Application Note
Earthing Systems: Basic Constructional Aspects

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SUMMARY

This Application Note discusses practical design of earthing electrodes, including the calculation of the earthing resistance for various electrode configurations, the materials used for electrodes and their corrosion performance. Equations are given for many common electrode geometries, including horizontal strips, rods, meshes, cable screens, and foundations.

Despite the fact that these formulae are derived under the false assumption that soil is boundless and homogenous and ignore the fact that the ground resistivity changes with moisture content, the obtained values, although approximate, are useful in predicting and optimizing performance.

INTRODUCTION

The concept of modern earthing was introduced in the Application Note '*Integrated Earthing Systems'*. It describes how all of the different earthing functions – lightning and short circuit protection, safety and electromagnetic compatibility – should be designed and implemented as one entity.

This was followed by a second Application Note in the domain of earthing, namely '*Earthing Systems: Fundamentals of Calculation and Design'*.

This is a third document in the same domain. It is concerned only with the part of an integrated system that is buried in the ground, called the earth or ground electrode, and gives practical guidance on the design of ground electrodes and the calculation of their properties.

The earthing system is an essential part of power networks at both high- and low-voltage levels. A good earthing system is required for:

- Protection of buildings and installations against lightning
- Safety of human and animal life by limiting touch and step voltages to safe values
- Electromagnetic compatibility (EMC) i.e. limitation of electromagnetic disturbances
- Correct operation of the electricity supply network and to ensure good power quality

In modern practice these functions are provided by a single system designed to fulfill the requirements of all of them. Although some elements of an earthing system may be provided to fulfill a specific purpose, they are nevertheless part of one single system – standards require that all earthing measures within an installation are bonded together, forming one system.

This Section offers design guidance, dealing with practical questions concerning calculation and aspects of design. The main issues considered here are:

- Earthing resistance for various earth electrode constructions
- Material used for earth electrode construction
- Corrosion of earth electrodes

In *'Earthing Systems: Fundamentals of Calculation and Design'*, basic definitions of, and formulas for calculating, earthing resistance and potential distribution for an idealized hemispherical earth electrode were given. Similar methods enable the formulation of relationships for other configurations of earth electrodes. However, all these formulas are derived under the false assumption that the soil has a homogenous structure and is boundless. Furthermore, the ground resistivity ρ changes with the soil moisture content and therefore with the seasons of the year. Because of this, the value of earthing resistance calculated with the formulas given here should not be considered to be exact. On the other hand, in practice, a high level of accuracy is not required in calculation or measurement of the earthing resistance. This parameter has only an indirect influence on the operation of electrical network and devices as well as protection against electric shock. In present-day standards and in the guidance of the majority of countries, the highest permissible values of earthing resistance are not specified, but only the lowest possible values are recommended [1]. Thus, the values of earthing resistance calculated with formulas given below should be treated as approximate, and in practice an inaccuracy of ±30% can be considered as acceptable. Because of this, there is no reason to derive exact relationships, especially for meshed and complex earthing systems.

An advantage of deriving formulas for simple earth electrode constructions is that it allows the basic relationship between earthing resistance and electrode geometry to be clearly visualized. Of course, it is always recommended that the most exact relationship available is used. However, in practice, while the formulas are used in the design of the earthing system, the most exact information concerning earthing resistance is actual measurement in situ.

The main subject considered here is the calculation of earthing resistance and earth surface potential distribution of various earth electrodes. Typical earth electrodes include:

- *Simple surface earth electrodes* in the form of horizontally placed strip band or wire in the form of a straight line or a ring
- *Rod (vertical) electrodes* of sufficient length to pass through soil layers of different conductivity; they are particularly useful where the shallow layers have poor conductivity in comparison to the deeper layers, or where there is a significant limitation of surface area in which to install the earth electrode
- *Meshed electrodes*, constructed usually as a grid placed horizontally at a shallow depth under the ground surface
- *Cable with earth electrode effect* – is a cable whose exposed metal sheath, shield or armouring provides a connection to earth of a similar resistance to that of strip-type earth electrodes
- *Foundation earth electrodes* – are conductive metal parts embedded in concrete, which is in contact with the earth over a large area

Functions of Earthing Systems and Fundamental Requirements

The function of earthing system is to provide:

- Protective earthing
- Functional earthing in electric power systems
- Lightning protection

The **protective earthing system** provides interconnection or bonding of all metallic parts (exposed and extraneous conductive parts) that a person or an animal could touch. Under normal, fault-free, circumstances there is no relative potential on these parts, but under fault conditions a dangerous potential may arise as fault current flows. The function of an earthing system is the protection of life against electric shock, the fundamental requirement being that the earthing potential, V_E, at a prospective short circuit current, I_E, does not exceed the permissible touch voltage V_F:

$$V_E \leq V_F \quad (1)$$

Thus, the maximum permitted value of earthing resistance is:

$$R = \frac{V_F}{I_E} \quad (2)$$

where I_E is the single-phase short circuit current under the most unfavourable conditions.

In industrial installations as well as in power substations, earthing systems of the low- and high-voltage systems are often common, due to the limited ground area available. In isolated earth (IT) installations, protective earthing should be implemented as a common system with the high-voltage protective earthing, independent of the type of neutral point arrangement (i.e. insulated or compensated).

