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Protection against lightning –

Part 3: Physical damage to structures and life hazard

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Protection against lightning –

Part 3: Physical damage to structures and life hazard

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PROTECTION AGAINST LIGHTNING –

Part 3: Physical damage to structures and life hazard

FOREWORD

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International standard IEC 62305-3 has been prepared by IEC technical committee 81: Lightning protection.

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The text of this first edition of IEC 62305-3 is compiled from and replaces

– IEC 61024-1, first edition (1990).

– IEC 61024-1-2, first edition (1998).

The text of this standard is based on the following documents:

FDIS	Report on voting
81/264/FDIS	81/269/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above Table.

This publication has been drafted, as close as possible, in accordance with the ISO/IEC Directives, Part 2.

IEC 62305 consists of the following parts, under the general title *Protection against lightning:*

Part 1: General principles

Part 2: Risk management

Part 3: Physical damage to structures and life hazard

Part 4: Electrical and electronic systems within structures

Part 5: Services[1]

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC website "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be:

- reconfirmed;
- withdrawn;
- replaced by a revised edition; or
- amended.

In the United States, based on the requirements of NFPA 780: Standard for the Installation of Lightning Protection Systems 2004 Edition and practical experience in the use of horizontal earth electrodes, the minimum length of horizontal earth electrodes is not required to be twice that required for vertical electrodes.

In France, Portugal and Spain:

– natural components cannot substitute as lightning protection components but may be used to complete/enhance the LPS;

– aluminium solid round diameters should be extended from 8 mm to 10 mm;

– stranded conductors cannot be used as down-conductors;

– diameter of solid round conductors should be extended from 16 mm to 18 mm;

– hot dip galvanized steel solid tape thickness should be extended from 2 mm to 3,5 mm.

[1] To be published

INTRODUCTION

This part of IEC 62305 deals with the protection, in and around a structure, against physical damage and injury to living beings due to touch and step voltages.

The main and most effective measure for protection of structures against physical damage is considered to be the lightning protection system (LPS). It usually consists of both external and internal lightning protection systems.

An external LPS is intended to:

a) intercept a lightning flash to the structure (with an air-termination system);

b) conduct the lightning current safely towards earth (using a down-conductor system);

c) disperse the lightning current into the earth (using an earth-termination system).

An internal LPS prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS (as defined in 3.2) components and other electrically conducting elements internal to the structure.

Main protection measures against injury to living beings due to touch and step voltages are intended to:

1) reduce the dangerous current flowing through bodies by insulating exposed conductive parts, and/or by increasing the surface soil resistivity;

2) reduce the occurrence of dangerous touch and step voltages by physical restrictions and/or warning notices.

The type and location of an LPS should be carefully considered in the initial design of a new structure, thereby enabling maximum advantage to be taken of the electrically conductive parts of the structure. By doing so, design and construction of an integrated installation is made easier, the overall aesthetic aspects can be improved, and the effectiveness of the LPS can be increased at minimum cost and effort.

Access to the ground and the proper use of foundation steelwork for the purpose of forming an effective earth termination may well be impossible once construction work on a site has commenced. Therefore, soil resistivity and the nature of the earth should be considered at the earliest possible stage of a project. This information is fundamental to the design of an earth-termination system and may influence the foundation design work for the structure.

Regular consultation between LPS designers and installers, architects and builders is essential in order to achieve the best result at minimum cost.

If lightning protection is to be added to an existing structure, every effort should be made to ensure that it conforms to the principles of this standard. The design of the type and location of an LPS should take into account the features of the existing structure.

PROTECTION AGAINST LIGHTNING –

Part 3: Physical damage to structures and life hazard

1 Scope

This part of IEC 62305 provides the requirements for protection of a structure against physical damage by means of a lightning protection system (LPS), and for protection against injury to living beings due to touch and step voltages in the vicinity of an LPS (see IEC 62305-1).

This standard is applicable to:

a) design, installation, inspection and maintenance of an LPS for structures without limitation of their height;
b) establishment of measures for protection against injury to living beings due to touch and step voltages.

NOTE 1 Specific requirements for an LPS in structures dangerous to their surroundings due to the risk of explosion are under consideration. Additional information is provided in Annex D for use in the interim.

NOTE 2 This part of IEC 62305 is not intended to provide protection against failures of electrical and electronic systems due to overvoltages. Specific requirements for such cases are provided in IEC 62305-4.

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.

IEC 60079-10:2002, *Electrical apparatus for explosive gas atmospheres – Part 10: Classification of hazardous areas*

IEC 60079-14:2002, *Electrical apparatus for explosive gas atmospheres – Part 14: Electrical installations in hazardous areas (other than mines)*

IEC 61241-10:2004, *Electrical apparatus for use in the presence of combustible dust – Part 10: Classification of areas where combustible dusts are or may be present*

IEC 61241-14:2004, *Electrical apparatus for use in the presence of combustible dust – Part 14: Selection and installation*

IEC 61643-12:2002, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low voltage power distribution systems – Selection and application principles*

IEC 62305-1, *Protection against lightning – Part 1: General principles*

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC 62305-5, *Protection against lightning – Part 5: Services*[1]

ISO 3864-1, *Graphical symbols – Safety colours and safety signs – Part 1: Design principles for safety signs in workplaces and public areas*

3 Terms and definitions

For the purposes of this document, the following terms and definitions, some of which have already been cited in Part 1 but are repeated here for ease of reference, as well as those given in other parts of IEC 62305, apply.

3.1
lightning protection system
LPS
complete system used to reduce physical damage due to lightning flashes to a structure

NOTE It consists of both external and internal lightning protection systems.

3.2
external lightning protection system
part of the LPS consisting of an air-termination system, a down-conductor system and an earth-termination system

3.3
external LPS isolated from the structure to be protected
LPS with an air-termination system and down-conductor system positioned in such a way that the path of the lightning current has no contact with the structure to be protected

NOTE In an isolated LPS, dangerous sparks between the LPS and the structure are avoided.

3.4
external LPS not isolated from the structure to be protected
LPS with an air-termination system and down-conductor system positioned in such a way that the path of the lightning current can be in contact with the structure to be protected

3.5
internal lightning protection system
part of the LPS consisting of lightning equipotential bonding and/or electrical insulation of external LPS

3.6
air-termination system
part of an external LPS using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes

3.7
down-conductor system
part of an external LPS intended to conduct lightning current from the air-termination system to the earth-termination system

[1] To be published

3.8
ring conductor
conductor forming a loop around the structure and interconnecting the down-conductors for distribution of lightning current among them

3.9
earth-termination system
part of an external LPS which is intended to conduct and disperse lightning current into the earth

3.10
earthing electrode
part or a group of parts of the earth-termination system which provides direct electrical contact with the earth and disperses the lightning current into the earth

3.11
ring earthing electrode
earthing electrode forming a closed loop around the structure below or on the surface of the earth

3.12
foundation earthing electrode
reinforcing steel of foundation or additional conductor embedded in the concrete foundation of a structure and used as an earthing electrode

3.13
conventional earth impedance
ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously

3.14
earth-termination voltage
potential difference between the earth-termination system and the remote earth

3.15
natural component of LPS
conductive component installed not specifically for lightning protection which can be used in addition to the LPS or in some cases could provide the function of one or more parts of the LPS

NOTE Examples of the use of this term include:

– natural air-termination;

– natural down-conductor;

– natural earthing electrode.

3.16
connecting component
part of an external LPS which is used for the connection of conductors to each other or to metallic installations

3.17
fixing component
part of an external LPS which is used to fix the elements of the LPS to the structure to be protected

3.18
metal installations
extended metal items in the structure to be protected which may form a path for lightning current, such as pipework, staircases, elevator guide rails, ventilation, heating and air-conditioning ducts, and interconnected reinforcing steel

3.19
external conductive parts
extended metal items entering or leaving the structure to be protected such as pipework, metallic cable elements, metal ducts, etc. which may carry a part of the lightning current

3.20
electrical system
system incorporating low voltage power supply components and possibly electronic components

3.21
electronic system
system incorporating sensitive electronic components such as communication equipment, computer, control and instrumentation systems, radio systems, power electronic installations

3.22
internal systems
electrical and electronic systems within a structure

3.23
lightning equipotential bonding
EB
bonding to the LPS of separated conductive parts, by direct connections or via surge protective devices, to reduce potential differences caused by lightning current

3.24
bonding bar
metal bar on which metal installations, external conductive parts, electric power and tele-communication lines, and other cables can be bonded to an LPS

3.25
bonding conductor
conductor connecting separated conductive parts to LPS

3.26
interconnected reinforcing steel
steelwork within a concrete structure which is considered electrically continuous

3.27
dangerous sparking
electrical discharge due to lightning which causes physical damage in the structure to be protected

3.28
separation distance
distance between two conductive parts at which no dangerous sparking can occur

3.29
surge protective device
SPD
device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component

3.30
test joint
joint designed to facilitate electrical testing and measurement of LPS components

3.31
class of LPS
number denoting the classification of an LPS according to the lightning protection level for which it is designed

3.32
lightning protection designer
specialist competent and skilled in the design of the LPS

3.33
lightning protection installer
person competent and skilled in the installation of the LPS

3.34
structures with risk of explosion
structures containing solid explosives materials or hazardous zones as determined in accordance with IEC 60079-10 and IEC 61241-10

4 Lightning protection system (LPS)

4.1 Class of LPS

The characteristics of an LPS are determined by the characteristics of the structure to be protected and by the considered lightning protection level.

Four classes of LPS (I to IV) are defined in this standard corresponding to lightning protection levels defined in IEC 62305-1 (see Table 1).

Table 1 – Relation between lightning protection levels (LPL) and class of LPS (see IEC 62305-1)

LPL	Class of LPS
I	I
II	II
III	III
IV	IV

Each class of LPS is characterized by the following.

a) Data dependent upon the class of LPS:
   - lightning parameters (see Tables 3 and 4 in IEC 62305-1);
   - rolling sphere radius, mesh size and protection angle (see 5.2.2);
   - typical distances between down-conductors and between ring conductors (see 5.3.3);
   - separation distance against dangerous sparking (see 6.3);
   - minimum length of earth electrodes (see 5.4.2).

b) Data not dependent upon the class of LPS:
   – lightning equipotential bonding (see 6.2);
   – minimum thickness of metal sheets or metal pipes in air-termination systems (see 5.2.5);
   – LPS materials and conditions of use (see 5.5);
   – material, configuration and minimum dimensions for air-terminations, down-conductors and earth-terminations (see 5.6);
   – minimum dimensions of connecting conductors (see 6.2.2).

Performance of each class of LPS is given in Annex B of IEC 62305-2.

The class of required LPS shall be selected on the basis of a risk assessment (see IEC 62305-2).

4.2 Design of the LPS

A technically and economically optimized design of an LPS is possible especially if the steps in the design and construction of the LPS are coordinated with the steps in the design and construction of the structure to be protected. In particular, the design of the structure itself should utilize the metal parts of the structure as parts of the LPS.

The design of the class and location of the LPS for existing structures shall take into account the constraints of the existing situation.

The design documentation of an LPS shall contain all the information necessary to ensure correct and complete installation. For detailed information, see Annex E.

4.3 Continuity of steelwork in reinforced concrete structures

Steelwork within reinforced concrete structures is considered to be electrically continuous provided that the major part of interconnections of vertical and horizontal bars are welded or otherwise securely connected. Connections of vertical bars shall be welded, clamped or overlapped a minimum of 20 times their diameters and bound or otherwise securely connected. For new structures, the connections between reinforcement elements shall be specified by the designer or installer, in cooperation with the builder and the civil engineer.

For structures utilizing steel reinforced concrete (including pre-cast, pre-stressed reinforced units), the electrical continuity of the reinforcing bars shall be determined by electrical testing between the uppermost part and ground level. The overall electrical resistance should not be greater than 0,2 Ω, measured using test equipment suitable for this purpose. If this value is not achieved, or it is not practical to conduct such testing, the reinforcing steel shall not be used as a natural down-conductor as discussed in 5.3.5. In this case it is recommended that an external down-conductor be installed. In the case of structures of pre-cast reinforced concrete, the electrical continuity of the reinforcing steel shall be established between individual adjacent pre-cast concrete units.

NOTE 1 For further information on the continuity of steelwork in reinforced concrete structures, see Annex E.

NOTE 2 In several countries, the use of reinforced concrete as a part of the LPS is not allowed.

5 External lightning protection system

5.1 General

5.1.1 Application of an external LPS

The external LPS is intended to intercept direct lightning flashes to the structure, including flashes to the side of the structure, and conduct the lightning current from the point of strike to ground. The external LPS is also intended to disperse this current into the earth without causing thermal or mechanical damage, nor dangerous sparking which may trigger fire or explosions.

5.1.2 Choice of external LPS

In most cases, the external LPS may be attached to the structure to be protected.

An isolated external LPS should be considered when the thermal and explosive effects at the point of strike, or on the conductors carrying the lightning current, may cause damage to the structure or to the contents (see Annex E). Typical examples include structures with combustible covering, structures with combustible walls and areas at risk of explosion and fire.

NOTE The use of an isolated LPS may be convenient where it is predicted that changes in the structure, its contents or its use will require modifications to the LPS.

An isolated external LPS may also be considered when the susceptibility of the contents warrants the reduction of the radiated electromagnetic field associated with the lightning current pulse in the down-conductor.

5.1.3 Use of natural components

Natural components made of conductive materials, which will always remain in/on the structure and will not be modified (e.g. interconnected reinforced steel, metal framework of the structure, etc.) may be used as parts of an LPS.

Other natural components should be considered as being additional to an LPS.

NOTE For further information, see Annex E.

5.2 Air-termination systems

5.2.1 General

The probability of structure penetration by a lightning current is considerably decreased by the presence of a properly designed air-termination system.

Air-termination systems can be composed of any combination of the following elements:

a) rods (including free-standing masts);

b) catenary wires;

c) meshed conductors.

To conform to this standard, all types of air-termination systems shall be positioned in accordance with 5.2.2, 5.2.3 and Annex A.

The individual air-termination rods should be connected together at roof level to ensure current division.

Radioactive air terminals are not allowed.

5.2.2 Positioning

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one or more of the following methods.

Acceptable methods to be used in determining the position of the air-termination system include:

– the protection angle method;
– the rolling sphere method;
– the mesh method.

The rolling sphere method is suitable in all cases.

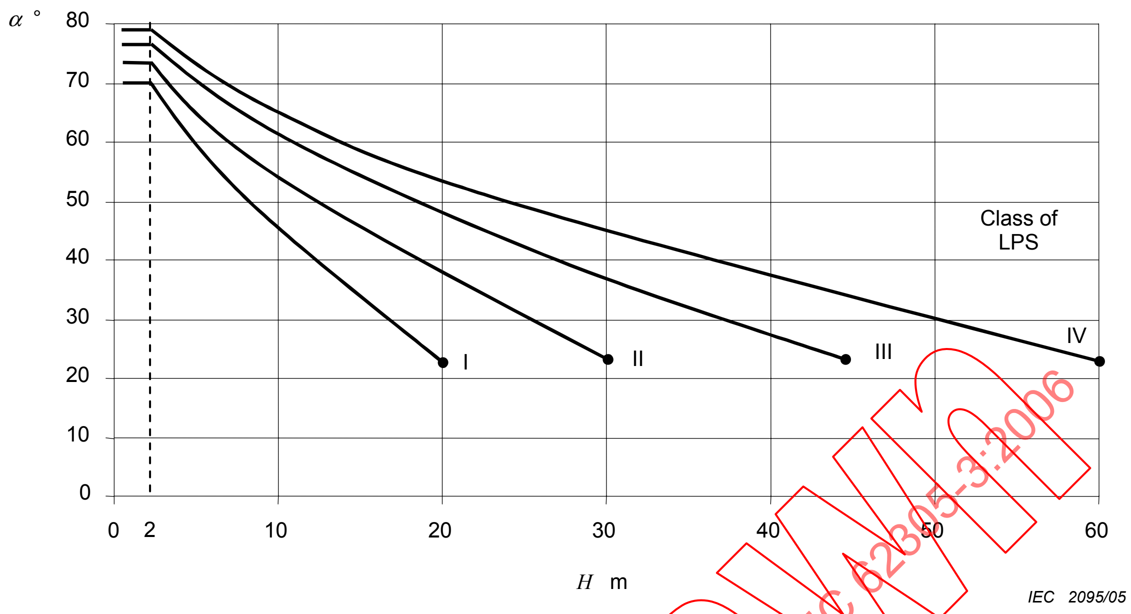
The protection angle method is suitable for simple-shaped buildings but it is subject to limits of air-termination height indicated in Table 2.

The mesh method is a suitable form of protection where plane surfaces are to be protected.

The values for the protection angle, rolling sphere radius and mesh size for each class of LPS are given in Table 2. Detailed information on the positioning of the air-termination system is given in Annex A.

Table 2 – Maximum values of rolling sphere radius, mesh size and protection angle corresponding to the class of LPS

Class of LPS	Protection method		
	Rolling sphere radius r m	Mesh size W m	Protection angle $\alpha°$
I	20	5 × 5	See figure below
II	30	10 × 10	
III	45	15 × 15	
IV	60	20 × 20	



NOTE 1 Not applicable beyond the values marked with •. Only rolling sphere and mesh methods apply in these cases.

NOTE 2 H is the height of air-termination above the reference plane of the area to be protected.

NOTE 3 The angle will not change for values of H below 2 m.

5.2.3 Air-terminations against flashes to the side of tall structures

On structures taller than 60 m, flashes to the side may occur, especially to points, corners and edges of surfaces.

NOTE In general the risk due to these flashes is low because only a few per cent of all flashes to tall structures will be to the side and moreover their parameters are significantly lower than those of flashes to the top of structures. However, electrical and electronic equipment on walls outside structures may be destroyed even by lightning flashes with low current peak values.

An air-termination system shall be installed to protect the upper part of tall structures (i.e. typically the topmost 20 % of the height of the structure) and the equipment installed on it (see Annex A).

The rules for positioning air-termination systems on roofs shall also apply to those upper parts of structures.

In addition, for structures taller than 120 m, all parts which may be endangered above 120 m should be protected.

5.2.4 Construction

Air-terminations of an LPS not isolated from the structure to be protected may be installed as follows:

– if the roof is made of non-combustible material the air-termination conductors may be positioned on the surface of the roof;

– if the roof is made of readily-combustible material, due care needs to be taken with regard to the distance between the air-termination conductors and the material. For thatched roofs where no steel bars are used for monitoring of the reed, a distance of 0,15 m is adequate. For other combustible materials a distance not lower than 0,10 m is considered adequate;

– Easily-combustible parts of the structure to be protected shall not remain in direct contact with the components of an external LPS and shall not remain directly under any metallic roofing membrane that might be punctured by a lightning flash (see 5.2.5).

Account shall also be taken of less combustible membranes such as wooden sheets.

NOTE If it is likely that water may accumulate on a flat roof, air-terminations should be installed above the maximum probable water level.

5.2.5 Natural components

The following parts of a structure should be considered as natural air-termination components and part of an LPS in accordance with 5.1.3.

a) Metal sheets covering the structure to be protected provided that:
   - the electrical continuity between the various parts is made durable (e.g. by means of brazing, welding, crimping, seaming, screwing or bolting);
   - the thickness of the metal sheet is not less than the value *t'* given in Table 3 if it is not important to prevent puncture of the sheeting or to consider ignition of any readily-combustible materials underneath;
   - the thickness of the metal sheet is not less than the value *t* given in Table 3 if it is necessary to take precautions against puncture or to consider hot spot problems;
   - they are not clad with insulating material.

Table 3 – Minimum thickness of metal sheets or metal pipes in air-termination systems

Class of LPS	Material	Thickness [a] *t* mm	Thickness [b] *t´* mm
I to IV	Lead	–	2,0
	Steel (stainless, galvanized)	4	0,5
	Titanium	4	0,5
	Copper	5	0,5
	Aluminium	7	0,65
	Zinc	–	0,7

[a] *t* prevents puncture, hot spot or ignition.

[b] *t´* only for metal sheets if it is not important to prevent puncture, hot spot or ignition problems.

b) Metal components of roof construction (trusses, interconnected reinforcing steel, etc.), underneath non-metallic roofing, provided that this latter part can be excluded from the structure to be protected.

c) Metal parts such as ornamentation, railings, pipes, coverings of parapets, etc., with cross-sections not less than that specified for standard air-termination components.

d) Metal pipes and tanks on the roof, provided that they are constructed of material with thicknesses and cross-sections in accordance with Table 6.

e) Metal pipes and tanks carrying readily-combustible or explosive mixtures, provided that they are constructed of material with thickness not less than the appropriate value of *t* given in Table 3 and that the temperature rise of the inner surface at the point of strike does not constitute a danger (for detailed information, see Annex E).

If the conditions for thickness are not fulfilled, the pipes and tanks shall be integrated into the structure to be protected.

Piping carrying readily-combustible or explosive mixtures shall not be considered as an air-termination natural component if the gasket in the flange couplings is not metallic or if the flange-sides are not otherwise properly bonded.

NOTE A thin coating of protective paint or about 1 mm asphalt or 0,5 mm PVC is not regarded as an insulator. Detailed information is given in Annex E.

5.3 Down-conductor systems

5.3.1 General

In order to reduce the probability of damage due to lightning current flowing in the LPS, the down-conductors shall be arranged in such a way that from the point of strike to earth:

a) several parallel current paths exist;
b) the length of the current paths is kept to a minimum;
c) equipotential bonding to conducting parts of the structure is performed according to the requirements of 6.2.

NOTE 1 Lateral connection of down-conductors at ground level and every 10 m to 20 m of height, in accordance with Table 4, is considered to be good practice.

The geometry of the down-conductors and of the ring conductors affects the separation distance (see 6.3).

NOTE 2 The installation of as many down-conductors as possible, at equal spacing around the perimeter interconnected by ring conductors, reduces the probability of dangerous sparking and facilitates the protection of internal installations (see IEC 62305-4). This condition is fulfilled in metal framework structures and in reinforced concrete structures in which the interconnected steel is electrically continuous.

Typical values of the distance between down-conductors and between horizontal ring conductors are given in Table 4.

More information on partitioning of the lightning current amongst down-conductors is given in Annex C.

5.3.2 Positioning for an isolated LPS

a) If the air-termination consists of rods on separate masts (or one mast) not made of metal or interconnected reinforcing steel, at least one down-conductor is needed for each mast. No additional down-conductors are required for masts made of metal or interconnected reinforcing steel.

   NOTE In several countries, the use of reinforced concrete as a part of the LPS is not allowed.

b) If the air-termination consists of catenary wires (or one wire), at least one down-conductor is needed at each supporting structure.
c) If the air-termination forms a network of conductors, one down-conductor is needed at least at each supporting wire end.

5.3.3 Positioning for a non-isolated LPS

For each non-isolated LPS the number of down-conductors shall be not less than two and should be distributed around the perimeter of the structure to be protected, subject to architectural and practical constraints.

An equal spacing of the down-conductors is preferred around the perimeter. Typical values of the distance between down-conductors are given in Table 4.

NOTE The value of the distance between down-conductors is correlated with the separation distance given in 6.3.

Table 4 – Typical values of the distance between down-conductors and between ring conductors according to the class of LPS

Class of LPS	Typical distances m
I	10
II	10
III	15
IV	20

A down-conductor should be installed at each exposed corner of the structure, where this is possible.

5.3.4 Construction

The down-conductors shall be installed so that, as far as practicable, they form a direct continuation of the air-termination conductors.

Down-conductors shall be installed straight and vertical such that they provide the shortest and most direct path to earth. The formation of loops shall be avoided, but where this is not possible, the distance s, measured across the gap between two points on the conductor and the length l of the conductor between those points (see Figure 1) shall conform to 6.3.

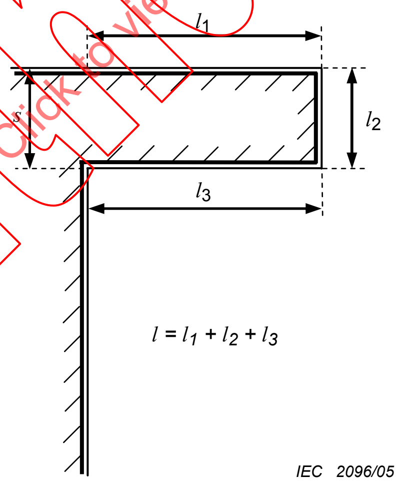


Figure 1 – Loop in a down-conductor

Down-conductors shall not be installed in gutters or down-spouts even if they are covered by insulating material.

NOTE The effects of moisture in the gutters lead to intensive corrosion of the down-conductor. It is recommended that the down-conductors be positioned such that a separation distance in accordance with 6.3 is provided between them and any doors and windows.

Down-conductors of an LPS not isolated from the structure to be protected may be installed as follows:

– if the wall is made of non-combustible material, the down-conductors may be positioned on the surface or in the wall;

– if the wall is made of readily-combustible material the down-conductors may be positioned on the surface of the wall, provided that their temperature rise due to the passage of lightning current is not dangerous for the material of the wall;

– if the wall is made of readily-combustible material and the temperature rise of down-conductors is dangerous, the down-conductors shall be placed in such a way that the distance between them and the wall is always greater than 0,1 m. Mounting brackets may be in contact with the wall.

When the distance from down-conductor to a combustible material cannot be assured, the cross-section of the conductor shall be not less than 100 mm^2.

5.3.5 Natural components

The following parts of the structure should be considered as natural down-conductors:

a) the metal installations provided that

   – the electrical continuity between the various parts is made durable in accordance with 5.5.2,

   – their dimensions are at least equal to that specified in Table 6 for standard down-conductors.

   Piping carrying readily-combustible or explosive mixtures shall not be considered as a down-conductor natural component if the gasket in the flange couplings is not metallic or if the flange-sides are not otherwise properly bonded.

   NOTE 1 Metal installations may be clad with insulating material.

b) the metal of the electrically-continuous reinforced concrete framework of the structure;

   NOTE 2 With prefabricated reinforced concrete, it is important to establish interconnection points between the reinforcing elements. It is also important that reinforced concrete contains a conductive connection between the interconnection points. The individual parts should be connected on-site during assembly (see Annex E).

   NOTE 3 In the case of pre-stressed concrete, attention should be paid to the risk of causing unacceptable mechanical consequences, due either to lightning current or as a result of the connection to the lightning protection system.

c) the interconnected steel framework of the structure;

   NOTE 4 Ring conductors are not necessary if the metal framework of steel structures or the interconnected reinforcing steel of the structure is used as down-conductors.

d) the facade elements, profile rails and metallic sub-constructions of facades, provided that

   – their dimensions conform to the requirements for down-conductors (see 5.6.2) and that for metal sheets or metal pipes thicknesses shall be not less than 0,5 mm,

   – their electrical continuity in a vertical direction conforms to the requirements of 5.5.2.

NOTE 5 For more information, see Annex E.

5.3.6 Test joints

At the connection of the earth termination, a test joint should be fitted on each down-conductor, except in the case of natural down-conductors combined with foundation earth electrodes.

For measuring purposes, the joint shall be capable of being opened with the aid of a tool. In normal use it shall remain closed.

5.4 Earth-termination system

5.4.1 General

When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous overvoltages, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 Ω when measured at low frequency) is recommended.

From the viewpoint of lightning protection, a single integrated structure earth-termination system is preferable and is suitable for all purposes (i.e. lightning protection, power systems and telecommunication systems).

Earth-termination systems shall be bonded in accordance with the requirements of 6.2.

NOTE 1 The conditions of separation and bonding of other earth-termination systems are usually determined by the appropriate national authorities.

NOTE 2 Serious corrosion problems can occur when earthing systems made of different materials are connected to each other.

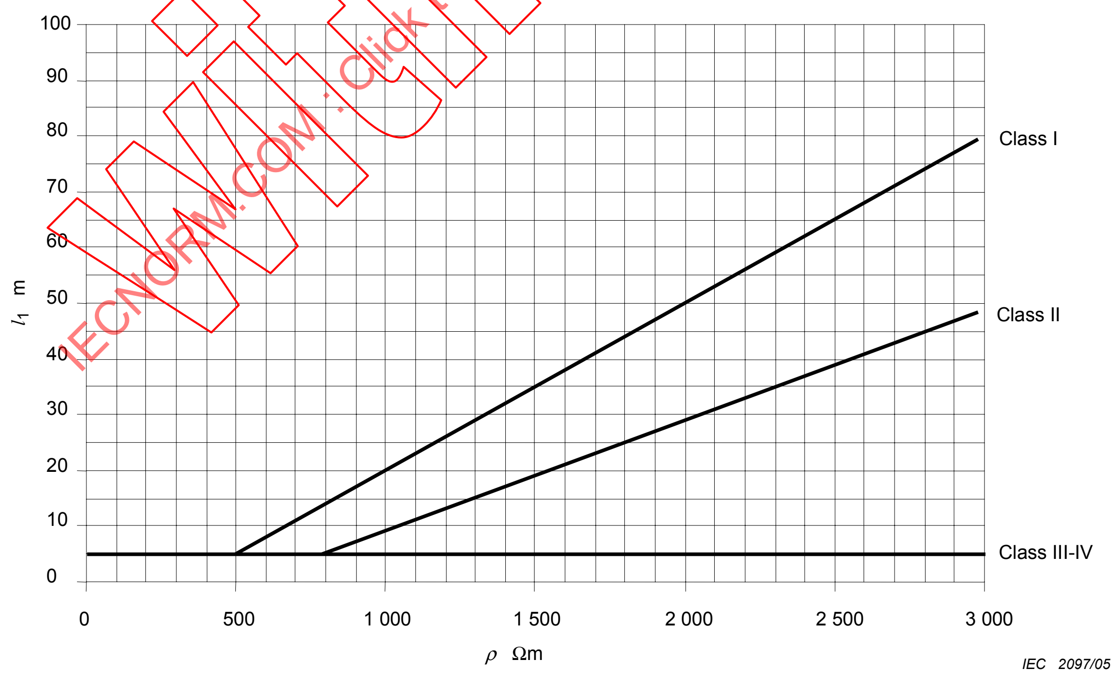
5.4.2 Earthing arrangement in general conditions

For earth-termination systems, two basic types of earth electrode arrangements apply.

5.4.2.1 Type A arrangement

This type of arrangement comprises horizontal or vertical earth electrodes installed outside the structure to be protected connected to each down-conductor.

In type A arrangements, the total number of earth electrodes shall be not less than two.



NOTE Classes III and IV are independent of soil resistivity.

Figure 2 – Minimum length l_1 of each earth electrode according to the class of LPS

The minimum length of each earth electrode at the base of each down-conductor is

– l_1 for horizontal electrodes, or
– 0,5 l_1 for vertical (or inclined) electrodes,

where l_1 is the minimum length of horizontal electrodes shown in the relevant part of Figure 2.

For combined (vertical or horizontal) electrodes, the total length shall be considered.

The minimum lengths stated in Figure 2 may be disregarded provided that an earthing resistance of the earth-termination system less than 10 Ω (measured at a frequency different from the power frequency and its multiple in order to avoid interference) is achieved.

NOTE 1 Reduction of earthing resistance by the extension of earth electrodes is practically possible up to 60 m.

NOTE 2 For further information, refer to Annex E.

5.4.2.2 Type B arrangement

This type of arrangement comprises either a ring conductor external to the structure to be protected, in contact with the soil for at least 80 % of its total length, or a foundation earth electrode. Such earth electrodes may also be meshed.

For the ring earth electrode (or foundation earth electrode), the mean radius r_e of the area enclosed by the ring earth electrode (or foundation earth electrode) shall be not less than the value l_1:

$$r_e \geq l_1 \tag{1}$$

where l_1 is represented in Figure 2 according to LPS class I, II, III and IV.

When the required value of l_1 is larger than the convenient value of r_e, additional horizontal or vertical (or inclined) electrodes shall be added with individual lengths l_r (horizontal) and l_v (vertical) given by the following equations:

$$l_r = l_1 - r_e \tag{2}$$

and

$$l_v = (l_1 - r_e)/2 \tag{3}$$

It is recommended that the number of electrodes shall be not less than the number of the down-conductors, with a minimum of two.

The additional electrodes should be connected to the ring earth electrode at points where the down-conductors are connected and, for as many as possible, equidistantly.

5.4.3 Installation of earth electrodes

The ring earth electrode (type B arrangement) should preferably be buried at a depth of at least 0,5 m and at a distance of about 1 m around the external walls.

The earth electrodes (type A arrangement) shall be installed at a depth of upper end at least 0,5 m and distributed as uniformly as possible to minimize electrical coupling effects in the earth.

Earth electrodes shall be installed in such a way as to allow inspection during construction.

The embedded depth and the type of earth electrodes shall be such as to minimize the effects of corrosion, soil drying and freezing and thereby stabilize the conventional earth resistance. It is recommended that the upper part of a vertical earth electrode equal to the depth of freezing soil should not be regarded as being effective under frost conditions.

NOTE Hence, for every vertical electrode, 0,5 m should be added to the value of the length l_1, calculated in 5.4.2.1 and 5.4.2.2.

For bare solid rock, only type B earthing arrangement is recommended.

For structures with extensive electronic systems or with high risk of fire (see IEC 62305-2), type B earthing arrangement is preferable.

5.4.4 Natural earth electrodes

Interconnected reinforcing steel in concrete foundations in accordance with 5.6, or other suitable underground metal structures, should preferably be used as an earth electrode. When the metallic reinforcement in concrete is used as an earth electrode, special care shall be exercised at the interconnections to prevent mechanical splitting of the concrete.

NOTE 1 In the case of pre-stressed concrete, consideration should be given to the consequences of the passage of lightning discharge currents which may produce unacceptable mechanical stresses.

NOTE 2 If a foundation earth electrode is used, a long-term increase in earthing resistance is possible.

NOTE 3 More extensive information on this topic is reported in Annex E.

5.5 Components

Components of an LPS shall withstand the electromagnetic effects of lightning current and predictable accidental stresses without being damaged.

Components of an LPS shall be manufactured from the materials listed in Table 5 or from other materials with equivalent mechanical, electrical and chemical (corrosion) performance characteristics.

NOTE Components made of material other than metal may be used for fixing.

Table 5 – LPS materials and conditions of use

Material	Use			Corrosion		
	In open air	In earth	In concrete	Resistance	Increased by	May be destroyed by galvanic coupling with
Copper	Solid Stranded	Solid Stranded As coating	Solid Stranded As coating	Good in many environments	Sulphur compounds Organic materials	–
Hot galvanized steel	Solid Stranded	Solid	Solid Stranded	Acceptable in air, in concrete and in benign soil	High chlorides content	Copper
Stainless steel	Solid Stranded	Solid Stranded	Solid Stranded	Good in many environments	High chlorides content	–
Aluminium	Solid Stranded	Unsuitable	Unsuitable	Good in atmospheres containing low concentrations of sulphur and chloride	Alkaline solutions	Copper
Lead	Solid As coating	Solid As Coating	Unsuitable	Good in atmosphere with high concentration of sulphates	Acid soils	Copper Stainless steel

NOTE 1 This table gives general guidance only. In special circumstances more careful corrosion immunity considerations are required (see Annex E).

NOTE 2 Stranded conductors are more vulnerable to corrosion than solid conductors. Stranded conductors are also vulnerable where they enter or exit earth/concrete positions. This is the reason why stranded galvanized steel is not recommended in earth.

NOTE 3 Galvanized steel may be corroded in clay soil or moist soil.

NOTE 4 Galvanized steel in concrete should not extend into the soil due to possible corrosion of the steel just outside the concrete.

NOTE 5 Galvanized steel in contact with reinforcement steel in concrete may, under certain circumstances, cause damage to the concrete.

NOTE 6 Use of lead in the earth is often banned or restricted due to environmental concerns.

5.5.1 Fixing

Air-terminations and down-conductors shall be firmly fixed so that the electrodynamic or accidental mechanical forces (for instance vibrations, slipping of slabs of snow, thermal expansion, etc.) will not cause conductors to break or loosen (see Annex D of IEC 62305-1).

5.5.2 Connections

The number of connections along the conductors shall be kept to a minimum. Connections shall be made secure by such means as brazing, welding, clamping, crimping, seaming, screwing or bolting.

Connections of steelwork within reinforced concrete structures shall conform to 4.3.

5.6 Materials and dimensions

5.6.1 Materials

Material and its dimensions shall be chosen bearing in mind the possibility of corrosion either of the structure to be protected or of the LPS.

5.6.2 Dimensions

Configurations and minimum cross-sectional areas of air-termination conductors, air-termination rods and down-conductors are given in Table 6.

Configurations and minimum dimensions of earth electrodes are given in Table 7.

Table 6 – Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods and down-conductors

Material	Configuration	Minimum cross-sectional area mm^2	Comments [10]
Copper	Solid tape	50 [8]	2 mm min. thickness
	Solid round [7]	50 [8]	8 mm diameter
	Stranded	50 [8]	1,7 mm min. diameter of each strand
	Solid round [3], [4]	200 [8]	16 mm diameter
Tin plated copper [1]	Solid tape	50 [8]	2 mm min. thickness
	Solid round [7]	50 [8]	8 mm diameter
	Stranded	50 [8]	1,7 mm min. diameter of each strand
Aluminium	Solid tape	70	3 mm min. thickness
	Solid round	50 [8]	8 mm diameter
	Stranded	50 [8]	1,7 mm min. diameter of each strand
Aluminium alloy	Solid tape	50 [8]	2,5 mm min. thickness
	Solid round	50	8 mm diameter
	Stranded	50 [8]	1,7 mm min. diameter of each strand
	Solid round [3]	200 [8]	16 mm diameter
Hot dipped galvanized steel [2]	Solid tape	50 [8]	2,5 mm min. thickness
	Solid round [9]	50	8 mm diameter
	Stranded	50 [8]	1,7 mm min. diameter of each strand
	Solid round [3], [4], [9]	200 [8]	16 mm diameter
Stainless steel [5]	Solid tape [6]	50 [8]	2 mm min. thickness
	Solid round [6]	50	8 mm diameter
	Stranded	70 [8]	1,7 mm min. diameter of each strand
	Solid round [3], [4]	200 [8]	16 mm diameter

1) Hot dipped or electroplated minimum thickness coating of 1 µm.

2) The coating should be smooth, continuous and free from flux stains with a minimum thickness coating of 50 µm.

3) Applicable for air-termination rods only. For applications where mechanical stress such as wind loading is not critical, a 10 mm diameter, 1 m long maximum air-termination rod with an additional fixing may be used.

4) Applicable to earth lead-in rods only.

5) Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0,07 %.

6) For stainless steel embedded in concrete, and/or in direct contact with flammable material, the minimum sizes should be increased to 78 mm^2 (10 mm diameter) for solid round and 75 mm^2 (3 mm minimum thickness) for solid tape.

7) 50 mm^2 (8 mm diameter) may be reduced to 28 mm^2 (6 mm diameter) in certain applications where mechanical strength is not an essential requirement. Consideration should, in this case, be given to reducing the spacing of the fasteners.

8) If thermal and mechanical considerations are important, these dimensions can be increased to 60 mm^2 for solid tape and to 78 mm^2 for solid round.

9) The minimum cross-section to avoid melting is 16 mm^2 (copper), 25 mm^2 (aluminium), 50 mm^2 (steel) and 50 mm^2 (stainless steel) for a specific energy of 10 000 kJ/Ω. For further information see Annex E.

