

**BRITISH STANDARD CODE OF PRACTICE**  
**CP 1013: 1965**  
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# EARTHING

**THE COUNCIL FOR CODES OF PRACTICE**  
**BRITISH STANDARDS INSTITUTION**

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**CP 1013 : 1965**

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**THE COUNCIL FOR CODES OF PRACTICE**  
**BRITISH STANDARDS INSTITUTION**

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## EARTHING

This Code of Practice has been prepared by a Committee convened by the Codes of Practice Committee for Electrical Engineering. Having been endorsed by the Council for Codes of Practice, it was published under the authority of the General Council on 26th July, 1965.

This Code of Practice makes reference to the following British Standards and British Standard Codes of Practice:

- B.S. 88. Electric fuses for circuits of voltage-ratings up to 660 volts.
- B.S. 205. Glossary of terms used in electrical engineering.
- B.S. 415. Safety requirements for radio or other electronic apparatus for acoustical or visual reproduction (electric-mains-supplied).
- B.S. 613. Components and filter units for radio interference suppression.
- B.S. 842. Voltage-operated earth-leakage circuit-breakers for use on consumers' premises.
- B.S. 951. Earthing clamps.
- B.S. 1320. High-voltage overhead lines on wooden poles for line voltages up to and including 11 kV, with conductors not exceeding 0.05 sq in.
- B.S. 2754. Memorandum on double-insulated and all-insulated electrical equipment.
- CP 321. Electrical installations.
- CP 325. Farm and horticultural electrical installations.
- CP 326. Protection of structures against lightning.
- CP 327. A series of Sub-codes dealing with telecommunication services in buildings.
- CP 327.401. Bell and call systems.
- CP 413. Design and construction of ducts for services.
- CP 1006. General aspects of radio interference suppression.
- CP 1008. Maintenance of electrical switchgear.

*British Standard Codes of Practice are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users ascertain that they are in possession of the latest amendments or editions.*

The following B.S.I. references relate to the work in this Code of Practice:  
Committee reference ELCP/17      Draft for comment CW(ELCP) 9328

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This Code of Practice represents a standard of good practice and therefore takes the form of recommendations. Compliance with it does not confer immunity from relevant legal requirements including byelaws.

Attention is, however, drawn to the fact that in certain byelaws, notably those Building Byelaws based upon one of the models issued for England and Wales and for Northern Ireland, and in the Scottish Building Regulations, compliance with the provision of certain British Standards or British Standard Codes of Practice, or of specific clauses therein, is 'deemed to satisfy' the requirements of certain of the byelaws in the fields covered by the British Standards and Codes of Practice, or by the specific clauses referred to.

## BRITISH STANDARD CODE OF PRACTICE CP 1013

## EARTHING

## FOREWORD

This Code was prepared as a result of a request from the Electrical Research Association. By a special arrangement, the bulk of the drafting and investigations was done by the Association, and this work is gratefully acknowledged by the Code Drafting Committee.

## SECTION ONE: GENERAL

**101. Scope.** This Code of Practice gives guidance on the methods which may be adopted to earth an electrical system for the purpose of limiting the potential (with respect to the general mass of the earth) of current-carrying conductors forming part of the system, and non-current-carrying metalwork associated with equipment, apparatus, and appliances connected to the system. The former object is normally essential to the security of the system, and this aspect is generally known as 'system earthing'. The latter aims at ensuring the safety of human life, of animals and of property, and this aspect is sometimes known as 'equipment earthing'.

The term 'earthing' is used in this regard whether or not reliance is placed on the earth itself as a low-impedance return path for fault currents.

Ships and aircraft are not covered by this Code.

**102. Definitions.** The definitions given in B.S. 205\* have in general been observed and the following definitions which are consonant with those contained in the relevant statutory Regulations apply for the purposes of this Code:

*Arc-suppression coil (Petersen coil).* An earthing reactor so designed that its reactance is such that the reactive current to earth under fault conditions balances the capacitance current to earth flowing from the lines so that the earth current at the fault is limited to practically zero.

*Bond, to.* To connect together electrically two or more conductors (whether or not normally used for conducting electricity).

*Dead.* The term applied to a conductor or circuit which is at or about earth potential and disconnected from any live system.

*Distributing main (distributor).* The portion of any main which is used or intended to be used for the purpose of giving origin to service lines for the purpose of general supply.

*Double insulation.* See Insulation, double.

\* B.S. 205, 'Glossary of terms used in electrical engineering'

*Earth.* *a.* The conducting mass of the earth or of any conductor in direct electrical connection therewith.

*b.* A connection, whether accidental or intentional, between a conductor and the earth.

*c.* (Verb.) To connect any conductor with the general mass of the earth.

*Earthed circuit.* A circuit one or more points of which are intentionally connected to earth.

*Earth-continuity conductor.* The conductor including any clamp, connecting to the earthing-lead or to each other those parts of an installation which are required to be earthed. It may be in whole or in part the metal conduit or the metal sheath of the cables, or the special continuity wire of a cable or flexible cord incorporating such a wire.

*Earth current.* A fault current flowing to earth.

*Earth-electrode.* A conductor buried in the earth for the purpose of providing a connection with the earth.

*Earthed-pole.* That pole or line of an earthed circuit which is connected to earth.

*Earthing resistor (Earthing resistance).* A resistor through which a system is earthed and which serves to limit the current flowing in the event of an earth fault.

*Earth terminal (Earthing terminal).* A terminal provided on the frame of a machine or piece of apparatus for the purpose of making a connection to earth.

*Earthed system.* A system in which the neutral or one conductor is deliberately connected to earth directly or through an impedance.

*Earthing-lead.* The final conductor by which the connection to the earth-electrode or other means of earthing is made.

*Earthing reactor.* A reactor connected between the midpoint or the neutral point of a system and earth for the purpose of limiting the current flowing to earth in the case of a fault between line and earth.

*Earth-wire.* A conductor connected to earth and usually situated in proximity to the associated line conductors.

*Fault.* Any defect in plant, apparatus or conductor, which impairs normal operation.

*Fault current.* A current flowing from one conductor to earth, or to another conductor, owing to a defect in the insulation.

*Feeder.* A line which supplies a point of a distributing network without being tapped at any intermediate point.

*Insulation, double. a.* Of a conductor. A conductor is said to have double insulation when insulating material intervenes not only between the conductor and its surrounding envelope (if a cable) or immediate support (if bare), but also between the envelope or support and earth.

*b.* Of a portable appliance. A portable appliance having accessible metal

parts is double-insulated when protective insulation is provided in addition to the normal functional insulation, in order to protect against electric shock in case of a breakdown of the functional insulation.

*Leakage.* The passage of electricity in a path, other than that desired, due to imperfect insulation.

*Leakage current.* A fault current of relatively small value, as distinguished from that due to a short circuit.

*Live (or alive).* An object is said to be 'live' when a difference of potential exists between it and earth.

*Middle wire.* That conductor of a three-wire system which is intermediate in voltage between the other two.

*Minimum fusing current* (of a fuse). The minimum current at which the fuse element in a fuse will melt.

*Network.* An aggregation of conductors intended for the distribution of electrical energy.

*Neutral point (Neutral).* a. Of a system. That point which has the same potential as the point of junction of a group of equal resistances, connected at their free ends to the appropriate main terminals or lines, of the system. The number of such resistances is 2 for single-phase, 4 for two-phase (applicable to 4-wire systems only) and 3 for three-, six-, or twelve-phase systems.

b. Of a symmetrical system. The point with respect to which the potential of the conductors is symmetrical. It is usually connected to earth.

NOTE. In this Code the term 'neutral' is used in relation to a single-phase system, derived from a three-phase system to denote that conductor which is connected with earth at one or more points.

*Pilot (pilot wire).* An auxiliary line intended for measurements, signals, protection or telecommunication, in an electrical network.

*Potential (electrical).* At a point. The potential difference between that point and earth.

*Potential gradient.* At a point. The potential difference per unit length measured in the direction in which it is a maximum. When an electric force is due to a potential difference it is equal to the potential gradient. Practical unit: volt per unit length.

*Protective system.* A system consisting of apparatus and connections responsive to a disturbance (over-voltage, current surge, fault to earth, etc.) protecting an electrical installation against the harmful effects which may result therefrom, by isolating the faulty section.

*Resistance area (for an earth-electrode only).* The area of ground (around an earth-electrode) within which practically the whole of the potential difference between the electrode and the general mass of earth occurs when it is carrying an earth fault or test current.

*Service line.* Any electric line through which energy may be supplied or intended to be supplied by the Electricity Supply Undertakers to a consumer either from any distributor or directly from the premises of the Electricity Supply Undertakers.

