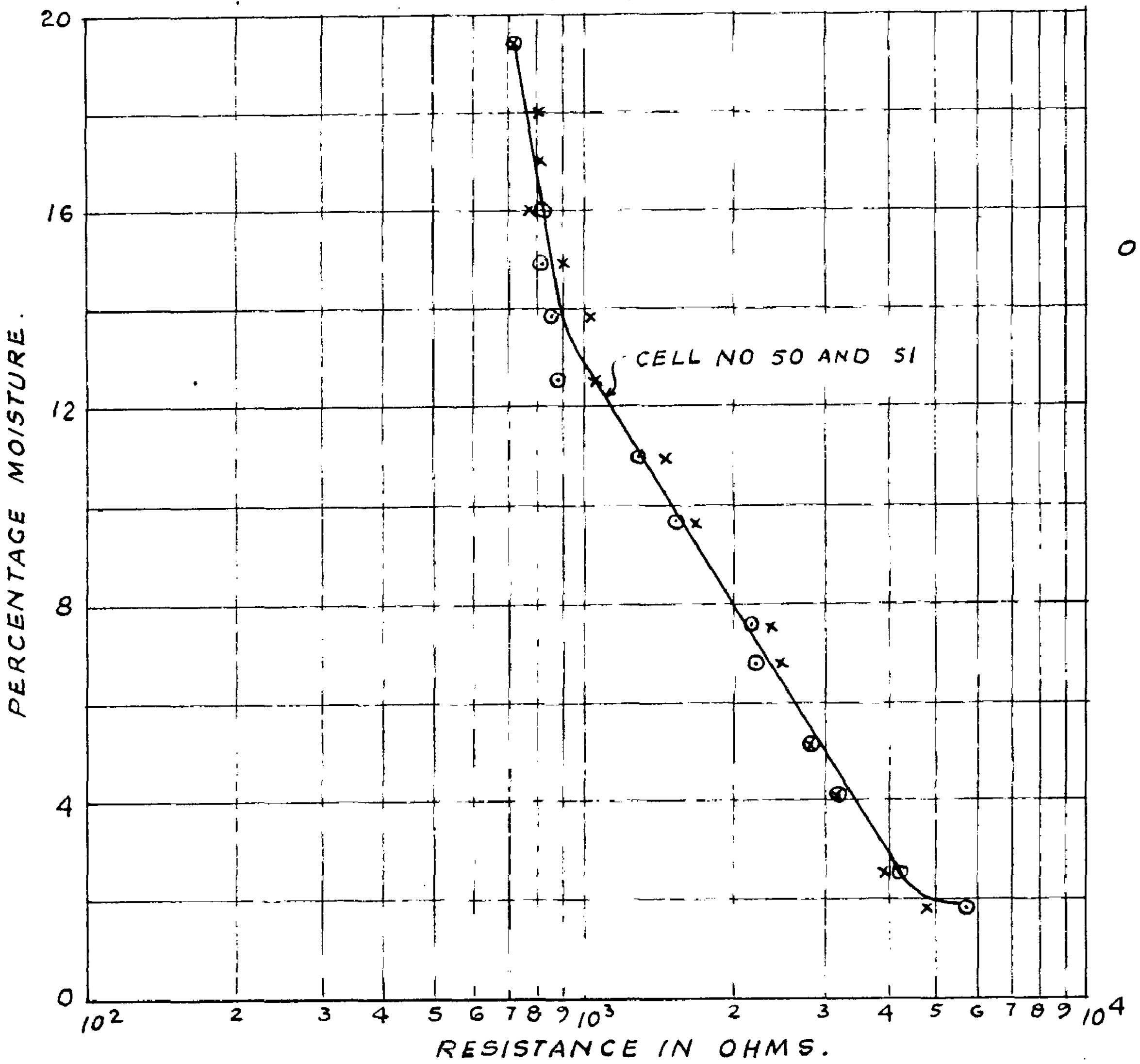
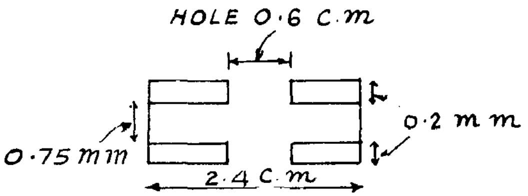


FIG. NO. 27

CELL No. 50 AND 51

D-TYPE WITH 0·75 m.m. GAP





INDEX.

CELL NO. 50 - ⊙
CELL NO. 51 - ×

FIG No. 28

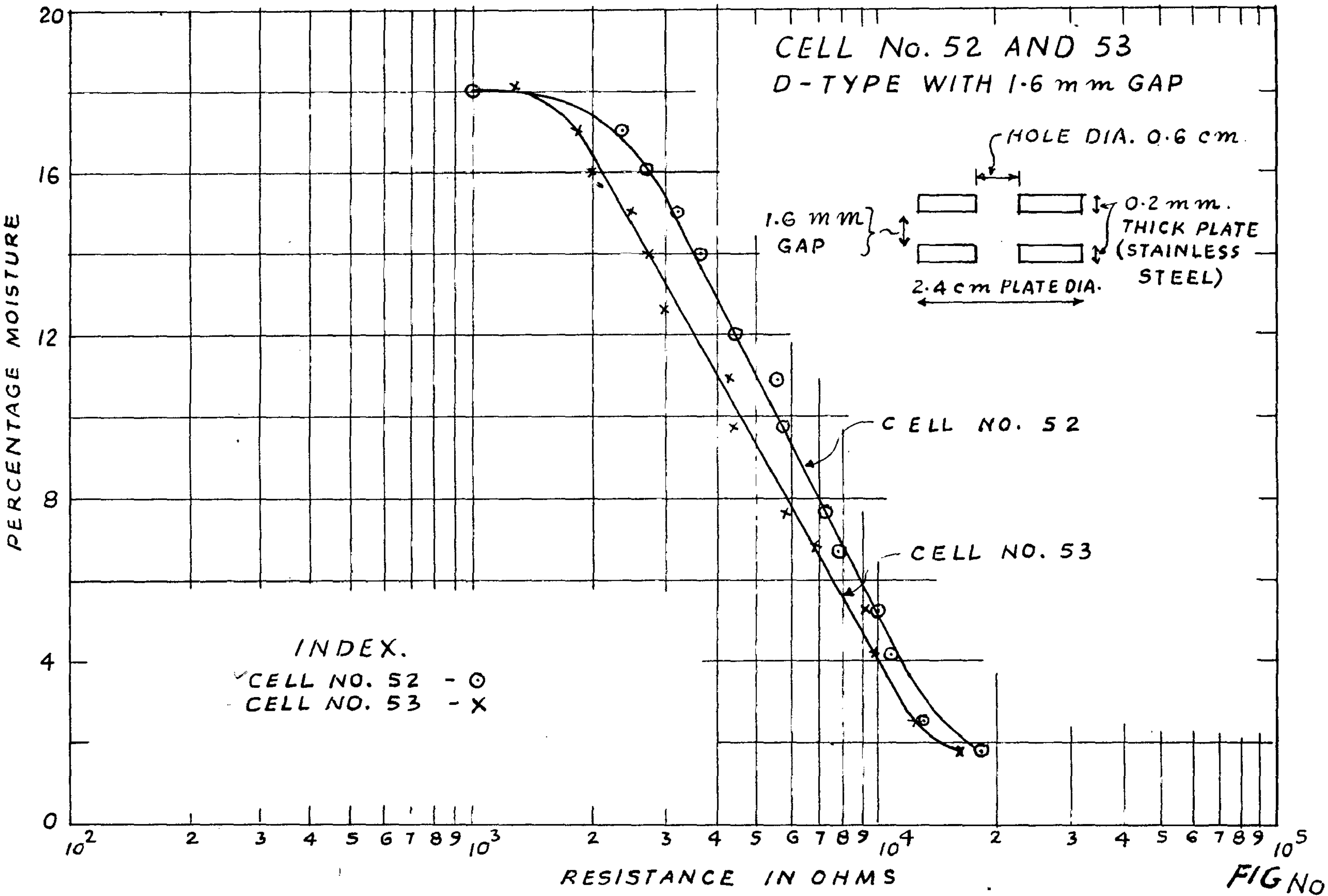

CELL No. 52 AND 53
D-TYPE WITH 1·6 mm GAP
HOLE DIA. 0·6 cm
0·2 mm. THICK PLATE (STAINLESS STEEL)
1.6 mm GAP
2·4 cm PLATE DIA.
CELL NO. 52
CELL NO. 53
INDEX.
CELL NO. 52 - ⊙
CELL NO. 53 - X
PERCENTAGE MOISTURE
20
16
12
8
4
0
10^2
2
3
4
5
6
7
8
9
10^3
2
3
4
5
6
7
8
9
10^4
2
3
4
5
6
7
8
9
10^5
RESISTANCE IN OHMS

FIG No. 29

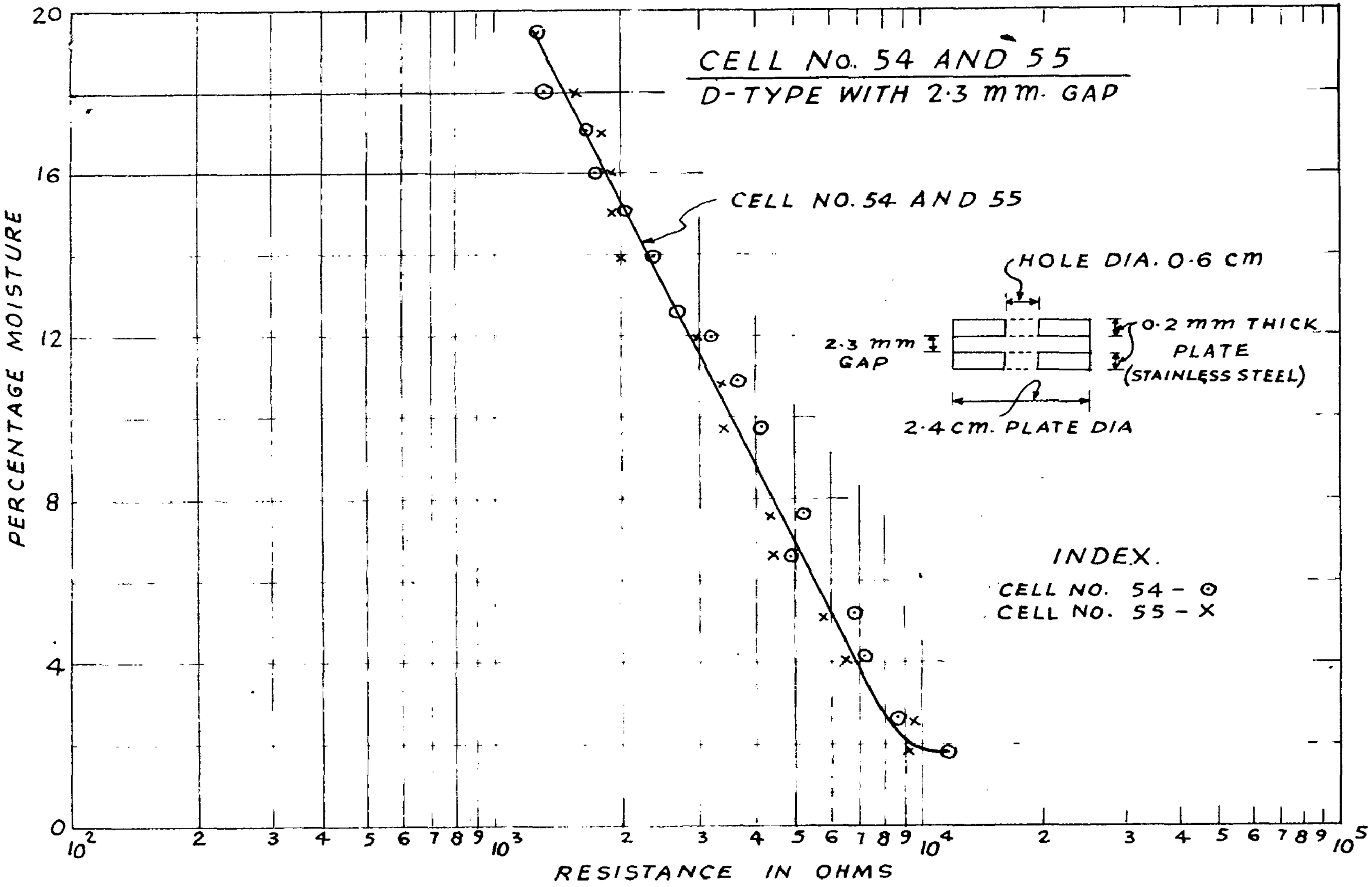

CELL No. 54 AND 55
D-TYPE WITH 2·3 mm. GAP
CELL NO. 54 AND 55
HOLE DIA. 0·6 cm
2·3 mm GAP
0·2 mm THICK PLATE (STAINLESS STEEL)
2·4 cm. PLATE DIA
INDEX.
CELL NO. 54 – ⊙
CELL NO. 55 – X
PERCENTAGE MOISTURE
0
4
8
12
16
20
RESISTANCE IN OHMS
10^2
2
3
4
5
6
7
8
9
10^3
10^4
10^5

FIG. No. 30

CELL No. 56 AND 57

D-TYPE WITH 3·2 mm. GAP.

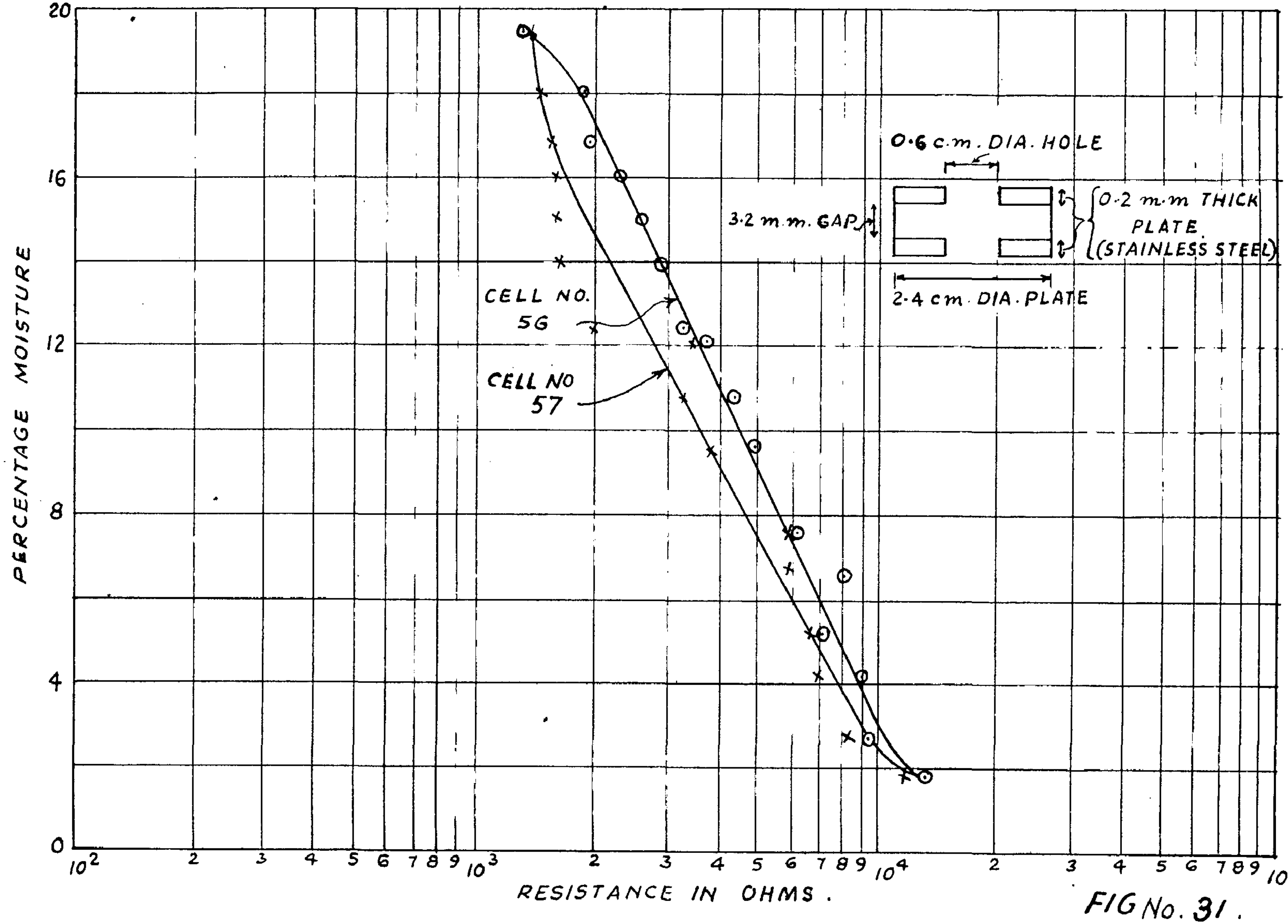


FIG No. 31.

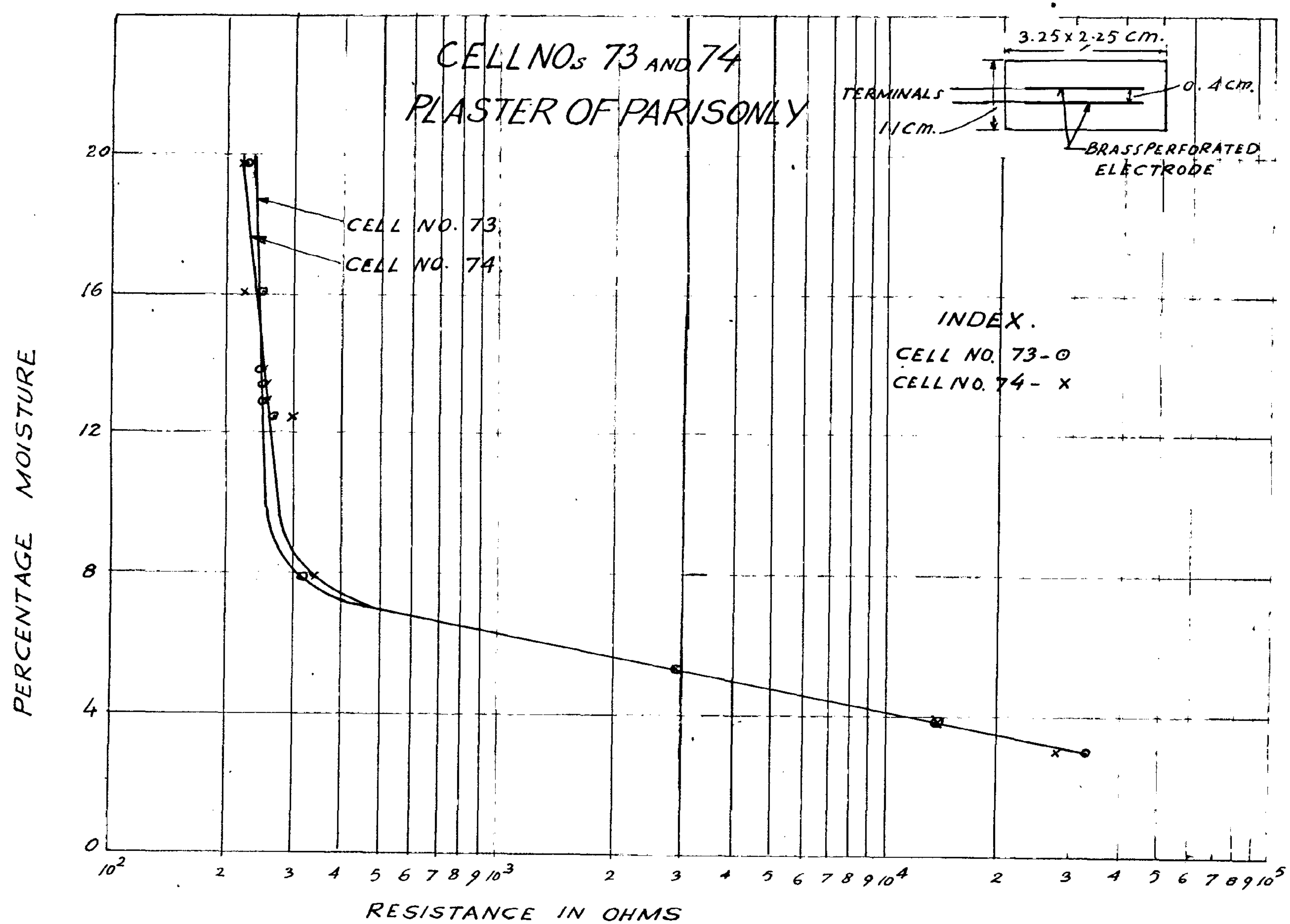

CELL NOs 73 AND 74
PLASTER OF PARIS ONLY
3.25 x 2.25 cm.
TERMINALS
0.4 cm.
1.1 cm.
BRASS PERFORATED ELECTRODE
CELL NO. 73
CELL NO. 74
INDEX.
CELL NO. 73 - ⊙
CELL NO. 74 - x
PERCENTAGE MOISTURE
0
4
8
12
16
20
10^2
2
3
4
5
6
7
8
9
10^3
2
3
4
5
6
7
8
9
10^4
2
3
4
5
6
7
8
9
10^5
RESISTANCE IN OHMS

FIG. NO- 31 (a)

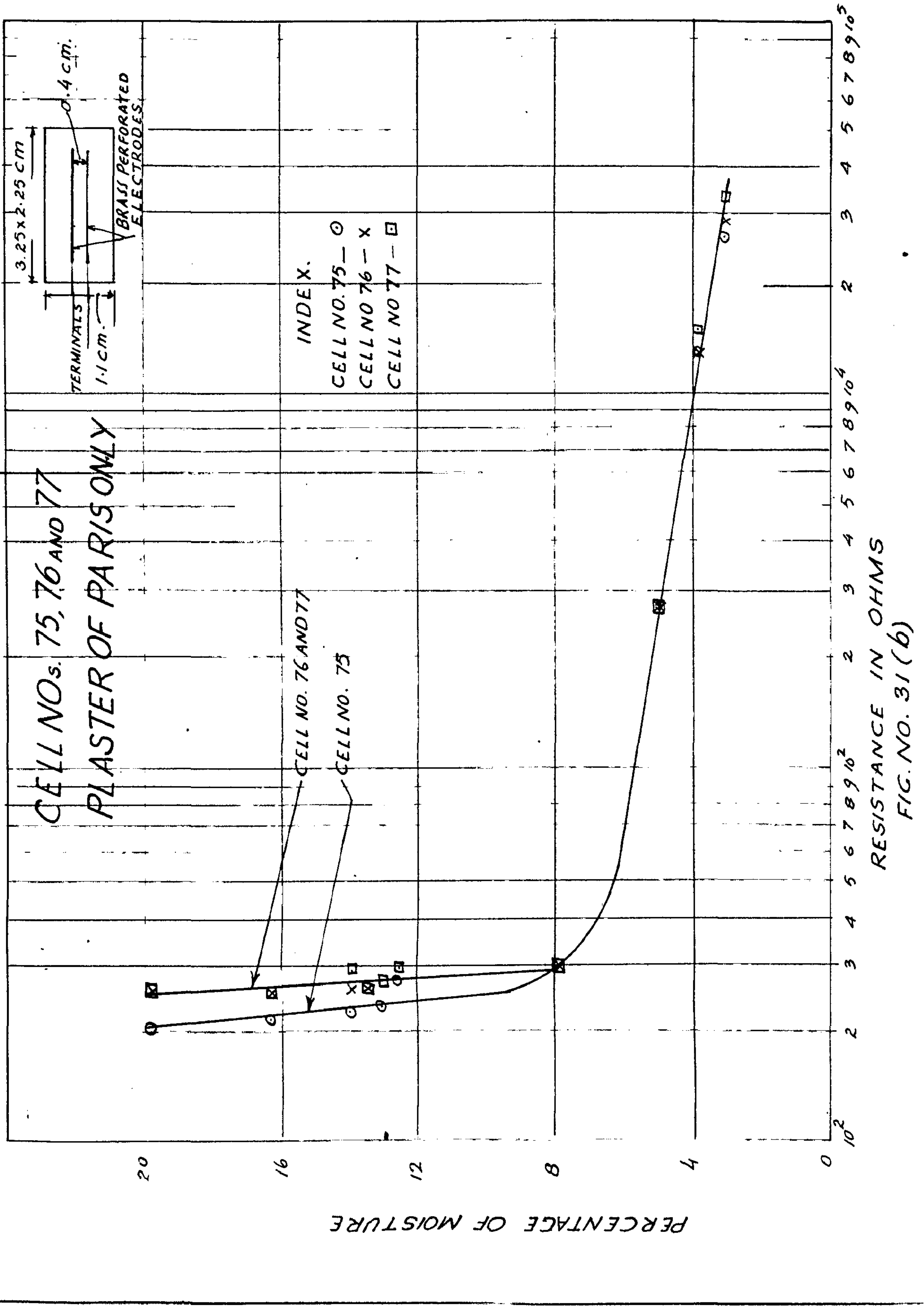

CELL NOs. 75, 76 AND 77
PLASTER OF PARIS ONLY
3.25 x 2.25 cm
0.4 cm.
BRASS PERFORATED ELECTRODES.
TERMINALS
1.1 cm.
INDEX.
CELL NO. 75 — ⊙
CELL NO 76 — x
CELL NO 77 — ⊡
CELL NO. 76 AND 77
CELL NO. 75
PERCENTAGE OF MOISTURE
20
16
12
8
4
0
RESISTANCE IN OHMS
10²
2
3
4
5
6
7
8
9
10²
2
3
4
5
6
7
8
9
10⁴
2
3
4
5
6
7
8
9
10⁵

FIG. NO. 31 (b)

CELL Nos. 78, 79 AND 80
PLASTER OF PARIS ONLY (USUAL TYPE)

