SOUTH AFRICAN TRANSPORT SERVICES

CHIEF ELECTRICAL ENGINEER's

DEPARTMENT

CODE OF PRACTICE :

EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS

CEE.0177.86

CODE OF PRACTICE : EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS

At all future Electric Light and Power and traction installations, the existing method of earthing by using earth spikes made of galvanised water pipe as depicted on drawing number CEE-E1B-142 and described in circular ENW-10/133 of the 3 September 1952, will be superseded by a deep earthing system as first choice. If, however, a survey indicates that a deep earth is not possible, a trench type earth may be installed. The deep earthing system incorporates the use of copper coated steel electrodes (similar to Copperweld) which are driven into the ground to the depth necessary to give a required earth resistance of 5 ohms or less.

The following procedure for the installation of the earthing system is outlined below for the guidance of System Electrical Engineers, Resident Engineers and other staff concerned.

A. SURVEY

A survey is necessary to determine the type of earthing system to be used and the best possible position of the earthing system within the limits of the site available.

EQUIPMENT REQUIRED FOR SURVEY

(i) A null balance Megger (or other type of resistance measuring instrument with 4 terminals plus a guard terminal and its own current generator). The instrument must be designed to block stray DC currents.

(ii) Five metal rods approximately 450 mm long to be used as test spikes.

(iii) Four lengths of insulated wire to connect the test spikes with the 4 terminals of the instrument. To ensure soil resistivity down to 45 metres, two of the wires should be about 90 metres long and two about 30 metres long. It is most convenient to use wires of different colours on spools mounted on a shaft for rapid unwinding and rewinding.

MEASUREMENT OF THE AVERAGE RESISTIVITY OF THE SOIL

The method described gives results that are accurate enough for all practical purposes wherever the stratification of the subsoil is more or less regular. In cases where the strata are very irregular the results may only approximate and in extreme cases they may be meaningless.

The four test spikes A, B, C and D are placed as shown in Annexure A - symmetrically in relation to the point at which the soil is to be measured in a straight line and at equal intervals "a". The fifth spike, G is driven equidistant from B and C and connected to the guard terminal on the instrument and it should be stressed that the accuracy of the distance between spikes is most important. The spikes should not be driven more than about 300 mm into the ground.

The two outer spikes A and D (current spikes) are connected to the current terminals of the test instrument. The two inner spikes B and C (potential spikes) are connected to the potential terminals of the test instrument.

A current generated by turning the crank of the test instrument passes through the two outer spikes and the instrument measures the voltage between the two inner spikes. The relation is given directly on the dial of the test instrument as "r" or resistance in ohms.

The reading "r" must in turn be converted to a figure expressing the average resistivity of the soil : vertically, between the surface and a depth equal to 75 % of interval "a" and horizontally between the two potential spikes. The formula for the conversion is :-

$$p = 2 \quad ra$$

in which p is the soil resistivity value in ohm-metres
r is the instrument reading in ohms
a is the distance between test spikes.

The soil resistivity figure obtained is the average (or apparent) of all the layers of soil between the surface and a certain depth "D". This depth is considered to be 75 % of the distance "a" between the spikes. In other words :-

$$D = 0{,}75\ a$$

The resistivity of the soil is measured down to successively greater depths by increasing the distance "a" as shown in the following typical series of measurements :-

Distance (metres) "a"	Depth (metres) "D"	Test reading (ohms) "r"	Resistivity (ohm metres) "p"
2	1,5	90	1 140
4	3	21,5	538
8	6	10	502
12	9	5,5	415
24	18	3	450
40	30	2	502
49,2	37,5	1,5	470

As the soil is rarely uniform to any great depth, the purpose of taking resistivity measurements at successive depths is to determine at what depths, to what extent and in what direction (up or down), the resistivity changes. These measurements indicate which layers of soil are most useful for obtaining a good earth connection.

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CALCULATION OF RESISTANCE OF EARTH ELECTRODES

The next step is to convert the series of resistivity measurements taken, into a corresponding series of figures showing the resistance "R" which sould be given by a single earth electrode driven to successively greater depths at the same point.

The conversion is made by the formula :-

$$R = 0{,}366 \frac{p}{D} \times \log \frac{(3D)}{d}$$

Where R is the resistance of the electrode in ohms.
P is the resistivity measurement at a particular depth in ohm-metres
D is that depth in metres
d is the diameter of the earth electrode to be used in metres.

For example, in the typical case described above, the resistance of a rod driven 3 metres is calculated as follows :-

$$R = 0{,}366 \times \frac{538}{3} \times \log \frac{(3 \times 3)}{0{,}016} \text{ ohms}$$

$\therefore$ R = 160 ohms (approx.)

IMPORTANT NOTES

Caution should be exercised to ensure that the survey is not executed close to buried conductors, i.e. metallic pipes, electric cables, existing earthing system ; or near the metallic conductors running above ground which are frequently earthed, i.e. fences and overhead transmission lines. The reason for this is that accuracy of the survey depends upon the current generated by the instrument taking its natural path through the soil. If buried conductors are in the close vicinty of the survey array, the current generated by the test set will take the line of least resistance along them and the survey results will be inaccurate. The minimum allowable distance between any of the test spikes and buried conductors should be 15 metres. It is preferable to execute a survey 15 metres or more from buried conductors in the vicinity as it is unlikely that the nature of the soil will change substantially over such a short distance.

Should it be absolutely impossible to avoid a buried conductor, then the survey array should be set to cross the conductor at right angles and never parallel to it.

If the soil in the area to be surveyed appears to be very dry or the initial instrument reading (when the distance "a" is 2 metres) is greater than 100 ohms, the ground in the area of the two outer current spikes must be watered. This is done by hammering the spikes into the ground to a depth of approximately 200 mm, removing them, filling the holes thus created with water and re-inserting the spikes to their full depth of about 300 mm. This procedure is then repeated each time the distance is increased until the survey is completed.

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SIMPLIFIED CALCULATIONS

The calculations involved in using the formulas given above can be simplified by the use of co-efficients. The formulas are reduced to a series of co-efficients pre-calculated for various depths. These co-efficients are only to be multiplied by the initial instrument reading "r" to give immediately both "p" and "R" for any given depth of electrode.

Attached is Annexure C with a list of resistivity and resistance co-efficients for various depths incorporated. This is a standard form and is to be used to tabulate measurements obtained from the survey.

EXAMPLE : (refer to Annexure C)

The distance between the test spikes is 6 metres, giving a depth D of 4,5 metres, the test instrument reading obtained is 0,50 ohms.

Multiplying 0,50 ohms by co-efficient "K" (37,75 at a depth of 4,5 metres) gives a resistivity (p) of 18,87 ohm metres.

Also multiplying 0,50 ohms by the co-efficient "K1" (8,98 at a depth of 4,5 metres) gives a theoretical resistance (R) for the deep earth electrode of 4,49 ohms.

