

Code of practice for

Earthing

(Formerly CP 1013 : 1965)



Committees responsible for this British Standard

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 ERA Technology Ltd.
 Electrical Contractors' Association
 Electricity Supply Industry in United Kingdom
 Engineering Equipment and Materials Users' Association
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Foreword

This British Standard has been prepared under the direction of the General Electrotechnical Standards Policy Committee. It supersedes CP 1013 : 1965, which is withdrawn.

There have been a number of important changes in legislation, in electricity supply practices and in installation regulations since CP 1013 was issued. The Electricity Supply Regulations were revised in 1988 and amended further in 1990. These superseded the Electricity (Overhead Lines) Regulations 1970. The Electricity at Work Regulations 1989 took effect in 1990. In Scotland, the Building Standards (Scotland) Regulations, with amendments, came into force during the period 1971 to 1980. For industrial installations, the Electricity at Work Regulations 1989 have replaced the earlier Electricity (Factories Act) Special Regulations of 1908 and 1944.

Protective multiple earthing (PME) is now widely adopted in the UK for public electricity supply at low voltage and the section covering consumers' installation earthing has been entirely rewritten to provide emphasis on the appropriate earthing practices. However, this standard describes all three types of electrical supply systems standardized by the International Electrotechnical Commission (IEC).

The development of international wiring regulations by the IEC and their adoption by the European Committee for Electrotechnical Standardization (CENELEC) has been recognized in the IEE Wiring Regulations and BS 7430 has been written so as to comply with the present requirements of the regulations. For installations connected to either earthed (TT) or unearthed (IT) supply systems, the use of earth leakage circuit breakers is accepted as an alternative means of circuit disconnection but, in contrast to CP 1013, the residual or out of balance device is now recommended.

Design data for earth electrodes have been considerably expanded, covering multiple electrode systems and the use of reinforced concrete foundations; and methods are included for calculating the ground surface potentials around electrodes.

BS 7430 now gives recommendations for earthing temporary structures. The section on generation has been expanded to cover standby generators, machines operating in parallel with an incoming supply, asynchronous machines and both three-phase and single-phase portable generators.

All the clauses concerned with specific applications have been reviewed and brought up to date, and where necessary considerable new text has been written to make this revision as comprehensive as possible.

Compliance with a British Standard does not of itself confer immunity from legal obligations. In particular, attention is drawn to the relevant legislation given in 3.1 and 27.1.

The Regulations for electrical installations, published by the Institution of Electrical Engineers (subsequently referred to as the Wiring Regulations or IEE Wiring Regulations) are not statutory, but compliance may satisfy the requirements of certain statutory regulations. It is advisable therefore to comply with these regulations where appropriate.



Section 1. General

1 Scope

This British Standard gives guidance on the methods that 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 proper operation of the system, and this aspect is generally known as 'system earthing'. The latter concerns 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 earth fault currents.

BS 7430 applies only to land-based installations; it does not apply to ships, aircraft or offshore installations, nor does it deal with the earthing of medical equipment (see BS 5724) or the special problems encountered with solid state electronic components and equipment due to their sensitivity to static electricity.

NOTE. The titles of the publications referred to in this standard are listed on page 81.

2 Definitions

For the purposes of this British Standard, the definitions given in BS 4727 apply, together with the following.

2.1 bonding conductor

¹⁾A protective conductor providing equipotential bonding.

2.2 caravan

A trailer leisure accommodation vehicle, used for touring, which meets the requirements for the construction and use of road vehicles.

2.3 caravan park

¹⁾An area of land that contains two or more caravan pitches.

2.4 caravan pitch

¹⁾A plot of ground upon which a single leisure accommodation vehicle or leisure home may stand.

2.5 caravan pitch electrical supply equipment

¹⁾Equipment that provides means of connecting and disconnecting supply cables from a leisure accommodation vehicle to a fixed external power supply.

¹⁾Identical with the definition given in the 16th edition of the IEE Wiring Regulations.

²⁾Effectively identical with the definition given in the IEE Wiring Regulations. The latter incorporates the substance of the note within the text.

2.6 class I equipment

¹⁾Equipment in which protection against electric shock does not rely on basic insulation only, but which includes means for the connection of exposed conductive parts to a protective conductor in the fixed wiring of the installation.

NOTE. For information on classification of equipment with regard to means provided for protection against electric shock see BS 2754.

2.7 class II equipment

²⁾Equipment in which protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as supplementary insulation are provided, there being no provision for the connection of exposed metalwork of the equipment to a protective conductor, and no reliance upon precautions to be taken in the fixed wiring of the installation.

NOTE. For information on classification of equipment with regard to the means provided for protection against electric shock see BS 2754.

2.8 double insulation

¹⁾Insulation comprising both basic insulation and supplementary insulation.

2.9 earth

¹⁾The conductive mass of the Earth, whose electric potential at any point is conventionally taken as zero.

2.10 earth electrode

¹⁾A conductor or group of conductors in intimate contact with, and providing an electrical connection to, earth.

2.11 earth electrode resistance

¹⁾The resistance of an earth electrode to earth.

2.12 earth fault current

¹⁾A fault current which flows to earth.

2.13 earth fault loop impedance

¹⁾The impedance of the earth fault current loop (phase to earth loop) starting and ending at the point of earth fault. This impedance is denoted by the symbol Z_s .

The earth fault loop comprises the following starting at the point of fault:

- the circuit protective conductor, and
- the consumer's earthing terminal and earthing conductor, and
- for TN systems, the metallic return path, and
- for TT and IT systems, the earth return path, and the path through the earthed neutral point of the transformer and the transformer winding, and
- the phase conductor from the transformer to the point of fault.

2.14 earth grid

An earth electrode in the form of two overlapping groups of buried, parallel, horizontal electrodes in the same rectangular area, usually laid approximately at right angles to each other, with the electrodes bonded at each intersection.

2.15 earth leakage current

¹⁾A current which flows to earth, or to extraneous conductive parts, in a circuit which is electrically sound. This current may have a capacitive component including that resulting from the deliberate use of capacitors.

2.16 earthed concentric wiring

¹⁾A wiring system in which one or more insulated conductors are completely surrounded throughout their length by a conductor, e.g. a metallic sheath, which acts as a PEN conductor.

2.17 earthing conductor

¹⁾A protective conductor connecting a main earthing terminal of an installation to an earth electrode or to other means of earthing.

2.18 earthing system

One or more earth electrodes with their earthing conductors, capable of being connected to a main earthing terminal.

2.19 electrically independent earth electrodes

¹⁾Earth electrodes located at such a distance from one another that the maximum current likely to flow through one of them does not significantly affect the potential of the other(s).

2.20 equipotential bonding

¹⁾Electrical connection maintaining various exposed conductive parts and extraneous conductive parts at substantially the same potential.

2.21 exposed conductive part

¹⁾A conductive part of equipment which can be touched and which is not a live part but which may become live under fault conditions.

2.22 extraneous conductive part

¹⁾A conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

2.23 fault

¹⁾A circuit condition in which current flows through an abnormal or unintended path. This may result from an insulation failure or the bridging of insulation. Conventionally the impedance between live conductors or between live conductors and exposed or extraneous-conductive-parts at the fault position is considered negligible.

2.24 final circuit

¹⁾A circuit connected directly to current-using equipment, or to a socket outlet or socket outlets or other outlet points for the connection of such equipment.

2.25 functional earthing

¹⁾Connection to earth necessary for proper functioning of electrical equipment.

2.26 ground potential

An electric potential with respect to the general mass of earth which occurs in, or on the surface of, the ground around an earth electrode when an electric current flows from the electrode to the ground.

2.27 leisure accommodation vehicle

¹⁾Unit of living accommodation for temporary or seasonal occupation which may meet requirements for construction and use of road vehicles.