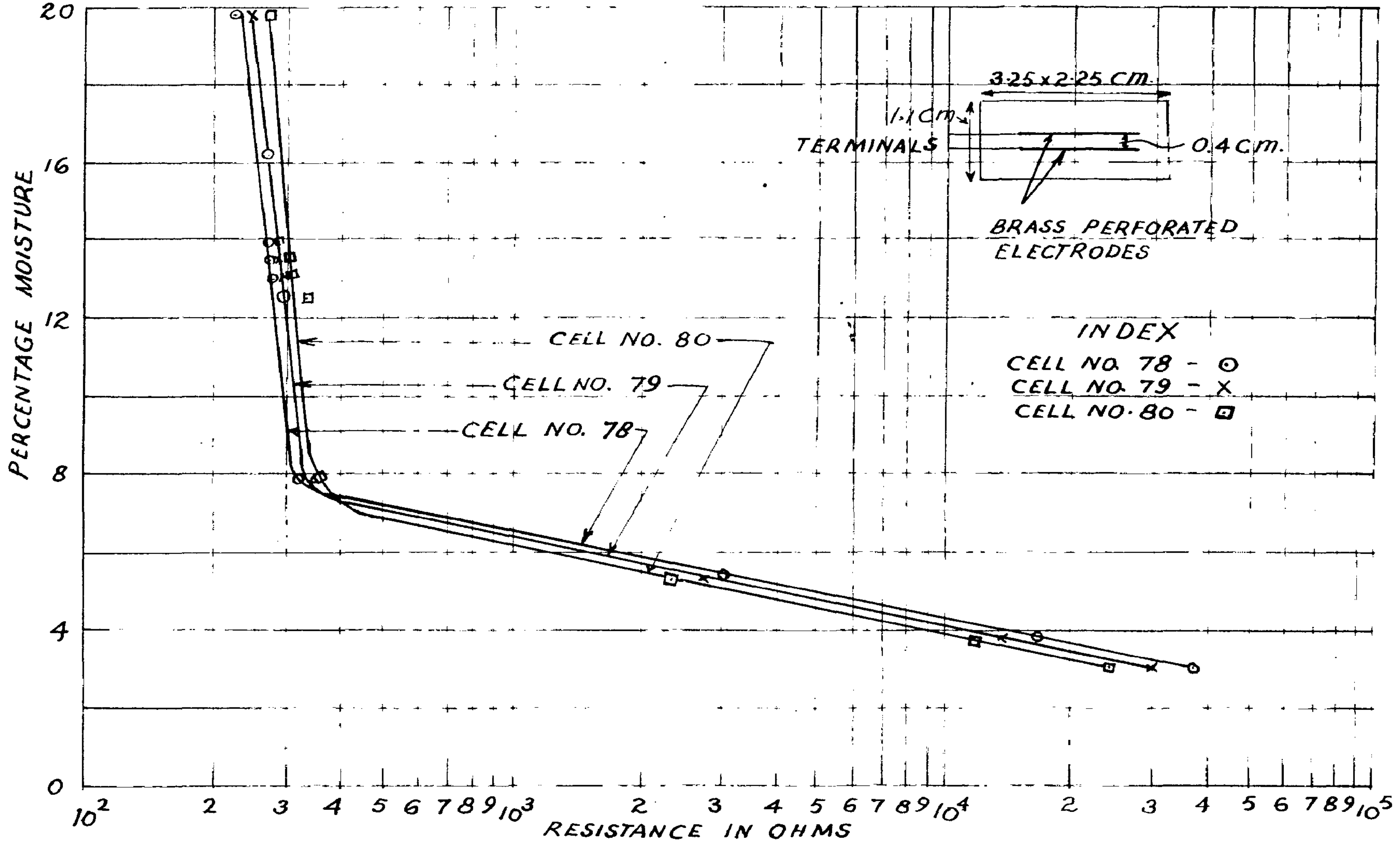


FIG. No. 32

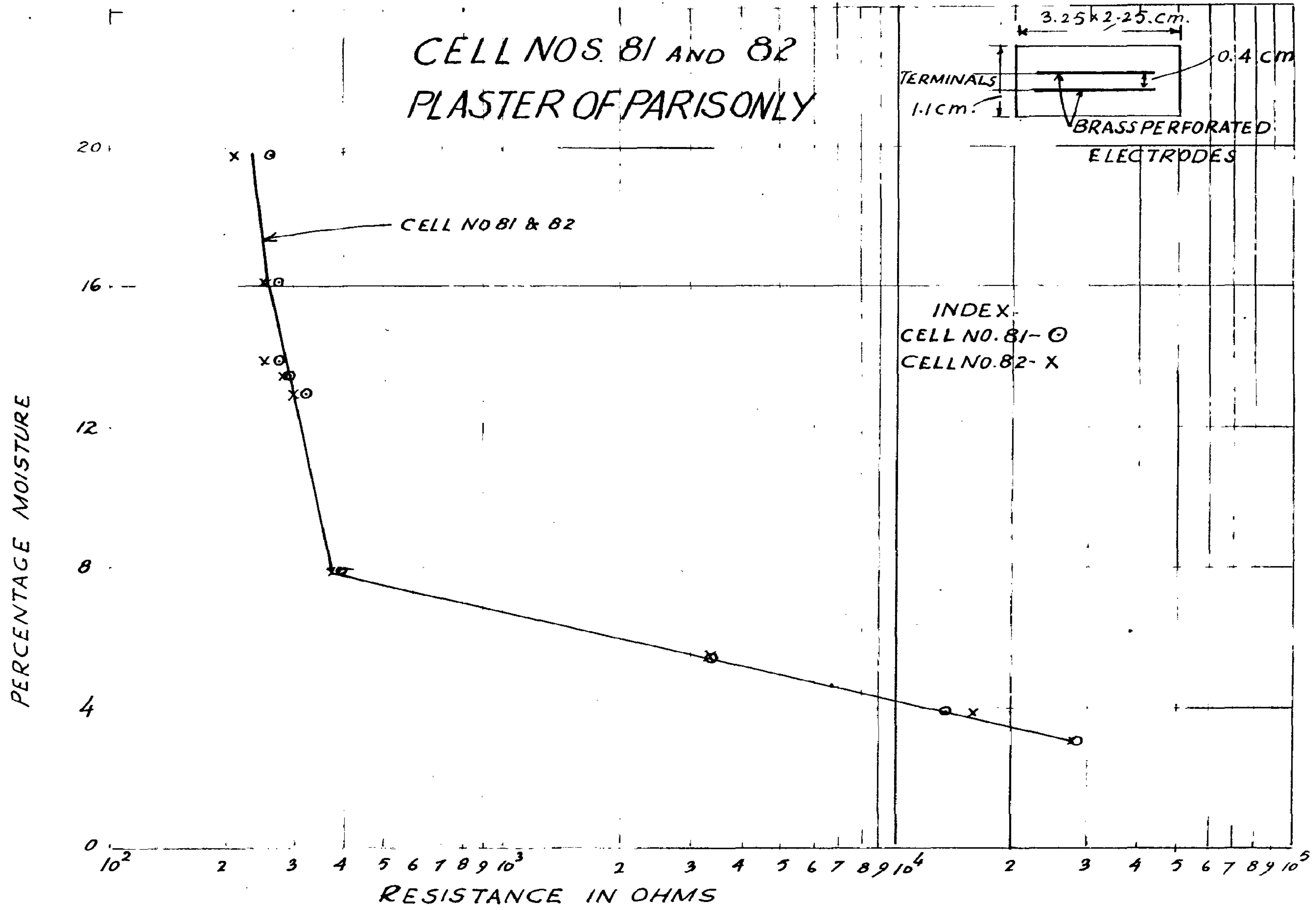

CELL NOS. 81 AND 82
PLASTER OF PARIS ONLY
3.25 × 2.25 cm.
0.4 cm
TERMINALS
1.1 cm.
BRASS PERFORATED ELECTRODES
CELL NO 81 & 82
INDEX
CELL NO. 81 - ⊙
CELL NO. 82 - X
PERCENTAGE MOISTURE
0
4
8
12
16
20
RESISTANCE IN OHMS
10^2
2
3
4
5
6
7
8
9
10^3
2
3
4
5
6
7
8
9
10^4
2
3
4
5
6
7
8
9
10^5

FIG. NO. 33

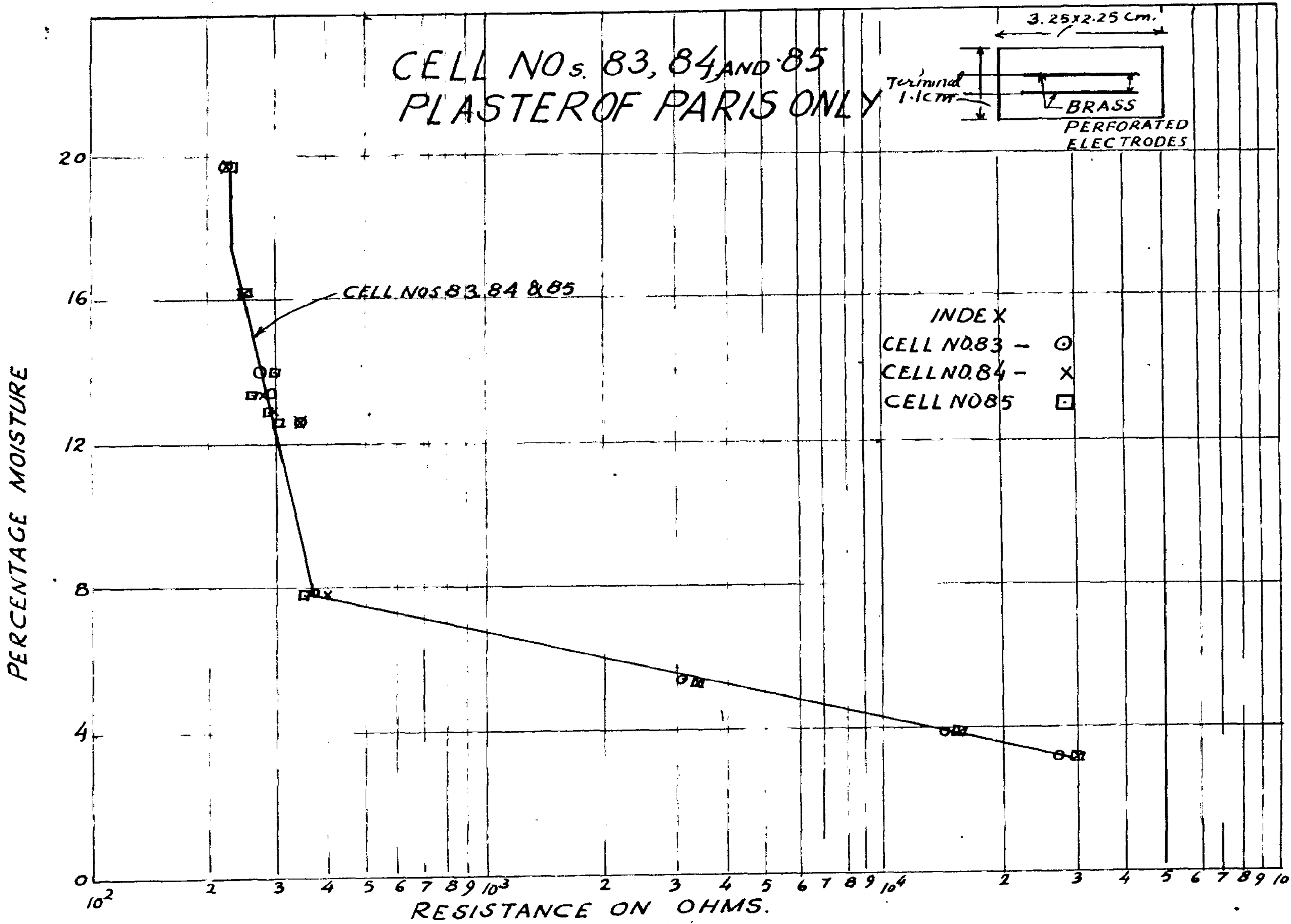
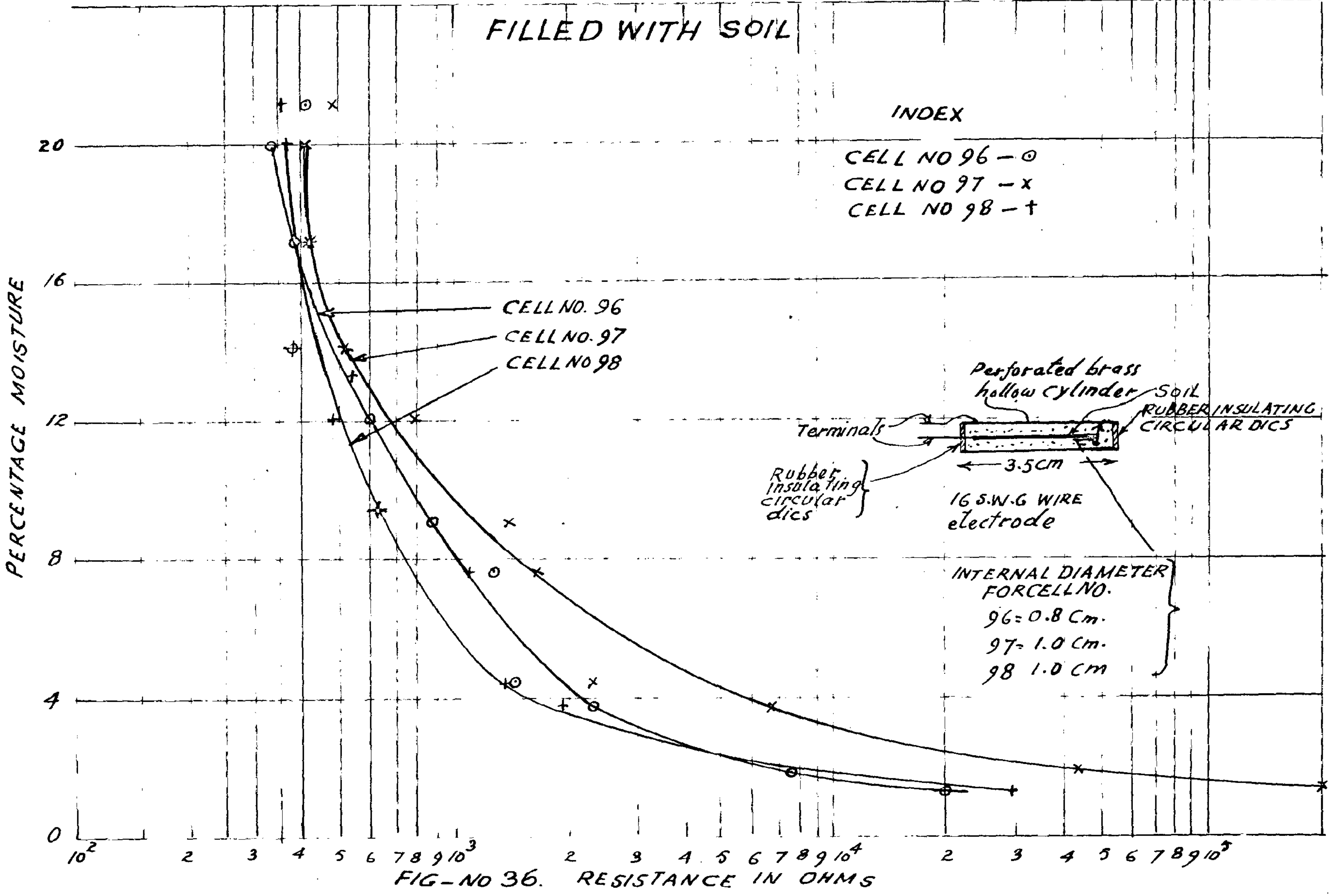

CELL NOs. 83, 84 AND 85
PLASTER OF PARIS ONLY
3.25x2.25 Cm.
Terminal
1.1cm
BRASS
PERFORATED
ELECTRODES
CELL NOs 83, 84 & 85
INDEX
CELL NO.83 – ⊙
CELL NO.84 – x
CELL NO.85 ⊡
PERCENTAGE MOISTURE
0
4
8
12
16
20
10^2
2
3
4
5
6
7
8
9
10^3
2
3
4
5
6
7
8
9
10^4
2
3
4
5
6
7
8
9
10^5
RESISTANCE ON OHMS.

FIG. NO. 34

CELL Nos 96, 97, AND 98
COPPER CYLINDRICAL CELL
FILLED WITH SOIL



FIG–NO 36.

CELL Nos 111 112, AND 113
PLASTER OF PARIS CELLS.

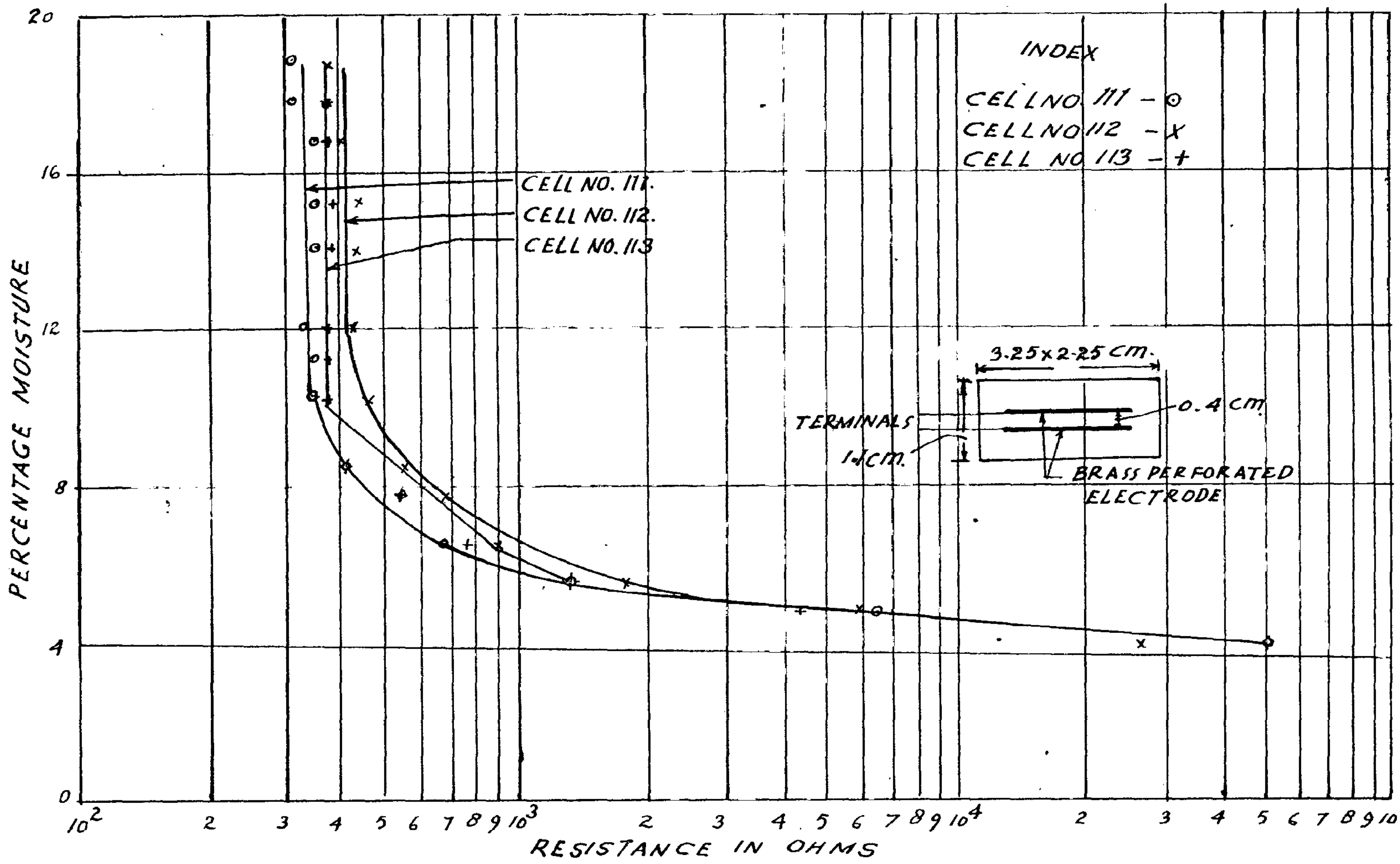


FIG-NO. 37

CELL Nos 114, 115, 116 AND 117
PLASTER OF PARIS CELLS.

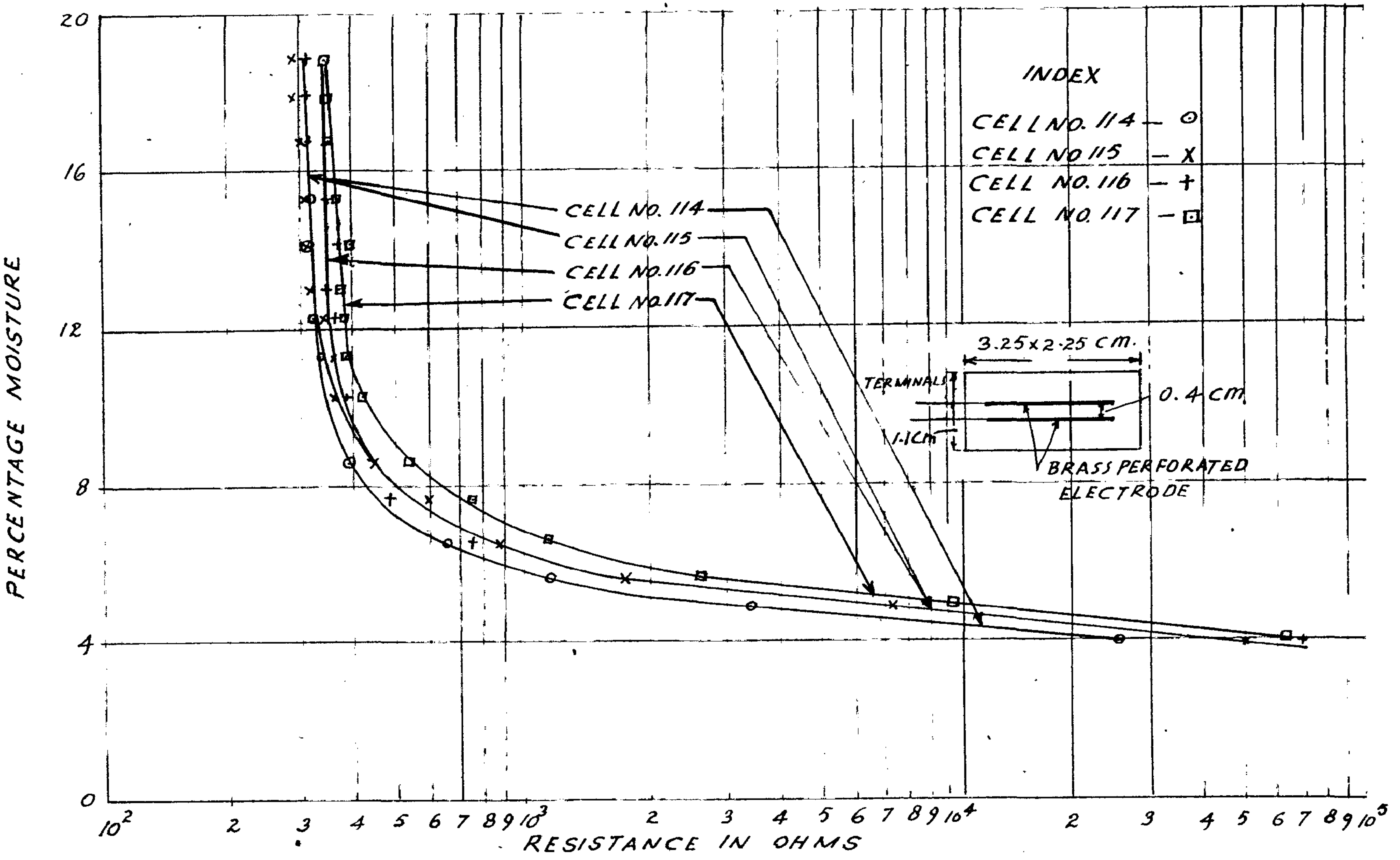


FIG- NO. 38

CELL Nos 118, 119 AND 120
PLASTER OF PARIS CELLS.

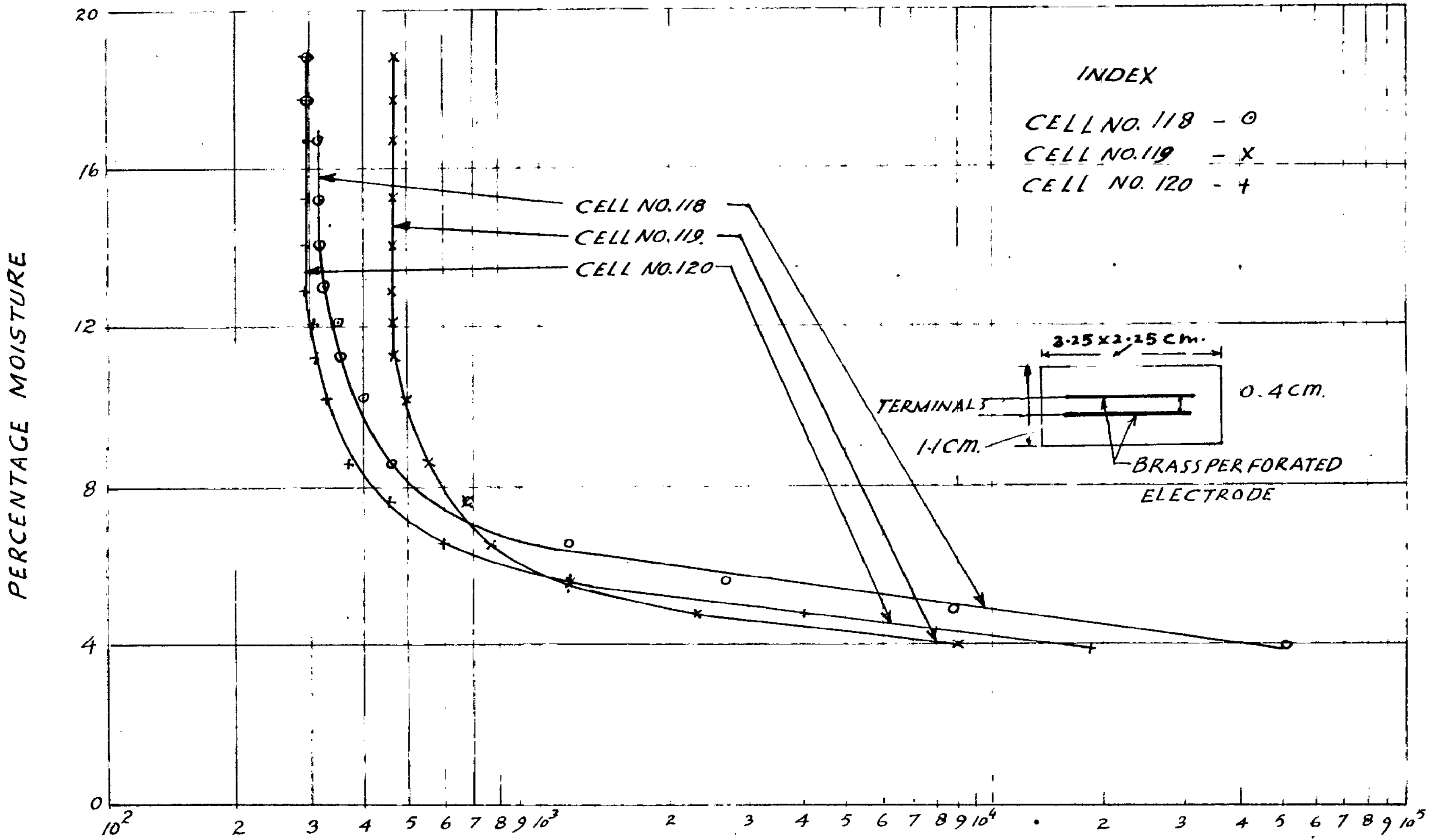


FIG-NO. 39

CELL Nos. 121, 122, AND 123.
PLASTER OF PARIS CELLS.