10) Thickness, width and diameter are defined at ±10 %.

Table 7 – Material, configuration and minimum dimensions of earth electrodes

Material	Configuration	Minimum dimensions			Comments
		Earth rod ∅ mm	**Earth conductor**	**Earth plate** mm	
Copper	Stranded 3)		50 mm²		1,7 mm min. diameter of each strand
	Solid round 3)		50 mm²		8 mm diameter
	Solid tape 3)		50 mm²		2 mm min. thickness
	Solid round	15 8)			
	Pipe	20			2 mm min. wall thickness
	Solid plate			500 x 500	2 mm min. thickness
	Lattice plate			600 x 600	25 mm x 2 mm section Minimum length of lattice configuration: 4,8 m
Steel	Galvanized solid round 1) 2)	16 9)	10 mm diameter		
	Galvanized pipe 1) 2)	25			2 mm min. wall thickness
	Galvanized solid tape 1)		90 mm²		3 mm min. thickness
	Galvanized solid plate 1)			500 x 500	3 mm min. thickness
	Galvanized lattice plate 1)			600 x 600	30 mm x 3 mm section
	Copper coated solid round 4)	14			250 µm minimum radial Copper coating 99,9 % copper content
	Bare solid round 5)		10 mm diameter		
	Bare or galvanized solid tape 5) 6)		75 mm²		3 mm min. thickness
	Galvanized stranded 5) 6)		70 mm²		1,7 mm min. diameter of each strand
	Galvanized cross profile 1)	50 x 50 x 3			
Stainless steel 7)	Solid round	15	10 mm diameter		
	Solid tape		100 mm²		2 mm min. thick

1) The coating shall be smooth, continuous and free from flux stains with a minimum thickness of 50 µm for round and 70 µm for flat material.

2) Threads shall be machined prior to galvanizing.

3) May also be tin-plated.

4) The copper should be intrinsically bonded to the steel.

5) Only allowed when completely embedded in concrete.

6) Only allowed when correctly connected together at least every 5 m with the natural reinforcement steel of the earth touching part of the foundation.

7) Chromium ≥ 16 %, nickel ≥ 5 %, molybdenum ≥ 2 %, carbon ≤ 0,08 %.

8) In some countries 12 mm is allowed.

9) Earth lead in rods are used in some countries to connect the down-conductor to the point where it enters the ground.

6 Internal lightning protection system

6.1 General

The internal LPS shall avoid the occurrence of dangerous sparking within the structure to be protected due to lightning current flowing in the external LPS or in other conductive parts of the structure.

Dangerous sparking may occur between the external LPS and other components such as:

– the metal installations;
– the internal systems;
– the external conductive parts and lines connected to the structure.

NOTE 1 Sparking occurring within the structure with danger of explosion is always dangerous. In this case additional protective measures are required which are under consideration (see Annex E).

NOTE 2 For protection against overvoltages of internal systems, refer to IEC 62305-4.

Dangerous sparking between different parts can be avoided by means of

– equipotential bonding in accordance with 6.2, or
– electrical insulation between the parts in accordance with 6.3.

6.2 Lightning equipotential bonding

6.2.1 General

Equipotentialization is achieved by interconnecting the LPS with

– structural metal parts,
– metal installations,
– internal systems,
– external conductive parts and lines connected to the structure.

When lightning equipotential bonding is established to internal systems, part of the lightning current may flow into such systems and this effect shall be taken into account.

Interconnecting means can be

– bonding conductors, where the electrical continuity is not provided by natural bonding,
– surge protective devices (SPDs), where direct connections with bonding conductors is not feasible.

The manner in which lightning equipotential bonding is achieved is important and shall be discussed with the operator of the telecommunication network, the electric power operator, and other operators or authorities concerned, as there may be conflicting requirements.

SPDs shall be installed in such a way that they can be inspected.

NOTE When an LPS is installed, metalwork external to the structure to be protected may be affected. This should be considered when designing such systems. Lightning equipotential bonding for external metalwork may also be necessary.

6.2.2 Lightning equipotential bonding for metal installations

In the case of an isolated external LPS, lightning equipotential bonding shall be established at ground level only.

For an external LPS which is not isolated, lightning equipotential bonding shall be installed at the following locations:

a) in the basement or approximately at ground level. Bonding conductors shall be connected to a bonding bar constructed and installed in such a way that it allows easy access for inspection. The bonding bar shall be connected to the earth-termination system. For large structures (typically more than 20 m in length), more than one bonding bar can be installed, provided that they are interconnected;

b) where insulation requirements are not fulfilled (see 6.3).

Lightning equipotential bonding connections shall be made as direct and straight as possible.

NOTE When lightning equipotential bonding is established to conducting parts of the structure, part of the lightning current may flow into the structure and this effect should be taken into account.

The minimum values of the cross-section of the bonding conductors connecting different bonding bars and of the conductors connecting the bars to the earth-termination system are listed in Table 8.

The minimum values of the cross-section of the bonding conductors connecting internal metal installations to the bonding bars are listed in Table 9.

Table 8 – Minimum dimensions of conductors connecting different bonding bars or connecting bonding bars to the earth-termination system

Class of LPS	Material	Cross-section mm^2
I to IV	Copper	14
	Aluminium	22
	Steel	50

Table 9 – Minimum dimensions of conductors connecting internal metal installations to the bonding bar

Class of LPS	Material	Cross-section mm^2
I to IV	Copper	5
	Aluminium	8
	Steel	16

If insulating pieces are inserted into gas lines or water pipes, inside the structure to be protected they shall, with the agreement of the water and gas supplier, be bridged by SPDs designed for such an operation.

SPDs shall have the following characteristics:

– class I test;

– $I_{imp} \geq k_c I$ with $k_c I$ being the lightning current flowing along the relevant part of the external LPS (see Annex C);

– the protection level U_P shall be lower than the impulse withstand level of insulation between parts;

– other characteristics conforming to IEC 61643-12.

6.2.3 Lightning equipotential bonding for external conductive parts

For external conductive parts, lightning equipotential bonding shall be established as near as possible to the point of entry into the structure to be protected.

Bonding conductors shall be capable of withstanding the part I_f of the lightning current flowing through them evaluated in accordance with Annex E of IEC 62305-1.

If direct bonding is not acceptable, SPDs with the following characteristics shall be used:

– class I test;

– $I_{imp} \geq I_f$ with I_f being the lightning current flowing along the considered external conductive part (see Annex E of IEC 62305-1);

– the protection level U_P shall be lower than the impulse withstand level of insulation between parts;

– other characteristics conforming to IEC 61643-12.

NOTE When equipotential bonding is required, but an LPS is not required, the earth-termination of the low voltage electrical installation can be used for this purpose. IEC 62305-2 provides information on the conditions where an LPS is not required.

6.2.4 Lightning equipotential bonding for internal systems

It is imperative that lightning equipotential bonding is installed in accordance with 6.2.2 a) and 6.2.2 b).

If the internal systems conductors are screened or located in metal conduits, it may be sufficient to bond only these screens and conduits (see Annex B).

NOTE Bonding of screens and conduits may not avoid failure due to overvoltages of equipment connected to the conductors. For protection of such equipment refer to IEC 62305-4.

If conductors of internal systems are neither screened nor located in metal conduits, they shall be bonded via SPDs. In TN systems, PE and PEN conductors shall be bonded to the LPS directly or with a SPD.

Bonding conductors and SPDs shall have the same characteristics as indicated in 6.2.2.

If protection of internal systems against surges is required, a “coordinated SPD protection” conforming to the requirements of IEC 62305-4, Clause 7 shall be used.

6.2.5 Lightning equipotential bonding for lines connected to the structure to be protected

Lightning equipotential bonding for electrical and telecommunication lines shall be installed in accordance with 6.2.3.

All the conductors of each line should be bonded directly or with an SPD. Live conductors shall only be bonded to the bonding bar via an SPD. In TN systems, PE or PEN conductors shall be bonded directly or via SPD to the bonding bar.

If lines are screened or routed into metal conduits, these screens and conduits shall be bonded; lightning equipotential bonding for conductors is not necessary provided that the cross-section S_c of these screens or conduits is not lower than the minimum value S_{cmin} evaluated in accordance with Annex B.

Lightning equipotential bonding of the cable screens or of the conduits shall be performed near the point where they enter the structure.

Bonding conductors and SPDs shall have the same characteristics as indicated in 6.2.3.

If protection against surges of internal systems connected to lines entering the structure is required, a "coordinated SPD protection" conforming to the requirements of IEC 62305-4, Clause 7 shall be used.

NOTE 1 When equipotential bonding is required, but an LPS is not required, the earth-termination of the low voltage electrical installation can be used for this purpose. IEC 62305-2 provides information on the conditions where an LPS is not required.

NOTE 2 For more information concerning equipotential bonding for telecommunication lines, see also IEC 62305-5.

6.3 Electrical insulation of the external LPS

The electrical insulation between the air-termination or the down-conductor and the structural metal parts, the metal installations and the internal systems can be achieved by providing a distance d between the parts greater than the separation distance s:

$$s = k_i \frac{k_c}{k_m} l \qquad (4)$$

where

k_i depends on the selected class of LPS (see Table 10);

k_c depends on the lightning current flowing on the down-conductors (see Table 11);

k_m depends on the electrical insulation material (see Table 12);

l is the length, in metres, along the air-termination or the down-conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point.

Table 10 – Isolation of external LPS – Values of coefficient k_i

Class of LPS	k_i
I	0,08
II	0,06
III and IV	0,04

Table 11 – Isolation of external LPS – Values of coefficient k_c

Number of down-conductors n	Detailed values (see Table C.1) k_c
1	1
2	1 … 0,5
4 and more	1 … 1/n

Table 12 – Isolation of external LPS – Values of coefficient k_m

Material	k_m
Air	1
Concrete, bricks	0,5
NOTE 1 When there are several insulating materials in series, it is good practice to use the lower value for k_m.	
NOTE 2 The use of other insulating materials is under consideration.	

In the case of the lines or external conductive parts connected to the structure, it is always necessary to ensure lightning equipotential bonding (by direct connection or connection by SPD) at their point of entry in the structure.

In structures with metallic or electrically continuous, connected, reinforced, concrete framework of the structures, a separation distance is not required.

7 Maintenance and inspection of an LPS

7.1 Application of inspections

The objective of the inspections is to ascertain that

a) the LPS conforms to the design based on this standard,

b) all components of the LPS are in good condition and capable of performing their designed functions, and that there is no corrosion,

c) any recently added services or constructions are incorporated into the LPS.

7.2 Order of inspections

Inspections should be made according to 7.1 as follows:

– during the construction of the structure, in order to check the embedded electrodes;

– after the installation of the LPS;

– periodically at such intervals as determined with regard to the nature of the structure to be protected, i.e. corrosion problems and the class of LPS;

NOTE For detailed information see Clause E.7.

– after alterations or repairs, or when it is known that the structure has been struck by lightning.

During the periodic inspection, it is particularly important to check the following:

– deterioration and corrosion of air-termination elements, conductors and connections;

– corrosion of earth electrodes;

– earthing resistance value for the earth-termination system;

– condition of connections, equipotential bonding and fixings.

7.3 Maintenance

Regular inspections are among the fundamental conditions for reliable maintenance of an LPS. The property owner shall be informed of all observed faults and they shall be repaired without delay.

8 Protection measures against injury to living beings due to touch and step voltages

8.1 Protection measures against touch voltages

In certain conditions, the vicinity of the down-conductors of an LPS, outside the structure, may be hazardous to life even if the LPS has been designed and constructed according to the above-mentioned requirements.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

a) the probability of persons approaching, or the duration of their presence outside the structure and close to the down-conductors, is very low;

b) the natural down-conductor system consists of several columns of the extensive metal framework of the structure or of several pillars of interconnected steel of the structure, with the electrical continuity assured;

c) the resistivity of the surface layer of the soil, within 3 m of the down-conductor, is not less than 5 kΩm.

NOTE A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick) generally reduces the hazard to a tolerable level.

If none of these conditions are fulfilled, protection measures shall be adopted against injury to living beings due to touch voltages as follows:

– insulation of the exposed down-conductor is provided giving a 100 kV, 1,2/50 µs impulse withstand voltage, e.g. at least 3 mm cross-linked polyethylene;

– physical restrictions and/or warning notices to minimize the probability of down-conductors being touched.

Protection measures shall conform to the relevant standards (see ISO 3864-1).

8.2 Protection measures against step voltages

In certain conditions, the vicinity of the down-conductors outside the structure may be hazardous to life even if the LPS has been designed and constructed according to the above-mentioned rules.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

a) the probability of persons approaching, or the duration of their presence in the dangerous area within 3 m from the down-conductors, is very low;

b) the resistivity of the surface layer of the soil, within 3 m of the down-conductor, is not less than 5 kΩm.

NOTE 1 A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick) generally reduces the hazard to a tolerable level.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to step voltages as follows:

– equipotentialization by means of a meshed earthing system;

– physical restrictions and/or warning notices to minimize the probability of access to the dangerous area, within 3 m of the down-conductor.

Protection measures shall conform to the relevant standards (see ISO 3864-1).

Annex A
(normative)

Positioning the air-termination system

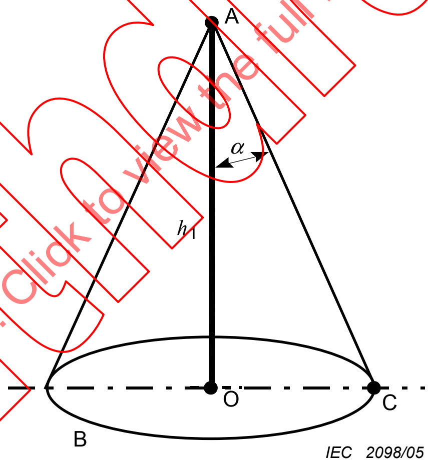
A.1 Positioning the air-termination system when utilizing the protective angle method

The position of the air-termination system is considered to be adequate if the structure to be protected is fully situated within the protected volume provided by the air-termination system.

For the determination of the volume protected only the real physical dimensions of the metal air-termination systems shall be considered.

A.1.1 Volume protected by a vertical rod air-termination system

The volume protected by a vertical rod is assumed to have the shape of a right circular cone with the vertex placed on the air-termination axis, semi-apex angle α, depending on the class of LPS, and on the height of the air-termination system as given in Table 2. Examples of the protected volume are given in Figures A.1 and A.2.



Key

A tip of an air-termination rod

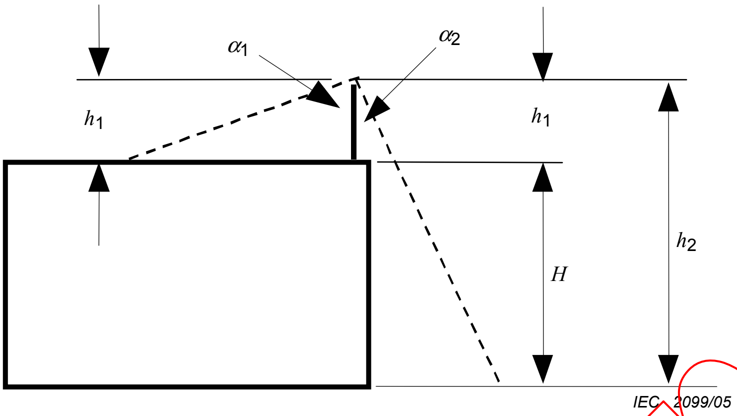
B reference plane

OC radius of protected area

h_1 height of an air-termination rod above the reference plane of the area to be protected

α protective angle according to Table 2

Figure A.1 – Volume protected by a vertical air-termination rod



Key

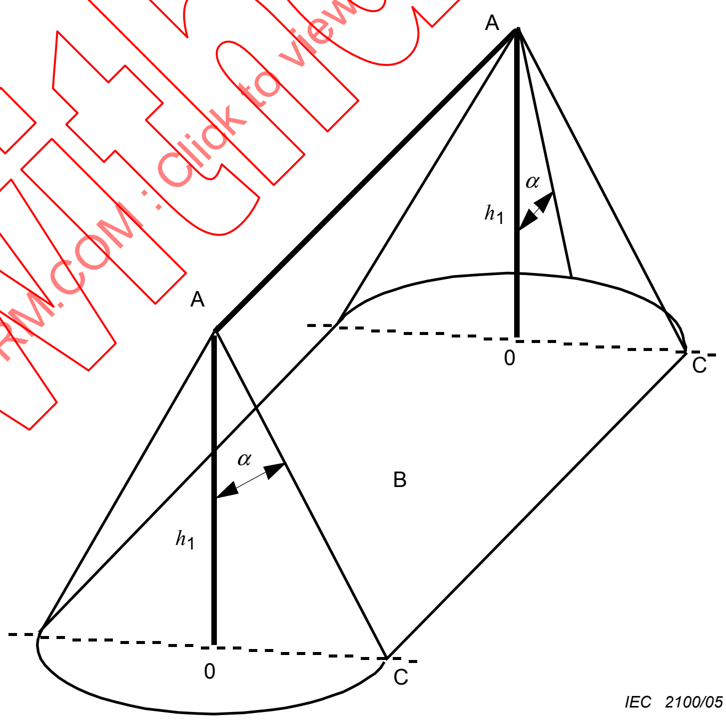
h_1 physical height of an air-termination rod

NOTE The protective angle α_1 corresponds to the air-termination height h_1, being the height above the roof surface to be protected; the protective angle α_2 corresponds to the height $h_2 = h_1 + H$, the ground being the reference plane; α_1 is related to h_1 and α_2 is related to h_2.

Figure A.2 – Volume protected by a vertical air-termination rod

A.1.2 Volume protected by a wire air-termination system

The volume protected by a wire is defined by the composition of the volume protected by virtual vertical rods having vertexes on the wire. Examples of the protected volume are given in Figure A.3.



NOTE See Figure A.1 for key.

Figure A.3 – Volume protected by a wire air-termination system

A.1.3 Volume protected by wires combined in a mesh

The volume protected by wires combined in a mesh is defined by a combination of the protected volume determined by the single conductors forming the mesh.

Examples of the volume protected by wires combined in a mesh is given in Figures A.4 and A.5.

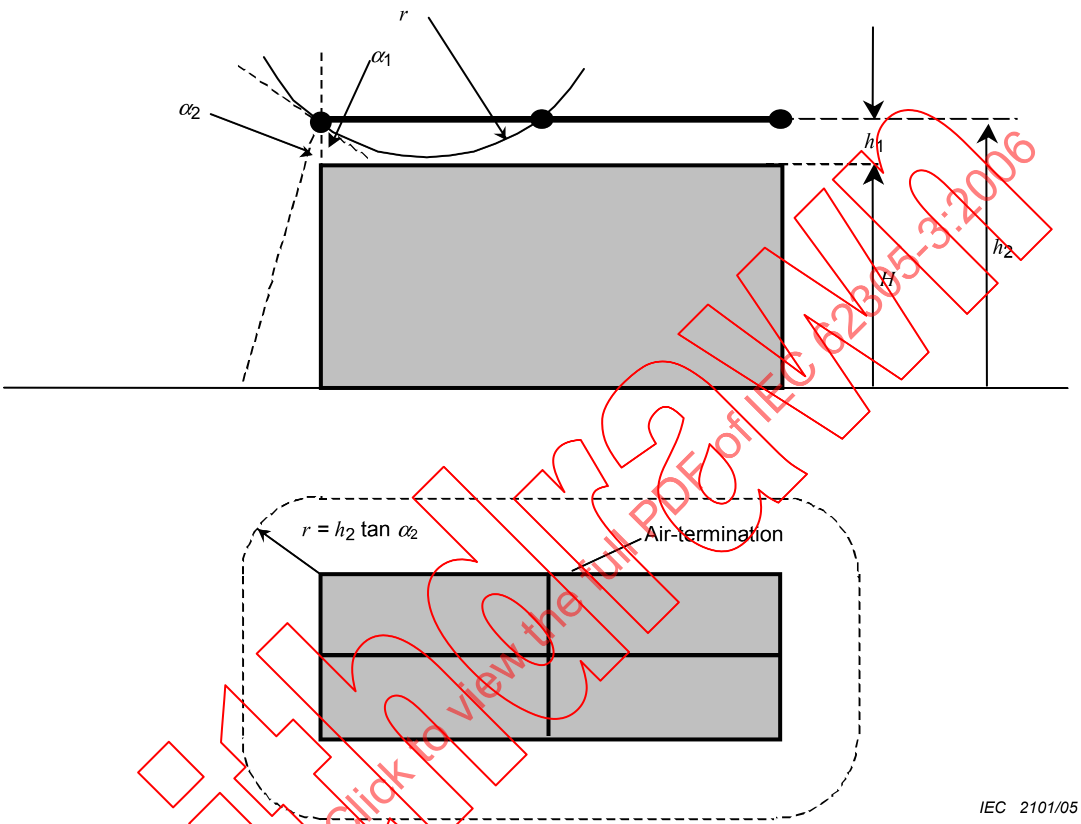
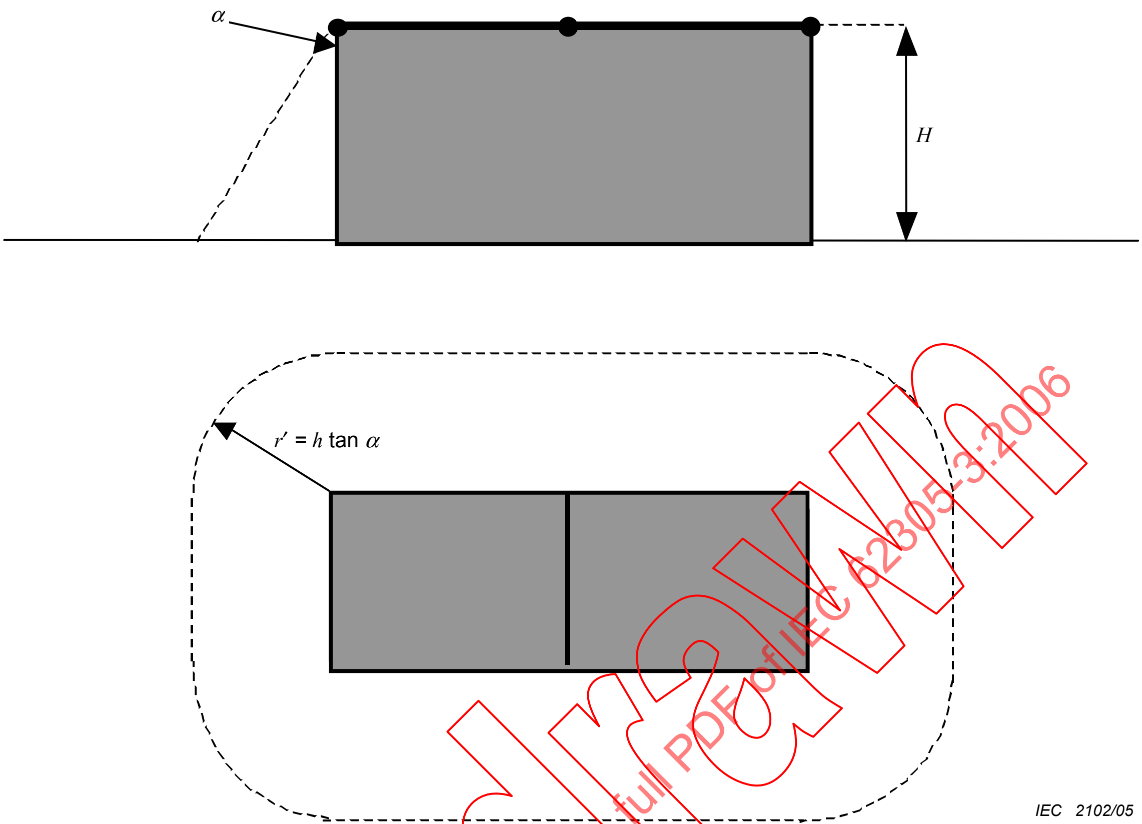


Figure A.4 – Volume protected by isolated wires combined in a mesh according to the protective angle method and rolling sphere method

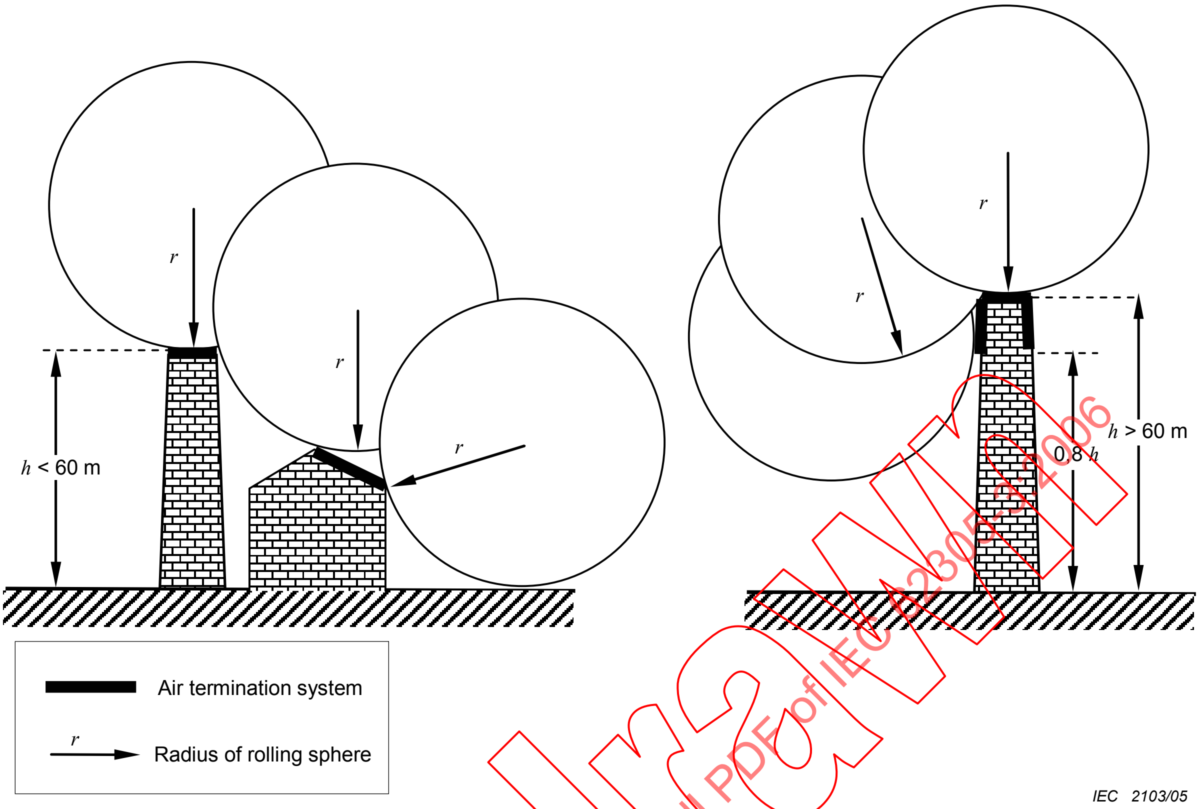


NOTE $H = h$.

Figure A.5 – Volume protected by non-isolated wires combined in a mesh according to the mesh method and the protective angle method

A.2 Positioning of the air-termination system utilizing the rolling sphere method

Applying this method, the positioning of the air-termination system is adequate if no point of the structure to be protected comes into contact with a sphere with radius, r, depending on the class of LPS (see Table 2), rolling around and on top of the structure in all possible directions. In this way, the sphere only touches the air-termination system (see Figure A.6).



NOTE 1 The rolling sphere radius r should comply with the selected class of LPS (see Table 2).

NOTE 2 $H = h$.

Figure A.6 – Design of an air-termination system according to the rolling sphere method

On all structures higher than the rolling sphere radius r, flashes to the side of structure may occur. Each lateral point of the structure touched by the rolling sphere is a possible point of strike. However, the probability for flashes to the sides is generally negligible for structures lower than 60 m.

For taller structures, the major part of all flashes will hit the top, horizontal leading edges and corners of the structure. Only a few per cent of all flashes will be to the side of the structure.

Moreover, observation data show that the probability of flashes to the sides decreases rapidly as the height of the point of strike on tall structures when measured from the ground. Therefore consideration should be given to install a lateral air-termination system on the upper part of tall structures (typically the top 20 % of the height of the structure). In this case the rolling sphere method will be applied only to the positioning of the air-termination system of the upper part of the structure.

A.3 Positioning of the air-termination system utilizing the mesh method

For the purposes of protecting flat surfaces, a mesh is considered to protect the whole surface, dependent upon all of the following conditions being fulfilled:

a) Air-termination conductors are positioned
   - on roof edge lines,
   - on roof overhangs,
   - on roof ridge lines, if the slope of the roof exceeds 1/10.

NOTE 1 The mesh method is suitable for horizontal and inclined roofs with no curvature.

NOTE 2 The mesh method is suitable for flat lateral surfaces to protect against side flashes.

NOTE 3 If the slope of the roof exceeds 1/10, parallel air-termination conductors, instead of a mesh, may be used provided the distance between the wires is not greater than the required mesh width.

b) The mesh dimensions of the air-termination network are not greater than the values given in Table 2.

c) The network of the air-termination system is constructed in such a way that the lightning current will always encounter at least two distinct metal routes to earth termination.

d) No metal installation protrudes outside the volume protected by air-termination systems.

NOTE 4 Further information can be found in Annex E.

e) The air-termination conductors follow, as far as possible, the shortest and most direct route.

Annex B
(normative)

Minimum cross-section of the entering cable screen in order to avoid dangerous sparking

The overvoltages between the active conductors and the screen of a cable may cause dangerous sparking due to the lightning current carried by the screen. The overvoltages depend on the material, the dimensions of the screen, and the length and positioning of the cable.

The minimum value S_{cmin} (in mm^2) of the cross-sectional area of the screen to avoid dangerous sparking is given by:

$$S_{c\,min} = \frac{I_f \times \rho_c \times L_c \times 10^6}{U_W} \quad (mm^2) \qquad (B.1)$$

where

I_f is the current flowing on the screen, in kA;

ρ_c is the resistivity of the screen, in Ωm;

L_c is the cable length, in m (see Table B.1);

U_w is the impulse withstand voltage of the electrical/electronic system fed by the cable, in kV.

Table B.1 – Cable length to be considered according to the condition of the screen

Condition of the screen	L_c
In contact with a soil with resistivity ρ (Ωm)	$L_c \leq 8 \times \sqrt{\rho}$
Insulated from the soil or in air	L_c distance between the structure and the closest earthing point of the screen

NOTE It should be ascertained whether an unacceptable temperature rise for the insulation of the line could occur when the lightning current flows along the line shield or the line conductors. For detailed information, see IEC 62305-4.

The limits of the current are given:

– for shielded cables, by $I_f = 8 \times S_c$; and

– for unshielded cables, by $I_f = 8 \times n' \times S'_c$

where

I_f is the current on the screen, in kA;

n' is the number of conductors;

S_c is the cross-section of the screen, in mm^2;

S'_c is the cross-section of each conductor, in mm^2.

Annex C
(informative)

Partitioning of the lightning current amongst down-conductors

The partitioning coefficient k_c of the lightning current amongst the down-conductors depends on the overall number of down-conductors n and their position, the interconnecting ring conductors, the type of air-termination system and the type of earth-termination system as indicated in Table C.1.

Table C.1 applies for type A earthing arrangements, provided that the earthing resistance of each electrode has a similar value, and for all type B earthing arrangements.

Table C.1 – Values of coefficient k_c

Type of air-termination system	Number of down-conductors n	k_c	
		Earthing arrangement type A	Earthing arrangement type B
Single rod	1	1	1
Wire	2	0,66 [d)]	0,5… 1 (see Figure C.1) [a)]
Mesh	4 and more	0,44 [d)]	0,25… 0,5 (see Figure C.2) [b)]
Mesh	4 and more, connected by horizontal ring conductors	0,44 [d)]	1/n… 0,5 (see Figure C.3) [c)]

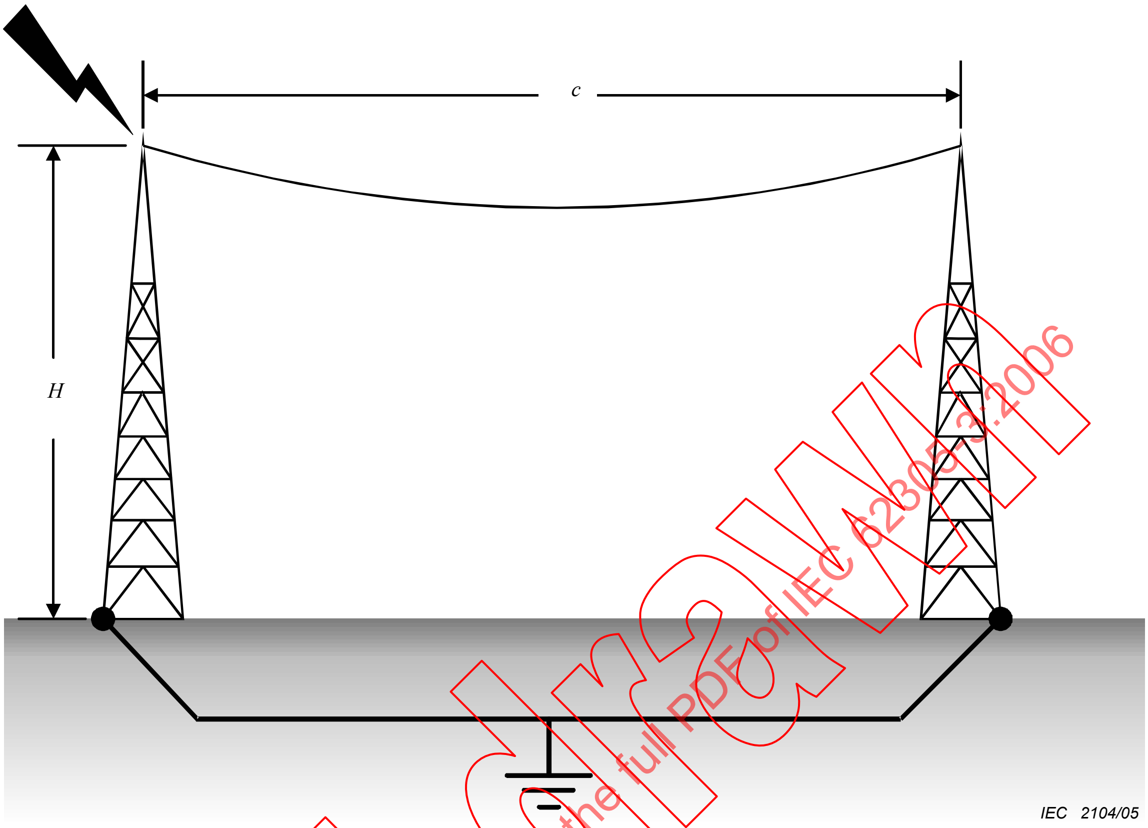
a) Values range from k_c = 0,5 where $c << h$ to k_c = 1 with $h << c$ (see Figure C.1).

b) The equation for k_c according to Figure C.2 is an approximation for cubic structures and for $n \geq 4$. The values of h, c_s and c_d are assumed to be in the range of 5 m to 20 m.

c) If the down-conductors are connected horizontally by ring conductors, the current distribution is more homogeneous in the lower parts of the down-conductor system and k_c is further reduced. This is especially valid for tall structures.

d) These values are valid for single earthing electrodes with comparable earthing resistances. If earthing resistances of single earthing electrodes are clearly different, k_c = 1 is to be assumed

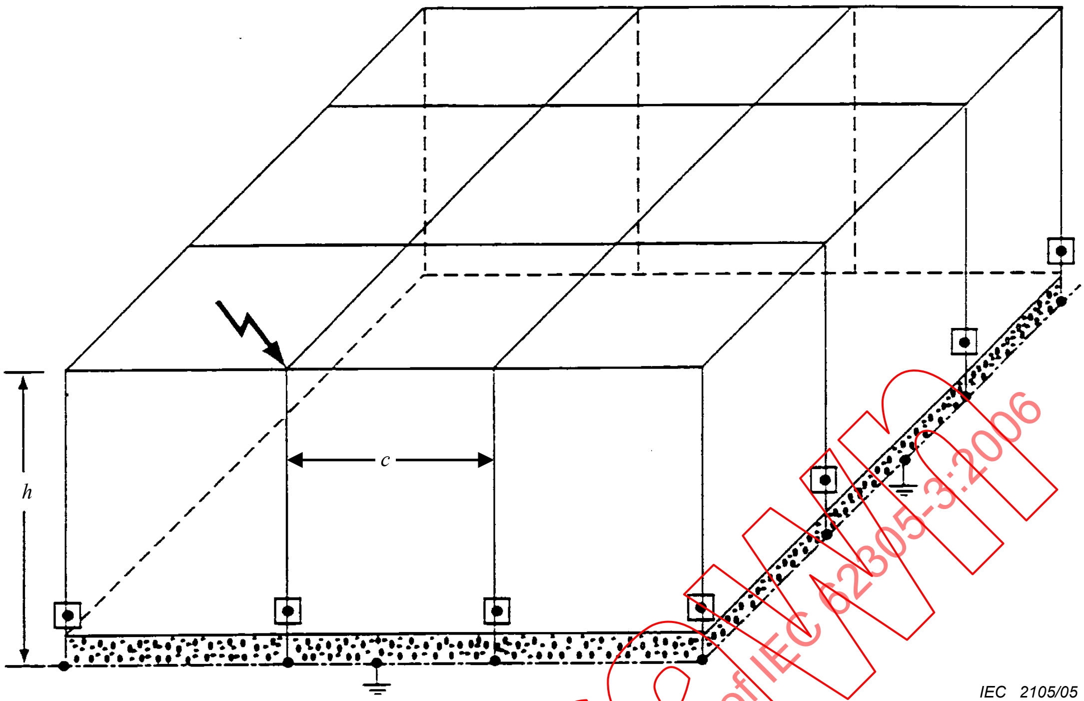
NOTE Other values of k_c may be used if detailed calculations are performed.



$$k_c = \frac{h+c}{2h+c}$$

NOTE $H = h$.

Figure C.1 – Values of coefficient k_c in the case of a wire air-termination system and a type B earth-termination system



$$k_c = \frac{1}{2n} + 0{,}1 + 0{,}2 \times \sqrt[3]{\frac{c}{h}}$$

Key

n total number of down-conductors

c distance of a down-conductor to the next down-conductor

h spacing (or height) between ring conductors

NOTE 1 For a detailed evaluation of coefficient k_c values, see Figure C.3.

NOTE 2 If internal down-conductors exist, they should be taken into account in evaluating k_c.

