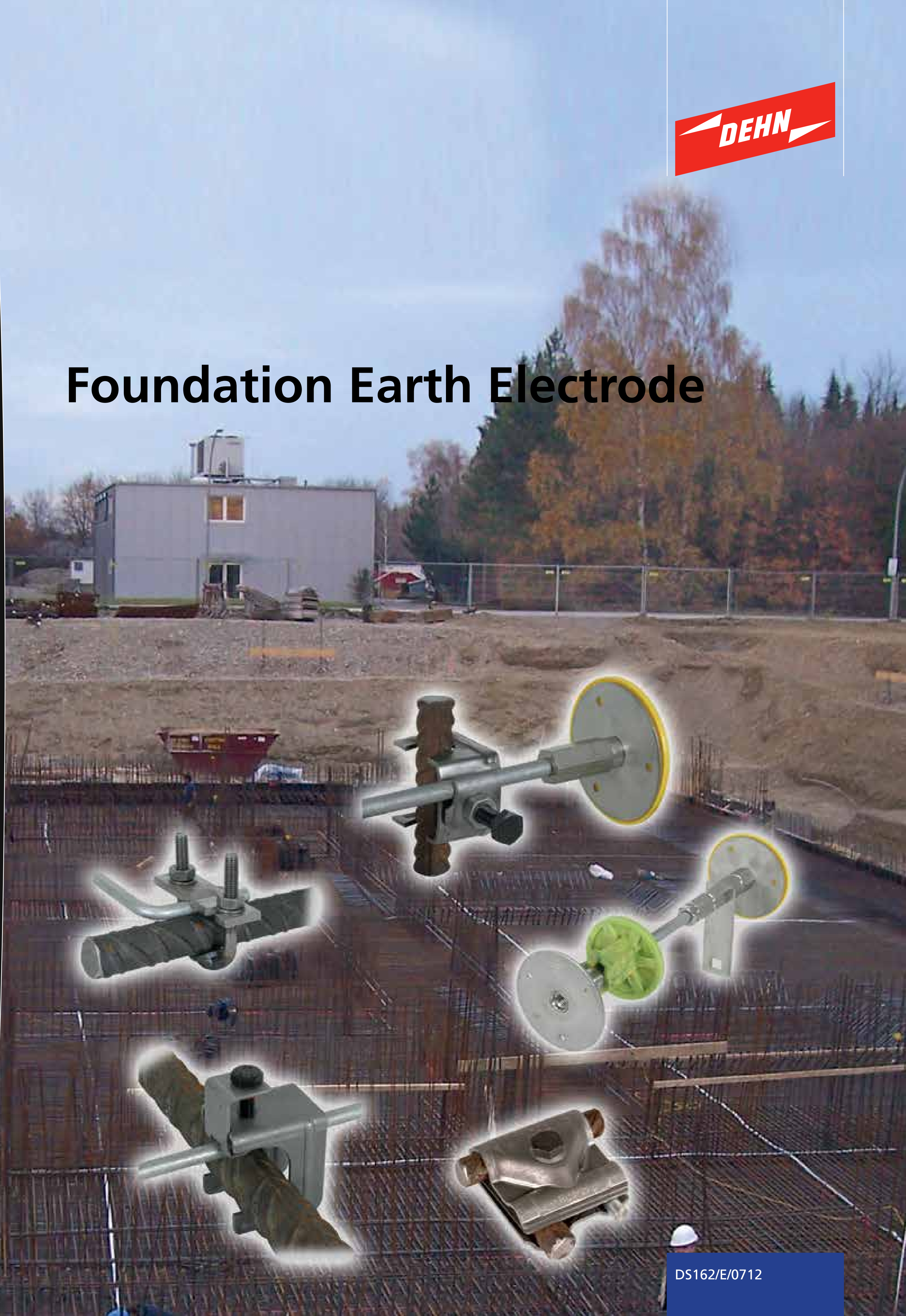
Foundation Earth Electrode



DS162/E/0712

A functional earth-termination system is an elementary part of the electrical and electronic installations of already existing buildings and new buildings. It is an important basis for the safety and functionality of installations in a building, for example, for

- personal safety (to achieve safe disconnection from supply and protective equipotential bonding),
- electric systems (power supply),
- electronic systems (data processing technology),
- lightning protection,
- overvoltage protection,
- electromagnetic compatibility (EMC) and
- antenna earthing.

These installations are subject to special requirements with regard to personal protection and operation safety, as specified in the various regulations of the different systems.

Standard Requirements

In Germany, for new buildings a foundation earth electrode is required according to DIN 18015 (Electrical installations in residential buildings) and the technical connection conditions (TAB) of the network operators. DIN 18014:2007-09 "Fundamenterder – Allgemeine Planungsgrundlagen", (English title: Foundation earth electrode – General planning criteria) basically regulates the design and installation of the earth-termination system of new buildings.

If a lightning protection system shall be installed in a building or structure the extended requirements of EN 62305-3 (VDE 0185-305-3) "Protection against lightning – Part 3: Physical damage to structures and life hazard" are applicable, or the requirements in EN 62305-4 (VDE 0185-305-4) "Protection against lightning – Part 4: Electrical and electronic systems within structures" considering the aspects of electromagnetic compatibility (EMC).

Smaller mesh sizes of the foundation earth electrode are required if there are for example large-scale IT systems in a building. Also the system provider specifications (e.g. data processing technology) have to be considered for the earth resistance and to be taken into account already when designing the earth-termination system.

For buildings with integrated medium voltage switchgear (MV systems), additionally DIN VDE 0101 (VDE 0101) "Starkstromanlagen mit Nennspannungen über 1 kV"; (English title: Power installations exceeding 1 kV) German version HD S1:1999, is applicable in Germany. Potentially high short-circuit currents (50 Hz) require higher earth-electrode cross sections and adequate clamps/connectors.

Installation of the Earth-Termination System

The foundation earth electrode fulfils essential safety functions and is therefore considered as part of the electrical system. That's why the earth-termination system shall be installed by lightning protection specialists, qualified electricians or under their surveillance.

