BRITISH STANDARD

BS EN 14505:2005

Cathodic protection of complex structures

The European Standard EN 14505:2005 has the status of a British Standard

ICS 77.060

British Standards

National foreword

This British Standard is the official English language version of EN 14505:2005.

Reference should also be made to BS 7361, Code of practice for land and marine applications, which will eventually be withdrawn when all the CEN standards relating to cathodic protection currently being prepared, are published.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Cathodic protection of complex structures

Protection cathodique des structures complexes

Kathodischer Korrosionsschutz komplexer Anlagen

This European Standard was approved by CEN on 15 March 2005.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Contents

Foreword

This European Standard (EN 14505:2005) has been prepared by Technical Committee CEN/TC 219 “Cathodic protection”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2005, and conflicting national standards shall be withdrawn at the latest by October 2005.

It may be difficult to obtain complete cathodic protection of certain structures when following the general guidelines in EN 12954. This may be due to an electrical connection to one or more metal structures (electrodes) situated in the same electrolyte as the structure, which is to be protected. In particular, the structure may be earthed in order to mitigate electrical hazards or the connection to the other structures may be dictated by construction or operational requirements.

An electrical connection to a foreign structure can result in a significantly increased cathodic protection current demand, since the current flows not only to the structure to be protected but also to the foreign structure. This unwanted increased current demand is enhanced when the foreign structure consists of a metal, which is more noble (having a more positive resting potential) than the metal in the structure to be protected. Connection to a copper earthing electrode or to the steel reinforcement in a concrete structure are examples of the latter.

These difficulties can mean that a significantly increased cathodic protection current is required because of structures electrically connected to the structure to be protected, resulting in inadequate cathodic protection, current distribution and shielding effects.

For this reason, the term “complex structure” has been used. It does not refer to the complexity of the structure or to the complexity of the cathodic protection system.

In such conditions the prerequisites, the criteria and the methods described in the present document expand those given in EN 12954.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

1 Scope

This European Standard applies to the cathodic protection of complex structures. It is applicable to structures, which are to be cathodically protected, but cannot be electrically isolated, whether for technical or safety reasons, from foreign metallic structures situated in the same electrolyte as the structure to be protected. Such a structure is referred to as a “complex structure”.

This European Standard is not applicable to structures that can be protected in accordance with EN 12954. When contacts with foreign structures or defective isolation from foreign structures exist, but can be corrected, EN 12954 is applicable instead of this document. As an example pipeline network distribution systems are not considered to be complex structures

It is assumed in this document that the design, installation, commissioning, inspection and maintenance are entrusted to adequately trained, experienced, competent and reliable personnel in order to achieve effective and efficient cathodic protection.

Annexes A and B show the principle scheme of a complex structure with examples.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12954:2001*, Cathodic protection of buried or immersed metallic structures — General principles and application for pipelines.*

EN 50162, *Protection against corrosion by stray current from direct current systems*.

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 12954:2001 and the following apply.

NOTE For other definitions related to corrosion, refer to EN ISO 8044:1999.

3.1
complex structure
structure composed of the structure to be protected and of one or more foreign electrodes, which, for safety or technical reasons, cannot be electrically separated from it

3.2
foreign electrode
electrode (anode or cathode), in contact with the structure under consideration

NOTE a foreign anode is a foreign electrode, which has a more negative potential than the structure, a foreign cathode is a foreign electrode, which has a more positive potential than the structure.

4 Criteria for the cathodic protection of complex structures

For complex structures, the cathodic protection criteria defined in EN 12954 should be used where possible. Indeed, the characteristics of complex structures and the special influential factors (see Clause 5) which can occur means that it is not always possible on every part of the complex structure to determine by measurement whether these criteria of cathodic protection are met. In this case alternative methods of verification may be selected to ensure an adequate reduction of the corrosion rate. Particular attention should be paid to the selection of these alternative methods, and these will depend upon the structure and the soil characteristics.

The following three alternative methods may be used as criteria. They are based upon practical experience and are widely used. All structure to electrolyte potential measurements are stated with respect to a copper/saturated copper sulphate reference electrode.

a) Potential measurement method

An on potential E_{on} equal to or more negative than –1,2 V, if the measuring point is outside the area of influence of the large foreign cathode (e.g. reinforced concrete or copper earthing system) and if the soil resistivity is sufficiently low (less than about 100 Ω·m) with the exception that an on potential E_{on} more negative than –0,8 V could be acceptable at entries to, and in the vicinity (within 0,5 m) of large foreign cathodes (demonstrating that the effect of a galvanic cell with the large foreign cathode is mitigated).

b) Current method

The purpose of this method is to demonstrate that current is able to enter the structure at critical locations either:

1) directly (i.e. when the protection current is switched on, a negative shift from the free corrosion potential E_n by at least 0,3 V indicating that probably sufficient current is entering the structure); or

2) by means of either current density or potential shift measurements at test probes or coupons.

NOTE A critical location is location where the probability to have an anodic current leaving the structure to be protected is high (e.g., vicinity of foreign cathode due to galvanic couple, heterogeneity of the soil or shielding effect).

c) Depolarisation measurement method

A positive shift (depolarisation) on test probes or coupons of at least 0,1 V measured from immediately after disconnection (E_{off}) to 1 h after disconnection from the structure indicates that the structure is polarized. These test probes/coupons are disconnected only for measurements.

One of these alternative criteria shall be used as a minimum. More than one of these alternative criteria may be required to verify adequate protection over the entire complex structure. Other criteria can be used if they can be shown to reduce the external corrosion rate to an acceptable level.

5 Prerequisites for the application of cathodic protection to a complex structure

5.1 General

The cathodic protection system depends on the size and shape of the complex structure, the type of coating, the aggressive action of the soil and its resistivity, d.c. and a.c interference, national regulations, and also on the technical and economic criteria.

To achieve cathodic protection, the conditions given in 5.2 to 5.4 should be satisfied.

5.2 Electrical continuity

In the case of a complex structure, all metallic parts of the structure to be protected should be electrically continuous. Foreign electrodes should also be electrically continuous.