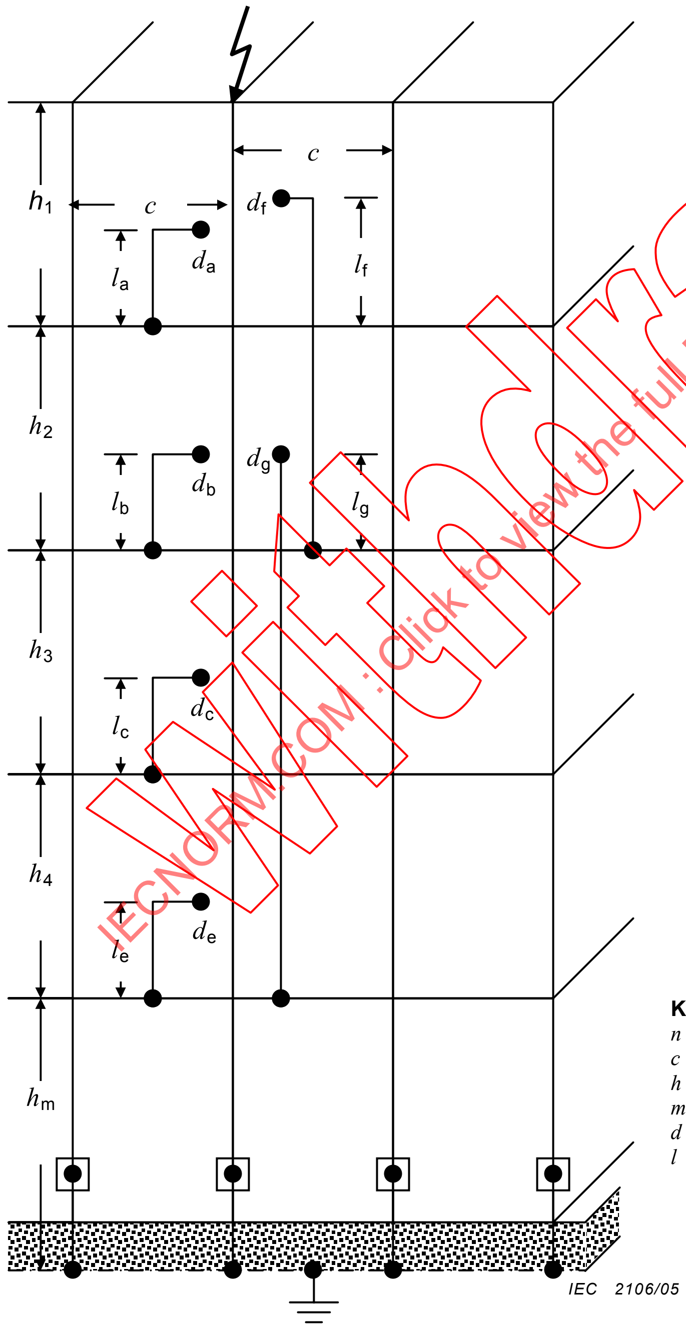
Figure C.2 – Values of coefficient k_c in the case of a mesh air-termination system and type B earth-termination system

$$d_a \geq s_a = \frac{k_i}{k_m} \times k_{c1} \times l_a \qquad d_b \geq s_b = \frac{k_i}{k_m} \times k_{c2} \times l_b \qquad d_c \geq s_c = \frac{k_i}{k_m} \times k_{c3} \times l_c$$

$$d_e \geq s_e = \frac{k_i}{k_m} \times k_{c4} \times l_e \qquad d_f \geq s_f = \frac{k_i}{k_m} \times (k_{c1} \times l_f + k_{c2} \times h_2) \qquad d_g \geq s_g = \frac{k_i}{k_m} \times (k_{c2} \times l_g + k_{c3} \times h_3 + k_{c4} \times h_4)$$

$$d_a \geq s_a = \frac{k_i}{k_m} \times k_{c1} \times l_a \qquad d_b \geq s_b = \frac{k_i}{k_m} \times k_{c2} \times l_b \qquad d_c \geq s_c = \frac{k_i}{k_m} \times k_{c3} \times l_c$$

$$d_e \geq s_e = \frac{k_i}{k_m} \times k_{c4} \times l_e \qquad d_f \geq s_f = \frac{k_i}{k_m} \times (k_{c1} \times l_f + k_{c2} \times h_2) \qquad d_g \geq s_g = \frac{k_i}{k_m} \times (k_{c2} \times l_g + k_{c3} \times h_3 + k_{c4} \times h_4)$$



$$k_c = \frac{1}{2n} + 0{,}1 + 0{,}2 \times \sqrt[3]{\frac{c}{h}}$$

$$k_{c2} = \frac{1}{n} + 0{,}1$$

$$k_{c3} = \frac{1}{n} + 0{,}01$$

$$k_{c4} = \frac{1}{n}$$

$$k_{cm} = k_{c4} = \frac{1}{n}$$

Key

n	Total number of down-conductors
c	Distance from the nearest down-conductor
h	Spacing (height) between ring conductors
m	Total number of levels
d	Distance to the nearest down-conductor
l	Height above the bonding point

Figure C.3 – Examples of calculation of the separation distance in the case of a meshed air-termination system, an interconnecting ring of the down-conductors at each level and a type B earth-termination system

Annex D
(informative)

Additional information for LPS in the case of structures with a risk of explosion

D.1 General

This annex supplies additional information for the design, construction, extension and modification of lightning protection systems for structures with a risk of explosion.

NOTE 1 Information provided in this annex is based on practically proven configurations of lightning protection systems installed in applications where a danger of explosion exists.

Where protection against lightning is required by the authority having jurisdiction, or as result of risk assessment performed in accordance with IEC 62305-2, at least a class II LPS should be adopted. Supplemental information is provided in this annex for specific applications.

NOTE 2 Exceptions to the use of lightning protection level II may be allowed when technically justified and authorized by the authority having jurisdiction. For example, the use of lightning protection level I is allowed in all cases, especially in those cases where the environments or contents within the structure are exceptionally sensitive to the effects of lightning. In addition, authorities having jurisdiction may choose to allow lightning protection level III systems where the infrequency of lightning activity and/or the insensitivity of the contents of the structure warrants such.

D.2 Additional terms and definitions

In addition to the terms and definitions of Clause 3 of this standard, the following terms and definitions are applicable to this annex.

D.2.1
isolating spark gap
component with discharge distance for isolating electrically-conductive installation sections

NOTE In the event of a lightning flash, the installation sections are temporarily connected conductively as the result of the discharge.

D.2.2
solid explosives material
solid chemical compound, mixture, or device with explosion as its primary or common purpose

D.2.3
zone 0
place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently

[IEV 426-03-03, modified]

D.2.4
zone 1
place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally

[IEV 426-03-04, modified]

D.2.5
zone 2
place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only

[IEV 426-03-05, modified]

NOTE 1 In this definition, the word "persist" means the total time for which the flammable atmosphere will exist. This will normally comprise the total of the duration of the release, plus the time taken for the flammable atmosphere to disperse after the release has stopped.

NOTE 2 Indications of the frequency of the occurrence and duration may be taken from codes relating to specific industries or applications.

D.2.6
zone 20
place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is present continuously, or for long periods, or frequently

[IEC 61241-10:1997, modified]

D.2.7
zone 21
place in which an explosive atmosphere in the form of a cloud of combustible dust in air, is likely to occur in normal operation occasionally

[IEC 61241-10:1997, modified]

D.2.8
zone 22
place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only

[IEC 61241-10:1997]

D.3 Basic requirements

D.3.1 General

The lightning protection system should be designed and installed in such a manner that, in case of a direct lightning flash, there are no melting or spraying effects except at the striking point.

NOTE Sparks or damaging impact at the striking point may also be experienced. This should be taken into consideration in the determination of air-termination device locations. Down-conductors should be installed in such a way that the auto-ignition temperature given by the source of the relative hazardous area will not be exceeded in those applications where it is not possible to install down-conductors outside of the hazardous area.

D.3.2 Required information

The lightning protection system installer/designer should be provided with drawings of the plant(s) to be protected, with the areas in which solid explosives material will be handled or stored and hazardous areas according to IEC 60079-10 and IEC 61241-10 appropriately marked.

D.3.3 Earthing

A type B arrangement for the earth-termination system, according to 5.4.2.2, is preferred for all lightning protection systems for structures with danger of explosion.

NOTE The construction of a structure may provide the effective equivalent of the ring conductor of type B arrangement (for example metallic storage tanks).

The earthing resistance of earth-termination systems for structures containing solid explosives materials and explosive mixtures should be as low as possible but not greater than 10 Ω.

D.3.4 Equipotential bonding

Lightning equipotential bonding between LPS components and other conductive installations, as well as between the components of all conductive installations, according to 6.2, should be assured inside hazardous areas and locations where solid explosive material may be present:

– at ground level;
– where the distance between the conductive parts is less than the separation distance s calculated assuming k_c = 1.

NOTE Because of dangerous partial discharges, the separation distances may only be considered in the areas without explosive mixtures. In those areas where a spark may cause ignition of the environment, additional equipotential bonding will be necessary in order to ensure no internal sparking in zone 0 and zone 20 hazardous areas.

D.4 Structures containing solid explosives material

The design of lightning protection for structures containing solid explosive material should take into consideration the sensitivity of the material in the configuration in which it is used or stored. For instance, some insensitive bulk explosive material may not require any additional consideration other than those contained within this annex. However, there are some configurations of sensitive explosive materials that may be sensitive to rapidly changing electrical fields and/or radiated by lightning impulsive electromagnetic field. It may be necessary to establish additional bonding or shielding requirements for such applications.

For structures containing solid explosive materials, an isolated external LPS (as defined in 5.1.2) is encouraged. Structures totally contained within a metallic shell of 5 mm thickness steel or equivalent (7 mm for aluminium structures) may be considered protected by a natural air-termination system as defined by 5.2.5. The earthing requirements of 5.4 are applicable for such structures.

Surge protective devices (SPDs) should be provided as part of the LPS for all locations where explosive material is present. Where practicable, SPDs should be positioned outside locations where solid explosive material is present. SPDs positioned inside locations where exposed explosives or explosive dust is present should be of explosion-proof type or contained within explosion-proof enclosures.

D.5 Structures containing hazardous areas

D.5.1 General

All parts of the external LPS (air-termination and down-conductors) should be at least 1 m away from a hazardous zone, where possible. Where this is not possible, conductors passing within 0,5 m of a hazardous zone should be continuous or connections should be made with compression fittings or by welding.

Where a hazardous area is located directly under a metal sheet that may be punctured by lightning (see 5.2.5) air-termination shall be provided in accordance with the requirements of 5.2.

D.5.1.1 Surge suppression

Surge protective devices should be positioned outside the hazardous zone where practicable. Surge protective devices positioned inside the hazardous zone should be approved for the hazardous zone in which they are installed or should be contained within an enclosure and the enclosures including surge suppression shall be approved for this service.

D.5.1.2 Equipotential bonding

In addition to the bonding requirements of D.3.4, common equipotential bonding should be provided for the lightning protection system in accordance with the normative requirements of this standard, IEC 60079-14, and IEC 61241-14.

Connections to piping should be of such a kind that, in the instance of a lightning current passage, there is no sparking. Suitable connections to piping are welded on lugs or bolts or tap holes in the flanges for taking up screws. Connections by means of clips are only allowed if, in the instance of lightning currents, ignition protection is proved by tests and procedures are utilized to ensure the reliability of the connection. Junctions should be provided for the joining of connection and earthing leads to containers and tanks.

D.5.2 Structures containing zones 2 and 22

Structures where areas defined as zones 2 and 22 exist may not require supplemental protection measures.

For production facilities made of metal (e.g. outdoor columns, reactors, containers with areas containing zones 2 and 22) of thickness and material meeting the requirements of Table 3, the following applies:

– air-termination devices and down-conductors are not required;

– production facilities should be earthed according to Clause 5.

D.5.3 Structures containing zones 1 and 21

For structures where areas defined as zones 1 and 21 exist, the requirements for zones 2 and 22 apply with the following additions:

– if there are insulation pieces in pipelines, the operator should determine the protective measures. For instance, a disruptive discharge can be avoided by the use of explosion-protected, isolating spark gaps;

– the isolating spark gaps and the insulation pieces should be inserted outside the explosion-endangered areas.

D.5.4 Structures containing zones 0 and 20

For structures where areas defined as zones 0 and 20 exist, the requirements of D.5.3 apply, supplemented by the recommendations given in this clause as applicable.

Lightning equipotential bonding connections between the lightning protection system and other installations/structures/equipment will be carried out with the agreement of the system operator. Lightning equipotential bonding connections utilizing spark gaps may not be made without the agreement of the system operator. Such devices shall be suitable for the environment in which they are installed.

For outdoor facilities with areas defined as zones 0 and 20, the requirements for zones 1, 2, 21 and 22 apply with the following additions:

– electrical equipment inside tanks containing flammable liquids should be suitable for this use. Measures for lightning protection should be taken according to the type of construction;

– closed steel containers with areas defined as zones 0 and 20 inside should have a wall thickness of at least 5 mm at the possible lightning striking points. In the case of thinner walls, air-termination devices should be installed.

D.5.5 Specific applications

D.5.5.1 Filling stations

At filling stations for cars, railways, ships etc., with hazardous areas defined as zones 2 and 22, the metal pipelines should be earthed according to Clause 5. Pipelines should be connected with steel constructions and rails, where existing (if necessary via isolating spark gaps approved for the hazardous zone in which it is installed), to take into account railway currents, stray currents, electrical train fuses, cathodic-corrosion-protected systems and the like. Decanting stations at electrical railways are subject to national standards.

D.5.5.2 Storage tanks

Certain types of structures used for the storage of liquids that can produce flammable vapours or used to store flammable gases are essentially self-protecting (contained totally within continuous metallic containers having a thickness of not less than 5 mm of steel or 7 mm of aluminium, with no spark gaps) and require no additional protection. Similarly, soil-covered tanks and pipelines do not require the installation of air-termination devices. Instrumentation or electrics used inside this equipment should be approved for this service. Measures for lightning protection should be taken according to the type of construction.

Isolated tanks or containers should be earthed according to Clause 5, depending on the greatest horizontal dimension (diameter or length):

– up to 20 m: once

– over 20 m: twice.

For tanks in tank farms (for example refineries and tank stores), the earthing of every tank at one point only is sufficient, independent of the greatest horizontal dimension. The tanks in tank farms shall be connected with each other. Beside connections according to Tables 7 and 8, pipelines, which are connected so that they are electrically-conductive according to 5.3.5, may also be used as connections.

NOTE In some countries additional requirements may exist.

In the case of floating-roof tanks, the floating-roof should be effectively bonded to the main tank shell. The design of the seals and shunts and their relative locations needs to be carefully considered so that the risk of any ignition of a possible explosive mixture by incendiary sparking is reduced to the lowest level practicable. When a rolling ladder is fitted, a flexible bonding conductor of 35 mm width should be applied across the ladder hinges, between the ladder and the top of the tank and between the ladder and the floating roof. When a rolling ladder is not fitted to the floating-roof tank, one or more, (depending on the size of the tank), flexible bonding conductors of 35 mm width, or equivalent, shall be applied between the tank shell and the floating roof. The bonding conductors should either follow the roof drain or be arranged so that they cannot form re-entrant loops. On floating roof tanks, multiple shunt connections should be provided between the floating-roof and the tank shell at about 1,5 m intervals around the roof periphery. Material selection is given by product and/or environmental requirements. Alternative means of providing an adequate conductive connection between the floating roof and tank shell for impulse currents associated with lightning discharges are only allowed if proved by tests and if procedures are utilized to ensure the reliability of the connection.

D.5.5.3 Pipelines

Overground metal pipelines outside the production facilities should be connected every 30 m to the earthing system, or should be earthed by a surface earthing electrode or an earthing rod.

The following applies for long distance lines for the transport of flammable liquids.

– in pumping sections, sliding sections and similar facilities, all lead-in piping including the metal sheath pipes should be bridged by lines with a cross-section of at least 50 mm^2;

– the bridging lines should be connected with specially welded-on lugs, or by screws which are self-loosening, secure to the flanges of the lead-in pipes. Insulating pieces should be bridged by spark gaps.

D.6 Inspection and maintenance

Recommendations on the inspection and maintenance of lightning protection systems are provided in Clause E.7.

Annex E
(informative)

Guidelines for the design, construction, maintenance and inspection of lightning protection systems

E.1 General

This annex provides guidance on the physical design and construction, maintenance and inspection of an LPS conforming to this standard.

This annex should be used and is only valid together with other parts of this standard.

Examples are given of protection techniques, which have the approval of international experts.

NOTE The examples given in this annex illustrate one possible method of achieving protection. Other methods may be equally valid.

E.2 Structure of this annex

In this annex the main clause numbers mirror the clause numbers of the main document. This gives an easy reference between the two parts.

To achieve this goal, Clause E.3 is not used in this annex.

E.3 Vacant

E.4 Design of lightning protection systems (LPS)

E.4.1 General remarks

The construction of an LPS for an existing structure should always be weighed against other measures of lightning protection conforming to this standard which give the same protection level for reduced costs. For selection of the most suitable protection measures, IEC 62305-2 applies.

The LPS should be designed and installed by LPS designers and installers.

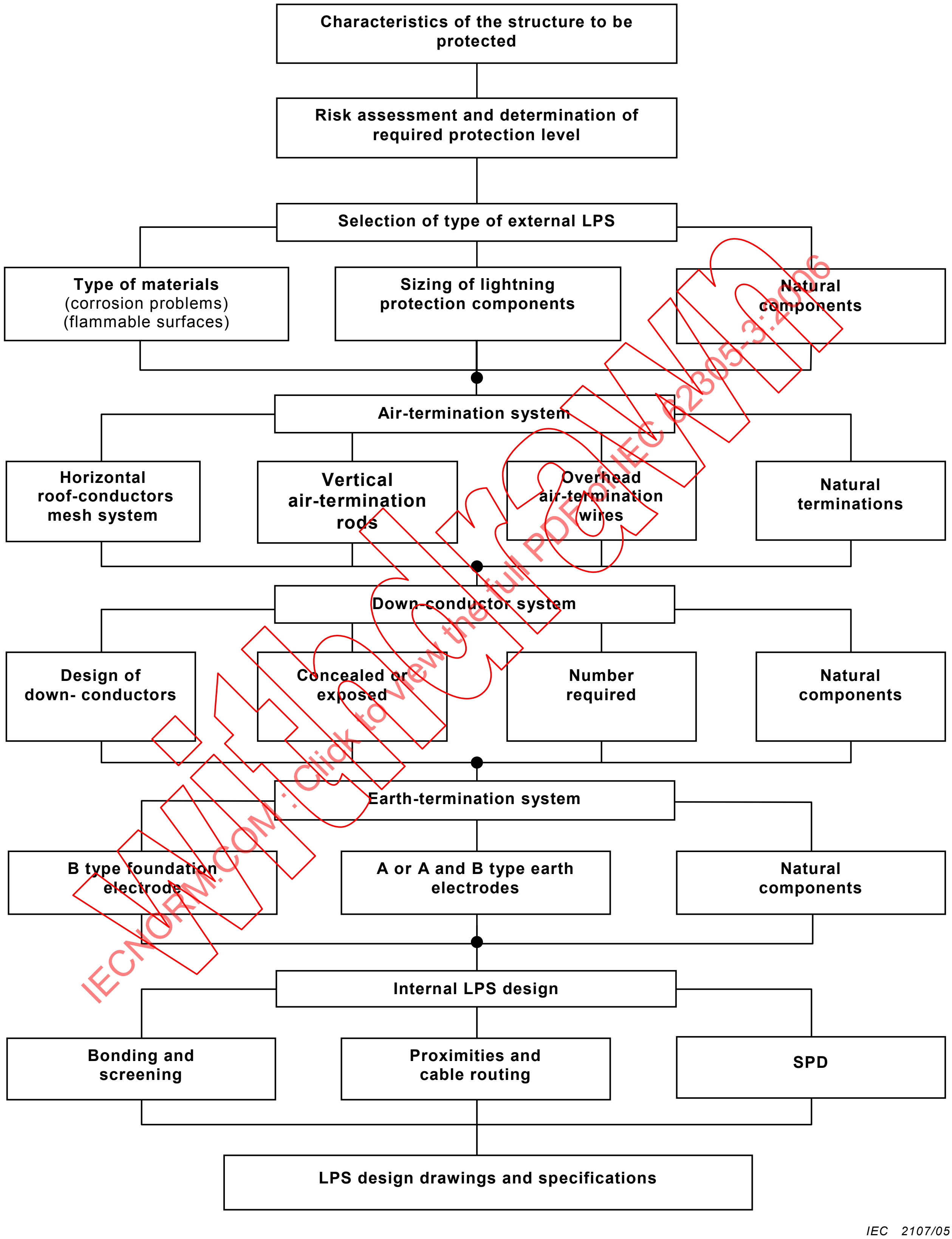
The designer and installer of an LPS should be capable of assessing both the electrical and mechanical effects of the lightning discharge and be familiar with the general principles of electromagnetic compatibility (EMC).

Furthermore, the lightning protection designer should be capable of assessing corrosion effects and judging when it is necessary to seek expert assistance.

The lightning protection installer should be trained in the proper installation of the LPS components in accordance with the requirements of this standard and the national rules regulating construction work and the building of structures.

The functions of an LPS designer and installer may be performed by the same person. A thorough knowledge of the relevant standards and several years of experience is required to become a specialized designer or installer.

Planning, implementation and testing of an LPS encompasses a number of technical fields and makes demands for coordination by all parties involved with the structure to ensure the achievement of the selected lightning protection level with minimum cost and lowest possible effort. The management of the LPS should be efficient if the steps in Figure E.1 are followed. Quality assurance measures are of great importance; in particular for structures including extensive electrical and electronic installations.



NOTE Interfaces ● require the full cooperation of the architect, engineer and lightning protection designer.

Figure E.1 – LPS design flow diagram

The quality assurance measures extend from the planning stage, in which all drawings should be approved, through the LPS construction stage during which all essential parts of the LPS inaccessible for inspection after the construction works have been finished should be checked. Quality assurance measurement continues through the acceptance stage, when final measurements on the LPS should be performed together with the completion of the final test documentation and finally through the entire lifetime of the LPS, by specifying careful periodic inspections in accordance with the maintenance programme.

Where modifications are made to a structure or its installations, a check should be made to determine whether the existing lightning protection still conforms to this standard. If it is found that the protection is inadequate, improvements should be implemented without delay.

It is recommended that the materials, extent and dimensions of the air-termination system, down-conductors, earth-termination system, bonding, components, etc. should conform to this standard.

E.4.2 Design of the LPS

E.4.2.1 Planning procedure

Before any detailed design work on the LPS is commenced, the lightning protection designer should, where reasonably practical, obtain basic information regarding the function, general design, construction and location of the structure.

Where the LPS has not already been specified by the licensing authority, insurer or purchaser, the lightning protection designer should determine whether or not to protect the structure with an LPS by following the procedures for risk assessment given in IEC 62305-2.

E.4.2.2 Consultation

E.4.2.2.1 General information

In the design and construction stages of a new structure, the LPS designer, LPS installer and all other persons responsible for installations in the structure or for regulations pertaining to the use of the structure (e.g. purchaser, architect, builder) should be in consultation regularly.

The flow diagram given in Figure E.1 will facilitate the rational design of an LPS.

In the design and construction stages of an LPS for an existing structure, consultations should be held as far as reasonably practical with the persons responsible for the structure, its use, installations and incoming services.

The consultations may have to be arranged through the owner, the building contractor of the structure or their appointed representative. For existing structures, the LPS designer should provide drawings which should be modified by the LPS installer, where necessary.

Regular consultations between the involved parties should result in an effective LPS at the lowest possible cost. For example, the coordination of LPS design work with construction work will often do away with the need for some bonding conductors and reduce the length of those which are necessary. Building costs are often reduced substantially by the provision of common routes for various installations within a structure.

Consultation is important throughout all stages of the construction of a structure as modifications to the LPS may be required due to changes in the structure design. Consultation is also necessary so that arrangements can be agreed to facilitate inspection of the parts of the LPS which will become inaccessible for visual control after the structure is completed. In these consultations, the location of all connections between natural components and the LPS should be determined. Architects are normally available to arrange and coordinate consultation meetings for new building projects.

E.4.2.2.2 The principal consulting parties

The lightning protection designer should hold relevant technical consultations with all parties involved in the design and construction of the structure, including the owner of the structure.

Particular areas of responsibility for the total installation of the LPS should be defined by the LPS designer in conjunction with the architect, electrical contractor, building contractor, the LPS installer (LPS supplier) and, where relevant, a historical adviser and the owner or owner's representative.

The clarification of responsibility for the various parties involved in the management of the design and construction of the LPS is of particular importance. An example might be where the waterproofing of the structure is punctured by roof-mounted LPS components or by earth electrode connection conductors made below the structure foundation.

E.4.2.2.2.1 Architect

Agreement should be reached with the architect on the following items:

a) routing of all LPS conductors;
b) materials for LPS components;
c) details of all metal pipes, gutters, rails and similar items;
d) details of any equipment, apparatus, plant installations, etc. to be installed on, within or near the structure which may require the moving of installations or may require bonding to the LPS because of the separation distance. Examples of installations are alarm systems, security systems, internal telecommunication systems, signal and data processing systems, radio and TV circuits;
e) the extent of any buried conductive service which could affect the positioning of the earth-termination network and be required to be placed at a safe distance from the LPS;
f) the general area available for the earth-termination network;
g) the extent of the work and the division of responsibility for primary fixings of the LPS to the structure. For example, those affecting the water tightness of the fabric (chiefly roofing), etc;
h) conductive materials to be used in the structure, especially any continuous metal which may have to be bonded to the LPS, for example stanchions, reinforcing steel and metal services either entering, leaving, or within the structure;
i) the visual impact of the LPS;
j) the impact of the LPS on the fabric of the structure;
k) the location of the connection points to the reinforcing steel, especially where they penetrate external conductive parts (pipes, cable shields, etc.);
l) the connection the LPS to the LPS of adjacent buildings.

E.4.2.2.2.2 Public utilities

Bonding of incoming services to the LPS directly or, if this is not possible, through spark gaps or SPD should be discussed with the operator or authorities concerned, as there may be conflicting requirements.

E.4.2.2.2.3 Fire and safety authorities

Agreement should be reached with the fire and safety authorities on the following items:

– the positioning of alarm and fire extinguishing system components;

– routes, construction material and sealing of ducts;

– the method of protection to be used in the case of a structure with a flammable roof.

E.4.2.2.2.4 Electronic system and external antenna installers

Agreement with the electronic system and antenna installer should be reached on the following items:

– the isolating or bonding of aerial supports and conductive shields of cables to the LPS;

– the routing of aerial cables and internal network;

– installation of surge protective devices.

E.4.2.2.2.5 Builder and installer

Agreement on the following items should be reached between the builder, installer, and those responsible for construction of the structure and its technical equipment:

a) the form, position and number of primary fixings of the LPS to be provided by the builder;

b) any fixings provided by the LPS designer (or the LPS contractor or the LPS supplier) to be installed by the builder;

c) the position of LPS conductors to be placed beneath the structure;

d) whether any components of the LPS are to be used during the construction phase, for example the permanent earth-termination network could be used for earthing cranes, hoists and other metallic items during construction work on the site;

e) for steel-framed structures, the number and position of stanchions and the form of fixing to be made for the connection of earth terminations and other components of the LPS;

f) whether metal coverings, where used, are suitable as components of the LPS;

g) the method of ensuring the electrical continuity of the individual parts of the coverings and their method of connecting them to the rest of the LPS where metal coverings are suitable as components of the LPS;

h) the nature and location of services entering the structure above and below ground including conveyor systems, television and radio aerials and their metal supports, metal flues and window cleaning gear;

i) coordination of the structure's LPS earth-termination system with the bonding of power and communication services;

j) the position and number of flag masts, roof-level plant rooms, for example lift motor rooms, ventilation, heating and air-conditioning plant rooms, water tanks and other salient features;

k) the construction to be employed for roofs and walls in order to determine appropriate methods of fixing LPS conductors, specifically with a view to maintaining the water-tightness of the structure;

l) the provision of holes through the structure to allow free passage of LPS down-conductors;

m) the provision of bonding connections to steel frames, reinforcement bars and other conductive parts of the structure;

n) the frequency of inspection of LPS components which will become inaccessible, for example steel reinforcing bars encapsulated in concrete;

o) the most suitable choice of metal for the conductors taking account of corrosion, especially at the point of contact between dissimilar metals;

p) accessibility of test joints, provision of protection by non-metallic casings against mechanical damage or pilferage, lowering of flag masts or other movable objects, facilities for periodic inspection especially for chimneys;

q) the preparation of drawings incorporating the above details and showing the positions of all conductors and main components;

r) the location of the connection points to the reinforcing steel.

E.4.2.3 Electrical and mechanical requirements

E.4.2.3.1 Electrical design

The LPS designer should select the appropriate LPS to obtain the most efficient construction. This means consideration of the architectural design of the structure to determine whether an isolated or non-isolated LPS, or a combination of both types of lightning protection, should be used.

Soil resistivity tests should be performed preferably prior to finalizing the design of an LPS and should take into consideration the seasonal variations of soil resistivity.

During the completion of the basic electrical design of the LPS, the use of suitable conductive parts of the structure should be considered as natural components of the LPS to enhance or act as essential components of the LPS.

It is the responsibility of the LPS designer to evaluate the electrical and physical properties of natural components of the LPS and to ensure that they conform to the minimum requirements of this standard.

The use of metal reinforcing, such as steel reinforced concrete, as lightning protection conductors requires careful consideration, and knowledge of the national construction standards applicable to the structure to be protected. The steel skeleton of reinforced concrete may be used as LPS conductors or may be used as a conductive shielding layer to reduce the electromagnetic fields generated by lightning in the structure as the lightning currents are conducted through an isolated LPS. This LPS design makes protection easier, in particular for special structures containing extensive electrical and electronic installations.

A stringent construction specification for down-conductors is required in order to meet the minimum requirements for natural components given in 5.3.5.

E.4.2.3.2 Mechanical design

The lightning protection designer should consult with the persons responsible for the structure on mechanical design matters following the completion of the electrical design.

Aesthetic considerations are particularly important as well as the correct selection of materials to limit the risk of corrosion.

The minimum size of lightning protection components for the various parts of the LPS are listed in Tables 3, 6, 7, 8 and 9.

The materials used for the LPS components are listed in Table 5.

NOTE For selection of other components, such as rods and clamps, reference may be made to the EN 50164 series. This will ensure that temperature rise and mechanical strength of such components are taken into account.

Where deviations are made from the dimensions and materials specified in Tables 5, 6 and 7, using the lightning discharge electrical parameters specified for the selected class of LPS given in Table 1, the lightning protection designer or installer should predict the temperature rise of lightning conductors under discharge conditions and dimension the conductors accordingly.

When excessive temperature rise is a concern for the surface on which the components are to be attached (because it is flammable or has a low melting point), either larger conductor cross-sections should be specified or other safety precautions should be considered, such as the use of stand-off fittings or the insertion of fire-resistant layers.

The LPS designer should identify all corrosion problem areas and specify appropriate measures.

The corrosion effects on the LPS may be reduced either by increases in material size, by using corrosion resistive components, or by taking other corrosion protection measures.

The LPS designer and LPS installer should specify conductor fasteners and fixtures which will withstand the electrodynamic forces of lightning current in the conductors and also allow for the expansion and contraction of conductors due to the increase in temperature that occurs.

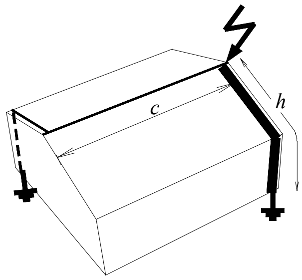
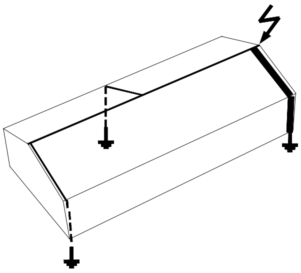
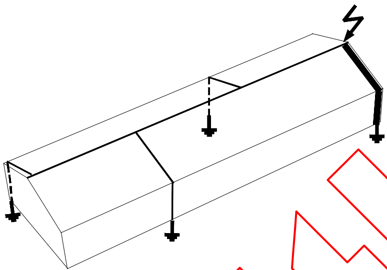
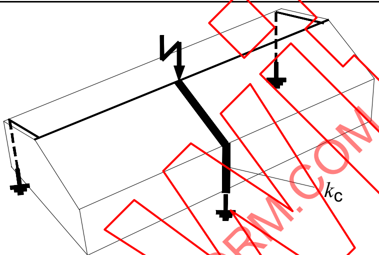
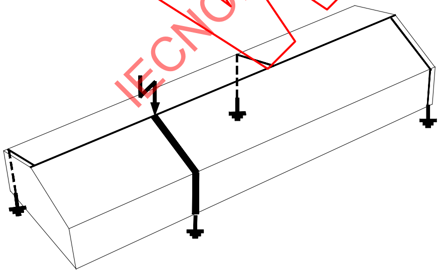
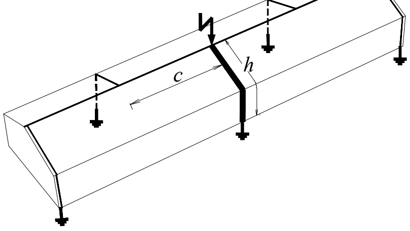
E.4.2.4 Design calculation

E.4.2.4.1 Evaluation of the coefficient k_c

The partitioning coefficient k_c of the lightning current among the down-conductors depends on the overall number n and on the position of the down-conductors, the interconnecting ring conductors, the type of air-termination system and the type of earth-termination system (see Table C.1 and Figures C.2 and C.3).

For the determination of k_c on roofs when earthing arrangement type A is installed, Figure E.2 may be used.

The necessary separation distance depends on the voltage drop of the shortest path from the point where the separation distance is to be considered, to the ground electrode or the nearest equipotential bonding point.

	$\frac{c}{h}$ =	**0,33**	**0,50**	**1,00**	**2,00**
	k_c	0,57	0,60	0,66	0,75
	k_c	0,47	0,52	0,62	0,73
	k_c	0,44	0,50	0,62	0,73
	k_c	0,40	0,43	0,50	0,60
	k_c	0,35	0,39	0,47	0,59
	k_c	0,31	0,35	0,45	0,58

c Distance from the nearest down-conductor along the ridge

h Length of the down-conductor from the ridge to the next equipotential bonding point or to the earth-termination system

The values of k_c, shown in the table, refer to the down-conductors represented by a thick line and a strike point

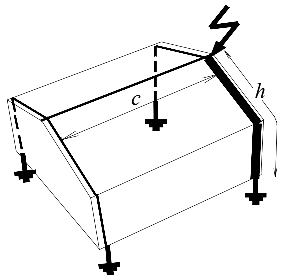
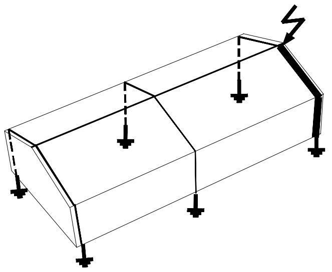
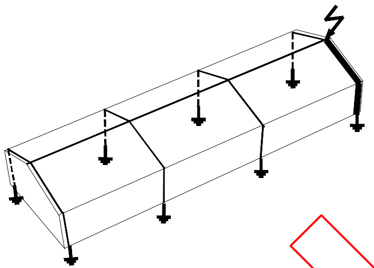
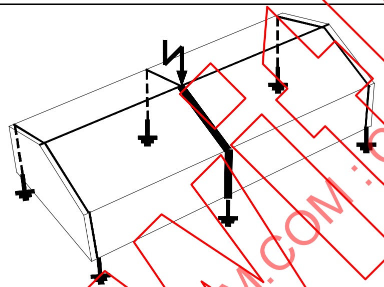
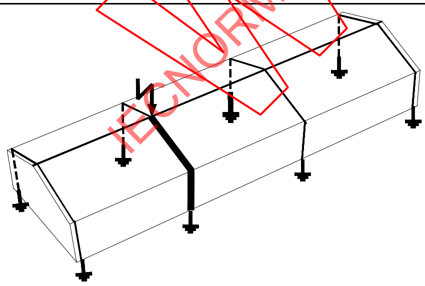
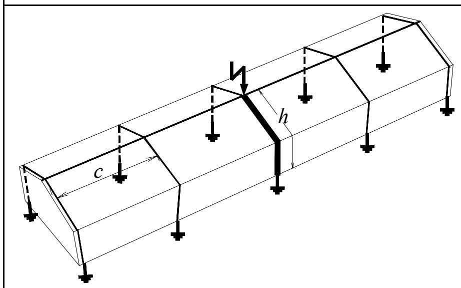
The location of the down conductor (to be considered for k_c) is to be compared with the figure representative for that down-conductor

The actual relation c/h is to be determined.
If this relation ranges between two values in the columns, k_c may be found by interpolation

NOTE 1
Additional down-conductors With more distance than illustrated in the figures are of nsignificant influence.

NOTE 2
In case of interconnecting ring-conductors below the ridge see Figure C.3

NOTE 3
The values are determined by simple calculation of parallel impedances following the formula of Figure C.1

	$\frac{c}{h}=$	**0,33**	**0,50**	**1,00**	**2,00**
	k_c	0,31	0,33	0,37	0,41
	k_c	0,28	0,33	0,37	0,41
	k_c	0,27	0,33	0,37	0,41
	k_c	0,23	0,25	0,30	0,35
	k_c	0,21	0,24	0,29	0,35
	k_c	0,20	0,23	0,29	0,35

c Distance from the nearest down-conductor along the ridge

h Length of the down-conductor from the ridge to the next equipotential bonding point or to the earth-termination system

The values of k_c, shown in the table, refer to the down-conductors represented by a thick line and a strike point

NOTE 1
Additional down-conductors With more distance than illustrated in the figures are of nsignificant influence.

NOTE 2
In case of interconnecting ring-conductors below the ridge see Figure C.3

NOTE 3
The values are determined by simple calculation of parallel impedances following the formula of Figure C.1

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Figure E.2 – Values of coefficient k_c in case of a sloped roof with air-termination on the ridge and a type B earthing system

If the conductor has the same current flowing down its total length, the formula for the necessary separation distance in air is given by

$$s = k_i \times k_c \times l \tag{E.1}$$

If the conductor has different values of current flowing down its length due to current division the equation has to consider the different (reduced) currents flowing down each section of the conductor. In that case:

$$s = k_i(k_{c1} \times l_1 + k_{c2} \times l_2 + ... + k_{cn} \times l_n) \tag{E.2}$$

The point of the strike, essential for k_c, and the point where the separation distance is to be considered, may be different.

