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British Standard Code of practice for Protection of structures against lightning

Protection des constructions contre la foudre — Code de bonne pratique

Leitfaden für den Schutz von Bauwerken gegen Blitzschlag

Foreword

This British Standard has been prepared under the direction of the General Electrotechnical Standards Policy Committee and supersedes BS 6651 : 1985, which is withdrawn.

It is recommended that the materials, extent and dimensions of the air terminations, down conductors, earth terminations, bonding, components, etc. as laid down in this standard should be adhered to in full, irrespective of any devices or systems employed which are claimed to provide enhanced protection.

This standard is intended to give guidance on the principles and practice that experience has shown to be important in protecting structures against damage from lightning. It examines the characteristics of the lightning phenomenon and indicates the statistical nature of the evidence on which assessments for protection are based. It also provides guidance on the need for protection and makes recommendations on the protection to be provided for structures in general and for specific structures that are considered to be most at risk, these recommendations being an economic compromise between absolute protection and the cost of the installation.

This edition incorporates the technical changes in Amendment No. 1 to BS 6651 : 1985 but does not reflect a full review or revision of the standard which will be undertaken in due course. This edition introduces a new appendix B which provides guidance on the application of the standard, however it is emphasized that the explanatory information provided in the appendix does not alter the technical content of the standard.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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Section one. General

0 Introduction

Lightning is a natural hazard, being the discharge of static electricity generated in parts, called 'cells', of storm clouds. In the UK, about one million flashes strike the ground each decade. Some of them damage buildings and a few kill or injure people and animals, either directly or indirectly by causing fire and explosions. Statistics for deaths by lightning show the risk to be very low, being one in two million per year (see 9.3).

This British Standard outlines the general technique aspects of lightning, illustrating its principal electrical, thermal and mechanical effects. Guidance is given on how to assess the risk of being struck and it offers a method of compiling an index figure as an aid in deciding if a particular structure is in need of protection.

The guidance given is of a general nature and its application to a specific lightning protection installation takes into account the particular conditions pertaining to that installation. In cases of difficulty, specialist advice should be sought.

It is emphasized that even where protection is provided it can never be completely effective in eliminating risk of damage to the structure.

NOTE 1. Consideration is being given to the protection of electrical installations with particular reference to structures containing sensitive electronic equipment.

NOTE 2. Some explanatory information about the recommendations of this standard is given in appendix A.

NOTE 3. All structures shown in figures are 'typical' only and are not intended as designs.

NOTE 4. Guidance on the application of the standard is given in appendix B.

1 Scope

This British Standard gives guidance on the design of systems for the protection of structures against lightning and on the selection of materials. Recommendations are made for special cases such as explosives stores and temporary structures, e.g. cranes and spectator stands constructed of metal scaffolding. Offshore oil and gas installations are not included.

NOTE 1. Where current-carrying conductors are directly associated with structures coming within the scope of this code, certain recommendations relating to them are included; however, the protection of radar stations, overhead telephone wires, electric traction and supply lines should, on account of their special nature, be determined by the appropriate authorities.

NOTE 2. The titles of publications referred to in this standard are listed on the inside back cover.

2 Definitions and abbreviations

2.1 Definitions

For the purposes of this British Standard, the following definitions apply.

2.1.1 lightning flash. An electrical discharge between cloud and earth, of atmospheric origin, comprising one or more impulses of many kiloamps.

2.1.2 lightning stroke. One of the single distinguishable current impulses of a lightning flash.

2.1.3 lightning strike. A lightning flash attaching to a structure.

2.1.4 lightning protection system. The whole system of conductors used to protect a structure from the effects of lightning.

2.1.5 air termination or air termination network. That part of a lightning protection system which is intended to intercept lightning discharges.

2.1.6 down conductor. A conductor that connects an air termination with an earth termination (see 2.1.10).

2.1.7 bond. A conductor intended to provide electrical connection between the lightning protection system and other metalwork and between various portions of the latter.

2.1.8 joint. A mechanical and/or electrical junction between two or more portions of a lightning protection system.

2.1.9 test joint. A joint designed and situated so as to enable resistance or continuity measurements to be made.

2.1.10 earth termination or earth termination network. That part of a lightning protection system which is intended to discharge lightning currents into the general mass of the earth.

NOTE. All points below the test points in down conductors are included in this term.

2.1.11 earth electrode. A conductive part which is intended to conduct lightning current or a group of conductive parts in intimate contact with and providing an electrical contact with the earth.

NOTE. It may comprise, for example, one or more driven rods, horizontal conductors or reinforced concrete foundations.

2.1.12 ring earth electrode. An earth electrode forming a closed loop round the structure below or on the surface of the earth, or within or under the foundations.

NOTE. It may be used for interconnecting other earth electrodes.

2.1.13 indicating plate. A plate detailing the number and position of earth electrodes.

2.1.14 reference earth electrode. An earth electrode capable of being completely isolated from an earth termination network for use in periodic testing.

2.1.15 isolation. The positioning of metal in and on a structure relative to the lightning protection system so that the metal is not required to carry any part of the lightning current.

2.1.16 log book. A record of tests and inspections of a lightning conductor installation.