Equipotential Bonding

Equipotential bonding is required for all newly installed electrical consumer's installations. In order to implement all requirements, the main earthing busbar (MEB) (previously main equipotential bonding bar (MEBB)) shall be connected to the foundation earth electrode. Equipotential bonding according to IEC 60364 equalises potential differences, i.e. it prevents hazardous touch voltages e.g. between the protective conductor of the low-voltage consumer's installation and metal installations (water, gas and heating pipes).
According to IEC 60364-4-41, equipotential bonding consists of the protective equipotential bonding (previously: *main equipotential bonding*) and the supplementary protective equipotential bonding (previously: *supplementary equipotential bonding*).

Protective equipotential bonding must be implemented in every building according to the above mentioned standards. The supplementary protective equipotential bonding is intended for those cases where special conditions for disconnection from supply have to be implemented or for special areas which conform to the IEC 60364 series Part 7.

Lightning Equipotential Bonding

Lightning equipotential bonding is an extension of the protective equipotential bonding. Lightning equipotential bonding and equipotential bonding have to be connected with the main earthing busbar (MEB) of the earth-termination system. Lightning equipotential bonding is that part of the internal lightning protection which provides a safe integration of all entering conductors into the equipotential bonding system if lightning strikes the protection system or entering conductors. Thus hazardous sparking will be avoided. Electrical power and IT installations have to be particularly protected because the external lightning protection system and the building installation shall not be directly connected via the earth-termination system and the equipotential bonding.

Types of Earth Electrodes

Foundation earth electrode
A concrete embedded closed earth electrode ring with a large-area earth contact. If, in case of "full-perimeter insulation" or a "white tank", this earth contact is not possible, a ring earth electrode will be installed outside the foundation which takes over the function of the foundation earth electrode.

Ring earth electrode
A soil embedded earth electrode as closed ring around the building or structure.

Earth rod
A vertically deep driven earth electrode generally made of round steel.

Natural earth electrode
Metal parts that are soil or concrete embedded and originally not intended as earth electrode, however, being effective in this sense (reinforcements of concrete foundations, pipelines, etc.).

Materials and conductor types for the foundation earth electrode

Materials for Earth-Termination Systems

The foundation earth electrode has to be made of

- round steel (min. diameter 10 mm) or
- strip steel (min. dimension 30 mm x 3.5 mm) which

has to be galvanised (or black) for laying in concrete, or StSt (V4A), material No. 1.4571 for laying in soil. Conductor materials should be selected in compliance with EN 50164-2 in order to simplify a later integration of a lightning protection system.

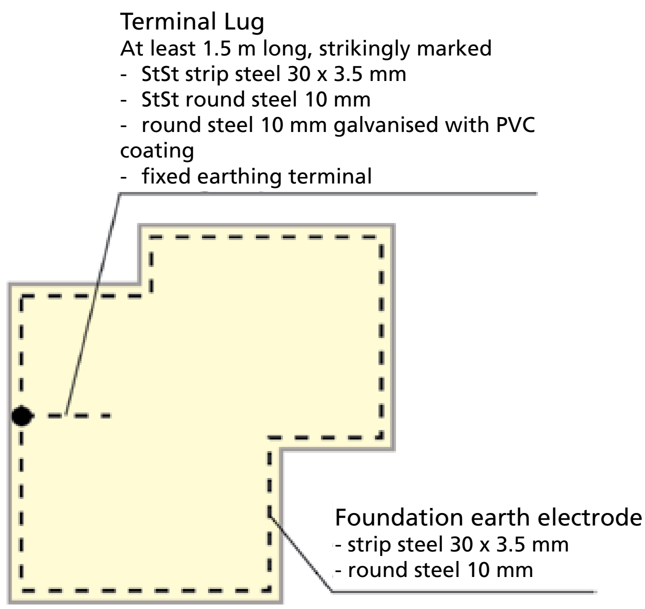
Buildings or structures with integrated transformer stations may require larger earth electrode cross sections (50 Hz short-circuit currents).

Connections to the Earth-termination System

Every earth-termination system has to be connected at least once to the main earthing busbar (MEB).
Further connections to the foundation earth electrode already have to be considered in the planning. These are to be provided for

- the supplementary protective equipotential bonding,
- metal installations such as lift rails, steel supports, facade elements,
- down conductors of the external lightning protection (possibly internal down conductors),
- downpipes,
- connections to the ring earth electrode, e.g. in case of white tanks or perimeter insulation,
- EMC measures,
- structural extensions,
- cable trays or junction canals from other buildings,
- supplementary earthing measures, e.g. earth rods.

Terminal lugs made of StSt



Connections to the external and internal systems generally have to be corrosion-resistant.

Suitable connection parts and materials e.g. are

- high-alloy round steel (diameter 10 mm) or flat steel (dimension 30 mm x 3.5 mm) out of StSt (V4A), material No. 1.4571,
- galvanized round steel (diameter 10 mm) with plastic coating,
- fixed earthing terminals.

Using round steel with plastic coating requires special mounting care due to the risk of breakage of the plastic coating at low temperatures or extreme mechanical stressing of the plastic coating (e.g. by stones) when backfilling and compacting the trench. This risk can be avoided by using StSt (V4A).

Terminals lugs from the entry point to the inside shall be 1.5 m long and they shall reach out of the ground surface for 1.5 m.

Incompetent staff often cut the terminal lugs carelessly which then can only be reconstructed at considerable effort and costs. During the construction phase terminal lugs therefore shall get a striking marking. A terminal lug protective cap both provides a significant marking and a protection against injuries (e.g. by burrs or edges).

Fixed earthing terminals for connection to the earth-termination system or equipotential bonding have proved in the past. This allows for implementing corrosion-resistant connections or bushings. Fitted into the formwork (flush with the wall) they cannot be "cut off" and can be intended for subsequent terminals.