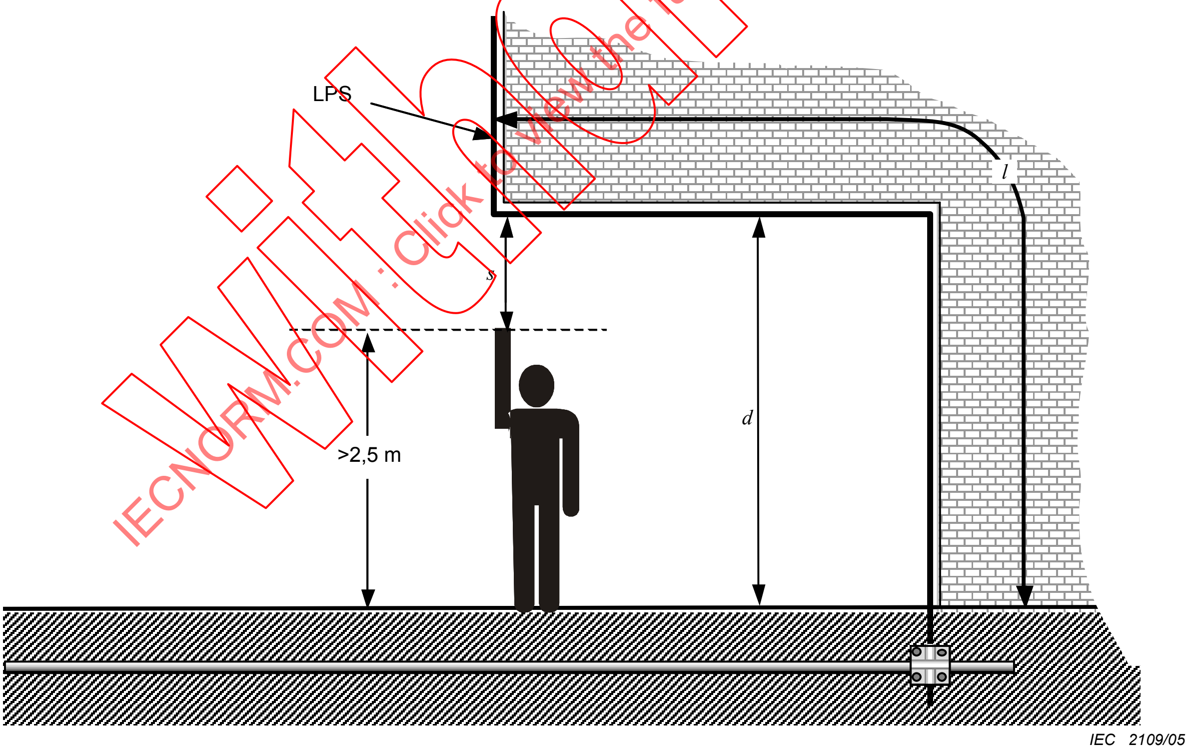
E.4.2.4.2 Structure with a cantilevered part

To reduce the probability of a person standing under a cantilevered construction from becoming an alternate path for lightning current flowing in the down-conductor running on the cantilevered wall, the actual distance, d, in metres should satisfy the following condition:

$$d > 2,5 + s \tag{E.3}$$

where s is the separation distance in metres calculated in accordance with 6.3.

The value 2,5 is representative of the height at the tips of a man's fingers when he stretches his arm vertically (see Figure E.3).



d Actual distance > s
s Separation distance according to 6.3
l Length for the evaluation of separation distance s

NOTE The height of the person with raised hand is taken to be 2,5 m.

Figure E.3 – LPS design for a cantilevered part of a structure

Loops in a conductor as shown in Figure 1 can produce high inductive voltage drops, which can cause a lightning discharge to pass through a structure wall thereby causing damage.

If the conditions in 6.3 are not met, arrangements should be made for direct routing through the structure at the points of re-entrant lightning conductor loops for those conditions shown in Figure 1.

E.4.3 Reinforced concrete structures

E.4.3.1 General

Industrial structures frequently comprise sections of reinforced concrete which are produced on site. In many other cases, parts of the structure may consist of prefabricated concrete units or steel parts.

Steel reinforcement in reinforced concrete structures conforming to 4.3 may be used as a natural component of the LPS.

Such natural components must fulfil the requirements of:

– down-conductors according to 5.3;
– earth-termination networks according to 5.4.

Moreover, the conductive reinforcement of concrete, when properly used, should form the cage for potential equalization of the internal LPS according to 6.2.

Furthermore, the steel reinforcement of the structure, if adequate, may serve as an electromagnetic shield, which assists in protecting electrical and electronic equipment from interference caused by lightning electromagnetic fields according to IEC 62305-4.

If the reinforcement of the concrete and any other steel constructions of a structure are connected both externally and internally so that the electrical continuity conforms to 4.3, effective protection may be achieved against physical damage.

The current injected into the reinforcing rods is assumed to flow through a large number of parallel paths. The impedance of the resulting mesh is thus low and, as a consequence, the voltage drop due to the lightning current is also low. The magnetic field generated by the current in the reinforcing steel mesh is weak due to the low current density and the parallel current paths generating opposing electromagnetic fields. Interference with neighbouring internal electrical conductors is correspondingly reduced.

NOTE For protection against electromagnetic interference, see IEC 62305-4 and IEC 61000-5-2.

When a room is totally enclosed by steel-reinforced concrete walls whose electrical continuity conforms to 4.3, the magnetic field due to lightning current flowing through the reinforcement in the vicinity of the walls is lower than that in a room of a structure protected with conventional down-conductors. Owing to the lower induced voltages in conductor loops installed inside the room, protection against failures of internal systems may be easily improved.

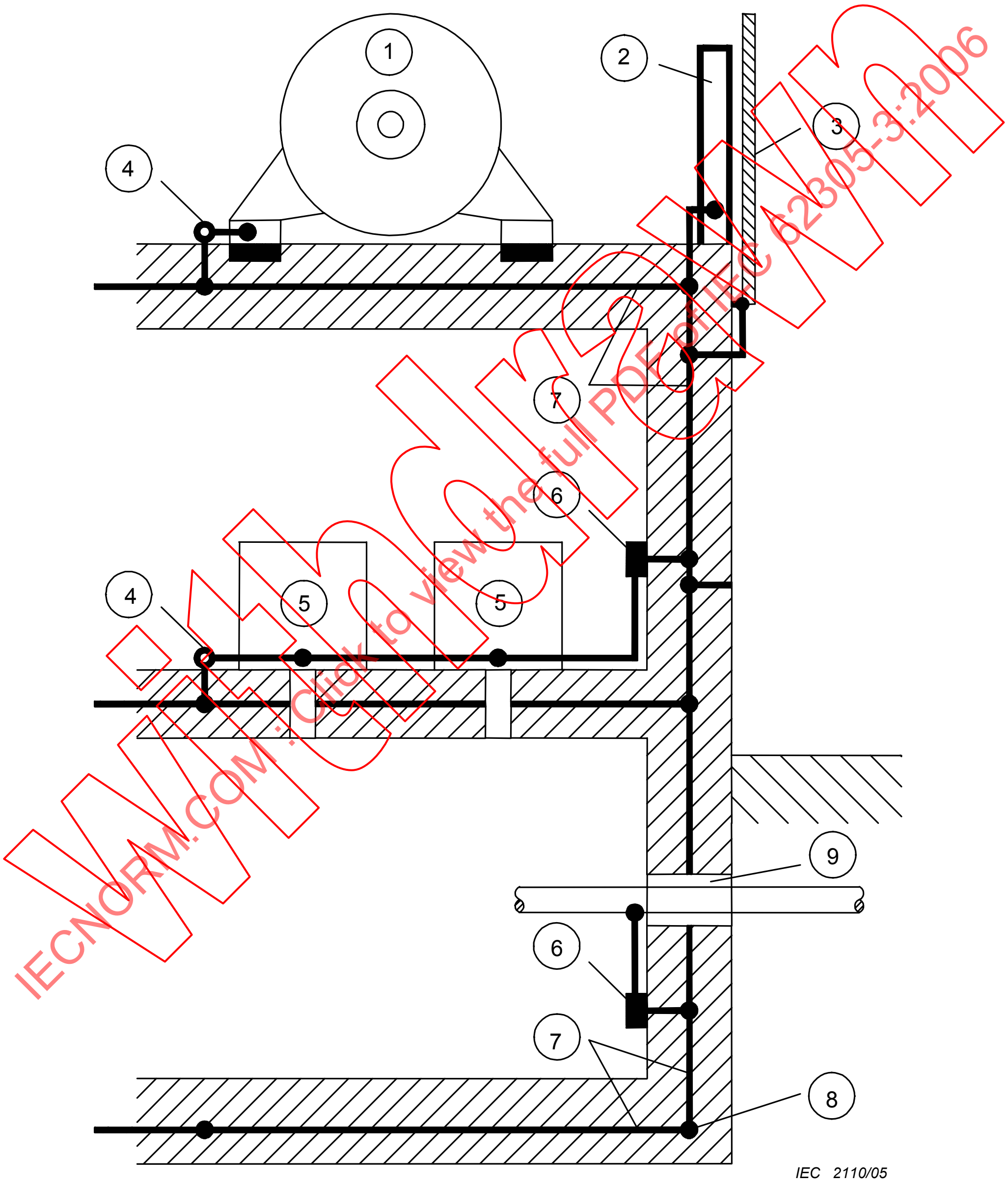
After the construction phase, it is nearly impossible to determine the layout and construction of the reinforcement steel. Therefore, the layout of the reinforcement steel for the purpose of lightning protection should be very well documented. This can be done utilizing drawings, descriptions and photographs taken during the construction.

E.4.3.2 Utilization of reinforcement in concrete

Bonding conductors or grounding plates should be furnished in order to provide reliable electrical connection to the reinforcement steel.

Conductive frames that, for example, are attached to the structure may be used as natural LPS conductors and as connection points for the internal equipotential bonding system.

A practical example is the use of foundation anchors or foundation rails of machines, apparatus or housings, to achieve potential equalization. Figure E.4 illustrates the arrangement of the reinforcement and the bonding bars in an industrial structure.



Key

1 Electrical power equipment	6 Bonding bar
2 Steel girder	7 Steel reinforcement in concrete (with superimposed mesh conductors)
3 Metal covering of the facade	8 Foundation earth electrode
4 Bonding joint	9 Common inlet for different services
5 Electrical or electronic equipment	

Figure E.4 – Equipotential bonding in a structure with a steel reinforcement

The location of bonding terminations in the structure should be specified at an early planning stage in the design of the LPS and should be made known to the civil works contractor.

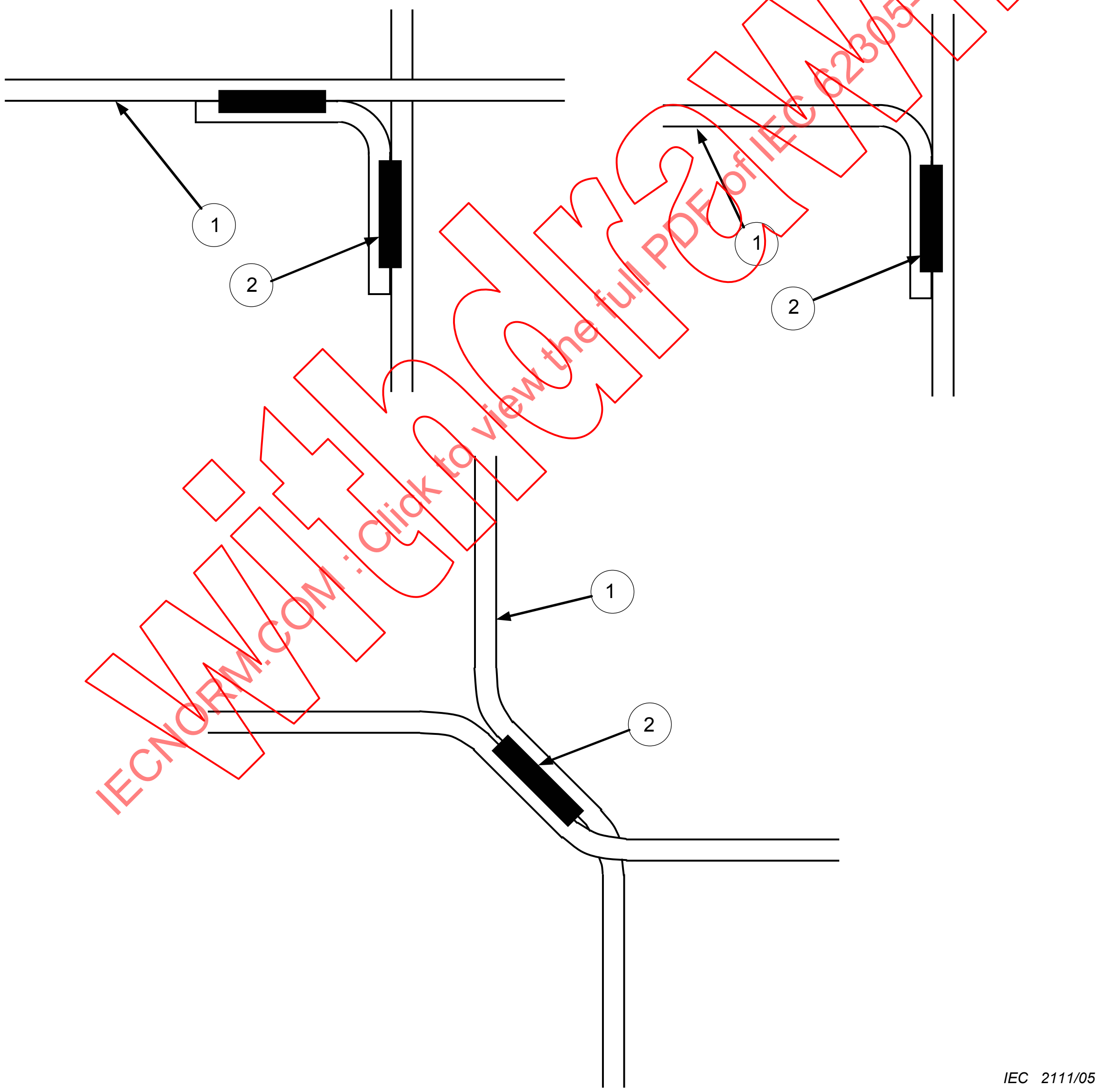
The building contractor should be consulted to determine whether welding to the reinforcing rods is permitted, whether clamping is possible or whether additional conductors should be installed. All necessary work should be performed and inspected prior to pouring of the concrete (i.e. planning of the LPS should be carried out in conjunction with the design of the structure).

E.4.3.3 Welding or clamping to the steel-reinforcing rods

The continuity of the reinforcing rods should be established by clamping or welding.

NOTE Clamps conforming to EN 50164-1 may be considered suitable.

Welding to the reinforcing rods is only permitted if the civil works designer consents. The reinforcing rods should be welded over a length not less than 30 mm (see Figure E.5).



Key
1 Reinforcing bars
2 Welded seam at least 30 mm long

Figure E.5 – Welded joints of reinforcing rods in reinforced concrete, if permitted

The connection to outside components of the lightning protection system should be established by a reinforcement rod brought out through the concrete at a designated location or by a connecting rod or ground plate passing through the concrete which is welded or clamped to the reinforcing rods.

Where joints between the reinforcing rods in concrete and the bonding conductor are made by means of clamping, two bonding conductors (or one bonding conductor with two clamps to different reinforcing bars) should always be used for safety reasons, since the joints cannot be inspected after the concrete has set. If the bonding conductor and reinforcing rod are dissimilar metals, then the joint area should be completely sealed with a moisture inhibiting compound.

Figure E.6 shows clamps used for joints for reinforcing rods and solid tape conductors. Figure E.7 shows details for connection of an external system to reinforcing rods.

The bonding conductors should be dimensioned for the proportion of lightning current flowing at the bonding point (see Tables 8 and 9).

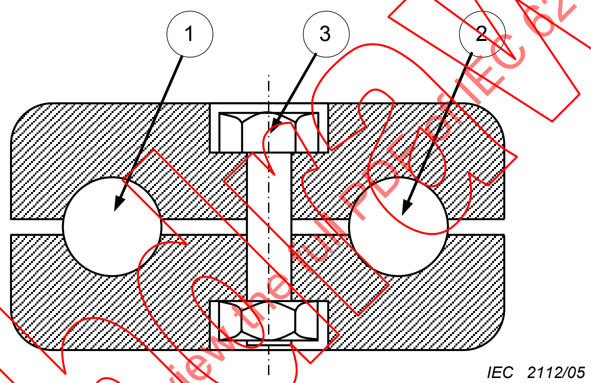


Figure E.6a – Circular conductor to a reinforcing rod

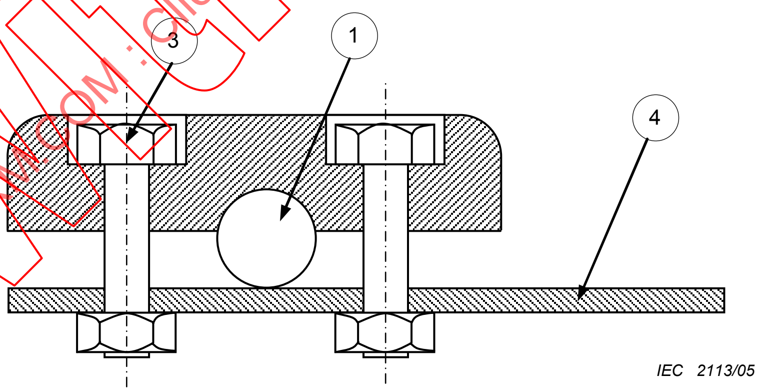


Figure E.6b – Solid tape conductor to a reinforcing rod

Key
1 Reinforcing rod
2 Circular conductor
3 Screw
4 Tape conductor

Figure E.6 – Example of clamps used as joints between reinforcing rods and conductors

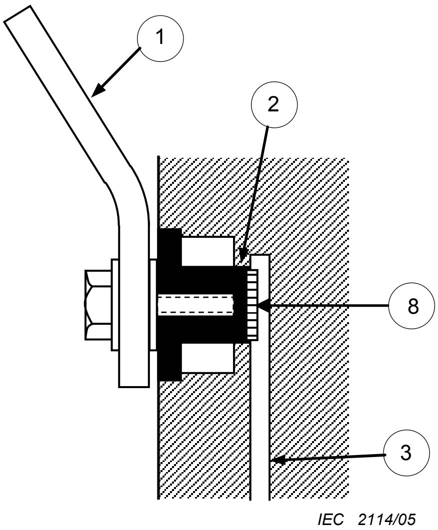


Figure E.7a

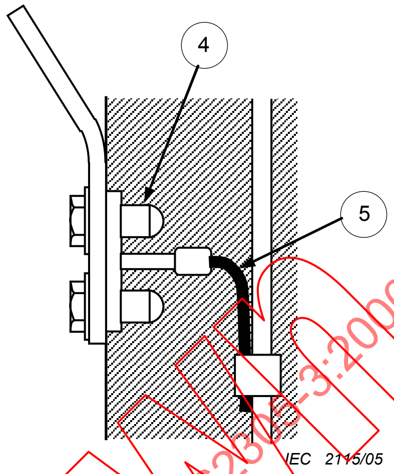


Figure E.7b

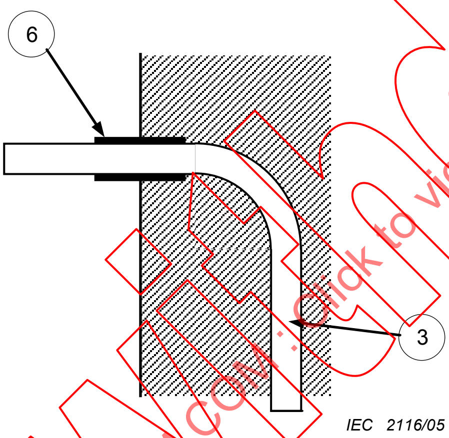


Figure E.7c

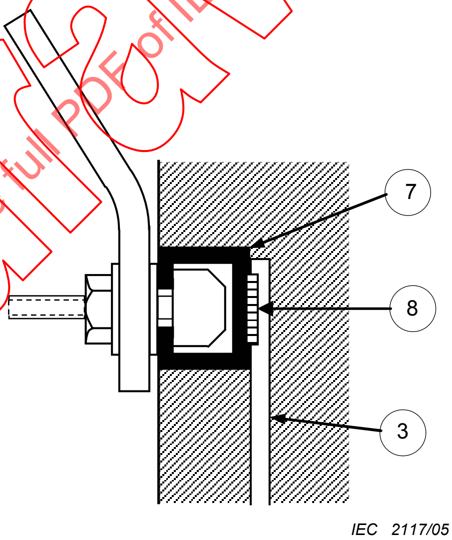


Figure E.7d

Key

1 Bonding conductor

2 Nut welded to steel bonding connector

3 Steel-bonding connector*

4 Cast in non ferrous bonding point

5 Stranded copper bonding connector

6 Corrosion protection measure

7 C-steel (C-shaped mounting bar)

8 Welding

* The steel-bonding connector is connected at many points by welding or clamping to the steel reinforcing bars.

NOTE Construction shown in Figure E.7c is not a generally accepted solution in terms of good engineering practice.

Figure E.7 – Examples for connection points to the reinforcement in a reinforced concrete wall

E.4.3.4 Materials

The following materials can be used as additional conductors installed in concrete for lightning protection purposes: steel, mild steel, galvanized steel, stainless steel and copper.

The use of galvanized steel rods in concrete is sometimes not permitted by the civil works contractor. This is based on a misunderstanding. The reinforcement steel is made passive by the concrete, resulting in a high potential protecting it from corrosion.

In order to avoid confusion between the different types of steel rods in concrete, it is recommended that round steel rods of at least 8 mm diameter with a smooth surface be used as additional conductors in contrast to the ordinary ribbed surface of the reinforcing rods.

E.4.3.5 Corrosion

Where steel reinforcement bonding conductors are brought through a concrete wall, particular attention should be paid to protection against chemical corrosion.

The simplest corrosion protection measure is the provision of a silicon rubber or bitumen finish in the vicinity of the exit point from the wall, e.g. 50 mm or more in the wall and 50 mm or more outside the wall (see Figure E.7c).

Where copper bonding conductors are brought through the concrete wall, there is no corrosion risk if a solid conductor, proprietary bonding point, PVC covering, or insulated wire is used (see Figure E.7b). For stainless steel bonding conductors, in accordance with Tables 6 and 7, no corrosion prevention measures need to be used.

In the case of extremely aggressive atmospheres, it is recommended that the bonding conductor projecting from the wall be made of stainless steel.

NOTE Galvanized steel outside of the concrete in contact with reinforcement steel in the concrete may, under certain circumstances, cause damage to the concrete.

When cast-in type nuts or mild steel pieces are used, these should be protected against corrosion on the outside of the wall. Serrated lock washers should be used to make electrical contact through the protective finish of the nut (see Figure E.7a).

For more information on corrosion protection, see E.5.6.2.2.2.

E.4.3.6 Connections

Investigations show that lashing is not suitable for lightning-current-carrying connections. There is a risk of the lashing wire exploding and damaging the concrete. However, on the basis of earlier investigations it can be assumed that at least every third wire lashing forms an electrically conductive link, so that practically all the rods of the reinforcement are electrically interconnected. Measurements carried out on reinforced concrete structures support this conclusion.

So for lightning-carrying connections welding and clamping are the preferred methods. Lashing as a connection is suitable for additional conductors for equipotentialization and for EMC purposes only.

Connections of external circuits to the interconnected reinforcement should be performed by means of clamps or by welding.

Welds within concrete should be at least 30 mm long. Crossing rods should be bent to run for at least 50 mm in parallel prior to welding.

When welded rods need to be cast into concrete, it is not sufficient to weld at crossing points with weld seam lengths of only a few millimetres. Such joints frequently break when the concrete is poured.

Figure E.5 shows correct welding of bonding conductors to the reinforcing rods of the reinforced concrete.

Where welding to the reinforcing rods is not permitted, clamps or additional dedicated conductors should be used. These additional conductors can be made of steel, mild steel, galvanized steel or copper. The additional conductors should be connected to a large number of reinforcing rods by lashings and clamps to take advantage of the shielding possibilities of the reinforcement steel.

NOTE Where welding is permitted, both conventional welding and exothermic welding are acceptable together with the appropriate welding methods.

E.4.3.7 Down-conductors

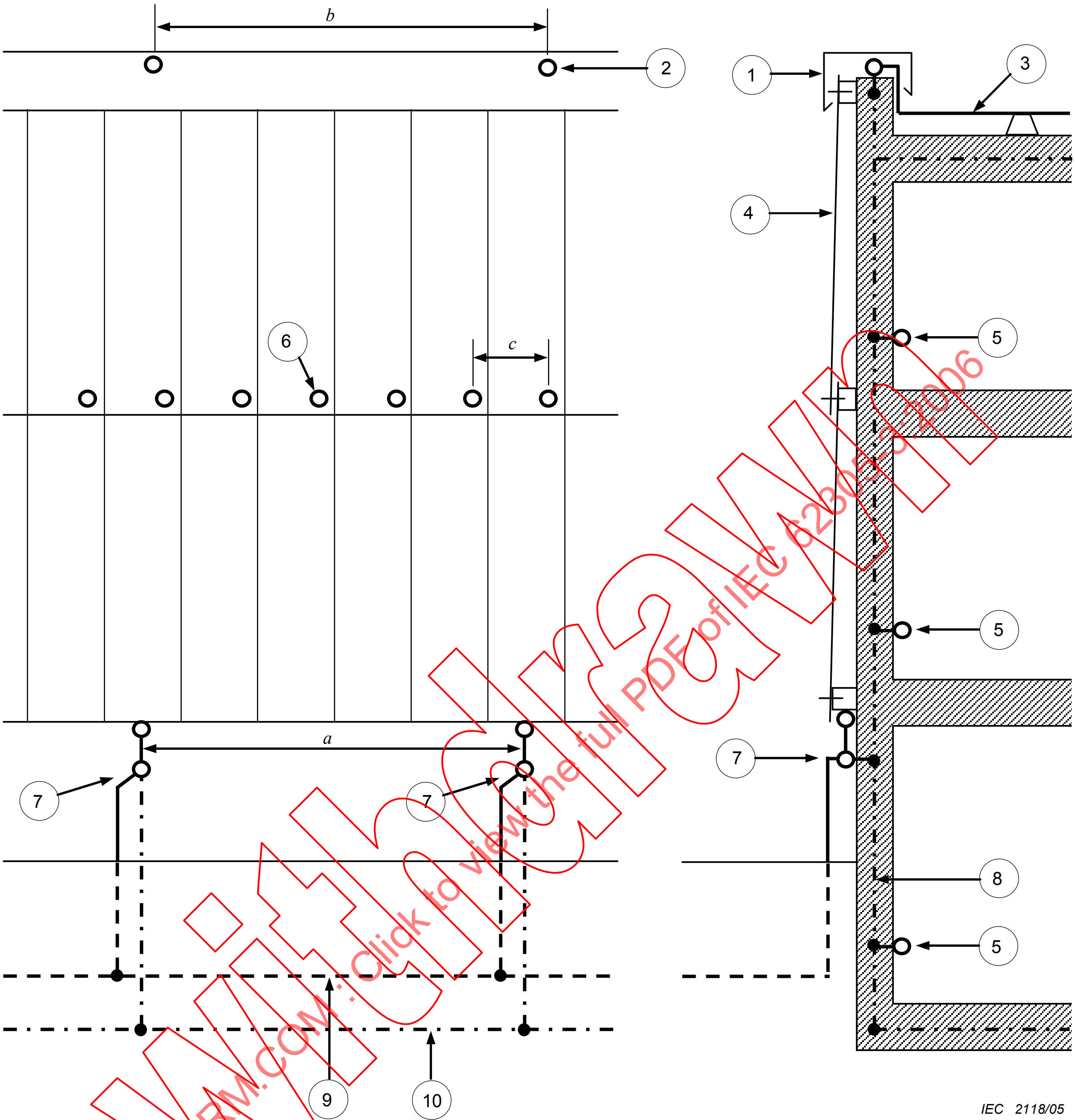
The reinforcing rods of walls or concrete columns and steel structural frames may be used as natural down-conductors. A termination joint should be provided on the roof to facilitate the connection of the air-termination system and, unless the reinforced concrete foundation is being used as the only earth termination, termination joints should be provided to facilitate the connection with the earth-termination system.

When using a particular rod of the reinforcement steel as the down-conductor, care should be taken in the route to earth to ensure that the rod that is located in the same position will be used all the way down, thereby providing direct electrical continuity.

When the vertical continuity of the natural down-conductors, providing a straight path from roof to ground cannot be guaranteed, additional dedicated conductors should be used. These additional conductors should be lashed to the reinforcement steel.

Wherever there is doubt as to the most direct route for the down-conductor (i.e. for existing buildings) an external down-conductor system should be added.

Figures E.4 and E.8 show construction details of natural components in the LPS for reinforced concrete structures. See also E.5.4.3.2 for the use of the rods of reinforced concrete elements as foundation earth electrodes.



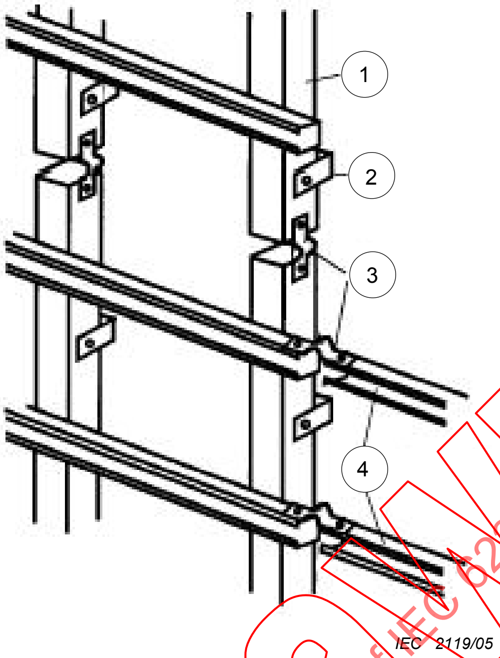
Key

1 Metallic covering of the roof parapet
2 Joint between façade plates and air-termination
3 Horizontal air-termination conductor
4 Metallic façade segment covering
5 Equipotentialization bar of the internal LPS
6 Joint between façade plates
7 Test joint
8 Steel reinforcement in concrete
9 Type B ring earth electrode
10 Foundation earth electrode

An applicable example may utilize the following dimensions a = 5 m b = 5 m c = 1 m.

NOTE For the joints between the plates, see Figure E.35.

Figure E.8a – Use of a metallic façade covering as a natural down-conductor system on a structure of steel reinforced concrete



Key

1 Vertical frame

2 Wall fixing

3 Connectors

4 Horizontal frame

Figure E.8b – Connection of facade supports

Figure E.8 – Use of metallic facade as natural down-conductor system and connection of facade supports

Internal down-conductors in the individual columns and the walls should be interconnected by means of their steel reinforcing rods and should conform to the conditions for electrical continuity according to 4.3.

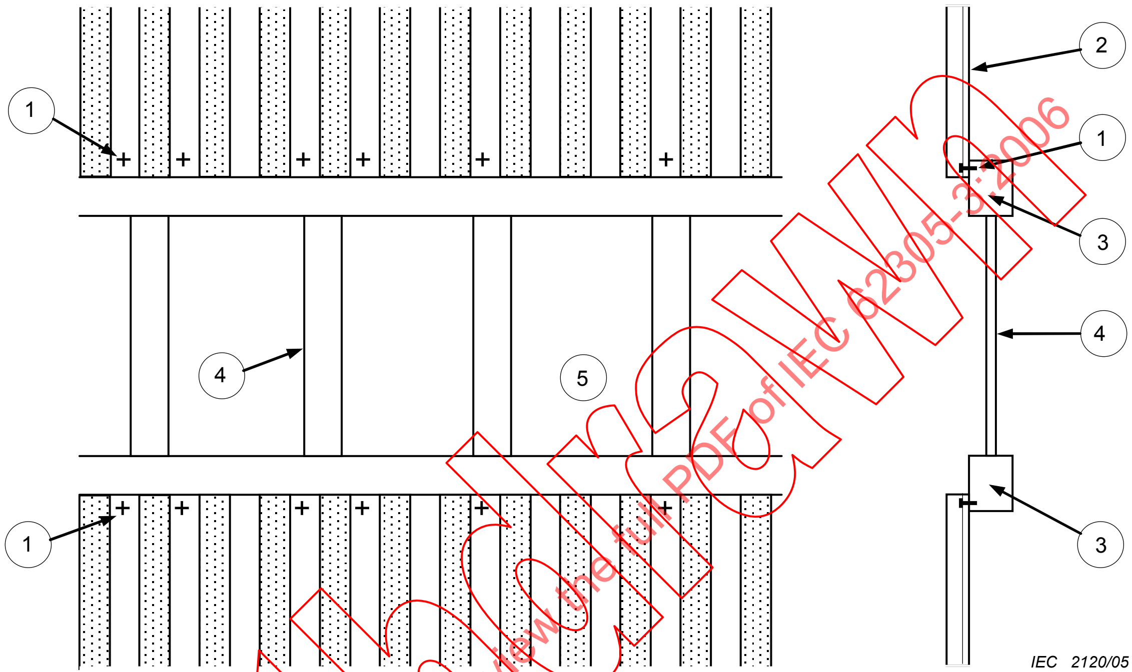
Steel reinforcing rods of individual prefabricated concrete elements and the reinforcing rods of concrete columns and concrete walls should be connected to the reinforcing rods of floors and roofs before the floors and roofs are cast.

Extensive continuously conductive parts exist within the reinforcing of all constructional elements, which are cast with concrete on site, for example, walls, columns, stairs and lift shafts. If floors are constructed of site-cast concrete, the down-conductors in the individual columns and walls should be interconnected by means of their reinforcing rods to ensure an even distribution of the lightning current. If floors are constructed of prefabricated concrete elements, such connections are generally not available. However, at little extra cost it is generally possible to prepare joints and terminations to connect the reinforcing rods of the individual prefabricated concrete elements to the reinforcing rods of the columns and walls before the floors are cast by insertion of additional connecting rods.

Prefabricated concrete elements used as suspended facades are not effective for lightning protection as bonding connections are not provided. If highly effective lightning protection is to be provided for equipment installed within a structure, such as office buildings with extensive information-processing equipment and computer networks, it is necessary for the reinforcing rods of such facade elements to be interconnected and connected to the reinforcing rods of the load-bearing elements of the structure in such a manner that the lightning current can flow through the complete outer surface of the structure (see Figure E.4).

If continuous strip windows are installed in the outer walls of a structure, it is essential that a decision be taken as to whether the connection of the prefabricated concrete parts above and below the continuous strip windows should be made by means of the existing columns or whether they should be interconnected at smaller intervals corresponding to the window pitch.

Extensive integration of conductive parts of the outer walls improves the electromagnetic shielding of the interior of the structure. Figure E.9 shows the connection of a continuous strip windows to a metal facade covering.



Key

1 Joint between a façade plate segment and the metallic strip window
2 Metallic façade plate
3 Horizontal metallic strip
4 Vertical metallic strip
5 Window

Figure E.9 – Connection of the continuous strip windows to a metal façade covering

If steel structures are used as down-conductors, every steel column should be connected to the steel reinforcing rods of the concrete foundation by bonding points as shown in Figure E.7. Steel bonding bars within the reinforced concrete of a structure should be interconnected by means of vertical conductors which should be manufactured of mild steel suitable for welding. New structures of steel-reinforced concrete should be constructed in accordance with 4.3.

NOTE For more information on the use of steel reinforcement of structure walls for the purpose of electromagnetic shielding, see IEC 62305-4.

In the case of large, low buildings such as halls, the roof is supported not only at the building circumference but also by internal columns. Conductive portions of the columns should be connected to the air-termination system at the top and to the equipotential bonding system at the floor, creating internal down-conductors. Increased electromagnetic interference occurs in the vicinity of such internal down-conductors.

Steel skeleton constructions generally use steel roof girders connected by means of bolted joints. Provided the bolts are tightened with the force required to achieve mechanical strength, all bolted steel parts may be considered electrically interconnected. The thin paint layer is pierced by the lightning current on initial discharge thus forming a conductive bridge.

The electrical connection may be improved by baring the seating surface of the bolt heads, bolt nuts and washers. A further improvement can be achieved by provision of a welding seam approximately 50 mm long after completion of the structural assembly.

On existing structures with extensive conductive parts in/on the outer walls, the continuity of conductive parts should be established for use as down-conductors. This technique is also recommended when high demands on the cultural aspects of architectural design have to be maintained in addition to the demands for protection against LEMP.

Interconnected equipotentialization bars should also be provided. Each equipotentialization bar should be connected to the conductive parts in the outer walls and in the floor. This may already be provided by the horizontal reinforcing bars at the ground level and each subsequent floor level.

If possible, a connection point to the steel reinforcement in the floor or in the wall should be provided. The connection should be made to at least three reinforcing rods.

In large structures, the equipotentialization bar acts as a ring conductor. In such cases connection points to the steel-reinforcing bars should be made every 10 m. Other than measures which may be prescribed for the basement, no other special measures to connect the reinforcement of the structure to the LPS are necessary.

E.4.3.8 Equipotentialization

When a large number of bonding connections to the reinforcement is required at different floors and a significant interest is given to achieve current paths of low inductance utilizing the reinforcing rods of the concrete walls for potential equalization and for shielding of the inner space of the structure, ring-conductors should be installed within or outside the concrete on the separate floors. These ring conductors should be interconnected by means of vertical rods at intervals not greater than 10 m.

This arrangement should be given preference due to its greater reliability, especially where the magnitude of the interference current is unknown.

A meshed-connection conductor network is also recommended. Connections should be designed to carry high currents in the event of a fault in the energy supply.

E.4.3.9 Foundation as earth-termination

For large structures and industrial plants the foundation is normally reinforced. The reinforcing rods of the foundation, foundation slab and outer walls in the region below the soil surface of such structures form an excellent foundation earth electrode, provided the requirements of 5.4 are satisfied.

The reinforcing rods of the foundation and the buried walls can be used as a foundation earth.

This method achieves good earthing at minimum cost. In addition, the metal enclosure, consisting of the steel reinforcement of the structure, in general offers a good potential reference for the electric power supply, telecommunication and electronic installations of the structure.

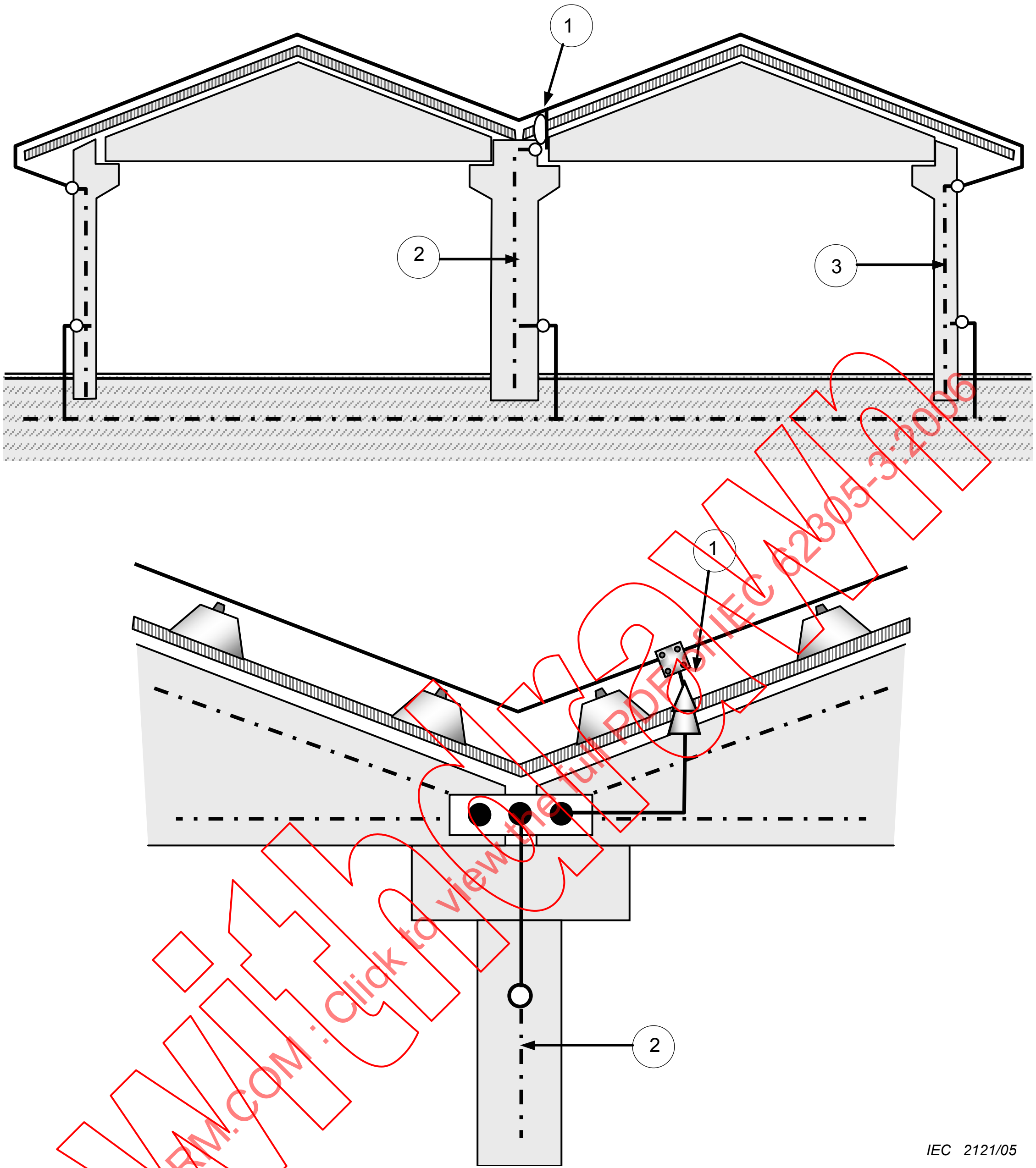
In addition to the interconnection of the reinforcing rods by wire-lashing, the installation of an additional meshed metal network to ensure good joints is recommended. This additional network should also be lashed to the reinforcement steel. The terminal conductors for connections of external down-conductors or structure elements used as down-conductors and for connection of the earth-termination installed externally should be brought out of the concrete at suitable points.