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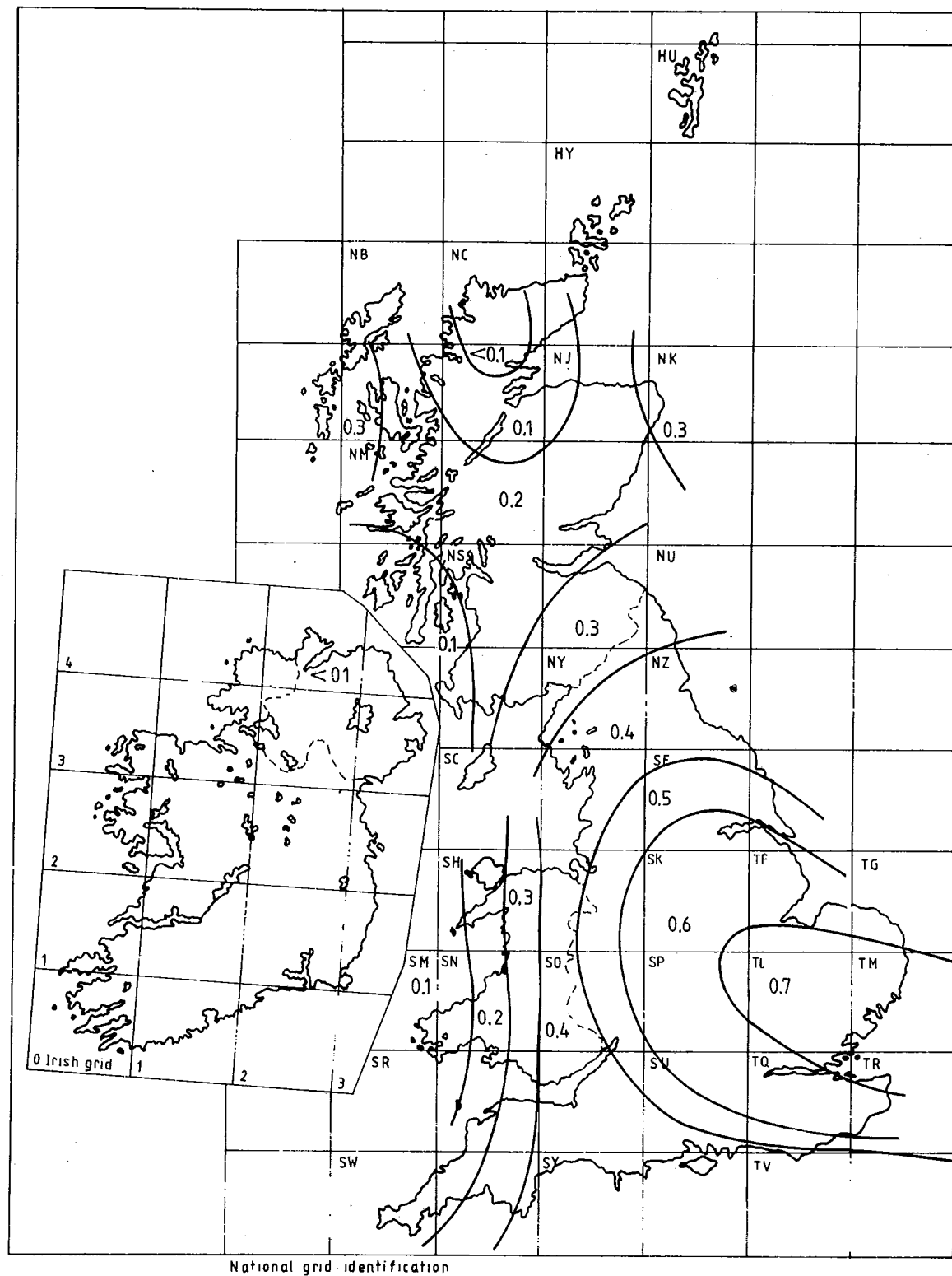


Figure 1. Number of lightning flashes to the ground per km² per year for the UK

2.2 Abbreviations

The following abbreviations are used in the figures of this British Standard:

DC	Down conductor
GL	Ground level
HC	Horizontal conductor
VC	Vertical conductor
ZP	Zone of protection and protective angles

NOTE. The boundary of a zone of protection is indicated in the figures by dashed lines.

3 Technical aspects of lightning

3.1 General

Lightning activity varies over the UK with more flashes in the East than in the West and more in the South than in the North (see figure 1). Furthermore, there is a variation of roughly 2:1 over a period of about 11 years, which corresponds with the sunspot cycle. It is for this reason that the decade is chosen as the time unit.

The first step in minimizing the danger from lightning is to learn as much as possible about its nature. The main characteristics are therefore briefly summarized in 3.2.

3.2 Characteristics of lightning

3.2.1 Current in a lightning stroke. Rather than describe an 'average' lightning flash, it is easier to give ranges for the various parameters. The important part of a lightning flash with regard to the resulting damage is the 'return stroke'. This is the part of the flash in which a charged cell in a thunder-cloud is discharged to earth. The current in this return stroke ranges from about 2000 A to about 200 000 A and its distribution of values is of the form which occurs frequently in nature, the so-called 'log normal' distribution, as follows:

1 % of strokes exceed	200 000 A
10 % of strokes exceed	80 000 A
50 % of strokes exceed	28 000 A
90 % of strokes exceed	8000 A
99 % of strokes exceed	3000 A

The current in most ground flashes is from the negatively charged cells in the thunder-cloud and the flash current is therefore a negative flow from cloud to ground; less frequently, strokes from a positive part of the cloud also occur. For either polarity, however, the current flow is unidirectional with a rise time of less than 10 µs for the negative flash (but considerably longer for the positive flash) and then a decay to a low value, for a simple single stroke, in 100 µs or less.

Some flashes comprise two or more strokes which individually conform to the description for a single stroke but which may be spaced in time 50 ms to 100 ms apart. The rare multi-stroke flash having more than 10 strokes may therefore last for up to 1 s.

For the purposes of design of lightning protection systems, the following values of peak lightning current ($i_{\max}$) and rate of rise of lightning current are considered to be the most severe:

$$i_{\max} = 200 \text{ kA}$$

$$\left(\frac{di}{dt}\right)_{\max} = 200 \text{ kA}/\mu\text{s}$$

3.2.2 Voltage. Before the flash takes place, the potential of the charge cell may be estimated very roughly by assuming the charge Q in the cell to be 100 C and the radius of an equivalent spherical cell to be 1 km. The capacitance C of the cell is therefore about 10^{-7} F and, from $Q = CV$, the potential V is estimated to be 10^9 V. It is reasonable therefore to assume that the cloud potential is more than 100 MV. This potential is high enough to ensure that the potentials sustained by whatever is struck will be controlled by the product of current and impedance, because this product will never be high enough in comparison with the cloud potential to modify the current magnitude.