Non-corrosive terminal lug StSt (V4A)

Protective cap on terminal lug

Application of the fixed earthing terminal

Application of the SV Clamp

Application of the MAXI MV Clamp

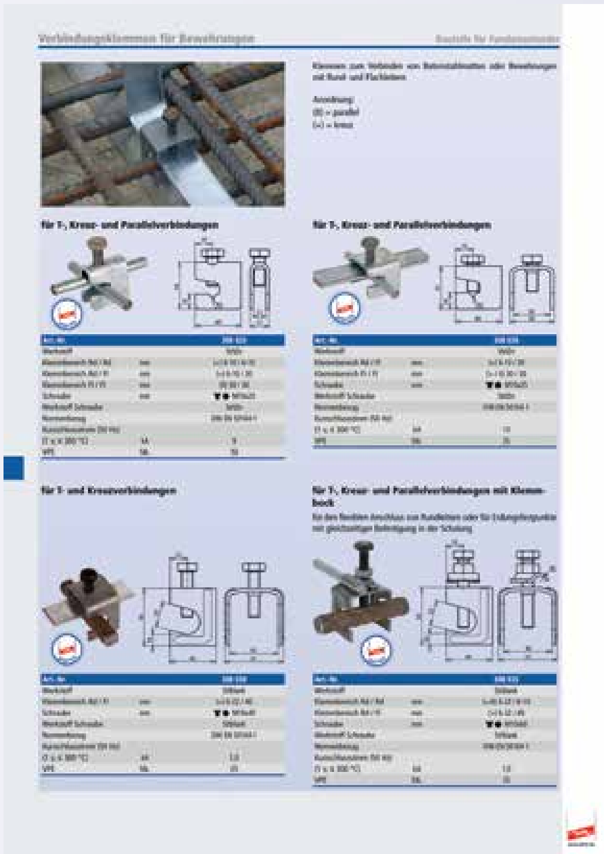
Application of the Connecting Clamp and SV Clamp

Connections

Connections of foundation earth electrode components have to be permanently electrically conductive and mechanically stable.

Natural iron components such as reinforcing steel mats, cages or bars improve the foundation earth electrode efficiency and shall therefore be connected with the foundation earth electrode. The distance between these electrically conductive connections shall be **2 m.**

Connections can be implemented by screwing, clamping or welding. These connections are performed efficiently by using screwed connections according to EN 50164-1 "Lightning Protection Components (LPC) – Part 1: Requirements for connection components".
In our Lightning Protection / Earthing catalogue corresponding clamps and connectors are labelled with the following symbol.



Welded connections necessitate the agreement of the responsible construction engineer and special knowledge of the fitter as well as the necessary welding apparatus and welding tool on site.

Wedge connectors are not allowed in case of mechanical compacting / vibrating of the concrete.
When using clamps / connectors at earth-termination systems for medium-voltage switchgear, their specification for the 50 Hz short-circuit currents has to be considered.

Foundation Plates

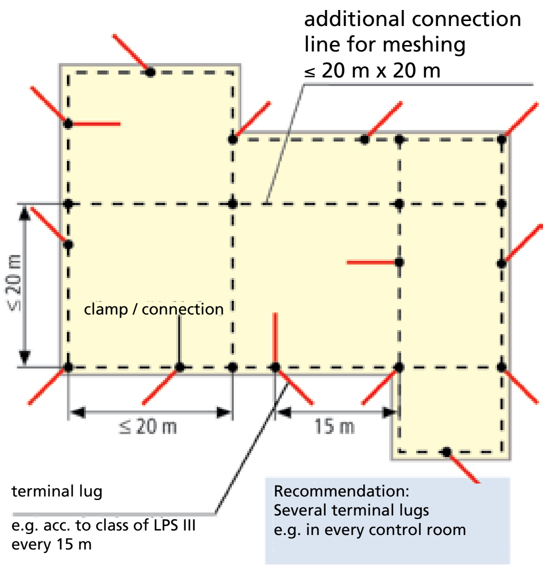
In case of reinforced foundation plates, the foundation earth electrode will be installed on the bottom reinforcement layer. A correctly installed foundation earth electrode out of galvanised round or strip steel is enclosed by a 5 cm thick concrete layer and is thus it is resistant against corrosion. Due to the hygroscopic characteristics of concrete, usually a sufficiently low earth resistance can be achieved.

The foundation earth electrode has to be installed as a closed ring in the range along the outer edges of the foundation plate, thus providing the basis of equipotential bonding.

The foundation earth electrode shall be implemented with meshes of ≤ 20 m x 20 m. A foundation earth electrode used as lightning protection earth electrode requires smaller mesh sizes.

Mesh sectioning as well as the necessary terminal lugs for the equipotential bonding inside and for the connection of external lightning protection down conductors outside have to be considered.

Modern concreting methods of reinforced foundations and the vibrating / compacting of the concrete ensures that also a horizontally installed flat strip will be completely enclosed by concrete, so that corrosion resistance is achieved. An edgewise installation of the flat strip is no longer necessary due to the mechanical compacting of the concrete.



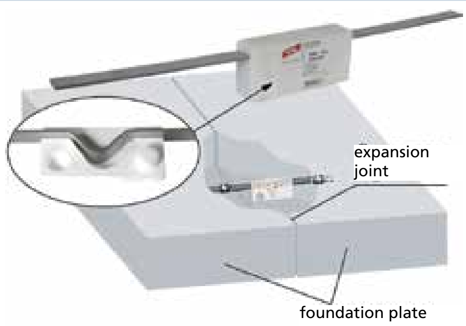
Foundation earth electrode with terminal lugs

Foundation earth electrode with meshes

Expansion Joints

The foundation earth electrode must not be installed across expansion joints. At these points it can be led out near walls and connected by means of fixed earthing terminals and bridging braids.

In case of large-size foundation plates the meshes of the installed foundation earth electrode have to cover also these expansion joints (sections or isolating joints) and there are no projecting terminal lugs. Special expansion straps can be used in this case, with a polystyrene block providing a recess in the concrete and an integrated flexible connection.
The polystyrene block with the expansion strap has to be inserted into one section of the foundation slab and continued with the loose end line in the next section.



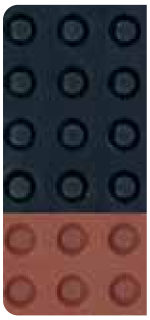
Bridging of the foundation earth electrode

Foil under the foundation plate

Foils at Foundation Plates

Often the granular subbase is covered with polyethylene foils of approx. 0.3 mm thickness as separation layer.

These foils overlapp just slightly and not waterproof. Usually they only have little influence on the earth-electrode resistance and thus can be neglected. Hence the foundation earth electrode can be laid in the foundation plate



Detail of the dimpled sheets

Application of the dimpled sheets

Dimpled Sheets

Dimpled sheets are used to replace the granular subbase for foundation slabs and often "enclose" the whole basement.