In general, the reinforcing of a foundation is electrically conductive except in cases where gaps are provided between different parts of the structure to allow different settling rates.

Gaps between conductive structure parts should be bridged by bonding conductors conforming to Table 6 using clamps and joints in accordance with 5.5.

Reinforcing rods of concrete columns, piers and walls standing on a foundation should be connected to the reinforcing rods of the foundation and to the conductive parts of the roof.

Figure E.10 shows the design of the LPS of a reinforced concrete structure for concrete piers, walls and a roof with conductive parts.



Key

1 LPS conductor passing a watertight bushing

2 Steel reinforcement in a concrete column

3 Steel reinforcement in concrete walls

NOTE The steel reinforcing of an internal column becomes a natural internal down-conductor when the steel reinforcing of the column is connected to the air-termination and the earth-termination of the LPS. The electromagnetic environment near the column should be considered when sensitive electronic equipment is installed near the column.

Figure E.10 – Internal down-conductors in industrial structures

When welding to reinforcing is not allowed, additional conductors should be installed in the piers, or the connections should be implemented by means of tested joints. These additional conductors should be lashed to the reinforcing steel.

After completion of construction and connecting all the services to the building via an equipotential bonding bar, it will often be impossible in practice to measure the earthing resistance as part of the maintenance programme.

If in certain conditions it is not possible to measure the earthing resistance of the foundation earth, the installation of one or more reference earth electrodes close to the structure provide a possible method of monitoring the changes in the environment of the earthing system over the years by performing a circuit measurement between the earth electrode and the foundation earthing system. However, good equipotentialization is the main advantage of the foundation earthing system and the resistance to earth tends to be less important.

E.4.3.10 Installation procedures

All lightning protection conductors and clamps should be installed by the installer of the LPS.

Agreement should be reached with the civil works contractor in sufficient time to ensure that the time schedule for construction work is not exceeded as a result of delay in installation of the LPS before pouring the concrete.

During construction, measurements should be taken regularly and an LPS installer should supervise the construction (see 4.3).

E.4.3.11 Prefabricated reinforced concrete parts

If prefabricated reinforced concrete parts are used for lightning protection, e.g. as down-conductors for shielding or as conductors for potential equalization, connection points according to Figure E.7 should be attached to them to allow later interconnection of the prefabricated reinforcement with the reinforcement of the structure in a simple manner.

The location and form of connection points should be defined during the design of the prefabricated reinforced concrete parts.

The connection points should be located so that in the prefabricated concrete part a continuous reinforcing rod runs from one bonding joint to the next.

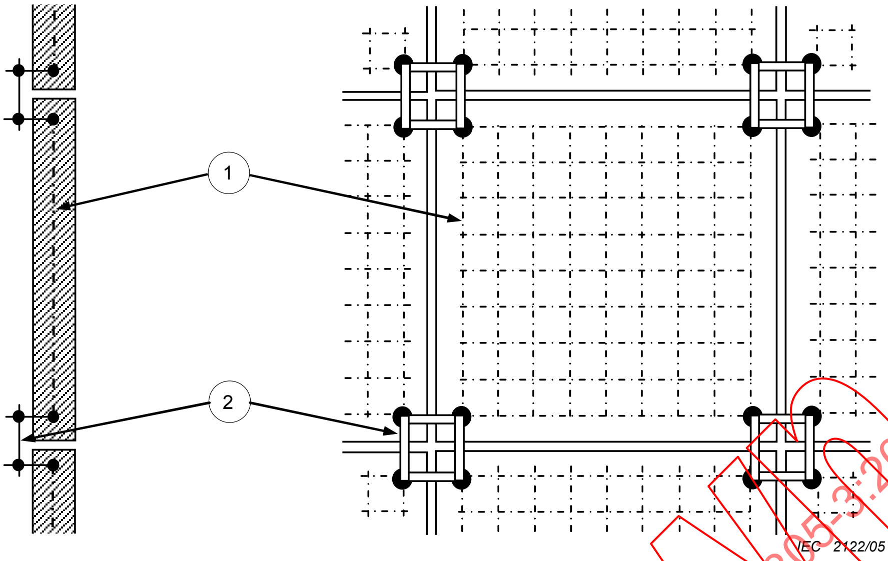
When the arrangement of continuous reinforcing rods in a prefabricated reinforced concrete part is not possible with standard reinforcing rods, an additional conductor should be installed and lashed to the existing reinforcement.

In general, one connection point and a bonding conductor is required at each corner of a plate-like prefabricated reinforced concrete part as illustrated in Figure E.11.

E.4.3.12 Expansion joints

When the structure comprises a number of sections with expansion joints, with allowance for settling of the structure sections, and extensive electronic equipment is to be installed in the building, bonding conductors should be provided between the reinforcement of the various structural sections across the expansion joints at intervals not exceeding one half of the distance between the down-conductors specified in Table 4.

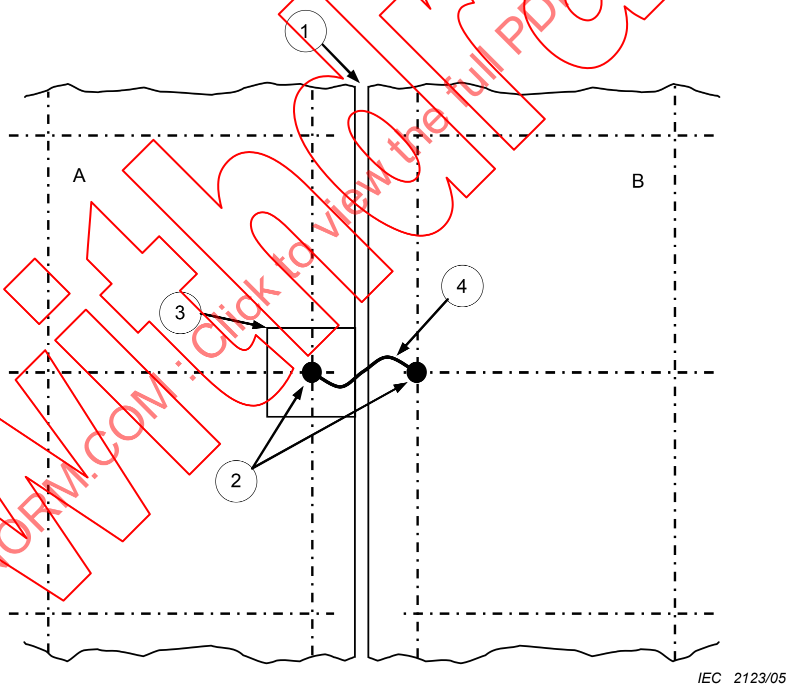
In order to ensure low-impedance potential equalization and effective shielding of the space inside a structure, expansion joints between sections of a structure should be bridged at short intervals (between 1 m and one half of the distance between down-conductors) by flexible or sliding bonding conductors depending on the required shielding factor, as shown in Figure E.11.



Key

1 Reinforced precast concrete
2 Bonding conductors

Figure E.11a – Installation of bonding conductors on plate-like prefabricated reinforced concrete parts by means of bolted or welded conductor links



Key

1 Expansion slot
2 Welded joint
3 Recess
4 Flexible bonding conductor
A Reinforced concrete part 1
B Reinforced concrete part 2

Figure E.11b – Construction of flexible bonds between two reinforced concrete parts bridging an expansion slot on a structure

Figure E.11– Installation of bonding conductors in reinforced concrete structures and flexible bonds between two reinforced concrete parts

E.5 External lightning protection system

E.5.1 General

E.5.1.1 Non-isolated LPS

In most cases, the external LPS may be attached to the structure to be protected.

When the thermal effects at the point of strike or on conductors carrying the lightning current may cause damage to the structure, or to the content of the structure to be protected, the spacing between LPS conductors and combustible material should be at least 0,1 m.

NOTE Typical cases are

– structures with combustible coverings,
– structures with combustible walls.

The positioning of external LPS conductors is fundamental to the design of the LPS and depends on the shape of the structure to be protected, the level of protection required and the geometric design method employed. The air-termination system design generally dictates the design of the down-conductor system, the earth-termination system and the design of the internal LPS.

If adjacent buildings have an LPS, those LPS should be connected to the LPS of the building under consideration.

E.5.1.2 Isolated LPS

An isolated external LPS should be used when the flow of the lightning current into bonded internal conductive parts may cause damage to the structure or its contents.

NOTE The use of an isolated LPS may be convenient where it is predicted that changes in the structure may require modifications to the LPS.

LPS that are connected to conductive structural elements and to the equipotential bonding system only at ground level, are defined as isolated according to 3.3.

Isolated LPS are achieved either by installing air-termination rods or masts adjacent to the structure to be protected or by suspending overhead wires between the masts in accordance with the separation distance of 6.3.

Isolated LPS are also installed on structures of insulating material, such as brickwork or wood, where the separation distance, as defined in 6.3, is maintained and no connection is made to conductive parts of the structure nor to equipment installed therein, with the exception of connections to the earth-termination system at ground level.

Conductive equipment within the structure and electrical conductors should not be installed with distances to the air-termination system conductors and to the down-conductors shorter than the separation distance defined in 6.3. All future installations should conform to the requirements of an isolated LPS. These requirements should be made known to the owner of the structure by the contractor responsible for the design and construction of the LPS.

The owner should inform future contractors performing work in or on the building about these requirements. The contractor responsible for such work should inform the owner of the structure if the contractor cannot meet these requirements.

All parts of equipment installed in a structure with an isolated LPS should be placed within the protected space of the LPS and satisfy the separation distance conditions. The LPS conductors should be mounted on insulated conductor fixtures, if conductor fixings attached directly to the structure walls are too close to conductive parts, so that the distance between the LPS and the inner conductive parts exceed the separation distance as defined in 6.3.

Flush-mounted conductive roof fixtures which are not connected to the equipotential bonding and have a distance to the air-termination system not in excess of the separation distance but a distance to the equipotential bonding in excess of the separation distance, should be connected to the air-termination system of the isolated LPS.

The design of an LPS and the safety instructions for work in the vicinity of a roof fixture should take account of the fact that the voltage on such fixtures will rise to that of the air-termination system in the event of a lightning strike.

Isolated LPS should be installed on structures with extensive interlinked conductive parts when it is desired to prevent lightning current from flowing through structure walls and internally installed equipment.

On structures consisting of continuously interlinked conductive parts such as steel construction or steel-reinforced concrete, the isolated LPS should maintain the separation distance to these conductive parts of the structure. To achieve adequate separation, LPS conductors may have to be fixed to the structure by insulated conductor fixtures.

It should be noted that columns and ceilings of reinforced concrete are often used in brick structures.

E.5.1.3 Dangerous sparking

Dangerous sparking between an LPS and metal, electrical and telecommunication installations can be avoided

– in an isolated LPS by insulation or separation according to 6.3,
– in a non-isolated LPS by equipotential bonding, according to 6.2, or by insulation or separation according to 6.3.

E.5.2 Air-termination systems

E.5.2.1 General

This standard does not provide any criteria for the choice of the air-termination system because it considers rods, stretched wires and meshed conductors as equivalent.

The arrangement of an air-termination system should be in accordance with the requirements of Table 2.

E.5.2.2 Positioning

For the design of the air-termination system, the following methods should be used, independently or in any combination, providing that the zones of protection afforded by different parts of the air-termination overlap and ensure that the structure is entirely protected according to 5.2:

– protection angle method;
– rolling sphere method;
– mesh method.

All three methods may be used for the design of an LPS. The choice of class of LPS depends on a practical evaluation of its suitability and the vulnerability of the structure to be protected.

The positioning method may be selected by the LPS designer. However, the following considerations may be valid:

– the protection angle method is suitable for simple structures or for small parts of bigger structures. This method is not suitable for structures higher than the radius of the rolling sphere relevant to the selected protection level of the LPS;
– the rolling sphere method is suitable for complex shaped structures;
– the mesh method is for general purposes and it is particularly suitable for the protection of plane surfaces.

The air-termination design method and LPS design methods used for the various parts of the structure should be explicitly stated in the design documentation.

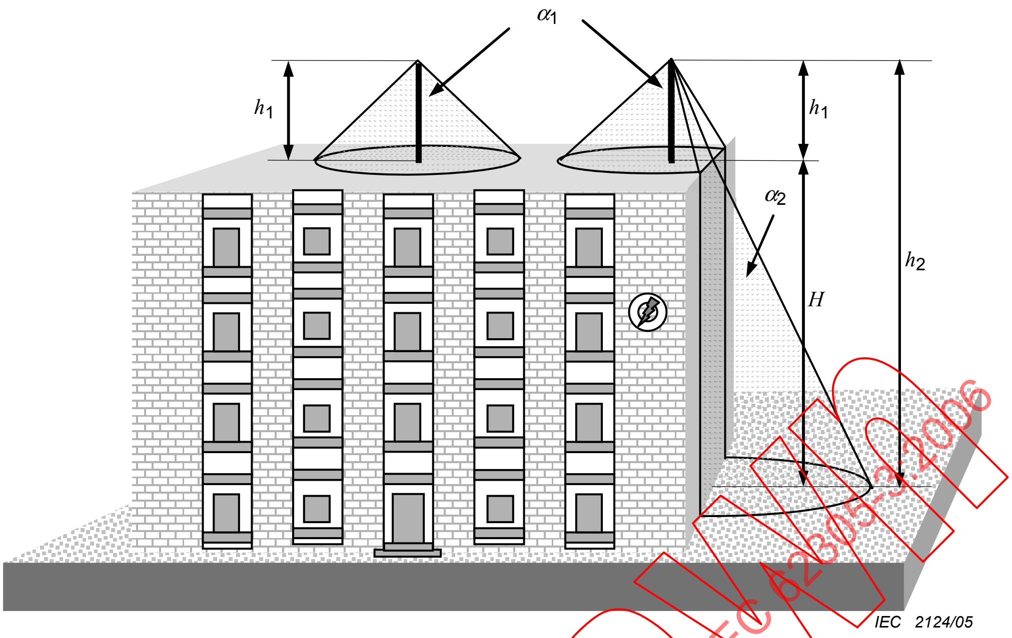
E.5.2.2.1 Protection angle method

Air-termination conductors, rods, masts and wires should be positioned so that all parts of the structure to be protected are inside the envelope surface generated by projecting points on the air-termination conductors to the reference plane, at an angle α to the vertical in all directions.

The protective angle α should conform to Table 2, with h being the height of the air-termination above the surface to be protected.

A single point generates a cone. Figures A.1 and A.2 show how the protected space is generated by the different air-termination conductors in the LPS.

According to Table 2, the protective angle α is different for different heights of air-termination above the surface to be protected (see Figures A.3 and E.12).



Key

H Height of the building over the ground reference plane

h_1 Physical height of an air-termination rod

h_2 $h_1 + H$, being the height of the air-termination rod over the ground

α_1 The protective angle corresponding to the air-termination height $h = h_1$, being the height above the roof surface to be measured (reference plane)

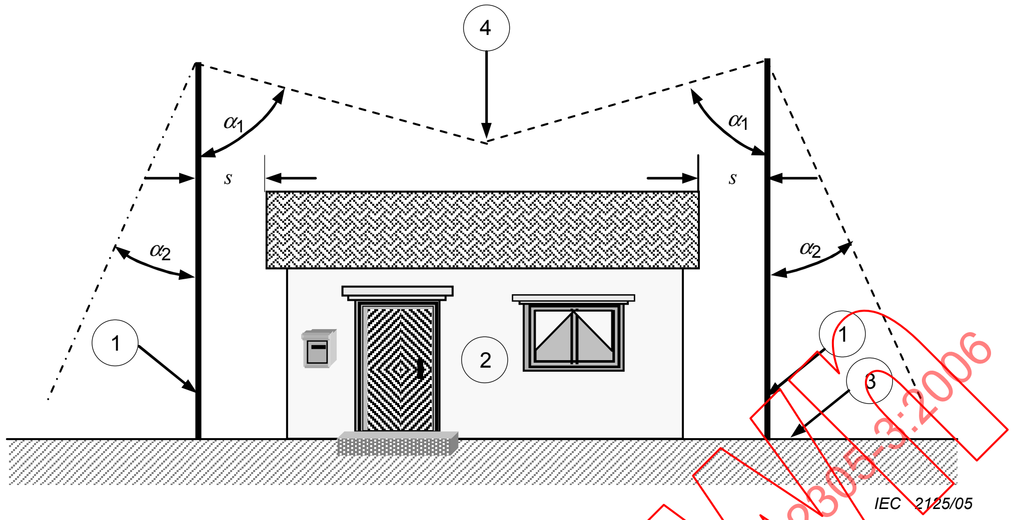
α_2 The protective angle corresponds to the height h_2

Figure E.12 – Protective angle method air-termination design for different heights according to Table 2

The protective angle method has geometrical limits and cannot be applied if h is larger than the rolling sphere radius, r, as defined in Table 2.

If structures on the roof are to be protected with finials and the protective volume of the finials is over the edge of the building, the finials should be placed between the structure and the edge. If this is not possible the rolling sphere method should be applied.

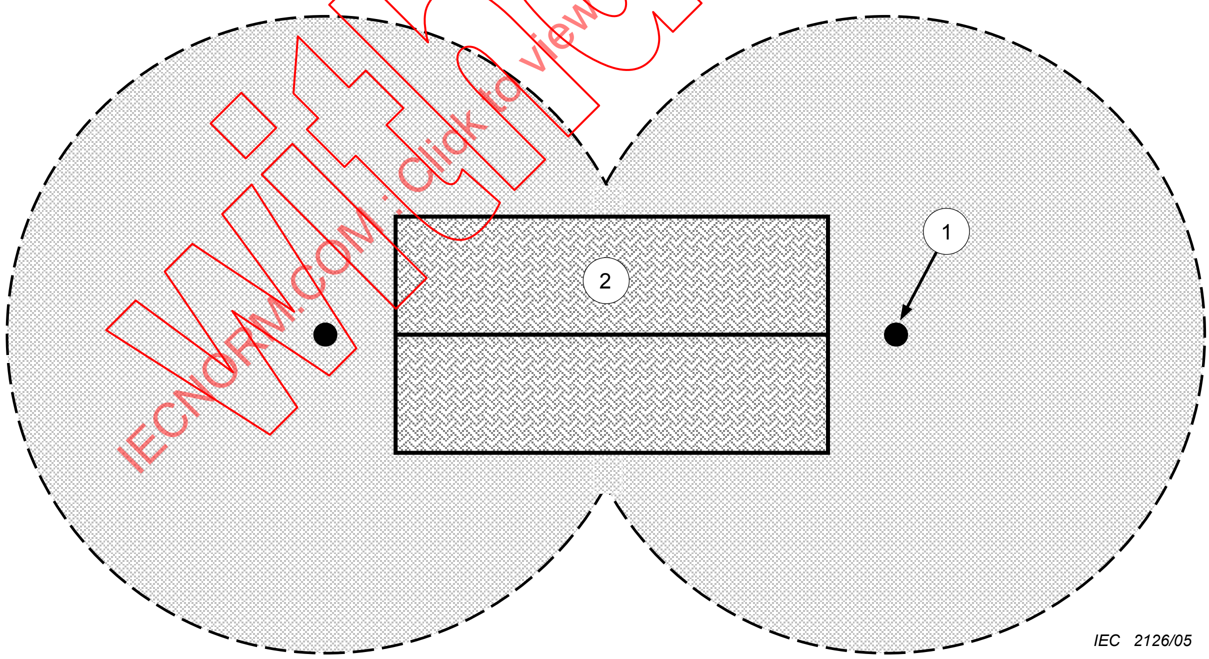
The design of air-termination using the protection angle air-termination design method is also shown in Figures E.13 and E.14 for an isolated LPS and in Figures E.15 and E.16 for a non-isolated LPS.



Key

1 Air-termination mast
2 Protected structure
3 Ground being the reference plane
4 Intersection between protective cones
s Separation distance according to 6.3
α_1, α_2 Protective angle complying with Table 2

Figure E.13a – Projection on a vertical plane



NOTE The two circles denote the protected area on the ground as the reference plane.

Figure E.13b – Projection on the horizontal reference plane

Figure E.13 – Isolated external LPS using two isolated air-termination masts designed according to the protective angle air-termination design method

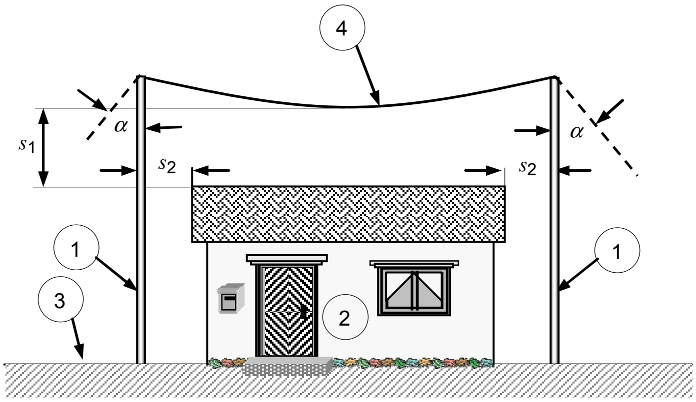


Figure E.14a – Projection on a vertical plane containing the two masts

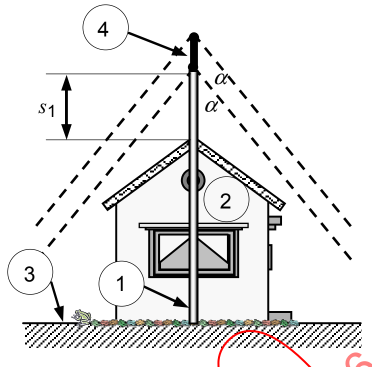


Figure E.14b – Projection on a vertical plane perpendicular to the plane containing the two masts

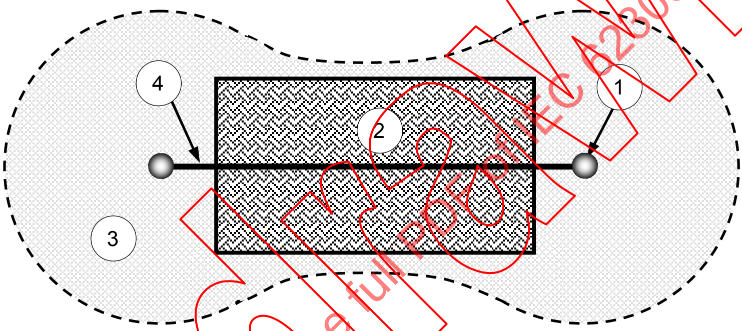


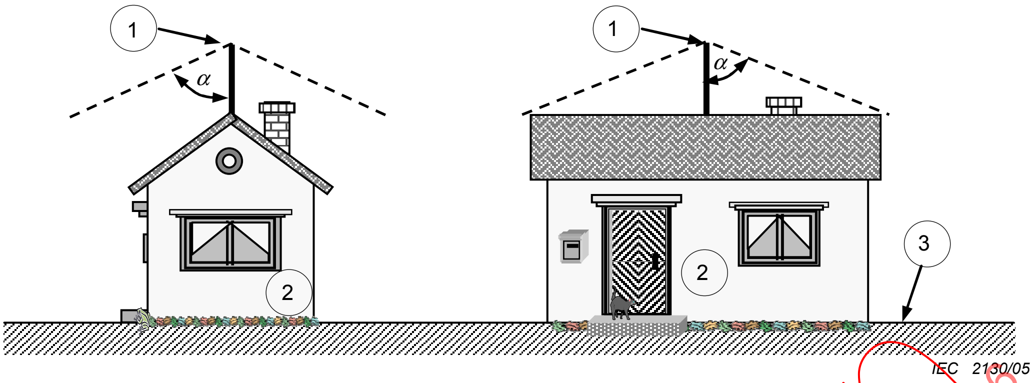
Figure E.14c – Projection on the horizontal reference plane

Key

1	Air-termination mast
2	Protected structure
3	Protected area on the reference plane
4	Horizontal wire air-termination
s_1, s_2	Separation distances according to 6.3
α	Protective angle complying with Table 2

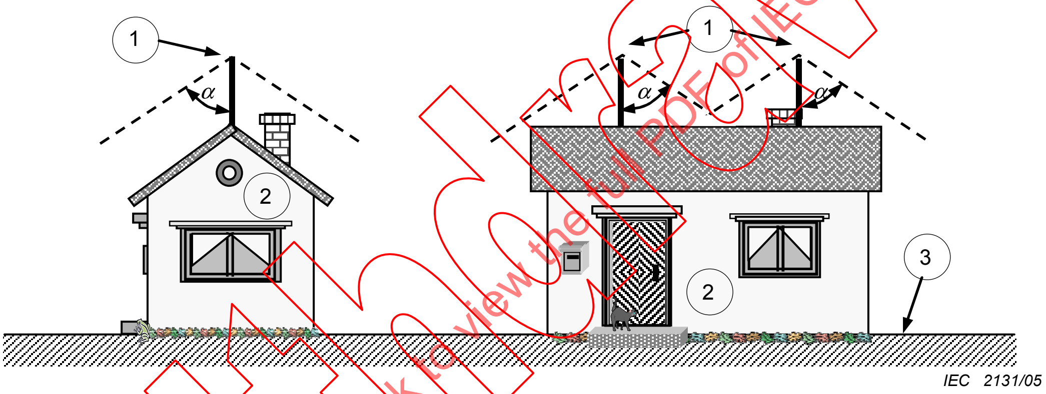
NOTE The air-termination system is designed according to the protective angle air-termination design method. The whole structure should be inside the protected volume.

Figure E.14 – Isolated external LPS using two isolated air-termination masts, interconnected by horizontal catenary wire



Key
1 Air-termination rod
2 Protected structure
3 Assumed reference plane
α Protective angle complying with Table 2

Figure E.15a – Example using one air-termination rod

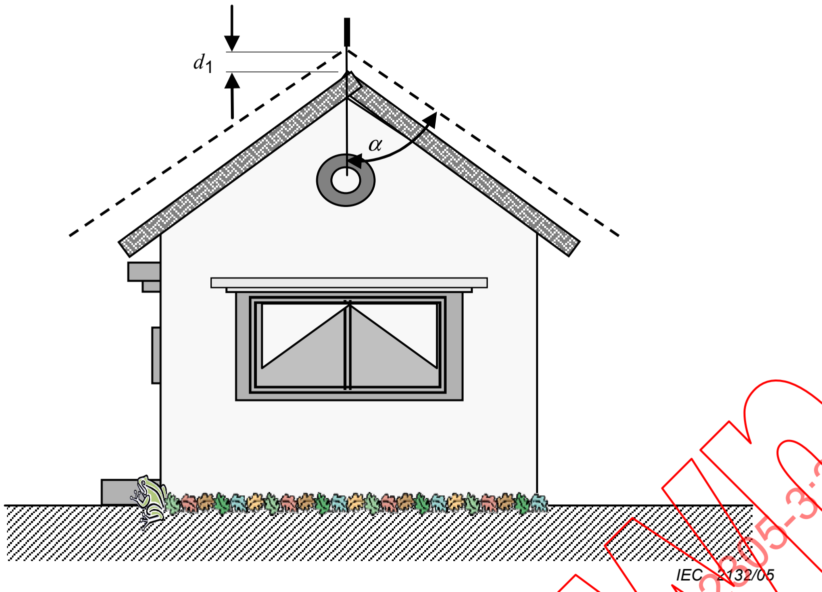


Key
1 Air-termination rod
2 Protected structure
3 Assumed reference plane
α Protective angle complying with table 2

Figure E.15b– Example using two air-termination rods

NOTE The whole structure should be inside the protected volumes of the air-termination rods.

Figure E.15 – Example of design of an air-termination of a non-isolated LPS by air-termination rods

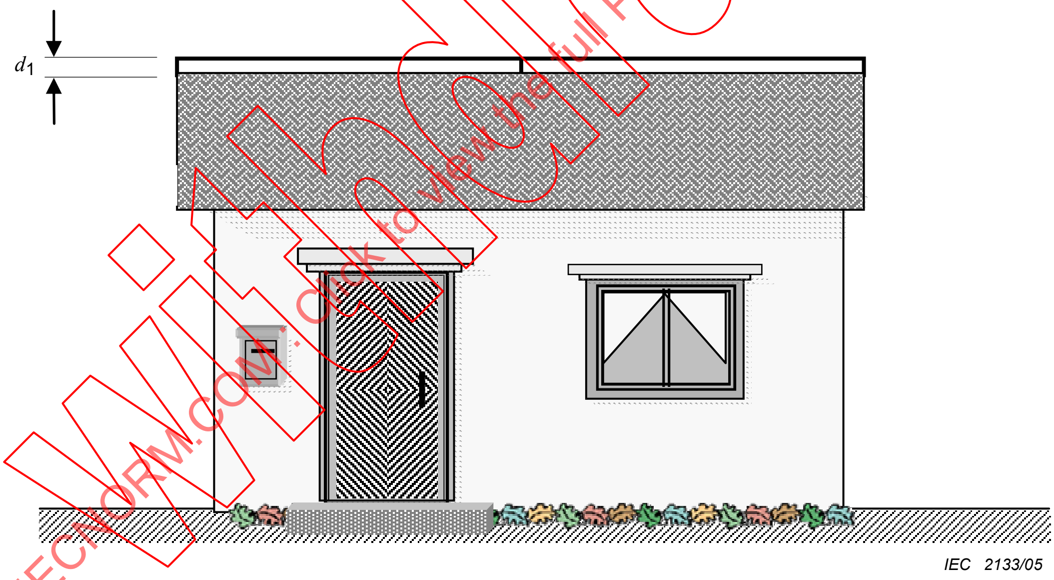


Key

α Protective angle complying with Table 2

d_1 Distance of horizontal wire from the roof

Figure E.16a – Projection on the vertical plane perpendicular to the plane containing the conductor



Key

α Protective angle complying with Table 2

NOTE The whole structure should be inside the protected volume.

Figure E.16b – Projection on a vertical plane containing the conductor

Figure E.16 – Example of design of an air-termination of a non isolated LPS by a horizontal wire according to the protective angle air-termination design method

If the surface on which the air-termination system is placed is inclined, the axis of the cone which forms the protected zone is not necessarily the air-termination rod, but is instead the perpendicular to the surface on which the air-termination rod is placed; with the top of the cone being equal to the top of the air-termination rod (see Figure E.17).

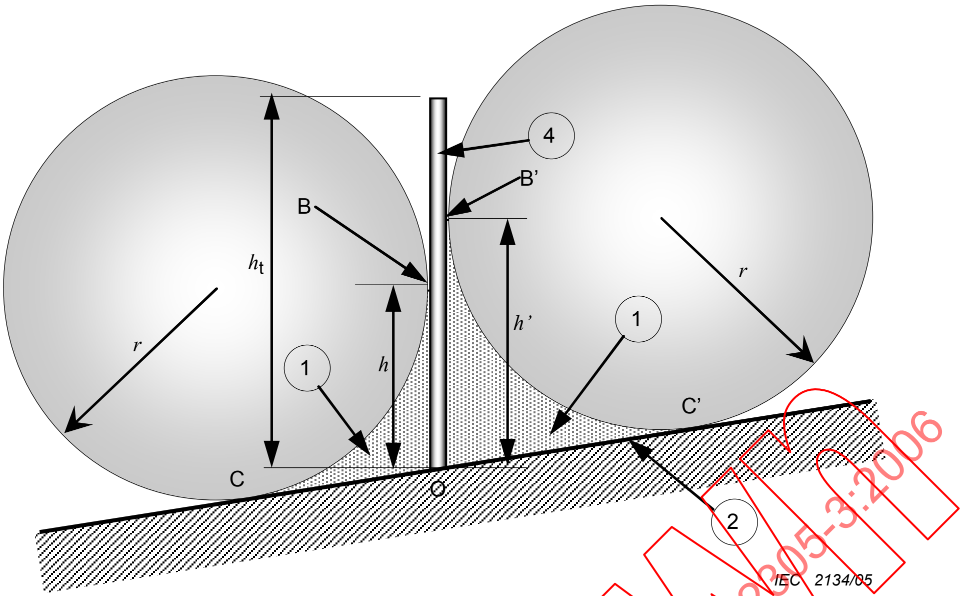


Figure E.17a – Protected volume of a mast on a sloped surface using the rolling sphere design method ($h_t > r$)

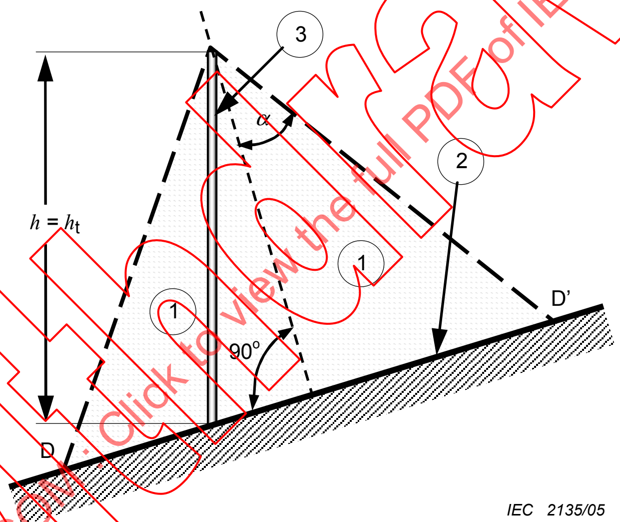


Figure E.17b – Protected volume of an air-termination rod on a sloped surface using the protection angle design method

Key

1	Protected volume
2	Reference plane
3	Air-termination rod
4	Mast
r	Radius of the rolling sphere according to Table 2
h, h'	Relevant heights of air-termination according to Table 2
h_t	Physical height of the mast above the reference plane
α	Protection angle
B, C, B', C'	Touching points with the rolling sphere
C, C',D, D'	Limit of the protected area

NOTE The heights h and h' should be less than h_t. Two values of h, e.g. h and h' are applicable on a sloped reference plane.

Figure E.17 – Protected volume of an air- termination rod or mast on a sloped surface

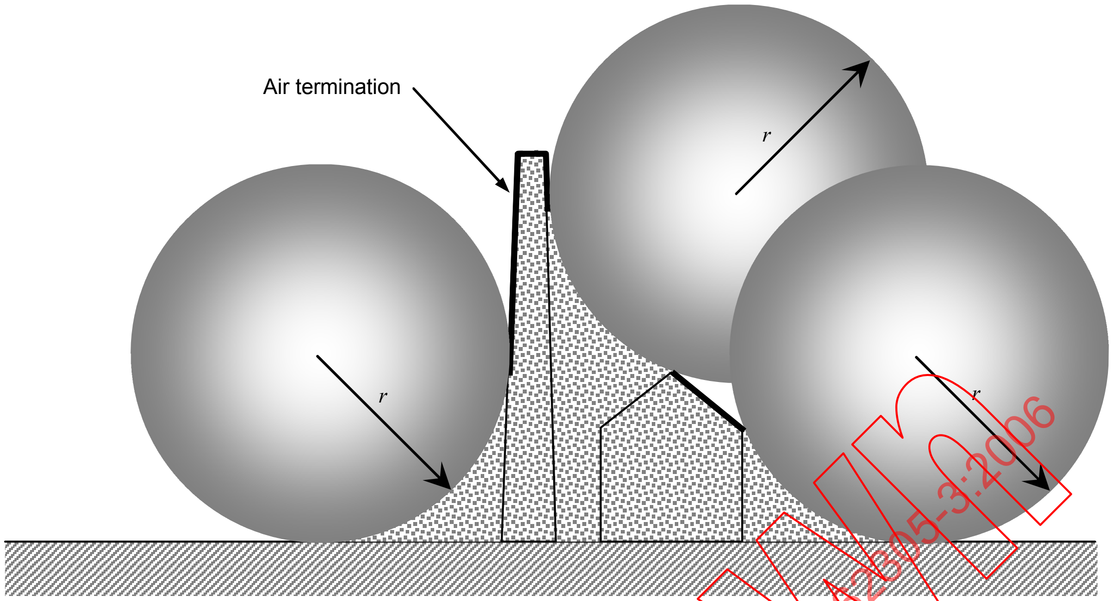
E.5.2.2.2 Rolling sphere method

The rolling sphere method should be used to identify the protected space of parts and areas of a structure when Table 2 excludes the use of the protective angle method.

Applying this method, the positioning of an air-termination system is adequate if no point of the volume to be protected is in contact with a sphere of radius, r, rolling on the ground, around and on top of the structure in all possible directions. Therefore, the sphere should touch only the ground and/or the air-termination system.

The radius r of the rolling sphere depends on the class of LPS (see Table 2).