2.28 live part

¹⁾A conductor or conductive part intended to be energized in normal use, including a neutral conductor but, by convention, not a PEN conductor.

2.29 main earthing terminal

¹⁾The terminal or bar provided for the connection of protective conductors, including equipotential bonding conductors, and conductors for functional earthing, if any, to the means of earthing.

2.30 motor caravan

¹⁾Self-propelled leisure accommodation vehicle, used for touring, which meets requirements for the construction and use of road vehicles. The accommodation may be fixed or demountable.

2.31 neutral conductor

²⁾A conductor connected to the neutral point of a system and capable of contributing to the transmission of electrical energy.

NOTE. The term also means the equivalent conductor of an IT or d.c. system unless otherwise specified in the IEE Wiring Regulations.

2.32 nominal voltage

Voltage by which an installation (or part of an installation) is designated.

NOTE 1. The following ranges of nominal voltage (r.m.s. values for a.c.) are defined:

(a) extra low	normally not exceeding 50 V a.c. or 120 V ripple free d.c., whether between conductors or to earth;
(b) low	normally exceeding extra low voltage but not exceeding 1000 V a.c. or 1500 V d.c. between conductors, or 600 V a.c. or 900 V d.c. between conductors and earth;
(c) high	exceeding 1000 V a.c. or 1500 d.c. between conductors, or 600 V a.c. or 900 V d.c. between conductors and earth.

NOTE 2. The actual voltage of the installation may differ from the nominal value by a quantity within normal tolerances.

¹⁾ Identical with the definition given in the 16th edition of the IEE Wiring Regulations.

²⁾ Effectively identical with the definition given in the IEE Wiring Regulations. The latter incorporates the substance of the note within the text.



2.33 PEN conductor

¹⁾A conductor combining the functions of both protective conductor and neutral conductor.

2.34 portable equipment

¹⁾Electrical equipment which is moved while in operation or which can easily be moved from one place to another while connected to the supply.

2.35 potential gradient (at a point)

The potential difference per unit length measured at that point in the direction in which it is a maximum.

2.36 protective conductor

²⁾A conductor used for some measures of protection against electric shock and intended for connecting together any of the following parts:

- exposed conductive parts;
- extraneous conductive parts;
- the main earthing terminal;
- earth electrode(s);
- the earthed point of the source, or an artificial neutral.

NOTE. See figure 23.

2.37 reinforced insulation

²⁾Single insulation applied to live parts, which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in the relevant standard.

NOTE. The term 'single insulation' does not imply that the insulation has to be one homogeneous piece. It may comprise several layers that cannot be tested singly as supplementary or basic insulation.

2.38 residual current device (RCD)

¹⁾A mechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions.

2.39 residual operating current

¹⁾Residual current which causes the residual current device to operate under specified conditions.

2.40 resistance area (for an earth electrode only)

¹⁾The surface area of ground (around an earth electrode) on which a significant voltage gradient may exist.

2.41 simultaneously accessible parts

²⁾Conductors or conductive parts which can be touched simultaneously by a person or, in locations specifically intended for them, by livestock.

NOTE. Simultaneously accessible parts may be:

- live parts;
- exposed conductive parts;
- extraneous conductive parts;
- protective conductors;
- earth electrodes.

2.42 supplementary insulation

¹⁾Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of basic insulation.

2.43 switchgear

¹⁾An assembly of main and auxiliary switching apparatus for operation, regulation, protection or other control of electrical installations.

¹⁾ Identical with the definition given in the 16th edition of the IEE Wiring Regulations.

²⁾ Effectively identical with the definition given in the IEE Wiring Regulations. The latter incorporates the substance of the note within the text.

Section 2. Earthing and the provision of a path for earth fault currents

3 Supply system earthing

3.1 Relevant legislation

In Great Britain earthing of an electricity supply system is governed by the following legislation and regulations:

- (a) Regulations 4 to 8 of the Electricity Supply Regulations 1988, as amended in 1990;
- (b) the Electricity at Work Regulations 1989.

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

The general provisions in the Electricity Supply Regulations apply to both overhead and underground systems of supply. The regulations require at least one point of every system to be connected with earth. This requirement 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.

The regulations include requirements for multiple earthing of low voltage (LV) systems and for the use of protective multiple earthing (PME), and this is the usual designation of the system shown in figure 1. In such cases there are requirements controlling the relative size of the phase and neutral conductors and the earthing of the system. In the case of protective multiple earthing, the sizes of bonding connections in the consumer's installation are specified.

3.2 General

A system is satisfactorily earthed if the protective gear operates to remove danger in the event of a fault to any metalwork having a continuous metallic connection to the system neutral. An earthed metallic sheath of an underground cable, the neutral of a PME system or an earth wire in a transmission line may provide a low resistance path from a fault back to the system neutral. With some overhead lines, because of high soil resistivity, it may not be possible economically to attain a sufficiently low resistance fault path and the operation of overcurrent protection may be slowed down or inhibited.

For the purposes of this standard it is convenient to consider a system as comprising a source of energy and an installation; the former including the supply conductors to the latter.

In the overwhelming majority of cases the source of energy is the property and responsibility of an electricity supplier, and the installation is a consumer's installation. Even in those industrial installations where the source of energy is owned and controlled by the user it is still convenient to consider the source separately from the circuit and current-using equipment in the installation.

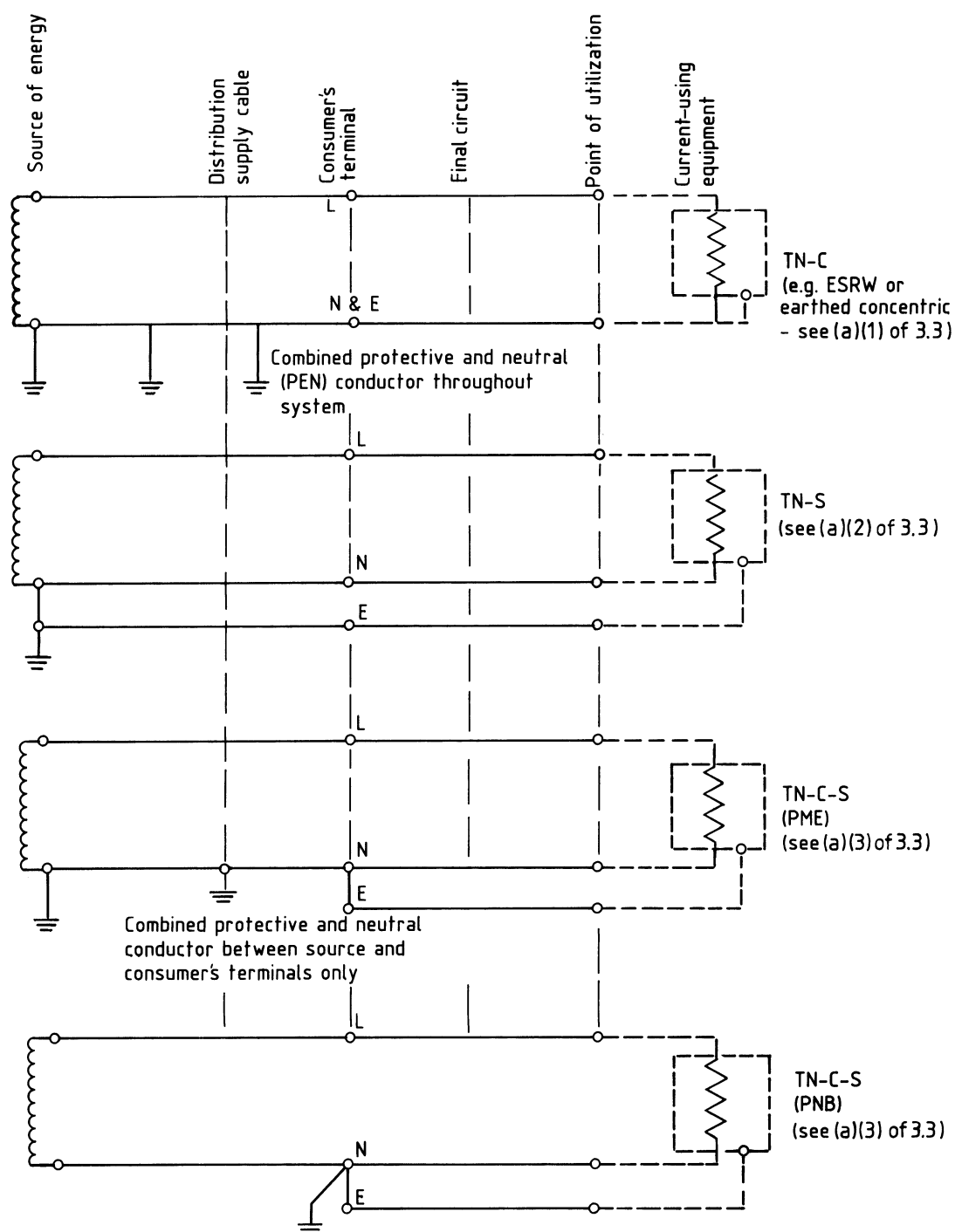
3.3 Classification of low voltage systems