Functional earthing relates to the need for certain points of the electrical system to be connected to the earthing system in order to ensure correct operation. A typical example is the earthing of the neutral point of a transformer.

Lightning protection earthing conducts lightning currents to the earth. Lightning currents can reach very high peak values, i_p, and cause very high values of earthing electrode potentials, V_E, which can be calculated with the following formula:

$$V_E \approx \sqrt{\left(L\frac{di_p}{dt}\right)^2 + \left(i_p R_p\right)^2} \qquad (3)$$

where

L is the inductance of earthing electrodes and lightning conductors

R_p is the impulse resistance of the earthing electrode.

Depending on the lightning current and the properties of the earthing system, potential V_E can reach very high values, up to some hundreds or even thousands of kV. Because these values are much higher than the network operating voltages, lightning often causes back-flashover or induced over-voltages in the network. Thus, full protection of installations against lightning requires the provision of a system of lightning arresters and spark gaps.

RESISTANCE AND SURFACE POTENTIAL DISTRIBUTION OF TYPICAL EARTH ELECTRODE CONSTRUCTIONS

Simple surface earth electrodes are metal rods, strips or pipes placed horizontally under the surface of the ground at a given depth, t, as shown in Figure 1. Usually the length of these elements, l, is much larger than t. Given this assumption, the earth surface potential distribution of the earth electrode, in direction x perpendicular to the length l, is described by following formula:

$$V_x = \frac{\rho I_E}{2\pi l}\ln\frac{\sqrt{l^2+4t^2+4x^2}+l}{\sqrt{l^2+4t^2+4x^2}-l} \qquad (4)$$

where:

V_x is the earth surface potential

V_E is the earth electrode potential at earthing current I_E

ρ is the earth resistivity [Ωm]

l is the length of the earth electrode.

Other symbols are explained in Figure 1.

The relative value of the potential V_x^* is given by:

$$V_x^* = \frac{V_x}{V_E} \qquad (4a)$$

where V_x^* is the relative value of earth surface potential.

The distribution of earth surface potential according to formulas 4 and 4a is presented in Figure 1, for particular values of earth electrode dimensions.

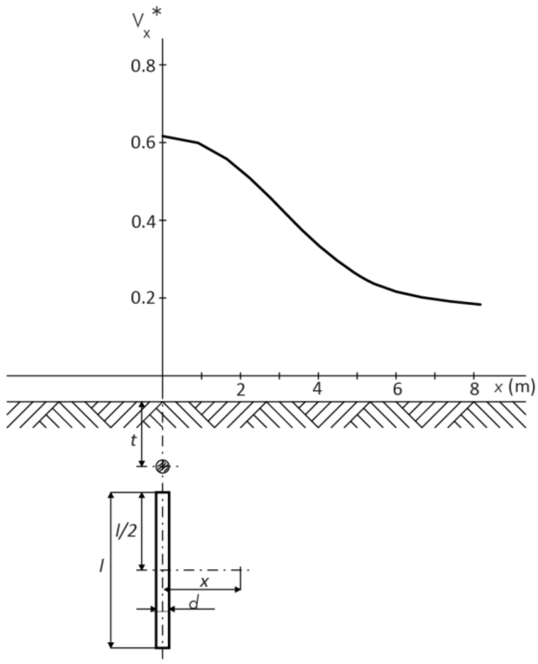


Figure 1 – Earth surface potential distribution V_x^* = f(x) in the axis perpendicular to the horizontally pipe-earth electrode with the length l = 10 m, diameter d = 0.02 m, placed in the depth t = 0.7 m.

The earthing resistance of a simple pipe placed in the soil can be calculated by the following formula:

$$R = \frac{V_E}{I_E} = \frac{\rho}{2\pi l} \ln \frac{l^2}{td} \tag{5}$$

Horizontal earth electrodes are usually made from a strip with a rectangular cross-section, usually 30-40 mm wide (b) and 4-5 mm thick (c). In this case the effective equivalent diameter d_e can be calculated by

$$d_e = \frac{2b}{\pi} \tag{6}$$

and substituted in equation 5. In some literature, it is suggested that $d_e = b/2$. is assumed.

The resistance of various constructions of horizontally placed simple earthing electrodes can be calculated using the following equation:

$$R = \frac{\rho}{2\pi l_\Sigma} \ln \frac{Bl^2}{td_e} \tag{7}$$

where B is a factor dependent on the electrode construction (given in table 1), and l_Σ is the aggregated length of all electrode elements.

The resistance of an earthing electrode in the form of a ring with diameter D, made from a band with a thickness c (Fig. 2), placed at a typical depth under the earth surface $t = 1$ *m*, can be calculated using the following formula [4]:

$$R = \frac{\rho}{2\pi^2 D} k \tag{8}$$

where k is the factor shown in Figure 3 (all dimensions as in equation 4).