INTERPRETATION AND PRACTICAL USE OF ABOVE MEASUREMENTS

Let us say that the survey has progressed to the stage where we have a complete list of soil resistivity readings (p) for progressive depths and the corresponding electrode resistance readings (R) and that these readings have been entered on form Annexure C. The tabulated results appear as in Annexure CC. The simplist way to interpret and make use of the measurements is then to plot them on a logarithmic grid, Annexure D. When plotted the results are represented by graphs as on Annexure DD. In general, and within certain limits, as long as the curve showing the calculated resistance values at successive depths drops off at least as sharply as the diagonals on the logarithmic grid it is more advantageous to keep driving a single electrode than to use a number of shorter electrodes connected in parallel. In some cases the soil resistivity does not decrease with depth and if this is so, the trench earthing system (decribed later) and not the deep earth must be installed.

USE OF PARALLEL ELECTRODES

When the resistance curves indicate that it is not advantageous to drive a single set of electrodes beyond a certain depth, or when the subsoil cannot be penetrated beyond a certain depth, the resistance obtained can be reduced by driving two or more electrodes in parallel. As a guide, two electrodes spaced at a distance equal to one and a half times their length and connected in parallel will give ± 60 %, of the resistance of one electrode ; three will give ± 43 % and four electrodes ± 33 1/3 % of the resistance of one electrode.

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B. APPLICATION OF DEEP EARTHING SYSTEM

EQUIPMENT REQUIRED

(i) Copper coated steel earthing rods approximately 1,2 metres (4 feet) and 16 mm (5/8 of an inch) diameter suitably threaded at each end. The survey will indicate the number of earthing rods required.

The copper coated earthing rods (similar to Copperweld) must conform to the following specifications :-

(a) The earthing rods to be composed of a steel core with a copper covering of not less than 0,38 mm thoroughly moltenwelded thereto so that an interlocking crystalline union exists between the two metals.

(b) The earthing rod when broken by successive bends shall show no seams, pits, slithers, or separation of copper from steel.

(c) The tensile strength of the earthing rods shall be not less than 400 megapascals.

(ii) External sleeve type threaded couplings made of non-zinc bronze for joining the earthing rods together.

(iii) High tensile steel driving bolts.

(iv) Two rod termination clamps for each set of electrodes.

(v) P.V.C. insulated (Anti-electrolysis) cable of not less than 70 mm^2 for connection of electrodes in parallel (if applicable) and for connection to equipment.

DRIVING METHODS

When only shallow electrodes are installed, hand driving with a hammer or weighted pipe as shown in Annexure H provides a simple and convenient method of installation.

When the electrodes are required to be driven to greater depths or through hard subsoil, it will be necessary to use some form of power driver. The actual type of power driver to be used is left to the discretion of the Engineer-in-charge of the installation. As a general guide, however, the petrol driven jack hammer is probably more convenient than the pneumatic or electric hammer as it is selfcontained. As the jack hammer should weigh in the vicinity of 20 to 30 kilograms only, with a cubic capacity of 250 cm^3 or larger, no difficulty should be experienced in manhandling it. Special adaptors for driving should be made from hardened and tempered steel to fit snugly over the driving bolt at the upper end of the electrode to be installed. See Annexure I for a typical type of adaptor in use.

METHOD OF INSTALLATION

The first section of the electrode to be installed should be fitted with a coupling. This coupling should be screwed on to the threaded end of the rod which is opposite the pointed end until all the threads on the rod are just covered. The coupling should then be held and a driving bolt inserted into it. The driving bolt should be screwed very tightly into the coupling so that a strong steel to steel abutment is created between the end of the driving bolt and the steel core of the rod. The rod is then driven vertically into the ground by importing hammer blows to the driving bolt head. The driving bolt is then removed and replaced with another earthing rod and coupling. The pointed end of the second rod is inserted into the coupling remaining on the rod which has previously been installed, ensuring that the threads of both rods are completely covered by the coupling. The first and second rod should then be tightened firmly together. The driving bolt is then screwed into the coupling at the upper end of the second earthing rod section as before, and this section is then driven into the ground.

This procedure is repeated until the electrode has been driven to the required depth and termination clamps fitted to its upper end.

Refer to Annexure B for details of the requirements at this upper end.

RECORDING OF ELECTRODE RESISTANCES DURING INSTALLATION

Readings of actual earth resistances must be taken every 1,2 metres (4 feet) of depth during installation of the deep earth system. These readings are to be recorded as a graph similar to Annexure E. (note that values of XX and YY axis are to be adjusted to suit local readings). Where more than one electrode is installed in order to obtain the required minimum resistance of 5 ohms, a graph should be compiled for each electrode and the overall resistance indicated.

C. APPLICATION OF TRENCH EARTH SYSTEM

In some cases the survey may indicate that the soil resistivity at the site does not decrease with depth, when this condition persists to a depth of approximately 20 metres, a trench earth must be installed.

The trench earth consists of copper conductors of not less than 40 sq. mm cross sectional area buried at least 600 mm below the surface of the soil. The earth may be installed as one of the following two type :-

(1) The radial trench earth as depicted diagrammatically at the bottom of Annexure F. The length of conductor needed to give a resistance of 5 ohms in soil with a resistivity of 100 ohm metres may be read off the chart Annexure F. Since the conductor resistance is proportional to the soil resistivity, the graph may be used for resistivities other than 100 ohm metres by multiplying by the appropriate factor. For practical purposes the soil resistivity indicated at a depth of 1,5 metres on the completed Annexure C chart may be used to calculate the length of trench earthing required.

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Example : A survey shows a soil resistivity of 500 ohm metres at a depth of 1,5 metres and a single wire trench earth is to be installed. What length of earth conductor is required ?

From the chart (Annexure F) the total length of conductor needed to give the required resistance of 5 ohms at a soil resistivity of 100 ohm metres is approximately 45 metres. At a soil resistivity of 500 ohm metres this length must be multiplied by 5 to give a total length of 225 metres.

The above example is for the installation of a single wire system and suitable adjustments can be made for 2, 3, 4 or 6 wire radial earth if required.

(2) The loop trench earth as depicted diagrammatically at the bottom of Annexure G. This type of trench earth may be installed where space is restricted. As with the radial trench earth, the soil resistivity indicated at a depth of 1,5 metres on the completed Annexure G chart may be used to calculate the length of the loop conductor.

Example : A survey indicates a soil resistivity of 100 ohm metres at a depth of 1,5 metres and a loop trench earth is to be installed. What length of conductor is required ?

From the chart Annexure G the total length required to give the required resistance of 5 ohms is 40 metres or, alternatively, the radius of the loop will be approximately 6,5 metres.

D. CONCLUSION

The staff responsible for the installation of an earthing system are required to forward to the Test and Research Engineer (Electrical) for record purposes the following :-

(a) Copies of Annexure D and E when the deep earthing system is installed.

(b) Copy of Annexure D and the final resistance reading when the trench earth system is installed.