Although the return stroke is the most important pulse of a lightning stroke, it is necessary to know something of the process which precedes it in order to understand why high structures are more vulnerable than low ones. The lightning stroke starts by a step by step descent from the cloud of a leader stroke stepping some tens of metres at a time. When the last step brings the tip of the leader sufficiently close to earth, an upward streamer leaves the earth to join the tip of the downward leader.

The initiation of this upward streamer depends on a critical field being exceeded at the earth emission point and so is a function of the charge deposited by the down-coming leader and any enhancement of the field caused by the geometry of the earth. The length of the upward streamer will be greater for greater charges and hence high current flashes will start preferentially from high structures for which the field enhancement is high.

4 Effects of lightning strike

4.1 Electrical effects

As the current is discharged through the resistance of the earth electrode of the lightning protection system, it produces a resistive voltage drop which may momentarily raise the potential of the protection system to a high value relative to true earth. It may also produce around the earth electrode a high potential gradient dangerous to people and animals. In the same general manner, the inductance of the protection system has also to be considered because of the steep leading edge of the lightning pulse.

The resulting voltage drop in the protection system is therefore the arithmetic sum of the resistive and inductive voltage components.

4.2 Side-flashing

The point of strike on the protection system may be raised to a high potential with respect to adjacent metal. There is therefore a risk of flashover from the protection system to any other metal on or in the structure. If such flashover occurs, part of the lightning current is discharged through internal installations, such as pipes and wiring, and so this flashover constitutes a risk to the occupants and fabric of the structure.

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4.3 Thermal effects

For the purposes of lightning protection, the thermal effect of a lightning discharge is confined to the temperature rise of the conductor through which the current passes. Although the current is high, its duration is short and the thermal effect on the protection system is usually negligible.

NOTE. This ignores the fusing or welding effects on damaged conductors or those which were not adequate in the initial installation.

In general, the cross-sectional area of a lightning conductor is chosen primarily to satisfy the requirements of mechanical strength, which means that it is large enough to keep the rise in temperature to 1 °C. For example, with a copper conductor of 50 mm² cross section, a severe stroke of 100 kA with a duration of 100 µs dissipates less than 400 J per metre of conductor, resulting in a temperature rise of about 1 °C. The substitution of steel for copper results in a rise of less than 10 °C.

4.4 Mechanical effects

Where a high current is discharged along parallel conductors in close proximity or along a single conductor with sharp bends, considerable mechanical forces are produced. Secure mechanical fittings are therefore essential (see figure 2 and table 1).

A different mechanical effect exerted by a lightning flash is due to the sudden rise of 30 000 K in the air temperature and the resulting explosive expansion of the adjacent air in the channel along which the charge is propagated. This is because, when the conductivity of the metal is replaced by that of an arc path, the energy increases about one hundred-fold. A peak power of about 100 MW/m can be attained in the return stroke and the shock wave close to this stroke readily dislodges tiles from a roof.

Similarly, with a side-flash inside the building, the shock wave can result in damage to the building fabric.

5 Function of a lightning conductor

A lightning conductor is incapable of discharging a thundercloud without a lightning flash. Its function is to divert to itself a lightning discharge which might otherwise strike a vulnerable part of the structure to be protected and to convey the current safely to earth. The range over which a lightning conductor can attract a lightning flash is not

constant but it is now believed to be a function of the severity of the discharge. The range of attraction is therefore a statistical quantity.

On the other hand, the range of attraction is little affected by the configuration of the conductor, so that vertical and horizontal arrangements are equivalent. The use of pointed air terminations or vertical finials is therefore not regarded as essential, except where dictated by practical considerations.

6 Materials

Table 2 gives some recommendations for materials to be used in the manufacture of the component parts of lightning protection systems. Characteristics for some of these materials are given in table 3.

PSA Standard Specification (M and E) No. 1 includes sections covering the components and installation of earthing and lightning protection systems.

Copper and aluminium are recommended for installations required to have a long life. If there is any difficulty in the use of copper or aluminium, galvanized steel of the same cross section as that recommended for copper may be used and this material may be preferred for some short life installations, e.g. exhibitions.

In making a choice, consideration should always be given to the risk of corrosion, including galvanic corrosion. General advice on this subject may be found in BS 5493 and DD 24.

For the protection of conductors, due consideration has to be given to protective coatings to prevent corrosion in less-favourable environments, as in the following examples.

(a) Covering the strip with lead (2 mm minimum thickness of coating) is the most suitable form of protection at the top of chimneys. Lead sheathing should be sealed at both ends and the sheathing should not be removed when making joints.

(b) A covering of polyvinyl chloride (PVC) complying with BS 2571 or BS 6746 (1 mm thickness of coating) will protect copper, steel and aluminium in many environments. Where insulating coatings or coverings are used, due regard should be given to their durability and flammability.

Where possible, air terminations should be of bare conductors but where corrosion of unprotected metal (particularly aluminium) is expected a thin (1 mm thick) PVC coating or paint may be used.

When non-metallic fixing materials are used, their possible degradation due to ultraviolet light, frost, etc., should be borne in mind and the advantages of easy installation and no electrogalvanic corrosion set alongside the possible need to replace the fixings more frequently.