These dimpled sheets are made of high density special polyethylene and are approx. 0.6 mm thick (dimples are approx. 8 mm high). The sheets are approx. 2 m to 4 m wide and shall overlap each other by approx. 20 cm to 25 cm so that they are also a sealant against water. Thus the foundation earth electrode cannot be laid in the foundation plate. The foundation earth electrode will be installed as ring earth electrode with the corresponding mesh size under the dimpled sheets in the soil, for example in case of perimeter insulation or closed tanks. For this purpose StSt (V4A) material No. 1.4571 shall be used.

Closed Tanks

White tank out of water-proof concrete
Water-proof concrete is a high water penetration resistance type of concrete. In civil and underground engineering closed tanks out of water-proof concrete are also called "white tanks".

Buildings out of concrete with high water penetration resistance are constructions implemented without additional external sealing coat, where just the concrete and constructive measures such as joint sealing and crack width limitation prevent from penetration of water. Erection of such waterproof concrete buildings requires special care, because all structural components as, for example, joint sealings, bushings for water, gas, power, telecommunication (multi-sectional service entrances), drains, other cables or conductors, terminals for the foundation earth electrode or equipotential bonding must be permanently watertight or pressure watertight. The builder is responsible for the structure to be water-tight.

The term water-proof concrete is no longer defined by the current standardisation in the field of concrete production. The concrete quality e.g. C20/25 stands for the compression strength of a cylinder / cube in N/mm² and says nothing about the water impermeability. The content of cement is the primarily decisive factor for the water impermeability of concrete mixtures. 1 m³ of waterproof concrete consists of at least 320 kg of cement (of low hydration heat), has a reduced shrinkage and a recommended minimum compression strength of C 25/30. Another important factor is the so-called water-cement-value, which has to be below 0.6.

Thus, the concrete part is not electrically connected to the soil. Approximately 1.5 cm is the specified value of water penetration depth into the used concrete. The foundation earth electrode, however, has to be encased in 5 cm of concrete corrosion. This concrete has to be considered as electrical insulator. Thus the earth contact is failing.

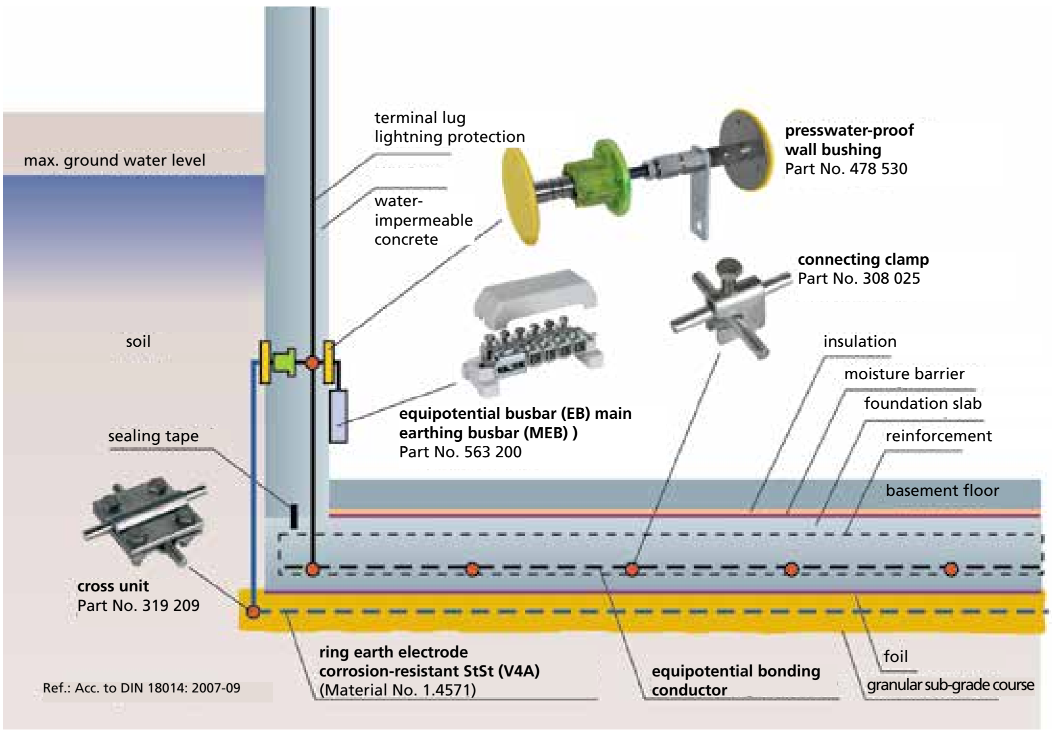
Therefore a ring earth electrode with a mesh size ≤ 20 m x 20 m has to be installed below the foundation slab in the blinding layer or soil in structures with white tank.

If a lightning protection system is installed on the building, or if EMC requirements are applicable, additionally an equipotential bonding conductor with a mesh size ≤ 20 m x 20 m has to be installed in the foundation slab, and a ring earth electrode with a mesh size ≤ 10 m x 10 m has to be installed in the soil or in the blinding layer, as required in EN 62305-3 (VDE 0185-305-3).

In case of a lightning strike, a reduced mesh size shall prevent possible flashover from the equipotential bonding conductor / reinforcement through the sealing (concrete) to the ring earth electrode installed below. The ring earth electrode installed under the foundation slab has to be connected with the "concrete-cast" equipotential bonding conductor and the reinforcement as well as with every down conductor of the lightning protection system in order to be effective as meshed earthing system. These connections may be implemented above groundwater level or below with pressure water-proof bushings.

Considering the service period of new buildings and of possible changes in use (including the requirements for lightning protection or EMC) an anticipatory planning is recommended and the ring earth electrode already with a mesh size ≤ 10 m x 10 m and also an equipotential bonding conductor in the foundation slab should be installed because a subsequent installation is not possible.

An Arrangement of a ring earth electrode and equipotential bonding conductor in case of a white tank is shown in the following illustrations.