The IEE Wiring Regulations have adopted the internationally agreed classification of low voltage system types as follows.

(a) A *TN system* has one or more points of the source of energy directly earthed and the exposed and extraneous conductive parts of the installation are connected only by means of protective conductors to the earthed point(s) of the source, i.e. there is a metallic path for earth fault currents to flow from the installation to the earthed point(s) of the source (see figure 1). TN systems are subdivided into the following.

- (1) TN-C systems where the neutral and protective functions are combined in a single conductor throughout the system. Earthed concentric wiring or earthed sheath return wiring (ESRW) are both examples of a TN-C system.
- (2) TN-S systems where there are separate neutral and protective conductors throughout the system. A system where the metallic path between the installation and the source of energy is the sheath and armouring of the supply cable is a TN-S system.
- (3) TN-C-S systems where the neutral and protective functions are combined in a single conductor but only in a part of a system. The type of distribution that is commonly called protective multiple earthing is TN-C-S, the supply itself being TN-C and the arrangement in the installation being TN-S. The protective neutral bonding (PNB) system is a variant of the TN-C-S system with single point earthing.





NOTE. For simplicity single-phase only is shown.

Figure 1. TN systems



(b) A *TT system* has one or more points of the source of energy directly earthed and the exposed and extraneous conductive parts of the installation are connected to a local earth electrode or electrodes that are electrically independent of the source earth(s).

(c) An *IT system* has the source either unearthed or earthed through a high impedance and the exposed conductive parts of the installation are connected to an electrically independent earth electrode (see figure 2). Attention is drawn to the requirements of the Electricity Supply Regulations 1988, as amended in 1990, which do not permit the use of this system for public supply networks in the UK.

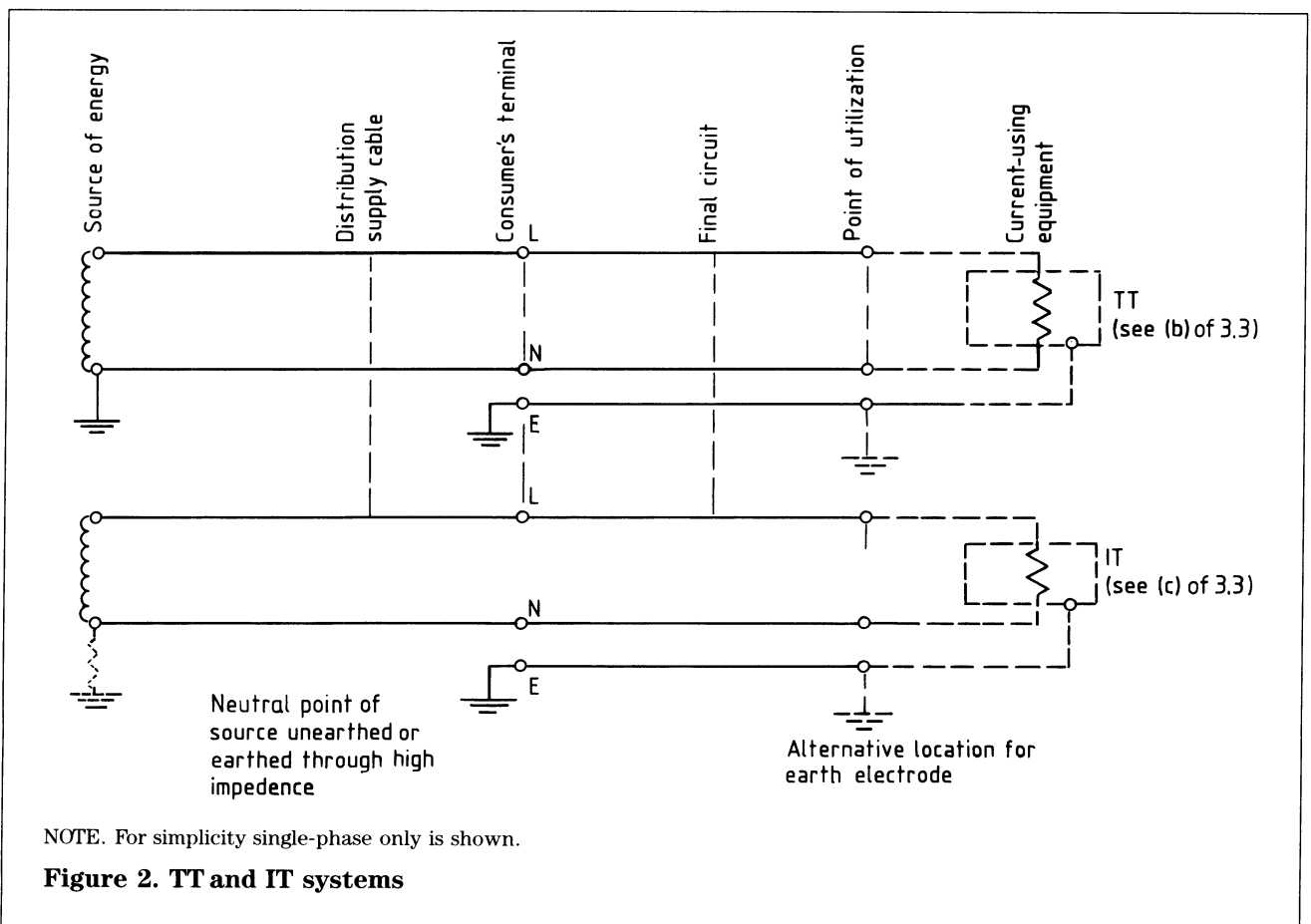
In practice a system may be an admixture of types, one example of this being an installation that is part of a TN system where a particular circuit or circuits may need to be protected by a residual current device. If the exposed conductive parts of that circuit or those circuits are connected to an independent earth electrode, that part of the installation has then to be treated as being in a TT system. The great majority of installations form a part of TN-S, TN-C-S or TT systems.

Attention is drawn to the requirements embodied in the Electricity Supply Regulations 1988, as amended in 1990, which cover the installation when the supplier provides multiple earthing. An individual exemption is required when it is intended to use earthed concentric wiring in the installation, this being a TN-C system and this exemption has to be obtained by the supplier concerned.

4 Electrical equipment earthing

The object of electrical equipment earthing is to ensure effective operation of the protective gear in the event of earth fault currents that might otherwise cause damage to property, and to protect against danger to life through shock due to installation metalwork being maintained at a dangerous potential relative to earth. The method used to connect such metalwork to earth has to be compatible with the type of installation and its supply system. The requirements for the connection of metalwork of electrical equipment, other than parts that are normally live or current carrying, to an earthing terminal, are specified, in general, in the regulations referred to in 3.1.