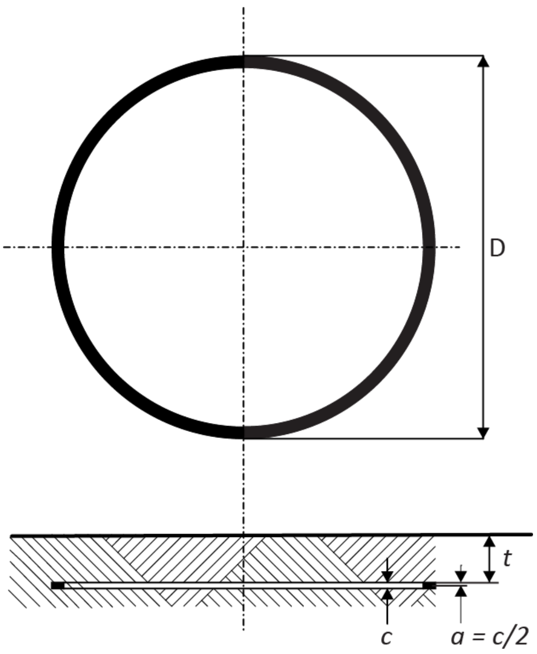


Figure 2 – Diagram of a simple ring earth electrode, according to equation (8).

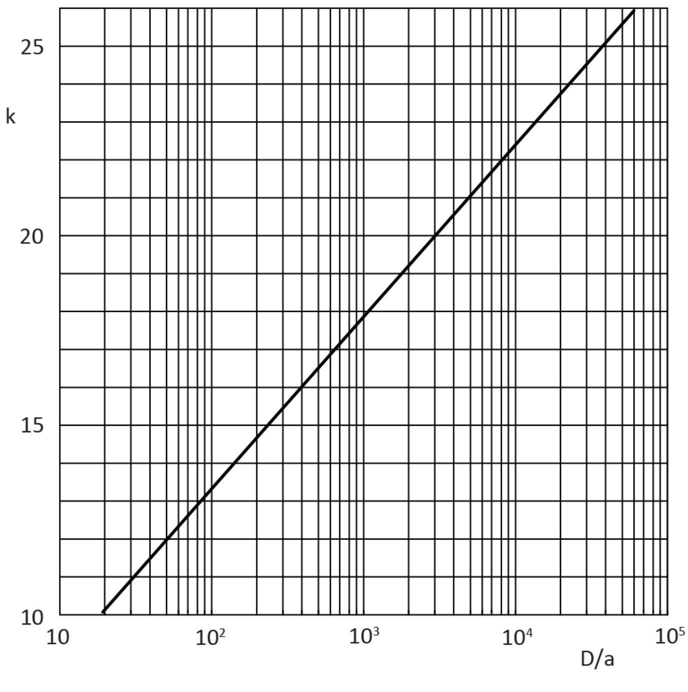


Figure 3 – Diagram of factor K = F(D/A) useful in equation (8).

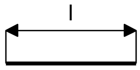
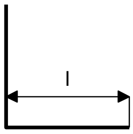
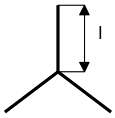
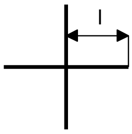
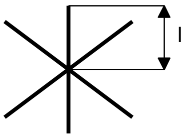
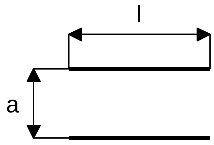
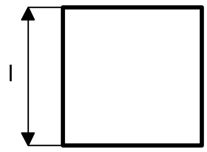
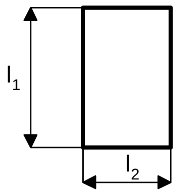
Earth electrode			Factor B in equation 7
Name	Horizontal projection		
Line			1
Square, two-arm			1,46
Three-arm, symmetrical			2,38
Four-arm, symmetrical			8,45
Six-arm, symmetrical			192
Two-arm, parallel			$\frac{l^2}{4a^2}$
Square			5,53
Rectangle, with various relations l_1/l_2 (1,5; 2; 3; 4)		1,5	5,81
		2	6,42
		3	8,17
		4	10,4

Table 1 – Values of the factor B for various geometrical forms of surface electrodes

Vertical rod electrodes are long metal rods or pipes placed vertically in the earth in order to pass through to the deep layers of the ground. Earth resistivity depends considerably on the ground depth, because of the higher soil moisture content in the deeper layers. Rod electrodes make contact with deeper layers where moisture content is likely to be higher and resistivity lower, so they are particularly useful where an electrode is required in a small surface area. Thus, vertical electrodes are recommended especially in areas of dense building, or where the surface is covered with asphalt or concrete. Vertical earth electrodes are often used in addition to horizontal ones in order to minimize the total earthing resistance.

An important disadvantage of the simple vertical rod electrode is an unfavourable surface potential distribution, which can be calculated with following formula, assuming that the earth current I_E is uniformly distributed on the whole electrode length:

$$V_x = \frac{\rho I_E}{2\pi l} \ln \frac{\sqrt{x^2+l^2}+l}{\sqrt{x^2+l^2}-l} \qquad (9)$$

Where *x* is the distance from the earth electrode

l is the electrode length.

Other dimensions are as for equation 4.

An example of the relative surface potential distribution $V_x^* = f(x)$ (4a), for certain electrode dimensions is presented in Figure 4. Comparison of characteristics in Figures 1 and 4 shows that the potential gradients on the earth surface are considerably higher for a vertical electrode and the touch voltages are unfavourable. The approximate relation of the vertical earth electrode resistance is:

$$R = \frac{V_E}{I_E} = \frac{\rho}{4\pi l} \ln \frac{4l^2}{r^2} \qquad (10)$$

where *r* is the radius of the rod electrode.