Arrangement of the ring earth electrode and equipotential bonding conductor in case of a white tank

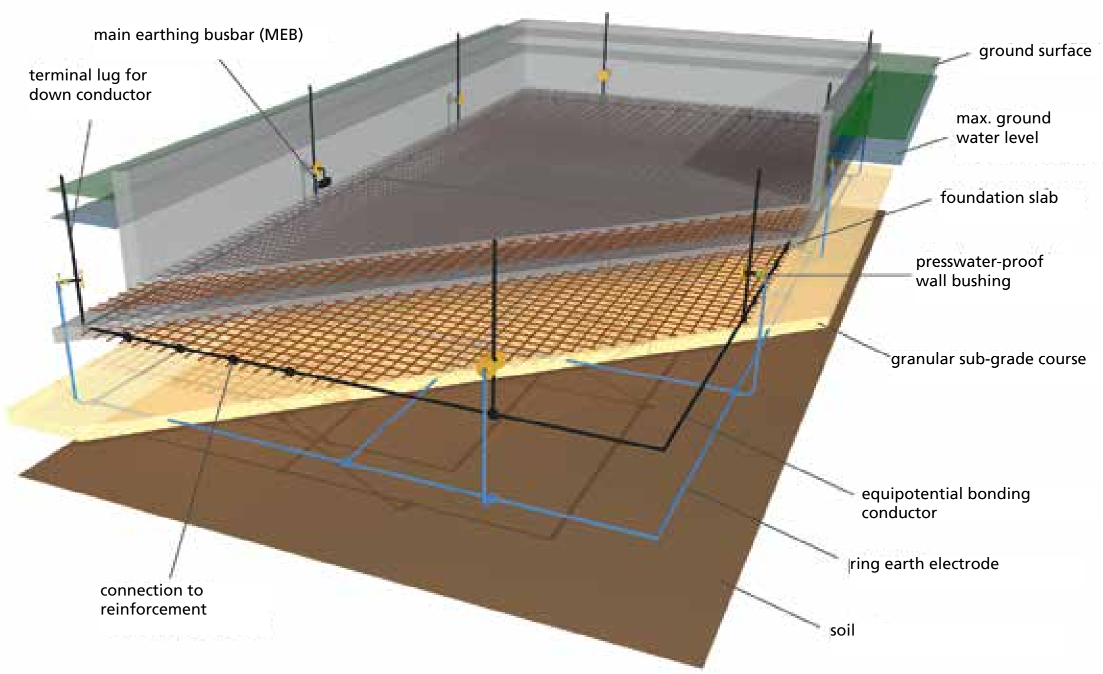


Illustration of ring earth electrode, equipotential bonding conductor and connections by means of presswater-proof wall bushings

Closed Tanks

Waterproof wall bushing for white tank

Connecting terminals of the ring earth electrode have to be impervious. On developing the waterproof wall bush-ing, DEHN + SÖHNE has applied the requirements specified for white tanks also on the product. Reality conform component specifications were especially important. When developing such components it has extremly important to fulfil real component requirements. The specimens were encased into a concrete body (Figure 1) and then submitted to a pressure water test. Installation sites in a depth of 10 m (such as required for underground car parks) are quite usual in the field of building technique.

These conditions were exerted on the specimens and a water pressure of 1 bar was imposed (Figure 2). After the concrete hardening, the specimens were subjected to a pressure water test and examined for watertightness during a 65 hours long-term test.
Capillary effects of bushings additionally increases the severity. In narrow gaps, cracks or tubes (capillaries) of the concrete, liquids such as water, in fact spread quite differently, developing a drawing or suction effect into the interior of the building. During the hardening and the concurrent shrinking process of the concrete, such narrow gaps or capillaries may result.

Therefore a professional, competent and correct installation of the wall bushing in the formwork, as described in detail in the installation instructions, is quite important.

Wall bushing with formwork installation

Set-up (cross section) with connection for presswater test

Waterproof wall bushing for white tank:

For example Part No. 478 550
- Tested with 5 bar compressed air according to FprEN 50164-5 (state 2008-06). Unit for formwork installation with water barrier and double thread M10/12 for connection to e.g. the equipotential bonding bar.
- Adjustable according to wall thickness with thread M10 and lock nut. The bushing can be shortened, if necessary, also at the thread.
- Including terminal fitting (St/tZn, dimension 30 x 4 mm) with square hole for connection with clamping frame at round conductor or with cross unit at strip conductors.

Waterproof wall bushing

Bituminised sealing sheets

Black Tank

A concrete foundation tank covered with multi layers of black bitumen on the soil facing side is called "black tank". For sealing purposes the building foundation body first has to be painted with bitumen/tar, followed by usually up to three layers of bituminous sheeting to be applied.
A ring earth electrode installed in the foundation slab above the sealing can serve for potential control in the structure. Due to the high-impedance outside insulation, however, the earth electrode is ineffective.
If a lightning protection system shall be implemented on the building or if EMC requirements are applicable, a ≤ 20 m x 20 m mesh-sized equipotential bonding conductor additionally has to be installed in the foundation slab, and a ≤ 10 m x 10 m mesh sized ring earth electrode below the foundation slab in the soil or in the blinding layer. This is required in IEC 62305-3 (EN 62305-3).

Wherever possible, the external ring earth electrode should be led into the structure above the seal, that means above the highest ground water level, in order to ensure the tightness of the tank also in the long term. A waterproof penetration of the black tank is only possible by using special components.

Perimeter Insulation

Present-day construction technique allows for a quite individual structural design and the corresponding sealing variants of building foundations.

Thermal protection regulations have also influenced the structuring of the strip foundations and foundation slabs. Sealing / insulation effects the installation and arrangement of the foundation earth electrodes, which, in case of new buildings will be established in accordance with the German Standard DIN 18014 Title (English): Foundation earth electrode – General planning criteria.

"Perimeter" means the wall and floor range of a building which is in contact with the soil. Perimeter insulation is the thermal insulation which encloses the structure to the outside. The perimeter insulation encloses the sealing layer and the whole structure on the outside, thus there are no thermal bridges and the sealing is additionally protected from mechanical damage.