5.3 Electrical isolation

For the cathodic protection system to be properly designed, the form and extent of the structure should be clearly defined in terms of its location and electrical isolation from foreign structures.

If the electrical isolation is ineffective and cannot be restored to its original condition, then the extent of the complex structure should be revised to take this into account.

5.4 External coating

Protective coatings are not always applied to components in a complex structure (e.g. earthing systems). Uncoated components significantly increase protection current demands and thus add to the difficulties of the application of cathodic protection and increase the risk of interference. Wherever possible, buried metallic components should be suitably coated.

6 Base data for design

6.1 General

In addition to following the principles laid out in EN 12954, other specific data, as given in 6.2 to 6.8, should be used when dealing with complex structures.

6.2 Structure details

The surface area of all buried or immersed components of a complex structure should be ascertained as well as the status of the coating (if any).

6.3 Coatings

Types of the different coating applied on all components of a complex structure should be taken into account.

6.4 Environment

Depending on the composition of some parts of a complex structure, particular environmental conditions should be considered, for example, the chloride content of the electrolyte when an integral part of a complex structure is made of stainless steel, or reinforcement steel in concrete (rebar).

6.5 Shielding

All relevant information should be obtained on any feature that might act as a shield to the cathodic protection current or its distribution, e.g. reinforced concrete foundations, pits, ducts, any geotextiles, and pipe sleeves. The location of the anodes with respect to the shields should be selected such that shielding is minimized.

A shield can be either conductive or non-conductive.

A conductive shield can be either a part of the complex structure itself or a foreign structure such as steel sleeves for pipes, large conducting structures (sheet piling and reinforced concrete foundations) close to the structure to be protected.

Non-conductive shields can be either a non-conductive object (e.g. plastic or a well coated steel sleeve pipe) or a mechanical protective material or a localized area with a higher resistivity (e.g. drained sands, gravels, sealed concrete).

6.6 Electrical isolation

The location and efficiency of electrical isolation should be taken into account at the defined complex structure limits and, if necessary, within the complex structure.

For example, isolation is ineffective if it is bypassed by metallic components or equipment that provide a parallel electrical path. Electrical earthing systems, instrumentation and/or telemetry cables, control pipework, and supporting structures are examples of possible parallel paths. Electrical isolation is also ineffective when pipelines carrying low resistivity liquids (e.g. brine) are equipped with inappropriate isolating joints.

NOTE Details concerning isolating joints are given in EN 12954.

6.7 Foreign electrodes

Details of the type, location and other detailed characteristics of foreign electrodes should be obtained.

In a complex structure, the presence of foreign electrodes which act as an anode (e.g. zinc or zinc-coated (galvanized) steel) or as a cathode (e.g. steel reinforcement in concrete (see Annex C), copper, stainless steel or silicon iron in carbonaceous backfill earthing systems) increases the protection current demand.

Zinc earthing systems should be used because they consume less current from the cathodic protection system than copper, stainless steel or silicon iron.

Electrical earthing systems associated with complex structures should utilize zinc or zinc-coated (galvanized) steel electrodes.

NOTE The connection of copper or cathodic earthing systems to buried steel not only increases cathodic protection current demand but, if cathodic protection is not applied, it will increase the corrosion risk to the buried steel.

6.8 Interference assessment

Interference:

- from any d.c. operated equipment to the complex structures or

- from the complex structure to foreign structures

should be assessed in accordance with EN 50162.

If necessary, appropriate measures should be taken to mitigate the effects of interference to maintain effective cathodic protection of the complex structure.

Particular attention should be paid to interference that can occur between the cathodic protection system(s) of the complex structure and the incoming/outgoing pipelines. Pipelines in the vicinity of the complex structure and their cathodic protection should be taken into account both in the design and the commissioning of the cathodic protection system of the complex structure to limit, or preferably, eliminate adverse interference effects.

7 Design and prerequisites

7.1 General

Complex structures include foreign electrodes that are often large cathodic surfaces (such as reinforcement steel and earthing systems). The result is that the cathodic protection current requirement is high and the effective distribution of the current is difficult to obtain.

Even though all known influences are taken into account in the design of the cathodic protection system, experience has shown that subsequent adjustments and additional cathodic protection installations can be necessary after the system has been switched on and a certain polarization time has elapsed. This is due to the characteristics of the structure to be protected, shielding effects and interference with foreign structures. For these reasons, the protection current requirements and current distribution cannot always be accurately determined during the design stage.

When a complex structure includes reinforcement steel in concrete that is bonded to the structure to be protected, efficient current distribution can be achieved by the application of an insulating coating to the buried concrete surface at entries or points of close proximity of the protected structure to the reinforced concrete (see 7.2 item b) and Annex D). This method may be applied whether local anodes to increase the soil potential are used or not.

A coating is used to reduce the effect of the local voltage gradient from the reinforced concrete structure and improve the current distribution.

The coating should extend on the concrete surface at least 1 m around the protected structure (e.g. pipeline) and up to the soil surface.

If pipelines are laid in soil parallel to steel reinforced concrete foundations and the spacing is less than twice the pipe diameter or less than 0,5 m, the coating should extend for the length of the parallelism from 1 m below the bottom of the pipe to ground level.

Test stations connected to reinforcement steel should be located in these areas (see also 7.8).

7.2 Cathodic protection methods for complex structures

To achieve the protection criteria detailed in Clause 4, cathodic protection can be achieved by three methods. The choice of the method depends on the complex structure in question.

a) By the use of impressed current groundbed(s) sufficiently remote from the complex structure to be protected (conventional groundbed). By using this method, high levels of cathodic protection current are often required because all components of the complex structure receive and consume current.

b) By the use of distributed or continuous groundbed(s) located along and close to the structure to be protected. The purpose of this method is to localize the application of cathodic protection current to the structure to be protected. (Complementary information is given in Annex D).

c) By a combination of the above two methods.