Extant instructions covering earthing and applicable to existing installations remain for the time being but such, together with drawing number CEE-E1B-142 (Diagram of Earthing Arrangement) and the Code of Practice for negative circuits will be revised in due course for all changes to existing, and for new, installation.

CHIEF ELECTRICAL ENGINEER'S OFFICE
JOHANNESBURG

REFERENCE : EWPOL 3/0/4
DATE : FEBRUARY 1979

TYPICAL EXAMPLE

SITE : REPUBLIC TRACTION SUBSTATION

EQUIPMENT BEING EARTHED : AC EQUIPMENT IN OUTDOOR YARD

DATE : 6 MARCH 1972

ANNEXURE CC TO CODE OF PRACTICE : EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS

1	2	3	4	5	6	7
Interval "a" (metres)	Depth "D" (metres)	Instrument Reading "r" (ohms)	Resistivity Co-efficient "K"	Resistivity "P" (ohm metres) col 3 x 4	Resistance Co-efficient "K1"	Calculated Resistance "R" col 3 x 6
2	1,5	124	12,58	1 560	7,49	929
4	3	51,4	25,16	1 293	8,44	434
6	4,5	15,6	37,75	589	8,98	140
8	6	8,01	50,20	402	9,36	75
10	7,5	4,27	62,90	269	9,65	41,2
12	9	2,70	75,40	204	9,89	26,7
14	10,5	1,97	88,00	173	10,10	19,9
16	12	1,53	100,60	154	10,30	15,8
18	13,5	1,28	113,50	145	10,45	13,4
20	15	1,14	125,66	143	10,57	12
22	16,5	0,93	138,23	129	10,70	9,95
24	18	0,73	150,80	110	10,80	7,88
26	19,5	0,52	163,50	85	10,90	5,67
28	21	0,38	176,00	66,9	11,00	4,18
30	22,5	0,21	188,50	39,6	11,10	2,33
32	24		201,00		11,20	
34	25,5		213,90		11,30	
36	27		226,00		11,35	
38	28,5		239,00		11,40	
40	30		251,80		11,50	
42	31,5		263,90		11,60	
44	33		276,80		11,65	
46	34,5		289,00		11,70	
48	36		301,40		11,75	
50	37,5		314,10		11,80	
52	39		326,60		11,84	
54	40,5		339,10		11,90	
56	42		351,70		12,00	

SITE : ....

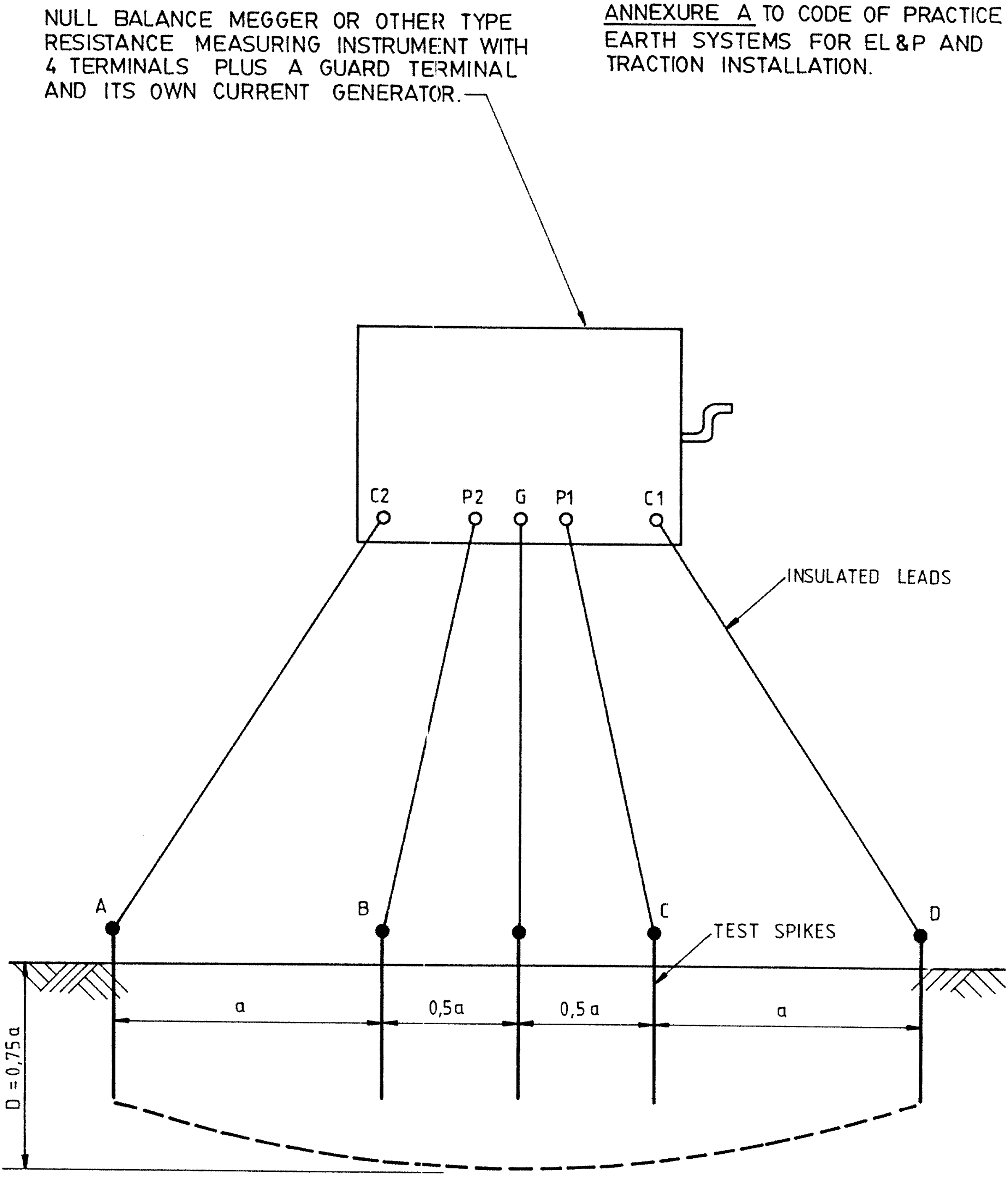
EQUIPMENT BEING EARTHED ....

DATE ....