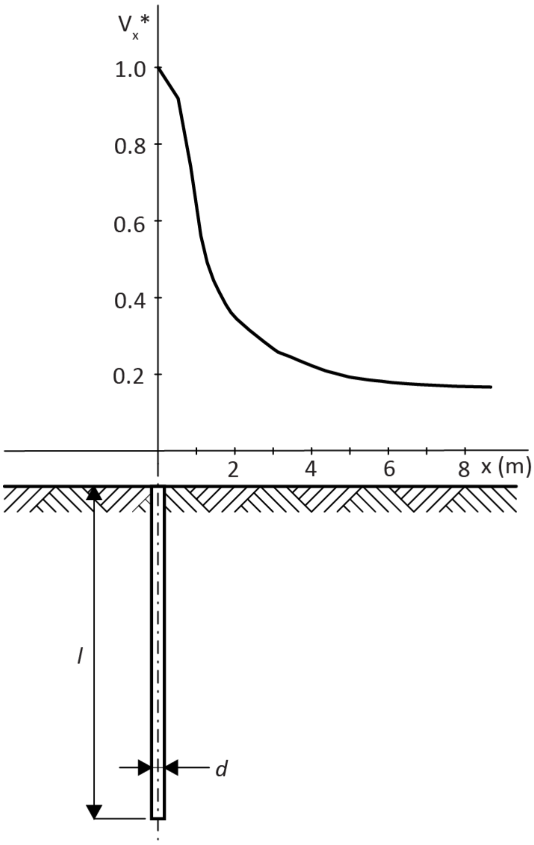


Figure 4 – Earth surface potential distribution V_x^* = f(x) around a vertical rod earth electrode with the length l = 3 m;, diameter d = 0.04 m.

Figure 5 shows resistance against length of rod for an electrode in earth of various resistivities.

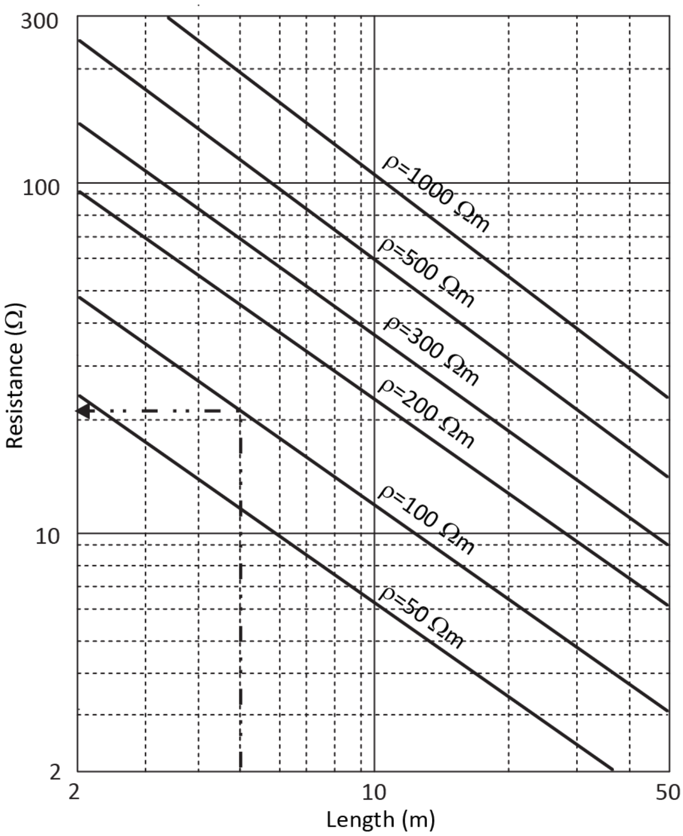


Figure 5 – Earth resistance of a rod electrode of length l and diameter 0.02 m*, in homogenous ground with resistivity ρ [2].*

In the case of n vertical rod electrodes installed in-line at a uniform distance a from each other, as shown in *Figure 6*, the effective earth resistance is as follows [4,8]:

$$\frac{1}{R} = \left(\sum_{i=1}^{n} \frac{1}{R_i}\right) k$$

where:

R_1, R_2, R_3...R_n are the earth resistances calculated for each rod, assuming it to be unaffected by the presence of the other earth rods and

k is the so called "filling" or "duty" factor, and $k \geq$ 1.

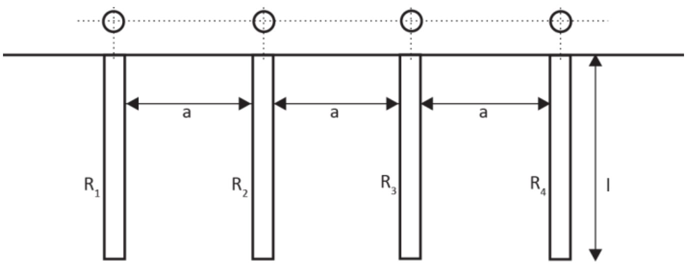


Figure 6 – Parallel arrangement of rod electrodes; R_1-R_4 - individual resistances of electrodes, a is electrode sepapration, l is electrode length.