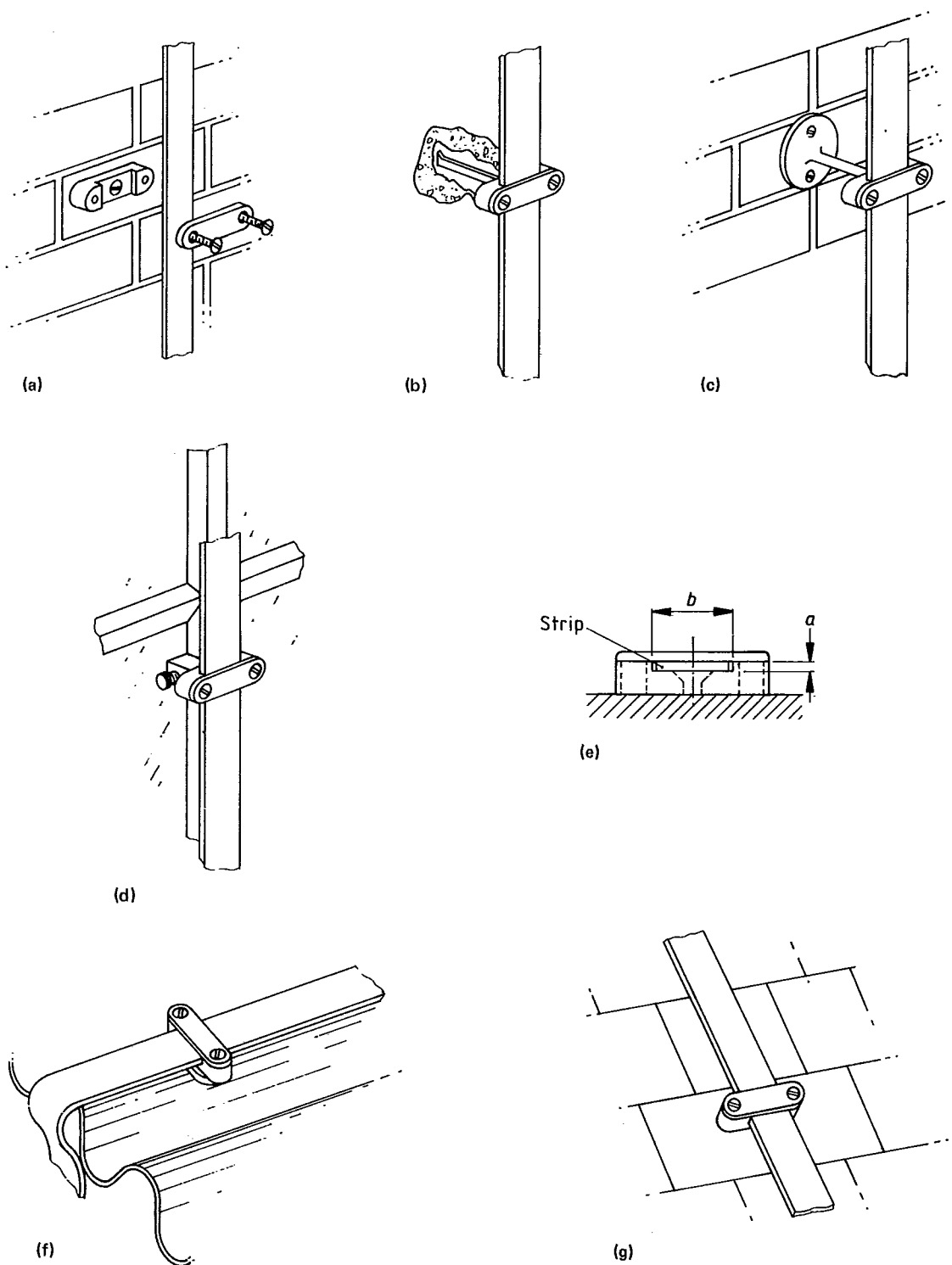
Although in the past it has been common practice to use material in the form of strip for horizontal air terminations, down conductors and bonds, it may sometimes be more convenient to use rod material, particularly as it facilitates the making of bends in any plane.

It is permissible for internal bonds to have approximately half the cross-sectional area of external bonds (see 15.10.2). Flexible bonds may be used and should then comply with the requirements of BS 6360.

Table 1. Recommended fixing centres for conductors

Arrangement	Fixing centres
	mm
Horizontal conductors on horizontal surfaces	1000
Horizontal conductors on vertical surfaces	500
Vertical conductors	1000
Vertical conductors over 20 m	750
Vertical conductors over 25 m	500

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



NOTE 1. Lightning conductor fixings should be purpose-made for each size of strip; dimension a in figure (e) should be equal to the thickness of the strip and b should be equal to the width plus 1.3 mm (for expansion). Conductors of circular section should be similarly treated.

NOTE 2. All fixings should be securely attached to the structure; mortar joints should not be used.

Figure 2. Typical designs for lightning conductor fixings

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Table 2. Recommended materials for the manufacture of lightning protection components

Materials and processes	BS No.	Grade or type	Materials and processes	BS No.	Grade or type
Ingots for cast components Leaded gunmetal Aluminium silicon bronze Aluminium alloy Cast iron Malleable iron	BS 1400 BS 1400 BS 1490 BS 1452 BS 6681	LG1, LG2 AB1, AB3 LM6M 220, 260 —	Nuts, bolts, washers, screws and rivet fixings for use on copper Phosphor bronze Naval brass Copper silicon	BS 2874 BS 2874 BS 2874	PB102-M CZ112, CZ132 CS101
Forgings and stampings (hot or cold formed) Copper Naval brass Aluminium Steel	BS 2872 BS 2872 BS 1474 BS 970 : Part 1	C101, C102 CZ112 6082TF All grades	Nuts, bolts, washers, screws and rivet fixings for use on aluminium Aluminium alloy Stainless steel Galvanized steel, galvanized to BS 729	BS 1473 BS 970 : Part 4 BS 970 : Part 1	6082 325S21 220M07
Pressings and fabrication (from strip, coil, foil and sheet) Annealed copper Aluminium Aluminium Naval brass Stainless steel Steel (for galvanizing) Steel (for galvanizing)	BS 2870 BS 1474 BS 1470 BS 2870 BS 1449 : Part 2 BS 4360 BS 1449 : Part 1	C101, C102 6082TF 6082TF CZ112 316S12, 325S21 43A —	Solid rounds, flats and stranded conductors <i>Copper</i> Annealed copper Hard drawn copper Copper (stranded) Copper (flexible) Hard drawn copper strand and copper cadmium	BS 1432 BS 1433 BS 6360 BS 6360 BS 125 or BS 2755	C101, C101, C102 Insulated —
Bars, rods and tubes (for machined components and fittings) Hard drawn copper Annealed copper Copper silicon Phosphor bronze Aluminium bronze Aluminium Naval brass Aluminium Steel (general use) Steel (for galvanizing) Stainless steel (general use) Stainless steel (austenitic)	BS 2874 BS 2874 BS 2874 BS 2874 BS 2871 : Part 3 BS 1471 BS 2874 BS 1474 BS 970 BS 4360 BS 970 : Part 4 BS 970 : Part 4	C101, C102 C101, C102 CS101 PB102-M CA102 6082TF CZ112 6082TF All grades 43A 325S21 316S12	<i>Aluminium</i> Aluminium strip/rod Aluminium strip/rod Aluminium (steel reinforced) Aluminium alloy Aluminium <i>Steel</i> Galvanized steel Galvanized strip (see note 1)	BS 2897 BS 2898 BS 3988 BS 215 : Part 2 BS 3242 BS 215 : Part 1 BS 302 BS 1449 : Part 1	1350 1350, 6101A — — — — — —