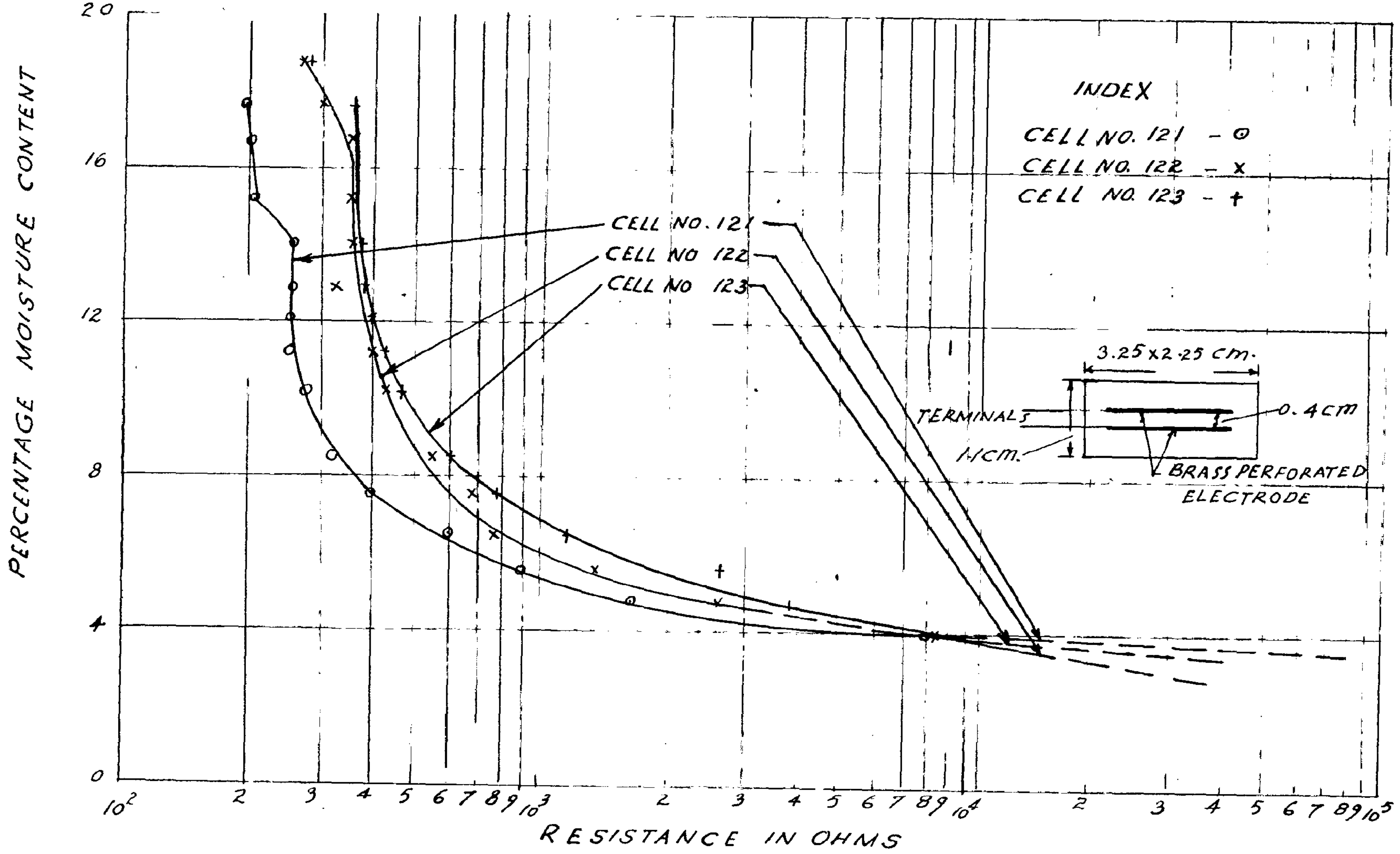
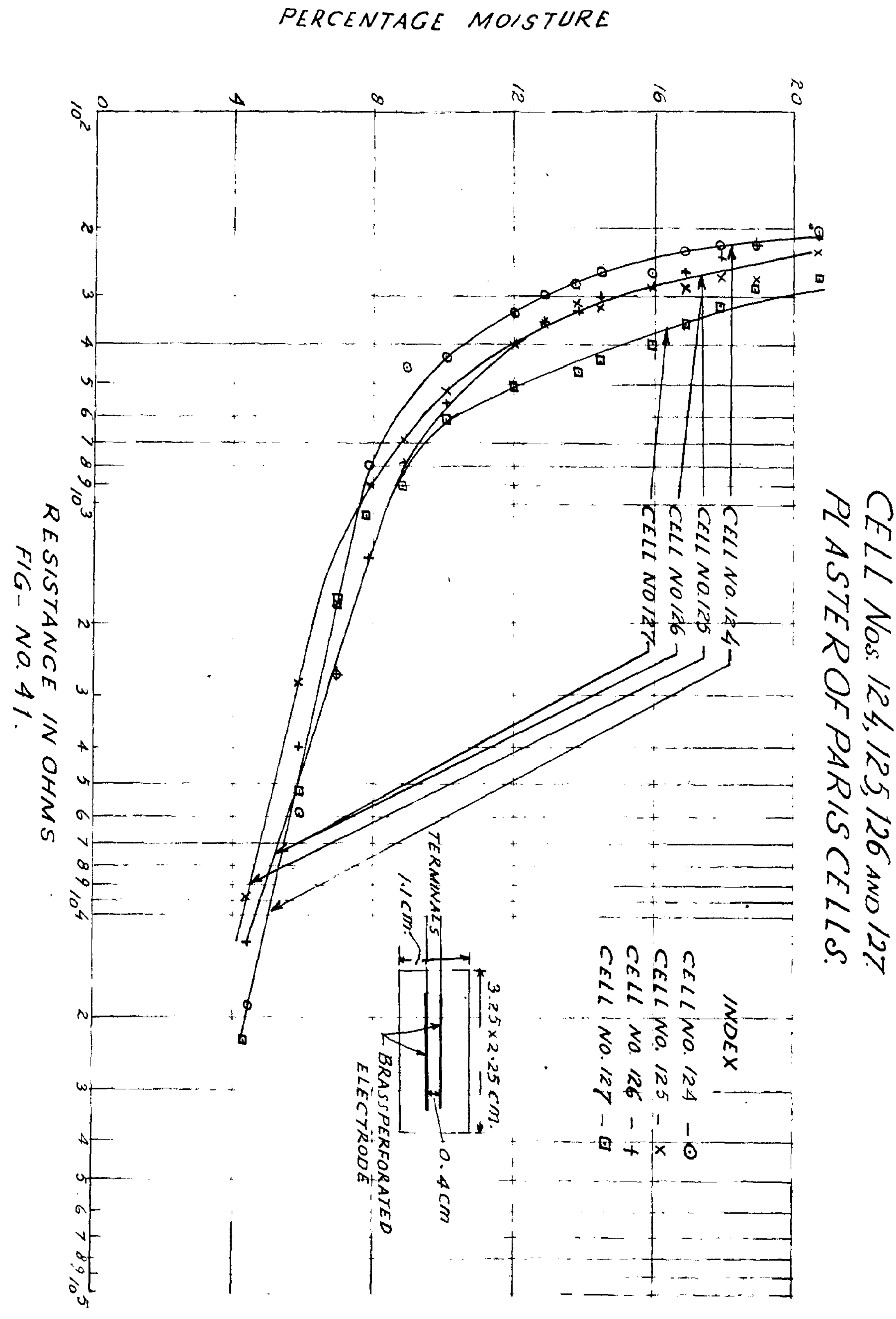


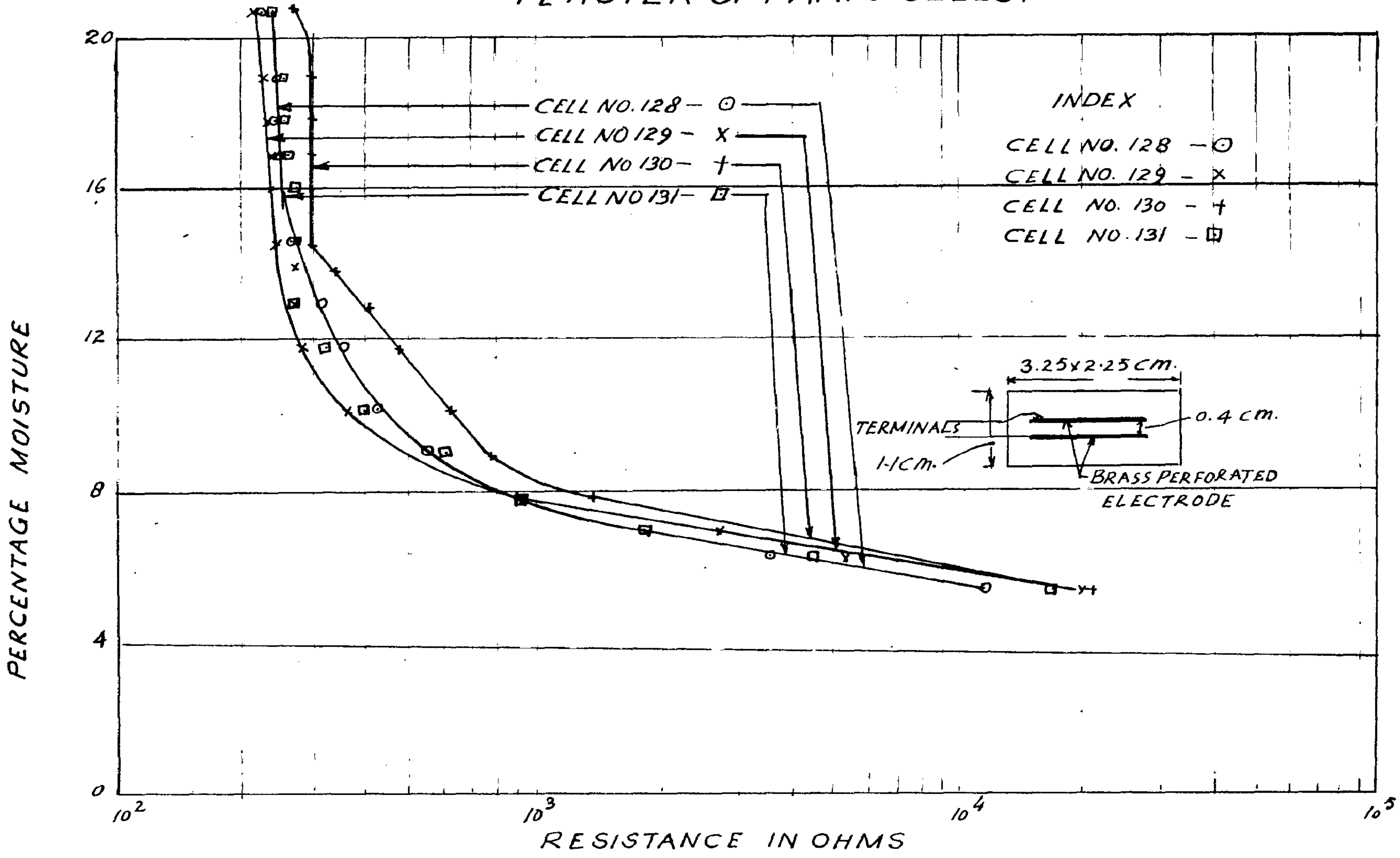
FIG- NO. 40.



CELL Nos. 124, 125, 126 AND 127
PLASTER OF PARIS CELLS.

FIG- NO. 41.

CELL Nos. 128, 129, 130 AND 131.
PLASTER OF PARIS CELLS.



FIG– NO. 42.

CHAPTER II

DESIGN OF PRESSURE MEASURING CELLS

CHAPTER II

DESIGN OF SOIL PRESSURE MEASURING CELLS

1. PURPOSE:

Earth pressures cells are used to determine the stresses at a point inside a soil mass, in a direction perpendicular to the plane of the cell. They are installed in earth structures and foundations to get a direct information on the development of stress distribution. The information so obtained will check on the current theoretical analysis or help in the development of analysis.

2. METHOD OF MEASURING SOIL PRESSURE :

There are only two possible methods for measuring soil pressures. They are given below :

(i) Indirect method: By measuring strains on structures that support the soil mass as in case of retaining walls. In case of pavements measurement of deflection of pavement slab will help in calculating the stresses in the supporting soil.

(ii) Direct method: By this method the pressures are recorded by measuring devices. Two measuring principles are adopted in this direct method. They are :

(a) Moving Type: in which the pressure transmitted to cell body, moves the whole unit. A good example of this is a piston type cell, in which the piston moves with increase or decrease of pressure.

(b) Deforming diaphram Type : In this pressure is transmitted to a deforming diaphram. This type is preferred by many investigators because of its ease of construction and also to avoid edge effects which are inherent in the piston type cell.

The discussions and design details given hereafter pertain to diaphram type of cells only.

The first earth pressure cell (diaphram type) was designed by A.T. Goldbeck in 1913 (7) and he is considered as the pioneer of cell design. At present more than 700 piston or diaphram type cells are in use.

3. FACTORS IN THE DESIGN OF PRESSURE CELLS :

The factors that enter the design of pressure cells are given below :

1. The elastic property of the cell with respect to the soil mass.
2. Diameter of pressure cell.
3. Particle size of the soil.
4. Diameter thickness ratio.
5. Diameter deflection ratio.
6. Ratio of sensitive area and total area of the cell.

3.1. ELASTIC PROPERTY OF CELL WITH RESPECT TO SOIL MASS :

The use of cell involves the introduction of a foreign body into the soil mass. This body has radically different stress deformation properties. Kogler and Scheidig (28) in 1927 called attention to this inherent difficulty in measuring earth pressure accurately with pressure cells. They pointed out that the cell which is more rigid than the soil indicate pressure greater than those present in the soil. Conversely a cell more compressible than soil gives reverse readings.

This has the defect of disturbing the original distribution of pressure in the vicinity of the body. The pressure cell having different stress deformation properties than that of the soil will give different soil-pressure reading than what would have been otherwise, if no cell was introduced.

It is very difficult, almost impossible, to construct a cell having the same elastic properties as that of the soil, specially when the elastic properties of the soil keep on varying with variation in moisture content, compaction and many other factors. More over the elastic properties of the soil vary from place to place and also with different ranges of pressure.

The best way of reducing the error due to two different elastic properties of the soil and the cell is to provide a cell having the same specific gravity as that of the soil.

3.2. DIAMETER OF PRESSURE CELL :

In case of pavements and other Engineering works, the soil deflects or deforms with the application of pressure. The deformation of the soil is either plastic or elastic or a combination of both. Whatever the type of deformation, the magnitude of deformation is proportional to the load intensity. It is now an accepted fact as pointed out by Housel (29) and many others, that for the same load intensity the settlement is more for bigger plates than for smaller ones. Same principle will apply to the diaphram typo cells which have also the shape of a plate. It is therefore highly desirable to have the diameter of the cell as less as possible, unless prevented by other reasons, as discussed under para 3.3.

It has already been pointed out that the introduction of foreign body having stress-deformation ratio more than the soil mass surrounding it, results into concentration of stresses on the body of the cell. This concentration will increase with the diameter of the cell. For example a small stone in a soil would not much disturb the distribution of stress in the soil mass as compared to a bigger stone.

Thus smaller the size of cell, more accurate it would be for pressure recording.

3.3. RELATION OF GRAIN SIZE TO CELL DIAMETER :

Kallstenius and Bergau (8) studied theoretically this effect with respect to the rigid piston. They considered a circular surface of radius 'a' free to move axially at periphery and discussed as follows :-

Let 'n' is the number of spherical grains acting on the surface. Each grain will than represent a partial surface with a hypothetical diameter d, so that

$$d \approx 2a \quad \sqrt{1/n} \qquad (\text{as } \Pi a^2 = \frac{\Pi d^2}{4} n)$$

where a = radius of the piston and n = number of grain particles.

Now we are interested in the random distribution of contact points at the periphery where the probable number of grains are

$$= n p = \frac{2 \Pi a}{2 a \sqrt{1/n}} = \Pi \sqrt{n}$$

Half of the partial surfaces of the peripherial grains will be outside the radius 'a'. To get a correct result of measurements, we must assume that half of these peripherial contact points be outside and the other half inside the circular face. On the other hand the probability of another distribution must be taken into consideration as these points need to move only very little to pass the periphery. The safest way to reckon with the possibility is, that the contact points of all peripherial grains are either entirely outside or entirely inside the cell radius. We further assume that all contact forces are equal.

The resulting error $\Delta P / P$ i.e. $\Delta\sigma/\sigma$ will then be

$$\frac{\Delta\sigma}{\sigma} \approx \frac{np}{2n} = \pm \frac{\Pi}{2\sqrt{n}}$$

For instance if the maximum error due to this cause shall be less than 3 p.c. (this would be permissible partial effect if the total error was about 5 p.c.) then we put

$$0.03 > \frac{\pi}{2\sqrt{n}}$$

and we obtain the condition $n > 2.750$

This would mean that the average hypothetical grain diameter should not exceed about 2 p.c. of the cell diameter.

The above recommendations apply to rigid piston type cell only. Kallstenius and Bergau (8), have further discussed the diameter of the flexible cover built in at the periphery as is usually obtained in diaphram type cells. They argue that in such case the given distribution has no great influence on the bending of the cover. On the other hand the grain distribution near the centre has the greatest influence. Rough calculations made by them indicate that the maximum grain size can be little greater than in the case of rigid piston.

From the discussions carried out in this para and also in para 3.2, we conclude that the diameter of the cell should be as less as possible but not less than 50 times the diameter of the largest size of soil particle.

3.4. DIAMETER THICKNESS RATIO :

In 1947 Taylor (19) carried out the theoretical analysis of soil pressure cell problem. He derived the following relationship between the cell error and the cell dimensions :

$$\frac{P_e}{P} = \frac{\frac{B}{D}\left(\frac{N}{M} - \frac{N}{M_c}\right)}{1 + \frac{N}{M_c} \cdot \frac{B}{D}}$$

Where P_e = Additional pressure recorded by the cell.

P = Field pressure existing at the plane of the cell.

B = Half the thickness of the cell.

D = Diameter of cell.

M = Stress-strain modulus of soil.

M_c = Stress-strain modulus of cell.

and N = Property of soil such that N/D is analogous to the coefficient of subgrade reaction.

Some of the above mentioned factors are very difficult to determine, In 1950 Monfore (24) carried out a rigorous analysis of the influence of the cell on the pressure distribution in and near a cell embedded in an infinite homogenous solid. He considered the cell to be embedded in an infinite elastic mass and took a section through the mass and cell on the plane of symmetry. This plane is assumed to remain plane after the application of pressure to the mass. He then considered the cell and surrounding mass to be divided into a number of concentric ring areas, and in order to keep the plane of symmetry plane, he considered the application of additional loads over and above the field stress to each of these ring areas. He then applied Boussinesq's equation for surface deflections of semi infinite mass and developed expressions for deflections of the ring areas in terms of the loads applied to them. The expressions were then solved simaltaneously to determine the loads on the ring areas. The actual values of ring loads depends upon Mc, M of soil and thickness of cell. Fig. 43 shows Monfore results.

Peattie and Sparrow (10) have modified the above equation given by Taylor and have given it as follows :

$$\frac{P_e}{P} = C_A \cdot B/D$$

Where C_A is known as "Cell action factor". They have given a graph of values of C_A for different values of Mc/M. This graph is reproduced in Fig. 44. This graph shows that the values of C_A is constant when Mc/M exceeds 9. Peattie and Sparrow recommended the use of the value of Mc/M greater than 10 so that small change in M may not increase the cell error.

From the equations and graphs mentioned in this para above, it is evident that the ratio of thickness to diameter should be as less as possible.

Research carried out at Waterway Experimental Station Vicksburg, U.S.A. (25) have shown that pressure cell with a diameter thickness ratio greater than 5, when placed near the centre in ottawa sand mass, in 71 cm. diameter pressure chamber indicated entirely the same pressure applied at the surface of the sand. Cells which had diameter thickness ratio less than 5 indicated pressure considerably greater than those applied at the surface, the discrepancy increasing with decreasing ratio. This indicate that in sand the diameter thickness ratio should be greater than 5. Beklam and Lancaster (3) have stated that in plastic soils diameter thickness ratio have no effect. McMahon and Yoder (30) therefore provided a diameter-deflection ratio of 4 in plastic soil.

No definite conclusion can be drawn from these investigations. With high diameter - $\overset{\text{Thickness}}{\text{deflection}}$ ratio the bending of the cell will tend to synchronize with the bending of the soil. It is therefore desirable to have this ratio as high as possible.

3.5. DIAMETER DEFLECTION RATIO :

Kallstenius and Werner (8) have discussed the theory of circular surface moving into elastic medium, as would happen in a piston type cells. They state as follows :

If a circular surface moves into semi-infinite elastic medium which is isotropic and follows hooks law; the pressure distribution can be calculated by using the theory of potentials. By means of this theory we can obtain the average increase or decrease in stress on the surface by a certain definite travel of, for instance centre of the surface. "This is also known as arching-effect".

Kallstenius and Warner have given the following expression due to arching :

$$\Delta\sigma = \frac{\delta}{2a} \quad E_s \quad \frac{m^2}{m^2 - 1} \cdot C \qquad (1)$$

Where

$\Delta\sigma$ = Average change in stress on the surface.

δ = Travel of centre of surface into the medium (i.e. deflection).

a = radius of circular surface.

E_s = Modulus of elasticity of medium.

1/m = Poisson's ratio of the medium.

and C = Constant depending upon surface deformation.

The constant 'C' has been deduced from Boussinesq's equation as interpreted by different authors (Hertz, H; Gesammelte Werke, Bd 1 Leipzig 1895 and (ii) Mises, F. Von; Differential gleichangen der Physik Bd. 2 Braunschweig 1935, p 301-312) for different kinds of surface curvature. The value of this constant is given in table No. 1. In calculating these factors the normal stress in the

Surface	Stress distribution	C
Part of sphere	Ellipsoidal, maximum at centre.	$8/3\Pi = 0.85$
Liquid surface	uniform	1.0
Rigid plane surface	Infinite stress at periphery, minimum at centre.	$4/\Pi$ 1.274

Table No. 1

medium outside the circular surface was assumed to be zero.

The deflection 'δ' is negative when the piston moves in the direction of the application of stress, resulting into decreasing change of stress. The deflection is positive when the piston move opposite to the direction of the application of stress, resulting into increasing change of stress. In case of diaphram type cells the deflection 'δ' is in the direction of application of stress.

The rate of decrease in average stress when the circular surface moves away from the medium is greater than the rate of corresponding increase in stress when the movement is opposite. Waben (29) has shown that when the deflected circular surface is part of a sphere, contact will be discontinued when

$$\delta = \frac{m^2 - 1}{m^2} \quad \frac{\sigma_o}{E_s} \cdot a \qquad \text{(ii)}$$

where σ_o = stress induced.

A soil differs from the ideal elastic medium in several important respects eg. limited shear strength, semi plastic nature, often negligible tensile strength and being anistropic, it does not follow hook's law.

Limited shear strength and semi-plasticity will tend to reduce the stress difference which occur in ideal elastic medium. Kallstenius and Bergau (8) state that the average change in stress on a circular surface can be expected to be smaller than that indicated by equation (i) and that the permissible travel away from the soil will be greater than that indicated by Equation (ii).

They further state that no straight line relationship can be expected between cell cover travel and change in soil stress. Frictional forces acting in radial direction between the soil and cell collar will arise in practice. They have a general tendency to increase the change in stress due to cover movement.

The above discussion show that (i) the deflection-diameter ratio ($\delta/2a$) is an important characteristic of the cell which affects the accuracy of the cell; (ii) the elastic properties of the soil ($E_s \frac{m^2}{m^2 - 1}$) have to be determined when calibrating cells with respect to boundry conditions. The boundry condition affect the shape of deformation and hence the stress conditions.

In case of flexible membrane built in at the periphery (as obtained in diaphram type cells) the deflection of the plate depends on bending moment caused by the load. Thus the eccentric load causes a smaller deflection than the centric load of the same magnitude. This makes the membrane less sensitive to the distrubing factors near the periphery. As the deflection curve is continuous, the stresses in the soil are more uniform and stress equilization by plastic flow is less probable than in case of rigid pavements. The maximum deflection is much greater than the average.

EXAMPLE:

Taking the case of the cell designed for this investigation we have the following values q, the intensity of stress = 0.88 Kgm/Cm^2; a, the radius of the cell 3.15 cm; u the poisson's ratio of carbon steel in the diaphram is assumed to be 0.3, E, the modulus of elasticity of carbon steel is taken as 2.1 Kg/Cm^2(30x10^6 psi) h, the thickness of the diaphrem plate = 0.09 cm; E_s, the modulus of elasticity of soil 1,000 Kg/Cm^2; u_s = 1/m , the poisson's ratio of the soil = 0.4, $C = 8/3\Pi = 0.85$.

Determine (i) the change in the applied stress due to the deflection of the circular diaphram and also determine (ii) the amount of deflection when the contact will be discontinued, and no further increase in stress will be recorded by the diaphram.

Deflection of the circular plate clamped at the edge, as per equation given by Timoshenko (35)

$$= \delta = \frac{q\,a^2}{64\,D} \qquad \text{where} \qquad D = \frac{E\,h^3}{12(1 - u^2)}$$

$$\therefore \delta = \frac{q\,a^2}{64\,\dfrac{Eh^3}{12(1-u^2)}} = \frac{3\,q\,a^2(1 - u^2)}{16\,Eh^3}$$

$$= \frac{3 \times 0.88 \times (3.15)^2 (1-0.09)}{16 \times 2.1 \times 10^6 \times (0.09)^3}$$

= 0.00097 cm.

(i) The change in the applied stress due to deflection of the circular diaphram by 0.00097 cm is given by

$$\Delta\sigma = \frac{\delta}{2\,a}\;E_s\;\frac{m^2}{m^2 - 1}\,.\,C$$

$$= \frac{-0.00097}{2 \times 3.15} \times 1000 \times \frac{25^2}{2.5^2 - 1} \times 0.85$$

$$= -\ 0.1558\ \mathrm{Kg/Cm}^2$$

(ii) The amount of deflection when the contact will be discontinued and no further increase in applied stress will be recorded by the diaphram,

$$= \delta_{\max.} = \frac{m^2 - 1}{m^2} \quad \frac{\sigma_o}{E_s} \cdot a$$

$$= \frac{2.5^2 - 1}{2.5^2} \times \frac{8.8}{1000} \times 3.15$$

$$= 0.0233\ \mathrm{cm.}$$

Thus we find that (i) for diameter deflection ratio of $\frac{6.3}{0.00097} = 6,500$ the change in applied stress due to deflection of the circular diaphram $= \frac{0.1558}{8.8} \times 100 = 1.8$ p.c. say and

(ii) The percentage increase in stress when the contact will be broken is $= \frac{0.0233 \times 8.8}{0.00097} \times 100 = 21,150$ p.c. which is very very high.

This effect of arching has also been discussed by Trollope in 1956. He argues as follows :

If the actual pressure p is increased by dp, the equivalent pressure increment transmitted to the diaphram will be less than dp due to deflection i.e. arching of the diaphram.

Experiments carried out at Vicksburg U.S.A . in 1944 (25) have shown that with the values of the ratios of the cell diameter to deflection (compression) which exceeds 2,000 very little change in indicated pressure occured. Hence diameter deflection ratio should be greater than 2,000. On the results of further experimentation carried out by the same organization for corps of Engineers in 1955 (31) it is recommended that diameter deflection ratio should be greater than 1,000, thus reducing the limit of the ratio.

In view of the above discussions, while designing the pressure cell, the value of diameter to deflection ratio has not been permitted to go below 1,000.

3.6. EFFECT OF THE RATIO OF SENSITIVE AREA TO THE TOTAL AREA OF THE CELL :

Peattie and Sparrow (10) state that high pressure will be developed towards the edges of the cell face and therefore the cell should not be sensitive towards the edges. They therefore recommend that for a cell of 7.6 cm. (3 in) dia; the sensitive area should only be 3.8 cm (1.5 in) diameter.

Beklam and Lancaster (32) state that the presence of a rim around a pressure responsive area would disturb the pressure area relationship because it would alter the distribution of pressure on the central area. They observed that with rim type cell, there was considerable variation in the reading obtained with different types of materials and different methods of embeddment. In plastic clays the physical dimensions of the cell did not produce a significant deviation in the pressure indicated.