Effective cathodic protection is usually achieved by a combination of these methods. Complex structures vary considerably in size and complexity and it is not possible to be prescriptive as to which single method will be successful.

NOTE Annex E covers groundbed data.

7.3 Electrical isolation of structures

If electrical isolation from the adjacent structures exists or is planned, this information should be used to determine the extent and limits of the complex structure.

Isolating joints in incoming or outgoing pipelines should be located outside the zone of influence of the cathodically protected complex structure so that unacceptable interference by the cathodically protected complex structure (due to voltage gradient) is avoided.

7.4 Safety

7.4.1 General

The design should not cause any additional hazards, (e.g. explosion, safety, personnel and interference).

7.4.2 Electrical earthing systems

Generally, earthing systems are electrically connected directly to the structure to be protected and are part of the complex structure. In order to prevent excessive drain of cathodic protection current to copper earthing systems, they can be separated from the structure to be protected by the use of decoupling devices.

7.4.3 Electrical safety bonding

7.4.3.1 Permanent bonding

Structures such as building frames, reinforcement steel in concrete, access platforms and stairways are often bonded to the complex structure to be protected and therefore become a part of the complex structure.

Permanent bonding should be taken into account when designing the cathodic protection system.

7.4.3.2 Temporary bonding

Temporary bonds are made when vehicles (road/rail) or ships are engaged in loading or unloading hazardous products.

All necessary safety precautions should be taken before transfer operations start e.g. equipotential bonding which may be by conductive hoses or cables (see EN 50162).

Temporary bonding should be taken into account when designing the cathodic protection system.

In hazardous installations, current may be flowing in both buried and above ground sections of pipework and so to avoid possible sparking when pipework modifications are made, the cathodic protection system should be switched off and a heavy duty cable bond should be applied across the pipe section to be separated. The bond should be maintained until the pipe is reconnected or the area declared safe.

7.5 Electrical continuity

Metallic bonds are installed to ensure electrical continuity of the complex structure and also to avoid interference and excessive voltage drops in the cathodic protection circuit.

7.6 Negative connections

To achieve optimum current distribution in the complex structure, several transformer rectifiers and/or several negative connections should be used.

7.7 Transformer–rectifiers

The rating of transformer–rectifiers should be designed with sufficient capacity to allow for the initial higher current requirement during the polarization period and for changing conditions. The output voltage should be kept as low as possible to help limit the interference levels (see also 7.9).

7.8 Test stations and measuring points

Test stations and measuring points should be located at sufficient locations to adequately represent the cathodic protection status of the structure.

Where measuring points are located in concrete or gravel areas, provision should be made for reference electrode contact to the soil beneath the concrete/gravel.

Measuring points should be located at critical points, permanently marked to ensure reproducible measurements. These critical points should take into account the presence of:

a) sleeve pipes;

b) sheet piling;

c) reinforced concrete structures;

d) entries to reinforced concrete structures;

e) electrical earthing systems;

f) foreign structures, especially when they are close to (or crossing) the considered structure;

g) potentially shielded locations;

h) locations most affected by galvanic couples;

i) locations closest to and most remote from groundbeds;

j) limits of the complex structure.

The use of probes, coupons and permanently installed reference electrodes at suitable locations should be considered, particularly if the verification of the cathodic protection effectiveness is to be performed in accordance with methods b) and c) of Clause 4.

7.9 Anode groundbeds

The current output of galvanic anodes is limited directly by the soil resistivity. For complex structures, magnesium anodes are not used when the electrolyte resistivity is greater than 50 Ω·m and zinc anodes are not used when the electrolyte resistivity is greater than 10 Ω·m. This limits their use in many cases.

Impressed current cathodic protection systems are generally used in complex structure applications.

Depending on the method chosen in 7.2, several configurations of groundbed may be considered (remote or close groundbeds: single point, distributed or continuous groundbeds) (see Annex E).

a) when designing a groundbed system the following shall be considered: Groundbed lifetime;

b) groundbed locations are selected to avoid inadmissible interference to foreign structures (see EN 50162) and shielding effects;

c) groundbed resistance to earth which should be kept as low as possible;

d) individual anodes and groundbed current control;

e) gas evolution from the groundbed.

7.10 Design document

Design documents should be prepared in sufficient detail to satisfy the requirements of safety, design, verification, installation procedures and future inspection.

8 Installation of cathodic protection systems

8.1 General

Installation procedures should be in accordance with EN 12954:2001, Clause 8.

8.2 Cables

If cables in ducts pass through hazardous areas, national regulations apply. These regulations may require that the ducts are sealed by adequate means to prevent inflammable liquids and gases from being carried into non-hazardous areas.

9 Commissioning

9.1 General

Commissioning procedures are described in EN 12954. For complex structures, cathodic polarization can require extended periods of time, during which adjustments are usually necessary to both the protection current and its distribution.

In some circumstances, the polarization rate may be enhanced by initially providing more current than is subsequently necessary to maintain protection.

9.2 Preliminary checking

Before a cathodic protection system is activated, care shall be taken to check that all installations are in accordance with the design. In particular, bonding, connections and safety measures (contact protection, lightning protection, explosion proofing) shall be confirmed and d.c. connections to the transformer rectifiers shall be checked for correct polarity.

The following measurements should be made and the values compared with the design requirements.

a) Resistance measurements:

   1) groundbed resistance to remote earth;

   2) resistance between the structure to be protected and the groundbed;

   3) resistance between the complex structure and foreign structures.

b) Potential measurements:

   1) free corrosion potential E_n of the structure at all measuring points;

   2) interference due to stray currents;

   3) structure to electrolyte potential of foreign structures;

   4) potential difference between the complex structure and foreign structures.

When an existing cathodic protection system is already operating and the criterion b)1 in Clause 4 is to be applied, the system should be switched off for a sufficiently long period of time to enable the structure to depolarize to a constant value approximating to E_n before commissioning.