NOTE 1. The recommended finish is galvanizing in accordance with BS 729, which has to be done after manufacture or fabrication.

NOTE 2. Stainless steel in contact with aluminium or aluminium alloys is likely to cause additional corrosion to the latter materials (see PD 6484). In these cases, it is important to take protective measures, e.g. the use of inhibitors.

NOTE 3. This table applies to finials, adornments and projections such as crosses or weather-vanes on churches which are used as part of the air termination network.

Table 3. Some characteristics of typical materials listed in table 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Material		General comments	Corrosion resistance†			Typical mechanical and electrical properties‡										Electrical resistivity	Density
Grade *	Type		Rural	Industrial	Marine	0.1 % proof stress					Ultimate tensile strength			Elongation			
			a	h	m	a	h	m	a	h	m	a	h	m			
1350	Aluminium	Good electrical conductor, ductile and easily bent.	A	B	A	N/mm ² —	N/mm ² —	N/mm ² 31	N/mm ² —	N/mm ² —	N/mm ² 60	% —	% —	% 25	Ω·m X 10 ⁻⁸ 2.8	kg/m ³ 2703	
6101A	Aluminium	Good electrical conductor, fairly rigid compared to grade 1350 and may require heating to make sharp bends.	B	B	B	—	180 §	—	—	210 §	—	—	10 §	—	3.1	2700	
6082	Aluminium alloy	Electrical conductivity not as good as grades 1350 or 6101A and not as commonly used but is a conductor stronger than grades 1350 or 6101A.	B	C	B	—	270	—	—	310 §	—	—	9 §	—	3.6	2700	
C101, C102	Annealed copper	Excellent electrical conductors with high ductility.	A A	A A	A A	60 60	325 325	— —	220 220	385 385	— —	55 55	4 4	— —	1.7 1.7	8900 8900	
C108	Copper cadmium	High strength and conductivity with good ductility.	A	A	A	60	460	—	280	700	—	45	4	—	2	8900	
CS101	Copper silicon	Moderate strength and ductility but with relatively low conductivity. Very good corrosion resistance, particularly in marine environments.	A	A	A	90	—	390	340	—	460	40	—	20	24	8550	
CZ112	Naval brass	Good strength with moderate conductivity.	A	A	A	—	—	250	—	—	430	—	—	30	6.5	8400	
PB102	Phosphor bronze	Good strength and corrosion resistance but relatively low conductivity.	A	A	A	120	420	—	340	540	—	55	20	—	11	8850	
304S12, 316S12	Austenitic stainless steel	Low conductivity. Excellent ductility. High strength. Excellent corrosion resistance.	A	A	¶	190	—	—	490	—	—	40	—	—	73	7905	

* For appropriate British Standards, see table 2.

† Letters in the corrosion resistance columns indicate the following:

A that normal conditions of exposure will cause only a slight weathering of the surface with time;

B that if the material is used unprotected there may be some loss in mechanical properties but this will be very slight and would normally be adequately covered by the conventional factors of safety applied in design;

C that advice should be sought before using this material without protection.

‡ Letters at the head of the typical mechanical and electrical properties columns indicate the following:

a annealed;

h hard;

m as manufactured.

§ The material is fully heat treated aluminium alloy.

|| In this case 0.2 % proof stress.

¶ Not suitable for continuous immersion in salt water.

7 Dimensions

The component parts of lightning protection systems should have dimensions not less than those given in tables 4 and 5, except in the special case considered in 26.4. In situations where inspection or repair is likely to be unusually difficult, consideration should be given to using a size greater than the minimum given in table 4.

The nearest standard size should be used, provided that the dimension is not smaller than that stated.

Table 4. Minimum dimensions of component parts

Component	Dimensions	Area	Component	Dimensions	Area
Air terminations: aluminium, copper and galvanized steel strip	mm	mm ²	Fixed connections (bonds) in aluminium, aluminium alloy, copper and galvanized steel:	mm	mm ²
aluminium, aluminium alloy, copper, phosphor bronze and galvanized steel rods	20 x 2.5	50.0	external strip	20 x 2.5	50.0
	8.0 dia.	50.0	external rods	8.0 dia.	50.0
			internal strip	20 x 1.5	30.0
			internal rods	6.5 dia.	33.0
Suspended conductors: stranded aluminium	7/3.0	50.0	Flexible or laminated connections (bonds):		
stranded copper	19/1.8	50.0	external, aluminium	20 x 2.5	50.0
stranded aluminium (steel reinforced)	7/3.0	50.0	external, annealed copper	20 x 2.5	50.0
stranded galvanized steel	7/3.0	50.0	internal, aluminium	20 x 1.5	30.0
			internal, annealed copper	20 x 1.5	30.0
Down conductors: aluminium, copper and galvanized steel strip	20 x 2.5	50.0	NOTE 1. For copper-clad steel rods, the core should be of low carbon steel with a tensile strength of approximately 600 N/mm² and of a quality not less than grade 43A of BS 4360. The cladding should be of 99.9 % pure electrolytic copper molecularly bonded to the steel core. The radial thickness of the copper should be not less than 0.25 mm. NOTE 2. Couplings for copper-clad steel rods should be made from copper-silicon alloy, grade CS101 or BS 2874, or aluminium bronze alloy, grade CA102 of BS 2871. NOTE 3. The use of internal phosphor bronze dowels may give a lower resistance than the external couplings of diameter greater than the rod. NOTE 4. For galvanized steel rods, steel of grade 43A specified in BS 4360 should be used, the threads being cut before hot-dip galvanizing to BS 729. NOTE 5. Stranded conductors are not normally used for down conductors or earths. NOTE 6. Greater dimensions are required for the following: (a) structures exceeding 20 m in height; (b) special classes of structure; (c) mechanical or corrosive reasons.		
aluminium, aluminium alloy, copper and galvanized steel rods	8.0 dia.	50.0			
Earth terminations: austenitic iron	14.0 dia.	153.0			
copper and galvanized steel strip	20 x 2.5	50.0			
copper and galvanized steel rods	8.0 dia.	50.0			
hard drawn copper rods for direct driving into soft ground	8.0 dia.	50.0			
hard drawn or annealed copper rods or solid wires for indirect driving or laying in ground	8.0 dia.	50.0			
rods for hard ground	12.0 dia.	113.0			
copper-clad or galvanized steel rods (see notes to table) for harder ground	14.0 dia.	153.0			