The value of k is greater than 1 because of the mutual influence of electrical fields produced by the adjacent rods. In effect, the symmetry of current flow from each individual electrode is deformed and the current density in the soil is changed. In the literature [8] exact values of the factor k for various configurations of the parallel rod electrodes are given. In a simple configuration, such as shown in Figure 6, the values of k can be assumed to be [4]:

for $a \geq 2l$, k = 1.25

for $a \geq 4l$, k = 1

Meshed electrodes are used mainly in earthing systems of large areas, for example electrical power substations. The grid of the whole electrode is usually constructed so that it corresponds to dimensions of the installation and ensures a favourable, approximately uniform, surface earth potential distribution. The earthing resistance of meshed electrodes can be calculated using the following simplified equation:

$$R = \frac{\rho}{4r_e} + \frac{\rho}{l_\Sigma} \qquad (11)$$

where r_e is the equivalent radius.

For square or approximately square areas the equivalent radius is that that gives a circular area equal to the actual area.

For rectangular areas, the equivalent radius is equal to the sum of external sides divided by π, if the electrode has a form of a very long rectangle (*Figure 7*b).

l_Σ is the sum of length of flanks of all meshes inside the grid – see 'Calculation examples', example E.

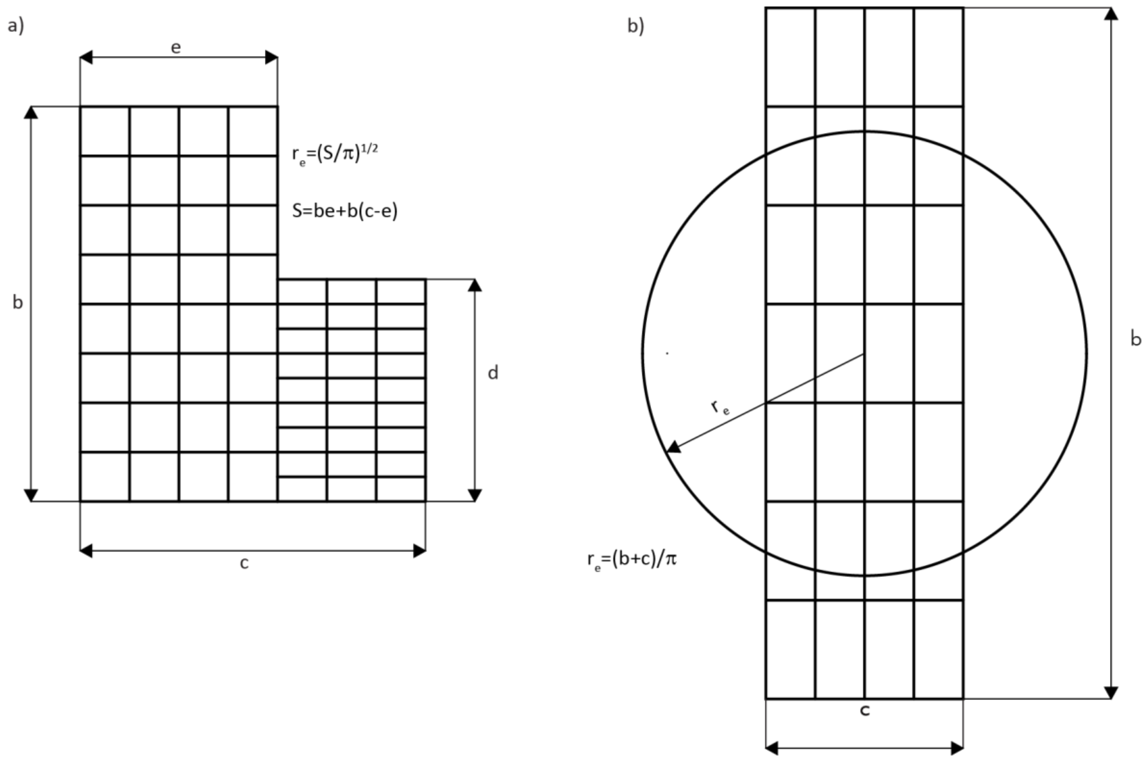


Figure 7 – Examples of meshed earth electrodes explaining manner of calculation of the equivalent radius r_e in equation (11), for two forms of the earth electrode: nearly similar to a square (a) and of a long rectangle (b).

Foundation earth electrodes are conductive metal parts embedded in the concrete of the building foundation. Concrete embedded directly in the ground has natural moisture content and can be considered as conductive matter, with conductivity similar to that of the earth. Because of the large area of this type of electrode, low resistance can be achieved. Furthermore, the concrete protects the metal parts against corrosion and steel electrode elements embedded in the concrete do not need any additional corrosive protection. Foundation earth electrodes are nowadays recommended as a very practical solution to building earthing [6, 7].

In practice there are two basic foundation earth electrode constructions:

a) In a foundation without concrete reinforcement (Figure 8)
b) In a foundation with concrete reinforcement (Figure 9).

In both cases the earth electrode is made from:

- Steel strip with rectangular cross section not less than 30 mm x 3.5 mm, or
- Steel bar with round cross section not less than 10 mm diameter.

The steel elements can be galvanised (i.e. with a zinc coating), but this is not necessary if the layer of concrete covering the electrode is greater than 50 mm [6], because the concrete ensures sufficient protection against the corrosion, as shown in *Figure 8*.

In a foundation without concrete reinforcement (*Figure 8*) the electrode usually follows the contour of building foundation, i.e. it is placed under the main walls. In buildings with extensive foundations, the electrode is made usually in the form of loops, covering all parts of foundation outlines, and connected to each other.