9.3 Start up

The following steps shall be carried out.

a) Switch on the impressed current station and confirm that it is functioning correctly.

b) Adjust the current output in order to achieve the design values. If major deviations occur, ascertain the causes by further investigation.

c) Make the following measurements:

   1) rectifier output voltage on impressed current station;

   2) protective current output;

   3) on potential at drain point;

4) on potential at critical locations;

5) potential measurement on foreign structures.

d) Check if stray current interference occurs on the structure to be protected and on neighbouring foreign structures in accordance with EN 50162.

e) Determine the level of interference on foreign structures during the “start up”.

9.4 Verification of the cathodic protection effectiveness

After a suitable period, the effectiveness of cathodic protection shall be checked in accordance with Clause 4.

9.5 Installation and commissioning documents

After the successful commissioning of the cathodic protection installations, the following documents should be prepared or collated.

a) as-built layout drawings of the complex structure including known foreign structures that are relevant to the cathodic protection;

b) cathodic protection design with as-built installation drawings and all details pertaining to the cathodic protection of the complex structure;

c) results of interference tests carried out on known foreign installations;

d) details of equipment operation and adjustment and the results of all measurements carried out before and during commissioning;

e) description of the installations with details and references to materials as well as information useful for the correct operations and maintenance of the installations, e.g. frequency and procedures of inspection. These data are the basis for subsequent system checks to be performed on the structure and therefore should be filed and retained.

10 Inspection and maintenance

10.1 General

Inspection and maintenance should ensure the effectiveness of cathodic protection throughout the life of a structure. For this to be achieved the criteria defined in Clause 4 should be maintained, which generally requires continuous operation of the cathodic protection system.

Inspection procedures shall be in accordance with Clause 10 of EN 12954:2001, and shall be validated subsequent to commissioning (see Clause 9). The inspection procedures should be appropriate to the type of structure and its cathodic protection system. The procedures should be subject to review to reflect operating experience and new technology.

A data management system for operation, inspection and maintenance is essential.

NOTE Manual data management systems can be acceptable for some data but, for large volumes of data, computer systems are preferred.

Instrumentation used for measurements shall be kept in good working order and shall be subjected to periodical calibration and safety checks.

The inspection of the effectiveness of applied cathodic protection is conveniently divided into two areas: equipment functional checks and cathodic protection measurements.

10.2 Functional checks

Functional checks shall include the verification of the operation of each transformer rectifier and should include the measurement current and voltage.

Functional checks at the connection of the foreign structure shall include an inspection to verify the continuity of the connection (bond) and may include measurement of the current in the bond.

Functional checks of safety and protection devices and test stations shall include an inspection to verify their mechanical and electrical integrity.

Functional checks should be carried out at the following typical frequencies described in Table 1.

Table 1 — Frequency of functional checks

Functional check	Frequency
Impressed current station	Every month
Connections to foreign structures	Annually
Safety and protection devices	Annually
Test stations and measuring points	Annually

NOTE If operational conditions require particular attention (hazardous areas, possibility of over voltage, stray currents), the intervals between functional checks may be reduced.

If the cathodic protection system is supervised by remote control, such that all significant variations of current or equipment malfunctions are immediately detected, then the frequency of functional checks laid out in Table 1 does not apply .

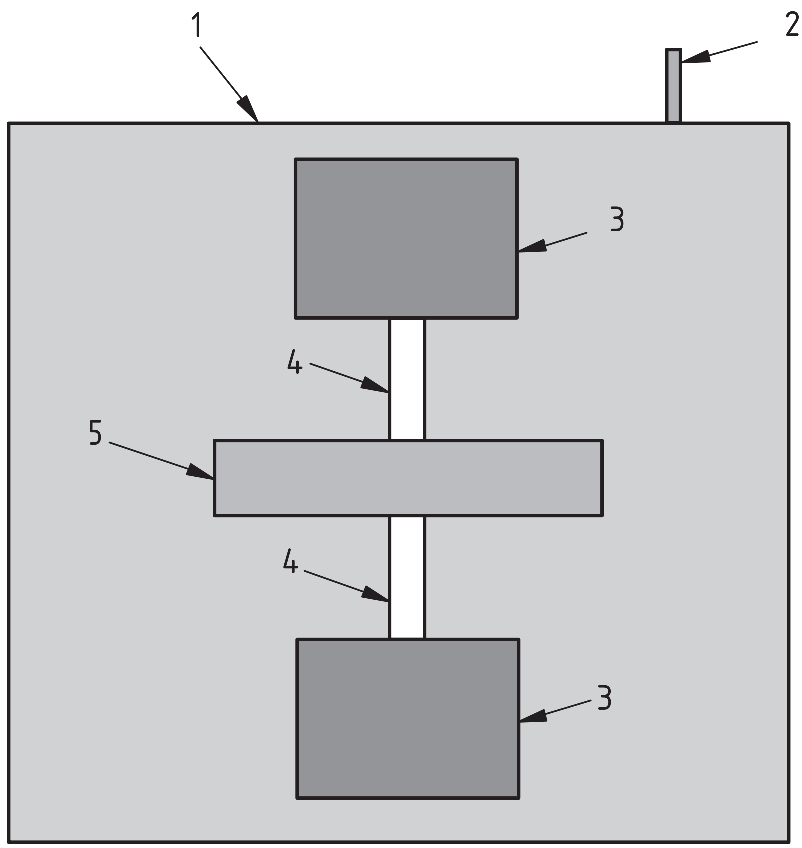
10.3 Cathodic protection measurements

To prove the effectiveness of cathodic protection, measurements shall be performed annually at selected locations in order to demonstrate that the criteria defined in Clause 4 are achieved.