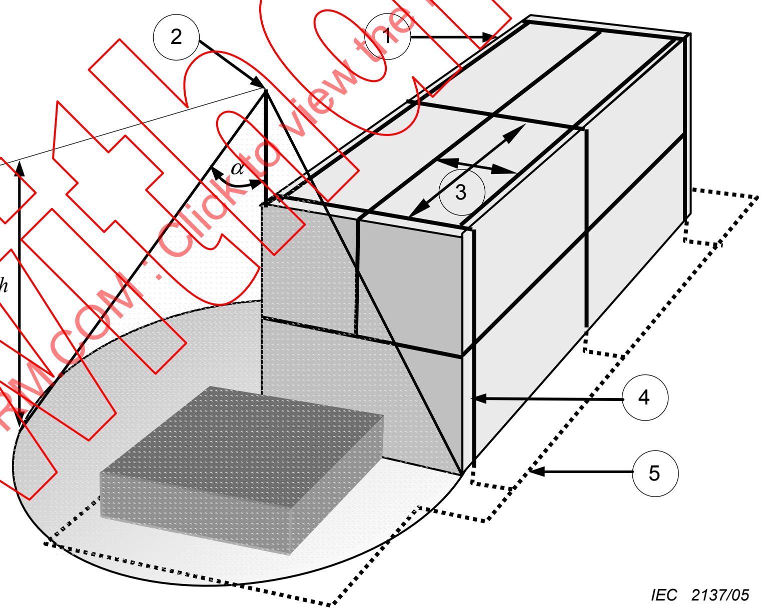
Figures E.18 and E.19 show the application of the rolling sphere method to different structures. The sphere of radius r is rolled around and over all the structure until it meets the ground plane or any permanent structure or object in contact with the ground plane which is capable of acting as a conductor of lightning. A striking point could occur where the rolling sphere touches the structure and at such points protection by an air-termination conductor is required.



r Radius of the rolling sphere according to Table 2.

NOTE Air-termination LPS conductors are installed on all points and segments which are in contact with the rolling sphere, whose radius complies with the selected protection level except for the lower part of the structure in accordance with 5.2.3.

Figure E.18a – Design of an LPS air-termination according to the rolling sphere method

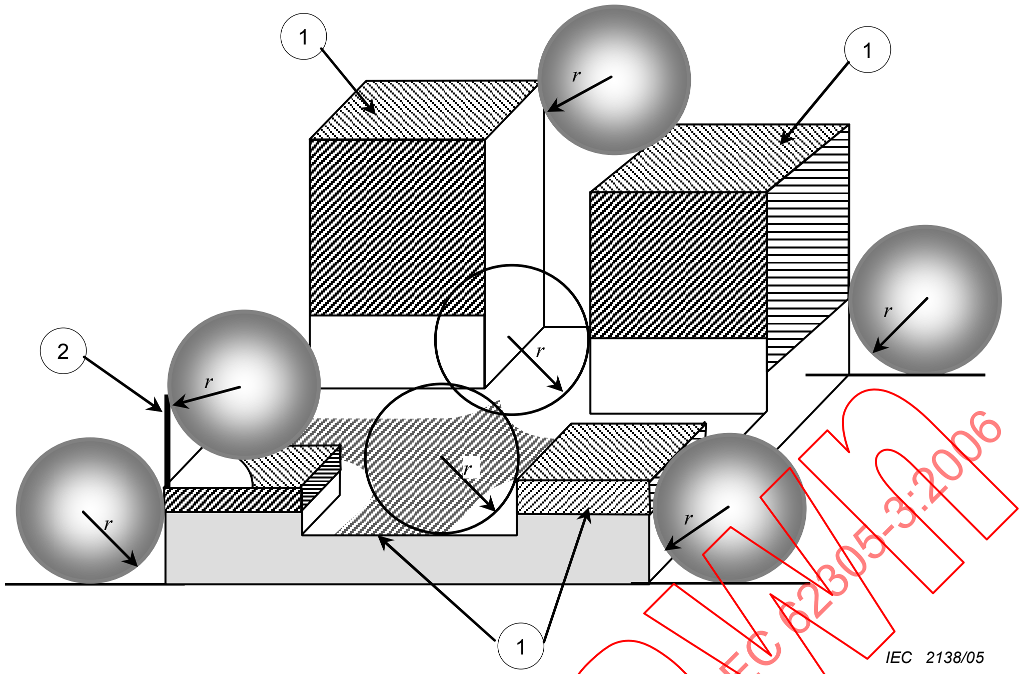


Key

1 Air-termination conductor
2 Air-termination rod
3 Mesh size
4 Down-conductor
5 Earthing system with ring conductor
h Height of the air-terminal above ground level
α Protective angle

Figure E.18b – General arrangement of air-termination elements

Figure E.18 – Design of an LPS air-termination according to the rolling sphere method, protective angle method, mesh method and general arrangement of air-termination elements



Key

1 Shaded areas, are exposed to lightning interception and need protection according Table 2

2 Mast on the structure

r Radius of rolling sphere according to Table 2

NOTE Protection against side flashes is required according to 5.2.3 and A.2.

Figure E.19 – Design of an LPS air-termination conductor network on a structure with complicated shape

When the rolling sphere method is applied to drawings of the structure, the structure should be considered from all directions to ensure that no part protrudes into an unprotected zone – a point which might be overlooked if only front, side and plan views on drawings are considered.

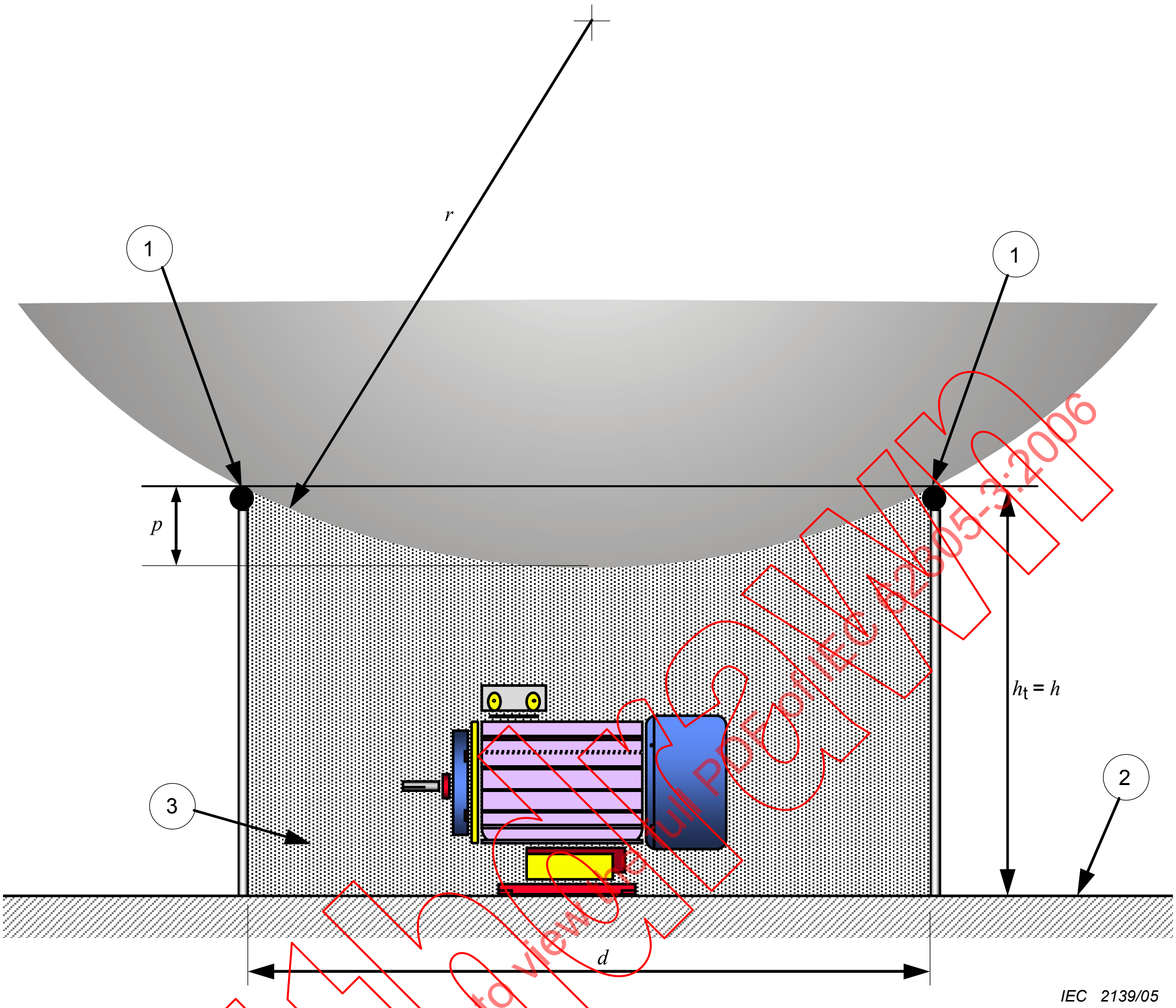
The protected space generated by an LPS conductor is the volume not penetrated by the rolling sphere when it is in contact with the conductor and applied to the structure.

Figure E.18 shows the protection afforded by an LPS air-termination system according to the mesh method, rolling sphere method and protection angle method with a general arrangement of air-termination elements.

In the case of two parallel horizontal LPS air-termination conductors placed above the horizontal reference plane in Figure E.20, the penetration distance p of the rolling sphere below the level of the conductors in the space between the conductors may be calculated:

$$p = r - [r^2 - (d/2)^2]^{1/2} \qquad \text{(E.4)}$$

The penetration distance p should be less than h_t minus the height of objects to be protected (the motor in Figure E.20).



Key

1 Horizontal wires

2 Reference plane

3 Space protected by two parallel air-termination horizontal wires or two air-termination rods

h_t Physical height of the air-termination rods above the reference plane

p Penetration distance of the rolling sphere

h Height of the air-termination according to Table 2

r Radius of the rolling sphere

d Distance separating two parallel air-terminal horizontal wires or two air-terminal rods

NOTE The penetration distance p of the rolling sphere should be less than h_t minus the largest height of objects to be protected, in order to protect objects in the space between the terminations.

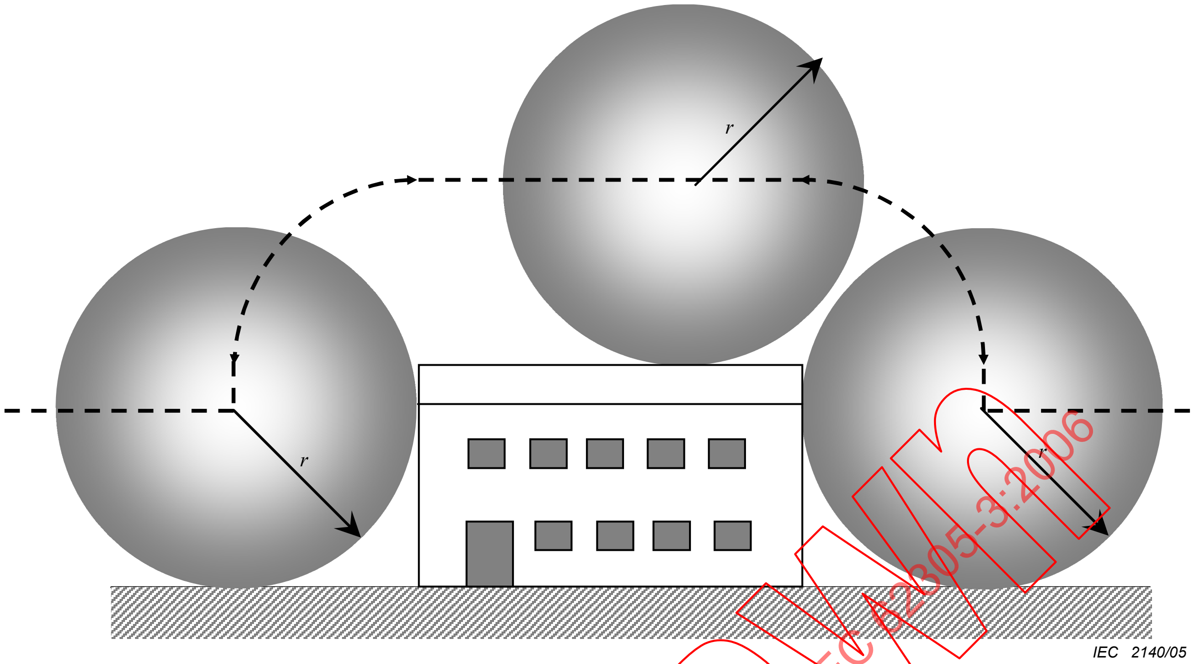
Figure E.20 – Space protected by two parallel air-termination horizontal wires or two air-termination rods ($r > h_t$)

The example shown in Figure E.20 is also valid for three or four air-termination rods; for example, four vertical rods placed at the corners of a square with the same applied height h. In this case, d in Figure E.20 corresponds to the diagonals of the square formed by the four rods.

NOTE Since the mid 1930s, it has been known that the radius of the rolling sphere is correlated with the peak value of the current in the lightning that strikes the structure: $r = 10I^{0,65}$ where I is defined as kA.

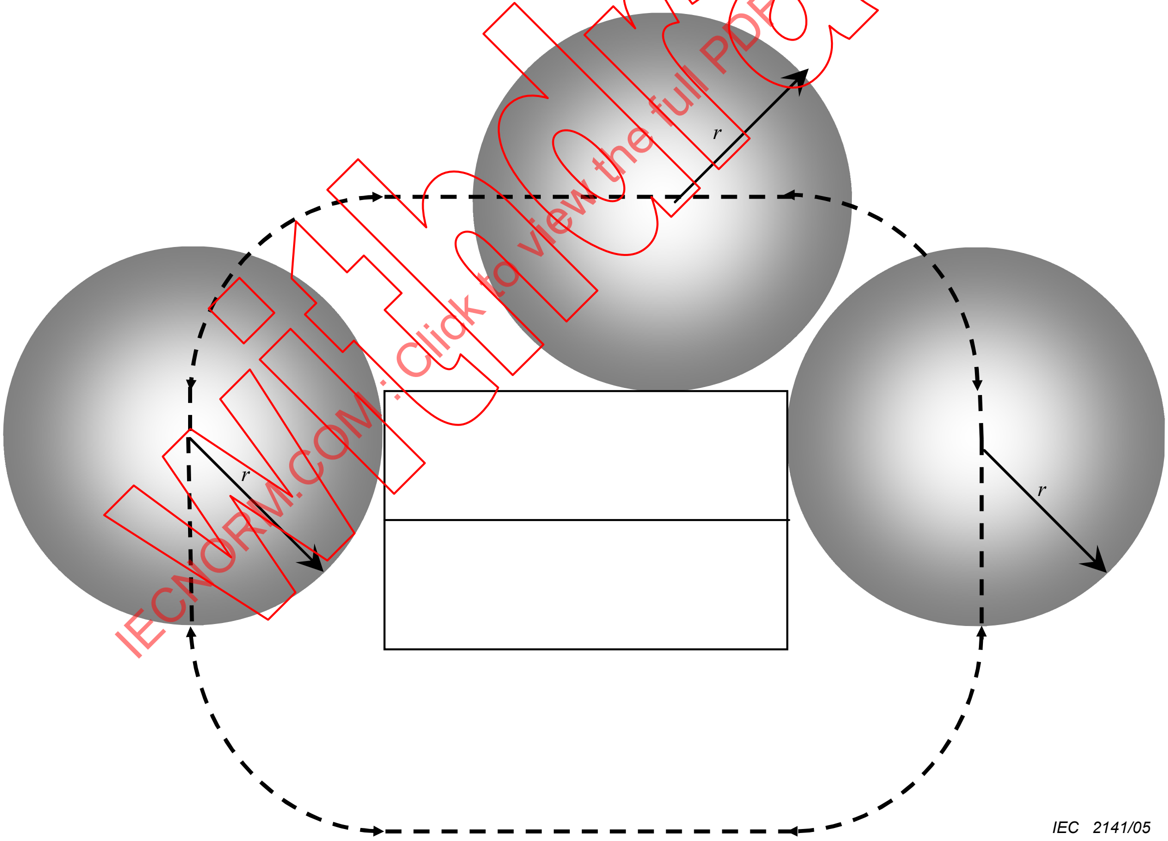
The points at which lightning will strike can be determined using the rolling sphere method. The rolling sphere method can also identify the probability of occurrence of a strike to each point of the building.

Figure E.21 shows a building over which the rolling sphere rolls . The dashed line depicts the path of the centre of the rolling sphere. This is also the geometrical location of the tip of the downward leader, from which the final discharge ensues. All those lightning flashes with tips lying on the path of the centre of the rolling sphere will discharge to the nearest point of the building. Around the edges of the roof there is a quarter circular path with possible positions of the tip of the downward leader which will discharge to the edge of the building. This shows that a considerable portion of the strikes will occur at the edge of the roof, some at the walls and some at the roof surface.



r Radius of the rolling sphere according to Table 2

Figure E.21a – Side view



r Radius of the rolling sphere according to Table 2

Figure E.21b – Plan view

Figure E.21 – Points at which lightning will strike a building

In order to make a prediction about the overall possibility of a strike to the wall, the plan view must also be considered (see Figure E.21b).

E.5.2.2.3 Mesh method

For the purpose of protecting flat surfaces, a mesh is considered to protect the whole surface if the following conditions are fulfilled.

a) As mentioned in Annex A, air-termination conductors are positioned on
   - roof edge lines,
   - roof overhangs,
   - roof ridge lines, if the roof slope exceeds 1/10,
   - the lateral surfaces of the structure higher than 60 m at levels higher than 80 % of the height of the structure;

b) the mesh dimensions of the air-termination network are not greater than the values given in Table 2;

c) the network of the air-termination system is accomplished in such a way that the lightning current will always encounter at least two distinct metallic routes to the earth and no metal installation protrudes outside the volume protected by air-termination systems;

   NOTE A larger number of down-conductors results in reduction of the separation distance and reduces the electromagnetic field within the building (see 5.3).

d) the air-termination conductors follow as far as possible short and direct routes.

   Examples of non-isolated LPS using the air-termination mesh method design are shown in Figure E.22a for a flat-roof structure and in Figure E.22b for a sloped-roof structure. Figure E.22c shows an example of an LPS on a industrial building. Figure E.22d shows an example of an LPS with concealed conductors.

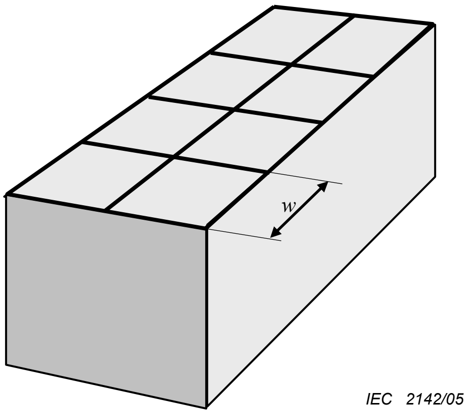
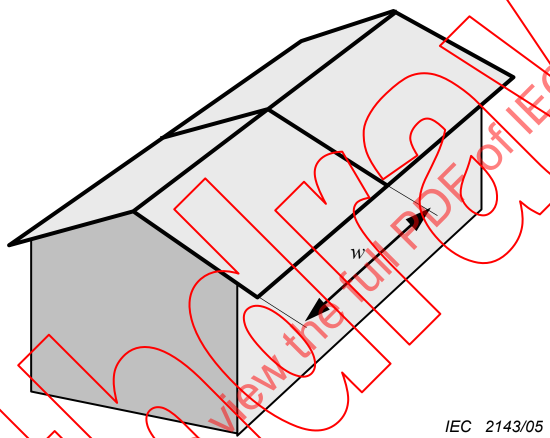


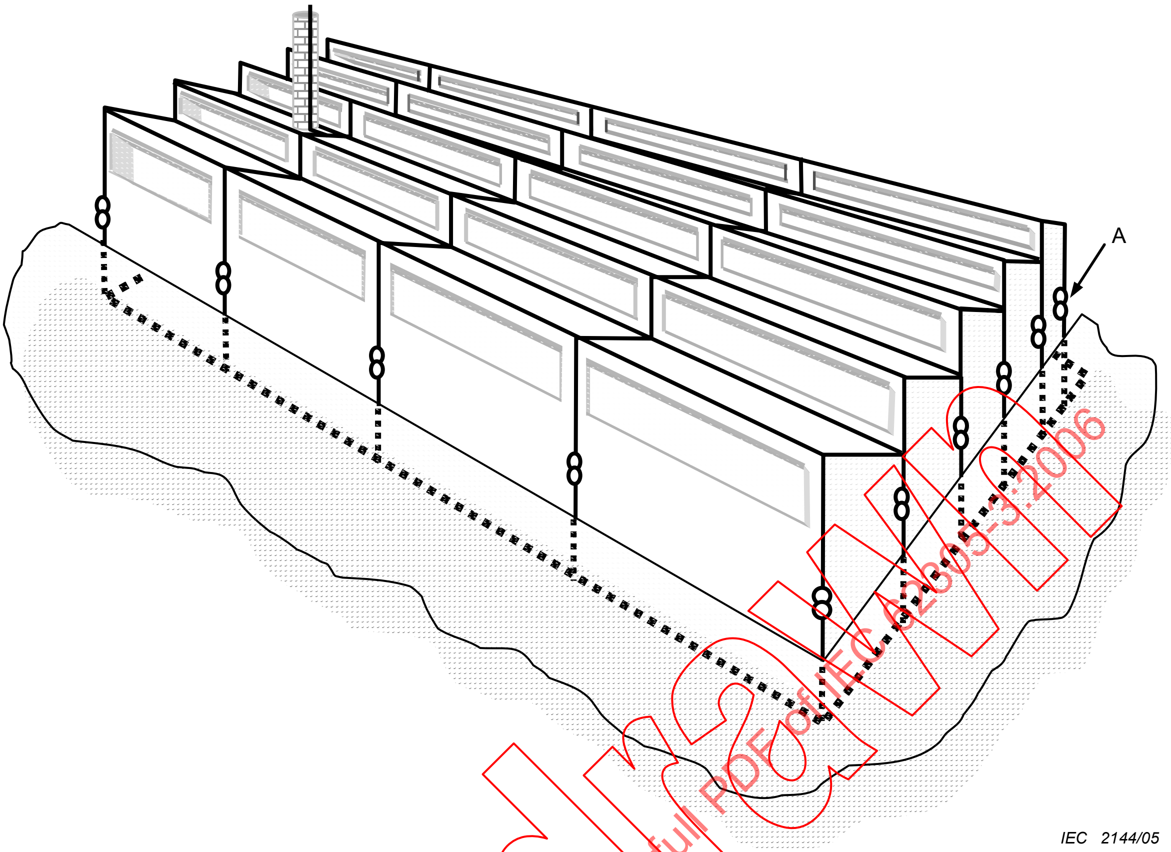
Figure E.22a – LPS air-termination on a flat-roof structure



Key
w Mesh size

NOTE The mesh size should comply with Table 2.

Figure E.22b – LPS air-termination on a sloped-roof structure



Key
A Test joint

NOTE All dimensions should comply with the selected protection level according to Tables 1 and 2.

Figure E.22c – An example of LPS on a shed roof structure

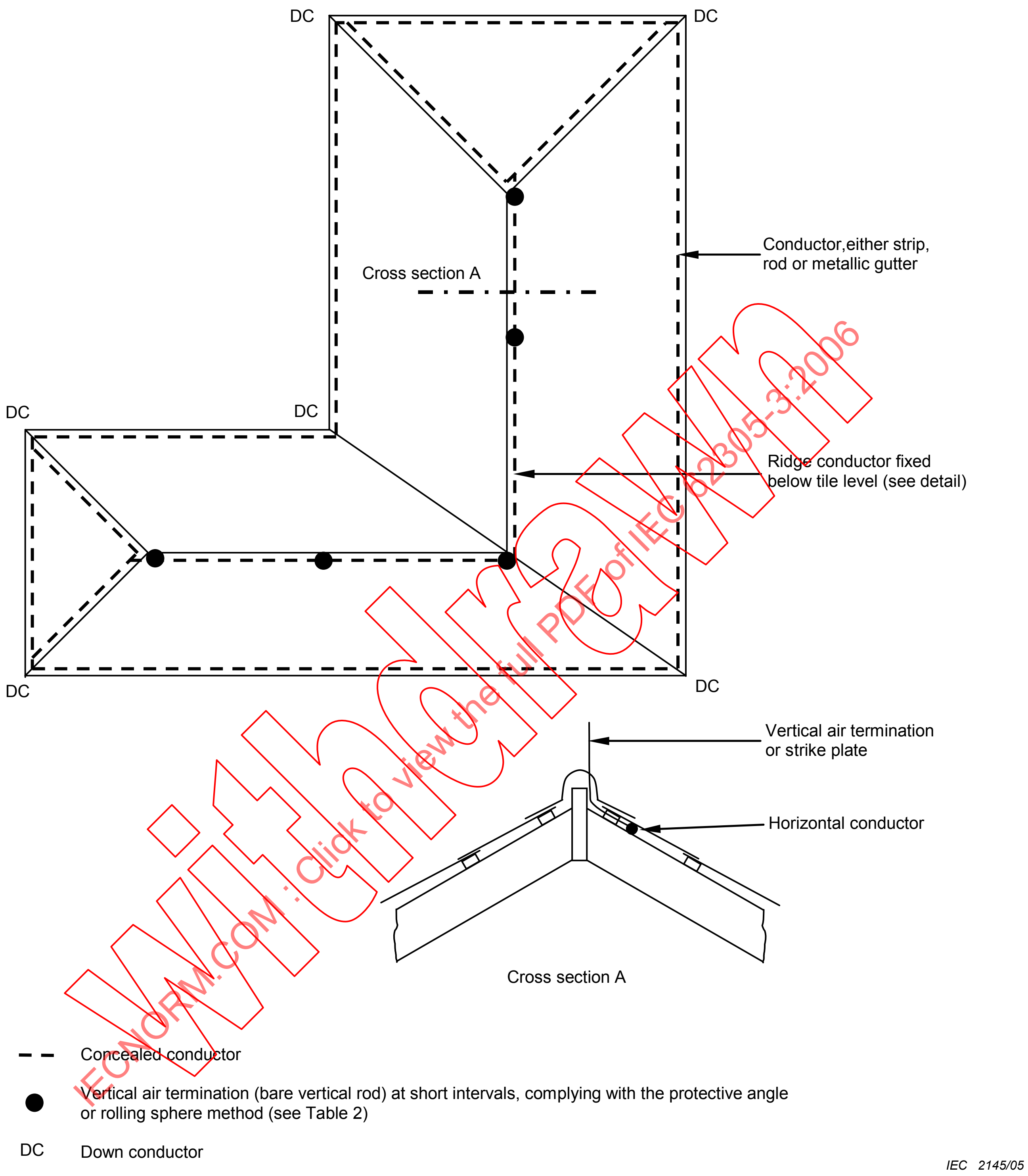


Figure E.22d – Air-termination and visually concealed conductors for buildings less than 20 m high, with sloping roofs

Figure E.22 – Example of design of non-isolated LPS air-termination according to the mesh method air-termination design

E.5.2.3 Air-terminations against flashes to the side on tall structures

In structures higher than 120 m, the topmost 20 % of lateral surfaces should be equipped with air-termination systems.

NOTE If sensitive parts (e.g. electronic equipment) are present on the outside of the wall in the upper part of the building, they should be protected by special air-termination measures, such as horizontal finials, mesh conductors or equivalent.

E.5.2.4 Construction

E.5.2.4.1 General information

The maximum permissible temperature for a conductor will not be exceeded if the cross-section of the conductor conforms to Table 6.

A roof or wall constructed from combustible material should be protected from the dangerous effect of lightning current heating the LPS conductors by using one or more of the following measures:

– reducing the temperature of the conductors by increasing the cross-section;
– increasing the distance between the conductors and the roof covering (see also 5.2.4);
– inserting a heat-protective layer between the conductors and the flammable material.

NOTE Research has shown that it is advantageous for air-termination rods to have a blunt tip.

E.5.2.4.2 Non-isolated air-termination

Air-termination conductors and down-conductors should be interconnected by means of conductors at the roof level to provide sufficient current distribution over the down-conductors.

Conductors on roofs and the connections of air-termination rods may be fixed to the roof using either conductive or non-conductive spacers and fixtures. The conductors may also be positioned on the surface of a wall if the wall is made of non-combustible material.

Recommended fixing centres for these conductors are shown in Table E.1.

Table E.1 – Suggested fixing centres

Arrangement	Fixing centres for tape and stranded conductors mm	Fixing centres for round solid conductors mm
Horizontal conductors on horizontal surfaces	500	1 000
Horizontal conductors on vertical surfaces	500	1 000
Vertical conductors from the ground to 20 m	1 000	1 000
Vertical conductors from 20 m and thereafter	500	1 000

NOTE 1 This table does not apply to built-in type fixings which may require special consideration.

NOTE 2 Assessment of environmental conditions (i.e. expected wind load) should be undertaken and fixing centres different from those recommended may be found to be necessary.

On small houses and similar structures with a roof ridge, a roof conductor should be installed on the roof ridge. If the structure is completely within the protected area provided by the roof-ridge conductor, at least two down-conductors should be routed over the gable edges at opposite corners of the structure.

NOTE The distance between the two down-conductors, measured along the perimeter of the structure should not exceed the distances stated in Table 4.

The gutters at the edge of the roof may be used as natural conductors provided that they conform to 5.2.5.

Figures E.23a, E.23b and E.23c depict an example of the arrangement of the conductors on a roof and down-conductors for a sloped roof structure.

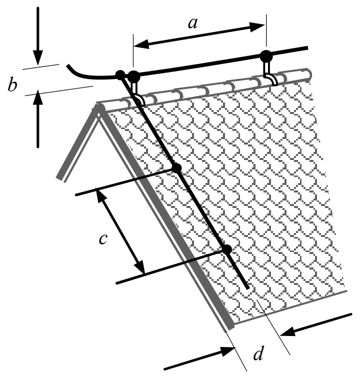


Figure E.23a – Installation of air-termination conductor on the ridge of a sloped roof and a roof down-conductor

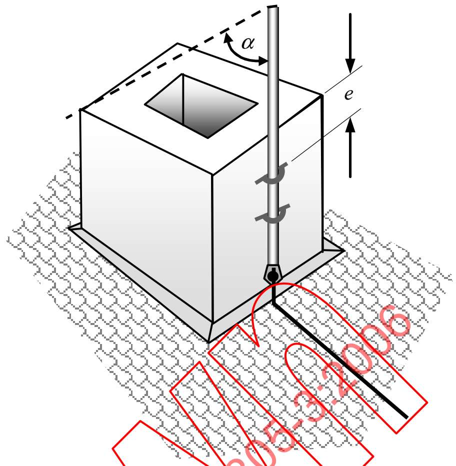


Figure E.23b – Installation of air-termination rod for protection of chimney using the protective angle air-termination design method

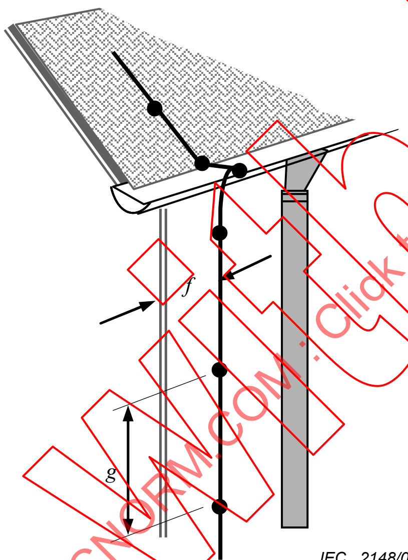


Figure E.23c – Installation of a down-conductor with connection to the gutter

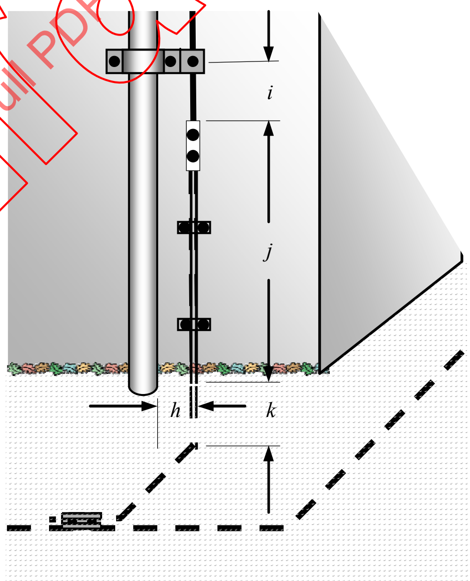


Figure E.23d – Installation of a test joint in a down-conductor and bonding to a drain-pipe

Examples of suitable dimensions:

a 1 m
b 0,15 m (not mandatory)
c 1 m
d as close to the edge as possible
e 0,2 m
f 0,3 m
g 1 m
h 0,05 m
i 0,3 m
j 1,5 m
k 0,5 m
α Protective angle according to Table 2

Figure E.23 – Some examples of details of an LPS on a structure with sloped tiled roofs

In the case of long structures, additional conductors in accordance with Table 4 should be connected to the air-termination conductors mounted on the roof ridge.

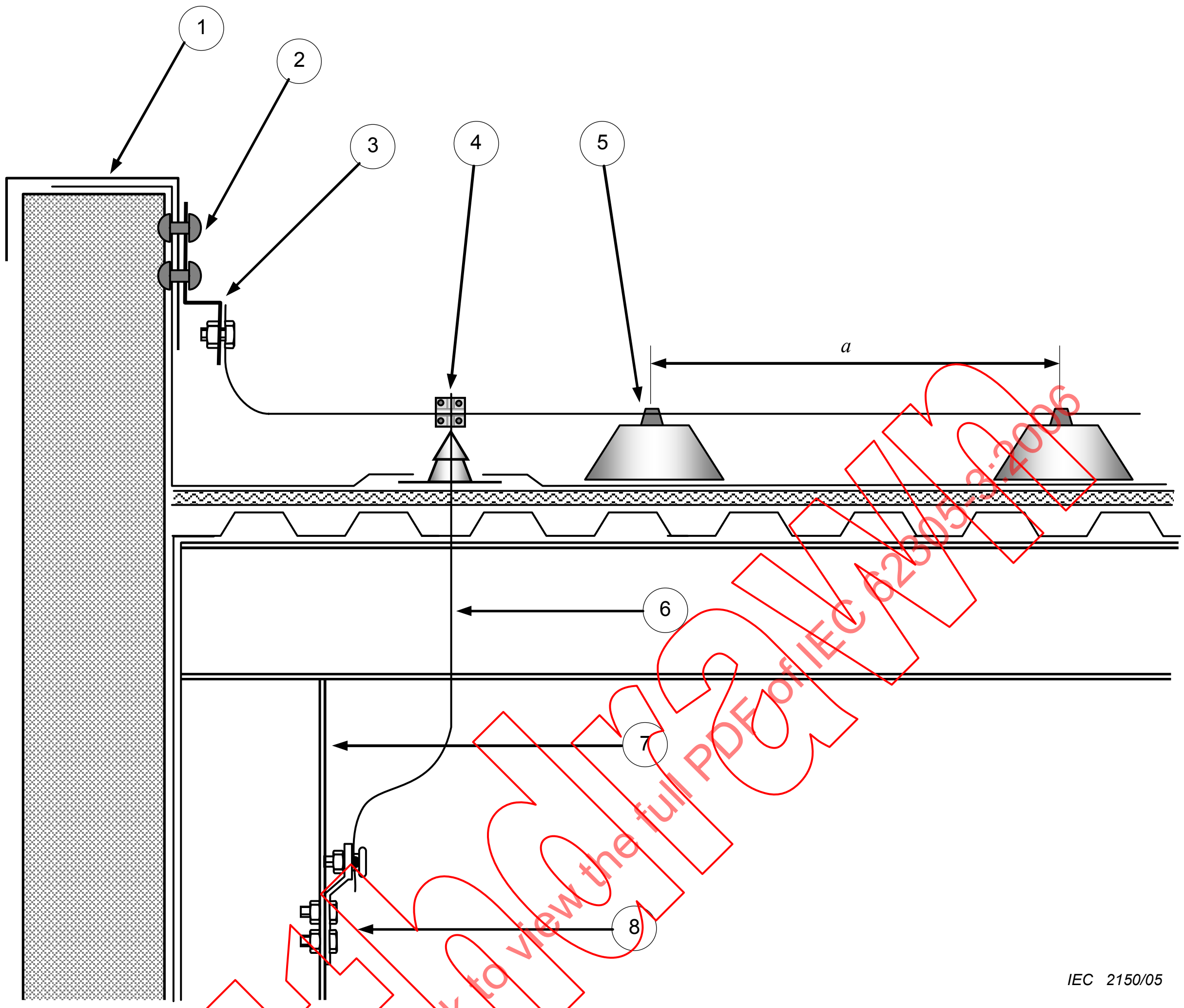
On buildings with large roof overhangs, the roof-ridge conductor should be extended to the end of the ridge. On the gable edge of the roof a conductor should be connected from the roof-ridge conductor to the down-conductor.

As far as is practicable, air-termination conductors, connecting conductors and down-conductors should be installed in a straight route. On non-conducting roofs, the conductor may be placed either under, or preferably over, the roof tiles. Although mounting it under the tiles has the advantage of simplicity and less risk of corrosion, it is better, where adequate fixing methods are available, to install it along the top of the tiles (i.e. externally) so reducing the risk of damage to the tiles should the conductor receive a direct flash. Installing the conductor above the tiles also simplifies inspection. Conductors placed below the tiles should preferably be provided with short vertical finials which protrude above roof level and are spaced not more than 10 m apart. Appropriate exposed metal plates may be also be used (see Figure E.20d) provided they are spaced not more than 5 m apart.

On structures with flat roofs, the perimeter conductors should be installed as close to the outer edges of the roof as practicable.

When the roof surface exceeds the mesh size stipulated in Table 2, additional air-termination conductors should be installed.

Figures E.23a, E.23b and E.23c show examples of the construction details of fixtures for air-termination conductors on the sloped roof of a structure. Figure E.24 provides an example of construction details for fixtures on a flat roof.