The IEE Wiring Regulations also deal with the earthing of installations.



5 System and equipment protection

5.1 General

A primary purpose of earthing is to enable a system or equipment to be disconnected from the source of energy so as to avoid the effects of excessive currents produced under earth fault conditions. The apparatus performing this task is referred to as the protection equipment.

5.2 Electrical protection of systems

This subject is highly specialized particularly in respect of high voltage (HV) systems, and readers requiring further information should refer to IEC Publication 255 Electrical relays : Part 20 : 1984 Protection (protective) systems, BS 142, relevant text books and equipment manufacturers.

5.3 Equipment protection: selection of devices for automatic disconnection of supply

The selection of suitable protective devices depends upon the characteristics of the electricity supply system (see clauses 3 and 4), the distribution circuits and the equipment being protected (see clause 20).

The selection of the various devices for the automatic disconnection of the supply in the event of a fault, and their characteristics is outside the scope of this standard, but relevant information can be obtained from relevant British Standards, including the following:

BS 88 Cartridge fuses for voltages up to and including 1000 V a.c. and 1500 V d.c.

NOTE 1. Parts 1, 2 and 4 are particularly relevant.

BS 842 Specification for a.c. voltage-operated earth-leakage circuit breakers

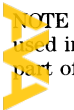
NOTE 2. The use of voltage-operated earth-leakage circuit breakers is not recommended for LV a.c. installations.

BS 1361 Specification for cartridge fuses for a.c. circuits in domestic and similar premises

BS 1362 Specification for general purpose fuse links for domestic and similar purposes (primarily for use in plugs)

NOTE 3. Although the fuses covered by this standard are used in plugs they can also be used in fixed installations as part of fuse connector units, etc.

BS 3036	Specification. Semi-enclosed electric fuses (ratings up to 100 amperes and 240 volts to earth)
BS 3871	Specification for miniature and moulded case circuit-breakers Part 1 Miniature air-break circuit-breakers for a.c. circuits
BS 3938	Specification for current transformers
BS 4293	Specification for residual current-operated circuit-breakers
BS 4444	Guide to electrical earth monitoring and protective conductor proving
BS 4752	Specification for switchgear and controlgear for voltages up to and including 1000 V a.c. and 1200 V d.c. Part 1 Circuit-breakers
NOTE 4. BS 4752 covers both moulded case circuit breakers and conventional air breakers.	
BS 4794	Specification for control switches (switching devices, including contactor relays, for control and auxiliary circuits, for voltages up to and including 1000 V a.c. and 1200 V d.c.)
BS 5311	Specification for high-voltage alternating-current circuit-breakers
BS 5486	Low-voltage switchgear and controlgear assemblies
BS 6581	Specification for common requirements for high-voltage switchgear and controlgear standards



Section 3. Earthing methods

6 Factors involved in effective earthing

Earthing of either a system or equipment involves the provision of a connection to the general mass of earth. This connection should have a resistance not greater than the design value and should be capable of carrying the expected maximum fault current.

It is therefore necessary to consider the various factors which affect the resistance to earth and fault current capacity of the buried conductor, designated the earth electrode. These include the size and shape of the earth conductor, the soil in which it is buried and the connection of the system to it. It is also necessary to give consideration to the current density at the surface of the earth electrode and the ground potentials in its vicinity.

7 Soil resistivity

7.1 The resistance to earth of a given electrode depends upon the electrical resistivity of the soil in which it is installed. This factor may therefore be important in deciding which of many protective systems to adopt.

The composition of the soil largely determines its resistivity and examples are given in table 1. Earth resistivity 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 vary seasonally, so that the table should only be taken as a general guide. For this purpose, columns 2 and 3 apply to most of the British Isles, but column 5 is applicable to certain areas, such as marshy flats around river estuaries.

Local values should be verified by measurement (see clause 16), and this is especially important where the soil is stratified as, owing to the dispersion of the earth current, the effective resistivity depends not only on the surface layers but also on the underlying geological formation. Stratification of the soil should be taken into account when the type of electrode and its depth are being considered.

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. It is therefore recommended that any part of an earth electrode system within 1 m of the soil surface should not be regarded as being effective under frost conditions.

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 electrode sites and of methods of preparing the site selected to secure the optimum resistivity. These measures are summarized in 7.2 to 7.5.

Table 1. Examples of soil resistivity

Type of soil	Climatic condition			
	Normal and high rainfall (i.e. greater than 500 mm a year)		Low rainfall and desert conditions (i.e. less than 250 mm a year)	Underground waters (saline)
	Probable value	Range of values encountered	Range of values encountered	Range of values encountered
Alluvium and lighter clays	Ω·m 5	Ω·m See note	Ω·m See note	Ω·m 1 to 5
Clays (excluding alluvium)	10	5 to 20	10 to 100	1 to 5
Marls (e.g. Keuper marl)	20	10 to 30	50 to 300	
Porous limestone (e.g. chalk)	50	30 to 100		
Porous sandstone (e.g. Keuper sandstone and clay shales)	100	30 to 300		
Quartzites, compact and crystalline limestone (e.g. carboniferous sediments, marble, etc.)	300	100 to 1000		
Clay slates and slatey shales	1000	300 to 3000	1000 upwards	30 to 100
Granite	1000			
Fissile slates, schists, gneiss and igneous rocks	2000	1000 upwards		
NOTE. Depends on water level of locality.				

7.2 Where there is any option, a site should be chosen in one of the following types of soil in the order of preference given:

- (a) wet marshy ground (but see **7.3**);
- (b) clay, loamy soil, arable land, clayey soil, clayey soil or loam mixed with small quantities of sand;
- (c) clay and loam mixed with varying proportions of sand, gravel, and stones;
- (d) damp and wet sand, peat.

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

7.3 A site should be chosen that is not naturally well drained. A water-logged situation is not, however, essential unless the soil is sand or gravel, as in general no advantage results from an increase in moisture content above about 15 % to 20 %. 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.

7.4 Where constructional work has taken place, or cut and fill or imported fill operations have been carried out, the resulting disturbance may alter site conditions. In these cases deeper driving of the electrode may be necessary to reach layers of reasonable resistivity and also to reach stable ground, such that the value of the earth electrode resistance remains stable if the top layers of the ground dry out.

7.5 Soil treatment or replacement to improve earth electrode contact resistance may be used in special or difficult locations. Migration and leaching of applied chemicals over a period of time reduces the efficiency of soil treatment progressively, requiring constant monitoring and replacement of the additives. Ecological considerations should be considered before such treatment is commenced and any deleterious effect upon electrode material has to be taken into account. However, for some temporary electrical installations in areas of high ground resistivity, this may be the most economic method for obtaining satisfactory earth contact over a short period. If a greater degree of permanence is envisaged, it may be desirable to replace the soil immediately around an electrode with a lower resistivity material, such as:

- (a) a clay based material formed by the decomposition of volcanic ash, such as bentonite;
- (b) concrete (see **11.2** and **15.1**);
- (c) conductive concrete or cement made with graded granular carbonaceous aggregate in place of the conventional sand or aggregate (see **8.2**).

Such treatment may be used to advantage in rocky terrain. Where holes are bored for insertion of vertical earth electrodes, or where strip earth electrodes are laid radially under shallow areas having a low resistivity which overlay rock strata, suitable treatment will reduce the contact resistance with respect to the general mass of ground.

The use of coke breeze as an infill is not recommended as it may result in rapid corrosion not only of the electrode itself but also of cable sheaths.