Annex A
(informative)

Principle scheme of a complex structure

The scheme shows the elements which constitute a complex structure and neighbouring foreign structures



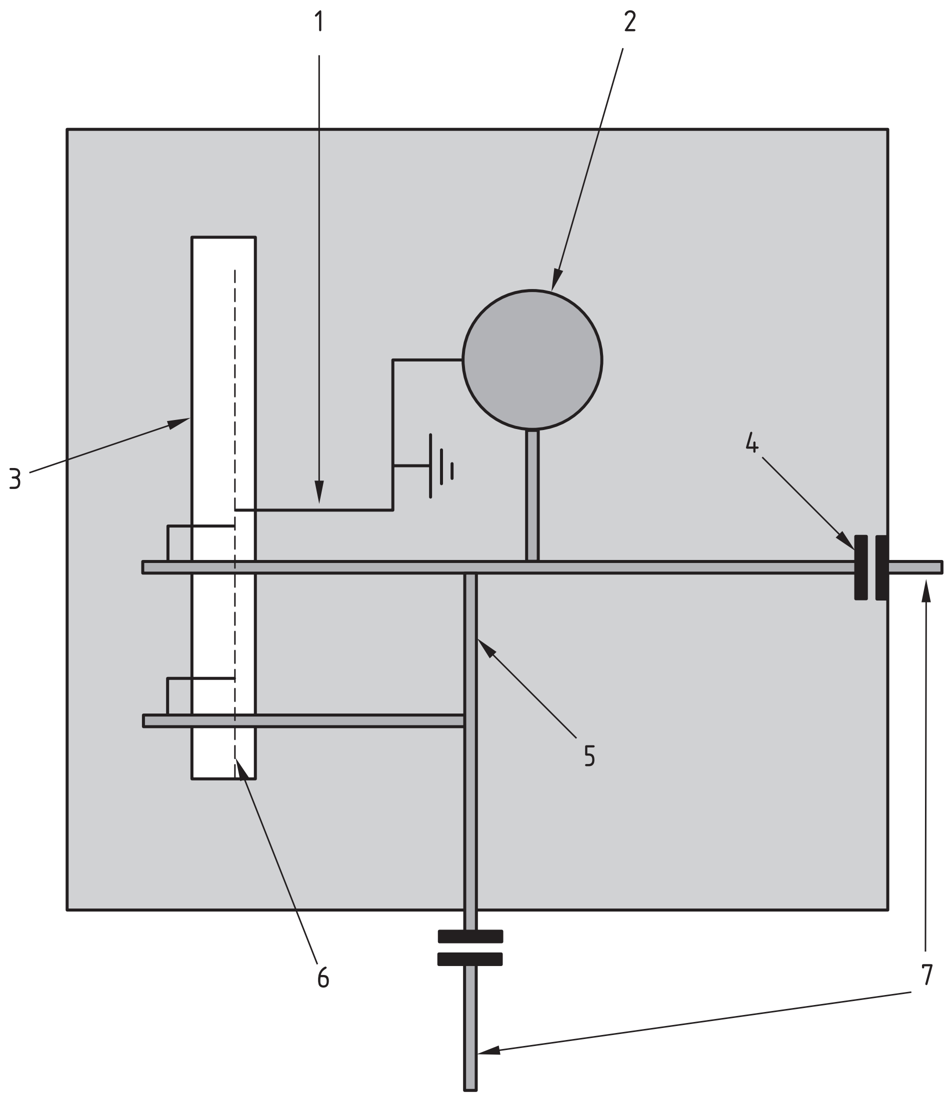
Key
1 Battery limit
2 Foreign structure
3 Foreign electrode
4 Bond
5 Structure to be protected

Figure A.1 — Complex structure

Annex B
(informative)

Example of an industrial complex structure

The scheme shows an example of an industrial structure which is considered as a complex structure



Key
1 Earthing system (foreign electrode)
2 Tank (structure to be protected)
3 Bond
4 Isolating joint
5 Station piping (structure to be protected)
6 Rebar in reinforced concrete (foreign electrode)
7 Foreign structures

Figure B.1 — Industrial complex structure

Annex C
(informative)

Reinforced concrete data in complex structures

C.1 Structure potential

The natural potential of steel in concrete is generally several hundreds of millivolts more positive than the potential of steel in soil.

Depending on the type and quantity of cement, the water-cement ratio, the chloride content, the moisture content and alkalinity of the concrete, potential values of 0,0 V up to -0,6 V (measured against a copper/copper sulphate reference electrode) are possible. The more positive values are caused by passivation of steel in concrete, the more negative values indicate either corrosion activity or loss of passivation.

On existing plants, where cathodic protection is to be retrospectively installed, the reinforcement can be partially polarized because of electrical connections between reinforcement steel and the earthing system. In the case of an earthing system using zinc-coated steel, the potential values of the reinforcement steel can be significantly more negative than the natural potential.

C.2 Cathodic polarization

In order to polarize reinforcement steel in concrete to a similar level to adjacent pipelines a protection current density of between (0,2 to 20) mA/m^2 of steel in concrete is required. In comparison, cathodic protection of buried pipelines requires approximately (1 to 100) µA/m^2 if well coated, or (2 to 50) mA/m^2 if uncoated steel in soil.

When reinforced concrete structures are connected to a complex structure, they achieve stable polarization over a period of weeks after switching on the protection current; the current density required to maintain this level of protection reduces by approximately 50 % during the next (12 to 24) months.

The protection current density to steel in concrete depends on the chloride concentration and the moisture conditions in the soil. Due to the large range for the protection current density, a current injection test on a limited and separated concrete device within the station may be suitable as the basis for the planning of local cathodic protection, but caution should be exercised due to the slow rate of polarization as indicated above.

For larger plants, a total polarization of the complete steel surface in concrete is not necessary, if in all areas of the complex structure which are required to be protected, the criteria in Clause 4 can be achieved. In this case, planning can be based on a lower value of protection current to the steel in concrete.

Only in low specific soil resistivities, below 50 Ω·m, and for concrete surfaces up to a few hundred square metres, can complete cathodic polarization of the reinforcement steel be economically justified as part of a complex cathodic protection system unless the reinforced concrete elements are themselves at risk of corrosion damage due to chloride contamination or acidification of the concrete.

NOTE Further information on cathodic protection of steel in concrete is given in EN 12696.