Table 5. Minimum thicknesses of sheet metal used for roofing and forming part of the air termination network

Material	Minimum thickness
	mm
Galvanized steel	0.5
Stainless steel	0.4
Copper	0.3
Aluminium and zinc	0.7
Lead	2.0

NOTE. The figures in this table are based on contemporary building practice and will be satisfactory where the roofs form part of the lightning protection system. However, damage by way of puncturing may occur with a direct arc-connected strike (see also A.2.4).

Section two. Basic considerations

8 General

Before proceeding with the detailed design of a lightning protection system, the following essential steps should be taken.

- It should be decided whether or not the structure needs protection and, if it does, what the special requirements are (see clauses 9 and 10).
- A close liaison should be ensured between the architect, the builder, the lightning protection system engineer and the appropriate authorities throughout the design stages.
- The procedures for testing, commissioning and future maintenance should be agreed.

9 Need for protection

9.1 General

Structures with inherent explosive risks, e.g. explosives factories, stores and dumps and fuel tanks usually need the highest possible class of lightning protection system and recommendations for protecting such structures are given in clause 21.

For all other structures, the standard of protection recommended in the remainder of this code is applicable and the only question remaining is whether protection is necessary or not.

In many cases, the need for protection may be self-evident, for example:

- where large numbers of people congregate;
- where essential public services are concerned;
- where the area is one in which lightning is prevalent;
- where there are very tall or isolated structures;
- where there are structures of historic or cultural importance;
- where there are structures containing explosive or flammable contents.

However, there are many cases for which it is not so easy to make a decision. In these cases, reference should be made to 9.2 to 9.8 where the various factors affecting the risk of being struck and the consequential effects of a strike are discussed.

However, some factors cannot be assessed and these may override all other considerations. For example, a desire that there should be no avoidable risk to life or that the occupants of a building should always feel safe may decide the question in favour of protection, even though it would normally be accepted that there was no need. No guidance can be given in such matters but an assessment can be made taking account of the exposure risk (that is the risk of the structure being struck) and the following factors:

- use to which the structure is put;
- nature of its construction;

(3) value of its contents or consequential effects;

(4) the location of the structure;

(5) the height of the structure (in the case of composite structures, the overall height).

9.2 Estimation of exposure risk

The probability of a structure or building being struck by lightning in any one year is the product of the 'lightning flash density' and the 'effective collection area' of the structure. The lightning flash density, N_g , is the number of flashes to ground per km² per year. Values of N_g vary significantly; estimates of the average annual density calculated from Meteorological Office observations over a period of 30 years are shown in figure 1 and corresponding information for overseas countries is given in figure 3 and table 6.

The effective collection area of a structure is the area of the plan of the structure extended in all directions to take account of its height. The edge of the effective collection area is displaced from the edge of the structure by an amount equal to the height of the structure at that point. Hence, for a simple rectangular building of length L , width W and height H (in m), the collection area has length $(L + 2H)$ m and width $(W + 2H)$ m with four rounded corners formed by quarter circles of radius H (in m). This gives a collection area, A_c (in m²), of:

$$A_c = LW + 2LH + 2WH + \pi H^2$$

This is shown in figure 29.

The probable number of strikes to the structure per year, P , is as follows:

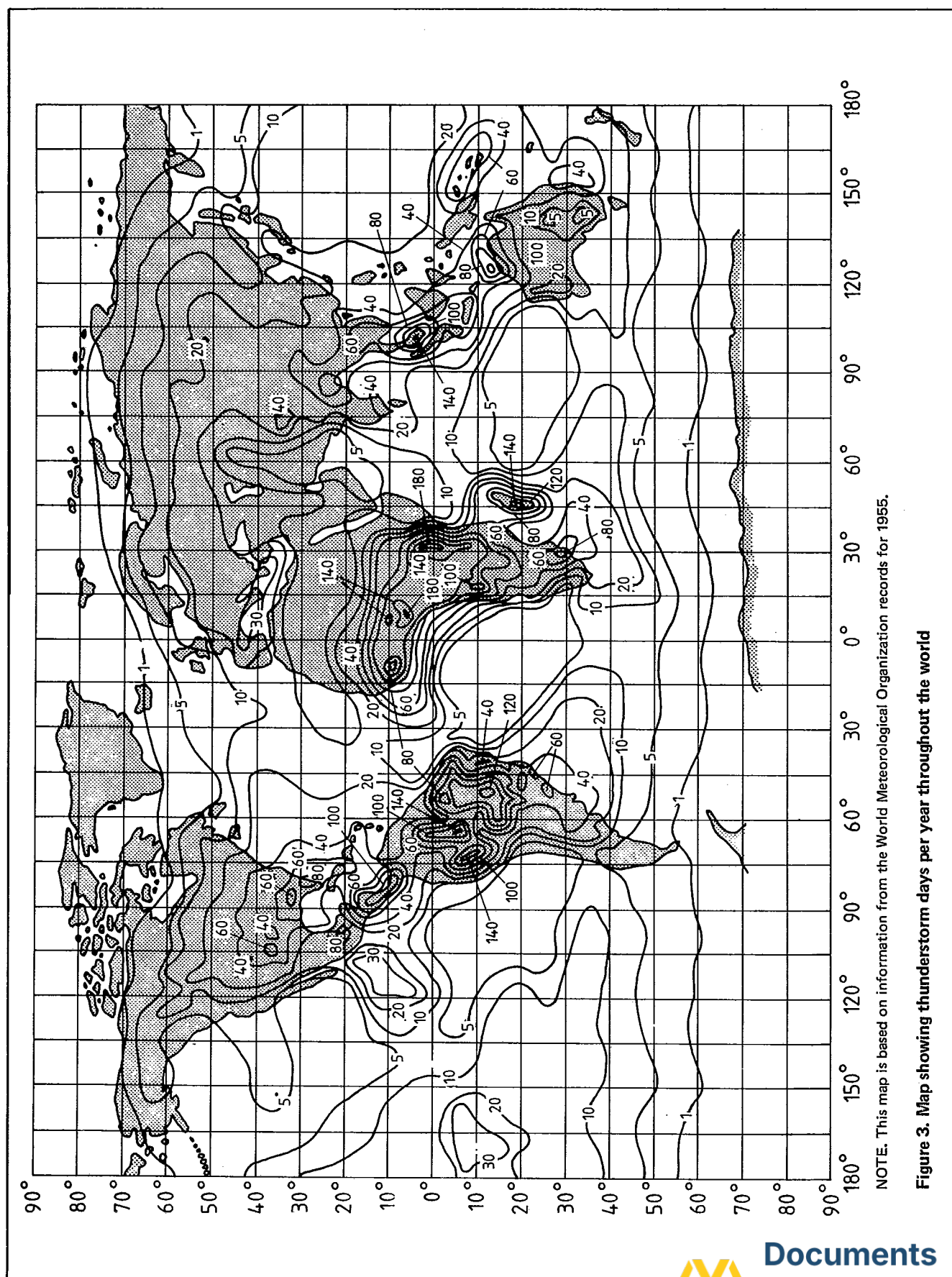
$$P = A_c \times N_g \times 10^{-6}$$

It should first be decided whether this risk P is acceptable or whether some measure of protection is thought necessary.

Table 6. Relationship between thunderstorm days per year and lightning flashes per km² per year

Thunderstorm days per year	Flashes per km ² per year	
	Mean	Limits
5	0.2	0.1 to 0.5
10	0.5	0.15 to 1
20	1.1	0.3 to 3
30	1.9	0.6 to 5
40	2.8	0.8 to 8
50	3.7	1.2 to 10
60	4.7	1.8 to 12
80	6.9	3 to 17
100	9.2	4 to 20

NOTE. The data for this table has been extracted from information in Anderson, R.B. and Eriksson, A.J. (Conference internationale des grands reseaux electriques (CIGRE)) Lightning Parameters for Engineering Application. *Electra*, 1980, 69, 65-102.



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9.3 Risks associated with everyday living

To help in viewing the risk from lightning in the context of the risks associated with everyday living, table 7 gives some figures based on UK government publications. The risk of death or injury due to accidents is a condition of living and many human activities imply a judgement that the benefits outweigh the related risks. Table 7 is intended simply to give an appreciation of the scale of risk associated with different activities. Generally, risks greater than 10^{-3} (1 in 1000) per year are considered unacceptable. With risks of 10^{-4} (1 in 10 000) per year, it will be normal for public money to be spent to try to eliminate the causes or mitigate the effects. Risks less than 10^{-5} (1 in 100 000) are generally considered acceptable, although public money may still be spent on educational campaigns designed to reduce those risks which are regarded as avoidable.

9.4 Suggested acceptable risk

On the basis of 9.3, the acceptable risk figure has been taken as 10^{-5} per year, i.e. 1 in 100 000 per year.

Table 7. Comparative probability of death for an individual per year of exposure (order of magnitude only)

Risk	Activity
1 in 400 (2.5×10^{-3})	Smoking (10 cigarettes per day)
1 in 2000 (5×10^{-4})	All accidents
1 in 8000 (1.3×10^{-4})	Traffic accidents
1 in 20 000 (5×10^{-5})	Leukaemia from natural causes
1 in 30 000 (3.3×10^{-5})	Work in industry, drowning
1 in 100 000 (1×10^{-5})	Poisoning
1 in 500 000 (2×10^{-6})	Natural disasters
1 in 1 000 000 (1×10^{-6})	Rock climbing for 90 s*, driving 50 miles by road*
1 in 2 000 000 (5×10^{-7})	Being struck by lightning

*These risks are conventionally expressed in this form rather than in terms of exposure for a year.

NOTE. The source of this table is Royal Commission on Environmental Pollution, Chairman Sir Brian Flowers, Sixth Report 'Nuclear Power and the Environment' (Cmnd 6618).

9.5 Overall assessment of risk

Having established the value of P , the probable number of strikes to the structure per year (see 9.2), the next step is to apply the 'weighting factors', as given in tables 8 to 12.

This is done by multiplying P by the appropriate factors to determine whether the result, the overall risk factor, exceeds the acceptable risk of $P_0 = 10^{-5}$ per year.

9.6 Weighting factors

In tables 8 to 12, the weighting factor values are given under the headings A to E and denote a relative degree of importance or risk in each case. Tables 8 to 12 are mostly self-explanatory.

Table 10 gives the weighting factor for contents or consequential effects. The effect of the value of the contents of a structure is clear; the term 'consequential effects' is intended to cover not only material risks to goods and property but also such aspects as the disruption of essential services of all kinds, particularly in hospitals.

The risk to life is generally very small but, if a building is struck, fire or panic can naturally result. All possible steps should therefore be taken to reduce these effects, especially among children, the old and the sick.