In a foundation with the concrete reinforcement the earth electrode is placed over the lowest layer of wire-mesh reinforcement (*Figure 9*) thus ensuring adequate corrosion protection for the electrode. The electrode should be fastened to the reinforcement mesh with wire strands at intervals of not more than 2 m over the electrode length. It is not necessary to make a sound electrical connection at each point because the main electrical connection is via the concrete. If the foundation is constructed as separate panels connected to each other with expansion joints, the earth electrodes of each panel should be galvanically connected to each other. These connections must be flexible and must be located so that they remain accessible for measurement and maintenance purposes [6].

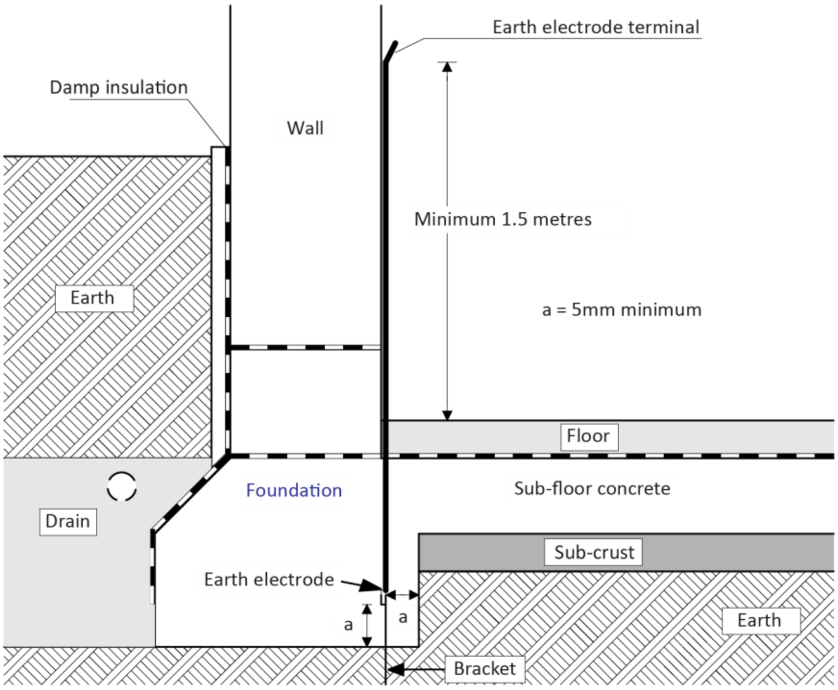


Figure 8 – Placement of the foundation earth electrode in a foundation without concrete reinforcement.

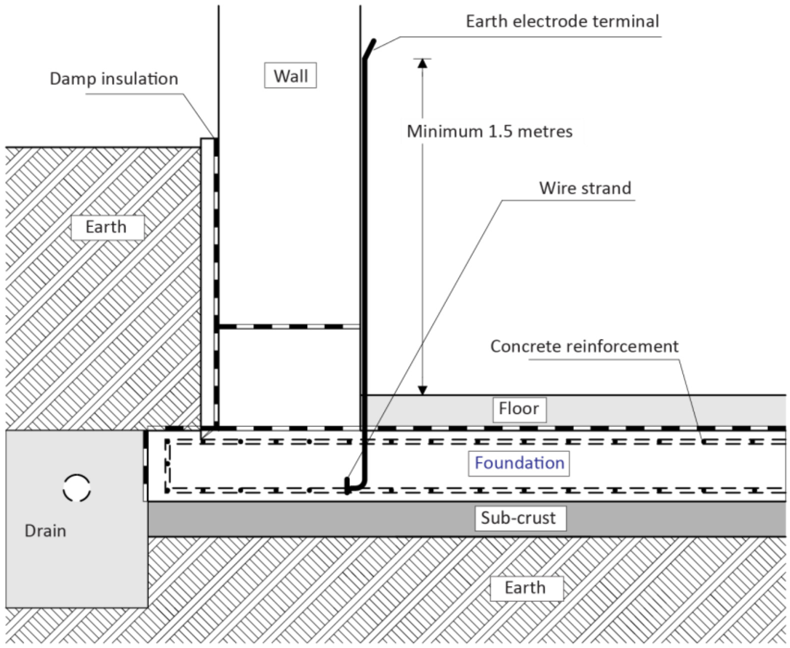


Figure 9 – Placement of the foundation earth electrode in a foundation with concrete reinforcement.

The foundation earth resistance can be calculated using the following simplified equation [2]:

$$R = 0.2\frac{\rho}{\sqrt[3]{V}} \qquad (12)$$

where:

R is in Ω,

V is volume of the foundation in m^3.

The terminal of the foundation earth electrode should have a minimum length of 150 cm above the floor level (*Figure 8* and *Figure 9*). It should be placed as close as possible to the main earthing terminal of the building installation. The connection between the foundation earth electrode and the lightning protection should be located outside of the building.

Computer programs are now available that enable exact calculation of parameters for various combined forms of earth electrodes, including the complex layer-ground structure. However, they are of only limited use since the ground-structure, the ground resistivity and its changes during the year are not known in practice. Exact calculation can be performed only for a certain season, and will be significantly different at other times. In any case, high accuracy in such calculations is not required; in practice an accuracy of ± 30% is usually satisfactory. Consequently, using the simple formulas given here is normally satisfactory. Of course, while calculation is essential for design, the efficiency of the system can only be verified by measurement of the resistance value after construction.