It has already been mentioned in para 3.5 that in case of flexible membranes built in at the periphery, the diaphram is less sensitive to the disturbing factors near the periphery.

The type of soil used for this investigation is silty clay and since flexible membrane diaphram type are proposed to be used no significant change in pressure is indicated.

4. PAST EXPERIENCE WITH DIAPHRAM TYPE PRESSURE CELLS :

The reasons for choosing a diaphram type cell as compared to piston type has been explained in para 2. Reviewing the diaphram type cells developed in the past, they can generally be classified as follows :

i) Pneumatic or hydraulic cell.
ii) Accoustic cell.
iii) Piezoelectric cell.
iv) Electro magnet type cell.
v) Capacitance type cell.
vi) Strain gauge cell.

4.1. PNEUMATIC OR HYDRAULIC CELLS :

A.T. Goldbeck (6) was the pioneer in the design of pressure cell. In 1913 he designed a pressure cell with the principle of balancing the earth pressure by application of air pressure.

His cell consists of a cylindrical metal case one end of which is open. A movable metal piston is fitted loosely in the open end of the case and held flush with the rim of the case by a thin metal diaphram.

After the pressure is applied by the earth on the outside of the diaphram, air pressure is applied through a pipe (0.3 cm dia) on the other side of the movable piston to counter act the earth pressure applied. An electrical contact is provided inside the case. As soon as earth pressure is applied and the piston deflects the electrical contact gets closed. The closing of the electrical circuit is shown by a lamp or ammeter. As long as earth pressure is more than the air pressure the electric circuit would remain closed. As soon as the two pressures balance the electrical circuit would open. The amount of air pressure applied would then indicate the pressure due to earth.

The principles of application of air or hydrostatic pressure has now been mostly suspended. However Vikramaratna (34) has designed a cell of 5 cm (2 in) dia; having stiff eleastic diaphram., the cell has considerable length. The pressure acting on the cell is inferred from the measurement of the central deflection of 0-500 micro-cm (0-200 micro inches) using the pheumatic gauging technique with a magnification of 35,000.

Now a days in most of the diaphram type cells the following two principlea are employed.

i) Converting the pressure into the vibrations of the wire directly attached to moving diaphram or

ii) Converting the pressure to change in electrical circuit.

4.2. ACCOUSTIC CELLS :

The development of accoustic cell appear to have started from Germany in 1935 , and later spread to U.S.A. Canada and other countries.

The accoustic cells can be used only for sustained or slowly varying earth pressure and cannot be used for rapid transient pressures caused by dynamic stresses. The cells employ the principle that the natural frequency of steel wire varies as the tension in the wire.

A wire is provided and so arranged in the cell that an external pressure applied to the face of plate or diaphram bends the plate and increase proportionately the tension (or compression) in the wire (or wires).

Any method of measuring frequency can be used. Usual method is vibrating the wire by means of small coil through which an electric current is switched momentarily. The vibration of the wire is then picked up and transmitted by the same coil and connector wires to an indication device like head phone or cathode ray oscillograph.

The frequency of the wire is matched either by direct comparision or by superimposition with that of an adjustable standard wire. The standard wire would consist of a similar tough wire with calibrated adjustable tension. The cell is first calibrated for frequency v/s pressure.

Accoustic cells are quiet sensitive. Three diagrammetic sketches of accoustic cells are shown in Fig. 45. They show some of the patterns used for varying the frequency of wire with respect to the pressure applied.

4.3. PIEZZOTECTRIC CELLS :

These were first developed at the Road Research Laboratory (33) for recording transient soil pressures of very short duration caused by dynamic stresses.

It consists of a pile of 4 quartz crystals connected electrically in parallel (Fig. 46.). When the crystals are pressed they produce an electrostatic charge. The voltage so generated is fed to a cathode ray tube via an amplifier. The movements of the spot on the cathode ray tube are photographed by a rotating drum camera.

It is only useful in short duration transient pressure as there will be leakage in insulating etc., which will affect the result when the cell is employed to record duration pressures. The cell ~~is~~ housed in a light aluminium - magnesium alloy to keep its density low, and have the same elastic propertios similar to those of quartz crystals.

The cells have to be calibrated for pressure. They can have an operating range of 0-10.5 Kg/cm^2 (0-150 psi). The operating range can however be varied at will by merely changing the diaphram thickness. The sensitivity of these cells is greater than electro magnet type cells.

Mention may be made of carbon pile cells which consisted of thick carbon discs mounted between metal plates. When pressure is applied to the stack, its electrical resistance decreases. The change is of sufficient magnitude to be measured by a simple wheat stone bridge. These cells were used for recording transient pressures under dynamic load. Since the pile does not retain its calibration, they have been abondoned.

4.4. ELECTRO MAGNET TYPE CELLS :

These cells employ electro magnet device where in diaphram movement causes a change of inductance. One exmaple is that of Lee and Brown in 1957 who used the cell for small scale models. The principle of this can be explained by Rowe's cell. It consists of two core inductive circuits carrying a central armature. The primary winding carry currents in opposite direction, while the secondary windings are connected in series. So, when the armature is central, equal and opposite electromotive forces are induced in the secondary windings so that no current flows round the secondary circuit. With the armature displacement, an increase occurs in the induced secondary emf of one circuit where as decrease occurs in the other. Since the primary circuits are reversed, a total current flows through the secondary circuit equivalent to twice the induced emf of one coil. The gauge is self compensating with respect to temperature changes. Its operating range is usually not very high. Two types of electro magnet cell are shown in Fig. 47.

4.5. CAPACITANCE TYPE CELL :

This type of cell was developed under the supervision of the author by Sri V. Subba Rao, Research Fellow. A detailed diagrammetic sketch of the cell is shown in Fig. 48. The diaphram which is fixed at its edges on deflection increases the capacitance, which is measured by a capacitance measuring bridge.

4.6. STRAIN GAUGE CELLS :

If a circular plate is clamped or fixed at its periphery radial and tangential stresses are induced. Timoshenkos (35) has given the following equations for circular plates clamped at the periphery.

1) $$M_r = - D \left(\frac{d^2 w}{dr^2} + \frac{u}{r} \frac{d w}{d r} \right) \ldots\ldots\ldots \quad (i)$$

$$M_t = - D \left(\frac{1}{r} \frac{d w}{d r} + u \frac{d^2 w}{d r^2} \right) \ldots\ldots\ldots \quad (ii)$$

$$\sigma_r = - \frac{E.z}{1-u^2} \left(\frac{1}{r} \frac{d^2 w}{d r^2} + \frac{u}{r} \frac{d w}{d r} \right) \ldots\ldots\ldots \quad (iii)$$

$$\sigma_t = - \frac{E.z}{1 - u^2} \left(\frac{1}{r} \quad \frac{d\,w}{d\,r} + u \frac{d^2\,w}{d\,r^2} \right) \quad ..... \quad (iv)$$

$$w = \frac{q}{64\,D} \left(a^2 - r^2 \right)^2 \quad .... \quad ..... \quad (v)$$

Where :

M_r , σ_r and e_r = Bending moment stress and strain respectively along the radius.

M_t , σ_t and et = Bending moment, stress and strain respectively along the tangent.

z = Distance from neutral axis;

D = Flexural rigidity = $\dfrac{E\,t^3}{12\,(1 - u^2)}$

a = Plate diameter.

y = deflection of the plate at any point.

t = thickness of the plate.

r = distance of any point from the centre.

E = modulus of elasticity of the plate.

q = intensity of load distribution over the plate.

u = Poisson's ratio.

From Equation (v) above we have

$$\frac{d\,w}{d\,r} = \frac{q}{64\,D}\; 2\,(a^2 - r^2)\,(-2r) = - \frac{q}{16\,D}.\; r(a^2 - r^2)$$

$$\frac{d^2 w}{dr^2} = - \frac{q}{16\,D} \left(a^2 - 3\,r^2 \right)$$

From eq. (iii) and (iv) we have

$$e_r = -\frac{z}{1-u^2}\left(\frac{d^2 w}{d r^2} + \frac{u}{r}\frac{d w}{d r}\right) \quad \ldots \quad (vi)$$

and
$$e_t = -\frac{z}{1-u^2}\left(\frac{1}{r}\frac{dw}{dr} + u\frac{d^2 w}{d r^2}\right) \quad \ldots \quad (vii)$$

By putting the values of dw/dr and $d^2 w/d r^2$ in equation (vi) and (vii) above and putting $z = t/2$.

We have.

$$e_r = -\frac{t}{2(1-u^2)}\left\{ -\frac{q}{16D}(a^2-3r^2) + \frac{u}{r}\left[-\frac{q}{16 D} r (a - r)\right] \right\}$$

$$= \frac{tq}{32(1-u^2)D}\left\{ a^2 - 3r^2 + u(a^2 - r^2) \right\}$$

$$= \frac{3q}{8Et^2}\left\{ a^2(1+u) - r^2(3+u) \right\}$$

$$= \frac{3qa^2}{8Et^2}\left\{ (1+u) - \frac{r^2}{a^2}(3+u) \right\}$$

$$e_t = -\frac{t}{2(1-u^2)}\left\{ -\frac{1}{r}\frac{q}{16D}(a^2-r^2) + u\frac{q}{16D}(a^2-3r^2) \right\}$$

$$= \frac{qt}{32D(1-u^2)}\left\{ (a^2-r^2) + u(a^2 - 3r^2) \right\}$$

$$= \frac{3qa^2}{8Et^2}\left\{ (1+u) - \frac{r^2}{a^2}(1+3u) \right\} \quad \ldots.(viii)$$

Thus when

(i) $\frac{r}{a} = 1$

$$e_r = -\frac{3\,q\,a^2}{4\,E\,t^2} \qquad e_t = -\frac{3\,q\,u\,a^2}{4\,E\,t^2}$$

$$= \frac{9}{40}\,\frac{qa^2}{Et^2} \quad \text{for } u=0.3 \quad \text{..(ix)}$$

(ii) When $\frac{r}{a} = 0$

$$e_r = e_t = \frac{3\,q\,a^2(1+u)}{8\,E\,t^2}$$

$$= \frac{39}{80}\,\frac{q\,a^2}{Et^2} \quad \text{for } u = 0.3 \qquad \text{(x)}$$

(iii) When $e_r = 0$

$$(1+u) - \frac{r^2}{a^2}(3+u) = 0$$

When $e_r = 0$; $\frac{r}{a} = \left(\frac{1+u}{3+u}\right)^{\frac{1}{2}} = 0.6277$ for $u = 0.3$ (xi)

(iv) When $e_t = 0$

$$(1+u) - \frac{r^2}{a^2}(1+3u) = 0$$

$$\therefore \quad r/a = \left(\frac{1+u}{1+3u}\right)^{\frac{1}{2}}$$

When $e_t = 0$; $r/a = 0.8273$ for $u = 0.3$ (xii)

A graph of radial and tangential strain at any point ofthe plate is thus shown in Fig. 49.

It can be observed from the above equations and Fig. No.49 that the radial and tangential strains on the underside of the plate change from positive to negative. The radial strain being zero when $r/z = 0.628$ and tangential strain being zero when $r/a = 0.827$.

When $r = 0$, i.e. at the centre of the plate, radial strain = tangential strain

$$= \frac{39}{80} \; \frac{q\,a^2}{E\,t^2} \quad \text{when } u = 0.3$$

and with $r = a$, i.e. at the circumference of the plate,

radial strain $= -\frac{3}{4} \; \frac{q\,a^2}{E\,t^2}$ irrespective of the value of u

and tangential strain $= \frac{9}{40} \; \frac{q\,a^2}{E\,t^2}$ when $u = 0.3$

If therefore strain gauge can be attached to measure tangential strain in the zone defined by positive tangential strain(shown in Fig. 49 hatched) and a second gauge to measure radial strains in the zone defined by negative radial strain shown dotted, the two active bridge arms with almost perfect temperature compensation will be secured and will cover and record most of the strains.

Redshaw (13) took advantage of the strains caused in the plate and designed a rosette pattern of strain gauge as shown in Fig. 50.

Thus we find that in redshaw cell the two diaphram and two strain gauge assembly give four active arm bridge with automatic temperature compensation. He maintained the resistance of each gauge as 30 ohms. Redshaw is claimed to have linear calibration curve and a sensitivity of 0.015 Kg./Cm^2 (0.2 psi).

Strain gauge pressure cells are getting very common for measurement of pressure in subgrade soil and foundation. Yoder (3) adopted two SR-4 gauges along the diameter, each strain gauge emerging in opposite direction from the center of the plate.

5. CALIBRATION OF CELLS:

Calibration is one of the most important part in the manufacture of any instrument. More important it becomes when the conditions under which the calibration is to be made are different from the conditions under which the instrument is to be used. In case of pressure cells the conditions in the laboratory will have to be simulated with the conditions in the field during calibration. Field calibration is almost practically impossible, in case of pressure cells. Many methods of calibration have been adopted by various investigators. They can be grouped into following heads.

i) Dead weight method.
ii) Pneumatic or hydrostatic pressure method.
iii) Soil pressure method.

In the first method the diaphram will be loaded with a dead weight and tested. Since the dead weights are rigid and would not yield with the plate, the pressure distribution willnot be uniform as would be obtained in soil under pressure. This method is therefore not used for calibration.

In case of calibration with pneumatic or hydrostatic pressure the cell is kept at the bottom of chamber containing air or any suitable liquid (preferably thick oil), respectively. Air or hydraulic pressure is applied and the cell calibrated. A typical chamber is shown in Fig. 52.

In case of calibration with soil various methods are suggested. The three typical patterns are (a) Swedish Geotechnique Institute type (b) Water ways Experimental Station Type (c) In triaxial cell.

In type (a) i.e. Geotechnique Institute type, the pressure Chamber is made up of eight rings each 50 cm. in dia; and 5 cm. in height. The rings are stacked one over the other with 1 mm. spacing between them. The details are shown in Fig.51(a).This set up is known as "Oedometer". The vertical deflection of the rings can be measured by the deflection gauges fixed to the sides. Strain gauges are fixed to each of the rings, so that horizontal stresses in the chamber can be measured. The pressure is applied at the top through a bladder filled with water. The whole apparatus behaves like a triaxial apparatus, so that the pressure acting on the cell can be measured accurately. The soil in the chambor is provided with the same dry density as obtained in the field.

In type (b) i.e. Water Ways Experimental Station Type, the pressure chamber consists of 71 cm (28 in.) diameter pipe section with flanged mouth. A 0.3 cm. (1/8in.) thick rubber membrane is stretched across the mouth and a lid is attached to the chamber as shown in Fig. 51(b). The lid is of such a shape as to provide a small air gap between the membrance and the bottom of the lid. The soil is compacted to dry density as obtained in the field, and the cells installed as shown in the figure. Air under pressure is delivered into the gap between the lid and the rubber membrane. It was found that the pressure on any horizontal section was uniform. Many variations of this type of cell have been used.

Type (c) triaxial cell was used by McMahon and Yoder (30) for checking the cell otherwise calibrated in air - pressure chamber. They used 15 cm x 30 cm. (6" x 12") clay-soil specimen from the field.

McMahon and Yoder (30) also checked the cells, calibrated in air pressure chamber in sand medium also. They found that the results of air pressure chamber agreed with those of the triaxial cell while with sand the data was erratic and co-relation very poor.

From the above mentioned technique on calibration we find that the type of material surrounding the cell to be calibrated will have considerable effect on the results of calibration. Most important factor that has to be kept in view is the arching effect as discussed in para 3.5. From the equation of

$$= \frac{m^2 - 1}{m^2} \quad \frac{\qquad}{E_s} \quad . \, a$$

given in this paragraph, we find that deflection of the diaphram and hence stress recorded is inversely proportional to the modulus of elasticity of soil. Thus during calibration arching effect will depend upon modulus of elasticity and poisson's ratio of the soil. These factors in turn depend upon the type of soil, moisture content and depth of cell in the calibration chamber. More plastic the soil, less the modulus of elasticity and more will be the deflection. Thus in case of cement concrete with very high modulus of elasticity, the deflection of the diaphram will tend to be zero, inspite of the heavy stresses developed in the layer immediately above the diaphram. The type of soil with respect to its grain size and other organic or salt contents will affect the deflection of the diaphram. Arching will be more in clayey soils than in sandy soils.

The amount of deflection of the diaphram will vary in the same type of soil depending, as mentioned above, on its moisture content due to change in its plasticity. This diaphram deflection and hence stress recorded will also vary with the depth of the cell below the top surface of the soil in the pressure chamber. This is due to internal friction and cohesion of the soil. The deflection decreases with increase in depth for the same amount of applied pressure. In the pressure chamber of Water Way Experiment station (discussed in this paragraph), it is claimed that the pressure on any horizontal section was uniform . If this is possible it will apply only to soils of higher elastic modulus.

The author has carried out number of tests and have come to the conclusion that the calibration should be carried out at full arching effect and hence calibration of cell in liquid (preferably thick oil) is the best. He found that even in case of dry graded sand calibration varied, depending upon the amount of initial compaction applied. He found out that if the graded sand is compacted so that no further compaction would take place, the calibration agrees with the calibration carried out with liquid medium. The calibration curve in case of liquid medium is the same straight line during loading or unloading operation. The investigation carried out by the author therefore collaborate with those carried out by McMahon and Yoder (30).

Redshaw (13) carried out calibration of his cells in a pressure chamber and subjected the cells to oil pressureby means of a dead weight caliber. He again calibrated the same cells embedded in graded sand by applying a load through a ram. He states that the calibration in graded sand agreed with the calibration in a liquid and both gave a straight line curve. He however states that due to locking action of grain particles of sand, a large hysteresis loop is obtained during unloading and results will not agree.

The locking action of soil particles is just another name of arching.

It has been recommended that whatever the method of calibration is adopted it is highly essential that it should be extended through the entire design pressure range of the cell, both for loading and unloading conditions and should be repeated several times and if feasible should include long time loading calibration. Except for long time and repetitive loading in some simple cases, all cells were calibrated for loading and unloading.

TEMPERATURE CALIBRATION:

Woodman (18) states that temperature calibration is not important since temperature changes within an earth mass usually are very small. The cell can be temperature callibrated by determining the shift in zero pressure reading at temperature ranging from 2°C (35°F) to 70°C (100°F) or whatever field temperature conditions are anticipated. The cell for testing must lie at a particular temperature for ½ to 1 hours.

During calibration carried out by the author the above statement was found to be correct if the dummy gauge was maintained under the same conditions as the active gauge, except for the load applied.

6. LIMITATIONS IN THE DESIGN OF PRESSURE CELLS :

From the discussions carried out in the foregoing paragraphs it is evident that the accuracy of the pressure cell in recording the earth pressures is subject to various limitations described below :

(i) The modulus of the soil surrounding the cell may be either large or small than the modulus (i.e. the stress deformation property) of the cell and this deviation may be a source of error in measurement since it can cause a distortion of the stress pattern in the immediate vicinity of pressure, cell. Moreover as already pointed out in para 3.1., the modulus of soil is a variable factor. It has been recommended that in order to reduce the error to minimum, the density of the cell should be about the same as that of the soil.

(ii) As discussed in para 3.3. the diameter and the size of the cell should be as small as possible but the diameter should not be less than 50 times the diameter of the largest size of soil particle.

(iii) As discussed in para 3.4. the ratio of diameter to thickness should be as high as possible. In case of sand the ratio should not be less than 5.

(iv) As discussed in para 3.5. the diameter deflection ratio should be greater than 1000.

(v) The ratio of the sensitive area to the total area should be as great as possible.

(vi) All care should be taken in determining the method and technique of calibration.

7. DESIGN OF CELL :

7.1. The limitations in the design of cell have been pointed out in para 6. They show that the cell size, in diameter as well as in thickness should be as small as practicable, keeping in view the grain size of the soil.

Diaphram type cells are the smallest in size. From the discussion of the past experience of the diaphram type cells, giving in paragraph 5, we find that strain gauge has the minimum volume as compared to other measuring devices. Strain gauge cell was therefore adopted for this investigation.

Before starting with the design of cell it was imperative to determine its maximum recording capacity. The maximum bearing capacity of the soil in which the cells are to be installed is 0.88 Kgm/ Cm^2 (0.8 tons/sq.ft) and hence the cells have been designed for a maximum load stress of 0.88 Kgm/Cm^2.

7.2. DIAMETER OF CELL ADOPTED :

The diameter of cell as mentioned in para 3.3 should be as less as possible with a minimum of 50 times the maximum size of the particle in the soil. The maximum size of the particle of the soil where these cells are proposed to be used is about 0.59 mm. (0.0232 in.) at 85 P.c. grading. Hence the diameter should not be less than 3.0 cm. (1.16 in.).

As per para 4.6 and Fig. 46 radial stresses in the diaphram due to distributed load changes its sign from positive to negative when the radius increases beyond 0.627 times the effective radius of the diaphram (Poisson's ratio of the material of the diaphram = 0.3). The strain gauge should lie within the circumference prescribed by this radius. If this is not done, the negative strain caused beyond this radius will compensate some of the positive strain and thus make the gauge less sensitive.

As already mentioned the effective length of strain gauge used is 2.0 cm. Hence the minimum effective diameter of the cell that could be adopted,

$= \frac{2.0}{0.627}$ = 3.2 cm. Thus if 3.2 is the effective diameter of the diaphram taken, the strain gauge has to be cemented exactly along the diameter with 1 cm. on either side of the centre of the diaphram. The amount of strain from centre to the ends of the strain gauge would reduce to zero (See Fig. 49). To increase the sensitivity of the cell and also to account for the error in cementing the strain gauge right in the centre of the diaphram, it was thought fit to increase the effective diameter to 5 cm.

7.3. DIAPHRAM THICKNESS ADOPTED :

Corps of Engineers, U.S.A (31) have recommended that the diameter deflection ratio $>$ 1000.

Timoshenko (35) has given the following equation for circular plate clamped at its edges.

$$\text{Maximum deflection} = w = \frac{q\,a^4}{64\,D}$$

(notations explained in para 4.6)

Taking $E = 21 \times 10^5$ Kg/Cm^2 (30×10^6 psi) ; $h = 0.9$ mm.
and $u = 0.3$ for steel

$$D = \frac{E\,t^3}{12(1 - u^2)} = \frac{21 \times 10^5 \times 0.09^3}{12(1 - 0.3^2)}$$

$$= 141 \text{ cm-kg.}$$

Taking $q = 0.88$ Kg/Cm^2 (12.5 psi), $a = 2.5$ cm.

$$w = \frac{0.88 \times 2.5^4}{64 \times 141} = 0.00381 \text{ cm.}$$

$$\therefore \frac{\text{Diameter}}{\text{Deflection}} = \frac{5}{0.00381} = 1{,}231 > 1000$$

Hence thickness of 0.9 mm is suitable for 5 cm. effective diameter of the cell.

7.4. STRAIN GAUGE AND ITS CEMENTING PROCEDURE ADOPTED :

7.4.1. MAIN REQUIREMENTS :

In choosing a strain gauge the quality of the strain gauge is of highest importance. The strain gauge should show constancy of the indicated zero pressure reading as well as constancy of identical pressure under a constant known load over a long period of time (5 years).

Instability may be due to aging or imperfect temperature compensation. Temperature effects from imperfect temperature compensations may be the cause of temperature differential influenced by the constant rise and fall of daily temperature or from longer period seasonal variations (31).

Pasting of strain gauge over the diaphram has to be carried out with proper skill and with most suitable cementing material. Instability of the strain gauge is also caused due to possible change in the elastic properties of the film caused by the cementing material. These changes may be short time cyclic changes induced by temperature differential or may be longer or slow aging changes and may be either positives or negative (31).

Though good quality strain gauges and cementing materials used for this purpose reduce all the above mentioned errors it may not be possible to make them zero.

7.4.2. STRAIN GAUGE USED :

Three types of strain gauges are obtained in the market. (i) Bonded wire gauge and (ii) Etched foil gauge (iii) Unbonded wire gauge. Bonded wire gauge consists of a base which may be of paper or plastic or any resinous material with a fine resistance wire attached to it. In the etched foil gauge a metallic foil instead of the wire, is used. Unbonded wire gauge has resistance wire between two supports. It is claimed that etched foil gauge (36) can stand repeated stresses and heavy electrical current and have less sensitivity to strain perpendicular to axis. All these gauges are useful upto 60°C temperature.

In the design of earth pressure cells where no repeated stresses are being measured, there is no need of sending heavy electrical currents through the resistance wire and moreover sensitivity perpendicular to strain gauge has no consequence. No unbonded wire gauge can be used in these pressure cells as they would be less sensitive. Bonded wires were therefore used for this purpose.

Paper type strain gauges though commonly used are less moisture proof and of less heat endurance quality than with bakelite or polyster base (36). Any moisture proof plastic base would be better than paper base. For this investigation strain gauges with paper base have been used because of availability, and also because strain gauges with paper bases were much cheaper and limited funds were available. However all precautions were taken while fixing and sealing to make the bases water proof. This has been explained later.

Strain gauges in India are mostly imported and a very few cottage industries have recently started making them. The choice of the quality and size therefore depended on their availability. The following strain gauges were tried (i) Strain gauge from one of the cottage industry in India (ii) Orion E.M.G. Hungarian paper strain gauge type 2359 resistance = 120 ohms ± 0.2 p.c. and gauge factor 2.08 ± 3.0 p.c. (iii) Paper strain gauge supplied by Shinko communication Industry Co., Ltd. Japan (type s_1) having gauge resistance of 120 ohms ± 0.3 p.c. and gauge factor of 2.08.

Strain gauges made by Shinko communication were ultimately selected. They were found not only the best but cheapest. The size of strain gauge obtained and used was 0.2 cm. length.

7.4.3. METHOD OF FIXING THE STRAIN GAUGE :

The strain gauges are cemented to the measuring surface by means of celluloid cement. Various patent products of celluloid cement are recommended by different agencies. The cementing and preparatory procedure for strain gauges adopted is explained below in nutshell. The procedure may be grouped as follows :

i) Preparation of measuring surface.
ii) Cementing of strain gauge.
iii) Drying of strain gauge.
iv) Preparation and placing of connecting cables.

v) Application of compensating gauge.

7.4.3.1. PREPARATION OF MEASURING SURFACE: The surface of the diaphram used was very smooth. In fact number of gauges fixed on the surface by various adhesive were found to be slipping. Ultimately the surface was provided with very light grooved lines in a chequered pattern. This prevented slipping of strain gauges. The surface was then cleaned by emery cloth to remove the rust. Rubbing continued till the surface was shining and no rust particles visible; even the grooves were clean. The surface was then wiped with dry clean cloth. To remove the emery, dust particles and grease if any, the surface was rubbed by means of cotton wool immersed in toulene (trichlorethylene or benzol can be used in place of toulene) Rubbing continued till very little (infact nil) dust or x rust particle was visible on the white cotton wool. The surface was then rubbed with white cotton immersed in acetone., (pure ethylacetate may also be used in place of acetone) until no dirt spot could be seen on white cotton wool. The colour of the spot decreased from black to light brown while using toulene, and brown to nil while using acetone.

7.4.3.2. CEMENTING OF STRAIN GAUGE: Durofix (made in England) is said to be one of the suitable materials. This was not available. Araldite supplied by Ciba Co., Ltd., would be suitable if thin layer would be obtained with it. A thin layer of cementing material without any bubbles is absolutely necessary to provide proper bond, otherwise the strain gauge would slip. Araldite, as supplied, consists of hardner and a cementing material which when mixed give a highly viscous material. To make this mixture less viscous it was dissolved in acetone to the required viscosity. This solution provided the thin surface required. The danger of providing solvent is that it reduces the temperature of the surface and thus may provide a water vapour condensate on the cement layer. This condensate may be indicated by a milk like precipitate. To avoid this danger, all strain gauges were fixed in non monsoon period during the month of June. Hungarian manufacturers Orion - EMG Dehnungs - messtreifen recommended that when such condensate takes place the surface should be heated to 25°C. Since the room temperature under which the strain gauges were fixed was always above 25°C, no such treatment was necessary.