The resistance of a vertical electrode surrounded by an infill of material such as bentonite or concrete is given approximately by the following equation:

$$R = \frac{1}{2\pi L} \left[(\rho - \rho_c) \left(\log_e \left[\frac{8L}{D} \right] - 1 \right) + \rho_c \left(\log_e \left[\frac{8L}{d} \right] - 1 \right) \right]$$

where

- ρ is the resistivity of soil, in $\Omega \cdot m$;
- ρ_c is the resistivity of infill material, in $\Omega \cdot m$;
- d is the diameter of electrode, in m;
- D is the diameter of infill, in m;
- L is the driven length of electrode, in m.

The resistivity of bentonite varies from about $3 \Omega \cdot m$ upwards, depending on its moisture content. It is hygroscopic and will absorb available moisture from the surrounding soil. Should it become dry, due to a complete absence of moisture in the surrounding soil, its resistivity rises appreciably and it will shrink away from the electrode.

The resistivity of concrete is in the range $30 \Omega \cdot m$ to $90 \Omega \cdot m$.

8 Effect of shape on electrode resistance

With single electrodes the greater part of the fall in potential occurs in the soil within a metre or so 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 condition is achieved 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.

9 Resistance of common types of earth electrodes

9.1 Plates

The approximate resistance to earth of a plate (R) in ohms can be calculated from the following equation:

$$R = \frac{\rho}{4} \sqrt{\left(\frac{\pi}{2A}\right)}$$

where

ρ is the resistivity of the soil (assumed uniform), in $\Omega \cdot \text{m}$;

A is the area of one face of the plate, in m^2 .

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 10 m, but for sizes of plate generally employed a separation of 2 m is sufficient to ensure that the total resistance will not exceed the value obtained from the above equation by more than 20 %. 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 $1.2 \text{ m} \times 1.2 \text{ m}$.

Plates are generally of cast iron not less than 12 mm thick and preferably ribbed. The earth connection should be joined to the plate at not less than two separate points.

Connections to copper plate electrodes should be by a copper conductor, welded, rivetted or otherwise attached without involving materials likely to cause corrosion. Such joints should be protected by a heavy coat of bitumen, or similar suitable material.

The connection between the earth plate and an above ground disconnecting link should be insulated to reduce electrolytic action. The plates should be set vertically and the depth of setting should be such as to ensure that the surrounding soil is always damp. The minimum cover should be 600 mm except that, where the underlying stratum is solid, e.g. chalk or sandstone, and near the surface, the top of the plate should be level with the top of the solid stratum. Sufficient solid stratum should be removed and replaced with fine soil or other suitable infill to obtain an acceptably low resistance.

The resistance to earth (R) in ohms of a $1.2 \text{ m} \times 1.2 \text{ m}$ plate is given approximately by the following equation:

$$R = \frac{\rho}{4}$$

where

ρ is the resistivity of the soil (assumed uniform), in $\Omega \cdot \text{m}$.

For conventional sizes the resistance is approximately inversely proportional to the linear dimensions, not to the surface area, i.e. a $0.9 \text{ m} \times 0.9 \text{ m}$ plate would have a resistance approximately 25 % higher than a $1.2 \text{ m} \times 1.2 \text{ m}$ plate.

9.2 Rods or pipes

The resistance to earth of a rod or pipe electrode (R) in ohms, is given by the following equation:

$$R = \frac{\rho}{2\pi L} \left[\log_e \left(\frac{8L}{d} \right) - 1 \right]$$

where

L is the length of the electrode, in m;

d is the diameter, in m;

ρ is the resistivity of the soil, in $\Omega \cdot \text{m}$ (assumed uniform).

The curves shown in figure 3 are calculated from this equation for electrodes of 12.5 mm, 25 mm and 100 mm diameter in a soil of $100 \Omega \cdot \text{m}$ resistivity. Change of diameter has a relatively minor effect, and size of pipe is generally governed by mechanical resistance to bending or splitting. It is apparent that the electrical resistance diminishes rapidly with the first metre or so of driving, but less so at depths greater than 2 m to 3 m 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 often assumed to be satisfied by a mutual separation equal to the driven depth. Little is to be gained by separation beyond twice the driven depth. A substantial gain is effected even at 2 m separation. Figure 4 shows the effect of inter-electrode spacing for two rod electrodes 3 m long by 15.9 mm diameter.



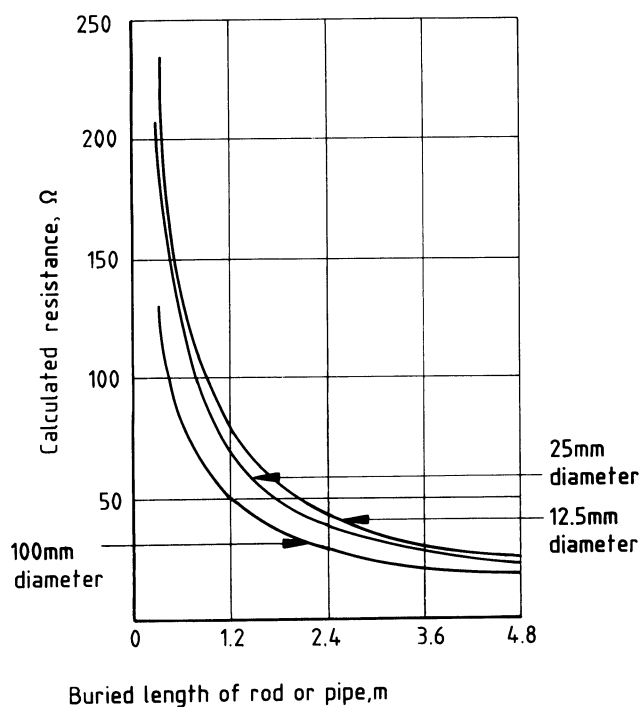


Figure 3. Effect of buried length of rod or pipe electrode on calculated resistance for soil resistivity of 100 Ω · m (assumed uniform)

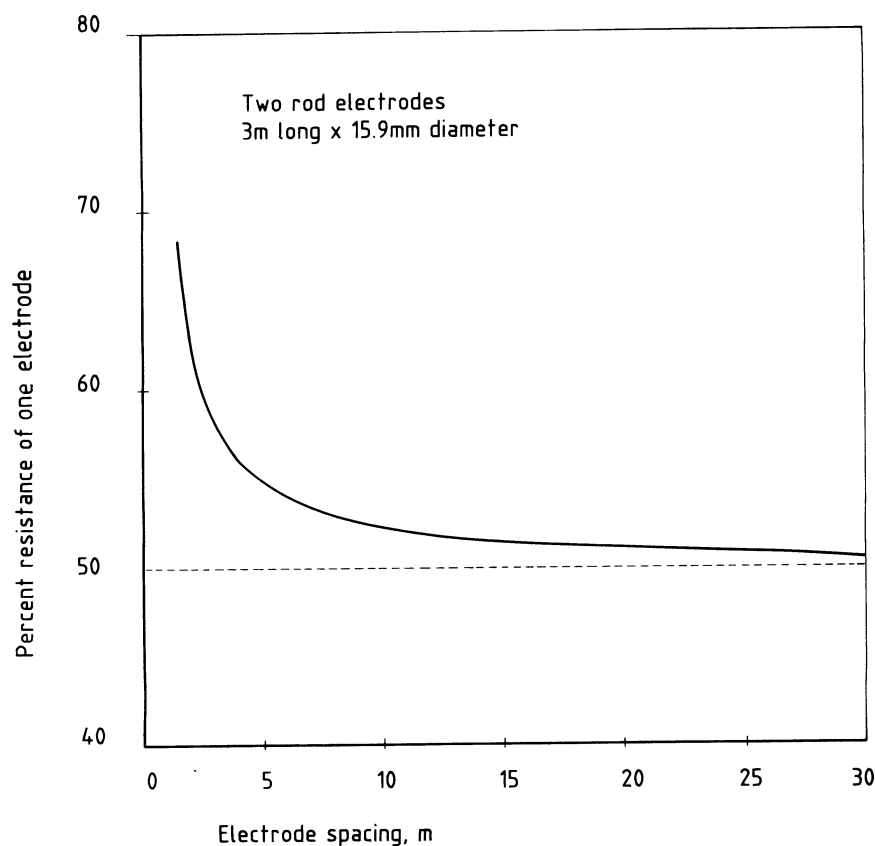


Figure 4. Effect of inter-electrode spacing on combined resistance

The combined resistance of n rod electrodes in parallel can be obtained from the following equations:

$$R_n = R \left(\frac{1 + \lambda a}{n} \right)$$

$$\text{in which } a = \frac{\rho}{2\pi R s}$$

where

- R_n is the resistance of n rods in parallel, in Ω ;
- R is the resistance of one rod in isolation, in Ω ;
- s is the distance between adjacent rods, in m;
- ρ is the resistivity of soil, $\Omega \cdot \text{m}$;
- λ is a factor given in table 2 or 3.