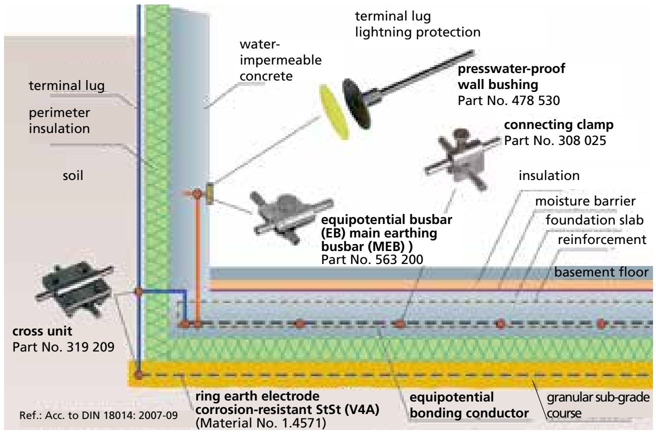
Considering the effects of perimeter insulations on the earth electrode resistance of foundation earth electrodes at conventional arrangements in the foundation slab, the specific resistance of the perimeter insulating plates is a significant factor.

The specific resistance of a polyurethane rigid foam with bulk density 30 kg/m^2, for example, is 5.4 x 10^{12} Ωm. The specific resistance of concrete, however, is between 150 Ωm and 500 Ωm. Even from these values it can be derived that, in the case of complete perimeter insulation, a conventionally arranged foundation earth electrode virtually is ineffective. Thus the perimeter insulation has the effect of an electrical insulator.

In case of a complete insulation of foundation slab and outer walls (full perimeter insulation), the correspondingly mesh sized ring earth electrode has to be installed underneath the bedplate in the blinding layer or in the soil. A corrosion resistant material, such as high-alloy stainless steel StSt (V4A), material No. 1.4571, has to be used.

Ring earth electrode in case of perimeter insulation

Detail view of ring earth electrode



Arrangement of the foundation earth electrode in case of a compact foundation

Foundation earth electrode in case of foundation blocks with terminal lug

Application of the spacer with cross unit

Foundation Blocks / Foundation Spots

For industrial building construction often foundation blocks, also called foundation spots, are used. These individual footings are used as ground slab, e.g. for steel supports or concrete girders of halls. A foundation plate is not erected. Also these structures need a reliable earth-termination system. Therefore earthing measures are necessary also in such foundation blocks. If the distance between the foundation blocks is more than 5 m one foundation earth electrode each will be installed. Distances of ≤ 5 m require a foundation earth electrode to be installed only into every second foundation block.

The round or strip steel (galvanised) foundation earth electrode in the foundation blocks must be at least 2.5 m long and the concrete enclosure shall be at least 5 cm thick.

These "individual earth-termination systems" have to be interconnected for giving no rise to potential differences within the earthing system. The connection shall be implemented on the lowest floor, with earth contact and the connecting conductors as well as the terminals of the foundation blocks shall be out of corrosion resistant StSt (V4A) material.

If these foundation blocks, for example, are out of highly impervious concrete (water-impermeable concrete), a ring earth electrode out of StSt (V4A) material and a mesh size of ≤ 20 m x 20 m has to be laid into the ground.

Strip Foundations (without reinforcement)

Spacers have to be used in unreinforced foundations, for example, in strip foundations of residential houses. Using spacers in intervals of approx. 2 m ensures that the foundation earth electrode is reliably supported (elevated) and thus can be encased into at least 5 cm of concrete. If the concrete will be machine compacted (vibrated), wedge connectors must not be used.

If because of a highly compacted underground (wet mix aggregate with stones etc.) spacers can not be used, the foundation earth electrode can only be installed directly on the ground and StSt material (V4A) has to be used.

Strip Foundations (with reinforcement)

In case of strip foundations with reinforcement, the foundation earth electrode will be laid as closed ring in concrete. The reinforcement will also be integrated and interconnected as permanent electrical conductor. Considering a possible corrosion, the foundation earth electrode has to be enclosed by 5 cm of concrete. The terminals / terminal lugs are required to be out of StSt (V4A) material, as described above.

Fibre Concrete

Fibre concrete is a type of concrete which due to the steel fibres added to the liquid concrete forms a heavy-duty concrete slab after hardening. Steel fibre concrete has both a high compression strength and also a high tensile strength and, compared to a conventional concrete slab with reinforcement, it also provides a considerably higher elasticity. In many cases the usually applied concrete reinforcement can be completely replaced. Steel fibre concrete will be poured, pumped or cast directly on site.

Main field of application in Germany is the industrial and residential construction. Applied steel fibres usually are 50 – 60 mm long and have a diameter of 0.75 – 1.00 mm. The mostly used steel fibres are straight with end hooks or slightly wavy. The required admixture of steel fibres depends on the stressing of the bedplate and on the performance of the used steel fibres. Selection basis of the necessary fibre type and quantity is a statistical calculation.
Steel fibres only have little influence on the electrical conductivity of concrete. For earthing measures in case of pure steel fibre concrete plates therefore an earth electrode with a mesh size of ≤ 20 m x 20 m has to be provided. The earth conductor can be set in the concrete and, if it is made of galvanised material, it must be encased in 5 cm of concrete for corrosion protection reasons. On site this is sometimes difficult to realise. It is therefore recommended to install a corrosion-resistant high-alloy stainless steel (V4A) ring earth electrode, Material No. 1.4571, below the subsequent concrete bedplate. The corresponding terminal lugs have to be considered.

View of a warehouse
Source: www.bekaert.com/building

Fresh concrete with steel fibres
More information at www.vdsev.de

According to DIN 18014, a documentation on the earth-termination system must be prepared. This documentation must include the result of the continuity measurement. Implementation plants and photos of the earth-termination system, if any, must be enclosed. A form is available on the internet at www.dehn.de and can be downloaded as writable pdf.