The araldite-acetone mixture so prepared was applied on the diaphram surface where the strain gauge was to be fixed and also on the rear side of the strain gauge, in as thin as possible, layer. Before applying on the paper of the strain gauge, the surface of the paper was slightly washed by running with cotton wool immersed in acetone. This was done to remove any dust particles. The cemented layer was allowed to dry. The time taken for drying varied from 3 to 5 minutes. The strain gauge was then placed on the diaphram surface. Since these strain gauges had felt cover over the wires, the inside of the felt was also coated with the araldite-acetone solution and then placed on the wires. This was done to provide a water proof surface over the wires.

The sides of the strain gauge so fixed, were covered with neat paper to prevent the terminal wires sticking with the araldite on the diaphram projecting beyond the limits of the strain gauge paper. The whole assembly was then covered with a thick layer of cotton woolen, and then a pad of foam rubber and then pressed with a dead weight of about 5 Kgms.

The dead weight along with rubber foam and cotton pad was removed on the next day (i.e. after about 15 hours). The surface surrounding the strain gauge was then mechanically erased with sharp tool to remove the paper or cotton sticking to it.

The gauge was then mechanically checked to see whether the two axes of the gauge had not been displaced from the wanted directions, and also for its adhesiveness. No such error was noted in any of the strain gauges so fixed.

7.4.3.3. <u>DRYING OF STRAIN GAUGE:</u> The strain gauge along with the diaphram plate was then placed in the dessicator for a minimum period of 48 hours. Drying may be done in an oven at 60°C. This was not done as properties of arladite -acetone were not correctly known. It was found that the araldite crumbles when heated over hot plate.

All the surface of the diaphram around the strain gauge and also the top of the strain gauge was then painted with araldite-acetone mixture to prevent any effect of moisture on the strain gauge. This paint also prevented corrosion of the inside surface of the diaphram.

The gauge was then checked for its continuity and also discontinuity between the gauge wire and the metal body, by means of an ohm-meter.

7.4.3.4. PREPARATION & PLACING OF THE CONNECTING CABLES: One of the most important rule is to prevent any strain on the lead wires of the gauge supplied. This will result into erractic readings and also may result into short circuit between the body and terminals or between terminals themselves. The lead wires should therefore be electrically well insulated and no mechanical forces should be transfered to the strain gauge.

The terminals of the strain gauge were welded with the lead wires by means of tin-lead solder and then the terminal along with the solder joint was provided with suitable sleeve. The sleeves extended over the base paper to as far as they could go. Thus there was no possibility of short circuiting.

To prevent the effect of mechanical forces, the lead wires were first circled inside the rim of the diaphram, as shown in Fig. 53, before taking them out through a hole in the cell. The gap between the hole and the lead wires was completely sealed with araldite. This seal would prevent any forces being transferred to the lead wires inside the cell. If by chance some pull or push is exerted on the lead wires inside the cell, the twisted loop would take over these forces without transferring them to the gauge.

7.4.3.5. APPLICATION OF COMPENSATING GAUGE : Compensating strain gauges are used to eliminate the effect of elongation caused by changes due to temperature variations. The compensating strain gauge should therefore be under the same temperature condition and should be cemented on the same material and also should not show any strain due to mechanically applied forces.

A small plate of the same material as that in the diaphram was prepared and the same type of strain gauge applied to it. This plate was placed in the same box, except for the variation in inside depth. For the compensating strain gauge the inside depth was increased by 1 cm., so that the deflection of the diaphram and/or base may not compress the gauge and thus bend it along with itself. The whole box containing the strain gauge was tested under load, and no change in resistance was recorded due to load.

7.5. TRIAL CELLS :

Number of trial cells were tried at the first instance to obtain a container with a minimum possible density and satisfy the other requirements discussed in para 6 and its subparas. The pattern chosen was a steel ring joined to the diaphram plate and an aluminium base, as shown in Fig. 'A' in this text.

A tight fit manufacture between the steel and aluminium piece so made, with an araldite as a material betwoen the joint gave the best results. Araldite not only provided the bond between the two pieces, but also provided very good water seal at the junction.

For sealing the gap between the terminals and the sides of the hole in the cell, bee wax, rubber araldite and many other materials were tried. Araldite filled in the whole and slightly projecting out gave the best results.

For joining the ring to the periphery of the diaphram riveting or soldering were tried. Rivetted joints completely failed while soldered joint stood pressure much more than the designed pressure.

Variable dimensioned cells with different types of joints and bonding had been tried. The dimension of three cells soldered at the periphery of the diaphram are given in Table No. 1. These cells were provided with tight fit joint and the joint bonded with araldite. Lesser diameters than shown in table No. 1 were tried. Their specific gravity was high and more over they showed erratic results when tested under plate bearing test in the field.

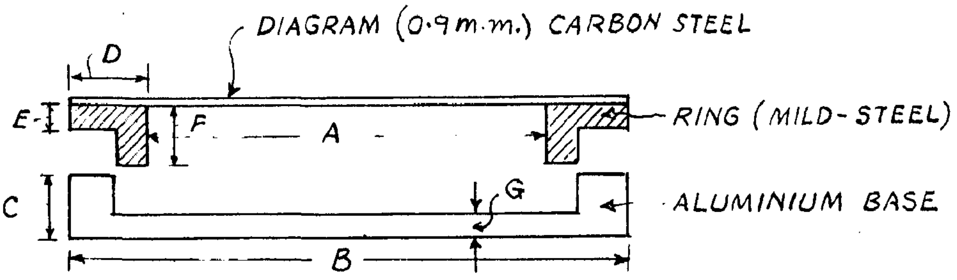


FIG. A :- CROSS-SECTION OF THE CELL TRIED.

FIG. A.

Cell No.	Dimensions in cm. Ref. Fig. 'A'							Specific Gravity of box
	A	B	C	D	E	E	G	
1.	5.5	6.0	0.4	0.45	0.15	0.45	0.183	3.57
2.	6.3	6.9	0.4	0.30	0.20	0.50	0.150	2.96
3.	6.3	6.9	0.4	0.30	0.20	0.40	0.220	3.14

Table No. 1.

All the three cells were found suitable. These cells were again tested in the field by placing them 1.5 cm. below the soil surface and loaded by means of 76 cm (30. in) diameter plate. They gave uniform results.

The cells were tested for moisture absorption by placing them in water for 3 days. No change in weight was noticed.

The results showed that any of the cells would be adopted. The best choice was therefore to adopt a cell of lowest specific gravity. Cell No. 3 was therefore adopted for manufacture. Due to manufacture on lathe, slight variations in diemensions were noted. Their specific gravity varied. In all 105 cells were manufactured, out of which 19 rejected mainly due to defect is water seal or inconsistant working of the strain gauges. The specific gravity of cells used for this investigation is given in table No. 2.

Table No. 2: Weight, Volume and Specific Gravity of Pressure cells.

S.no.	Cell No.	Weight in Gms.	Thickness in Gms.	Volume in Cm^3 37.4xCol.4	Specific Gravity $\frac{W}{V} = \frac{Col.3}{Col.5}$
1	2	3	4	5	6
1	2	53.71	0.59	22.06	2.43
2	3	60.76	0.65	24.31	2.50
3	4	63.98	0.65	24.31	2.66
4	5	63.54	0.64	23.93	2.65
5	6	58.45	0.61	22.82	2.56
6	7	61.41	0.64	23.93	2.56
7	8	62.55	0.66	24.68	2.53
8	9	61.55	0.63	23.56	2.61
9	10	63.01	0.66	24.68	2.55
10	11	62.81	0.69	25.80	2.43
11	12	62.79	0.63	23.56	2.66
12	13	62.08	0.65	24.31	2.56
13	14	54.24	0.65	24.31	2.23
14	15	57.11	0.69	25.80	2.21
15	16	54.48	0.60	22.44	2.43
16	18	63.38	0.69	25.80	2.46
17	19	61.97	0.62	23.18	2.67
18	20	62.31	0.63	23.56	2.69
19	21	59.20	0.64	23.93	2.47
20	22	58.44	0.69	25.80	2.27
21	23	56.90	0.65	24.31	2.34
22	24	63.44	0.65	24.31	2.61
23	25	60.72	0.61	22.82	2.66
24	26	58.05	0.62	23.18	2.51
25	27	60.36	0.59	22.06	2.74
26	28	55.56	0.62	23.18	2.40
27	29	58.81	0.62	23.18	2.54
28	31	61.97	0.64	23.93	2.59
29	33	59.16	0.61	22.82	2.59
30	35	58.81	0.64	23.93	2.46
31	36	62.36	0.62	23.18	2.69
32	39	66.41	0.68	25.42	2.61
33	40	55.15	0.63	23.56	2.34
34	41	65.00	0.68	25.42	2.55
35	42	61.44	0.61	22.82	2.69
36	43	61.53	0.64	23.93	2.57
37	44	60.08	0.62	23.18	2.62
38	45	59.01	0.62	23.18	2.55
39	46	60.39	0.64	23.93	2.52
40	47	57.01	0.61	22.82	2.50
41	48	61.37	0.66	24.68	2.46
42	49	62.79	0.65	24.31	2.58
43	51	62.20	0.62	23.18	2.69

1	2	3	4	5	6
44	52	62.18	0.64	23.93	2.60
45	53	64.66	0.66	24.68	2.62
46	54	60.91	0.66	24.68	2.47
47	55	57.52	0.68	25.43	2.26
48	56	58.23	0.65	24.31	2.40
49	57	57.45	0.60	22.44	2.56
50	58	60.45	0.63	23.56	2.57
51	59	57.36	0.62	23.18	2.48
52	60	60.85	0.61	22.82	2.67
53	61	60.70	0.63	23.56	2.58
54	62	64.87	0.66	24.68	2.63
55	63	60.99	0.63	23.56	2.58
56	64	53.37	0.57	21.32	2.55
57	65	56.24	0.61	22.82	2.47
58	66	59.08	0.66	24.68	2.39
59	67	57.97	0.62	23.18	2.50
60	68	62.15	0.62	23.18	2.68
61	69	57.24	0.60	23.44	2.55
62	70	60.32	0.65	24.31	2.48
63	71	59.28	0.60	22.44	2.64
64	72	61.85	0.64	23.93	2.58
65	73	60.26	0.67	25.05	2.41
66	74	55.18	0.56	20.94	2.64
67	75	55.69	0.59	22.06	2.52
68	78	61.29	0.66	24.68	2.49
69	79	58.87	0.68	25.42	2.32
70	81	58.11	0.59	22.06	2.63
71	82	52.67	0.57	21.31	2.47
72	84	57.13	0.65	24.31	2.35
73	85	62.89	0.68	25.42	2.47
74	86	56.40	0.62	23.18	2.43
75	87	59.03	0.60	22.44	2.63
76	88	63.23	0.66	24.68	2.56
77	89	60.98	0.65	24.31	2.51
78	90	59.62	0.63	23.56	2.53
79	91	55.85	0.54	26.19	2.77
80	92	58.53	0.55	20.57	2.84
81	93	57.38	0.62	23.18	2.47
82	95	62.64	0.65	24.31	2.58
83	97	49.32	0.54	20.19	2.44
84	99	57.57	0.59	22.06	2.61
85	102	55.35	0.61	2.82	2.43
86	103	59.83	0.68	25.43	2.36

7.6. DESIGN ADOPTED :

As a result of the above mentioned investigations the following design of the cell was adopted. The cell consisted of three parts each of different material. (i) Aluminium base (ii) Mild steel ring and (iii) Carbon steel plate obtained from the blades. The carbon steel diaphram was soldered by means of tin-lead to the ring. The strain gauge was then cemented on the inside surface of the diaphram. The preparatory and cementing procedure for strain gauge has been described in para 7. Araldite was then spread over the proposed contact surfaces of the ring and the aluminium plate and also in the hole for the wires. The ring with the diaphram was then hard pressed into the aluminium disc. The whole assemply was pressed in a jack for about 12 hours. As a precautionary measure, a thin coat of araldite over the rim was provided. The cell so formed was allowed to dry in dessicator for 3 days. The cell was then painted with plastic paint, and the paint allowed to dry. After the paint had dried the cells were checked for water absorption by keeping them in water for 3 days. If no absorption of the cell was noticed and the strain gauge showed continuity but discontinuity with the metal box, the cell was thought to be satisfactory.

As a further precaustions at later stage about 50 p.c. of the cells were dipped in rubber solution and then dried.

The cells were later calibrated as discussed later in para No. 7.7.

7.7. The different methods of calibration and the experience of the author is discussed in para No. 5. About 100 cells were calibrated by the author in SAE 30 Mobil oil and in the chamber shown in Fig. 52.

The calibration curves are shown from Fig. 54 to 73.

8. INSTALLATION OF CELLS :

Great care has to be taken while installing the pressure cells. As the cells measure stresses normal to the cell face only, the cells were installed horizontally, parallel to the base of the proposed slab. The horizontality of the cell face was checked with a round spirit level.

BIBLIOGRAPHY

1. Soil Pressure Cells. Proc. Am. Rly. Engg. Assn. 1950, 51 p 711-719.

2. Third progress report on soil pressure cells Proc. Am. Rly. Engg. Assn., 1951, 52 p. 482-9.

3. Benkelman, A.C., & Lancaster, R.J., Some important considerations in the design and use of soil pressure cells - Proc. High Res. Bd., 1941, 20, p 299-313 or Public Roads 1940/41 Vol. 20 Nr. 12 p. 235-243.

4. Cooper, A.M., & others; Strain gauge cell measures soil pressu Agricul. Engg. - 1957, 38 p. 232-5.

5. Evans, W.H., ; Dynamometer for measuring ground pressures- Engg. 1940, 149, p. 433-4.

6. Gold beck, A.T.- Soil pressure cell measures accurately to tenth of pound. Public Roads 1920, 3 (28), p. 3-6.

7. Goldbeck, A.T., & Smith, E.B., ; An apparatus for determining soil pressures - Proc. A.S.T.M., 1916, Vol. 16. p. 309-319

8. Torsten Kallstenius and Werner Bergau; W., ; Investigations of soil pressures, measuring by means of cells Proc., No. 12 Royal Swedish Geotechnique Institute 1956, No. 12.

9. Morrison, I.F., & Cornish, W.E., Description of a pressure cell for the measurement of earth pressures - The Engineer, 1940, 169 p. 504.

10. Peattie, K.R. & Sparrow, R.W., A review of the design of earth pressure cells - Civil Engineering (L) 1955, 50-P. 872-6.

11. Pbantema, G., A soil pressure cell and calibration equipment Proc. 3rd Int. Conf. S.M. & F.E., Zurich, 1953, 1, p.283-6.

12. Pbantema , G., Soil pressure measurements during loading tests on a runway-ibid p. 289-98.

13. Redshaw, S.C., ; A sensitive miniature pressure cell. Journal of Scientific Instruments 1954, Vol. 31 p. 467-9.

14. Seaquist, W.H. Accuracy of Goldbeck cells in laboratory tests Engineering News Record, 1934, 112 p. 730-2.

15. Carlson, R.W., Five years of improvement of the elastic wire strain meter- Engineering News Record, 1935, 114(20 p. 696-7.

16. Huntington, W.C., & Luetzel Schwarz, E.J., New type of pressure cell for granular material - Engg. News Record, 1936, 116(1) p 20-2.

17. Steyn. A.K., Pressure cells. Trans. S.A. Inst. of Civil Eng. 1951 1, p. 282.

18. Woodman, W.H., Pressure cells for field use - U.S. Waterways Experiment Station Bulletin, 1955, 40.

19. Taylor, D.W., Review of pressure distribution theories, Earth pressure cell investigations and pressure distribution data Progress Report. U.S. Waterways Experiment Station. Bull. 1947.

20. Corps of Engineers, U.S. Army Investigations of Pressures and deflections for flexible pavements. Report No. 4 T.M. No. 3-223, Waterways Expt. Station - 1954.

21. Mossison & Cornish - Description of a pressure cell for the measurement of earth pressures - Canadian Jnl. of Res. 1939, 17 (11).

22. Smith, F.D., & Luxford, C.A. - Stress measurement by Magnetostriction - Proc. Inst. of Mech. Engr. 1940, 143 p. 56.

23. Whiffin, A.C., and Smith, R.T. A gauge for measuring sustained stresses in soil. The Engineer, July 6, 1951.

24. Monfore, G.E., ; An analysis of the stress distribution in and near stress gauges embedded in elastic solids U.S. Burn. of Reclam. Structural Lab. Report, No. S.P.26, Denves, Col. June 1950.

25. Soil pressure cell investigation. Tech. Memorandum No. 201-1 U.S. Waterway Experiment Station. Vicksburg Miss. July 1944. Interim report, Vicksburg. Miss. U.S.A. July 1944.

26. Trollope and I.K.Lee- Measurement of soil pressures - Proc. 5th Int. Conf. of Soil Mechanics and Fund. Engg. 1961 P 493.

27. Wikramaratna - Proc. 5th Int. Conference of soil Mech. & Found Engg. 1961 page 509.

28. Kogler F. and Scheidig A., " Druckverteiting im Baugrunde" No. 31-1927.

29. Waben C. Ett. Fall av. deformation; halvoandlight elastiskt medium. Tekn Ts 72 (1942) H. 34 p.1185-1200.

30. McMahon T.F. and Yoder E.Y. "Design of Pressure sensitive cell and Model studies of pressure in a flexible pavement. " H.R.B. Proc. Vol. 39 page 650 - 1960.

31. Corps of Engineers, U.S. Army -"Pressure cells for field use" U.S. Waterway Experiment Station Vicksburg, Miss - 1955.

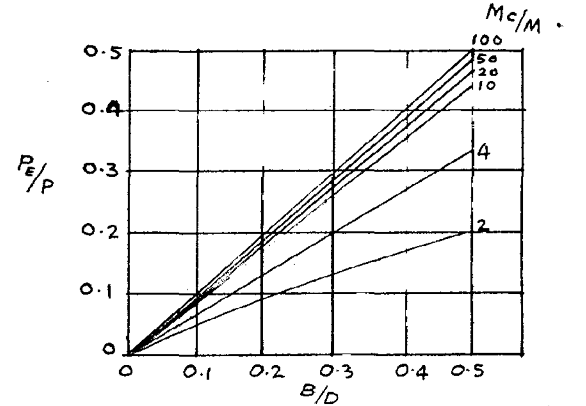
32. Becklam A.C. and Lancaster R.J. - " Some important considerations in design and use of soil pressure cells." Public Roads U.S.A. Vol. 21 No. 12 235, Feb. 1941.

33. Morris S.A.H. " The R.R.L. Piezoelectric pressure gauge. Road Research note No. RN/4043/SAHM. Sept. 1961 Revision of RN/1896.

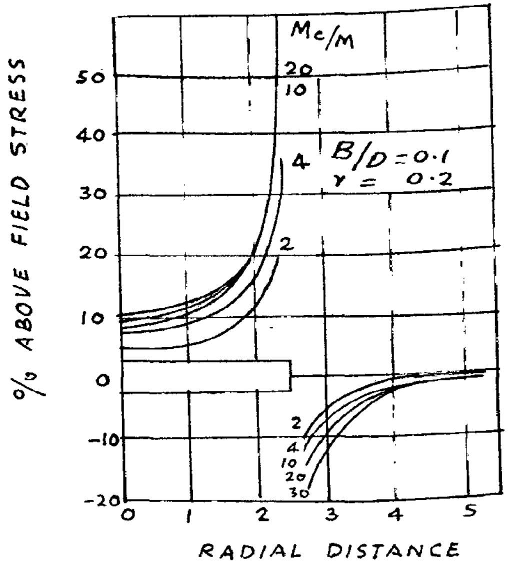
34. Wikramaratra P.H.D.S. " A new earth pressure cell." Proc. of 5th Int. Conf. of Soil Mechanics and Found. Eng. 1961-p. 509.

35. Timoshenko.S, Theory of Plates and Shells - Mcgraw Hills. Chap. 111.

36. Shinkok products catalogue No. 151, Mc. 60; 30(s). Issued by Shinkok Communication Industry Co., Ltd., No. 760, Sakurayama, Zushi-shi, Kanagawa - Ken Tokyo.

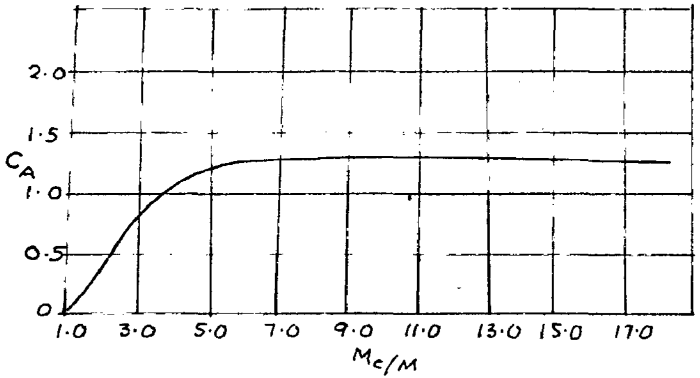


VARIATION OF CELL ERROR WITH B/D AND Mc/M FOR N/M = 1



MONFORE'S RESULTS

FIG. 43.



VARIATION OF C_A WITH Mc/M

FIG. 44.

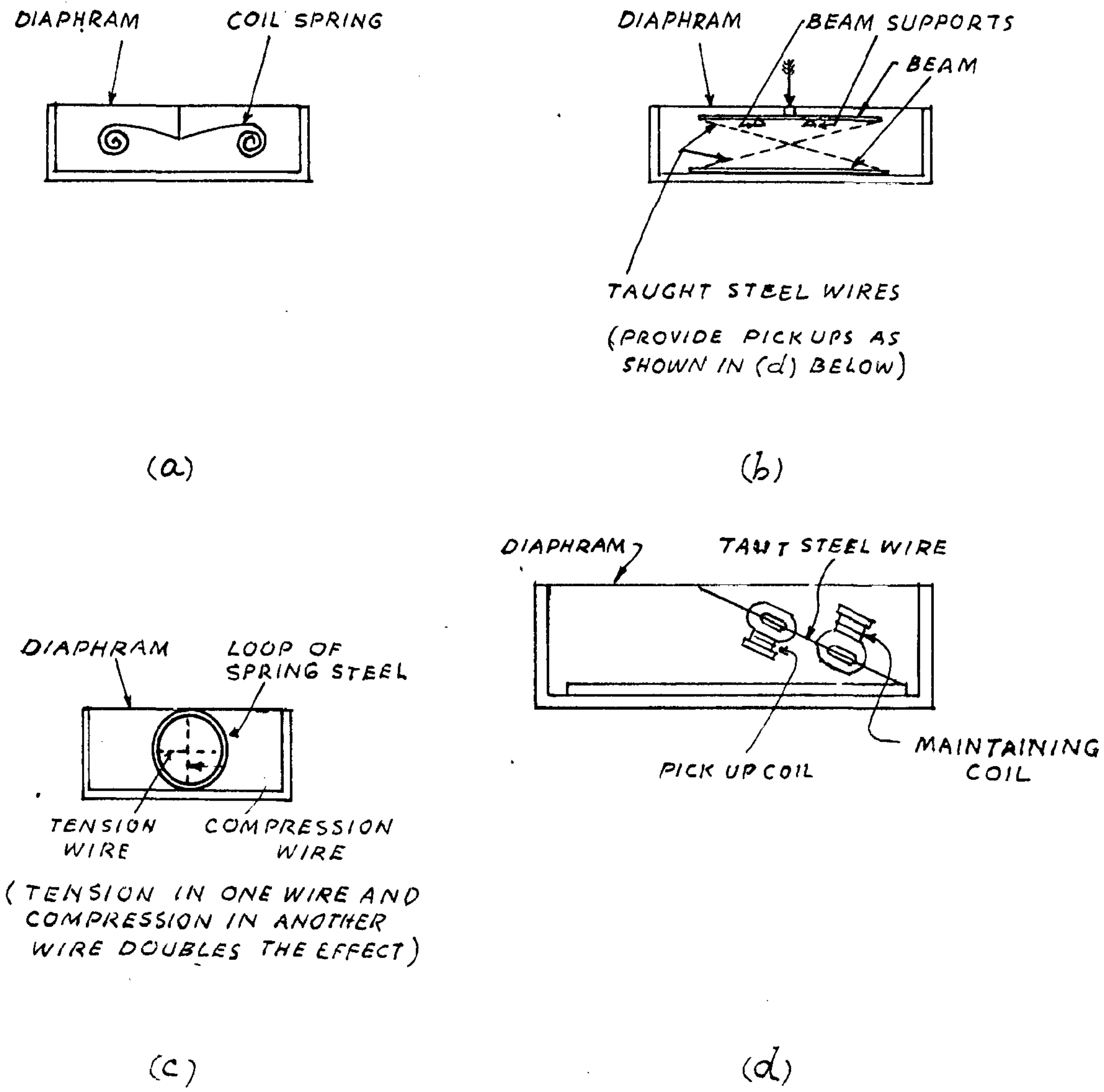


FIG. 45 — DIAGRAMMETIC SKETCHES OF ACCOUSTIC TYPE PRESSURE CELLS.

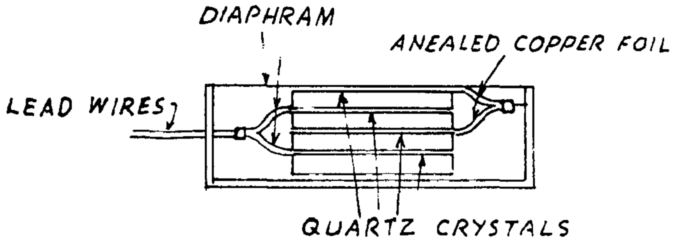
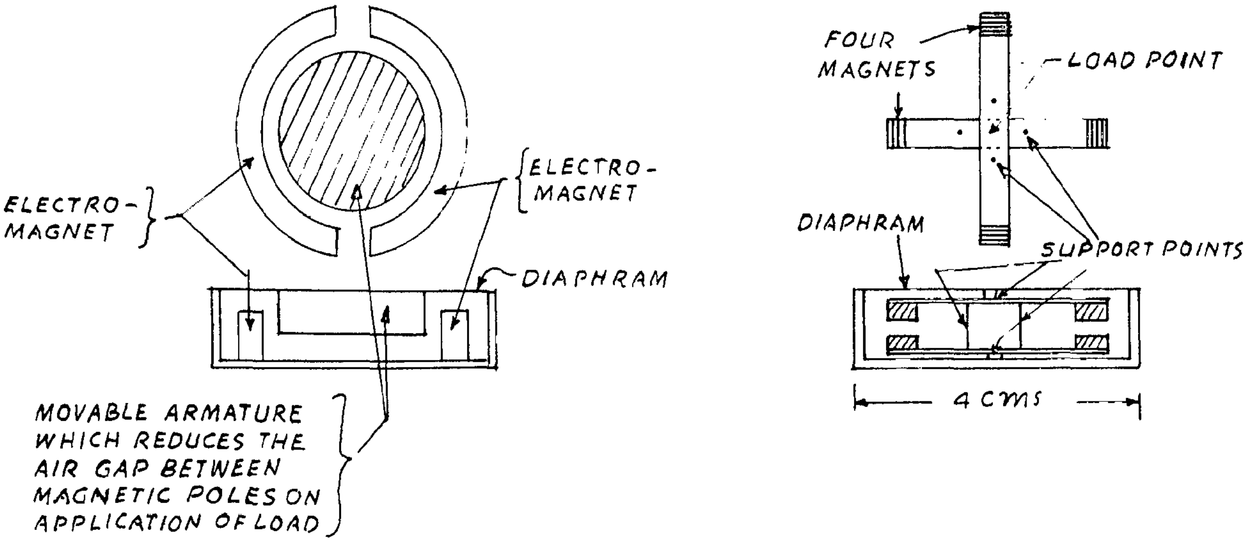


FIG. 46:- PIEZOELECTRIC CELL.