Annex D
(informative)

Increasing soil potential

D.1 General

It is not always possible to achieve the cathodic protection criteria in Clause 4 using anode groundbeds remote from the complex structure. If the criteria in Clause 4 cannot be achieved by the application of cathodic protection current from a distant anode, it is possible to lower the structure/soil potential by locally increasing the soil potential since this will have the same resultant effect.

D.2 Anode groundbed potential gradient

The anode groundbed can be regarded as a point source for equipotential lines. Equipotential lines exist at a distance remote from the anode. Close to the anode groundbed the anode potential lines will be concentrated and hence the potential gradient in volts per metre (V/m) will be steeper and the soil potential will be raised.

D.3 Calculating the soil potential at ground level

D.3.1 General

In a simplified uniform electrolyte the soil potential at the surface can be calculated. These calculations may be used to indicate the influence of anodes in close proximity to the complex structure.

Nevertheless, this influence also depends on the geometry and area of the complex structure.

The potential line as an extension of the anode groundbed axis (*x*-axis) is different from the line at right angles to the anode groundbed axis (*z*-axis).

The following Equations (1) to (3) apply to horizontal groundbeds and (4) to (6) to vertical groundbeds:

$$U_x = \frac{\rho I}{2\pi L} \ln \left[\frac{x + L + \sqrt{t^2 + (x+L)^2}}{x + \sqrt{t^2 + x^2}} \right] \tag{1}$$

$$U_z = \frac{\rho I}{2\pi L} \ln \left[\frac{L + \sqrt{4t^2 + 4z^2 + L^2}}{-L + \sqrt{4t^2 + 4z^2 + L^2}} \right] \tag{2}$$

$$U_\mathrm{A} = \frac{\rho I}{4\pi L} \left\langle \ln \left[\frac{L + \sqrt{d^2 + L^2}}{-L + \sqrt{d^2 + L^2}} \right] + \ln \left[\frac{L + \sqrt{(4t-d)^2 + L^2}}{-L + \sqrt{(4t-d)^2 + L^2}} \right] \right\rangle \tag{3}$$

$$U_y = \frac{\rho I}{2\pi L} \ln \left[\frac{t + L + \sqrt{y^2 + (t + L)^2}}{t + \sqrt{y^2 + t^2}} \right] \quad (4)$$

$$U_A = \frac{\rho I}{2\pi L} \ln \left[\frac{2L}{d} \sqrt{\frac{4t + 3L}{4t + L}} \right] \quad (5)$$

Equation (5) applies if d « L, otherwise the following equation is used:

$$U_A = \frac{\rho I}{4\pi L} \left\langle \ln \left[\frac{L + \sqrt{d^2 + L^2}}{-L + \sqrt{d^2 + L^2}} \right] + \ln \left[\frac{4t + 3L + \sqrt{d^2 + (4t + 3L)^2}}{4t + L + \sqrt{d^2 + (4t + L)^2}} \right] \right\rangle \quad (6)$$

where

U_A	is the anode voltage to pipeline measured against remote earth	[V]
U_x	is the voltage at ground surface at point x	[V]
U_y	is the voltage at ground surface at point y	[V]
U_z	is the voltage at ground surface at point z	[V]
t	is the groundbed depth in metres	[m]
L	is the groundbed length in metres	[m]
d	is the groundbed cross section diameter in metres	[m]
ρ	is the soil resistivity (assume 100 Ω·m)	[Ω·m]
I	is the current applied to the anode groundbed	[A]

D.3.2 For horizontal anode groundbeds

NOTE See D.3.1 for explanation of symbols.

Graphs are established using equations (1), (3) with d = 0,4m and t = 1m

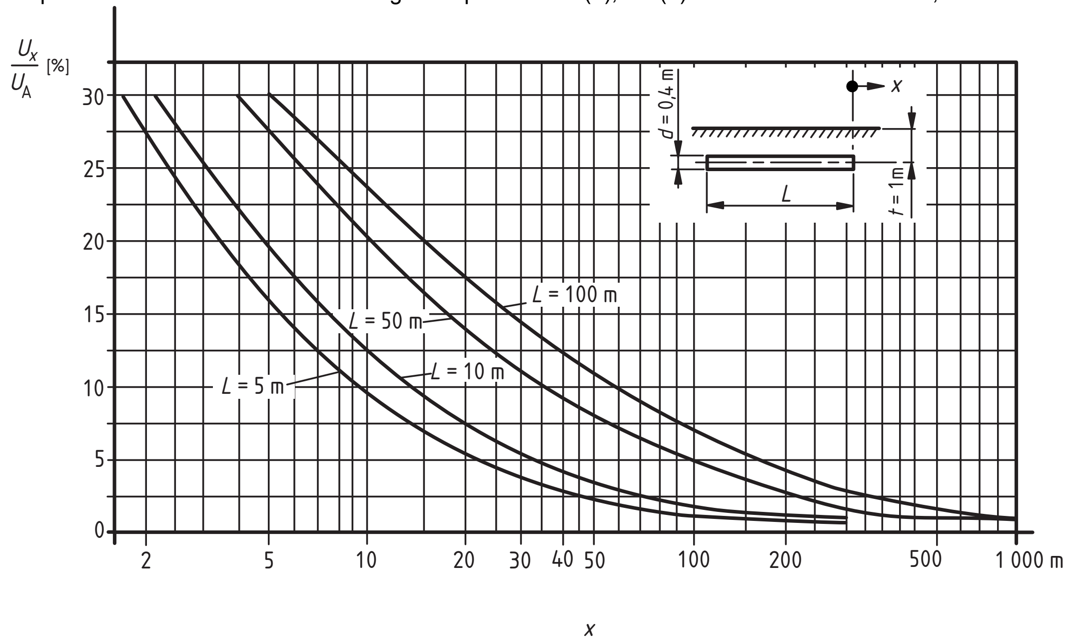
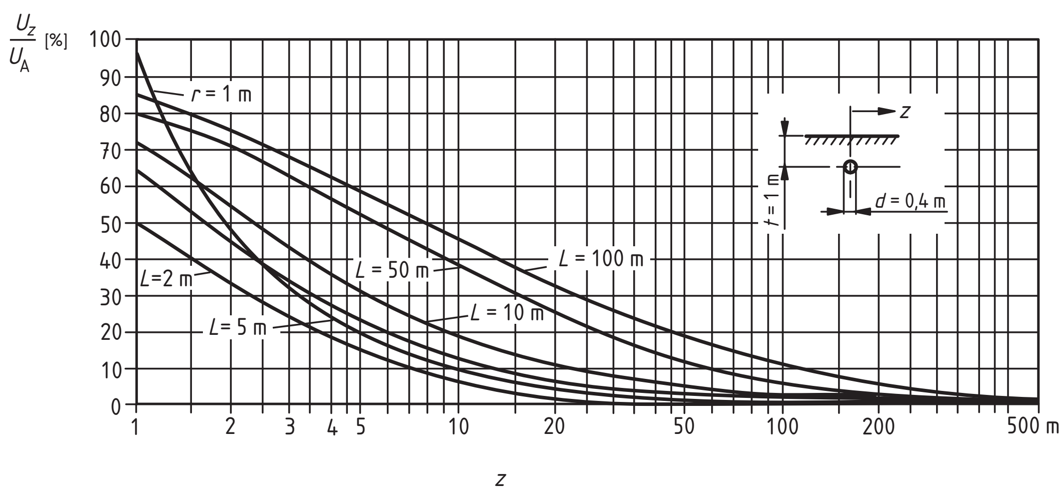