DEHN Form No. 2120/E/0612 Page 1

Documentation of the earth-termination system according to DIN 18014

Provider ______________ Date ______________ Report No. ________

Proprietor of the building	Name: ______ Contact: ______ Address: ______
Details on the building	Location: ______ Use: ______ Type of construction: ______ Type of foundation: ______ Contractor: ______ Built in (year): ______
Address of the earth-termination system designer	Name: ______ Contact: ______ Address: ______
Installer of the earth-termination system	☐ Specialised company for electrical installation ☐ Specialised company for lightning protection ☐ Contractor supported by electrical installation/lightning protection specialist
	Name: ______ Contact: ______ Address: ______ Address: ______
Purpose of the earth-termination system	☐ Protective earthing for electrical safety
	Functional earthing for: ☐ Lightning protection system ☐ Antenna system ☐ ______
	Any other requirements applicable for the earth-termination system e.g. 50 Hz short-circuit currents (DIN VDE 0101/0141) ☐ Yes ☐ No
Design/Type of earth-termination system	Type of earth-termination system: ☐ Foundation earth electrode ☐ Ring earth electrode
	Material of foundation earth electrode: ☐ Steel bare ☐ Steel galvanised Material of ring earth electrode: ☐ Stainless steel StSt (V4A) ☐ ______
	☐ Round material ☐ Strip material ☐ ______ according to DIN EN 50164-2 Dimensions: ______
	Connecting elements meet the requirements according to DIN EN 50164-1 ☐ Yes ☐ No
	Internal connecting elements: ☐ Stainless steel StSt (V4A) ☐ Fixed earthing terminal ☐ St/tZn with plastic coating ☐ ______
	External connecting elements: ☐ Stainless steel StSt (V4A) ☐ Fixed earthing terminal ☐ St/tZn with plastic coating ☐ ______

Documentation of the earth-termination system according to DIN 18014

Provider ______________ Date ______________ Report No. ________

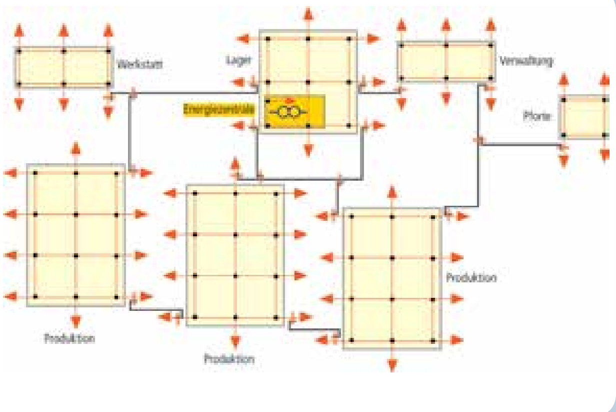
Description, drawings, figures	☐ External lightning protection system ☐ Earth-termination system	☐ Not available ☐ Available	☐ Drawing No. ________ ☐ Figure No. ________
Purpose of documentation	☐ Acceptance / Completion ☐ Repeat test	☐ ________	
Soil composition:	☐ rocky / stony ☐ sand	☐ gravel ☐ loam	☐ ________ ☐ ________
Soil state:	☐ dry	☐ humid	☐ wet
Test result:	The system is according to the existing plans	☐ Yes	☐ No
	The system is without deficiencies with regard to the requirements of DIN 18014 Resistance value of < 1 ohm (reference value) in the continuity measurement	☐ Yes	☐ No
	The test revealed the following deficiencies:		
The test report comprises this paper and following enclosures (e.g. drawings, photos)			

______________ ______________ ______________

Location Date Signature

Notes for the proprietor of the building

- The proprietor has to remedy the deficiencies.
- In case of structural alteration or alteration of use immediately contact the service company.



Intermeshed earth-termination system

Intermeshed Earth-termination System at Industrial Objects

If a larger structure comprises more than one building, and if these are connected by electrical and electronic conductors, combining the individual earth-termination systems can reduce the (total) earth resistance. In addition, the potential differences between the structures will be reduced considerably and the voltage load of the electrical and electronic connecting cables will be noticeably reduced.

The individual earth-termination systems of the structures should be interconnected in a meshed network. The meshed earthing network should be contacted with the earth-termination systems at the same points where the vertical down conductors of the lightning protection system are connected.

The smaller the mesh size of the earth-termination system, the lower the potential differences between the structures in case of a lightning strike. This depends on the total area of the structure. Mesh sizes of 20 m x 20 m up to 40 m x 40 m have proved to be cost-effective. If, for example, high vent stacks (preferred points of strike) are existing, the connections around this part of the plant should be close to each other and, if possible, star shaped with circular interconnections (potential control). When selecting the material for the conductors of the earth-termination system meshes, the corrosion must be taken into account. Galvanised steel is recommended to be used in concrete (e.g. connection duct) and StSt (V4A), material No. 1.4571 in soil.

Ring equipotential bonding

50 Hz Short-circuit Current Loading of Earth Conductors, Equipotential Bonding Connection and Connection Elements

Equipment of different electric systems interact in electrical facilities.

- High voltage technology (HV systems)
- Medium voltage technology (MV systems)
- Low voltage technology (LV systems)
- Information technology (IT systems)

Basis for a reliable cooperation of the different systems is a common earth-termination system and a common equipotential bonding system. It is important that all conductors, clamps and connectors are specified for the different cases of application.

For buildings with integrated transformers, DIN VDE 0101 (VDE 0101) "Starkstromanlagen mit Nennwechselspannungen über 1 kV", title (English) "Power installations exceeding 1 kV" has to be considered.

Conductor materials and connection elements for use in HV, MV and LV systems have to be able to carry 50 Hz currents. Due to the prospective short-circuit currents (50 Hz) the cross sections of the earth electrode material for the individual systems / structures have to be determined especially. Earth fault currents (standard requirement double earth fault current I''_{kEE}) must not lead to inadmissible heating of these components.

Without special indications by the distribution system operator, 1 second as standardised duration of fault current (disconnecting time), and 300°C as maximum permissible temperature for the used earth conductor and connection component / clamp material, are taken as basic data. The material and the current density (in A/mm²) in relation to the duration of the fault current are decisive for selecting the earth conductor cross section.

For detailed values of the short-circuit current (I_k) for the current flow period of 1 s of the earth conductors, earth rods and different connection components / clamps, please see our main catalogue Lightning Protection or the product data sheets (www.dehn.de – Product Data).

Calculation of the earth fault current for the designing of the earth conductor is shown by the following example:

Variant 1
Specification of the 3-pole short-circuit current by the system operator e.g. $I''_{k3} \approx 15000$ A

Variant 2
The calculation specifies a theoretical worst case, assuming that the feeding voltage does not collapse (reduce).

The short-circuit voltage (u_k) is the basis for determining the max. 3-pole short-circuit current. The 3-pole short-circuit current I"K3 is the max. 3-pole short-circuit current at the transformer, neglecting an impedance on fault site (Z = 0).