(a) (b)

FIG. 47 - DIAGRAMMETIC SKETCH OF ELECTRO MAGNET TYPE PRESSURE CELLS.

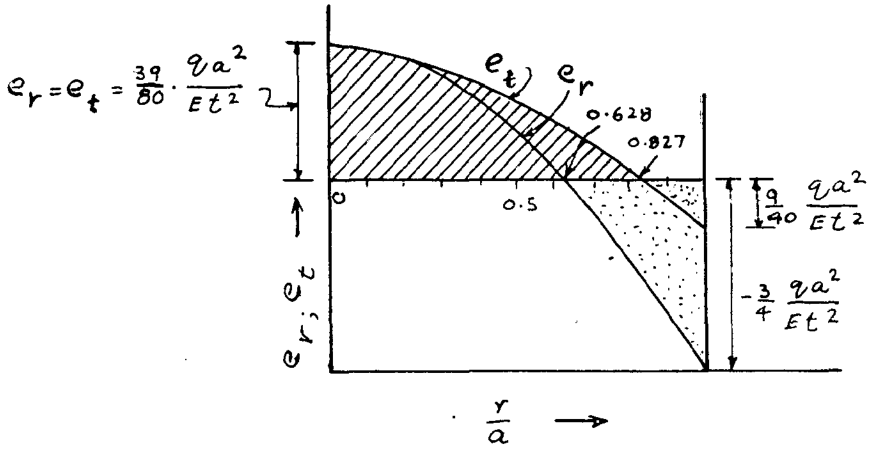
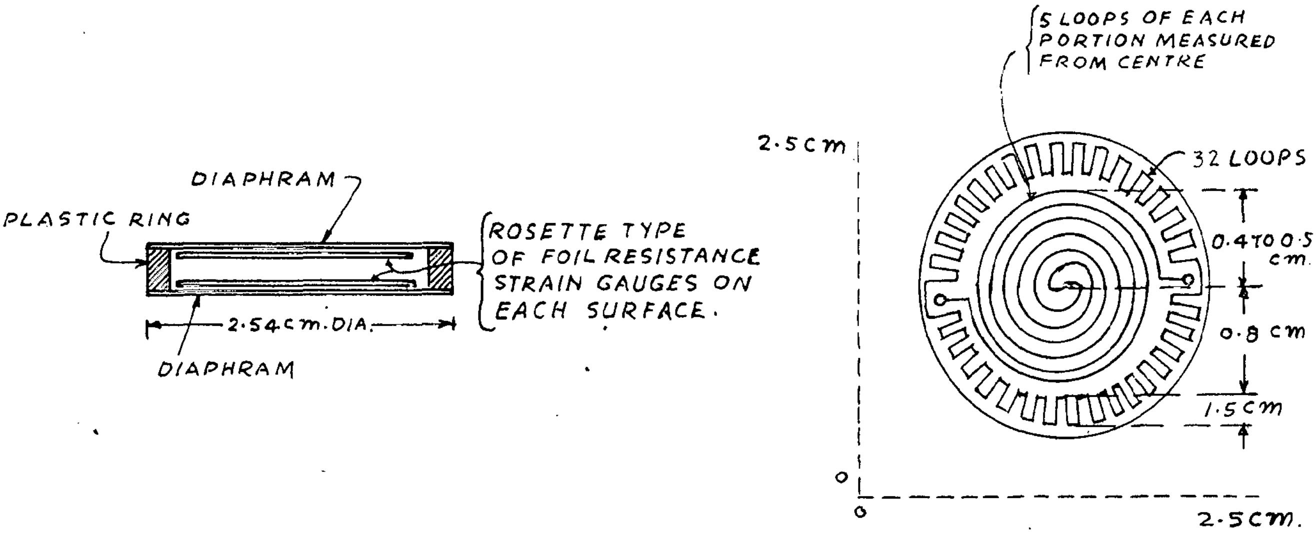


FIG. 49 — RADIAL AND TANGENTIAL STRAINS OF LOWER FACE OF A UNIFORMLY LOADED CIRCULAR PLATE FIXED ALONG ITS PERIPHERY, TAKEN ALONG ANY RADIUS, FOR $u = 0.3$.



REDSHAW CELL

FIG. 50 — REDSHAW CELL. IT CONSISTS OF TWO GAUGES DOUBLE SPIRAL PATTERN FOR MEASURING CIRCUMFERENTIAL STRAIN. (2) RADIAL PATTERN FOR MEASURING THE STRAIN OF OPPOSITE SIGN IN THE OUTER REGION.

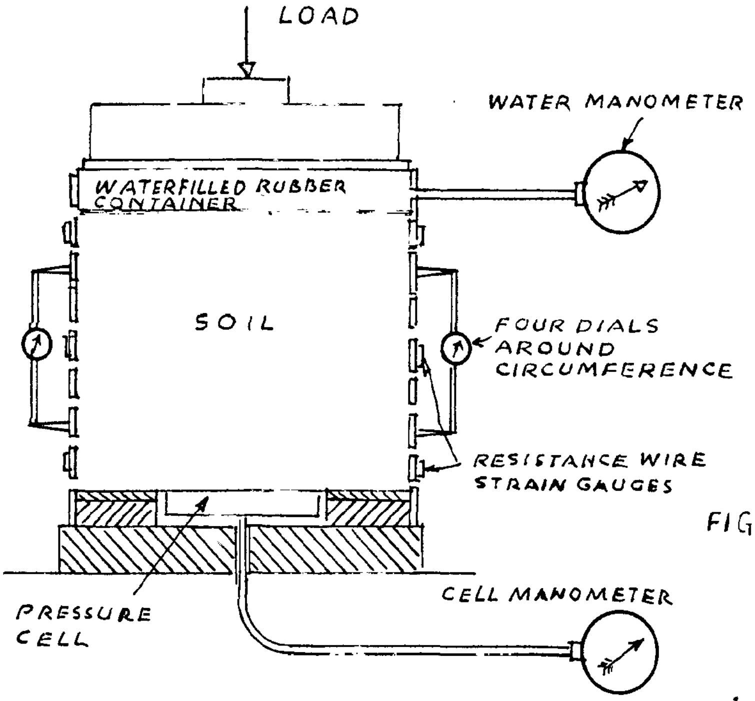


FIG. 51(a) CALIBRATION SET UP. (SWEDISH GEOTECH. INSTT. TYPE.)

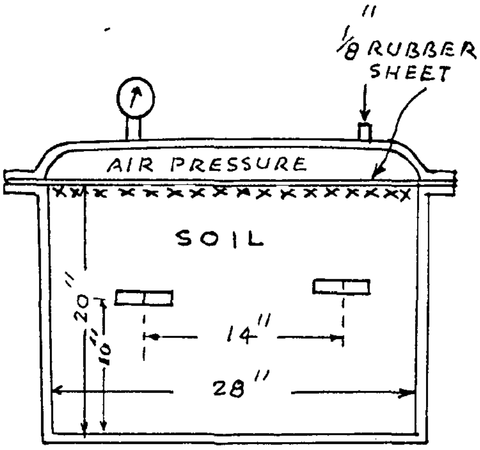


FIG. 51(b) CALIBRATION SET UP (WATER WAY EXPERIMENTAL STATION TYPE)

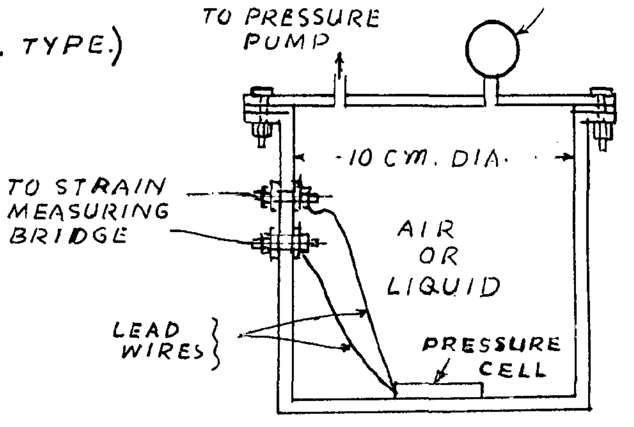


FIG. 52. - CYLINDRICAL CHAMBER FOR CALIBRATION OF PRESSURE CELLS.

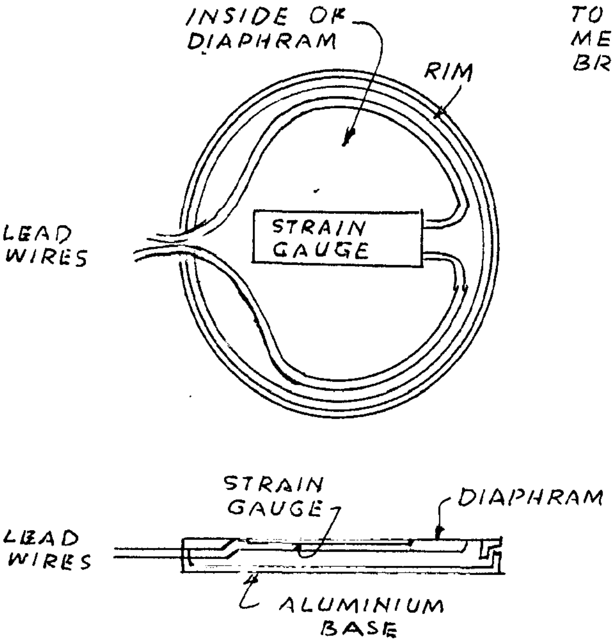


FIG. 53(a) PRESSURE CELL.

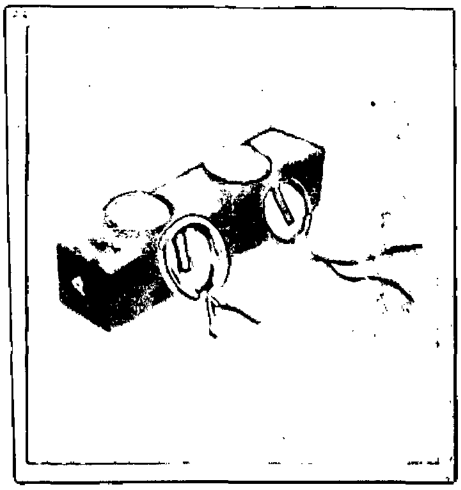


FIG. 53(b). PRESSURE CELL.

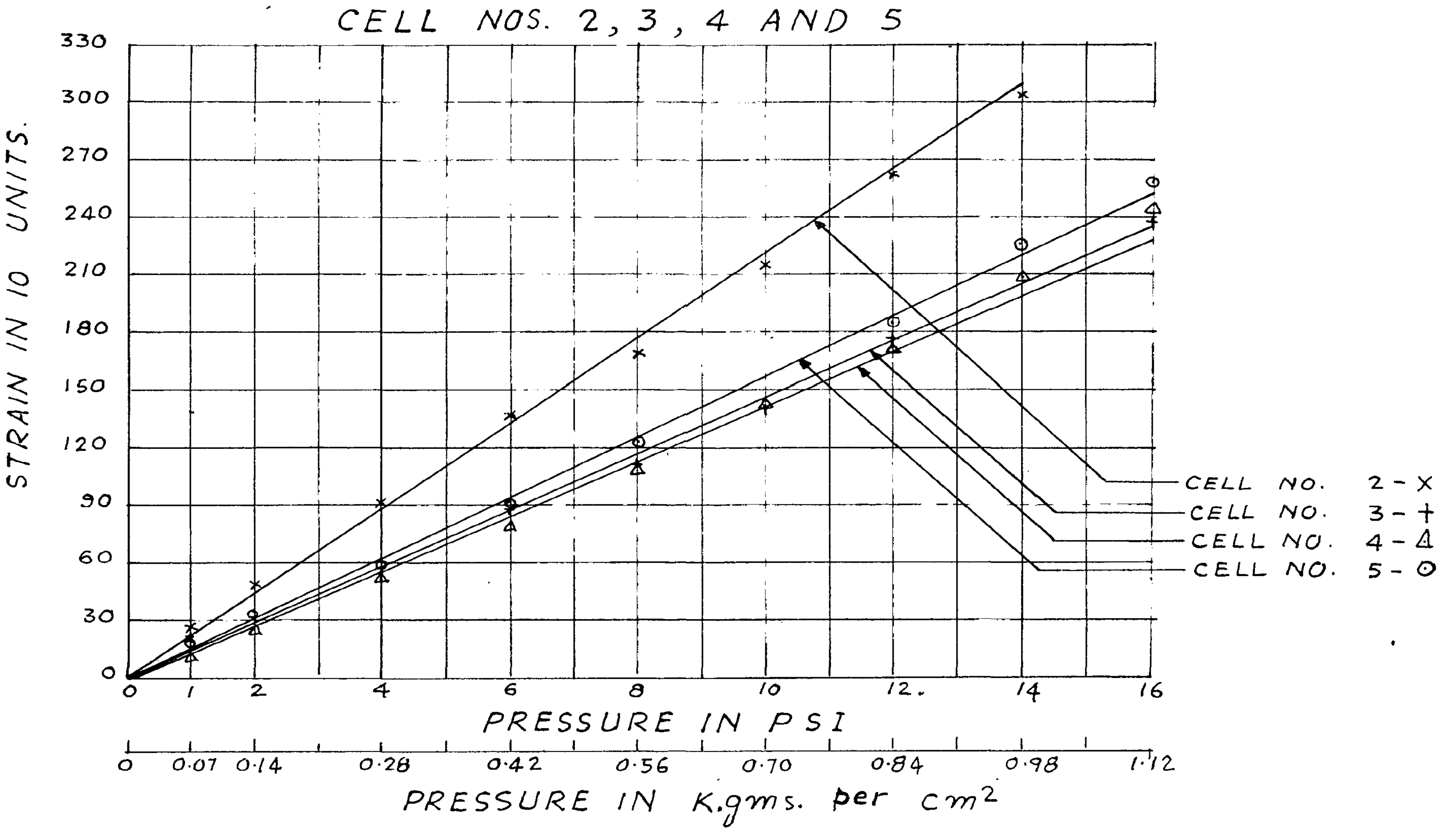


FIG. 54 - CALIBRATION CHART OF PRESSURE CELLS.

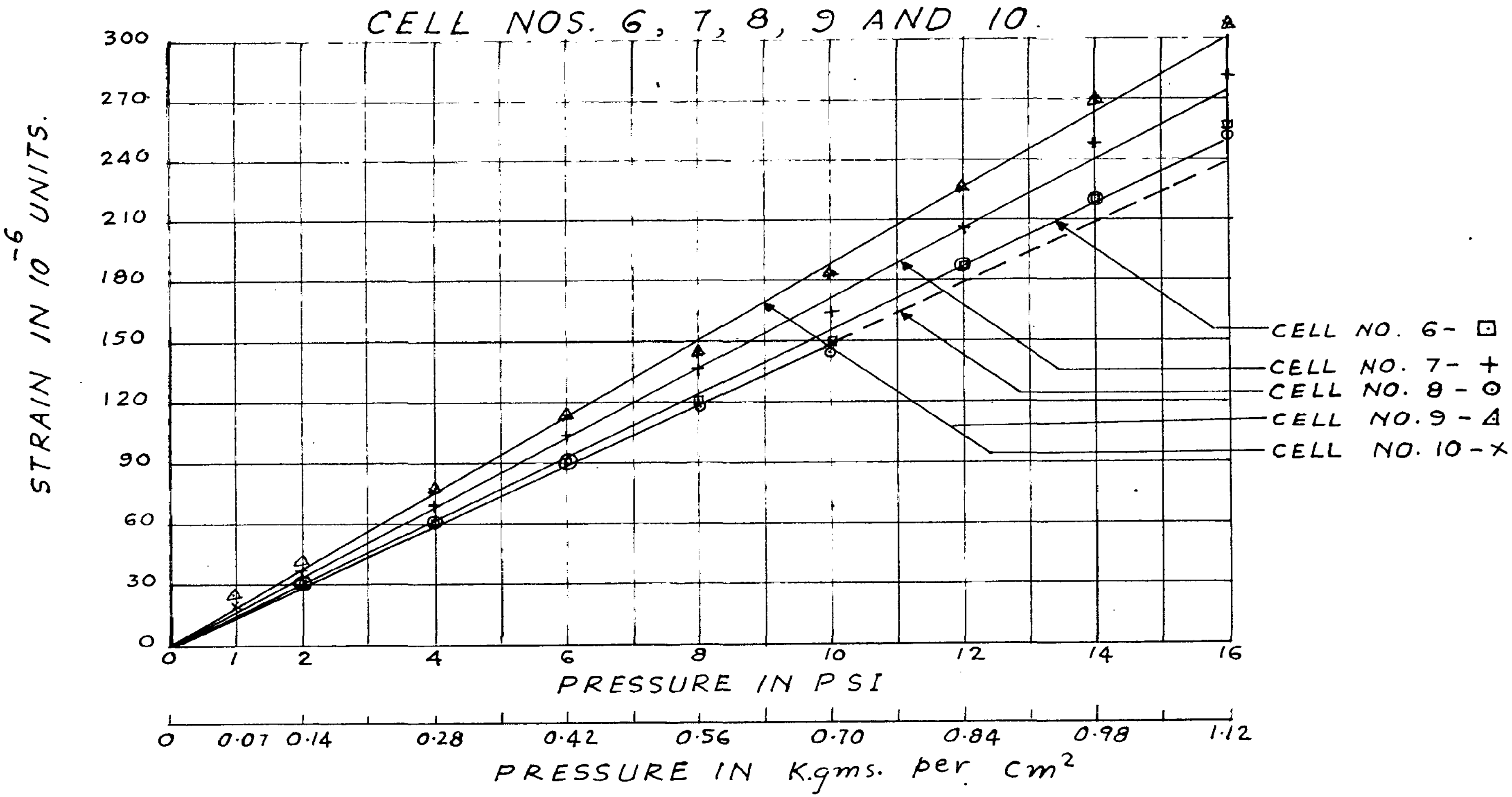


FIG. 55 – CALIBRATION CHART OF PRESSURE CELLS.

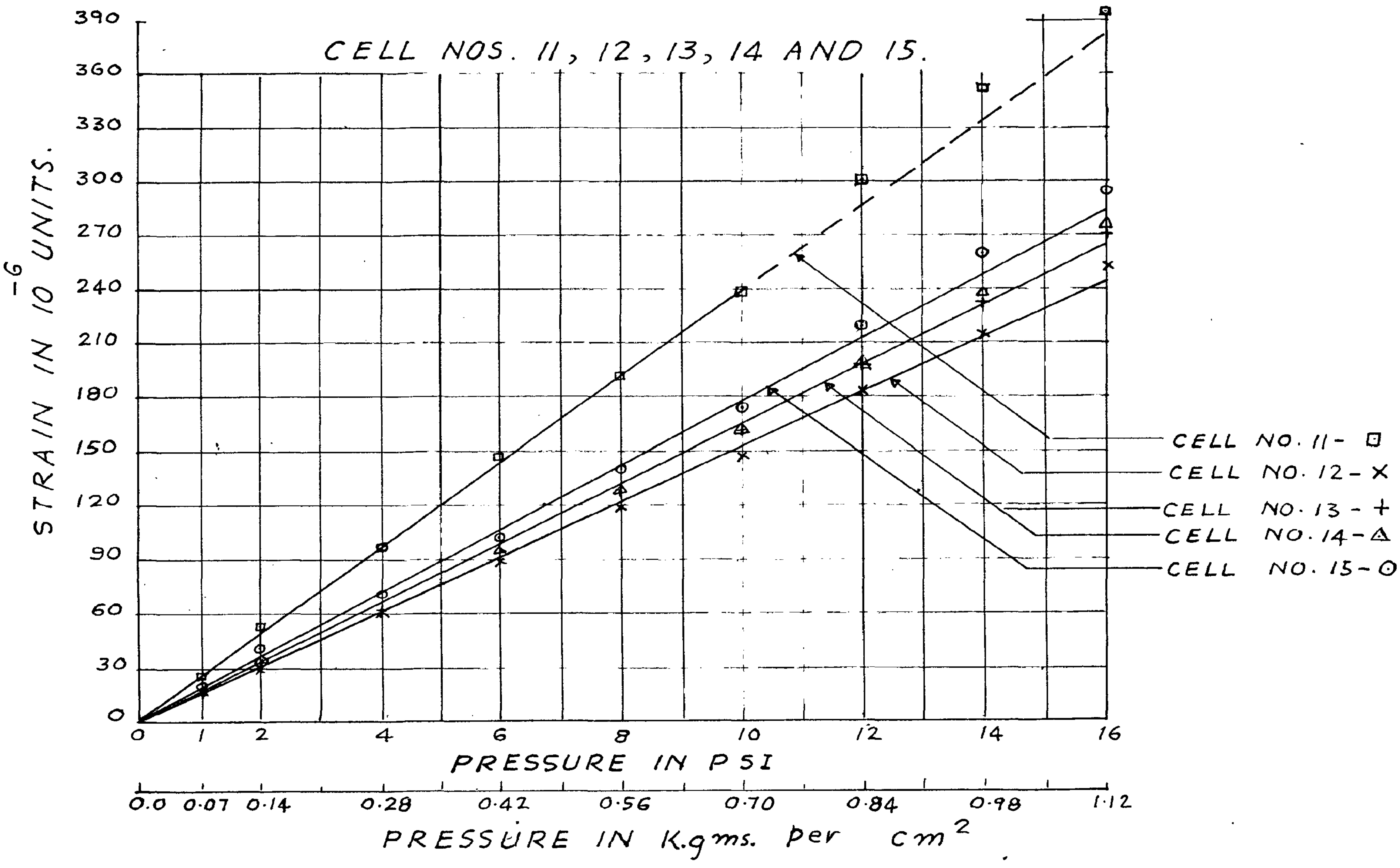


FIG. 56 – CALIBRATION CHART OF PRESSURE CELLS.

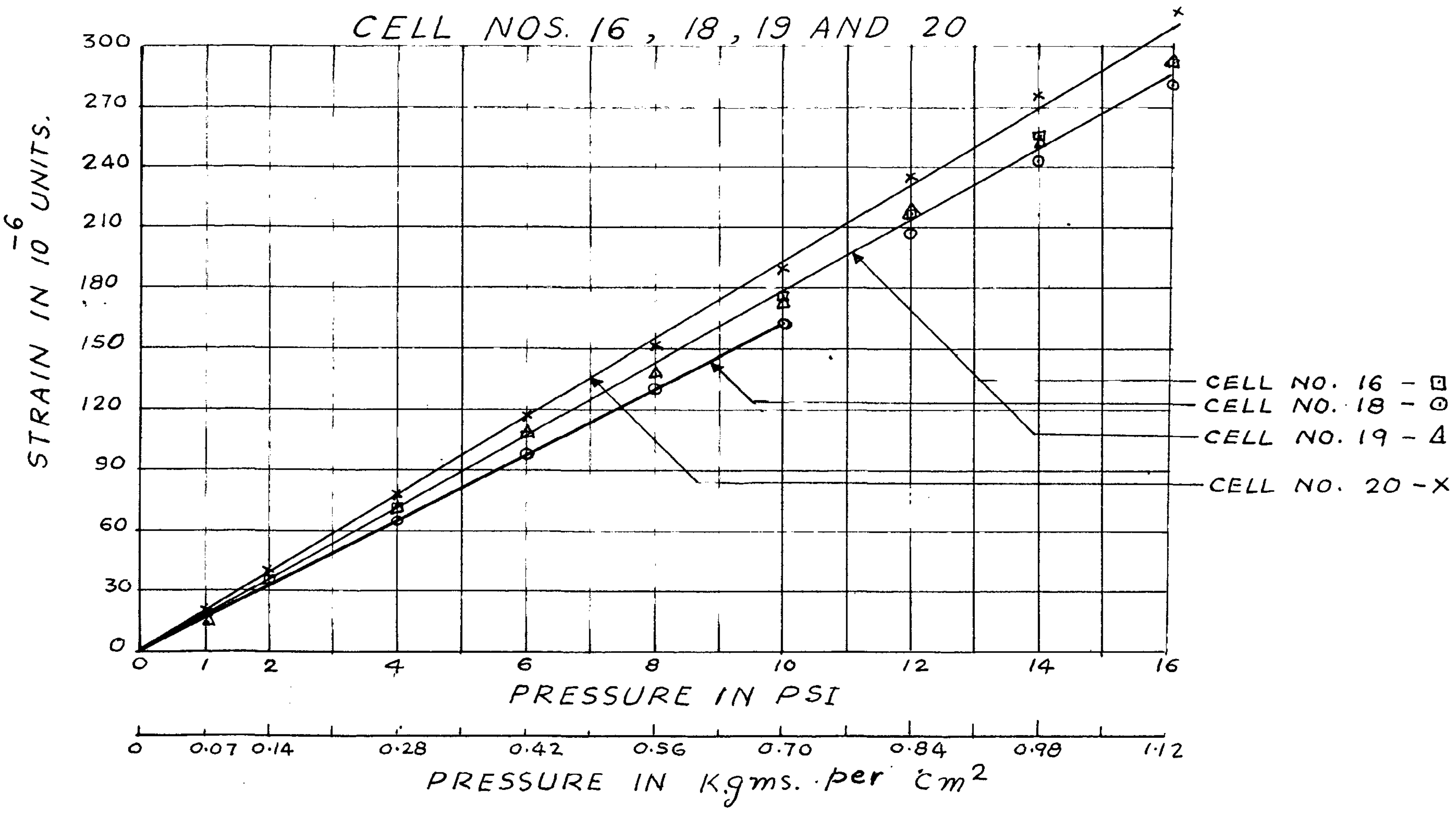
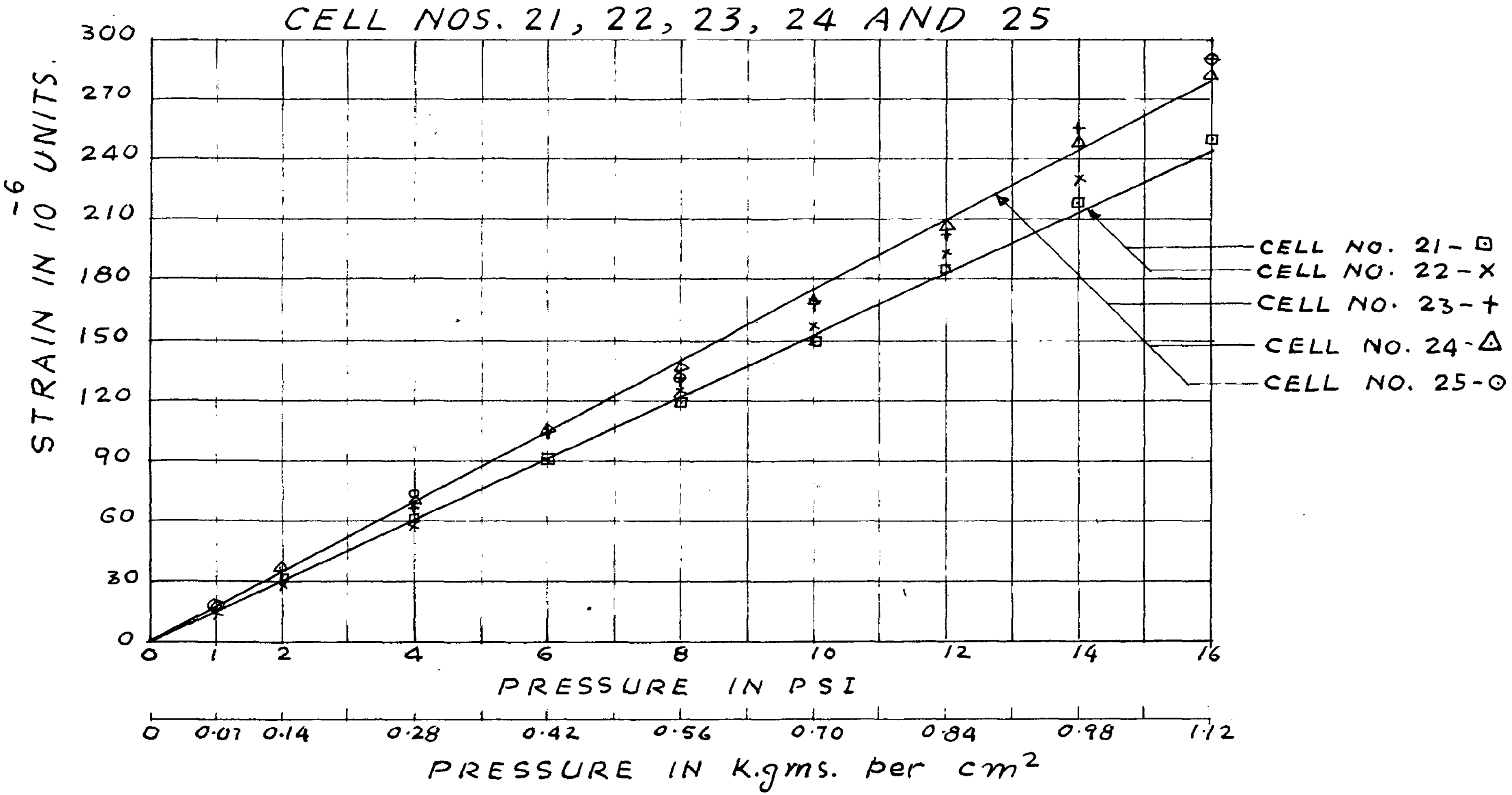


FIG. 57 – CALIBRATION CHART OF PRESSURE CELLS.