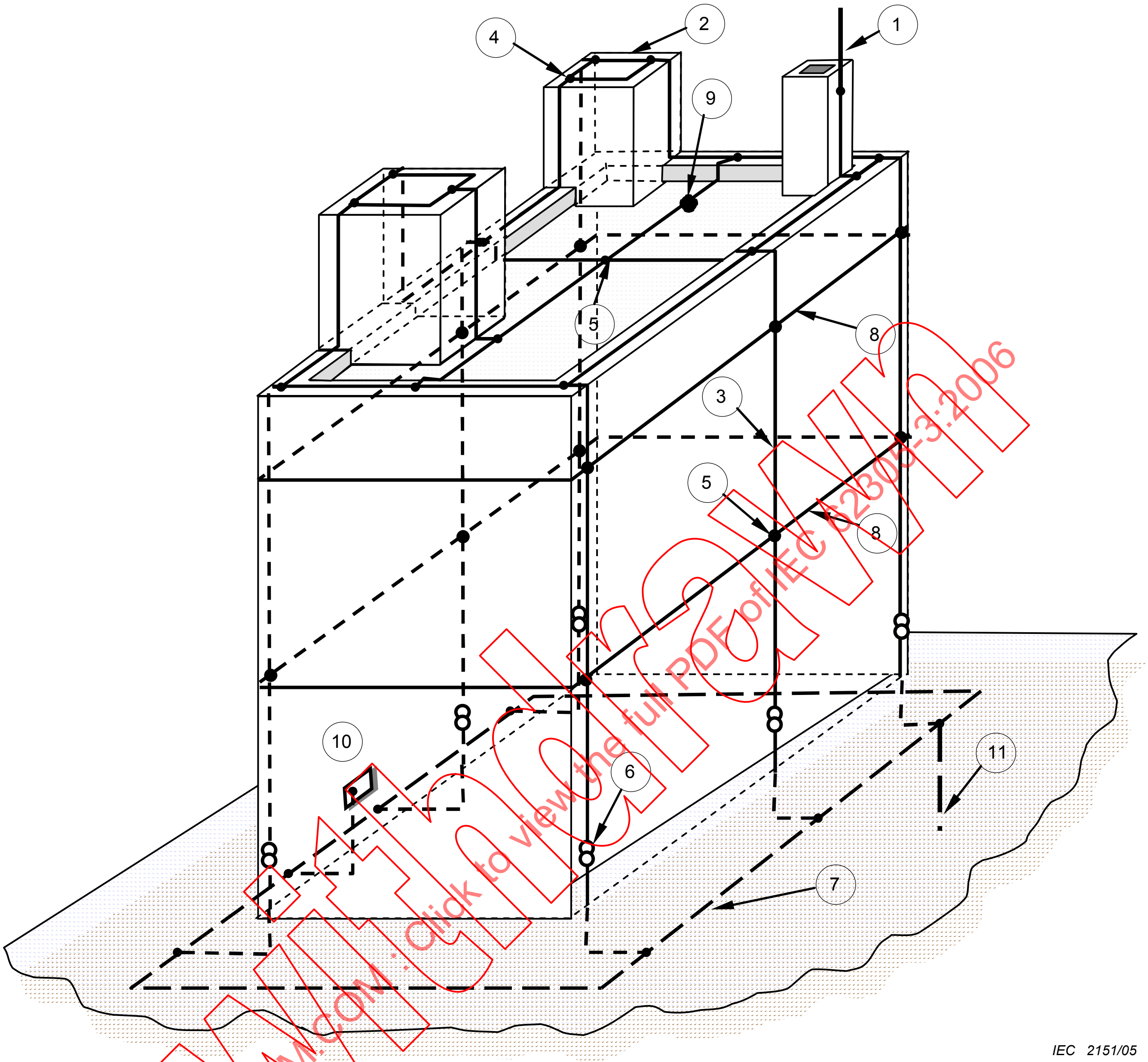
Key

a 500 mm to 1 000 mm, see Table F.1
1 Roof parapet
2 Flexible conductor
3 Joints
4 T-joints
5 Air-termination conductor fixture
6 LPS passing a watertight bushing
7 Steel girder
8 Joint

NOTE Metallic covering on the roof parapet is used as an air-termination conductor and is connected to the steel girder used as a natural down-conductor of the LPS.

Figure E.24 – Construction of an LPS using natural components on the roof of the structure

Figure E.25 shows the positioning of the external LPS on a structure with a flat roof made of insulating material such as wood or bricks. The roof fixtures are within the space to be protected. On high structures, a ring connected to all down-conductors is installed on the facade. The distances between these ring conductors are given in Table 4. Ring conductors below the level of the rolling sphere radius are needed as equipotentialization conductors.



Key

1 Air-termination rod
2 Horizontal air-termination conductor
3 Down-conductor
4 T-type joint
5 Cross-type joint
6 Test joint
7 B-type earthing arrangement, ring earth electrode
8 Equipotentialization ring conductor
9 Flat roof with roof fixture
10 Terminal for connecting the equipotentialization bar of the internal LPS
11 A-type earthing arrangement

NOTE An equipotentialization ring is applied. The distance between the down-conductors complies with the requirements in Table 4.

Figure E.25 – Positioning of the external LPS on a structure made of insulating material e.g. wood or bricks with a height up to 60 m with flat roof and with roof fixtures

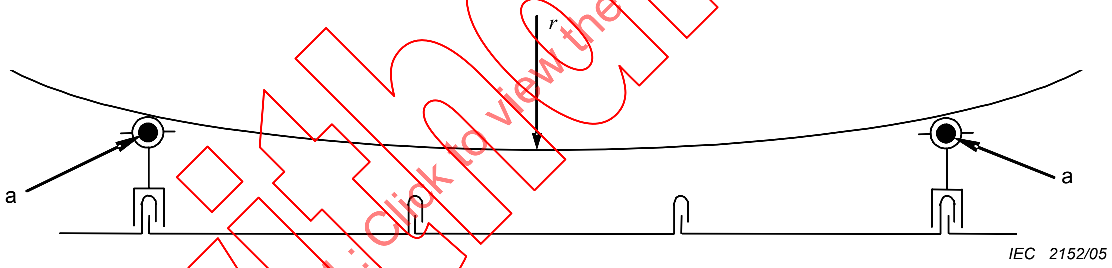
LPS conductors and rods should be mechanically secured so that they are capable of withstanding stress due to wind or weather and work carried out on the roof surface.

Metal covering provided for mechanical protection of outer walls may be used as a natural component of the air-termination, according to 5.2.5, if there is no risk of fire ignition by melting metal. The combustibility depends on the type of material under the metal cladding. The combustibility of the material employed should be confirmed by the contractor.

The roof sealing arrangement on metallic roofs, as with other types of roof, can be perforated by a lightning flash. In such a case, water can penetrate and leak through the roof at a point far from the striking point. If this possibility is to be avoided, an air-termination system should be installed.

Light cupolas and smoke and heat outlet flaps are normally closed. The design for the protection of such flaps should be discussed with the purchaser/owner of the building to decide whether protection should be applicable for the flaps in the open, closed and all intermediate positions.

Roof coverings of conductive sheet which do not conform to 5.2.5 may be used as air-terminations where melting at the striking point of lightning can be accepted. If this is not acceptable, the conductive roof sheeting should be protected by an air-termination system of sufficient height (see Figure E.20 and Figure E.26).



Key
r Radius of the rolling sphere, Table 2
a Air-termination conductors

NOTE The rolling sphere should not touch any part of the metallic roof including the standing seams.

Figure E.26 – Construction of air-termination network on a roof with conductive covering where puncturing of the covering is not acceptable

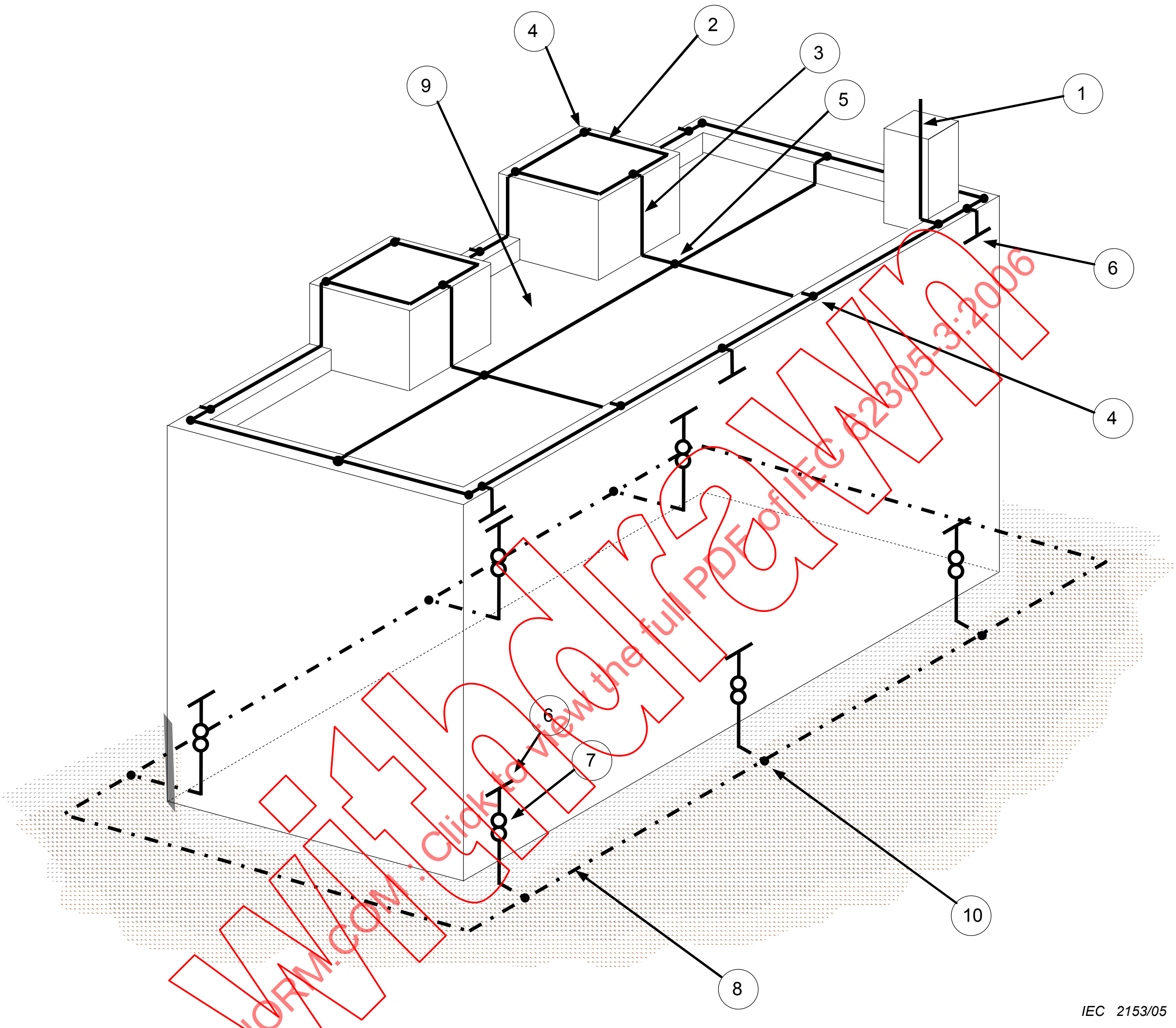
When insulating supports are used, the conditions for the separation distance to the conductive sheet stipulated in 6.3, should be fulfilled.

When conductive supports are used, the connection to the roof-sheet should withstand partial lightning current (see Figure E.26).

Figure E.24 shows an example of natural air-termination using a roof parapet as the air-termination conductor at the edge of the roof area.

Flush-mounted and protruding structures on the roof surface should be protected by means of air-termination rods. Alternatively, extraneous metalwork should be bonded to the LPS unless it conforms to 5.2.5.

Figure E.27 gives an example of the connection of air-termination with the natural down-conductors in concrete.



Key

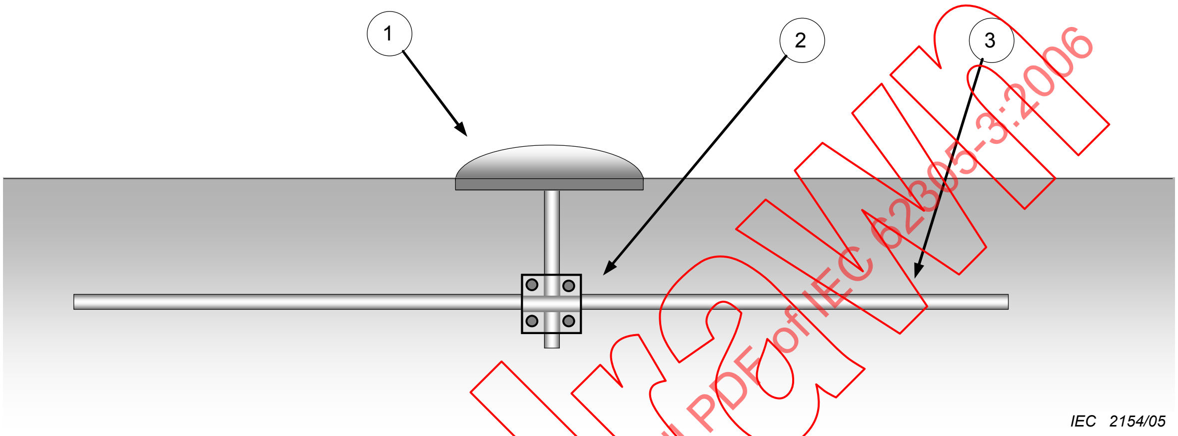
1 Air-termination rod
2 Horizontal air-termination conductor
3 Down-conductor
4 T-type joint
5 Cross type joint
6 Connection to steel reinforcing rods (see E 4.3.3 and E.4.3.6)
7 Test joint
8 Type B earthing arrangement, ring earth electrode
9 Flat roof with roof fixtures
10 T-type joint – corrosion resistant

NOTE The steel reinforcement of the structure should comply with 4.3. All dimensions of the LPS should comply with the selected protection level.

Figure E.27 – Construction of external LPS on a structure of steel-reinforced concrete using the reinforcement of the outer walls as natural components

E.5.2.4.2.1 Lightning protection for multi-storey car park roofs

For the protection of this type of structure, air-termination studs may be used. These studs can be connected to the reinforcement steel of a concrete roof (see Figure E.28). In the case of roofs where a connection to the reinforcement cannot be made, the roof conductors can be laid in the seams of the carriageway slabs and air-termination studs can be located at the mesh joints. The mesh width shall not exceed the value corresponding to the protection class given in Table 2. In this case, the persons and vehicles on this parking area are not protected against lightning.



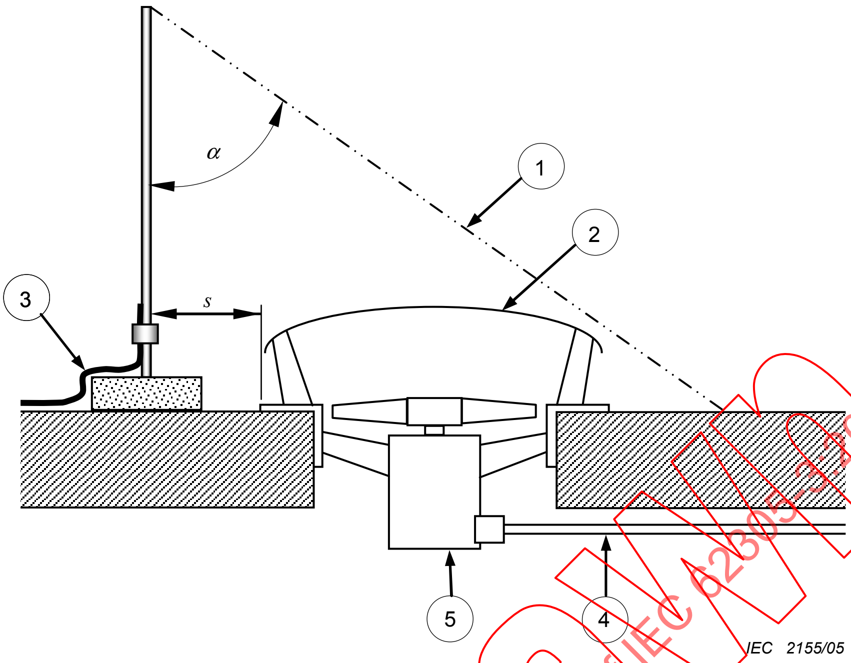
Key

1 Air-termination stud
2 Steel conductor connecting to several bars of the reinforcement steel
3 Steel reinforcement to concrete

Figure E.28 – Example of an air-termination stud used on car park roofs

If the topmost parking area is to be protected against direct lightning strikes, air-termination rods and overhead air-termination wires should be employed.

For determination of the safety clearance, an approximation is given by the height of the air-termination conductors in Figure E.29.



Key

1 Protective cone
2 Metallic roof fixture
3 Horizontal air-termination conductor
4 Electric power installation line, preferably enclosed in a conductive shield
5 Electric equipment
s Separation distance according to 6.3
α Protective angle, see Table 2

NOTE The height of the air-termination rod should comply with Table 2.

Figure E.29 – Air-termination rod used for protection of a metallic roof fixture with electric power installations which are not bonded to the air-termination system

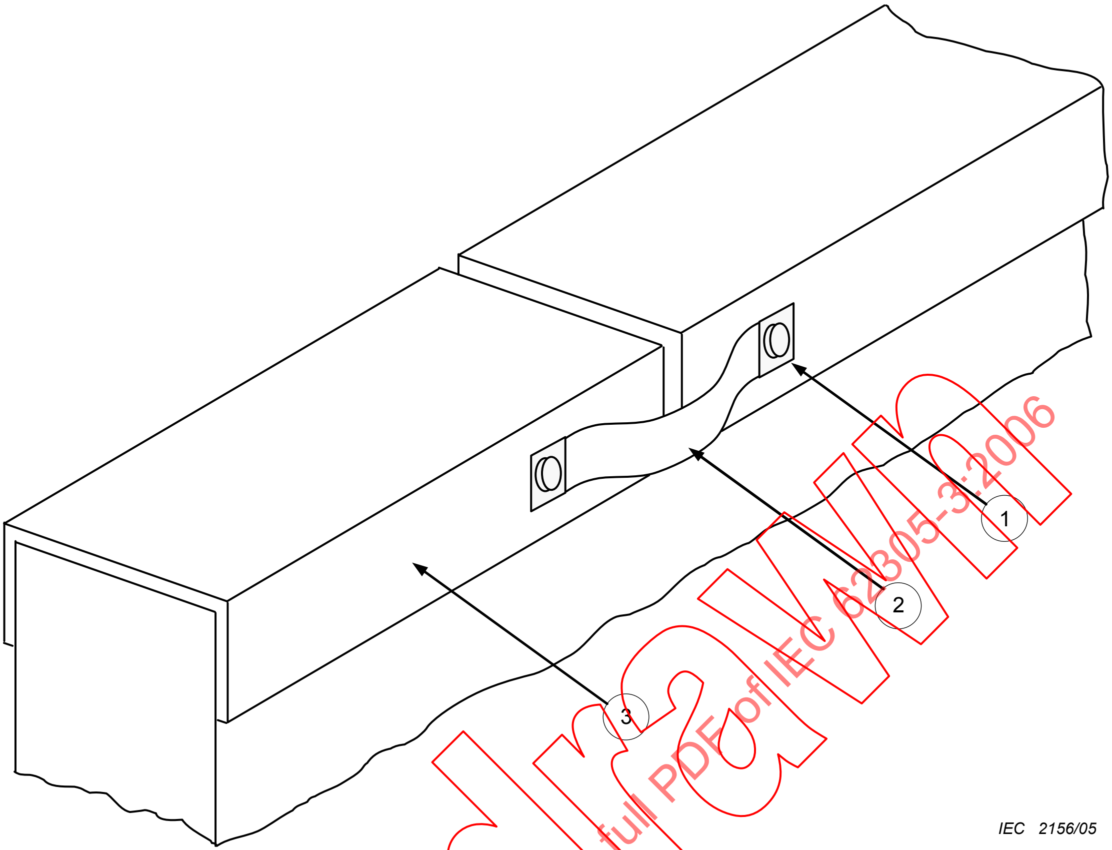
In the case of vertical conductors, the area which is possible to reach by hand should be taken into account. The necessary safety clearance can be achieved either by provision of barriers or by protective wiring.

Signs should be provided at the entrances drawing attention to the danger of lightning strikes during thunderstorms.

The touch and step voltages may be disregarded if the roof is covered by a layer of asphalt of at least 5 cm thickness. Additionally, the step voltages may be disregarded if the roof is constructed of reinforced concrete with interconnected reinforcement steel with continuity conforming to 4.3.

E.5.2.4.2.2 Flat-roofed, steel-reinforced concrete structures with roofs not accessible to the public

On a flat roof not accessible to the public which incorporates an external air-termination system, air-termination conductors should be installed as shown in Figure E.27. For the equipotential ring conductor on the roof, the metal cladding on the roof parapet may be used as shown in Figure E.24 and Figure E.30.



Key

1 Corrosion-resistant joint
2 Flexible conductor
3 Metallic covering of the parapet

NOTE Special attention should be paid to the proper selection of materials and good design of joints and bridging conductors to avoid corrosion.

Figure E.30 – Method of achieving electrical continuity on metallic parapet cladding

Figure E.27 shows a method of installing meshed conductors on a roof.

When temporary mechanical damage of the waterproof layer on the roof of a structure is acceptable, the air-termination mesh covering the flat area of the roof may be replaced with natural air-termination conductors consisting of steel reinforcement bars in concrete according to 5.2.4**.** An acceptable alternative is that the LPS air-termination conductors may be fixed directly on the concrete roof.

In general, a lightning flash to the reinforcement of a concrete roof will damage the waterproof layer. Rainwater may then cause corrosion of the steel-reinforcing rods leading to damage. If reduction in the mechanical strength of concrete due to the corrosion is not permitted, an air-termination system should be installed and preferably bonded to the reinforcement steel, preventing direct lightning flashes to the steel-reinforced concrete.

Metal covering that is provided for mechanical protection of outer walls may be used as a natural component of the air-termination according to 5.2.5 if there is no risk of fire ignition by melting metal.

Roof coverings of conductive sheets not conforming to Table 3 may be used as air-termination conductors where melting at the point of lightning flashes can be tolerated. If not, the conductive roof sheeting should be protected by an air-termination system of sufficient height (see Figures E.20 and E.26). In this case, the rolling sphere method should be applied. To conform to this method the mesh size has to be smaller and the supports higher than that for an ordinary mesh air-termination system.

When insulating supports are used, the conditions for the separation distance to the conductive sheet, stipulated in 6.3, should be fulfilled. When conductive supports are used, the connection to the roof-sheet should withstand partial lightning current (see Figure E.29).

Figure E.24 shows an example of a natural air-termination using a roof parapet as the air-termination conductor at the edge of the roof area.

When it is acceptable for temporary damage to the facade to occur, and shattered parts of up to 100 mm of broken concrete to fall down from the structure, 5.2 permits the ring conductor on the roof to be replaced by a natural ring conductor consisting of steel reinforcement in concrete.

Metal parts which do not satisfy the conditions of air-terminations stipulated in 5.2.5 may, however, be used to connect the different lightning-current-carrying parts within the domain of the roof area.

E.5.2.4.2.3 Provision of adequate structure shielding

The outer walls and roof of a structure may be used as an electromagnetic shield in order to protect electrical and information-processing equipment within the structure (see IEC 62305-2, Annex B and IEC 62305-4).

Figure E.27 provides an example of a steel-reinforced concrete structure using the interconnected reinforcing steel as down-conductors and as electromagnetic shielding of the enclosed space. For more details see IEC 62305-4.

Within the domain of the air-termination system on the roof, all conductive parts with at least one dimension larger than 1 m should be interconnected to form a mesh. The meshed shield should be connected to the air-termination system at the roof edge and also at other points within the roof area in accordance with 6.2.

Figures E.24 and E.30 show the construction of air-terminations on structures with conductive skeletons using a roof parapet as a natural air-termination and the steel skeleton as natural down-conductors.

In Figure E.30 an example is given of how to provide electrical continuity of natural components in an LPS.

As a result of the reduced mesh size of steel structures compared with Table 2, the lightning current is distributed over several parallel conductors, resulting in a low electromagnetic impedance and consequently in accordance with 6.3, the separation distances are reduced and the necessary separation distances between the installations and the LPS are much more easily obtained.

In most structures the roof is the least shielded part of the structure. Therefore particular attention should be paid to improve the shielding efficiency of roof constructions.

When no conductive structural elements are incorporated in the roof, shielding may be improved by reducing the spacing of the roof conductors.

E.5.2.4.2.4 Protection of flush-mounted or protruding roof fixtures without conductive installations

Air-termination rods for the protection of metal, flush-mounted roof fixtures or protruding roof fixtures should be of such height that the fixture to be protected lies fully within the rolling sphere protection space of the air-termination rod or is fully within the cone of the protective angle in accordance with Table 2. The separation distance between the air-termination rods and the roof fixtures should be such that the proximity condition stipulated in 6.3 is satisfied.

Figure E.29 shows an example of roof fixture protection by air-termination rods using the protective angle air-termination design method. The value of the protective angle shall be consistent with the protection level of the LPS stipulated in Table 2.

Metal roof fixtures, not protected by air-termination rods, do not require additional protection if their dimensions do not exceed the following:

– height above the roof level 0,3 m;

– the total area of the superstructure 1,0 m^2;

– the length of the superstructure 2,0 m.

Non-conductive roof fixtures which are not within the protected volume by air-termination rods and which do not protrude by more than 0,5 m above the surface formed by the air-termination system do not require additional protection from air-termination conductors.

Conductive installations, such as electrical conductors or metallic pipes, which lead from flush-mounted roof fixtures into the interior of the building can conduct a considerable portion of the lightning current into the interior of the building. Where such conductive connections exist, the protruding fixtures on the roof surface should be protected by air-termination systems. If protection by means of an air-termination system is not possible or cost-effective, insulated parts, with lengths corresponding to at least twice the specified separation distance, can be installed in the conductive installations (e.g. compressed air pipes).

Chimneys of insulating material should be protected by means of air-termination rods or air-termination rings when they are not within the protective space of an air-termination system. The air-termination rod on a chimney should be of such height that the complete chimney lies within the protective space of the rod.

A lightning flash to a non-conductive chimney is possible when the chimney is not situated within the protective space of an air-termination system, due to the fact that the inner surface of the chimney is covered by a soot deposit possessing a conductivity such that, even in the absence of rain, it is capable of conducting the current of a streamer discharge of great length.

Figure E.23b shows the construction of an air-termination rod on a chimney made of insulating bricks.

Metal flush-mounted roof fixtures should be bonded to the air-termination system when the necessary clearance for conformity to the separation distance according to 6.3 cannot be maintained.

E.5.2.4.2.5 Protection of roof fixtures enclosing electrical or information-processing equipment

All roof fixtures of insulating or conducting material, which contain electrical and/or information-processing equipment, should lie within the protective space of the air-termination system.

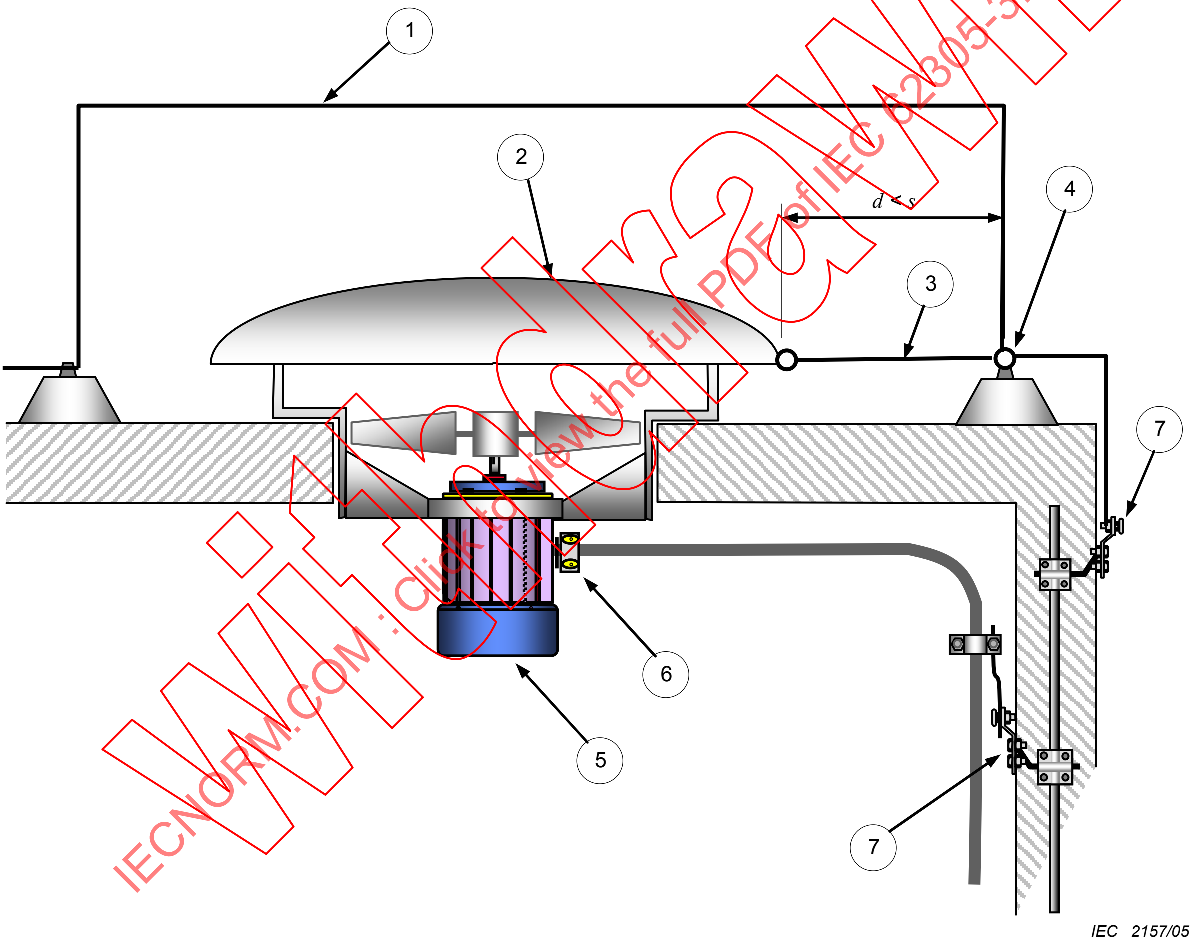
A direct flash into equipment installed inside the protective space of the air-termination system is improbable.

A direct flash into the roof fixture would lead not only to its destruction but would also cause extended damage to the connected electrical and electronic equipment not only in the roof fixtures, but also inside the building.

Roof fixtures on steel structures should also lie in the protective space of the air-termination system. In this case air-termination conductors should be bonded not only to the air-termination system but also to the steel structure directly, if possible. When bonded to the structure they need not conform to the separation distance.

The requirements for roof fixtures should also apply to fixtures installed on vertical surfaces to which a lightning strike is possible, i.e. which can be touched by the rolling sphere.

Figure E.29 and Figure E.31 contain examples of air-termination constructions which protect the roof fixtures of conducting and isolating material enclosing electrical installations. Figure E.31 is only suitable if the separation distance s cannot be maintained.



Key

1 Air-termination conductor
2 Metallic cover
3 Bonding conductor
4 Horizontal air-termination conductor
5 Electric equipment
6 Electric power junction box with SPD
7 Bonding joint to the conductive elements of the structure

NOTE The enclosed electric equipment is bonded to the air-termination system and to the conductive elements of the structure, complying with F.5.2.4.2.6, through the metallic cable shield withstanding a substantial part of the lightning current.

Figure E.31 – Metallic roof fixture protected against direct lightning interception, connected to air-termination system

NOTE If the fixtures need extra protection, SPDs on the active cables connected to it can be provided at roof level.

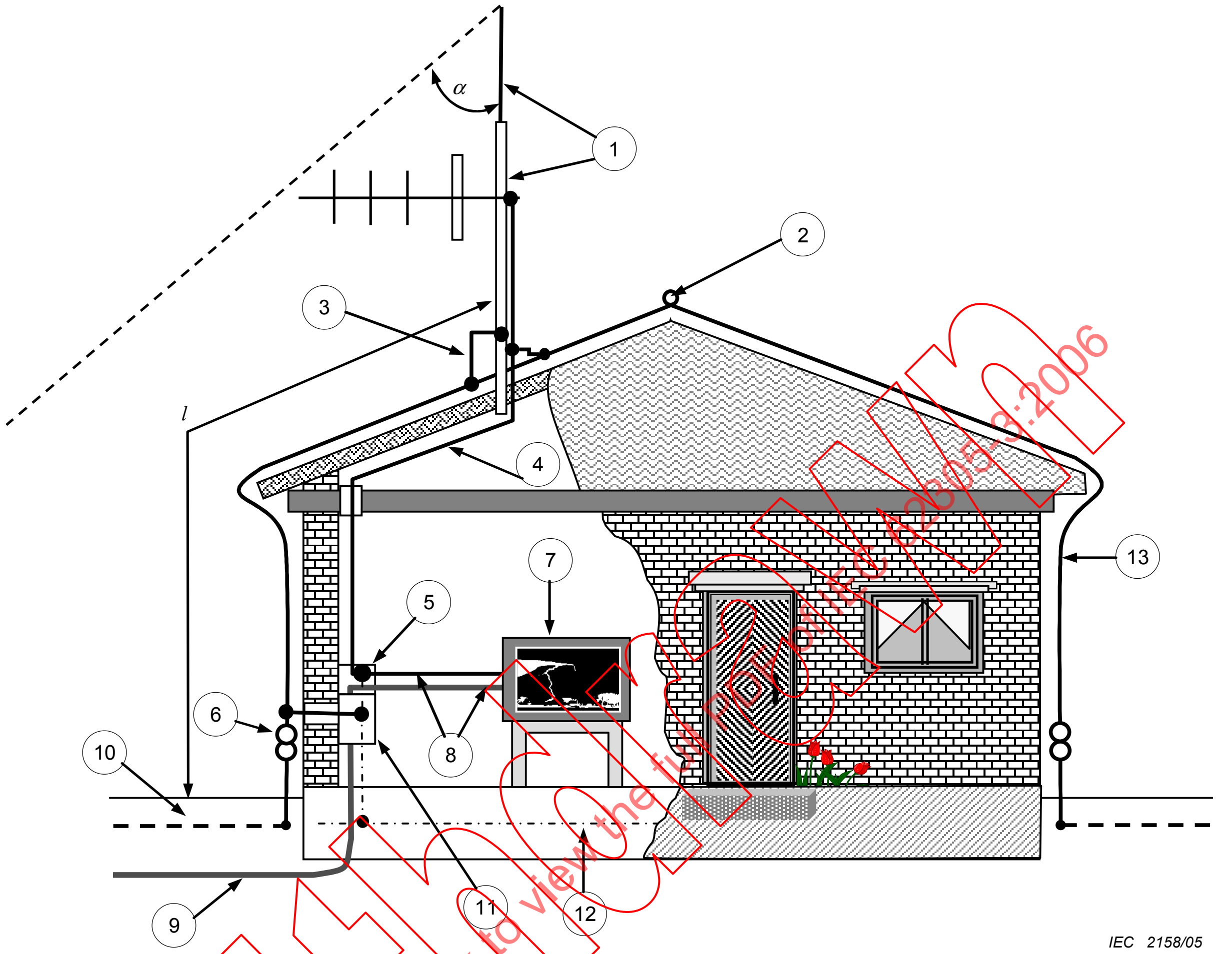
The required separation distance should be maintained not only in air but also for the path through solid material (k_m = 0,5).

E.5.2.4.2.6 Electrical installation protruding from the space to be protected

Antenna masts on the roof of a structure should be protected against direct lightning flashes by installing the antenna mast in an already protected volume or by installing an isolated external LPS.

If this is not possible, the antenna mast should be bonded to the air-termination system. Then partial lightning currents will be treated inside the structure to be protected.

The antenna cable should enter the structure preferably at the common entrance for all services or near the main LPS bonding bar. The antenna cable conductive sheath should be bonded to the air-termination system on roof level and to the main bonding bar (see Figure E.32).



Key

1 Metallic mast
2 Horizontal air-termination conductor on the ridge of the roof
3 Joint between the roof down-conductor and the metallic antenna mast
4 Antenna cable
5 The main bonding bar; metallic shield on the antenna cable is connected to the bonding bar
6 Test joint
7 TV
8 Parallel routing of the antenna cable and the electric power cable
9 Electric power cable
10 Earth termination system
11 The main electric power distribution box with SPD
12 Foundation earth electrode
13 LPS conductor
l Length for separation distance
α Protective angle

NOTE For small structures only two down-conductors may be sufficient, according to 5.3.3.

Figure E.32 – Example of construction of lightning protection of a house with a TV antenna using the mast as an air-termination rod

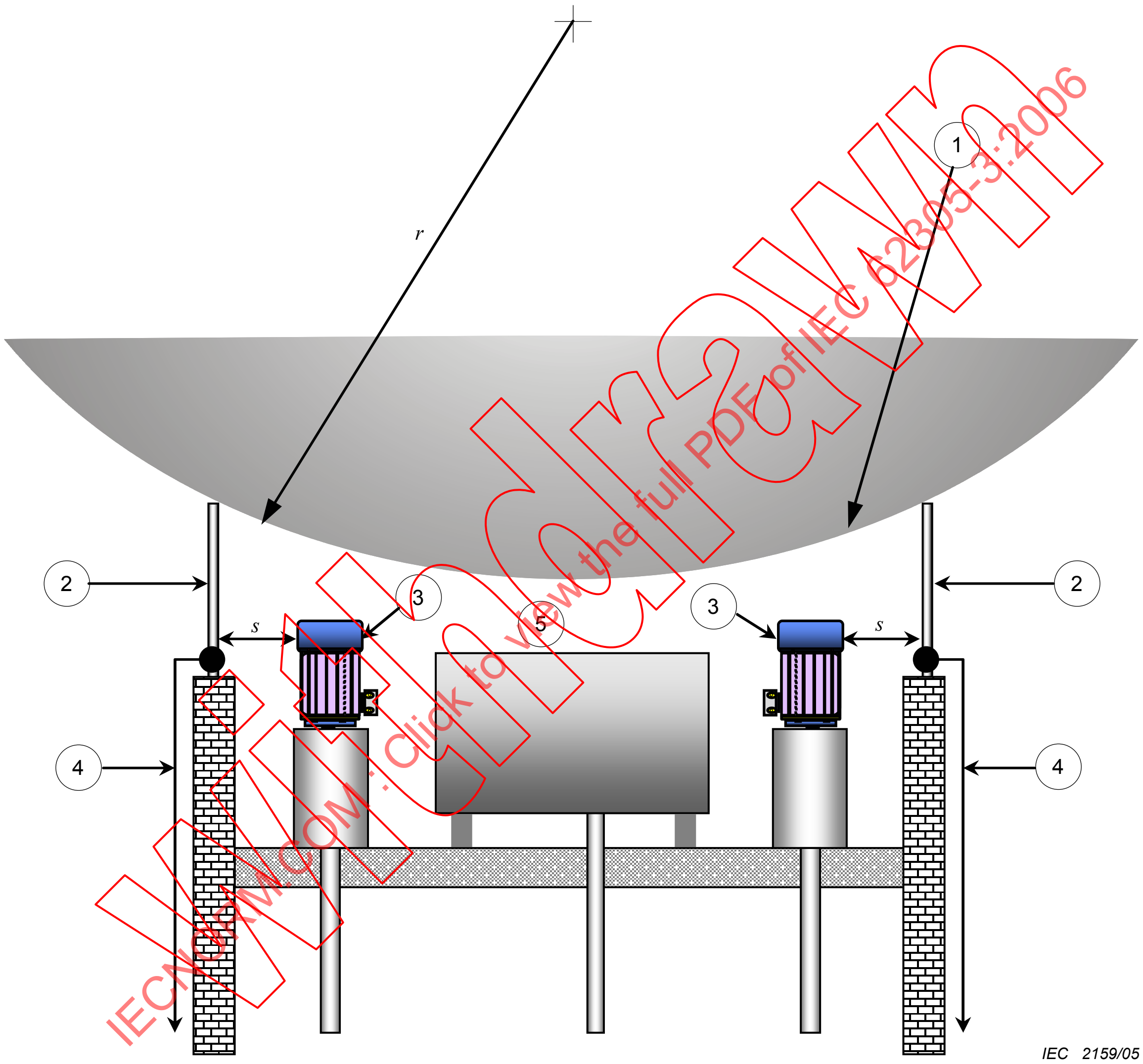
Roof fixtures housing electrical equipment for which the separation distance cannot be maintained, should be bonded to the air-termination system and to the conductive elements of the roof fixtures and the conductive shield of its electrical equipment in accordance with Table 9.

Figure E.31 is an example of the method of bonding a roof fixture with conductive parts to an electrical installation and the air-termination of a structure.

E.5.2.4.2.7 Protection of conductive parts on the roof

Conductive items, such as those with insufficient wall thickness, which cannot withstand lightning strikes and which are installed on roofs, and also conductive roof coverings or other parts on structures which do not meet the requirements for natural air-termination systems according to 5.2.5 and Table 3, and in which a lightning flash cannot be tolerated, should be protected by air-termination conductors.