*Voltage, extra-low.* A voltage normally not exceeding 30 volts r.m.s. alternating current or 50 volts direct current.

*Voltage, low\*.* A voltage normally exceeding extra low voltage, but not exceeding 250 volts r.m.s. alternating current or direct current.

*Voltage, medium.* A voltage normally exceeding low voltage, but not exceeding 650 volts r.m.s. alternating current or direct current.

*Voltage, high.* A voltage normally exceeding medium voltage.

*Voltage, gradient.* See Potential gradient.

**103. Related Codes.** Reference should be made, as required, to the following related Codes:

CP 321. Electrical installations.

CP 326. Protection of structures against lightning.

The 327 series of Codes dealing with telecommunication facilities in buildings.

CP 413. Design and construction of ducts for services.

CP 1008. Maintenance of electrical switchgear.

**104. British Standards.** Materials, appliances and components should comply with the relevant British Standards, including the following:

B.S. 842. Voltage-operated earth-leakage circuit-breakers for use on consumers' premises.

B.S. 951. Earthing clamps.

\* For the purpose of this Code, the term 'low-voltage' includes medium voltage unless specifically stated otherwise.

## SECTION TWO: DESIGN CONSIDERATIONS

### SUBSECTION 2A: INTRODUCTION

**201. System earthing.** The question of how a system shall be earthed is, in Great Britain, governed by the following legislation, extracts from which are given in Clause 601:

1. Paragraph c of Section 10 of the Schedule to the Electric Lighting (Clauses) Act, 1899.
2. Regulations 4 and 8 of the Electricity Supply Regulations, 1937.

In Northern Ireland, Regulations made by the Ministry of Commerce for Northern Ireland apply.

The legislation is so worded as to permit any type of earthing system, provided that it is as safe as is practicable and that it is not likely to interfere with telecommunication.

The Regulation that one point of every system shall, unless otherwise allowed, be earthed, is designed primarily to preserve the security of the system by ensuring that the potential on each conductor is restricted to such a value as is consistent with the level of insulation applied. From the point of view of safety, it is equally important that earthing should ensure efficient and fast operation of protective gear in the case of earth faults. Most high-voltage public supply systems are earthed. Approval has been given in recent years to unearthed overhead line systems, but these have only been small 11 kV systems derived from 33 kV mains, where the capacity earth current is less than 4 amperes and circumstances are such that the system will not be appreciably extended.

The limitation of earthing to one point on each system is designed to prevent the passage of current through the earth under normal conditions, and thus to avoid the accompanying risks of electrolysis and interference with communication circuits. With a suitably designed system, properly operated and maintained, earthing at several points may be permitted. In such cases the Postmaster General imposes conditions. A typical set of such conditions is given in Clause 602. This method of earthing was adopted for the British grid, and becomes economically essential in systems at 200 kV and upwards.

The system earth-resistance must be such that when any fault occurs against which earthing is designed to give protection, the protective gear will operate to make the faulty main or plant harmless. In most cases such operation involves isolation of the faulty main or plant, e.g. by circuit-breakers or fuses.

In the case of underground systems there is no difficulty whatever, but, for example, in the case of overhead-line systems protected by fuses or circuit-breakers fitted with overcurrent protection only, there may be difficulty in arranging that the value of the system earth-resistance is such that a conductor falling and making good contact with the ground shall result in operation of

the protection. The general requirement of low system-earth resistances remains even in cases where an arc-suppression coil is installed, as its operation may be frustrated by too high an earth-electrode resistance.

Earthing may not give protection against faults which are not essentially earth faults. For example, if a phase conductor on an overhead spur line breaks, and the part remote from the supply falls to the ground, it is unlikely that any protective gear relying on earthing, other than current balance protection at the substation, will operate, since the earth-fault current circuit includes the impedance of the load which would be high relative to the rest of the circuit.

**202. Equipment earthing.** Earthing of all metalwork of electrical equipment, other than parts which are normally live or current-carrying, is specified, in general, in the Regulations\*. The object is to ensure effective and rapid operation of the protective gear in the event of earth fault currents which might otherwise be undetected and cause fire; and to protect against danger to life through shock due to installation metalwork being maintained at a dangerous potential relative to earth.

### **203. Soil resistivity.**

*a.* The resistance to earth of an electrode of given dimensions is dependent on the electrical resistivity of the soil in which it is installed. It follows, therefore, that an important consideration in deciding which of the alternative methods of protection is to be adopted for a particular system or location is the soil resistivity in the area concerned.

The type of soil largely determines its resistivity, and representative values are given in Table 1. Earth conductivity is, however, essentially electrolytic in nature, and is affected therefore by the moisture content of the soil and by the chemical composition and concentration of salts dissolved in the contained water. Grain size and distribution, and closeness of packing are also contributory factors since they control the manner in which the moisture is held in the soil. Many of these factors vary locally and some seasonally, so that the table should only be taken as a general guide. For this purpose, Column A applies to most of the British Isles, but Column C is applicable to certain areas such as marshy flats around river estuaries.

Local values should be verified by actual measurement, and this is especially important where the soil is stratified, as, owing to the dispersion of the earth

\* The principal Regulations are:

1. Regulations for the Electrical Equipment of Buildings (issued by the Institution of Electrical Engineers);
2. The Electricity (Factories Act) Special Regulations, 1908 and 1944 (applicable to premises to which the Factories Acts apply);
3. The Electricity Commissioners Overhead Line Regulations, Ref. El.C.53 (1947 Revise);
4. The Electricity Supply Regulations, 1937;
5. Regulations for mines and quarries which are listed in Clause 225; and
6. The Electric Lighting (Clauses) Act, 1899.

TABLE 1. GENERAL DATA ON EARTH RESISTIVITY

| Type of soil                                                                     | Climatic condition                                                |                             |                                                                          |                              |
|----------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------------------|--------------------------------------------------------------------------|------------------------------|
|                                                                                  | A                                                                 |                             | B                                                                        | C                            |
|                                                                                  | Normal and high rainfall (e.g. greater than 20 in (51 cm) a year) |                             | Low rainfall and desert conditions (e.g. less than 10 in (25 cm) a year) | Under-ground waters (saline) |
|                                                                                  | Probable value                                                    | Range of values encountered | Range of values encountered                                              | Range of values encountered  |
|                                                                                  | ohm cm                                                            | ohm cm                      | ohm cm                                                                   | ohm cm                       |
| Alluvium and lighter clays                                                       | 500                                                               | *                           | *                                                                        | 100 to 500                   |
| Clays (excluding alluvium)                                                       | 1 000                                                             | 500 to 2 000                | 1 000 to 10 000                                                          | 300 to 1 000                 |
| Marls (e.g. Keuper marl)                                                         | 2 000                                                             | 1 000 to 3 000              | 5 000 to 30 000                                                          | 1 000 to 3 000               |
| Porous limestone (e.g. chalk)                                                    | 5 000                                                             | 3 000 to 10 000             |                                                                          |                              |
| Porous sandstone (e.g. Keuper sandstone and clay shales)                         | 10 000                                                            | 3 000 to 30 000             |                                                                          |                              |
| Quartzites, compact and crystalline limestone (e.g. carboniferous, marble, etc.) | 30 000                                                            | 10 000 to 100 000           |                                                                          |                              |
| Clay slates and slaty shales                                                     | 100 000                                                           | 30 000 to 300 000           | 100 000 upwards                                                          | 3 000 to 10 000              |
| Granite                                                                          | 100 000                                                           |                             |                                                                          |                              |
| Fissile slates, Schists Gneiss and Igneous rocks                                 | 200 000                                                           | 100 000 upwards             |                                                                          |                              |

\* Depends on water level in locality.

current, the effective resistivity depends not only on the surface layers but also on the underlying geological formation.

Some typical values so measured are given in Table 2.

It should also be noted that soil temperature has some effect, but is only important near and below freezing point, necessitating the installation of earth-electrodes at depths to which frost will not penetrate.