CELL NOS. 21, 22, 23, 24 AND 25

FIG. 58– CALIBRATION CHART OF PRESSURE CELLS.

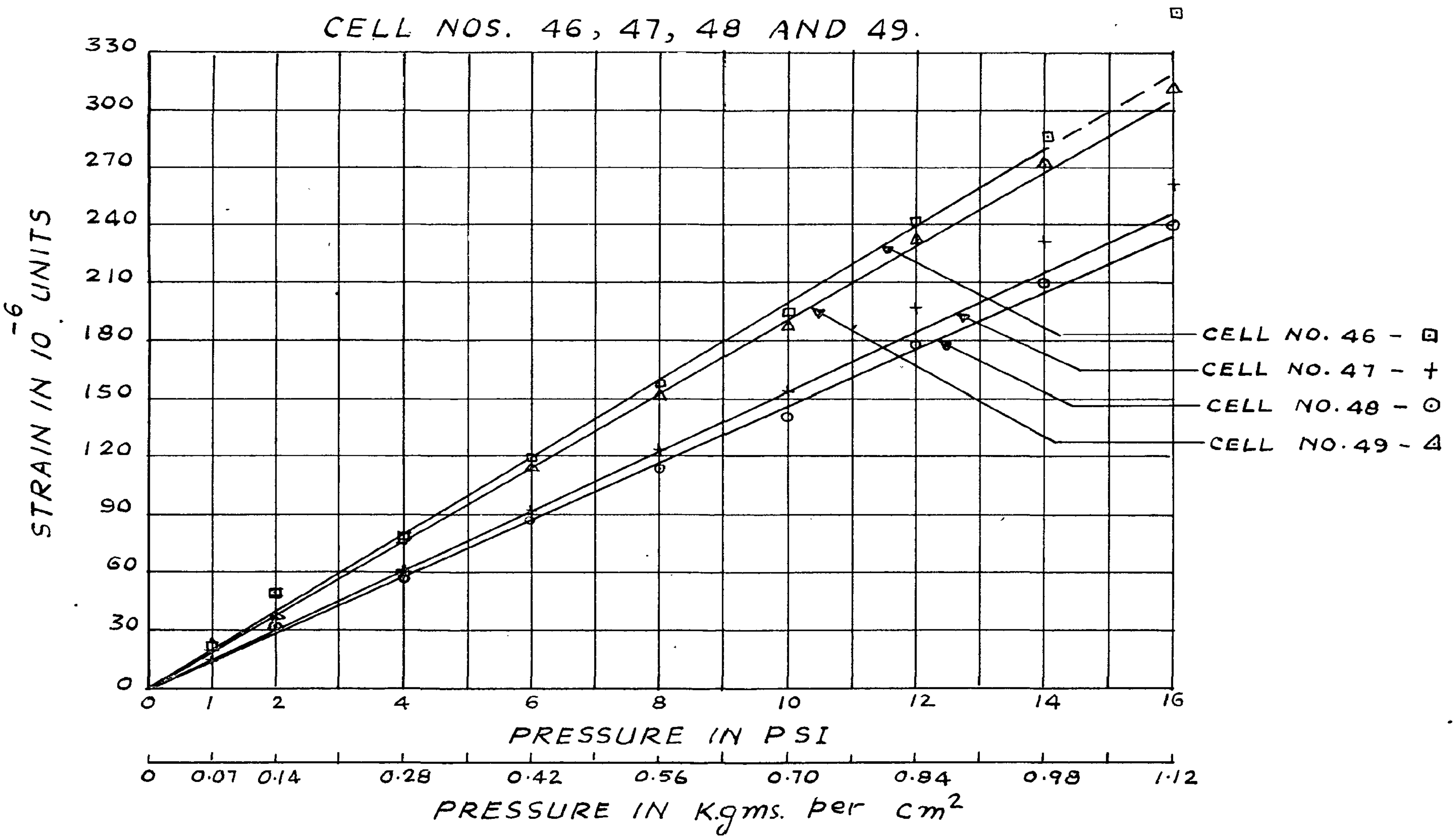


FIG. 63 – CALIBRATION CHART OF PRESSURE CELLS.

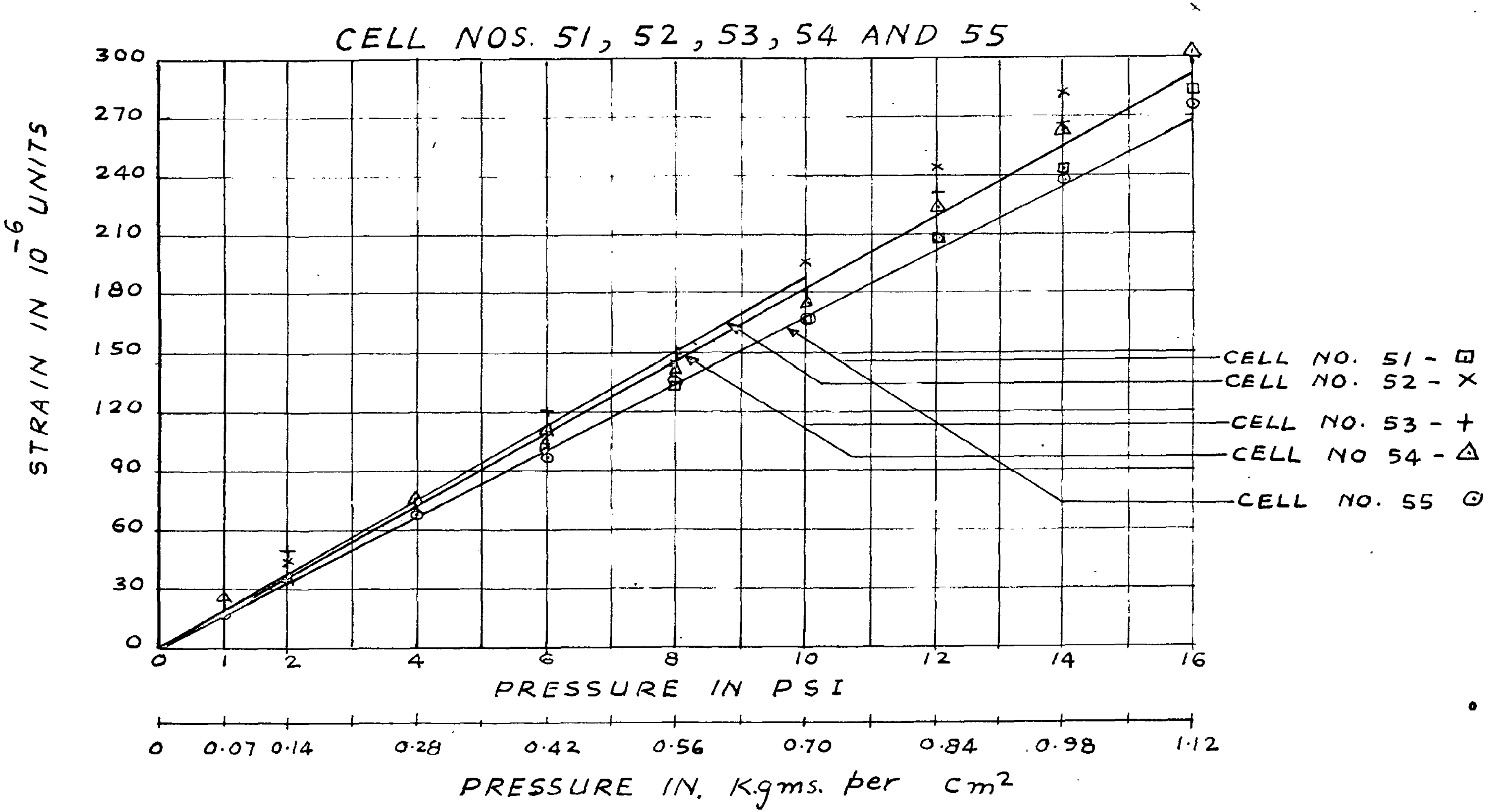


FIG. 64 - CALIBRATION CHART OF PRESSURE CELLS.

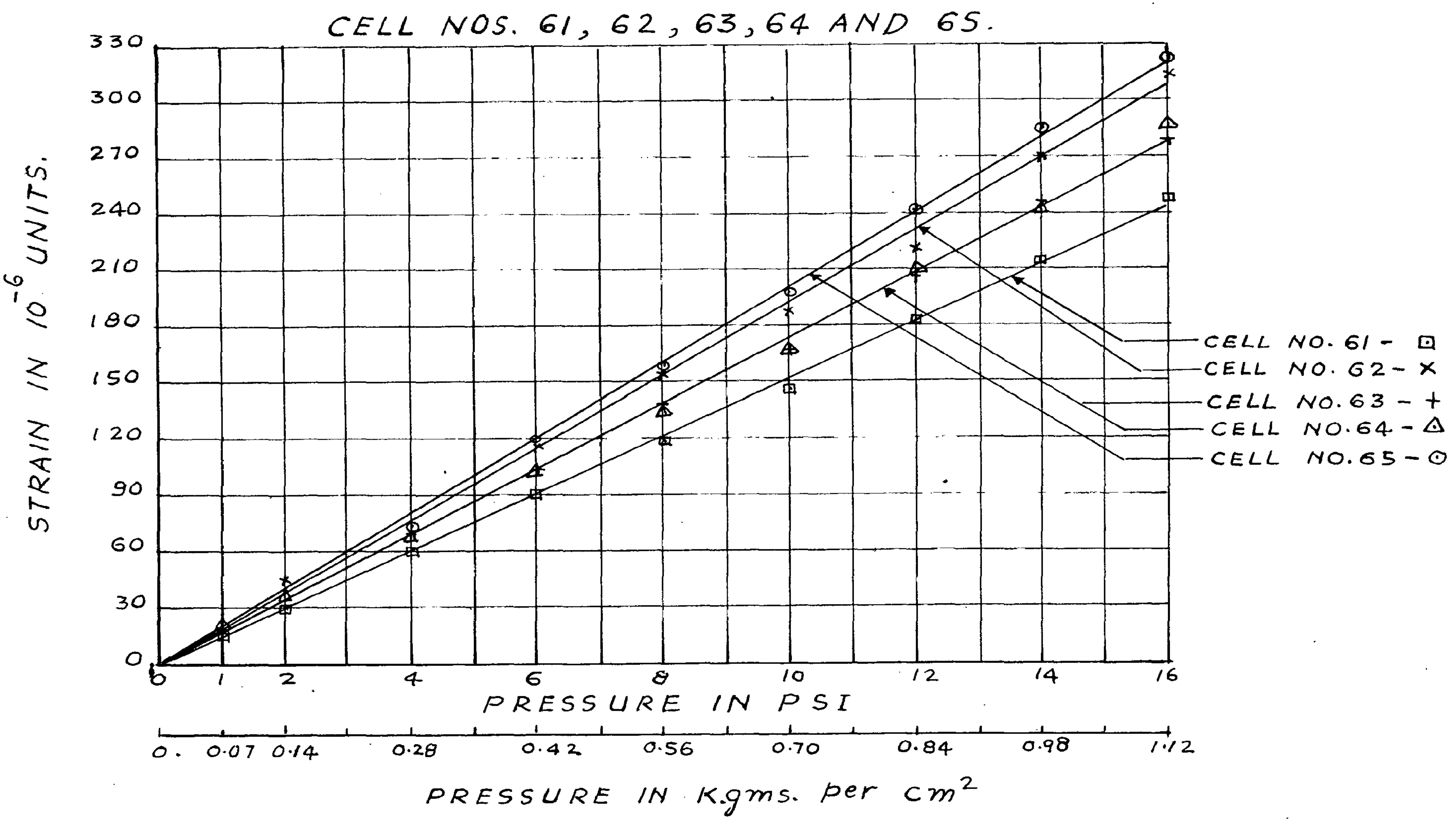


FIG. 66 - CALIBRATION CHART OF PRESSURE CELLS.

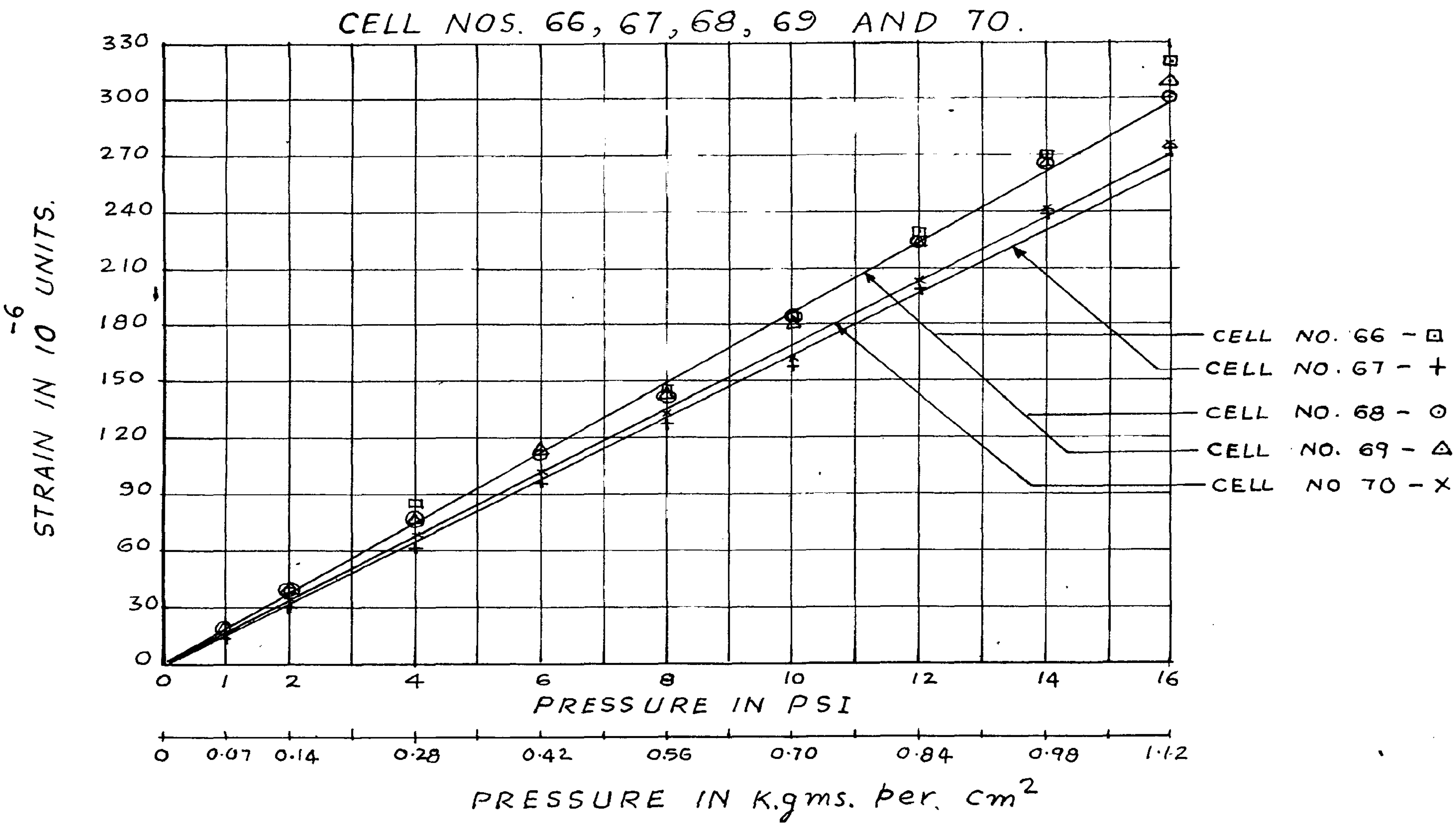
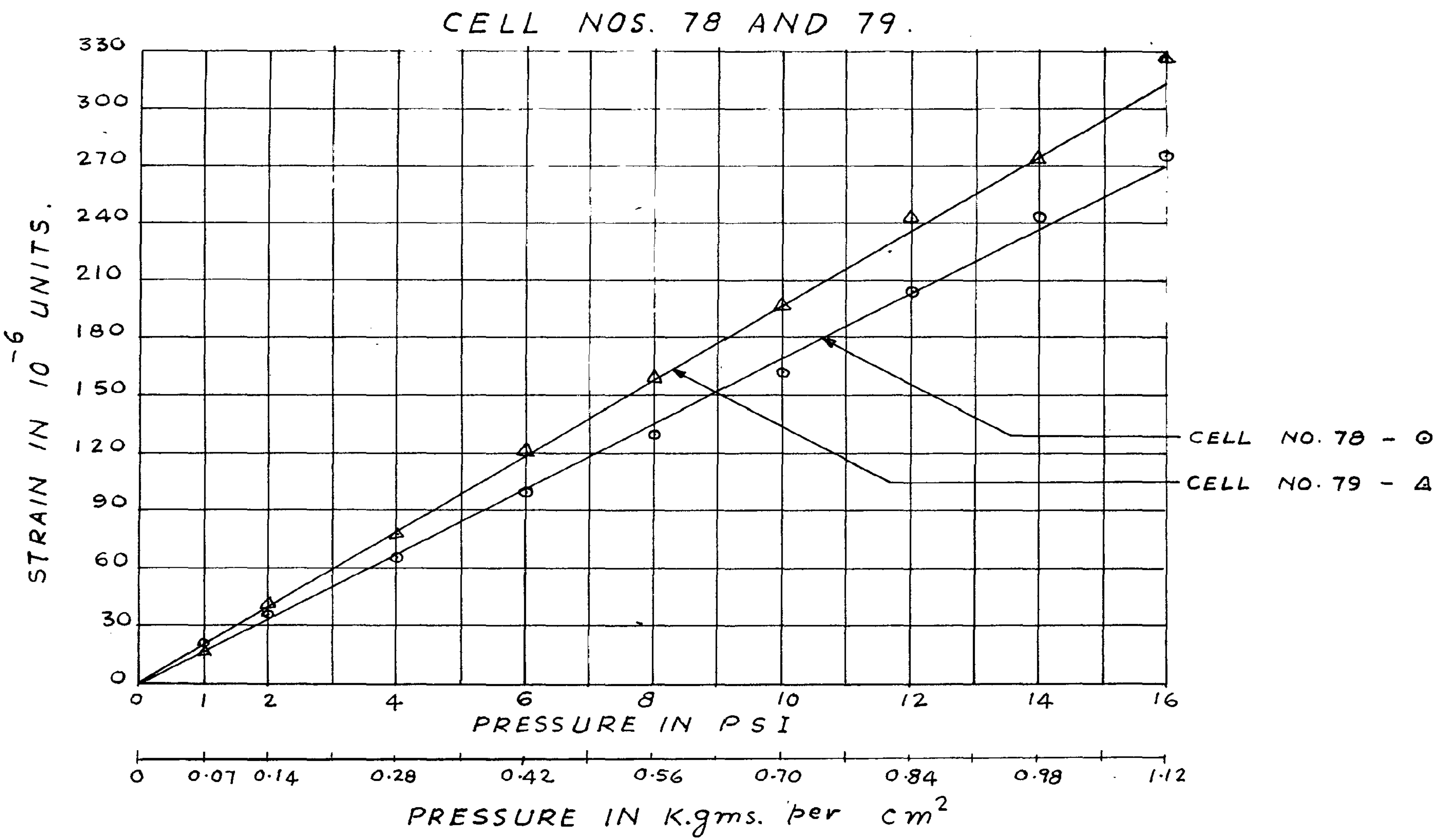


FIG. 67 - CALIBRATION CHART OF PRESSURE CELLS.



CELL NOS. 78 AND 79.

FIG. 69- CALIBRATION CHART OF PRESSURE CELLS.

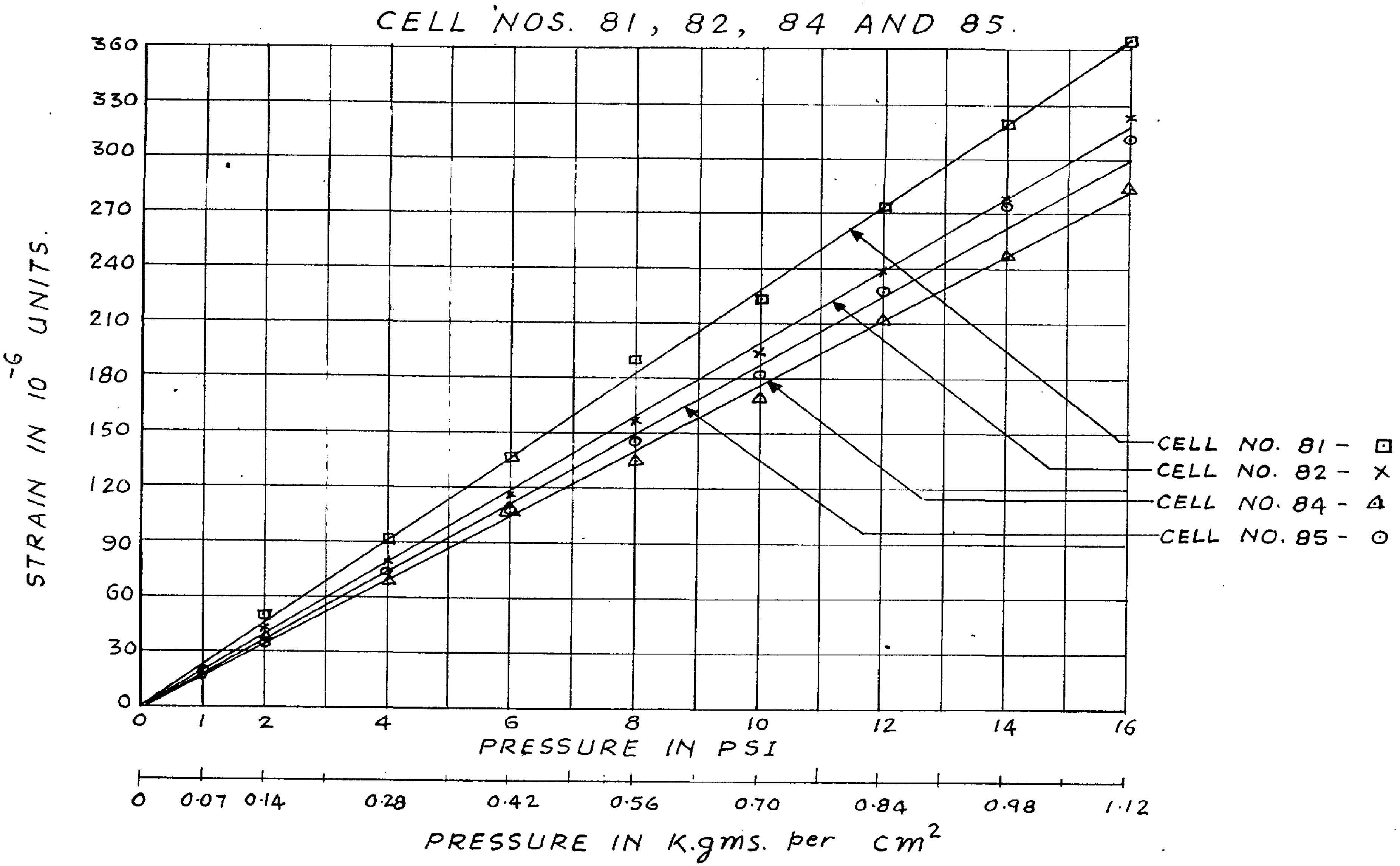


FIG. 70 – CALIBRATION CHART OF PRESSURE CELLS.