The above equations assume that rod electrodes can be represented approximately by hemispherical electrodes, having the same earthing resistance, located in the soil surface. This assumption is satisfactory provided that the spacing between the rods is not less than their length.

If the rods are equally spaced in a straight line an appropriate value of λ may be taken from table 2.

Table 2. Factors for parallel electrodes arranged in line

Number of electrodes (n)	Factor λ
2	1.00
3	1.66
4	2.15
5	2.54
6	2.87
7	3.15
8	3.39
9	3.61
10	3.81

For electrodes equally spaced around a hollow square, e.g. around the perimeter of a building, the equations given above are used with a value of λ taken from table 3.

For three rods placed in an equilateral triangle, or in an L formation, a value of $\lambda = 1.66$ may be assumed.

Table 3. Factors for electrodes arranged in a hollow square

Number of electrodes (n) along each side of the square	Factor λ
2	2.71
3	4.51
4	5.48
5	6.14
6	6.63
7	7.03
8	7.36
9	7.65
10	7.90
12	8.32
14	8.67
16	8.96
18	9.22
20	9.40

NOTE. The total number of electrodes around the square is $4(n-1)$.

The reduction in combined earth resistance provided by additional electrodes inside the square is small, but such electrodes will reduce the potential gradient over the soil surface inside the square. A practical example of this is the use of strip electrodes forming an earth grid within the square.

Table 3 may also be used for electrodes arranged in a rectangle, where n is given by (total number of electrodes/4) + 1. Provided that the length to width ratio of the rectangle does not exceed 2, the error will be less than -6 %.

Pipes may be of cast iron of not less than 100 mm diameter, 2.5 m to 3 m long and 13 mm thick (see BS 143 & 1256). Such pipes cannot be driven satisfactorily and may therefore be more expensive to install than plates for the same effective area. Alternatively, steel tubes up to 50 mm diameter, whose dimensions permit them to be driven, are sometimes employed (e.g. see BS 1387); these are less durable than copper rods.

Driven earth rods generally consist of solid circular copper, molecular bonded clad steel, stainless steel, or galvanized steel (see clause 10). The preferred nominal diameters for earth rods are 9 mm, 12.5 mm and 15 mm for copper and copper-clad steel rods and 16 mm for galvanized and stainless steel rods; departures from these preferred diameters should be limited to those necessary for the provision of rolled screw threads, or taper fit tolerances.

The preferred lengths of extensible earth rods are 1.2 m for 9 mm rods and 1.2 m or 1.5 m for 15 mm rods.

Minimum sizes for these components should comply with the data given in table 4.

Table 4. Minimum sizes of components for earth electrodes

Electrode type	Cross-sectional area	Diameter or thickness
Copper strip	mm ² 50	mm 3
Hard drawn or annealed copper rods or solid wires for driving or laying in ground	50	8
Copper-clad or galvanized steel rods (see notes) for harder ground	153	14
Stranded copper	50	3 per strand

NOTE 1. For copper-clad steel rods the core should be of low carbon steel with a tensile strength of approximately 600 N/mm² and a quality not inferior to grade 43A complying with BS 4360. The cladding should be of 99.9 % purity electrolytic copper, molecularly bonded to the steel core. The radial thickness of the copper should be not less than 0.25 mm.

NOTE 2. Couplings for copper-clad steel rods should be made from silicon bronze alloy, grade CS101 complying with BS 2874 or aluminium bronze alloy, grade CA102 complying with BS 2871.

NOTE 3. For galvanized steel rods, steel of grade 43A complying with BS 4360 should be used, the threads being cut before hot-dip galvanizing in accordance with BS 729.

Cruciform and star-shaped sections are more rigid when being driven, but the apparent additional surface does not confer a noticeable advantage in current-carrying capacity or reduction of resistance. In some circumstances the addition of horizontal electrodes is advantageous.

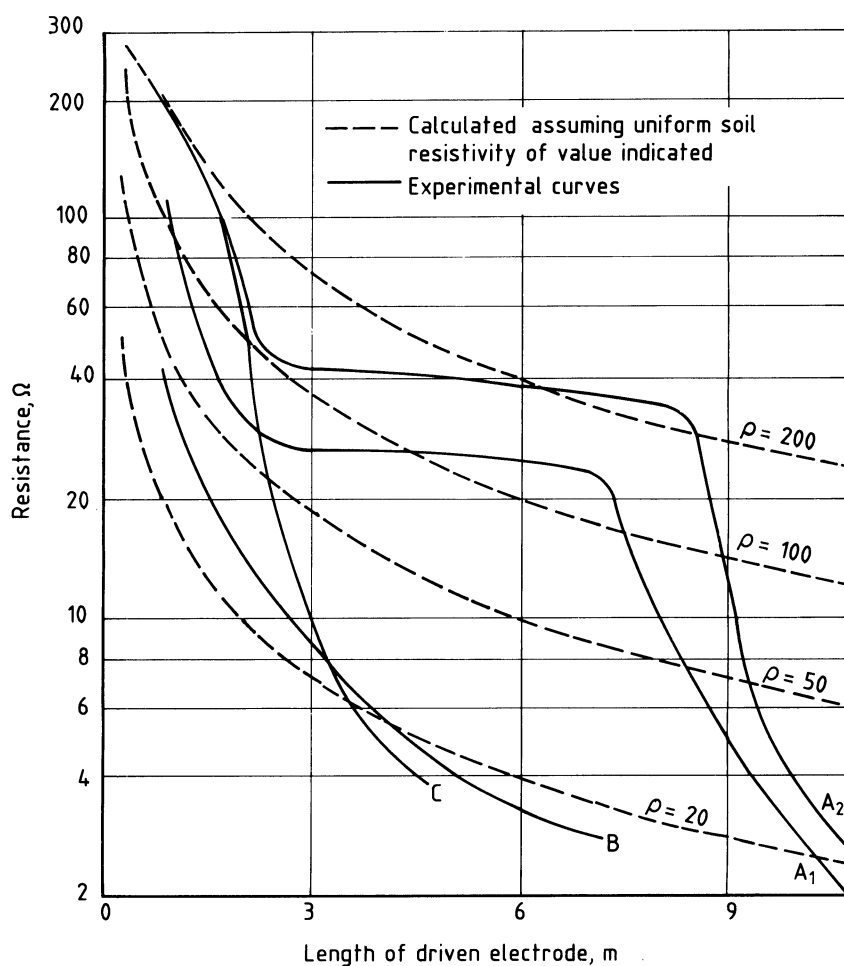
Rods may be coupled together to give longer lengths. Except in special conditions, a number of rods in parallel is to be preferred to a single long rod. Deeply driven rods are, however, effective where the soil resistivity decreases with depth or where substrata of low resistivity occur at depths greater 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 figure 5 for a number of sites. For curves A₁ and A₂ it was known from previously sunk boreholes that the soil down to a depth of between 6 m and 9 m 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 8 m in one case was 150 Ω·m; at 11 m the mean value for the whole depth was 20 Ω·m 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 1.5 m 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.