ANNEXURE C TO CODE OF PRACTICE EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS

1	2	3	4	5	6	7
Interval "a" (metres)	Depth "D" (metres)	Instrument Reading "r" (ohms)	Resistivity Co-efficient "K"	Resistivity "P" (ohm metres) col 3 x 4	Resistance Co-efficient "K1"	Calculatec Resistance "R" col 3 x 6
2	1,5		12,58		7,49	
4	3		25,16		8,44	
6	4,5		37,75		8,98	
8	6		50,20		9,36	
10	7,5		62,90		9,65	
12	9		75,40		9,89	
14	10,5		88,00		10,10	
16	12		100,60		10,30	
18	13,5		113,50		10,45	
20	15		125,66		10,57	
22	16,5		138,23		10,70	
24	18		150,80		10,80	
26	19,5		163,50		10,90	
28	21		176,00		11,00	
30	22,5		188,50		11,10	
32	24		201,00		11,20	
34	25,5		213,90		11,30	
36	27		226,00		11,35	
38	28,5		239,00		11,40	
40	30		251,80		11,50	
42	31,5		263,90		11,60	
44	33		276,80		11,65	
46	34,5		289,00		11,70	
48	36		301,40		11,75	
50	37,5		314,10		11,80	
52	39		326,60		11,84	
54	40,5		339,10		11,90	
56	42		351,70		12,00	

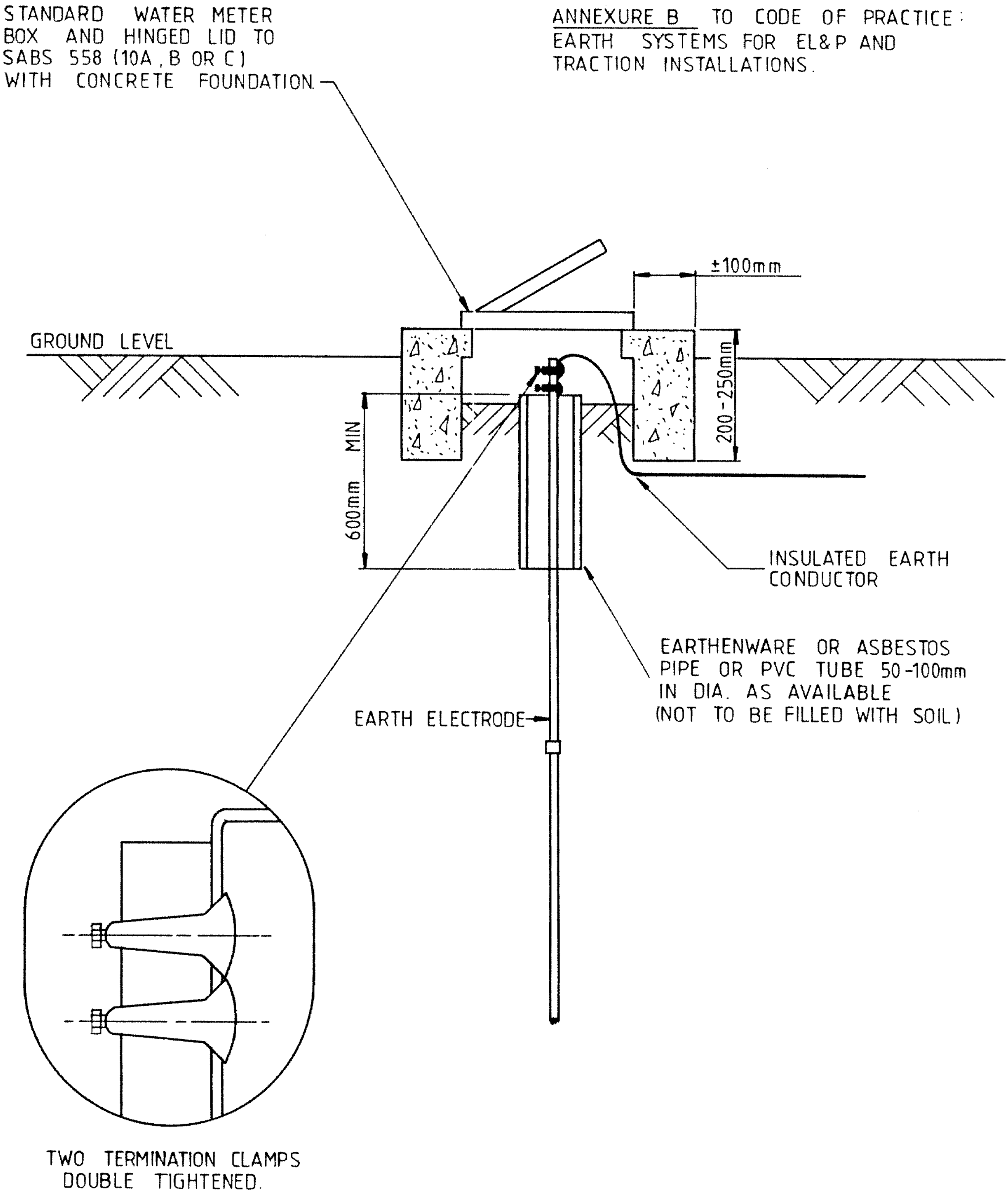
ANNEXURE A TO CODE OF PRACTICE EARTH SYSTEMS FOR EL&P AND TRACTION INSTALLATION.



REQUIREMENTS FOR TESTING AVERAGE SOIL RESISTIVITY.

AMENDMENT

DRG. TEK No CEE-MB-6 Sht Vol 1.



ARRANGEMENT FOR TERMINATION
OF EARTH ELECTRODE.

ANNEXURE D TO CODE OF PRACTICE: EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS

LOCALITY. ______________________

EQUIPMENT BEING EARTHED. ______________________

DATE. ____________

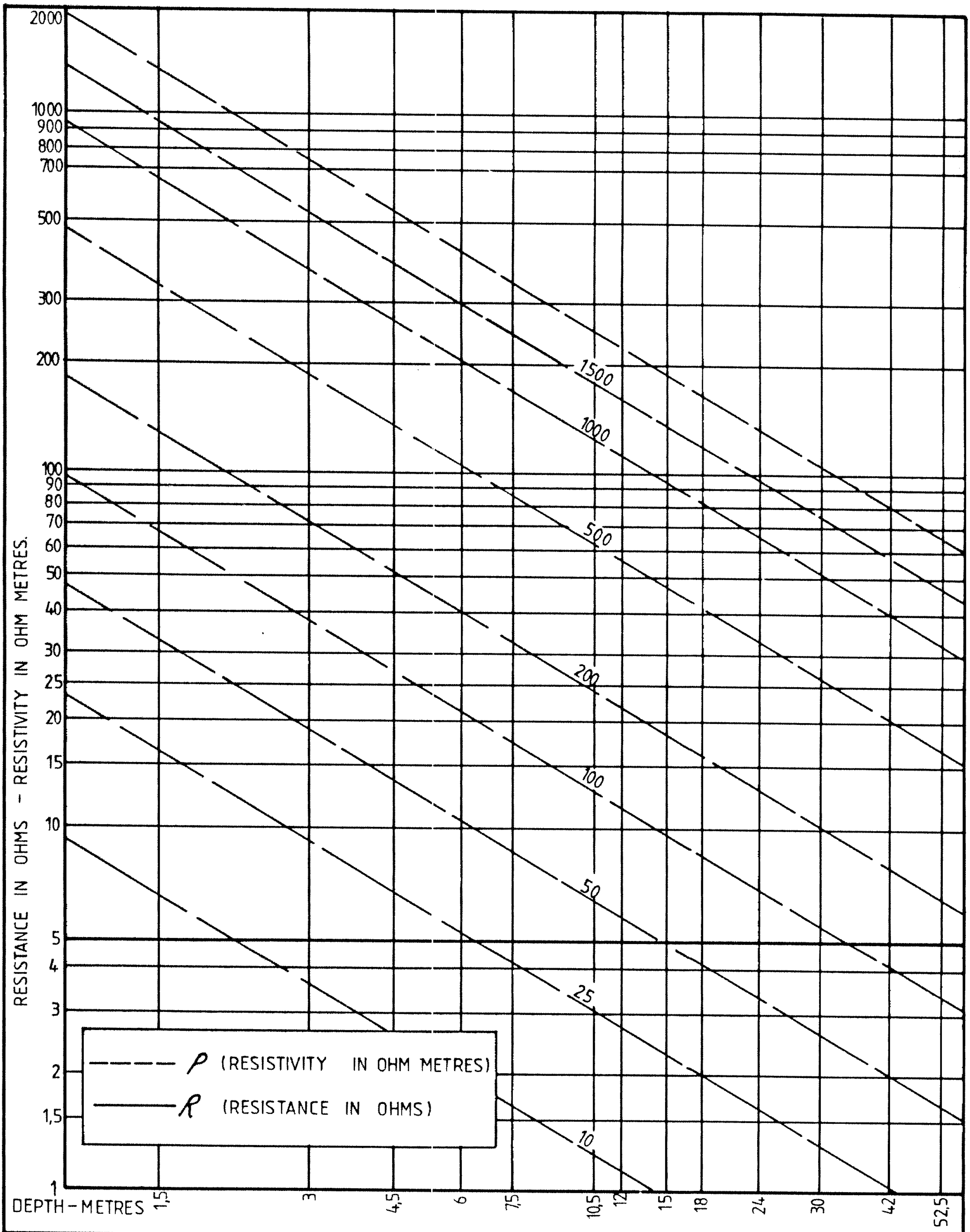


CHART TO RECORD (a) MEASUREMENTS OF SOIL RESISTIVITY.

(b) CALCULATED RESISTANCE OF EARTH ELECTRODES

AMENDMENT

DRAWING TEKENING No	CEE-MB-6	SHT VEL 3

OF PRACTICE: EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS.

LOCALITY. REPUBLIC TRACTION SUBSTATION.

EQUIPMENT BEING EARTHED. A.C. EQUIPMENT IN OUTDOOR YARD.

DATE. 6 th MARCH 1972.

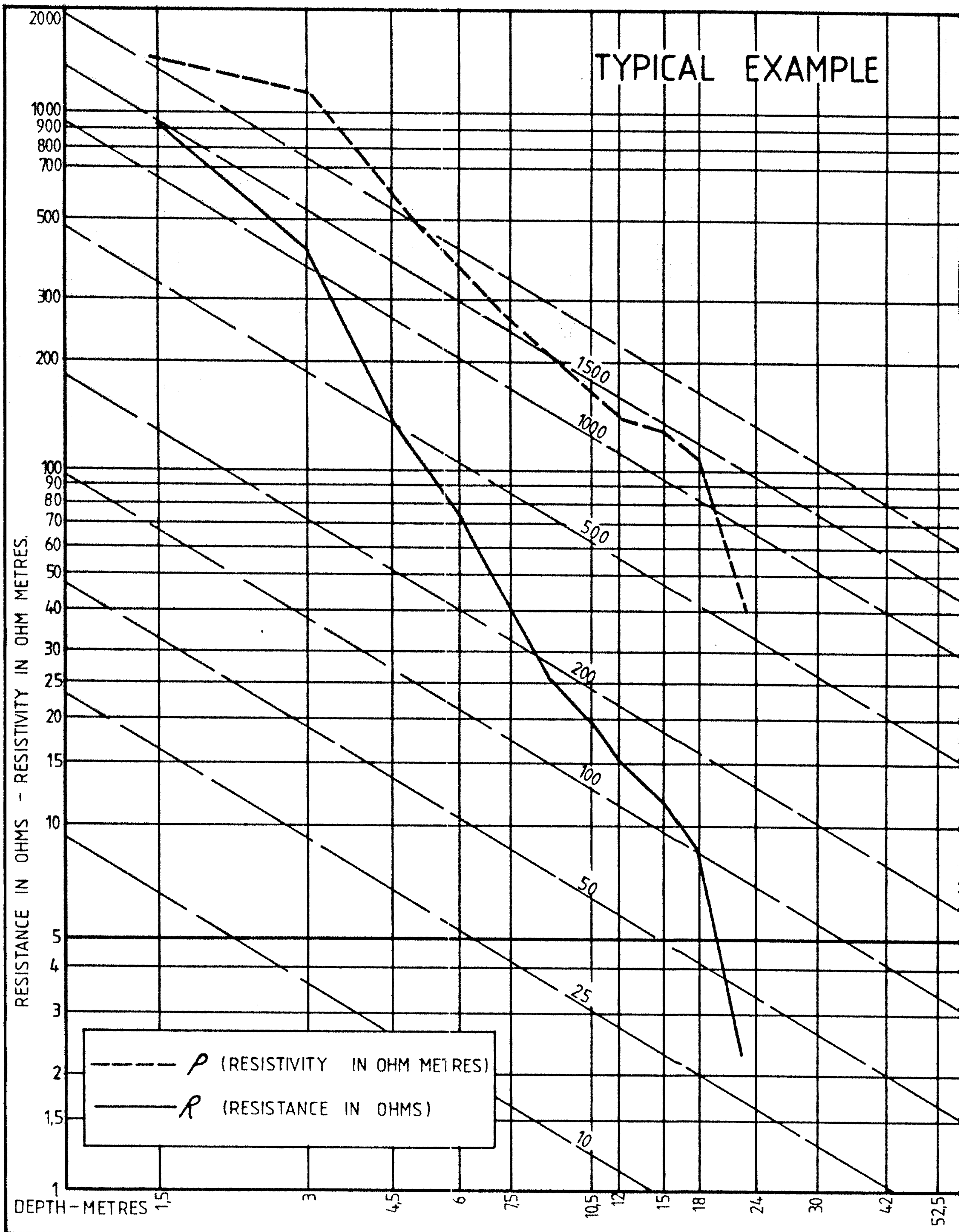


CHART TO RECORD (a) MEASUREMENTS OF SOIL RESISTIVITY.

(b) CALCULATED RESISTANCE OF EARTH ELECTRODES.