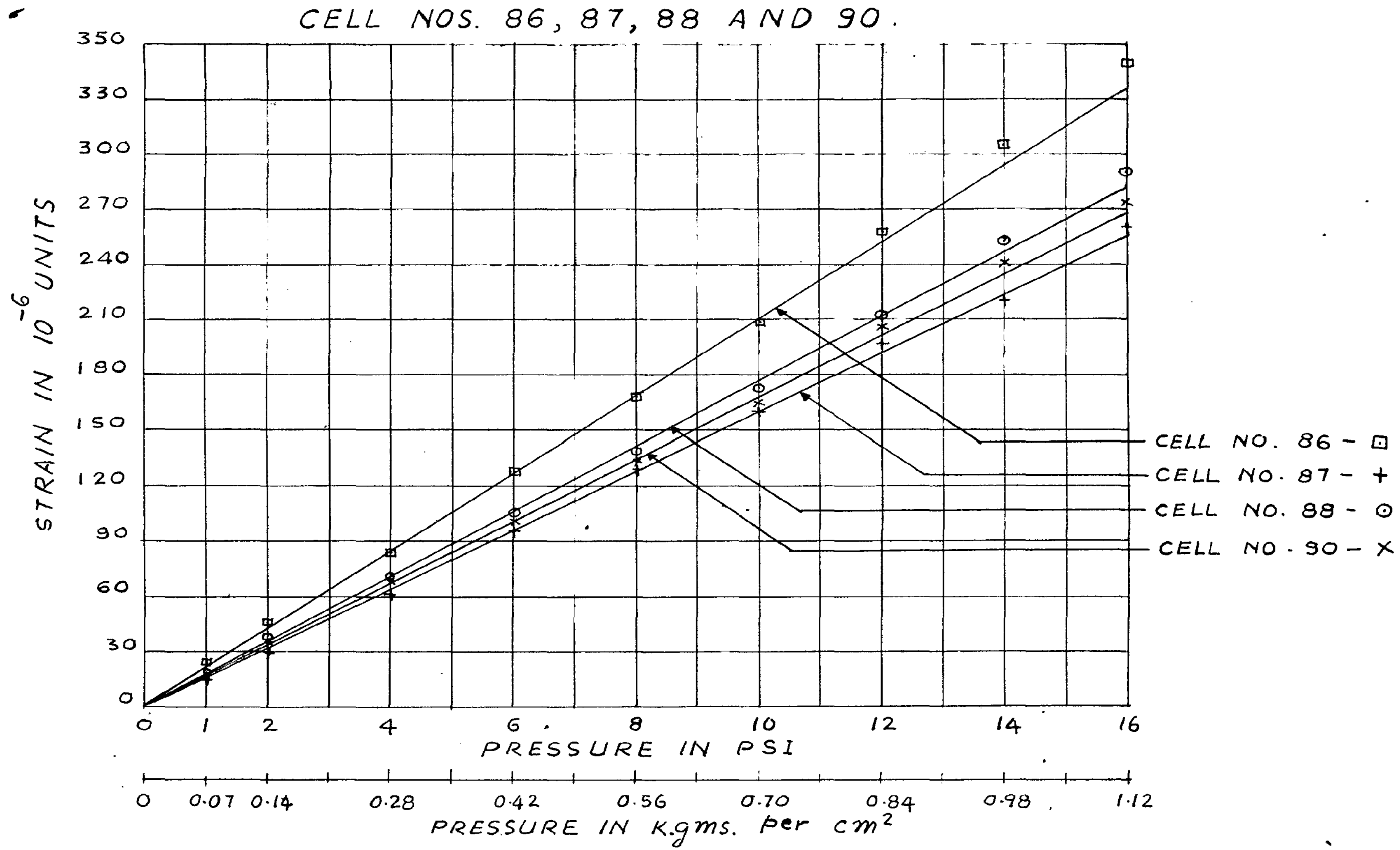


FIG. 71- CALIBRATION CHART OF PRESSURE CELLS.

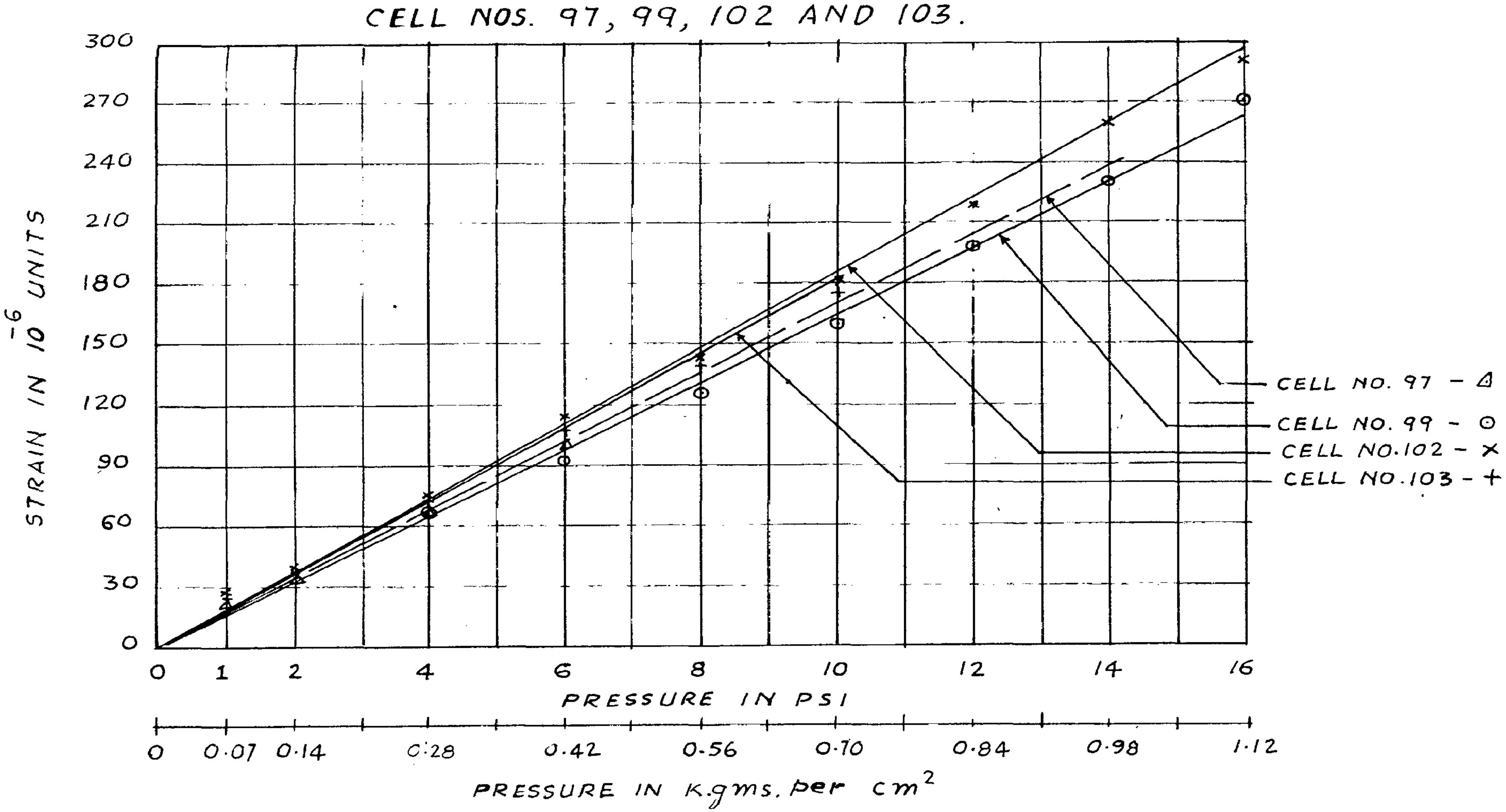


FIG. 73 — CALIBRATION CHART OF PRESSURE CELLS.

CHAPTER III

THERMOCOUPLES

CHAPTER III

THERMOCOUPLES

1. There are different methods of recording temperatures. The only suitable method of recording temperature at any point of a solid mass is by means of thermocouple.

Seebeck in 1928 discovered that if in a circuit formed by joining two dissimiliar metals, the two junction are kept at different temperatures, a current flows round the circuit. Such current is termed as "Thermoelectric current" and the emf produced is called 'thermo electric force'.

The magnitude of this emf depends on (i) the metals, their value of resistivity and temperature co-efficient and (ii) the temperature difference between the two junctions. Thus for a given pair of metal wires the ratio of emf generated to the temperature difference between the junctions can be determined, if the average temperature is specified. This ratio for a specified average temperature is known as the thermoelectric power 'e' of the circuit.

3. Choice of metals for thermocouples:- The pairs of metals commonly used for thermocouples are

(i) Iron against constantan.

(ii) Chromel against alumel

(iii) Platinium against platinium - rhodium alloy

(iv) Copper and constantan

(v) Copper and Eureka

Published tables are available which give the thermoelectric emf between the pair of the wires mentioned above for different temperatures.

Specific resistance or resistivity and other properties of metals for thermocouples.

Specific resistance depends upon the nature of the material, and is represented as follows:-

$$\text{Resistance} \times \frac{\text{Length of conductor}}{\text{Cross-sectional area}} \times \text{specific resistance}$$

Thus the unit of resistivity is ohm-cm.. Copper has low specific resistance while constantan, Eureka and manganin has high specific resistance. Table No. 1 give their properties.

4. DESIGN ADOPTED

Type of wires:- The maximum and minimum temperature at Roorkee, where this investigation is proposed to be carried out is 40 °C and 0 °C respectively. In this investigation thermocouples are to be installed in soil underneath the pavement and also in different bases and concrete pavements. The maximum and minimum temperature will be in the concrete pavement which is not expected to go beyond the range of 0°C to 60 °C. Temperature readings taken in sun during the month of June and July 1962, have shown that these ranges are acceptable.

Table No. 1 shows that copper with constantan or Eureka produce a thermoelectric emf of 40 micro-volts per °C. Any of these two metals with copper could therefore be useful. Eureka-copper

TABLE NO. 1

PROPERTIES OF METALS

Sl. No.	Material	Resistivity Micro ohms x cm	Temp. Coeff per °C	Thermo electric emf against Cu. Micro-volts per °C	Remarks
1.	Copper	1.7	0.004	-	
2.	Steel	15-50	0.0052 to 0.006	-	
3.	Constantan (35 to 55 p.c. Ni + 65 to 45 p.c. Cu. + 0 to 20 p.c. Zn.)	49-52	0.00001	40	Cheap. High resistivity. Very low temp. co-efficient. High thermo electric emf.
4.	Eureka (60 p.c. Cu + 40 p.c. Ni.)	50	0.00001	40	--Do--
5.	Manganin (70 p.c. Cu. + 30 p.c. Mn.)	42	0 to 0.00003	3-8	High resistivity, very low temp. co-efficient and very low thermo-electric emf.
6.	Nichrome	95	0.0004	-	Very high resistivity.

wire thermocouples were adopted. The Eureka wire was of 18 gauge and copper wire of 22 gauge.

Type of Junction: The method of joining the two wires is very important. The method adopted may thermostatically alter the metals near the junctions by corrosion or contamination or by changing the crystal structure. The junction in fact becomes a short length of wire composed of third metal; but if this short length is at the same uniform temperature, the effect is the same as if the two metal wires were joined at the same place without making the third type of metal (1). Junctions can be of many types e.g. brazed or soldered; beaded or fused, and clamped. Clamped junctions are undesirable as they give erratic results. Brazed or soldered junctions are quite good, if the temperature is uniform in the vicinity of the junction.

In case of concrete and even in soil, the small junction point is likely to lose good contact with its surrounding medium. It was therefore desirable to increase the contact area of the junction specially when sensitivity adopted was too low i.e. about 1 $^{\circ}$C. The design of junction therefore adopted wes, as explained below.

The copper wire was wrapped round the constantan wire for a length of about $\frac{3}{8}$ cm. The junction so made was placed on one naya paisa (a copper alloy of 1.5 cm dia and 0.05 cm thick, put in the shape of a coin). The whole assembly was soldered with tin-lead. This type of junction is shown in fig. 74.

INSTALLATION

Callibration

Since Eureka and copper wires were soldered together and at the same time with a copper alloy, there was every possibility of the variation in calibration from the standard calibration supplied by the manufacturers.

Number of thermocouples were calibrated by (i) placing in water at varying temperature (ii) Placing them in soil and varying the temperature of soil and (iii) embedding them in concrete block and placing the concrete block in water whose temperature was varied. The method of testing for embeddment in soil and concrete is shown in fig. 75.

Two methods of reading thermocouples were adopted (i) By direct method i.e. measuring the amperage and (ii) Null point method i.e. measuring the thermoelectric emf. Emf method no doubt possess the advantage of elimination of the variable 'r' (resistance) which is function of ambient tempeature. Emf was measured by comparing the thermoelectric emf with a reference emf of a wet battery. The balacing operation was carried out by a balancing circuit of a potentiometer. The circuit diagram is shown in fig. 76 ~~and (b)~~. The micro amps were measured directly on a microammeter. Calibration charts for thermocouples placed in concrete and soil in terms of microamps and millivolts are shown in fig. 77. Since the slope of straingth lines for water, concrete and soil is the same, a general graph applicable to all the three types of embeddments with the readings obtained, have been drawn in this graph.

REFERENCES

1. Baker H.^{D}. Ryder E.A and Baker N.H. "Temperature measurement in Engineering" Vol. I John Wiley and Sons.
2. National Research Council of Canada. Division of Building Research. Technical note No. 113.

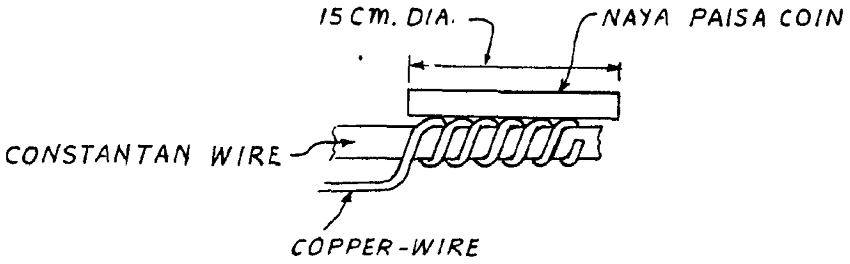


FIG. 74 – TYPE OF JUNCTION ADOPTED FOR THERMOCOUPLE.

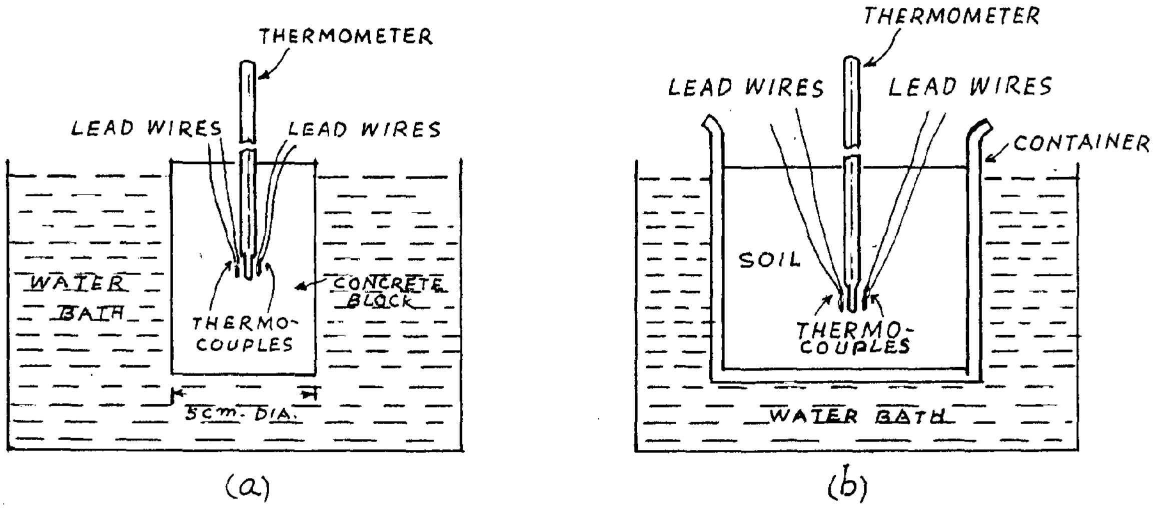


FIG. 75 – CALIBRATION OF THERMOCOUPLE (a) EMBEDDED IN CONCRETE (b) EMBEDDED IN SOIL.

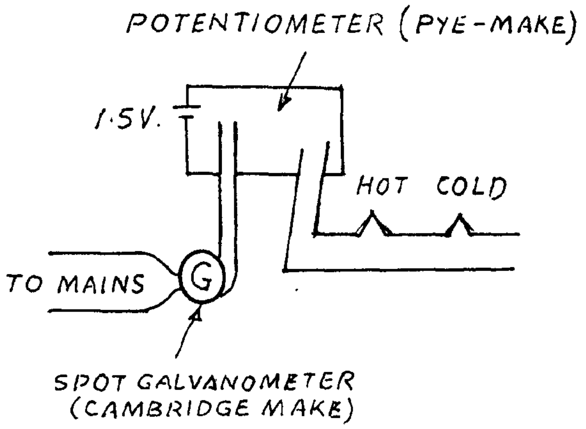


FIG. 76 – CIRCUIT DIAGRAM FOR MEASURING VOLTAGE.

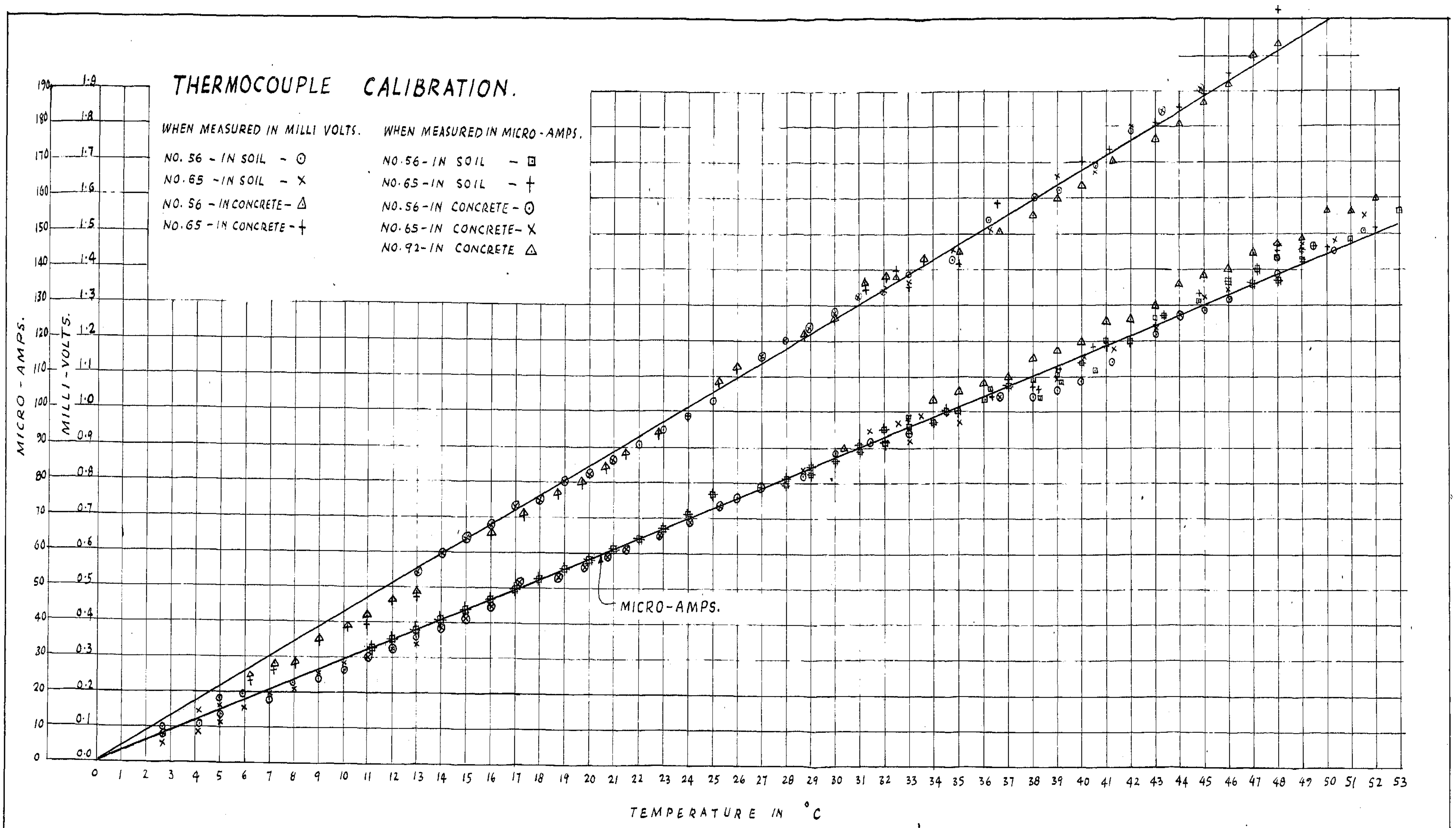

THERMOCOUPLE CALIBRATION.
WHEN MEASURED IN MILLI VOLTS.
NO. 56 - IN SOIL - ⊙
NO. 65 - IN SOIL - ×
NO. 56 - IN CONCRETE - △
NO. 65 - IN CONCRETE - +
WHEN MEASURED IN MICRO-AMPS.
NO. 56 - IN SOIL - ⊡
NO. 65 - IN SOIL - +
NO. 56 - IN CONCRETE - ⊙
NO. 65 - IN CONCRETE - X
NO. 92 - IN CONCRETE △
MICRO-AMPS.
MILLI-VOLTS.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
MICRO-AMPS.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53
TEMPERATURE IN °C

FIG. 77.

CHAPTER IV

DEFLECTION DEVICES

CHAPTER IV

DEFLECTION DEVICES

4.1 **Introduction:** Burmister's theory is based on deflection of layered system. For verification and design on the basis of Burmister's theory it was proposed to measure deflections ofthe top of subgrade, base course and concrete pavement. The deflections to be determined independently for given amount and type of loading.

4.2 **Construction of the device** The arrangement adopted consists of 0.6 cm (¼ in.) diameter rod with 2.5 cm. square base plate. This rod passes axially through a 1.8 cm (¾ in.) diameter conduit fixed with washers at its ends. The internal diameter of these washers is 1.8 cm. and external diameter is 4 cm.. The 1.8 cm. conduit again passes through a 3 cm. (1¼ in.) diameter conduit. The 3 cm. conduit is also provided with washers having internal diameter of 3 cm. and external diameter of 5 cm.. The arrangement is shown in fig. 78.

The above plate of the 0.6 cm. diameter rod remains embedded in the top of subgrade by 1 cm depth and this rod should be free to deflect along with the subgrade only through the base and concrete pavement. The 1.8 cm. diameter conduit around it and passing through the base course and concrete pavement provides for its free deflection.

In order to prevent against free movement of the rod and thus disturbing the subgrade of the base plate, when the deflection device is not in use, provision is made to fix the rod temporaily with the top of 1.8 cm. conduit pipe by means of a cork as shown in deteril 'A' of fig. 78. This cork also helps in keeping the rod in the central axis of the conduit pipe when the base course is being laid.

To keep the rod in the central axis of the conduit pipe at the bottom, the rod was passed through a tar paper and a circle of diameter equal to the external diameter of the washer was drawn on the paper with its centre at the center of the rod. After the rod was embedded in the ground this tar paper was pushed through the rod followed by the conduit pipe. The washer of the conduit pipe was kept in line with the circumference of the circle already drawn on the paper. Theconduit pipe was thus placed on the subgrade and its top corked as mentioned above.

To prevent access of subgrade material to the rod at the junction of the conduit pipe and subgrade, a tar paper with a hole equal to the diameter of conduit pipe was placed on the top of the bottom washer of the conduit pipe. The detail of this is shown in 'C' fig. 78.

The base course thus could be laid without affecting the central rod.

Before laying the concrete pavement a tar paper with a hole equal to the diameter of 1.8 cm. was placed around the 1.8 cm. diameter conduit pipe on the top of base course. This paper had also a circle drawn with the center at the centre of the hole and diameter equal to the external diameter of the washer on the 3.0 cm. diameter conduit pipe.

The 3.0 cm. diameter conduit pipe was then placed on the paper with the washer in line with the circle so drawn. The top end of the 3.0 cm. diameter conduit pipe was corked as shown in detail 'B' of fig. 78. The 1.8 cm. diameter conduit pipe thus remained centrally in the 3.0 cm. diameter conduit pipe.

To prevent access of cement concrete to the 1.8 cm. diameter conduit pipe at its junction with the top of base couse, one more tar paper was placed on the top of the bottom washer of the 3.0 cm. conduit pipe, in the similar manner as was done before on the top of subgrade.

The cement concrete pavement could thus be laid without affecting the 1.8 cm. diameter conduit pipe.

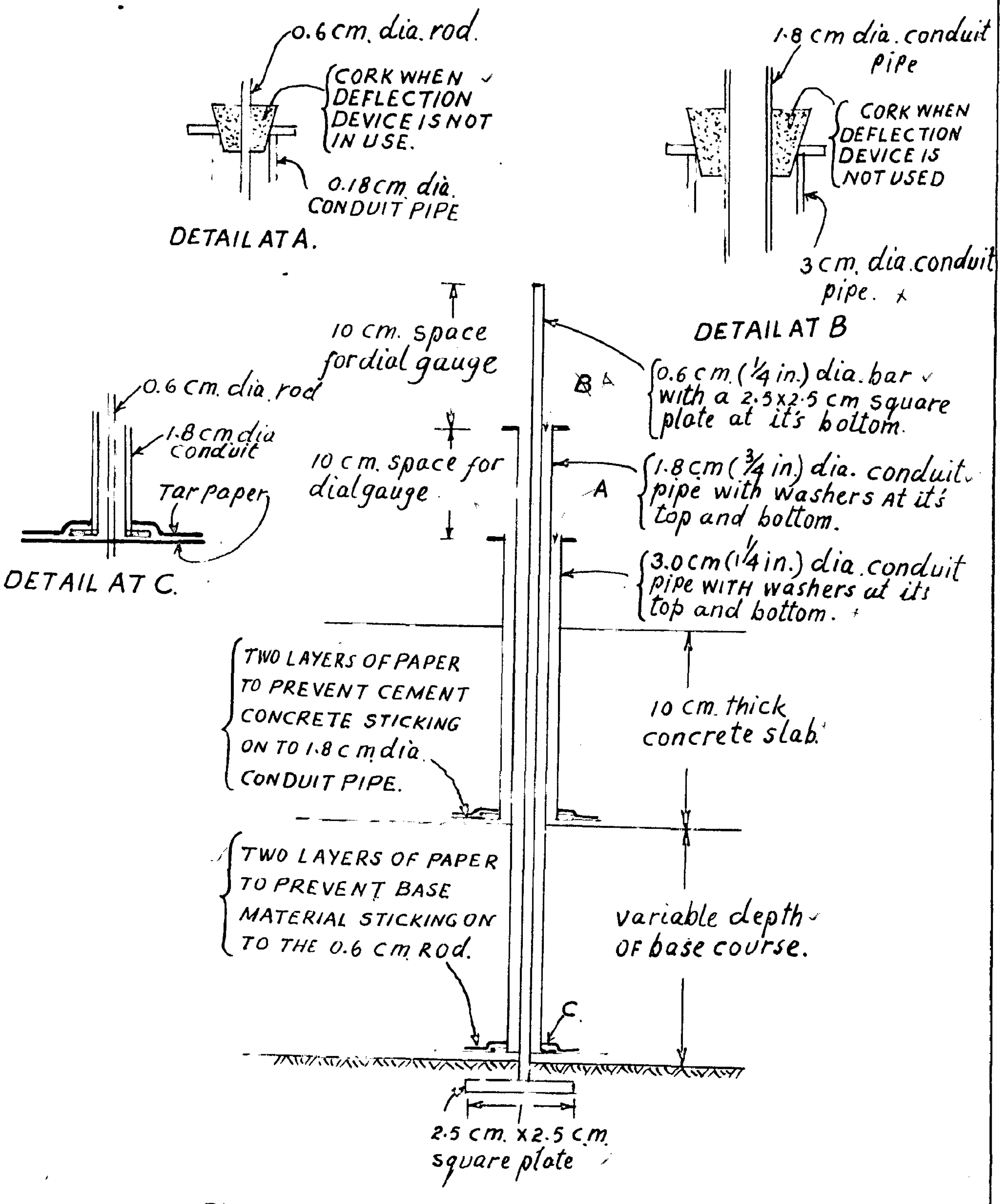


FIG_ 78. DEFLECTION DEVICES TO MEASURE DEFLECTION OF SUB GRADE, BOTTOM OF BASE AND BOTTOM OF CONCRETE SLAB.