The calculation example is a showcase of a transformer with following data:

Nominal power of the transformer S = 630 kVA
Nominal voltage on low-voltage side U = 400 V
Short-circuit voltage u_k = 6.05 %

Designing for short-circuit

Linear conversion for the short-circuit voltage (worst case)

$$I''_{k3} = \frac{S}{\sqrt{3} \cdot U \cdot u_K}$$

$$I''_{k3} = \frac{630 \cdot 10^3\ \mathrm{VA}}{\sqrt{3} \cdot 400\mathrm{V} \cdot 0.0605} \approx 15000\ \mathrm{A}$$

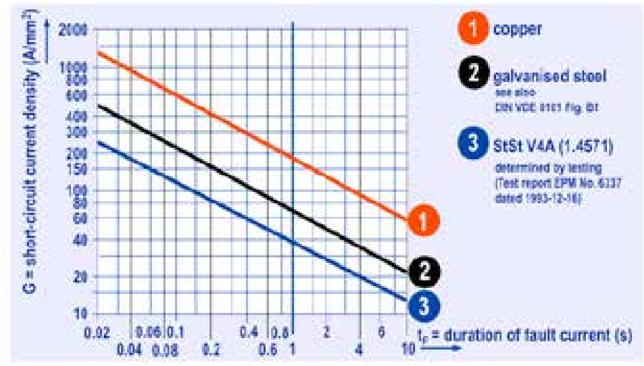
For dimensioning the cross section of an earth conductor, the worst case of a double earth fault in a system has to be assumed. Therefore earth-termination systems have to be designed for the double earth fault current (I''_{kEE}).

$$I''_{kEE} = 0.85 \cdot I''_{k3}$$

$$I''_{kEE} = 0.85 \cdot 15000\ \mathrm{A} \approx 12750\ \mathrm{A}$$

The German standard DIN VDE 0101 "Starkstromanlagen mit Nennwechselspannungen über 1 kV", title (English) "Power installations exceeding 1 kV" specifies the factor 85 % for the dimensioning of the earth fault current on the basis of the 3-pole earth fault current.

All connection lines directly to the transformer shall be dimensioned for this double earth fault current I''_{kEE}.
If the short-circuit current spreads over the direct connection lines to the transformer into the mesh of an intermeshed earth-termination system, the current probably will be distributed in two directions at the nodal point of the earth-termination system. With sufficient accuracy an imbalance in the intermeshing of the earth-termination system of 65 % to 75 % can be expected.



Current carrying capacity of earth electrode materials

The diagram shows the permissible 50 Hz short-circuit current density (G) for the conductor materials copper, steel and high-alloy stainless steel StSt (V4A) (material No. 1.4571).

The earth fault current to be considered for the earth-termination mesh is specified as I''_{kEE} (branch) in our example.

$$I''_{kEE\,(branch)} = 0.65 \cdot I''_{kEE}$$

$$I''_{kEE\,(branch)} = 0.65 \cdot 12750\ \mathrm{A} \approx 8300\ \mathrm{A}$$

For dimensioning of the cross section of the earth-termination mesh in the shown example therefore the current I''_{kEE} (branch) = 8304 A is taken as basis.

Determination of the resulting cross section
The conductor cross section depends on the material and the disconnecting time. The German standard VDE 0101 specifies the maximum short-circuit current density G [A/mm²] for different materials (see VDE 0101 Figure B1).

time	St/tZn	Copper	StSt
0,3 s	129 A/mm²	355 A/mm²	70 A/mm²
0,5 s	100 A/mm²	275 A/mm²	55 A/mm²
1 s	70 A/mm²	195 A/mm²	37 A/mm²
3 s	41 A/mm²	112 A/mm²	21 A/mm²
5 s	31 A/mm²	87 A/mm²	17 A/mm²

Table: Short-circuit current density G

The minimum cross section A_{min} of the conductor is determined by dividing this calculated current by the current density G of the respective material and by the assigned disconnecting time.

$$A_{min} = \frac{I''_{kEE\,(branch)}}{G}\ [\mathrm{mm^2}]$$

The conductor now will be selected according to the calculated cross section. The nominal cross section is always rounded up to the next bigger size.

Legend:

S	nominal capacity	[VA]
U	nominal voltage (low voltage)	[V]
u_k	short-circuit voltage	[%]
I_k	short-circuit current	[A]
I''_{k3}	3-pole short-circuit current	[A]
I''_{kEE}	double short-circuit current to earth	[A]
G	short-circuit current density	[A/mm²]
A_{min}	minimum cross section	[mm²]

Connecting Clamps for Reinforcements

The foundation earth electrode has to be connected with the reinforcement of the foundation plate in distances of 2 m. Different connections are possible.

The clamping connection has turned out to be the most economic, as it can be carried out on site quickly and easily. According to the current lightning protection standards, reinforcement steels shall be used among others as natural components of the discharge system.

The following table shows a survey of the nominal and outer diameters as well as cross sections of the reinforcement steels according to the German standard DIN 1045-1.

For the selection of the connection components / clamps, the outer diameter of the reinforcement steels is applicable.

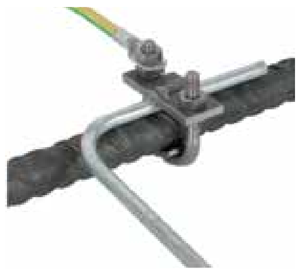
The outer diameter including corrugation is approx. $d_a = 1.15 \times d_s$

Nominal diameter d_s (mm)	6	8	10	12	14	16	20	25	28	32	40
Outer diameter incl. corrugation d_a (mm)	6.9	9.2	11.5	13.8	16.1	18.4	23	29	32	37	46
Nominal cross section (mm²)	28.3	50.3	78.5	113.1	154	201	314	491	616	804	1257

Figure 1: Diameters of reinforcement steels

Pressure U-clamp for foundation earth electrodes and reinforcements Part No. 308 031 and 308 036

Connecting clamp for fixed earthing terminal and reinforcement steel Part No. 308 035



U-clamp terminal for large diameters Part No. 308 045

Connecting clamp for fixed earthing terminal and reinforcement steel Part No. 308 045

Surge Protection
Lightning Protection / Earthing
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