AMENDMENT

DRAWING TEKENING No. CEE-

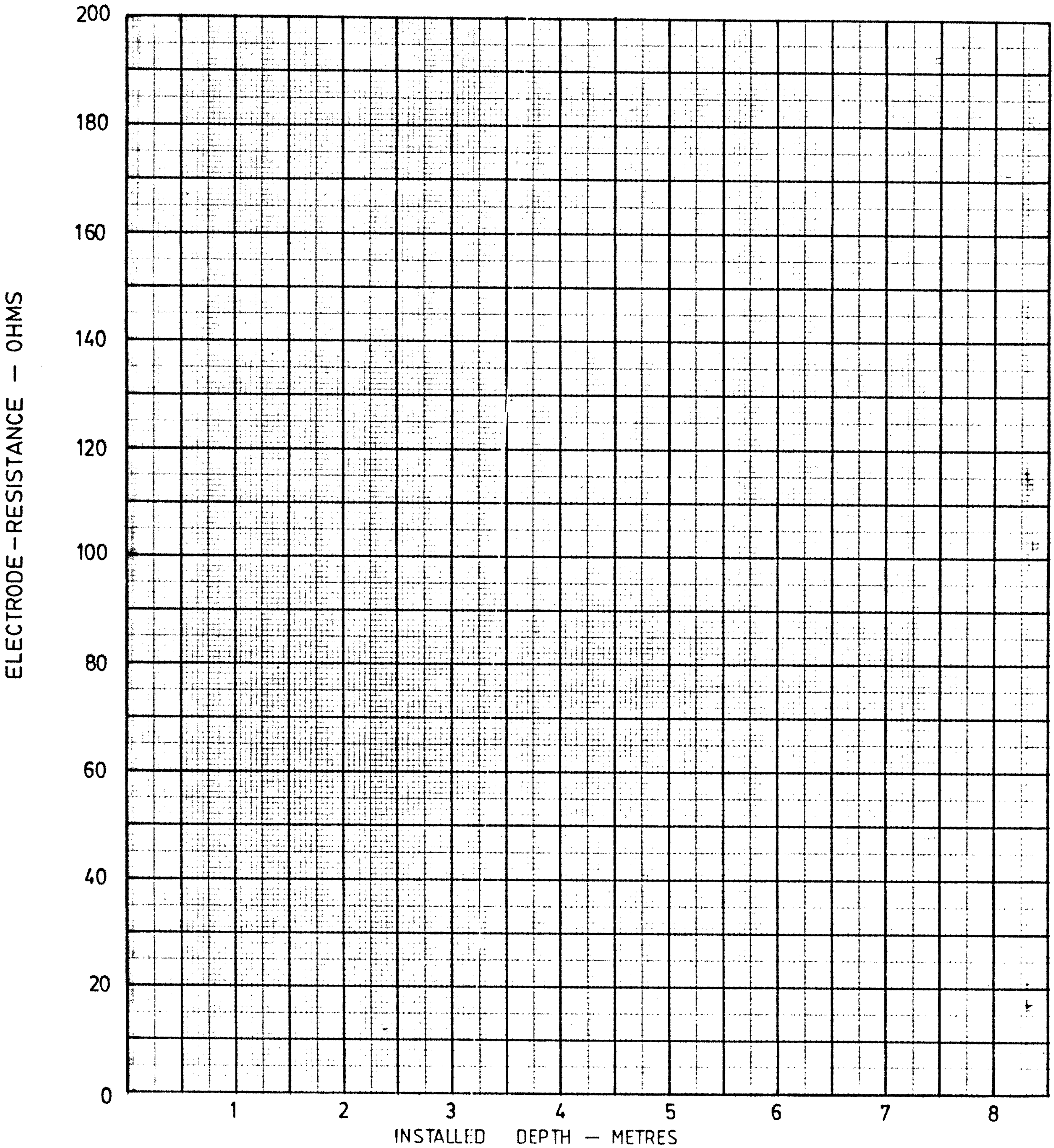
MB-6 SHT VEL 4

ANNEXURE E TO CODE OF PRACTICE: EARTH SYSTEMS FOR EL & P AND TRACTION INSTALLATIONS

LOCALITY ___________

EQUIPMENT BEING EARTHED___________

DATE_______

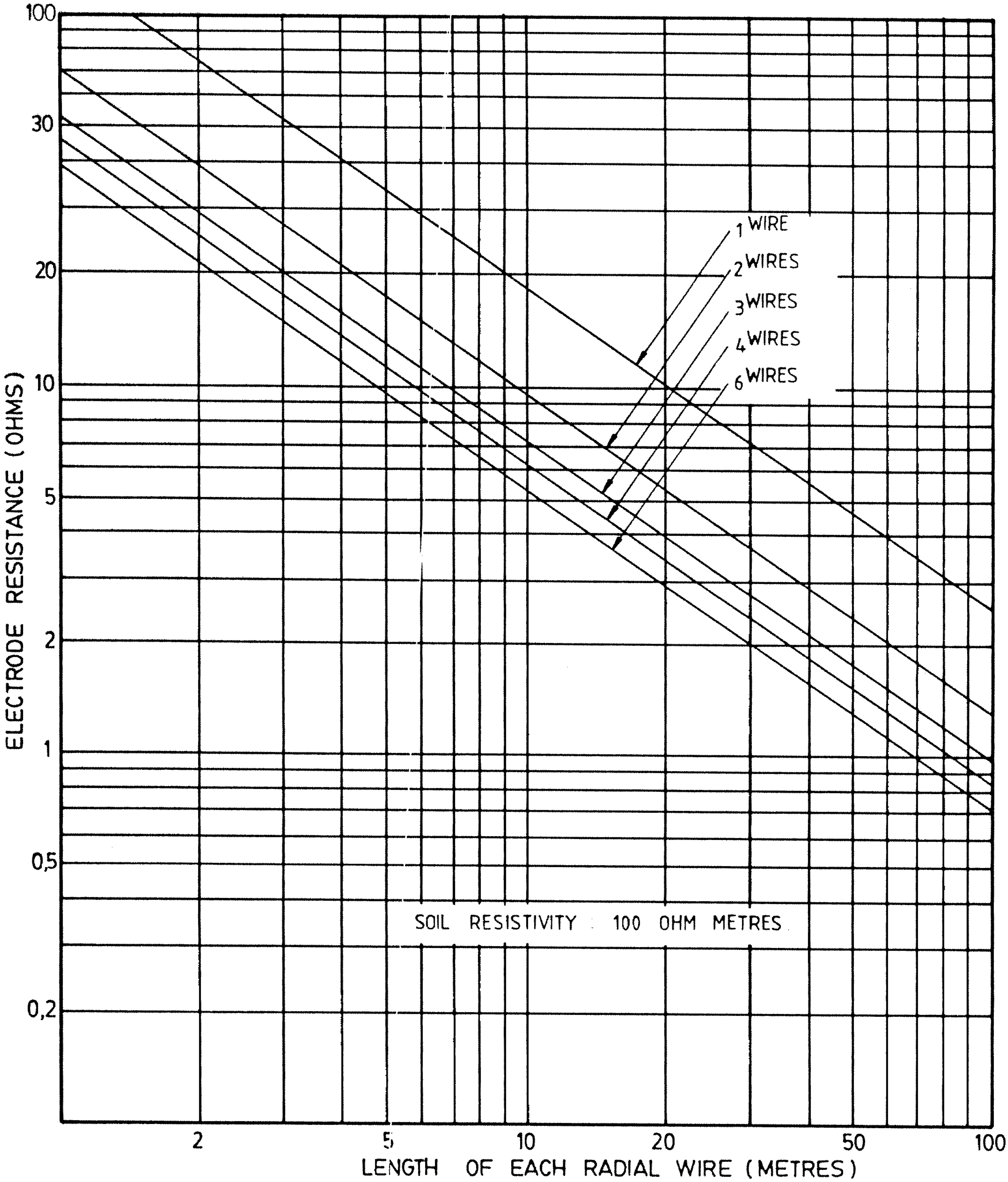


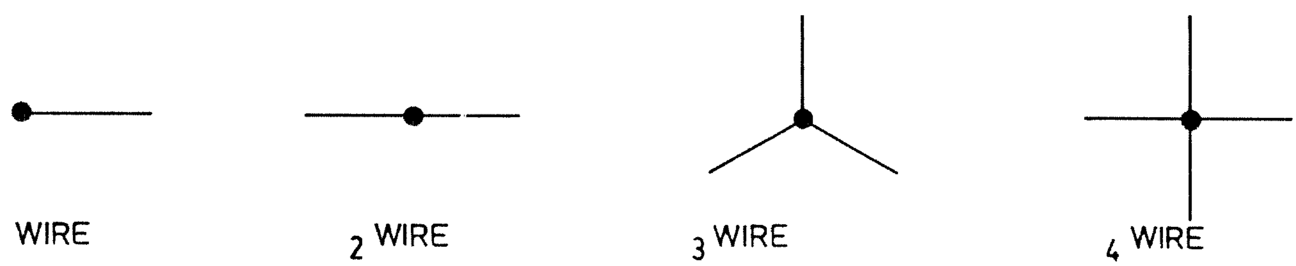
ELECTRODE RESISTANCES RECORDED. DURING INSTALLATION.

AMENDMENT