CALCULATION EXAMPLES

In all examples it is assumed that the ground has a homogenous structure, with resistivity ρ = 100 Ωm.

EXAMPLE A)

The resistance of a simple electrode, placed horizontally 1 metre deep in the earth with following dimensions:

Width b = 40 mm

Thickness c = 5 mm

Length l = 5 m

can be calculated using equations (6) and (7), and Table 1. The equivalent diameter d_e (6) is as follows:

$$d_e = \frac{2b}{\pi} = \frac{2\times 0.04\ m}{\pi} = 0.025\ m$$ (Factor B from Table 1 is = 1)

The resistance of the earth electrode is:

$$R = \frac{\rho}{2\pi l_\Sigma} \ln \frac{Bl^2}{td_e} = \frac{100\Omega m}{2\pi \times 5\ m} \ln \frac{1 \times 5^2 m^2}{1\ m \times 0.025\ m} \approx 22\ \Omega$$

EXAMPLE B)

An electrode consisting of two 5 metre bars placed as a four-arm symmetrical construction (Table 1), has the following parameters:

d_e = 0.025 m,

l = 2.5 m,

B = 8.45.

The resistance of the earth electrode is:

$$R = \frac{\rho}{2\pi l_\Sigma} \ln \frac{Bl^2}{td_e} = \frac{100\Omega m}{2\pi \times 10\ m} \ln \frac{8.45 \times 2.5^2 m^2}{1\ m \times 0.025\ m} \approx 12.2\ \Omega$$

EXAMPLE C)

A horizontally placed round electrode (Figure 2), 1 metre deep, with diameter D = 5 m, made from the same strip as in example A. The factor k in Figure 3 can be estimated for D/a = 5 m/0.0025 m = 2000, where $a = c/2$, Figure 2. The resistance of the earth electrode can be calculated using the equation (8):

$$R = \frac{\rho}{2\pi^2 D} k = \frac{100\Omega m}{2 \cdot \pi^2 \cdot 5m} \cdot 19{,}2 \approx 19{,}4\Omega$$

EXAMPLE D)

A vertically placed rod electrode with diameter 20 mm and length 5 m, has resistance calculated from the equation (10):

$$R = \frac{\rho}{4\pi l} \ln \frac{4l^2}{r^2} = \frac{100\Omega m}{4\pi \times 5\ m} \ln \frac{4 \times 5^2 m^2}{0.01^2 m^2} \approx 21.9\ \Omega$$

Similar value can be derived from the diagram in Figure 5.

EXAMPLE E)

A rectangular, horizontally placed meshed earth electrode has dimensions as shown in *Figure 10*.

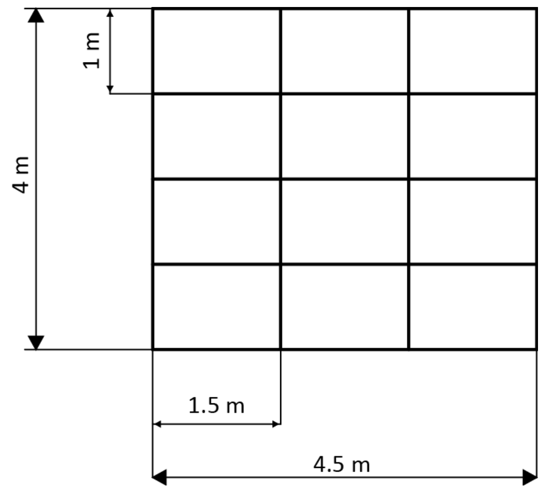


Figure 10 – Sketch diagram of the meshed earth electrode to the example E.

The resistance is calculated using equation 11 and the equivalent radius r_e calculated as shown in Figure 6.

$$r_e = \sqrt{\frac{S}{\pi}} = \sqrt{\frac{4\,m \times 4.5\,m}{\pi}} \approx 2.4\,m$$

The sum of length of branches in a single mesh is:

(1,5 m + 1 m) · 2 = 5 m

The sum of length of all meshes inside the grid:

$$l_{\Sigma} = 5\,m \times 12\,meshes = 72\,m$$

Thus, the resistance of the earth electrode:

$$R = \frac{\rho}{4r_e} + \frac{\rho}{l_{\Sigma}} = \frac{100\,\Omega m}{4 \times 2.4\,m} + \frac{100\,\Omega m}{72\,m} \approx 11.8\,\Omega$$

CONSTRUCTION ASPECTS OF EARTHING ELECTRODES

Earthing systems should be constructed in such a manner, and of such materials, that they perform correctly over the whole expected lifetime, at a reasonable construction cost. The required properties are:

- Low earthing resistance and favourable earth surface potential distribution
- Adequate current carrying capacity
- Long durability.

Earthing resistance should not exceed the values required by guidance or standards under the most unfavourable climatic conditions (long dry weather, heavy frost). If there are no exact requirements, the earthing resistance should be as low as possible.

Earth surface potential distribution should be such that the touch and step voltages do not exceed the permitted values. The most favourable potential distribution on the earth surface is achieved by using a horizontally placed meshed earth electrode. Sometimes it is necessary to place additional horizontal elements, in order to reach the desired potential distribution in the earth surface.