While the fundamental nature and properties of a soil in a given area cannot be changed, use can be made of purely local conditions in choosing suitable

**TABLE 2. TYPICAL SOIL RESISTIVITIES**  
(Measured by the Electrical Research Association)

Resistivities are mean values at depths varying from 2 ft to 8 ft (0.6 m to 2.4 m)

|                     | Resistivity     | Place of measurement           |
|---------------------|-----------------|--------------------------------|
|                     | ohm cm          |                                |
| Clay                | 2 000-2 700     | Stowmarket, Suffolk            |
| Clay                | 500-1 700       | Cuffley, Herts                 |
| Clay                | 400-1 000       | Alperton, Middlesex            |
| Brick clay          | 2 600-2 800     | Enfield, Middlesex             |
| Hard clay           | 5 000-15 000    | Hastings, Sussex               |
| Chalk               | 9 000-14 000    | Thetford, Norfolk              |
| Chalk               | 6 000-12 000    | Stevenage, Herts               |
| Chalk               | 14 000-15 000   | Welford                        |
| Chalk               | 18 000-30 000   | Easton                         |
| Chalk               | 9 000           | East Shefford                  |
| Chalk               | 11 000-13 000   | East Garston                   |
| Chalk               | 11 000-40 000   | Belmont                        |
| Chalk               | 26 000-33 000   | New Barn Farm                  |
| Chalk               | 16 000-20 000   | Balldown                       |
| Chalk               | 10 000          | White Wall Spur                |
| Chalk               | 14 000          | Barrow Hill Spur               |
| Sand                | 9 000-19 000    | Coddenham, Suffolk             |
| Sand                | 17 000          | Blythburgh, Suffolk            |
| Sand                | 40 000-45 000   | Wenhaston, Suffolk             |
| Sand                | 57 000-68 000   | Reydon Mount Pleasant, Suffolk |
| Sand                | 12 000-18 000   | Reydon Village, Suffolk        |
| Sand                | 57 000-88 000   | Southwold, Suffolk             |
| Sand                | 53 000          | Bulchamp, Suffolk              |
| Sand                | 300 000-800 000 | Newchurch Common, Cheshire     |
| Marsh               | 220-270         | Blythburgh, Suffolk            |
| Peat                | 20 000          | North Wales                    |
| Rocky mountain area | 100 000         | North Wales                    |
| Sandy gravel        | 30 000-50 000   | Riding Mill, Northumberland    |

Berkshire  
and  
Hampshire

electrode sites and of methods of preparing the site selected, to secure the optimum resistivity. These measures may be summarized as in Subclauses *b* to *f* below.

*b.* Where there is any option, a site should be chosen in one of the following types of soil in the order of preference indicated:

1. wet marshy ground (however, see Subclause *c* below);
2. clay, loamy soil, arable land, clayey soil, clayey soil or loam mixed with small quantities of sand;
3. clay and loam mixed with varying proportions of sand, gravel, and stones;
4. damp and wet sand, peat.

Dry sand, gravel chalk, limestone, whinstone, granite, and any very stony ground should be avoided, also all locations where virgin rock is very close to the surface.

*c.* A site should be chosen which is not naturally well-drained. A waterlogged situation is not, however, essential, unless the soil be sand or gravel, as in general no advantage results from an increase in moisture content above about 15 to 20 per cent. Care should be taken to avoid a site kept moist by water flowing over it (e.g. the bed of a stream) as the beneficial salts may be entirely removed from the soil in such situations.

*d.* Plate electrodes should be situated in soil which has a fine texture and which is packed by watering and ramming as tightly as possible. Where practicable the soil should be sifted, and all lumps should be broken up and stones removed in the immediate vicinity of the electrode.

*e.* Recourse may be had to chemical treatment of the soil to improve its conductivity. Common salt is most generally used for this purpose, and the addition of less than one part by weight of salt to 200 of soil moisture has been found to reduce the resistivity by 80 per cent, but there is little advantage in increasing the salt content above 3 per cent. Calcium chloride, sodium carbonate and other substances have been found beneficial, but before chemical treatment is applied it should be verified that no deleterious effect on the electrode material will result (see Subclause 212*d*).

*f.* Use should be made where possible of natural salts in the soil produced by bacteriological action on decaying vegetation. The resistivity of soil on which vegetation is growing will be lower than that of the same soil in the absence of vegetation.

## SUBSECTION 2B: EARTH-ELECTRODES

**204. Effect of shape on electrode resistance.** With all electrodes other than extended systems the greater part of the fall in potential occurs in the soil within a few feet of the electrode surface, since it is here that the current density is highest. To obtain a low overall resistance the current density should be as

low as possible in the medium adjacent to the electrode, which should be so designed as to cause the current density to decrease rapidly with distance from the electrode. This requirement is met by making the dimensions in one direction large compared with those in the other two—thus a pipe, rod or strip has a much lower resistance than a plate of equal surface area. The resistance is not, however, inversely proportional to the surface area of the electrode. The theoretical principles relating to the calculation of resistance of earth-electrodes are dealt with in Clause 603.

## 205. Resistance of common types of earth-electrode.

*a. Plates.* As shown in Clause 603, the approximate resistance to earth of a plate can be calculated from:

$$R = \frac{\rho}{4} \sqrt{\frac{\pi}{A}}$$

where  $\rho$  is the resistivity of the soil (assumed uniform) in ohm cm and  $A$  is the total area of the two sides of the plate in cm<sup>2</sup>.

For practical purposes, this may be written:

$$R = \frac{\rho}{122} \sqrt{\frac{\pi}{A'}}$$

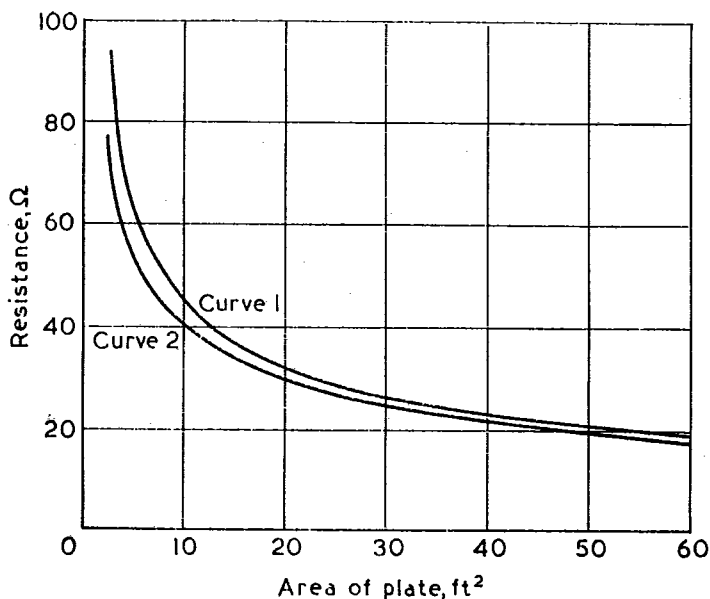
where  $A'$  is the total area in ft<sup>2</sup>.

This gives Curve 1 of Fig. 1, the area concerned being the total of the two sides. This curve may be used as stated in Clause 603 for plates buried horizontally at normal depths. In practice plates are generally set vertically. Experimental data on the resistance in this case is lacking, but Fig. 1 may be used for guidance.

Where the resistance of a single plate is higher than the required value, two or more plates may be used in parallel, and the total resistance is then inversely proportional to the number employed, provided that each plate is installed outside the resistance area of any other. This normally requires a separation of about 30 ft but for sizes of plate generally employed a separation of 6 ft is sufficient to ensure that the total resistance will not exceed the above value by more than 20 per cent. Even at the latter spacing, it is generally more economical to use two plates in parallel, each of a given size, than one of twice that size. The size employed is therefore normally not greater than 4 ft by 4 ft.

The depth at which plates are set should be such as to ensure that the surrounding soil is always damp. Where the underlying stratum is solid, e.g. chalk or sandstone and near the surface the top of the plate should be approximately level with the top of the solid stratum.

Plates are generally either of copper not less than 0.104 in (12 SWG) in thickness or of cast iron not less than ½ in thick.



- Curve 1.** Circular plate on surface of ground (calculated resistance plotted against area of one side).
- Curve 2.** Horizontal square plate 4 ft below surface (calculated resistance plotted against total area of the two sides).

**Fig. 1. Variation of resistance of plate electrodes with area, for uniform soil resistivity of 10 000 ohm cm**

Plates are, however, in general a most uneconomic form of earth-electrode. They should only be used where current-carrying capacity is the prime consideration.

*b. Pipes or rods.* The resistance of a pipe or rod electrode is given (see Clause 603) by:

$$R = \frac{\rho}{83l} \log_{10} \frac{48l}{d}$$

where  $l$  is the length in feet,

$d$  is the diameter in inches and

$\rho$  is the resistivity of the soil in ohm cm (assumed uniform).

The curves of Fig. 2 are calculated from this equation for electrodes of  $\frac{1}{2}$  in, 1 in and 4 in diameter respectively in a soil of 10 000 ohm cm resistivity. Change of diameter has a relatively minor effect, and size of pipe is generally governed by resistance to bending or splitting. It is apparent that the resistance diminishes

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rapidly with the first few feet of driving, but less so at depths greater than 6 to 8 ft in soil of uniform resistivity.