For the design of the lightning protection for conductive parts on the roof the rolling sphere air-termination design method should be applied (see Figure E.33).



Key

1 Rolling sphere
2 Air-termination rod
3 Electric equipment
4 Down-conductor
5 Metallic vessel
r Radius of the rolling sphere, see Table 2
s Separation distance according to 6.3

Figure E.33 – Installation of lightning protection of metallic equipment on a roof against a direct lightning flash

Figure E.31 is an example of the design of an air-termination system protecting a conductive roof fixture against a direct lightning flash when the separation distance s cannot be maintained.

E.5.2.4.2.8 Protection of structures covered by soil

For structures incorporating a layer of soil on the roof and where people are not regularly present, a normal LPS may be utilized. The air-termination system should be a meshed air-termination system on top of the soil, or a number of air-termination rods, connected by a buried mesh, conforming to the rolling sphere or protective angle method. If this is not possible, it should be recognized that a buried meshed air-termination system without rods or finials will offer a reduced interception efficiency.

Structures with a roof layer of soil up to 0,50 m where people are regularly present, will need a meshed air-termination system with meshes of 5 m × 5 m to prevent dangerous step voltages. To protect the people on the ground from direct lightning flashes, air-termination rods conforming to the rolling sphere method, may also be necessary. These rods can be replaced by natural air-termination components, such as fences, lighting masts, etc. The height of the air-termination systems shall take into account people's height allowance of 2,5 m along with the necessary separation distances (see also Figure E.3).

If nothing of the kind is available, people should be made aware that during a thunderstorm they may be exposed to a direct lightning flash.

For underground structures with a layer of soil over 0,5 m, measures are under consideration. As long as there is no research available, it is adviseable to use the same measures as for layers of soil up to 0,5 m.

For underground structures containing explosives materials, an additional LPS shall be required. Such an additional LPS may be an isolated LPS over the structure. The earthing systems of both protection measures should be interconnected.

E.5.2.5 Natural components

On structures with flat roofs, the metal covering of a roof parapet represents a typical natural component of an LPS air-termination network. Such covering comprises extruded or bent parts of aluminium, galvanized steel or copper in U-form which protect the upper surface of the roof parapet against the influence of weather. The minimum thickness given in Table 3 shall be applied for such an application.

The air-termination conductors, conductors on the roof surface and the down-conductors should be connected to the roof parapet covering.

Conductive bridging should be provided at the joints between sections of parapet covering plates, unless there is good, reliable continuity between them.

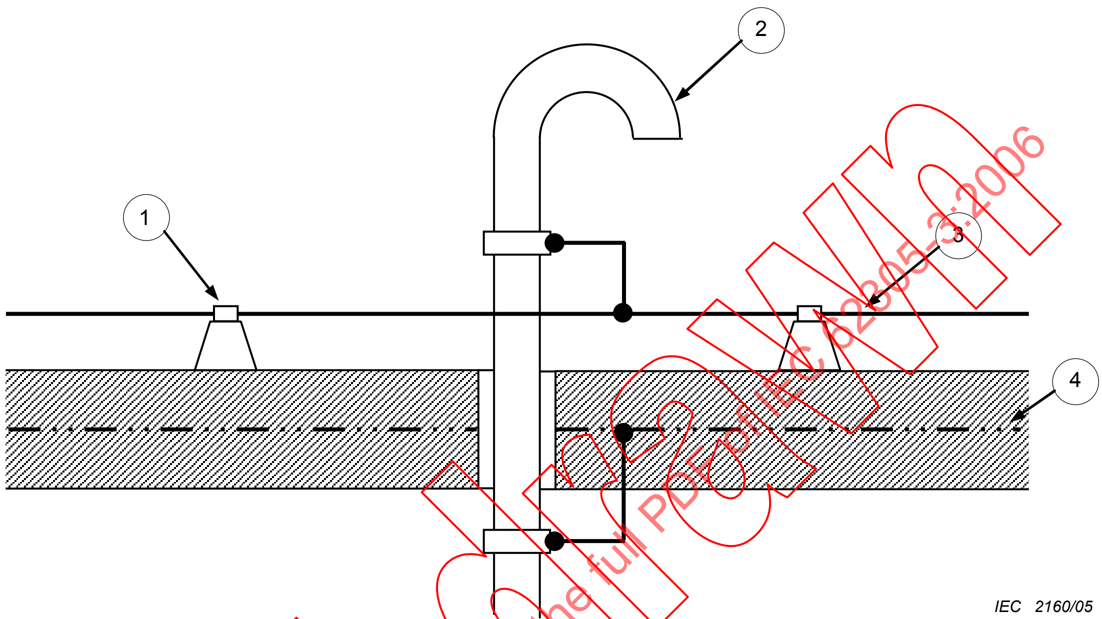
Figure E.24 is an example of an air-termination construction using the conductive covering of parapets as a natural air-termination conductor of the LPS.

Conductive parts, such as metal tanks, metal pipework and railings mounted on or extending above a roof surface should be treated as natural components of an air-termination system provided their wall thickness conforms to Table 3.

Vessels and pipework, which contain gas or liquids under high pressure or flammable gas or liquids, should not be used as natural air-terminations. Where this cannot be avoided, the heating effects of lightning current should be taken into account when designing the pipework.

Conductive parts above the roof surface such as metal tanks are often naturally connected to equipment installed within the structure. In order to prevent conduction of the full lightning current through the structure, it is necessary to provide a good connection between such natural components of the LPS and the air-termination mesh.

Figure E.34 is an example, which show details of the bonding of conductive roof fixtures to air-termination conductors.



Key

1 Air-termination conductor fixing
2 Metallic pipe
3 Horizontal air-termination conductor
4 Steel reinforcement within concrete

NOTE 1 The steel pipe should comply with 5.2.5 and Table 6, the bonding conductor should comply with Table 6 and the reinforcement should comply with 4.3. The roof bonding should be watertight.

NOTE 2 In this particular case bonding is provided to the reinforcement of the reinforced concrete structure.

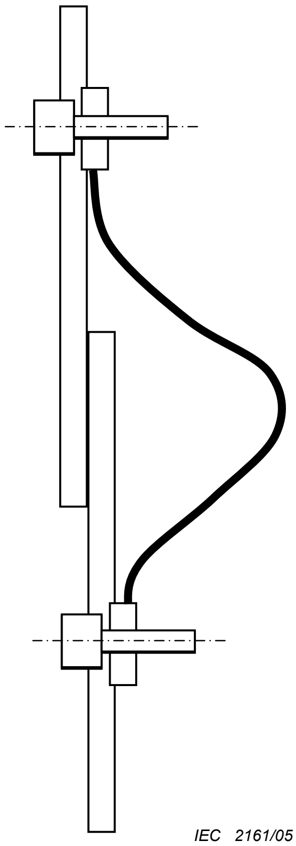
Figure E.34 – Connection of natural air-termination rod to air-termination conductor

Conductive parts above the roof surface such as metal tanks and steel reinforcing rods of oncrete should be connected to the air-termination network.

When a direct lightning strike into the conductive part on the roof is not acceptable, the conductive part shall be installed inside the protective space of an air-termination system.

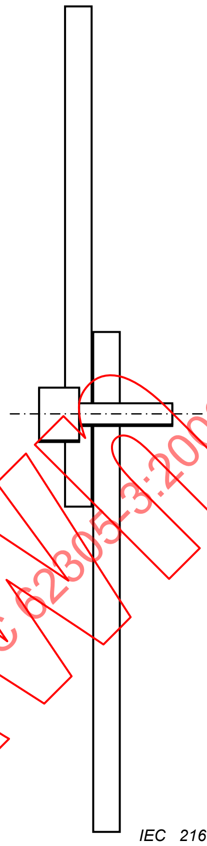
Conductive coverings on facades and equivalent parts of structures where the risk of fire is negligible should be treated in accordance with 5.2.5.

Figure E.35 shows an example of conductive bridging between metal facade plates acceptable in those applications where the plates are to be used as natural down-conductors. Two methods are presented: bridging by flexible metal strapping and bridging by means of self-threading screws. Only bridging by flexible metal strapping may be used in applications where the plates are used as natural lightning conductors. Bridging by means of self-threading screws is only suitable for shielding purposes (protection against LEMP).



IEC 2161/05

Figure E.35a – Flexible metal strapping bridging



IEC 2162/05

Figure E.35b – Self tapping screw bridging

NOTE Electrically conducting bridging improves, in particular, the protection against LEMP. More information concerning protection against LEMP can be found in IEC 62305-4.

Figure E.35 – Construction of the bridging between the segments of the metallic façade plates

E.5.2.6 Isolated air-termination

Air-termination masts adjacent to structures or equipment to be protected are intended to minimize the possibility of lightning strikes to structures within their zone of protection when an isolated LPS is installed.

When more than one mast is installed, they may be interconnected by means of overhead conductors and the proximity of the installations to the LPS should be in accordance with 6.3.

Overhead conductor connections between the masts extend the protected volume and also distribute the lightning current between several down-conductor paths. The voltage drop along the LPS and the electromagnetic interference in the space to be protected are therefore lower than in the case when the overhead conductors are not present.

The strength of the electromagnetic field in the structure is reduced because of the greater distance between the installations within the structure and the LPS. An isolated LPS may also be applied to a structure of reinforced concrete, which will improve the electromagnetic shielding even more. However, for tall structures the construction of an isolated LPS is not practical.

Isolating air-termination systems made of stretched wires on insulated supports could be suitable where a large number of extensive protruding fixtures on the roof surface are to be protected. The insulation of the supports should be adequate for a voltage calculated from the separation distance in accordance with 6.3.

E.5.3 Down-conductor systems

E.5.3.1 General

The choice of number and position of down-conductors should take into account the fact that, if the lightning current is shared in several down-conductors, the risk of side flash and electromagnetic disturbances inside the structure is reduced. It follows that, as far as possible, the down-conductors should be uniformly placed along the perimeter of the structure and with a symmetrical configuration.

The current sharing is improved not only by increasing the number of down-conductors but also by equipotential interconnecting rings.

Down-conductors should be placed as far as possible away from internal circuits and metallic parts in order to avoid the need for equipotential bonding with the LPS.

It should be remembered that

– the down-conductors should be as short as possible (to keep inductance as small as possible),
– the typical distance between down-conductors is shown in Table 4,
– the geometry of down-conductors and equipotential interconnecting rings has an influence on the value of the separation distance (see 6.3),
– in cantilevered structures the separation distance should also be evaluated with reference to the risk of side-flashing to persons (see E.4.2.4.2).

If it is not possible to place down-conductors at a side, or part of a side, of the building because of practical or architectural constraints, the down-conductors that ought to be on that side should be placed as extra compensating down-conductors at the other sides. The distances between these down-conductors should not be less than one-third of the distances in Table 4.

A variation in spacing of the down-conductors of ±20 % is acceptable as long as the mean spacing conforms to Table 4.

In closed courtyards with more than 30 m perimeter, down-conductors have to be installed. Typical values of the distance between down-conductors are given in Table 4.

E.5.3.2 Number of down-conductors for isolated LPS

No additional information.

E.5.3.3 Number of down-conductors for non-isolated LPS

No additional information.

E.5.3.4 Construction

E.5.3.4.1 General information

External down-conductors should be installed between the air-termination system and the earth-termination system. Wherever natural components are available they can be used as down-conductor.

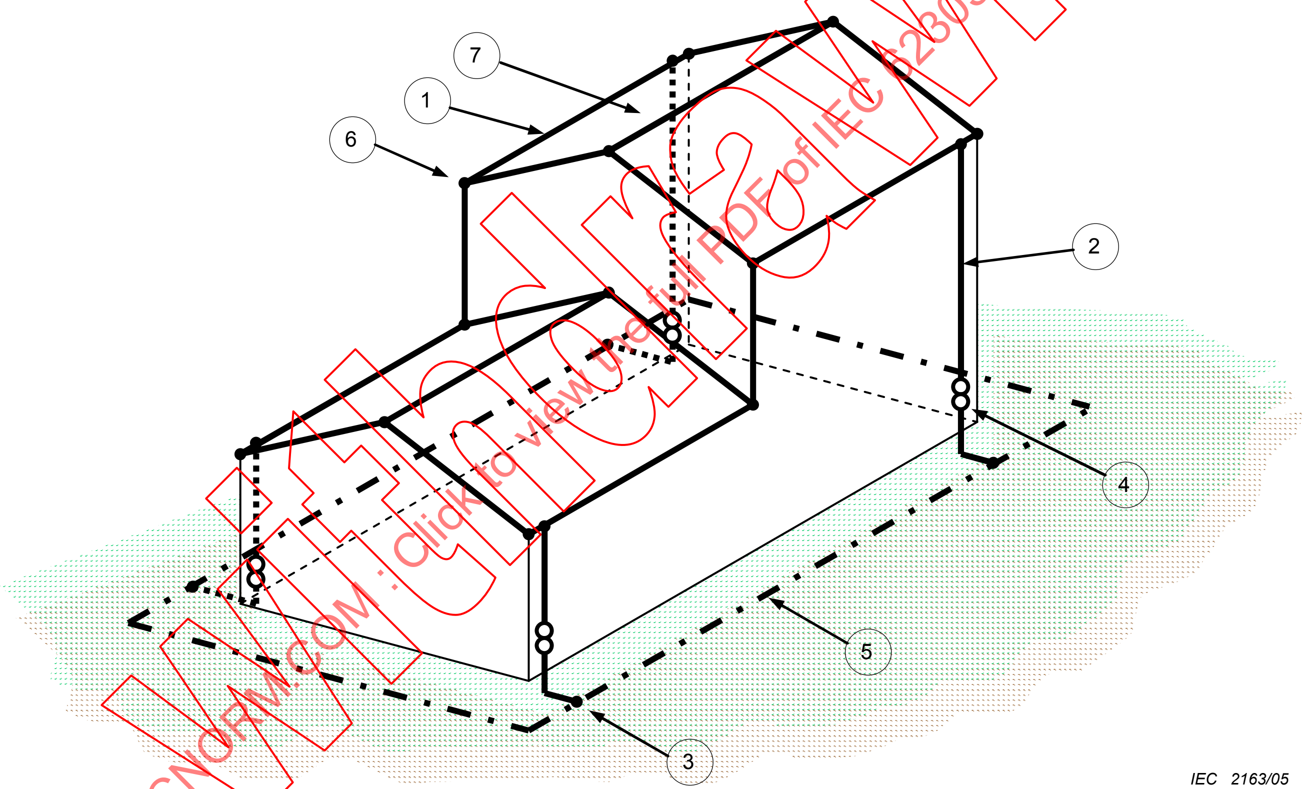
If the separation distance between down-conductors and the internal installations, calculated on the basis of the down-conductor spacing according to Table 4, is too large, the number of down-conductors should be increased to meet the required separation distance.

Air-termination systems, down-conductor systems and earth-termination systems should be harmonized to produce the shortest possible path for the lightning current.

Down-conductors should preferably be connected to junctions of the air-termination system network and routed vertically to the junctions of the earth-termination system network.

If it is not possible to make a straight connection because of large roof overhangs etc. the connection of the air-termination system and the down-conductor should be a dedicated one and not through natural components like rain gutters etc.

Figure E.36 is an example of an external LPS for a structure with different levels of roof construction and Figure E.25 is an example of the external LPS design for a 60 m high structure with a flat roof with roof fixtures.



Key

1 Horizontal air-termination conductor
2 Down-conductor
3 T-type joint – corrosion resistant
4 Test joint
5 Type B earthing arrangement, ring earth electrode
6 T-type joint on the ridge of the roof
7 Mesh size

NOTE The distance between the down-conductors should comply with 5.2, 5.3 and Table 4.

Figure E.36 – Installation of external LPS on a structure of isolating material with different roof levels

In structures without extensive continuous conductive parts, the lightning current only flows through the ordinary down-conductor system of the LPS. For this reason the geometry of down-conductors determines the electromagnetic fields within the interior of the structure (see Figure E.37).

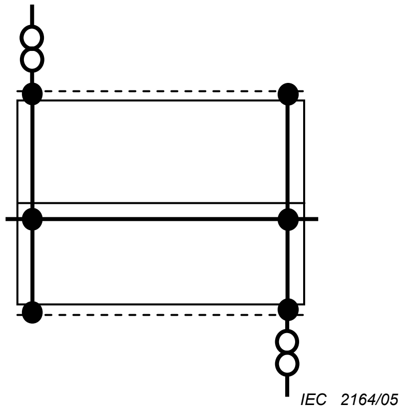


Figure E.37a

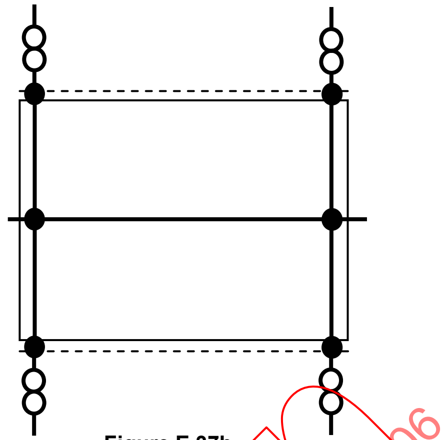


Figure E.37b

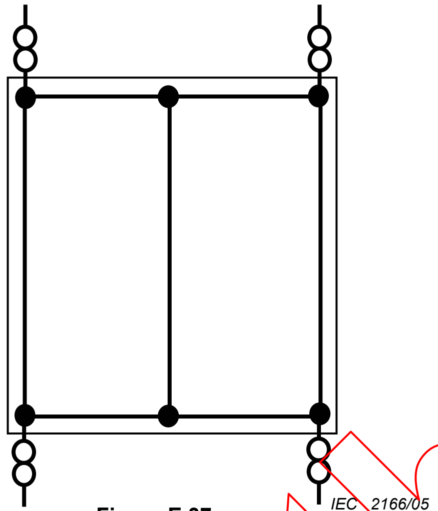


Figure E.37c

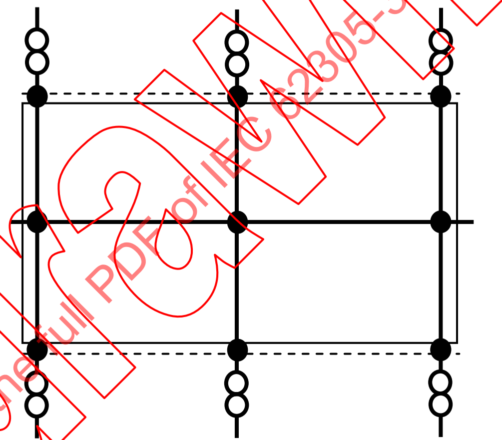


Figure E.37d

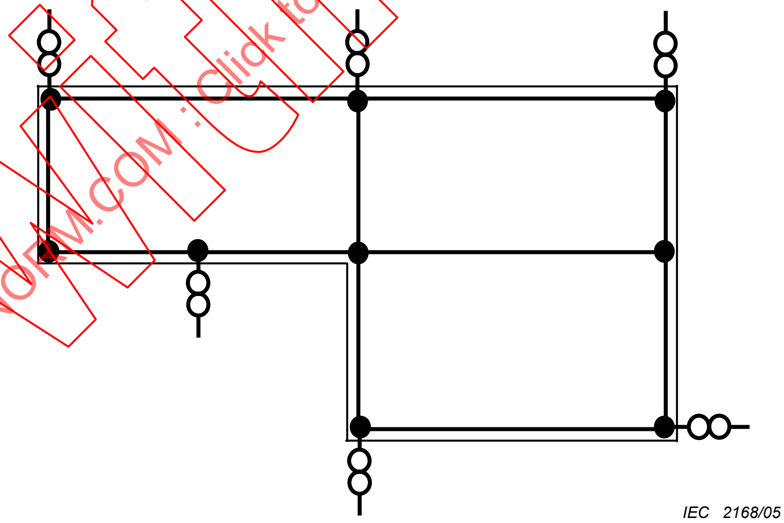


Figure E.37e

- - - - - - Natural components of the LPS, e.g. gutters

LPS conductors

Test Joint

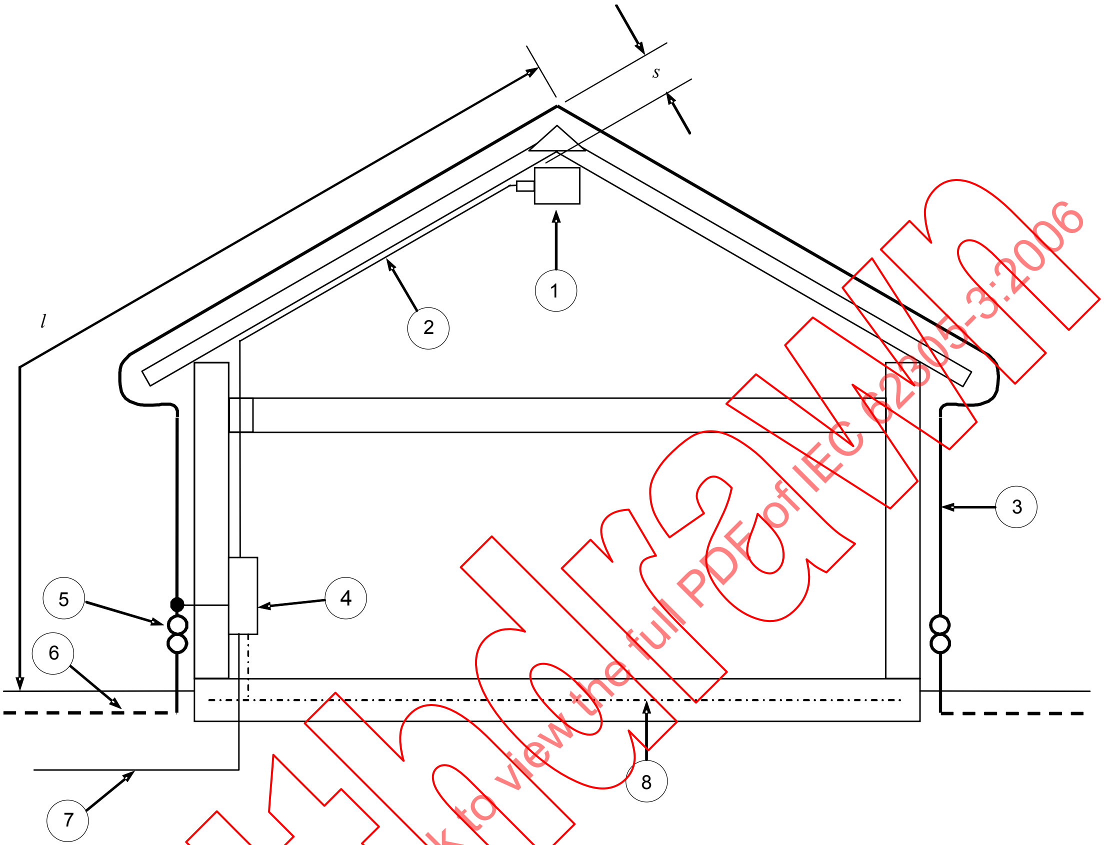
Joint

NOTE The distance between the down-conductors and the mesh size should comply with the selected lightning protection level according to Tables 2 and 4.

Figure E.37 – Examples of geometry of LPS conductors

When the number of down-conductors is increased, the separation distance can be reduced according to the coefficient k_c (see 6.3).

According to 5.3.3, at least two down-conductors should be used on a structure (see Figures E.38 and E.36).



Key

1 Electric equipment
2 Electric conductors
3 LPS conductors
4 Main electric power distribution box with SPD
5 Test joint
6 Earth-termination system
7 Electric power cable
8 Foundation earth electrode
s Separation distance according to 6.3
l Length for the evaluation of the separation distance s

NOTE The example illustrates the problems introduced by electric power or other conductive installations in the roof space of a building.

Figure E.38 – Construction of an LPS using only two down-conductors and foundation earth electrodes

For large structures, such as high-rise apartment buildings and, in particular, industrial and administrative structures, which are often designed as steel skeletons or steel and concrete skeleton structures, or which use steel-reinforced concrete, the conductive structure components may be used as natural down-conductors.

The total impedance of the LPS for such structures is fairly low and they afford a very efficient lightning protection for inner installations. It is particularly advantageous to use conductive wall surfaces as down-conductors. Such conductive wall surfaces might be: reinforced concrete walls, metallic sheet facade surfaces and facades of prefabricated concrete elements, provided they are connected and interlinked according to 5.3.5.

Figure E.4 provides a detailed description of the proper construction of an LPS using natural LPS components such as interconnected steel.

Use of natural components containing structural steel reduces the voltage drop between the air-termination system and the earth-termination system and the electromagnetic interference caused by lightning current within the structure.

If the air-termination system is connected to the conductive parts of the columns within the structure complex and to the equipotential bonding at ground level, a portion of the lightning current flows through these internal down-conductors. The magnetic field of this partial lightning current influences neighbouring equipment and has to be considered in the design of the internal LPS and electrical and electronic installations. The magnitude of these partial currents depends on the dimensions of the structure and on the number of columns, assuming the current waveform follows the waveform of the lightning current.

If the air-termination system is insulated from the internal columns no current flows through the columns within the structure complex, provided the insulation does not break down. If the insulation breaks down at an unpredicted point, a larger partial current may flow through a particular column or group of columns. The current steepness may increase due to the reduced virtual duration of the wave front caused by the breakdown and the neighbouring equipment is affected to a greater extent than it would be in the case of controlled bonding of columns to the LPS of the structure.

Figure E.10 is an example of the construction of internal down-conductors in a large steel-reinforced concrete structure used for industrial purposes. The electromagnetic environment near to the inner columns shall be considered when planning the internal LPS.

E.5.3.4.2 Non-isolated down-conductors

In structures with extensive conductive parts in the outer walls, the air-termination conductors and the earth-termination system should be connected to the conductive parts of the structure at a number of points. This will reduce the separation distance according to 6.3.

As a result of these connections the conductive parts of a structure are used as down-conductors and also as equipotential bonding bars.

In large, flat structures (typically industrial structures, exhibition halls, etc.) with dimensions over four times the spacing of the down-conductors, extra internal down-conductors should be provided approximately every 40 m, wherever possible.

All internal columns and all internal partition walls with conductive parts, such as steel reinforcing rods, which do not fulfil the separation distance conditions, should be connected with the air-termination system and with the earth-termination system at suitable points.

Figure E.10 shows the LPS of a large structure with internal columns made of steel-reinforced concrete. To avoid dangerous sparking between different conductive parts of the structure, the reinforcement of the columns is connected to the air-termination system and to the earth-termination system. As a result, a portion of the lightning current will flow through these internal down-conductors. However, the current is divided among numerous down-conductors and has approximately the same waveform as the current in the lightning stroke. The steepness of the wavefront, however, is reduced. If these connections are not made and a flashover occurs, only one or a few of these internal down-conductors may carry the current.

The waveform of the flashover current will be considerably steeper than the lightning current, so the voltage induced in neighbouring circuit loops will be considerably increased.

For such structures, it is particularly important that before commencing the design of the structure, the structure's design as well as the design of the LPS should be harmonized so that conductive parts of the structure can be utilized for lightning protection. By means of well-coordinated design, a highly effective LPS is achieved at minimum cost.

Lightning protection of space and persons below an overhanging upper storey, such as a cantilevered upper floor, should be designed according to 4.2.4.2 and Figure E.3.

E.5.3.4.3 Isolated down-conductors

If, due to architectural considerations, the down-conductors cannot be surface mounted, they should be installed in open slits in the brickwork. In this case, consideration should be given to maintaining the separation distance, as given in 6.3, between the down-conductor and any metal parts inside the structure.

Direct installation within the external plaster is not recommended since the plaster may be damaged as a result of thermal expansion. Moreover, the plaster may be discoloured as a result of chemical reaction. Damage to the plaster is particularly likely as a result of temperature rise and mechanical forces exerted by lightning current; PVC-covered conductors prevent staining.

E.5.3.5 Natural components

The use of natural down-conductors to maximize the total number of parallel current conductors is recommended as this minimizes the voltage drop in down-conductor systems and reduces the electromagnetic interference within the structure. However, it should be ensured that such down-conductors are electrically continuous along the entire path between the air-termination system and the earth-termination system.

The steel reinforcement in concrete walls should be used as a natural component of the LPS as illustrated in Figure E.27.

Steel reinforcement of newly erected structures should be specified in accordance with E.4.3. If electrical continuity of the natural down-conductors cannot be guaranteed, conventional down-conductors should be installed.

For structures with low protection requirements, a metallic rain-pipe which satisfies the conditions for natural down-conductors according to 5.3.5, may be used as a down-conductor.

Figures E.23a, E.23b and E.23c show examples of fixing the conductors on the roof and the down-conductors including appropriate geometrical dimensions, and Figures E.23c and E.23d show the connections of the down-conductor to the metallic rain-pipe, the conductive gutters and the earth-termination conductor.

The reinforcing rods of walls or concrete columns and steel structural frames may be used as natural down-conductors.

A metal facade or a facade covering on a structure may be used as a natural down-conductor conforming to 5.3.5.

Figure E.8 shows construction of a natural down-conductor system using metal facade elements and steel reinforcing in the concrete walls as the equipotentialization reference plane to which the equipotentialization bars of the internal LPS are connected.

Connections should be provided at the top of the wallcovering, to the air-termination system and at the bottom of the earth-termination system and to the reinforcing rods of the concrete walls, if applicable.

The distribution of current in such metal facades is more consistent than in reinforced concrete walls. Sheet metal facades comprise individual panels generally of trapezoidal cross-section with a width between 0,6 m and 1,0 m and a length corresponding to the height of the structure. In the case of high-rise structures, the panel length does not correspond to the structure height due to transport problems. The whole facade then comprises a number of sections mounted one above the other.

For a metal facade, the maximum thermal expansion should be calculated as the difference in length produced by a maximum temperature of the metal facade in sunlight of approximately +80 °C and a minimum temperature of –20 °C.

The temperature difference of 100 °C corresponds to a thermal expansion of 0,24 % for aluminium and 0,11 % for steel.

Thermal expansion of the panels results in movement of the panels with respect to the next section or to the fixtures.

Metal connections, such as those depicted in Figure E.35, encourage uniform current distribution in metal facades and thus reduce the influence of the electromagnetic field inside the structure.

A metal facade produces maximum electromagnetic shielding when it is electrically interconnected over its whole area.

High electromagnetic shielding efficiency of a structure is obtained when permanent bonding of adjacent metal facades is carried out at sufficiently small intervals.

Symmetry of current distribution relates directly to the number of connections.

If stringent requirements with respect to shield attenuation exist and continuous strip windows are incorporated in such a facade, the continuous strip windows should be bridged by means of conductors at small intervals. This may be done by means of metal window frames. The metal facade should be connected to the window frame at short intervals. Generally, each ridge is connected to the horizontal tie-beam of the window frame at intervals not exceeding the spacing of the vertical members of the window construction. Bends and detours should always be avoided (see Figure E.9).

Metal facades comprised of relatively small elements which are not interconnected cannot be used as a natural down-conductor system or for electromagnetic shielding.

More information on the protection of electrical installations and electronics in structures is available in IEC 62305-4.

E.5.3.6 Test joint

Test joints facilitate measurements of the earth resistance of earth-termination system.

Test joints conforming to 5.3.6, should be installed in the connection of the down-conductors to the earth-termination system. These joints facilitate the determination by measurement that an adequate number of connections to the earth-termination system still exists. It is thus possible to validate the existence of continuous connections between the test joint and the air-termination system or the next bonding bar. On tall structures, ring-conductors are connected to the down-conductors, which may be installed in the wall and invisible to the eye; their existence may only be confirmed by electric measurement.

Figure E.39a through Figure E.39d show examples of test joint designs, which may be installed on the inner or outer wall of a structure or in a test box in the earth outside the structure (see Figure E.39b). To make the continuity measurements possible, some conductors may have to have insulating sheaths on critical sections.

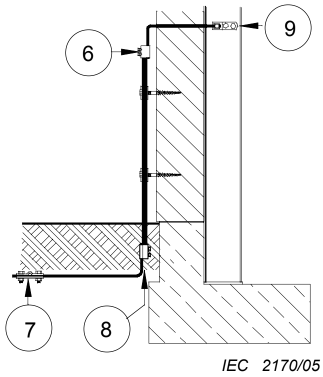


Figure E.39a

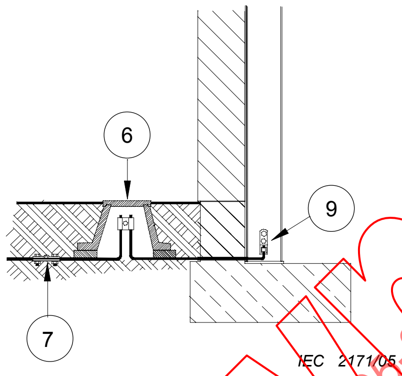


Figure E.39b

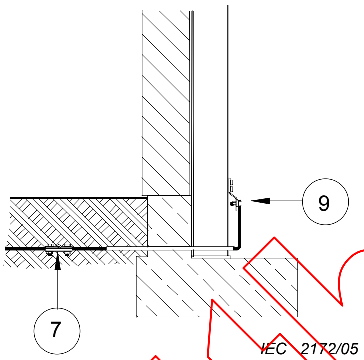


Figure E.39c

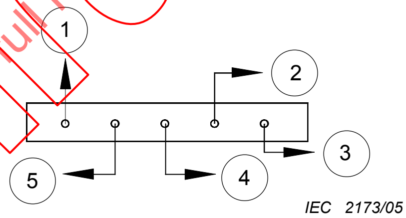


Figure E.39d

Alternative 1 – Test joint on wall

1 Down-conductor
2 Type B earth electrode, if applicable
3 Type A earth electrode, if applicable
4 Foundation earth electrode
5 Bonding to the internal LPS
6 Test joint on the wall
7 Corrosion-resistant T-joint in soil
8 Corrosion-resistant joint in soil
9 Joint between lightning conductor and a steel girder

Alternative 2 – Test joint in the floor

1 Down-conductor
2 Type A earth electrode, if applicable
3 Bonding bar of the internal LPS
4 Type B - Ring earth electrode
5 Type B - Ring earth electrode
6 Test joint in the floor
7 Corrosion-resistant T- joint in soil
8 Corrosion-resistant joint in soil
9 Joint between lightning conductor and a steel girder

NOTE 1 The test joint detailed in Figure F.39d should be installed on the inner or outer wall of a structure or in a test box in the earth outside the structure.

NOTE 2 To make the loop resistance measurements possible, some of the connecting conductors should have insulating sheaths along critical sections.

Figure E.39 – Examples of connection of earth termination to the LPS of structures using natural down-conductors (girders) and detail of a test joint

If it makes sense (e.g. in the case of earthing connections to steel columns via connecting conductors), connections from natural down-conductors to earth-termination electrodes may be provided with insulated conductor segments and testing joints. Special reference earth electrodes shall be installed to facilitate monitoring of the earth-termination system of an LPS.

E.5.4 Earth-termination system

E.5.4.1 General

The LPS designer and the LPS installer should select suitable types of earth electrodes and should locate them at safe distances from entrances and exits of a structure and from the external conductive parts in the soil. The LPS designer and the LPS installer should make special provisions for protection against dangerous step voltages in the vicinity of the earth-termination networks if they are installed in areas accessible to the public (see Clause 8).

The embedded depth and the type of the earth electrodes should be such as to minimize the effects of corrosion, soil drying and freezing and thereby stabilize the equivalent earth resistance.

It is recommended that the first metre of a vertical earth electrode should not be regarded as being effective under frost conditions.

Deep-driven earth electrodes can be effective in special cases where soil resistivity decreases with depth and where substrata of low resistivity occur at depths greater than those to which rod electrodes are normally driven.

When the metallic reinforcement of concrete is used as an earth electrode, special care should be exercised at the interconnections to prevent mechanical splitting of the concrete.

If the metal reinforcement is also used for the protective earth, the most severe measure in respect of thickness of the rods and the connection should be chosen. In this case, larger sizes of reinforcement bars could be considered. The need for short and straight connections for the lightning protection earthing should be recognized at all times.

NOTE In the case of pre-stressed concrete, consideration should be given to the consequences of the passage of lightning discharge currents, which may produce unacceptable mechanical stresses.

E.5.4.2 Types of earth electrode arrangements

E.5.4.2.1 Type A arrangement

The type A earth-termination system is suitable for low structures (for example family houses), existing structures or an LPS with rods or stretched wires or for an isolated LPS.

This type of arrangement comprises horizontal or vertical earth electrodes connected to each down-conductor.

Where there is a ring conductor, which interconnects the down-conductors, in contact with the soil the earth electrode arrangement is still classified as type A if the ring conductor is in contact with the soil for less than 80 % of its length.

In a type A arrangement the minimum number of earth electrodes should be two.

E.5.4.2.2 Type B arrangement

The type B earth-termination system is preferred for meshed air-termination systems and for LPS with several down-conductors.

This type of arrangement comprises either a ring earth electrode external to the structure in contact with the soil for at least 80 % of its total length or a foundation earth electrode.

For bare solid rock, only the type B earthing arrangement is recommended.

E.5.4.3 Construction

E.5.4.3.1 General

Earth-termination systems should perform the following tasks:

– conduction of the lightning current into the earth;

– equipotential bonding between the down-conductors;

– potential control in the vicinity of conductive building walls.

The foundation earth electrodes and the type B ring-type earth electrodes meet all these requirements. Type A radial earth electrodes or deep-driven vertical earth electrodes do not meet these requirements with respect to equipotential bonding and potential control.

The structure foundations of interconnected steel-reinforced concrete should be used as foundation earth electrodes. They exhibit very low earthing resistance and perform an excellent equipotentialization reference. When this is not possible, an earth-termination system, preferably a type B ring earth electrode, should be installed around the structure.

E.5.4.3.2 Foundation earth electrodes

A foundation earth electrode, which conforms to 5.4.4, comprises conductors, which are installed in the foundation of the structure below ground. The length of additional earth electrodes should be determined using the diagram in Figure 2.

Foundation earth electrodes are installed in concrete. They have the advantage that, if the concrete is of adequate construction and covers the foundation earth electrode by at least 50 mm, they are reasonably protected against corrosion. It should also be remembered that reinforcing steel rods in concrete generate the same magnitude of galvanic potential as copper conductors in soil. This offers a good engineering solution to the design of earth-termination systems for reinforced concrete structures (see E.4.3).

Metals used for earth electrodes should conform to the materials listed in Table 7, and the behaviour of the metal with respect to corrosion in the soil should always be taken into account. Some guidance is given in 5.6. When guidance for particular soils is not available, the experience with earth-termination systems in neighbouring plants, with soil exhibiting similar chemical properties and consistency, should be ascertained. When the trenches for earth electrodes are refilled, care should be taken that no fly ash, lumps of coal or building rubble is in direct contact with the earth electrode.

A further problem arises from electrochemical corrosion due to galvanic currents. Steel in concrete has approximately the same galvanic potential in the electrochemical series as copper in soil. Therefore, when steel in concrete is connected to steel in soil, a driving galvanic voltage of approximately 1 V causes a corrosion current to flow through the soil and the wet concrete and dissolve steel in soil.

Earth electrodes in soil should use copper or stainless steel conductors where these are connected to steel in concrete.