The current carrying capacity is the highest current value that can be carried through the earth electrode to the earth, without any excessive heating of the electrode elements and the surrounding soil itself. At too high current values and current densities, the water in the soil at the soil-electrode interface evaporates, leaving dry soil with high resistivity.

The durability of the earth electrode is its life from construction up to the time when, due to the corrosion of metallic parts, electrical continuity is lost. The durability of an earth electrode should exceed the expected lifetime of the installation. For the majority of power installations, lifetime can exceed 25 years and for power lines, 35 - 50 years. The earthing system should be included in repair and maintenance cycles.

The durability of an earthing system depends mainly on its capability to withstand corrosion. The earth electrodes, being directly in contact with the soil or with water, operate in corrosive conditions. There are three main factors determining the rate of corrosion of metal objects in the soil:

- DC currents in the earth,
- Chemical contamination of the soil,
- Electrochemical (galvanic) phenomena between various metals located in the soil

Corrosion due to **DC currents** occurs mainly in the neighbourhood of DC networks, (for example, DC railway supplies). There are standards and regulations (for example DIN VDE 0150) covering the requirements in such cases.

Corrosion due to **chemical substances in the soil** is not normally of great importance, affecting only those systems in chemical factories or near the ocean. In such cases, earth electrodes should be constructed from metals resistant to the specific chemical corrosion. In order to minimise the chemical corrosion it is recommended, in some cases, to measure the pH of the soil. For an alkaline soil (pH > 7) copper electrodes are recommended, and for acid soil electrodes made from aluminium, zinc or galvanised steel are preferred.

Galvanic corrosion is caused by a DC current flowing in a circuit supplied by the electrochemical potential difference between two pieces of metal in the damp soil, which in this case acts as an electrolyte. Of the commonly used electrode metals copper has the lowest potential. Other metals have a positive potential with respect to the potential of copper (*Table 2*). This small DC current flowing continually causes the metal ions from the anode to flow to the cathode. Thus, metal is lost from the anode and builds up on the cathode. From this point of view, favourable metal combinations can be deduced. For example, steel covered by copper is a favourable solution because the amount of copper remains the same. An opposite example is steel covered by zinc, where zinc is always the anode and its amount continually diminishes. Note that the electrochemical potential of steel embedded in concrete is very close to that of copper. Thus, steel constructions in building foundations are cathodes in relation to other steel or zinc objects located in the soil (not only earth electrodes, but also, for example, water pipes). This means that the large foundations cause significant corrosion of these metal objects due to electrochemical corrosion.

Metal	Electrochemical potential to a copper electrode [V]
Zinc or steel covered by zinc	0.9 - 1.0
Steel	0.4 - 0.7
Steel in concrete	0 - 0.3

Table 2 – Values of electrochemical potential of various metals to the copper electrode [2].

The most frequently used electrode materials are following:

- Steel (for example in foundation earthing systems)
- Galvanised steel
- Steel covered by copper
- High-alloy steel
- Copper and copper alloys

Mechanical strength and corrosion conditions dictate the minimum dimensions for earth electrodes given in Table 3 [5].

- Copper 16 mm^2
- Aluminium 35 mm^2
- Steel 50 mm^2

Material		Type of electrode	Minimum size				
			Core			Coating/sheath	
			Diameter [mm]	Cross-section [mm]	Thick-ness [mm]	Single values [µm]	Average values [µm]
Steel	Hot-galvanised	Strip [2]		90	3	63	70
		Profile (incl. plates)		90	3	63	70
		Pipe	25		2	47	55
		Round bar or earth rod	16			63	70
		Round wire for horizontal earth electrode	10				50
	With lead sheath [1]	Round wire for horizontal earth electrode	8			1000	
	With extruded copper sheath	Round bar for earth rod	15			2000	
	With electrolytic copper sheath	Round bar for earth rod	14,2			90	100
Copper	Bare	Strip		50	2		
		Round wire for horizontal earth electrode		25 [3]			
		Stranded cable	1,8 [4]	25			
		Pipe	20		2		
	Tinned	Stranded cable	1,8 [4]	25		1	5
	Galvanised	Strip		50	2	20	40
	With lead sheath [1]	Stranded cable	1,8 [4]	25		1000	
		Round wire		25		1000	

[1] not suitable for direct embedding in concrete

[2] strip, rolled or cut with rounded edges

[3] in extreme conditions, where experience shows that the risk of corrosion and mechanical damage is extremely low, 16 mm^2 can be used

[4] for single wire

Table 3 – Type and minimum dimensions of earth electrode materials ensuring mechanical strength and corrosion resistance [5].

CONCLUSIONS

The following factors must be considered in the construction of the earthing system:

- Function
- Electrical properties
- Construction material

The main electrical properties of an earthing system are:

- Earthing resistance
- Earth surface potential distribution
- Current carrying ability

The most favourable earth surface potential distribution concepts have horizontal earth electrodes, especially meshed ones, whose surface potential can be controlled relatively easily. The potential distribution of vertical electrodes is the most unfavourable, with high values of touch potential. On the other hand, vertical electrodes can easily reach low earthing resistance with stable values, largely independent from seasons. Vertical electrodes are also used in combination with horizontal ones in order to reach lower values of earthing resistance.

The choice of electrode material is usually a compromise between cost and durability. The corrosion susceptibility of the electrode material and the corrosion aggressiveness of the soil are the main factors limiting the life time of earthing systems.

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