A number of rods or pipes may be connected in parallel and the resistance is then practically proportional to the reciprocal of the number employed so long as each is situated outside the resistance area of any other. In practice this is satisfied by a mutual separation of 10 ft (provided that they are not driven to a

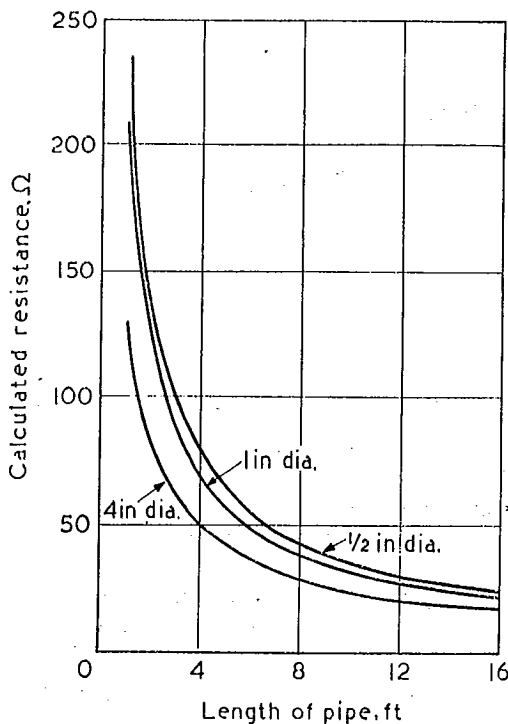


Fig. 2. Effect of length of pipe electrode on calculated resistance for soil resistivity of 10 000 ohm cm (assumed uniform)

depth much exceeding this) which for two electrodes results in a combined resistance of 54 per cent of the individual value of each, and for any number arranged in line gives a value which does not exceed by more than 20 per cent the resistance of a single electrode divided by the number in parallel. A substantial gain is effected even at 6 ft separation.

Pipes may be of cast iron of not less than 4 in diameter 8 ft to 10 ft long and 1/2 in thick. Such pipes cannot be driven satisfactorily and may therefore be

more expensive to install than plates for the same effective area. Alternatively mild-steel water-pipes of 1½ in to 2 in diameter are sometimes employed. These can be driven but are less durable than copper rods.

Driven rods generally consist of ½ in to ¾ in round copper, 4, 8, 12 or 16 ft long. Cruciform and star shaped sections are also available and are more rigid while being driven, but the apparent additional surface does not confer a noticeable advantage in current-carrying capacity or reduction of resistance.

Such rods may be coupled together to give longer lengths. Except in special conditions, a number of rods in parallel are to be preferred to a single long rod. Deeply driven rods are, however, effective where the soil resistivity decreases with depth or where sub-strata of low resistivity occur at depths greater than those to which rods, for economic reasons, are normally driven. In such cases the decrease of resistance with depth of driving may be very considerable as is shown by the measurements plotted in Fig. 3 for a number of sites; for curves A<sub>1</sub> and A<sub>2</sub> it was known from previously sunk boreholes that the soil down to a depth of between 20 and 30 ft consisted of ballast, sand and gravel, below which occurred London clay. The rapid reduction in resistance when the electrodes penetrated the latter was very marked. The mean resistivity up to a depth of 24 ft in one case was 15 000 ohm cm; at 34 ft the mean value for the whole depth was 2000 ohm cm owing to the low resistivity of the clay stratum. Similarly for curve C the transition from gravelly soil to clay at a depth of about 5 ft was very effective. In the case of curve B, however, no such marked effect occurred although there was a gradual reduction in average resistivity with increase in depth, as can be seen by comparison with the dotted curves, which are calculated on the assumption of uniform resistivity.

For deeply driven rods, joints between sections are usually made by means of a screwed coupling, which must not, however, be of greater diameter than that of the rods which it joins.

Other factors which affect a decision whether to drive deep electrodes or to employ several rods or pipes in parallel are the steep rise in energy required to drive them with increase in depth and the cost of couplings. The former can be offset by reducing the diameter of the rods, since a ½ in diameter rod can be driven to considerable depths without deformation or bending if the technique of using a large number of comparatively light blows is adopted rather than a smaller number of blows with a sledge hammer. Power-driven hammers suitable for this purpose are available.

In cases where impenetrable strata or high-resistivity soil occur at relatively small depths, considerable advantage may result from driving rods at an angle of about 30° to the horizontal, thus increasing the length installed for a given depth.

*c. Strip or conductor electrodes.* These have special advantage where high resistivity soil underlies shallow surface layers of low resistivity. They are frequently in the form of untinned copper strip of not less than 1 in by ½ in section,

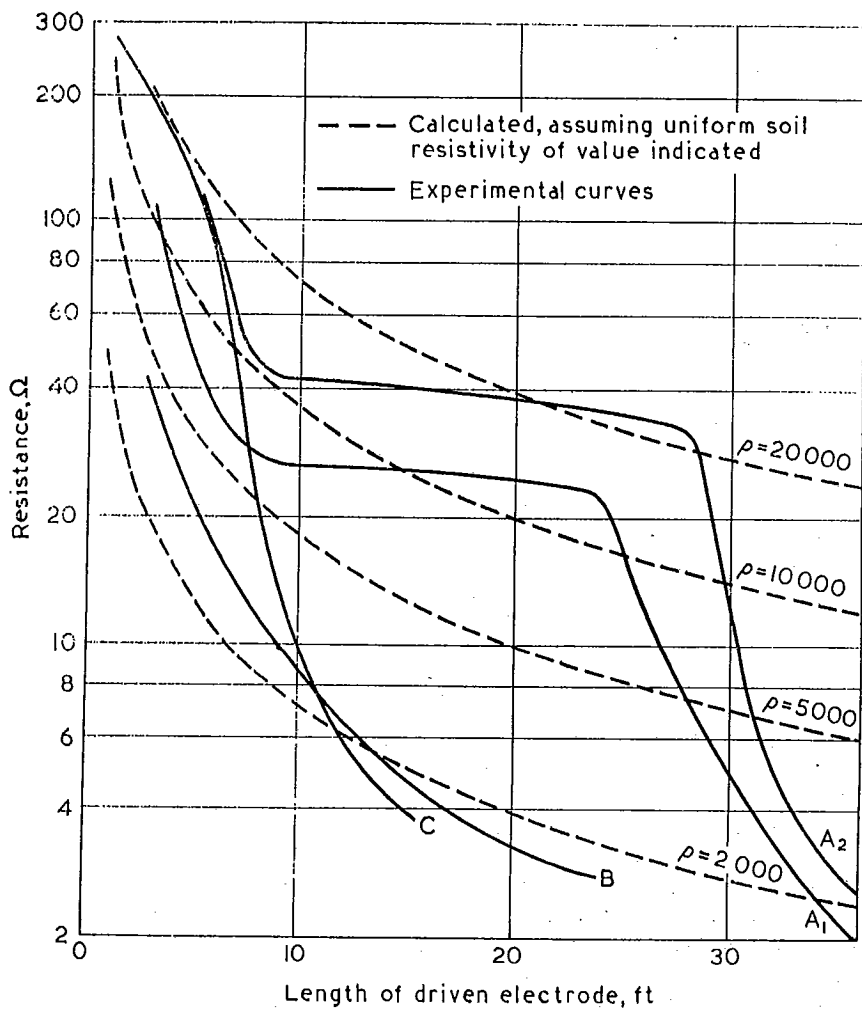


Fig. 3. Calculated and experimental curves of resistance of  $\frac{1}{2}$  in diameter driven rod electrodes

but may be of bare copper conductor as used for overhead lines. The resistance is given by:

$$R = \frac{\rho}{83l} \log_{10} \frac{24l^3}{wt}$$

where  $\rho$  is the resistivity in ohm cm (assumed uniform),

$l$  is the length in feet,

$w$  is the width (in the case of strip) or twice the diameter (in the case of circular conductors) in inches and

$t$  is the depth in feet.

Care should be taken in positioning these electrodes especially to avoid damage by agricultural operations.

Such electrodes are often most effective if buried in ditches under hedge-rows where the bacteriological action arising from the decay of vegetation maintains a low resistivity.