Other factors that affect a decision whether to drive deep electrodes or to employ several rods or pipes in parallel are the steep rise in the 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 12.5 mm 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.

9.3 Horizontal strip or round conductor electrodes

Horizontal strip or round conductor electrodes have special advantages 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 25 mm by 3 mm section, but may be of bare copper conductor as used for overhead lines. The minimum size should comply with the value given in table 4.



NOTE. Values of ρ are in $\Omega \cdot m$

Figure 5. Calculated and experimental curves of resistance of 12.5 mm diameter driven rod electrodes

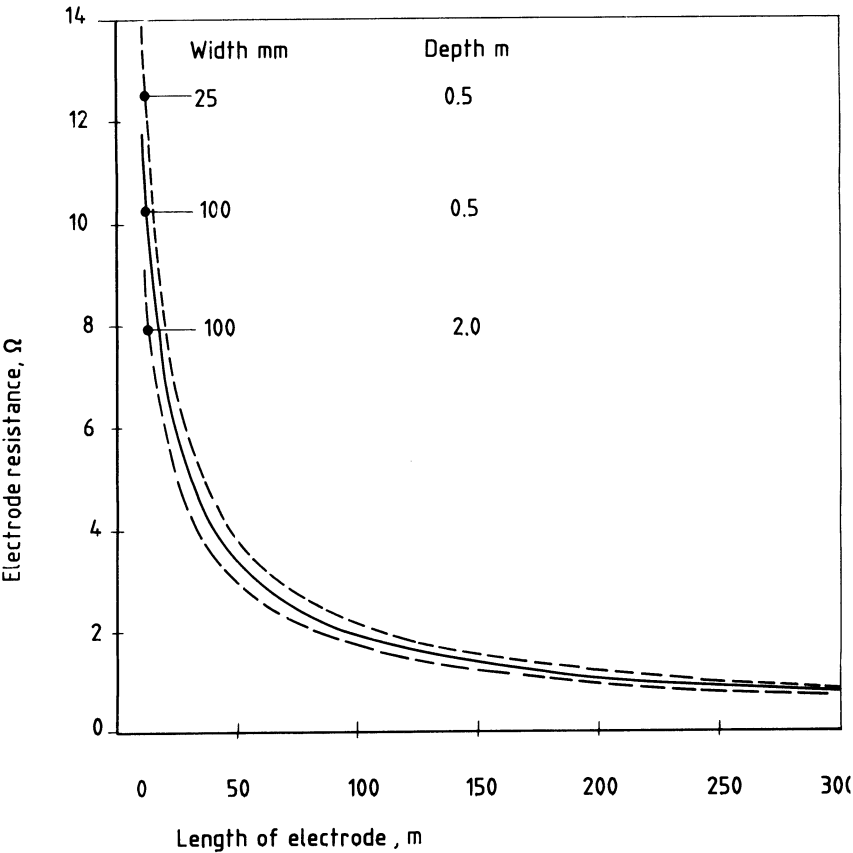


Figure 6. Resistance of horizontal strip electrodes

For a strip or round conductor electrode the resistance (R) in ohms is given by the following equation:

$$R = \frac{\rho}{P\pi L} \left[\log_e \left(\frac{2L^2}{wh} \right) + Q \right]$$

where

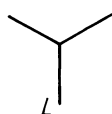
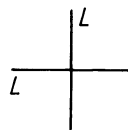
- L is the length of the strip or conductor, in m;
- h is the depth of electrode, in m;
- w is the width of strip or diameter of conductor, in m;
- ρ is the resistivity of soil, in $\Omega \cdot \text{m}$;
- P and Q are coefficients given in table 5 for different arrangements of electrode.

The thickness of a strip electrode is usually not greater than about one-eighth of the width. Within this limitation it has a negligible effect on the electrode earth resistance. Earthing resistance is principally affected by length. For the values most frequently used, the depth of burial and diameter or width have a relatively minor effect. Figure 6 compares the effects of these parameters for strip electrodes.

If the required resistance needs a number of electrodes connected in parallel, they may be installed either in parallel lines or radiating from a point. Figure 7 shows the effect of spacing between two parallel electrodes, each 20 m long. The improvement with increase in spacing is relatively small for spacings greater than about 15 % of the length.

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

Table 5. Coefficients for strip or round conductor electrodes

Electrode arrangement	Coefficient		
	P	Q	
		Strip	Round
Single length ¹⁾ 	2	-1	-1.3
Two lengths at 90° 	4	0.5	0.9
Three lengths at 120° 	6	1.8	2.2
Four lengths at 90° 	8	3.6	-4.1

¹⁾ Where two or more straight lengths, each of length L in metres and of separation s in metres, are laid parallel to each other and connected together the combined resistance can be calculated from the following equation:

$$R_n = FR_1$$

where

R_n is the resistance of n straight conductors in parallel, in Ω ;

R_1 is the resistance of one straight conductor in isolation calculated from the equation and coefficients given above, in Ω .

F has the following value:

for two lengths, $F = 0.5 + 0.078(s/L)^{-0.307}$

for three lengths, $F = 0.33 + 0.071(s/L)^{-0.408}$

for four lengths, $F = 0.25 + 0.067(s/L)^{-0.451}$
provided that $0.02 \leq (s/L) \leq 0.3$.

10 Selection of a material for an earth electrode or a buried uninsulated earthing conductor

10.1 General

Although the material does not affect the earth resistance of an electrode, care should be taken to select a material that is resistant to corrosion in the type of soil in which it will be used. Recommended materials for the manufacture of earthing components are given in table 6.

There are two aspects which should be considered regarding the corrosion resistance of an earth electrode or an earthing conductor, compatibility with the soil itself and possible galvanic effects when it is connected electrically to neighbouring metalwork. The latter is most likely to come about when the earthing system is bonded to exposed metal structural components.

10.2 Corrosion and type of soil

The factors associated with the corrosion of metals in contact with soil are the chemical nature of the soil, in particular acidity and salt content, differential aeration, and the presence of anaerobic bacteria.

A general picture of the aggressiveness of soils is given by the following list, which places various types of soil in increasing order of aggressiveness:

- gravelly soils
- sandy soils
- silty soils (loam)
- clays
- peat and other organic soils
- made up soils containing cinders

Calcium carbonate in a soil will reduce the rate of corrosion. Non-cohesive soils, made from mixtures of the first three items above, are generally the least aggressive providing they are well drained and contain little or no dissolved salts. Location of electrodes should be chosen to avoid the drainage of fertilizer and other materials into the area. Top soil should not be mixed with the backfill around an electrode. The least aggressive soils tend to be those having a high resistivity.

More detail can be obtained by measuring the electrical resistivity of the soil, which provides an indication of corrosivity under aerated conditions, and the redox potential, which indicates the risk of corrosion due to the presence of anaerobic bacteria. These tests are described in BS 1377.

Guidance on the corrosivity of some electrode materials in relation to these soil parameters is given in table 7. Further information can be obtained from the TRRL Supplementary Report 'A review of soil corrosiveness with particular reference to reinforced earth' by R A King¹⁾, from which the above table has been summarized.

Copper is one of the better and commonly used materials for earth electrodes and underground conductors. Solid copper is particularly suitable where high fault currents are expected; for other installations copper-covered steel (e.g. as earth rods) is effective and provides better mechanical strength in the smaller sections. However, the adverse effect of dissolved salts, organic acids and acid soils generally should be noted.

Steel in concrete foundation work is generally protected against corrosion by the concrete and can act as a satisfactory electrode, if provision is made to ensure electrical continuity and adequate conductivity. Steel in concrete has an electropotential similar to that of copper and may therefore be bonded to copper or copper-covered earth electrodes. Note, however, that galvanized steel is strongly electronegative to both copper and steel in concrete so that an earth electrode of bare galvanized steel should not be bonded to either of them.