Figure D.1 — Voltage attenuation curve around an horizontal groundbed measured in the direction of "X" (longitudinal axis of the groundbed)



NOTE See D.3.1 for explanation of symbols.

Graphs are established using equations (2), (3) with d = 0,4 m and t = 1 m

The curve "r=1m" corresponds to a theoretical hemispherical groundbed of radius r = 1 m which is used as a reference

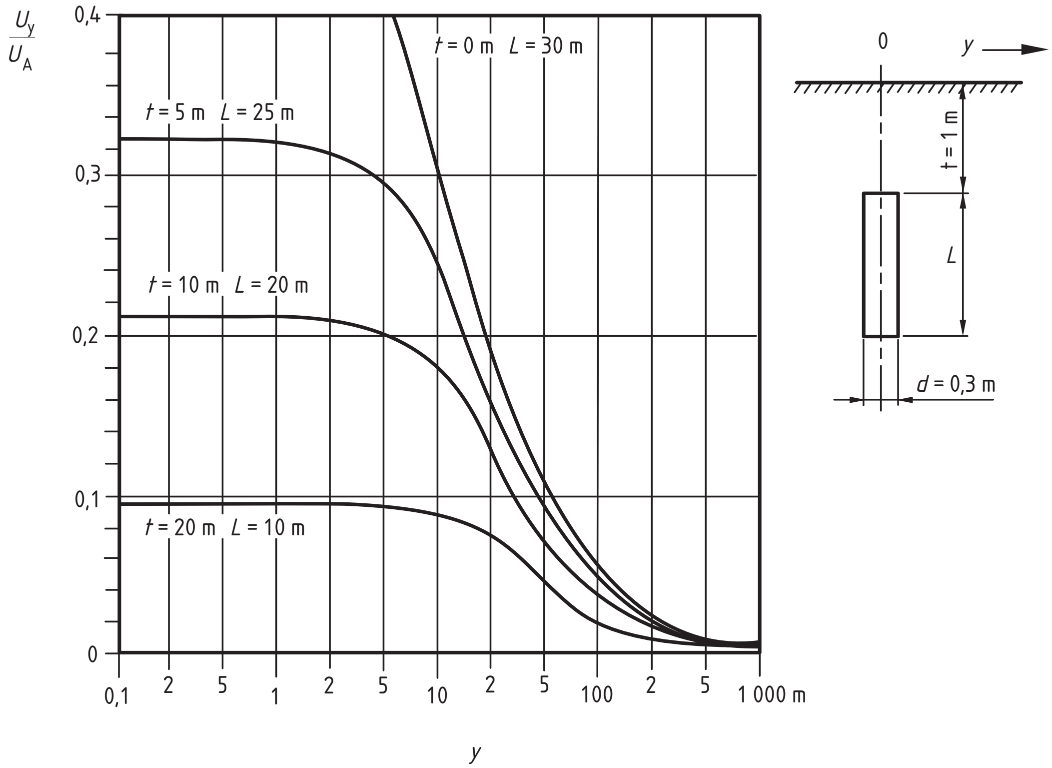
Figure D.2 — Voltage attenuation curve around an horizontal groundbed measures in the direction "Z" (perpendicular to the axis of the groundbed)]

The voltage attenuation curve (anode voltage "cone" expressed by the ratios U_x and U_z divided by U_A) developed around horizontal anodes at ground surface is calculated using Equations (1) to (3), where d = 0,4 m and L = 1 m.

a) in x axis (as an extension of the grounded)

b) in *z* axis (at right angles to the anode at the centre of the anode)

D.3.3 For vertical anode groundbeds



NOTE See D.3.1 for explanation of symbols.

The voltage attenuation curve (anode voltage "cone" expressed by the ratios U_y divided by U_A) developed around vertical anodes at ground surface, is calculated using Equations (4) and (5) or (4) and (6), where *d* = 0,3 m.

Figure D.3 — Voltage attenuation curves around a vertical groundbed measured in a direction "Y" at ground surface

Annex E
(informative)

Groundbed data

E.1 General considerations

The application of cathodic protection to complex structures, as described in this document, usually needs particular configurations of the groundbeds. Sometimes a configuration with a remote groundbed can be used, but more often a local groundbed system is necessary.

In order to ensure suitable current and voltage outputs, the earthing resistance of the anodes should be carefully calculated and, where necessary, techniques should be used to lower the groundbed resistance to earth.

When designing a groundbed system, it is important to take into consideration all factors that can affect the groundbed lifetime. In selecting groundbed sites and voltage output, care should be exercised to avoid interference to other structures. The presence of electrical shielding between the groundbed and the structure to be protected should be avoided.