Fig. 4 shows the variation of calculated earth-resistance of strip or conductor

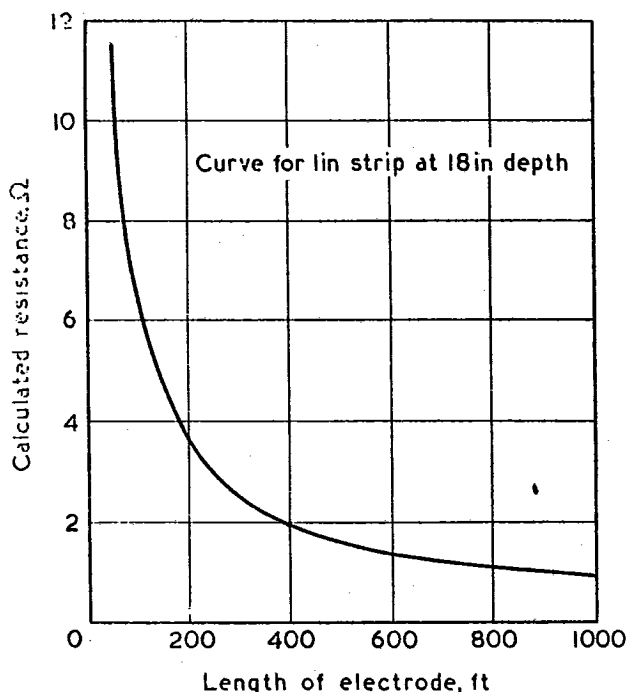


Fig. 4. Effect of length of strip or conductor electrodes on calculated resistance for soil resistivity of 10 000 ohm cm (assumed uniform)

electrodes with length for a soil resistivity of 10 000 ohm cm. Effect of conductor size and depth over the range normally used is very small.

If several strip electrodes are required for connection in parallel in order to reduce the resistance they may be installed in parallel lines, or they may radiate from a point. In the former case, the resistance of two strips at a separation of 8 ft is less than 65 per cent of the individual resistance of either of them.

*d. Water pipes.* In urban districts and other areas, where a piped water supply is available, the use of water pipes for consumers' earth electrodes has been common in the past. Though generally very effective so long as the consumers' pipes and water-mains to which they are connected are all metal, and all joints are of metal-to-metal construction, the use of water-pipes for this purpose cannot now be considered to be good practice because of the growing use of non-conducting material for pipes. Asbestos cement and plastics are used both for water-mains and consumers' pipes, and rubber rings are widely used for jointing metal water-mains. Copper service pipes are often wrapped with insulating tape.

For new installations, therefore, a water pipe should not be used as the only means of earthing. Cross-bonding of the water service with the exposed metal-work of the electrical installation and the gas service (if any) is, however, permissible, and indeed necessary in some circumstances (see Subclauses 223 / and *p* and Clause 224), subject to the provision of earthing facilities which are independent of the water service.

For existing installations in which a water pipe is used as the sole earth-electrode for low-impedance earthing, an independent means of earthing should be provided at the first practicable opportunity. In the meantime, the resistance to earth of the water pipe should be measured at frequent intervals to ascertain if the earthing remains effective; arrangements should be made for the consumer (or other person responsible for the electrical installation) to be advised of any change in the water system which might affect his earthing, preferably in advance of the work being carried out.

The earth resistance of a metallic water pipe principally depends on the length of the pipe and the resistivity of the soil; for typical urban water systems, values range from 0.2 to 1.0 ohm per 1000 ohm cm soil resistivity.

*e. Cable sheaths.* Where an extensive underground cable system is available the lead sheath and armour form a most effective earth-electrode. In the majority of cases the resistance to earth of such a system is less than 1 ohm. A freshly installed jute or hessian served cable is insulated from earth, but the insulation resistance of the jute deteriorates according to the moisture content and nature of the soil. However, cable sheaths are more commonly used to provide a metallic path to the fault current returning to the neutral. This aspect is dealt with fully in Subclause 220c.

*f. Structural steelwork.* The resistance to earth of steel frames or reinforced concrete buildings will vary considerably according to the type of soil and its moisture content, and the design of the stanchion bases. For this reason it is

essential to measure the resistance to earth of any structural steelwork which it is proposed to employ as a low-impedance earth connection both before so employing it and at frequent intervals thereafter.

*g. Reinforcement of piles.* At power stations and large substations, it is often possible to secure an effective earth-electrode by making use of the reinforcement in concrete piles. The earth strap should be bonded to a minimum of four piles and all the piles between the bonds should be bonded together. Each set of four piles should be connected to the main earthing-strap of the substation.

**206. Selection of metals for earth-electrodes.** Although electrode material does not affect initial earth resistance, care should be taken to select a material which is resistant to corrosion in the type of soil in which it will be used. Tests in a wide variety of soils have shown that copper, whether tinned or not, is entirely satisfactory (subject to the precautions given in the next paragraph)—the average loss in weight of specimens 6 in  $\times$  1 in  $\times$   $\frac{1}{8}$  in buried for 12 years in no case exceeded 0.2 per cent per year. Corresponding average losses for unprotected ferrous specimens (e.g. cast iron, wrought iron or mild steel) used in the tests were as high as 2.2 per cent per year. Considerable, and apparently permanent, protection appears to be given to mild steel by galvanizing, the test showing galvanized mild steel to be little inferior to copper with an average loss not greater than 0.5 per cent per year. Only in a few cases was there any indication in all these tests that corrosion was accelerating and in these cases the indications were not very significant.

The possibility of damage to cables and other underground services and structural metalwork in the vicinity of earth-electrodes due to electrolytic action between dissimilar materials should not be overlooked when the material for earth-electrodes is selected. Materials compatible with other metal structures in the vicinity should be selected or other remedial action taken.

**207. Current loading of earth-electrodes.** An earth-electrode should be designed to have a loading capacity adequate for the system of which it forms a part, i.e. it should be capable of dissipating without failure the energy in the earth path at the point at which it is installed under any condition of operation on the system. Failure is fundamentally due to excessive temperature rise at the surface of the electrode and is thus a function of current density and duration as well as electrical and thermal properties of the soil.

In general, soils have a negative temperature coefficient of resistance so that sustained current loading results in an initial decrease in electrode resistance and a consequent rise in the earth fault current for a given applied voltage. As soil moisture is driven away from the soil-electrode interface, however, the resistance increases and will ultimately become infinite if the temperature rise is sufficient. This occurs in the region of 100°C and results in complete failure of the electrode.

Three conditions of operation require consideration, viz. long-duration

loading, as with normal system operation, short-time over-loading, as under fault conditions in directly earthed systems, and long-time over-loading, as under fault conditions in systems protected by arc-suppression coils.

The little experimental work which has been done on this subject has been confined to model tests with spherical electrodes in clay or loam of low resistivity and has led to the following tentative conclusions:

1. Long-duration loading due to normal unbalance of the system will not cause failure of earth-electrodes provided that the current density at the electrode surface does not exceed 0.025 ampere/in<sup>2</sup>. Limitation to values below this would generally be imposed by the necessity to secure a low-resistance earth.
2. Time to failure on short-time overload is inversely proportional to the specific loading, which is given by  $i^2\rho$  where  $i$  is the current density at the electrode surface and  $\rho$  the resistivity of the soil. For the soils investigated the maximum permissible current density is given by:

$$i = \sqrt{\frac{2400}{\rho t}} \text{ ampere/in}^2$$

where  $t$  is the duration of the earth fault in seconds,

$i$  is the current density in amperes/in<sup>2</sup> and

$\rho$  is the resistivity of the soil in ohm cm.

Experience indicates that this value may be adopted for plate electrodes.

**208. Voltage gradient around earth-electrodes.** Under fault conditions the earth-electrode is raised to a potential with respect to the general mass of the earth which can be calculated from the prospective fault current and the earth resistance of the electrode. This results in the existence of voltages in the soil around the electrode which may be injurious to telephone and pilot cables, whose cores are substantially at earth potential, owing to the voltage to which the sheaths of such cables are raised; the voltage gradient at the surface of the ground may also constitute a danger to life, especially where cattle are concerned.

The former risk arises mainly in connection with large electrode systems, as at power stations and substations, and is dealt with in detail in Subclause 212f.

Danger to animals occurs principally with pole-mounted substations on low-voltage systems. In rural areas it is by no means uncommon for the earth-path resistance to be such that faults are not cleared within a short period, and in such cases animals, which frequently congregate near a pole, are liable to receive a dangerous shock. The same trouble sometimes occurs at farms, where earth electrodes are provided for individual appliances. An effective remedy is to earth the neutral conductor at some point on the system inaccessible to animals, rather than earthing the neutral at the transformer itself. Alternatively, in the case of wood-pole lines, pipe or rod electrodes may be buried with their tops

below the surface of the soil and connection made to them by means of insulated leads. The maximum voltage gradient over a span of 6 ft, adjacent to a 1 in diameter pipe electrode is reduced from 85 per cent of the total electrode potential when the top of the electrode is at ground level to 20 per cent and 5 per cent when it is buried 1 ft and 3 ft 6 in respectively.