ANNEXURE F TO CODE OF PRACTICE : EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS.

RESISTANCE (IN OHMS) OF A RADIAL EARTH ELECTRODE IN RELATION TO A SOIL RESISTIVITY OF 100 OHM METRES.



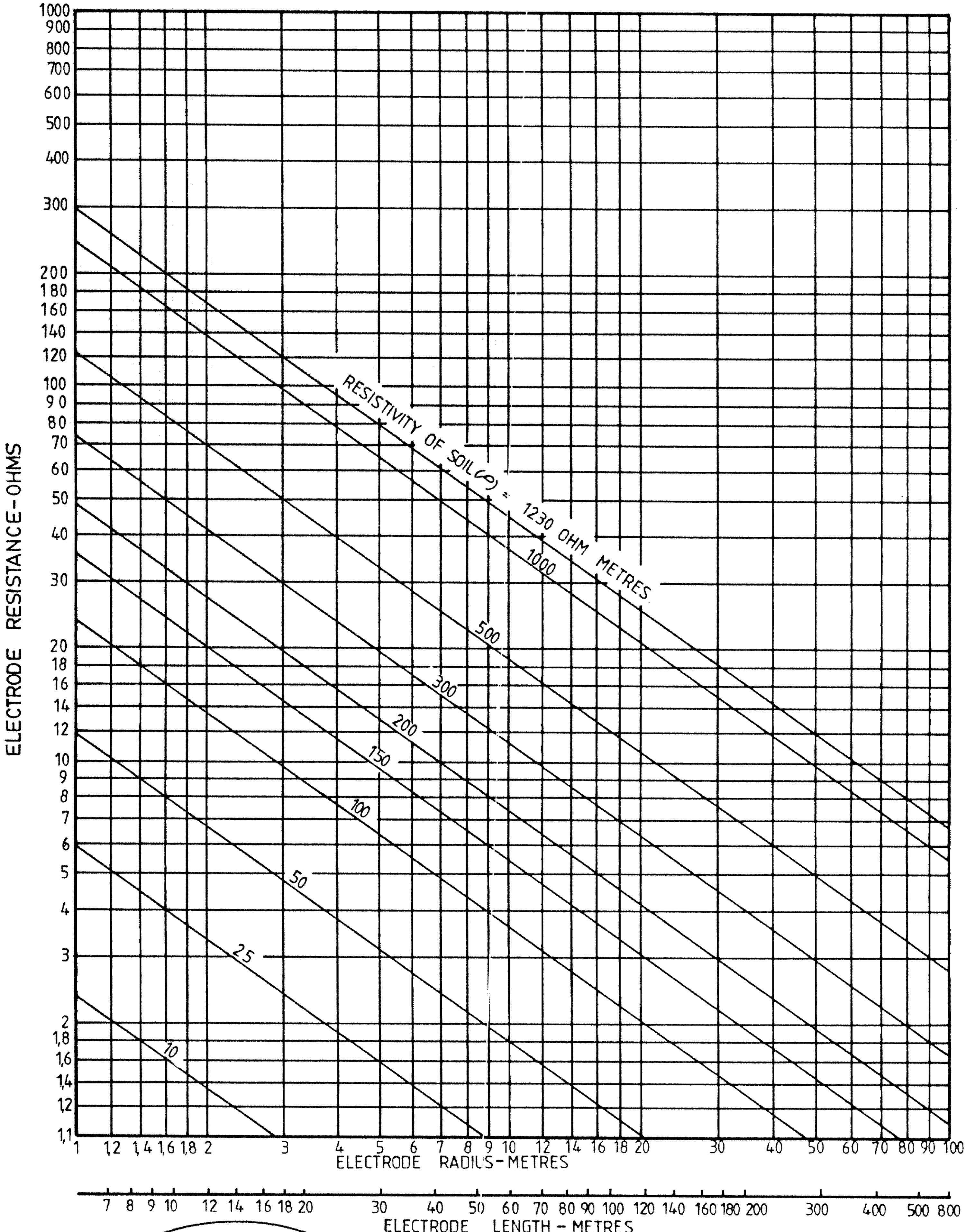


AMENDMENT

TRENCH EARTHING (RADIAL)	DRAWING TEKENING NO. CEE-MB-6	SHT VEL 6

ANNEXURE G TO CODE OF PRACTICE: EARTH SYSTEMS FOR ELECTRIC LIGHT AND POWER AND TRACTION INSTALLATIONS.