E.2 Type of groundbed

E.2.1 General

For a general description and characteristics of shallow and deep groundbed reference should be made to EN 12954.

E.2.2 Remote groundbeds

A cathodic protection installation equipped with a remote groundbed provides a wide distribution of the current all over the structure to be protected.

A deep well groundbed is often preferred over a shallow groundbed to provide better current distribution over the complex structure because groundbed to structure distance can be maximized while remaining within the plant boundaries.

E.2.3 Local groundbed

When a local groundbed system is used, the anodes are placed close to the structure to be protected.

There are two types of local groundbed:

a) distributed groundbed made of anodes that are generally placed at short intervals throughout or along the major dimensions of the structure to be protected

b) continuous groundbed made using flexible wire anodes or anodes placed in a continuous carbonaceous backfill at suitable intervals.

With a continuous groundbed, a uniform current distribution along the structure is provided, less overall current and voltage output is needed and shielding and interference problems are generally avoided.

Shallow groundbeds, both horizontal or vertical, are generally used as local groundbeds.

Local groundbeds are, if possible, installed as deep as the structure to be protected.

E.3 Anode type

E.3.1 High silicon cast iron anodes

High-silicon cast iron alloys for anodes are of two types, with or without chromium.

The chromium free alloy can be used only in halide-free environments to avoid a too high consumption rate.

The high-silicon chromium cast iron alloy is suitable for all applications whatever the halide content is (e.g. sea water).

The use of high-silicon chromium cast iron anodes can be subjected to national limitations.

A typical material composition of high silicon chromium cast iron anodes is given in Table E.1 (in accordance with ASTM A518).

Table E.1 —Composition of high silicon chromium cast iron anodes

Material	Content %
Silicon	14,20 to 14,75
Chromium	3,25 to 5,00
Carbon	0,70 to 1,10
Manganese	max. 1,50
Copper	max. 0,50
Molybdenum	max. 0,20
Iron	balance

The performance of this material as a material for cathodic protection anodes depends on the formation of a thin layer of silicon dioxide on the surface of the anode. This film is partially protective. Its formation is favoured if the alloy contains as a minimum 14,2% of silicon (which is always obtained with the Table E1) and, in environments containing halides about 4 % of chromium (which has to be specified because not guaranteed in Table E1).

The most common anode shapes are cylindrical rods and tubes. It is recommended to install these anodes in a carboneaous backfill poured out in the hole or to use pre-packaged anodes with carbonaceous backfill inside steel canisters or bags.

Underground applications include deep vertical, shallow vertical, or horizontal beds with or without backfill.

The consumption rates vary from (0,1 to 0,5) kg/A per year and depend on the alloy composition, the environment and the maximum current density applied, which can range from (10 to 50) A/m².

E.3.2 Mixed-metal oxide anodes

Mixed-metal oxide anodes consist of electro catalytic activated coatings on a high-purity titanium substrate.

The coatings consist of a mixture of highly conductive oxides. The titanium serves as a support for the oxides and is protected by a thin adherent film, which resists the passage of current in the anodic direction. The oxide coating is the anode material.

The following anode shapes are mostly used:

a) tubular, both bare and pre-packaged in steel canisters filled with carbonaceous backfill;

b) wires and rods, usually in steel canisters with carbonaceous backfill;

c) mesh;

d) strips.

Mixed metal oxide (MMO) anodes are suitable for applications in seawater, in freshwater, in mud and in soil preferably in carbonaceous backfill.

The maximum current density ranges from (35 to 50) A/m² in freshwater, to 100 A/m² in soil and in carbonaceous backfill and to 500 A/m² in seawater.

In underground applications bed drying, resulting in increased bed resistance, has sometimes been observed at high current density.

E.3.3 Conductive polymer anodes

Conductive polymer anodes consist of a carbon based anode material incorporated into polymer material and coated onto a copper conductor.

The maximum output current density is about 52 mA/m² and the consumption rate can be negligible if the anode is adequately surrounded in a carbonaceous backfill and operated at low current density.

E.4 Technical aspects for groundbed

The soil resistivity and the distance between the anodes influence the earth resistance of the groundbed.

Individual anodes can have relatively little separation, however, if they are spaced at a distance at least twice their length they can be considered as parallel resistances as far as resistance to earth calculations are concerned.

Close located groundbeds can distribute a large amount of current even if each individual anode current output is low. Consequently, the header cable used to distribute the current to the anodes should be suitably sized to avoid significant voltage attenuation that would result in reduced voltage to the more remote anodes.

Bibliography

Standards publications

1. ASTM A518/A518M-99: 2003, *Standard specification for corrosion-resistant high-silicon iron castings*.

2. EN 12696:2000, *Cathodic protection of steel in concrete*.

3. EN ISO 8044:1999*, Corrosion of metals and alloys — Basic terms and definitions (ISO 8044:1999)*.

Further reading

The following is a non-exhaustive list of different basic European documents known and accepted as good guides for the application of cathodic protection techniques.

1. Baeckmann, W.v., Schwenk, W. and Prinz, W., *Handbook of cathodic protection* [*Handbuch des kathodischen Korrosionsschutzes*]. Weinheim: 4th edition, 1999. Texas: 3rd edition, 1995.

2. Bianchi, G. and Mazza, F., *Corrosion and protection of metals* [*Corrosione e protezione dei metalli*], Milan: 1980.

3. CEOCOR, *Guide of the measuring techniques in cathodic protection* [*Leitfaden der Messtechnik für den kathodischen Korrosionsschutz; Guide des techniques des mesures en protection cathodique*]. Vienna: 1994. Paris: 1994.

4. CEOCOR, *Practical guide for cathodic protection* [*Praktischer Leitfaden für den kathodischen Korrosionsschutz; Guide Pratique de la protection cathodique*]. Ehningen bei Böblingen: 1991. Paris: 1991.

5. Lazzari, L. and Pedeferri, P., *Cathodic protection*, [*Protezione Catodica*], Milan: CLUP, 1982.

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