Earth electrodes other than those used for the earthing of the fence itself should not be installed in proximity to a metal fence, to avoid the possibility of the fence becoming live, and thus dangerous at points remote from the substation, or alternatively giving rise to danger within the resistance area of the electrode by introducing a good connection with the general mass of the earth.

## SUBSECTION 2C: POWER STATIONS AND SUBSTATIONS

**209. Requirements for power stations and substations.** In general, earthing provision will be required at power stations and substations for the following:

1. The neutral points of each separate system which has to be earthed at the station; the various systems concerned will be of different voltages.
2. Apparatus frameworks and other non-current-carrying metalwork associated with each system, e.g. transformer tanks and the sheaths of power cables.
3. Extraneous metalwork not associated with the power systems, e.g. boundary fences, sheaths of communication cables, etc.

From the point of view of safety to personnel the aim is to ensure that in both normal or abnormal conditions no dangerous voltages can appear on the equipment to which a man has legitimate access. In this respect 'earthed' is essentially a relative term. Particularly with the high earth-fault currents possible on h.v. systems having directly earthed neutrals, it is not practicable to ensure that, during fault conditions, all metal parts nominally earthed are at the true earth potential. The aim must, therefore, be to ensure that there is an effective connection of very low impedance and adequate current-carrying capacity between the parts with which anyone may be in simultaneous contact. At the same time it is desirable to arrange that as far as possible large fault currents do not flow between such points.

From the point of view of the possible damage to apparatus, it is desirable in fault conditions to have the least practicable voltage appearing between the earthed parts of station equipment generally and the main body of earth, so that insulation breakdown or burning does not occur on apparatus earthed outside the station (e.g. apparatus connected to pilot or telephone cables, cable sheaths, etc.). For similar reasons, the voltage drop between earthed points in the station should also be kept to a minimum. In addition, the effectiveness of any surge protection provided depends in part on the adequacy of the connection of the protective

devices to earth. In this case the high instantaneous currents, often containing high-frequency components, require that the earth connection shall not only be of low resistance but of low reactance, i.e. as short and as free from changes of direction as practicable.

The resistance to the general mass of the earth of an earth-electrode which is common to two electrically separate power systems constitutes a coupling between these systems when an earth fault occurs in either. Similarly if non-current-carrying metalwork is connected to the same earth-electrode as the neutral point of the supply, an earth fault will raise the potential of such metalwork by the product of the resistance of this electrode\* and the fault current which it carries.

To maintain complete separation between systems at different voltages, therefore, separate earth-electrodes should, on these grounds, be used for the neutral point of each supply system to be earthed at the site and for the extraneous metalwork at each station or substation. If such a method is adopted, however, each system at a given site must be insulated from the others and from extraneous metalwork to withstand the maximum voltage which can be developed across any earth-electrode at that site. Generally speaking, this will be the voltage with respect to the general mass of the earth to which the metalwork or neutral of the highest voltage system may be raised either by penetration of a lightning surge to an earthed neutral, or by a flash-over due to lightning or other causes from conductors of the highest-voltage system to the earthed metalwork associated with that system. Insulation of such an order is rarely practicable and a compromise has to be sought.

The question of using a common earth or separate earths for the systems of different voltages at a transforming point affects:

1. the probability of breakdown occurring in a transformer between the higher and lower voltage sides due to lightning or other surges; and
2. the safety of the community (and its property) served by any low-voltage system emanating from that point against a rise of potential of the neutral due to a breakdown of insulation on the high-voltage side (e.g. transformer bushing).

The former risk is reduced by use of a common earth and the latter only arises if the earth-electrode resistances are not low enough. In general where the earth-electrode resistance attainable is of the order of 1 ohm or less as is usual in the case of power stations, large outdoor substations, and substations serving a cable network, there is some advantage in using a common earth.

The disturbances transmitted from one electrical system to the other under

\* Here and elsewhere in this context, the resistance concerned is that of the electrode together with any other metalwork in contact with the earth to which it may be intentionally or inadvertently connected.

fault conditions are not excessive if the resistances of earth-electrodes are small compared with the total impedances which limit earth-fault currents. In high-voltage systems at voltages of 66 kV and below, if earth-fault currents are not suitably limited by the normal impedance of the circuit it is customary to achieve this limitation by the insertion of resistors between the system neutral and the earth-electrode\*. Such resistors are not normally necessary for this purpose† on systems of the highest voltages (100 kV and upwards) where the system at the next stage of transformation can usually withstand under fault conditions a temporary excess voltage of the order of the product of the higher-voltage fault current and the earth-electrode resistance, although when the transformation ratio is large the electrode resistance must be kept low.

As an alternative to resistors for the above purpose, arc-suppression coils may be used where practicable. In Great Britain special authority‡ from the Ministry of Power/Secretary of State for Scotland is required for the use of arc-suppression coils for this purpose because the installation of such coils does not comply with the requirements in Regulation 17 (Overhead Line Regulations) that 'adequate means shall be provided to render any line dead in the event of its falling due to breakage or otherwise'; 'dead' means at or about earth potential and disconnected from any live system. Furthermore, special attention should be paid to the long-time fault-current capacity of earth-electrodes used on systems protected by arc-suppression coils (see Clause 207). Provision is often made for the automatic short-circuiting of arc-suppression coils after a stipulated period of fault.

By arrangement with the Postmaster-General, means are also available for transmitting an alarm over the public telephone system in the event of the arc-suppression-coil operating for an appreciable time.

In rural situations where overhead lines are used, it may, in certain circumstances, be inadvisable to use a common earth.

The requirements are, therefore, best considered separately in relation to substations where low voltage is confined to auxiliary supplies within the substation itself, to substations which give an external low-voltage supply, and to power stations.

In what follows, no attempt has been made to deal with neutral earthing switchgear since the subject is so broad that it is not possible to lay down any general rules which can be applied in practice.

A wide range of switchgear is available for this purpose and it is necessary to exercise care in selecting the most appropriate type according to the envisaged operating conditions.

\* It is essential that the connection between neutral and any such resistor be adequately insulated from earth.

† Neutral resistors may, however, be necessary for other reasons, e.g. to ensure stability, of the system.

‡ A typical example is shown in Clause 604.

**210. General earthing arrangements at substations.**

*a. Substations giving no external low-voltage supply.* It is usual to use a common earth-electrode for all system earths and the equipment earth. This gives the highest degree of security at the site in question and the disturbances propagated elsewhere in the systems in consequence of the common coupling are not in general excessive. The neutral of any low-voltage system used for internal supplies, e.g. station lighting, power and auxiliary circuits, may safely be connected to the main station earth since, on the occurrence of a fault to earth on any high-voltage system, the potential of the low-voltage neutral will be raised with respect to the general mass of earth but not with respect to any exposed metalwork connected to the common earth-electrode.

Where a high-voltage line with no earth wire terminates at the station there is some advantage in connecting the earth side and associated metalwork of the earthing switch, provided for use during maintenance, to a separate electrode.

The perimeter fence may need to be earthed separately from the main station earth electrode system (see Subclause 214a).

*b. Substations giving an external low-voltage supply (excluding pole-mounted transformers).* Here two possibilities exist for the earthing of the low-voltage system and its associated equipment:

1. They may be earthed by a separate earth-electrode outside the resistance area of the main station earth. In this case, frameworks, etc., directly associated with the low-voltage system must be suitably insulated from the metalwork, including the transformer tanks associated with the high-voltage system, which will be bonded to the main station earth. The earth electrode resistance of the high voltage system must then be sufficiently low to avoid as far as possible the risk that a flashover from the high-voltage system to earthed metalwork may raise the potential of the transformer tank, etc., and cause consequent breakdown of the insulation of the low-voltage system within the resistance area of the substation.
2. Alternatively, the low-voltage system neutral may be connected to the station earth, except in substations supplying a protective multiple earthing system. The electrode resistance must then be sufficiently low to avoid as far as possible the risk that an earth fault on the high-voltage system may cause a voltage rise of the neutral of the low-voltage system and consequent damage on that system outside the resistance area of the station.

Method 1 is generally not applicable to indoor substations, or those substations to which all connections are by metal-sheathed cable, since a sufficiently low earth-resistance is available to avoid danger. Where method 1 is used it must not be possible for a man to touch simultaneously metalwork bonded to separate earthing systems. The lead sheaths of low-voltage cables from a substation fed by high-voltage overhead lines should be insulated within the resistance area of

the substation earth-electrode unless it can be shown that there is no risk of a dangerous rise of potential.