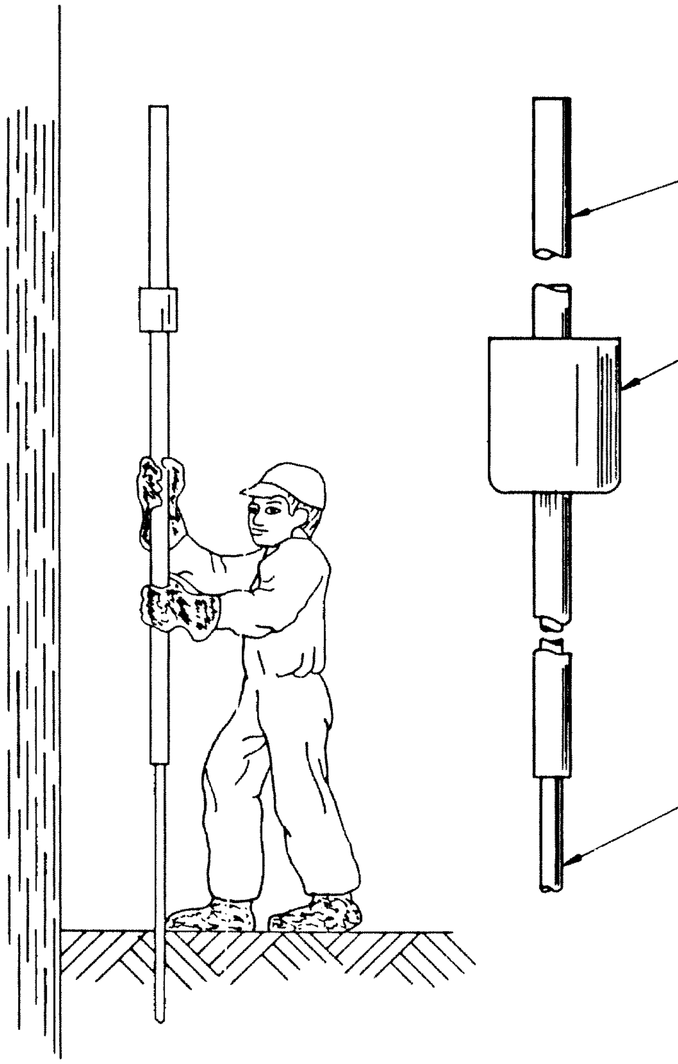
RESISTANCE (IN OHMS) OF AN EARTH CONDUCTOR BURIED IN THE FORM OF A LOOP IN RELATION TO THE RESISTIVITY ρ OF THE SOIL IN OHM METRES



MEND.

LOOP

TRENCH EARTHING (LOOP)	DRAWING TEKENING No CEE-
	MB-6 SHT VEL 7

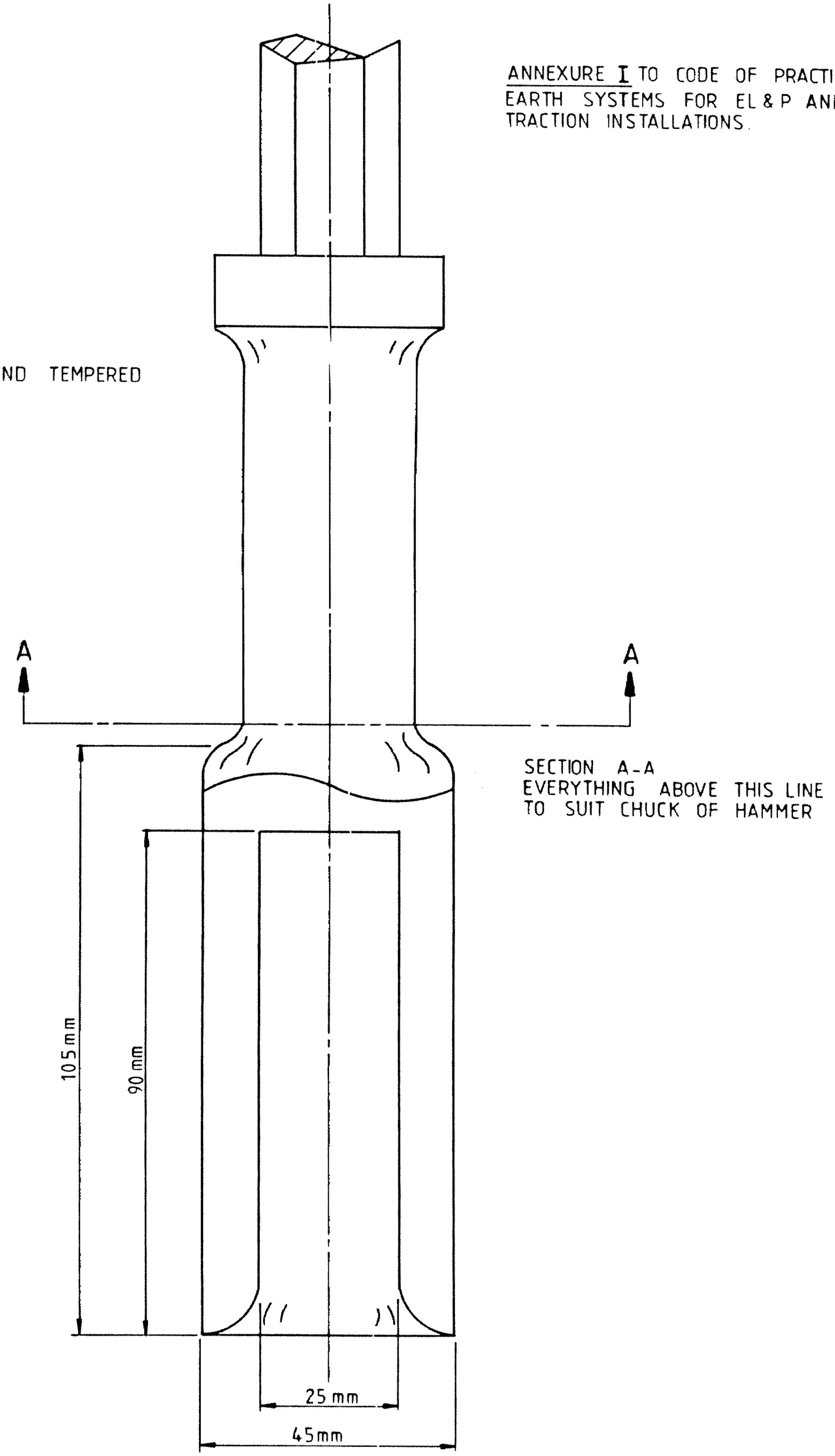


METHOD OF INSTALLING ELECTRODE BY MEANS OF A WEIGHTED PIPE.

AMENDMENT

ANNEXURE I TO CODE OF PRACTICE:
EARTH SYSTEMS FOR EL & P AND TRACTION INSTALLATIONS.

MATERIAL
HARDENED AND TEMPERED STEEL.



TYPICAL ADAPTOR FOR USE IN JACK HAMMER TO INSTALL EARTH ELECTRODES.

AMENDMENT

DRG TEK NO CEE-MB-6 SHT VEL 9