10.3 Corrosion due to interconnection with another metallic item

The possibility of damage to cables, other underground services and structural metalwork in the vicinity of earth electrodes, to which the earthing system is to be bonded, due to electrolytic action between dissimilar metals should not be overlooked. The rate of corrosion depends on the metals involved and to some extent on their relative surface areas. In some cases connection of neighbouring underground metalwork may also increase the rate of corrosion of earth electrode material. Materials compatible with the neighbouring items should be selected or other precautions taken.

Table 8 summarizes the situation for some construction and earthing materials.

¹⁾ Available from the Transport and Road Research Laboratory, Crowthorne, Berkshire.

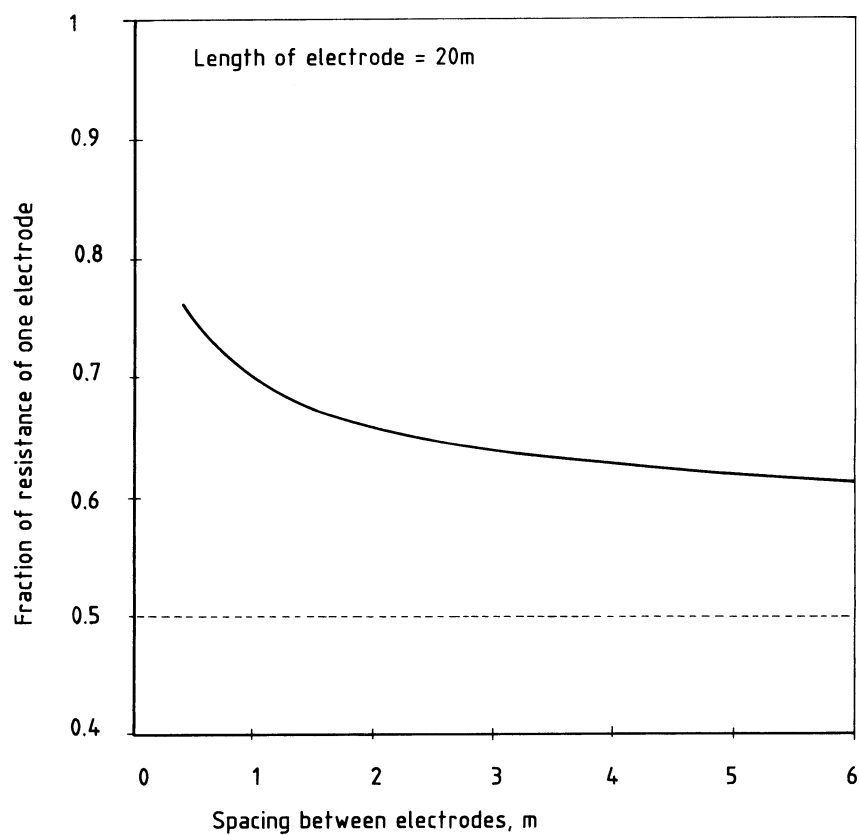


Figure 7. Effect of spacing on combined resistance of two horizontal strip electrodes

Table 6. Recommended materials for the manufacture of earthing components

Materials and processes	BS No.	Grade or type
<i>Ingots for cast processes</i>		
Leaded gunmetal	BS 1400	LG-1, LG-2
Aluminium bronze	BS 1400	AB1, AB2
Aluminium silicon bronze	BS 1400	AB3
Aluminium alloy	BS 1490	LM6M
Cast iron	BS 1452	14 or 17
Malleable iron	BS 6681	
<i>Forgings and stampings</i> (Hot or cold formed)		
Copper	BS 2872	C101, C102, C106
Aluminium	BS 1474	6082TF
Steel	BS 970	All grades
<i>Pressings and fabrication</i> (From strip, coil, foil and sheet)		
Copper annealed	BS 2870	C101, C102, C104, C106
Aluminium	BS 1474	6082TF
Aluminium	BS 1470	6082TF
Stainless steel	BS 1449 : Part 2	316S12, 325S21
Steel (for galvanizing)	BS 4360 or BS 1449 : Part 1	43A —
<i>Bars, rods and tube</i>		
For machined components and fittings:		
Copper, hard drawn or annealed	BS 2874	C101, C102, C106
Copper silicon	BS 2874	CS101
Phosphor bronze	BS 2874	PB102M
Aluminium bronze	BS 2874	CA102
Aluminium	BS 1474	6082TF
Steel (general use)	BS 970	All grades
Steel (for galvanizing)	BS 4360	43A
Stainless steel (general use)	BS 970	325S21
Stainless steel (austenitic)	BS 970	316S12

Table 6. Recommended materials for the manufacture of earthing components (concluded)

Materials and processes	BS No.	Grade or type
<i>Nuts, bolts, washers, screws, rivet fixings and internal dowels in earth rods</i>		
For use on copper:		
Phosphor bronze	BS 2874	PB102M
Copper silicon	BS 2874	CS101
<i>Nuts, bolts, washers, screws and rivet fixings</i>		
For use on aluminium:		
Aluminium alloy	BS 1473	6082
Stainless steel	BS 970	325S21
Galvanized steel (see note 1)	BS 970	220M07
<i>Solid rounds, flats and stranded conductors</i>		
<i>Copper</i>		
Copper, annealed	BS 1432	C101, C102
hard-drawn	BS 1433	C101, C102
Copper (stranded)	BS 6360	Insulated
Copper (flexible)	BS 6360	
Hard-drawn copper strand and copper cadmium (Fine wire braids are not recommended)	BS 125 or BS 2755	
<i>Aluminium</i>		
Aluminium strip/rod	BS 2898	1350, 6101A
Aluminium	BS 3988	Insulated
Aluminium (steel reinforced)	BS 215 : Part 2	—
Aluminium alloy	BS 3242	—
Aluminium	BS 215 : Part 1	—
<i>Steel</i>		
Galvanized steel (see note 1)	BS 302	—
Galvanized strip (see note 1)	BS 1449 : Part 1	
NOTE 1. The recommended finish is galvanizing in accordance with BS 729, which has to be done after manufacture or fabrication.		
NOTE 2. Stainless steel in contact with aluminium or aluminium alloys is likely to cause additional corrosion to the latter materials (see PD 6484). In these cases it is important to take protective measures such as the use of inhibitors.		



Table 7. Corrosion resistance of some electrode materials related to soil parameters

Soil parameter		Electrode material			
		Mild steel	Galvanized steel	Austenitic steel	Copper
Resistivity in $\Omega \cdot m$	<7	nn	n	g	g
	7 to 40	n	n	gg	g
	>40	gg	gg	gg	gg
Redox potential in mV	>400	gg	gg	gg	gg
	200 to 400	g	g	gg	g
	<200	nn	nn	n ±	n
Moisture content in %	<80	g	g	g	g
	10 to 80	n	n	g	g
	<10	gg	gg	gg	gg
Dissolved salts chloride		n	n	g	n
		n	n	n	n
pH acidic	<6	n	nn	g	n
	neutral	gg	gg	gg	gg
	alkaline	g	n	gg	g
Organic acids		n	n	g	nn

Key
gg = corrosion resistance generally unaffected;
g = corrosion resistance affected only slightly;
n = corrosion resistance affected;
nn = marked reduction in corrosion resistance.

Table 8. Suitability of materials for bonding together

Material assumed to have the larger surface area	Electrode material or item assumed to have the smaller surface area			
	Steel	Galvanized steel	Copper	Tinned copper
Galvanized steel	✓	✓	✓	✓
Steel in concrete	×	×	✓	✓
Galvanized steel in concrete	✓	✓ ¹⁾	✓	✓
Lead	✓	✓ ¹⁾	✓	✓

Key
× = not suitable for bonding;
✓ = suitable for bonding.

¹⁾ The galvanizing on the smaller surface may suffer.