*c. Pole-mounted transformers.* In the case of pole-mounted transformers on overhead line systems difficulties may arise in areas of high soil resistivity. Here, if the pole carries also isolating switchgear with low-level operating handle, up to three separately earthed electrode systems may be required. That for the neutral of the low-voltage system, discussed more fully later, is usually provided not nearer than one pole span away on the low voltage line. That for the high-voltage metalwork (transformer tank, switch framework, support metalwork), consists of one earth electrode at or near the pole. Resistances of 5 to 50 ohms are sometimes the minimum economically possible. In addition, an earth mat must be provided, near the ground surface, in the position taken up by a person operating the switch handle; this mat must be connected to the switch handle. The mat should be electrically separated from the main electrode; this is considered to be achieved by spacing the nearest element of that electrode at least 3 ft from the periphery of the mat and by placing the two earthing-wires on opposite sides of the pole. The tops of the main electrodes should be at least 9 in, and preferably 2 ft, below the ground, to make the earthing wire to the main electrode of outdoor type rubber or plastics-insulated cable up to a point 7 ft above ground level, and to place this cable, between the bottom of the pole and the electrode, in a 2 in diameter earthenware duct filled solid with bitumen.

Avoidance of danger from voltage gradients around electrodes associated with pole-mounted transformers is dealt with in Clause 208.

*d. Tertiary windings of transformers.* The tertiary winding of a power transformer should be connected to the transformer tank by a connection of sufficient cross-sectional area to carry the primary short circuit current.

## 211. General earthing arrangements at power stations.

*a. Neutral earthing of transformer-connected generators.* Two methods have been generally used in Great Britain, while a third is in common use elsewhere. These are:

1. earthing through the primary winding of a voltage transformer;
2. earthing through a resistor; and
3. earthing through the primary winding of a distribution-type transformer, with resistor across the secondary (developed in the U.S.A.).

In method 1 the impedance of the voltage transformer limits the current due to an earth fault on one phase to a negligible value and minimizes the direct danger of serious damage to the stator. If desired, the generator can remain in service until operational conditions permit its withdrawal. This, however, imposes a higher voltage to earth on the unearthed phases and, unless this is

taken into account in the machine design, the permissible period of such operation is usually very short. The secondary winding is connected to a relay which can be arranged to trip, or to give an alarm only, as desired.

The practice of shunting the primary winding with a fuse is not recommended since in the event of a stator fault, the fuse will blow and the solid earth connection to the star point of the stator winding will be replaced by a very high impedance earth connection, just at the very time when a stable earth is most required to prevent the possibility of over-voltages increasing the fault damage. Similarly, the shunting of the primary winding by a surge diverter has its attendant risks due to difficulties which may arise from the possible maloperation of the surge diverter.

In method 2, each individual generator neutral point is earthed through a resistor.

This method necessitates immediate and automatic disconnection of the generator and interruption of its field on the occurrence of an earth fault on the stator winding or its associated transformer connections and windings.

Method 3 is used extensively in the U.S.A. and in Canada, but is used only to a limited extent at present in Great Britain.

After careful consideration of operating experience with methods 1 and 2, the latter has been preferred in recent years by the supply authorities in Great Britain for the larger power stations. The values of resistance are such that, with one line terminal earthed, a maximum current of 300 amperes would flow for normal voltage conditions.

*b. Neutral earthing of busbar-connected generators.* A few busbar-connected generators are still in service in Great Britain, but no accepted code exists for the earthing of these. Two general systems exist: individual earthing and neutral bar earthing. General practice is to follow the recommendations of the manufacturers. The earthing resistor is generally designed to carry full-load current for 30 seconds; it may be of either liquid or metallic type but the latter is more usual.

*c. Earthing of power station auxiliary systems.* There are in common use three methods of earthing the neutral point in power-station auxiliary systems:

1. Solid earthing.
2. Earthing through a voltage transformer (or voltage relay) with a surge diverter (but not a fuse) shunting the primary winding (or the relay).
3. Resistance earthing.

Methods 1 and 3 involve the automatic disconnection of the individual faulty circuit.

With method 2, an alarm can be arranged to operate from the secondary of the voltage transformer and the scheme enables all auxiliaries to be kept in service until it is convenient to shut the board down.

The current tendency for the larger power stations is to use method 1 or 3, since method 2 has certain disadvantages, such as the complication in arranging for speedy identification of the individual faulty circuit and the possible difficulties arising from malfunctioning of the surge diverter.

Recommended practice is related to size of unit and voltage of system as follows:

1. *3.3 kV Systems at stations with 30 MW sets:*  
Solid earthing.
2. *3.3 kV and 6.6 kV Systems at stations with sets larger than 30 MW but not exceeding 100 MW:*  
Solid earthing for preference with resistance earthing as an alternative where special reasons operate for reducing the maximum earth fault current, e.g. with the 3.3 kV auxiliary supply for 100 MW sets.
3. *3.3 kV and 6.6 kV Systems at stations with sets larger than 100 MW:*  
Resistance earthing for preference.
4. *415 Volt Systems at all stations:*  
Solid earthing for preference.

The factors governing the design of the neutral earthing resistor are the expected neutral earth fault current and the overall protective characteristics of the system.

*d. Equipment earthing at power stations.* Practice in regard to equipment earthing at power stations is governed by the same principles, and follows generally the same lines, as that for large substations giving no external low-voltage supply (see Subclause 210a), that is, a common earth is used for the neutral earthing of generators and power-station auxiliaries and for all apparatus frameworks, power cable sheaths, and extraneous metalwork not associated with the power systems other than the perimeter fence (see Subclause 214a).

## 212. Power station and substation electrodes.

*a. General requirements.* The required characteristics of the main-station electrode and of any separate electrode used for low-voltage system earthing are:

1. A suitably low resistance is necessary under all climatic conditions, depending on the system voltage and fault currents envisaged. The resistance, and hence possible rise in potential between the station-earth system\* and the general body of earth, should be as low as can economically be contrived. In the absence of specific local Regulations a maximum rise in potential of 430 V should be aimed at; higher values which may occur with difficult site conditions may be tolerated but necessitate special

\* Here and elsewhere in this context, the resistance concerned is that of the electrode together with any other metalwork in contact with the earth to which it may be intentionally or inadvertently connected.

precautions in external connections of any form to the station site. In particular special insulating and isolating equipment on Post Office circuits are in these circumstances necessary (see Subclause 226*b*).

2. The electrode needs to be capable of carrying such currents as may arise in normal operating and during fault and surge conditions without unduly increasing in resistance.
3. The electrode needs to be so placed that all lightning protective earth leads may be brought to the earth-electrode by as short and straight a path as possible to minimize surge impedance.

In addition, all electrodes should be of material which is suitably resistant to such corrosion and other deteriorating influences as may exist at the site and which will not cause damage to other underground services and structural metalwork in the vicinity through electrolytic action between dissimilar metals (see Clause 208). Where it is impracticable to avoid the latter danger by selection of compatible metals the adoption of cathodic protection or other remedial action may be necessary.

At power stations it is often possible to secure an effective earth 'electrode' by making use of buried iron piping for cooling water or penstocks. Sheet steel piling where available at power stations and large substations may be used for the same purpose, in which case the earth strap should be bonded to a minimum of four piles and all the piles between the bonds should be welded together. The main earthing strap provided for the station will itself, if laid direct and without serving, contribute appreciably to provision of an efficient earth. If it can be shown by tests that such adventitious earths are adequate as regards resistance and current-carrying capacity and that they will remain so under all climatic and fault conditions, no other electrodes need be provided.

Where no such adventitious earths exist or where they are inadequate, it is necessary to provide specially installed electrodes. Subsection 2B deals generally with such earth-electrodes but some aspects of design practice adopted at power stations and substations are covered in Subclauses *b* to *f* below.

In any case all steelwork such as that referred to above should be bonded to the station earthing system as also should all structural steelwork, but attention is drawn to the warning given in Subclause 205*f* against relying on the latter as an earth-electrode.

*b. Choice and design.* Where high prospective fault currents govern the choice of electrodes, plates are recommended for normal soil conditions. They may be of copper not less than 0.104 in (12 SWG) in thickness or of cast iron not less than  $\frac{1}{2}$  in thick and preferably ribbed. The common size employed is 4 ft by 4 ft.

As an alternative to plates in the above conditions cast-iron pipes not less than 4 inches in diameter, 8 ft to 10 ft long, and not less than  $\frac{1}{2}$  in thick may be used, but are more expensive to install than plates for the same effective area.

A further alternative sometimes employed is the use of mild-steel water pipes 1½ in to 2 in diameter. These can be driven, but, being less durable than copper rods, should be used, if at all, only for temporary work.

For low fault current and where soil resistivity is high, copper rods are preferred to plates and pipes. They are normally driven in groups with a spacing between them not less than their length. While rods are easy to install in soft deep soil, they are not suitable where the sub-soil is stony or hard; they have an advantage, however, where the water table is too deep to be reached easily by excavation, and the surface layers have relatively high resistance, e.g. in sandy soils.

In regions of high soil-resistivity, bare copper strip, stranded conductor, or mesh may be used, but in certain circumstances the cost may be high. This form of electrode has particular advantage where rock is at or near the surface of the area including or surrounding the station, and may also be employed over a limited area as an 'earth mat' where it is particularly desirable to ensure absolute protection to a man standing at a certain spot, e.g. to operate an air-break switch (see also Subclause 210c).

*c. Number and location.* Small substations, whether indoor or outdoor, supplying an extensive cable distribution-network, generally do not require any specially installed earth-electrode, the earthing facilities provided by the cable sheaths being adequate. Where these need reinforcement, however, a single electrode or group of electrodes is provided immediately adjacent to the substation (if indoor) or within or adjacent to the perimeter fence (if outdoor). Alternatively, a bare strip or stranded conductor may be buried with outgoing cables provided the cables are served; with unserved cables the possibility of electrolytic action arises. For small outdoor substations which do not supply such a cable network, the main station earth generally consists of a single electrode or group of electrodes within the perimeter fence. Where such a substation gives an external low-voltage supply by overhead line only, if a separate electrode is necessary for earthing the neutral of the latter and its associated equipment in accordance with Subclause 210b, such electrode must be located outside the resistance area of the main station earth.

At large sites, apart from securing a sufficiently low resistance and adequate current-carrying capacity, a reasonable distribution of electrodes is necessary. For power stations, the use of adventitious earths (see Subclause 212a) generally secures this, and any additional electrodes necessary are located at convenient points within the area of the station site. For large outdoor substations, however, it is necessary to plan the system of electrodes in relation to the layout of the equipment. As a guide it is suggested that one electrode or group of electrodes should be placed as near as practicable to each main transformer, transformer bank, circuit-breaker, surge diverter, or other possible source of earth-fault current.

*d. Salt-treated electrodes.* As mentioned in Clause 203 the conductivity of the soil (and therefore the resistance of an earth-electrode buried in it) may be improved by chemical treatment. This is effective, however, only in very small stations where the designed earth electrode represents the major contact with the main body of the earth. In larger stations, the effect of the fortuitous earthing provided by other buried metalwork generally and, in particular, by the buried earth-strip interconnectors from the electrode system to the individual items of equipment, will far outweigh the effect of the designed earth electrodes, so that the earth resistance of a large station becomes virtually a function of the area of the earthing mesh. It is patently impracticable to soil-treat the entire station area. In the case of single isolated electrodes, some improvement may be expected from soil treatment but if the improvement is to be maintained the treatment must be periodically repeated. The frequency with which this should be done will depend on drainage conditions and can only be determined by making periodic measurements. With clay or loam the improvement has been found effective for periods of 8 to 10 years, but with sandy or porous soils the effect may entirely disappear within 2 years. The chemical (generally common salt) may be applied, in the case of electrodes installed in a trench, as a top dressing left to percolate through the soil with the surface moisture, or preferably by mixing with the excavated soil when refilling. In the case of pipe electrodes it has been found effective to perforate these and to treat the soil by pouring brine down them, but the treatment in general remains effective for shorter periods with this method than with external or surface application. The preferred method for pipe electrodes is to excavate to a depth of about 18 in round the top and put salt in this cavity, subsequently returning the soil. The grade of salt employed does not appear to be important; no significant difference has been observed in results between common cooking salt, agricultural salt, and 3 in lumps of rock salt.

The corrosive action of soils is generally increased by salting, the relative increase being greater in those soils which are naturally least corrosive. In the tests referred to in Clause 206, however, in which a number of different metals buried in a wide variety of soils were investigated, the average loss of weight over 12 years for a given metal in salted soil was never greater than three times that for the same metal in natural soil of the same type.

*e. Coke-treated electrodes.* Although substantial reduction of earth resistance can be effected by the use, for a distance of 9 in all round the electrode, of coke breeze if the soil has a relatively high resistivity, this method is not recommended as it may result in rapid corrosion not only of the electrode itself but also of cable sheaths, water pipes, or steel frameworks to which it may be bonded. For equal cost a much lower resistance may be obtained by using driven rods or pipes. Coke-treated electrodes should not be located within

20 ft of other metalwork which may be affected unless the latter is suitably protected.

*f. Voltage gradient around electrodes.* As mentioned in Clause 208, voltage gradients around earth electrodes under fault conditions may be such as to damage telephone and pilot cables in the vicinity. The area over which such injurious voltages may occur is dependent on whether the feeders are mainly overhead lines or cables laid direct. For substations unaffected by the latter and having the station earth-electrode or electrodes within the perimeter fence, approximately 50 per cent of the voltage drop from the electrode occurs within a distance from the centre of the station equal to half the maximum diagonal of the boundary fence, and 75 per cent of the voltage drop occurs within twice this distance\*. The effect of buried power cables laid direct in the vicinity of the station is virtually to extend the area of the electrode system and thus to increase the distance at which a given proportion of the electrode potential exists. This effect is dependent upon the resistance to earth of the cable covering. It is recommended that steps should be taken to protect any pilot or light-current lines within the area over which a dangerous voltage may be expected to exist, by applying suitable sheath insulation to such lines where they are in cable. An alternative solution for stations where both the feeders and the pilot cables are laid direct, is to run the latter in a line as far removed as possible from the route of the power cables.

Guidance on the segregation of telecommunication circuits is given in the Appendices to the 327 series of codes, dealing with telecommunication facilities in buildings.

Precautions which should be taken in connection with pole-mounted transformers to avoid danger to animals from voltage gradients are dealt with in Clause 208.

*g. Test facilities.* To permit periodic testing of an extensive earthing system such as may exist at a large outdoor station, each main electrode or group of electrodes may be connected to the main earthing bars through a bolted link. Separate links for each pipe or rod of a group are not required. The link may be mounted adjacent to the electrodes in a concrete box with a slab cover, sunk level with the ground. In the case of indoor substations it is often convenient to bring an insulated conductor from the electrode to a disconnecting point inside the substation.

For notes on the testing and maintenance of earth electrodes see Clauses 401 and 501.

## **213. Earthing conductors for power stations and substations.**

*a. Disposition.* It is necessary to provide permanent and substantial connections between all equipment and the earth electrodes so as to afford a low-

\* See Report F/T86: 'Earth Current Voltage Gradients Around Substations' by H. G. Taylor. (Published by the Electrical Research Association.)

resistance path for fault currents both to earth and between items of equipment. In addition all other metal plant in or about the station should be connected into the main station earthing system. The most efficient disposition of earthing conductors required will depend on the layout of equipment, and the following may be taken as a guide:

1. *Indoor equipment.* A main earth bar should be provided and connected to the framework of each item and to the earth-electrodes. Except for the smallest installations there should be a connection to the earth-electrodes at each end of the earth bar or, if this is in the form of a ring, at several points on the ring. These connections may, depending on the layout, be buried cables of a size adequate for the short-circuit current. Where the structure of a switchboard is extensive or occupies more than one floor, a further parallel main earth bar may be required which should be cross-connected to its companion bar at one point at least in each section of the switchboard.

The main earth bar should be so placed that cable sheaths can be readily connected to it. When cables are so connected, the bonds should be made to the cable gland on which the lead sheath should be plumbed and the armouring clamped. The main earth bar should be accessible for the connection of any detachable earthing devices provided with the switchgear.

Branch connections from the main earth bar should be provided to all accessory equipment such as control and relay panels, constructional steelwork, fire-extinguishing equipment, etc.

Where busbar protection is effected at switchboards by frame leakage two main earth bars are required. The frame bar interconnecting the framework of the switch units will be connected to the true earth bar through a current transformer and bolted links for test purposes. The true earth bar should be run separately from the frame earth bar in convenient position for the connection of cable sheaths and earthing devices. Where it is mounted on the switch units it should be insulated therefrom by insulation capable of withstanding a test voltage of 4 kV r.m.s. alternating current for 1 minute.

Where insulated cable glands are used, it is recommended that 'island' insulation should be provided to facilitate testing.

2. *Outdoor equipment (excluding pole-mounted transformers).* A main earth bar should be provided, so disposed as to allow of the shortest subsidiary connections to all major equipment such as transformers or circuit-breakers. Wherever possible, this should be arranged to form a ring round the station. The main earth bar (or ring) should be connected where required to earth-electrodes. For larger stations the ring should be reinforced by one or more cross-connections.

From the main earth bar, branch connections should be taken to each item of apparatus, and where several such items lie together, a subsidiary