For multiple use buildings, the value of weighting factor A applicable to the most severe use should be used.

Table 8. Weighting factor A (use of structure)

Use to which structure is put	Value of factor A
Houses and other buildings of comparable size	0.3
Houses and other buildings of comparable size with outside aerial	0.7
Factories, workshops and laboratories	1.0
Office blocks, hotels, blocks of flats and other residential buildings other than those included below	1.2
Places of assembly, e.g. churches, halls, theatres, museums, exhibitions, department stores, post offices, stations, airports, and stadium structures	1.3
Schools, hospitals, children's and other Homes	1.7

Table 9. Weighting factor B (type of construction)

Type of construction	Value of factor B
Steel framed encased with any roof other than metal*	0.2
Reinforced concrete with any roof other than metal	0.4
Steel framed encased or reinforced concrete with metal roof	0.8
Brick, plain concrete or masonry with any roof other than metal or thatch	1.0
Timber framed or clad with any roof other than metal or thatch	1.4
Brick, plain concrete, masonry, timber framed but with metal roofing	1.7
Any building with a thatched roof	2.0
* A structure of exposed metal which is continuous down to ground level is excluded from the table as it requires no lightning protection beyond adequate earthing arrangements.	

Table 11. Weighting factor D (degree of isolation)

Degree of isolation	Value of factor D
Structure located in a large area of structures or trees of the same or greater height, e.g. in a large town or forest	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure completely isolated or exceeding at least twice the height of surrounding structures or trees	2.0

Table 12. Weighting factor E (type of country)

Type of country	Value of factor E
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300 m and 900 m	1.3
Mountain country above 900 m	1.7

Table 10. Weighting factor C (contents or consequential effects)

Contents or consequential effects	Value of factor C
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents	0.3
Industrial and agricultural buildings with specially susceptible* contents	0.8
Power stations, gas installations, telephone exchanges, radio stations	1.0
Key industrial plants, ancient monuments and historic buildings, museums, art galleries or other buildings with specially valuable contents	1.3
Schools, hospitals, children's and other Homes, places of assembly	1.7
* This means specially valuable plant or materials vulnerable to fire or the results of fire.	

9.7 Interpretation of overall risk factor

The risk factor method given in this code is intended to give guidance on what can, in some cases, be a difficult problem. If the result obtained is considerably less than 10^{-5} (1 in 100 000) then, in the absence of other overriding considerations, protection does not appear necessary; if the result is greater than 10^{-5} , say for example 10^{-4} (1 in 10 000), then sound reasons would be needed to support a decision not to give protection.

When it is thought that the consequential effects will be small and that the effect of a lightning strike will most probably be merely slight damage to the fabric of the structure, it may be economic not to incur the cost of protection but to accept the risk. Even though this decision is made, it is suggested that the calculation is still worthwhile as giving some idea of the magnitude of the risk being taken.

Structures are so varied that any method of assessment may lead to anomalies and those who have to decide on protection have to exercise judgement. For example, a steel framed building may be found to have a low risk factor but, as the addition of an air termination and earthing system will give greatly improved protection, the cost of providing this may be considered worthwhile.

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A low risk factor may result for chimneys made of brick or concrete. However, where chimneys are free-standing or where they project for more than 4.5 m above the adjoining structure, they will require protection regardless of the factor. Such chimneys are, therefore, not covered by the method of assessment. Similarly, structures containing explosives or flammable substances are subject to additional consideration (see clause 21 and 10.3).

Results of calculations for different structures are given in table 13 and a specific case is worked through in 9.8.

NOTE. Table 13 should be read in conjunction with figure 4.

9.8 Sample calculation of overall risk factor

A hospital in mid-Norfolk is 10 m high and covers an area of 70 m x 12 m. The hospital is located in flat country and isolated from other structures. The construction is of brick and concrete with a non-metallic roof.

To determine whether or not lightning protection is needed, the overall risk factor is calculated, as follows.

(a) *Number of flashes per km² per year.* The map in figure 1 gives a value for N_g of 0.7 flashes per km² per year.

(b) *Collection area.* Using the first equation in 9.2, the collection area, A_c in m², is given by:

$$\begin{aligned} A_c &= (70 \times 12) + 2(70 \times 10) + 2(12 \times 10) + (\pi \times 100) \\ A_c &= 840 + 1400 + 240 + 314 \\ A_c &= 2794 \text{ m}^2. \end{aligned}$$

(c) *Probability of being struck.* Using the second equation in 9.2, the probable number of strikes per year, P , is given by:

$$\begin{aligned} P &= A_c \times N_g \times 10^{-6} \\ P &= 2794 \times 0.7 \times 10^{-6} \\ P &= 2.0 \times 10^{-3} \text{ approximately} \end{aligned}$$

(d) *Applying the weighting factors.* The following weighting factors apply:

$$\begin{aligned} \text{factor A} &= 1.7 \\ \text{factor B} &= 1.0 \\ \text{factor C} &= 1.7 \\ \text{factor D} &= 2.0 \\ \text{factor E} &= 0.3 \end{aligned}$$

$$\begin{aligned} \text{The overall multiplying factor} &= A \times B \times C \times D \times E \\ &= 1.7 \end{aligned}$$

Therefore, the overall risk factor = $2.0 \times 1.7 \times 10^{-3} = 3.4 \times 10^{-3}$. The conclusion is, therefore, that protection is necessary.

10 Zone of protection

10.1 General

In simple terms, the zone of protection is the volume within which a lightning conductor gives protection against a direct lightning strike by directing the strike to itself.

The size and shape of the zone varies according to the height of the building or vertical conductor. Generally, for structures not exceeding 20 m in height for a vertical conductor rising from ground level, the zone has been defined as a cone with its apex at the tip of the conductor and its base on the ground; for a horizontal conductor the zone has been defined as the volume generated by a cone with its apex on the horizontal conductor moving from end to end. For structures exceeding 20 m in height, these zones are not necessarily applicable and it is recommended that additional lightning protection conductors be provided in the manner shown in figure 5 (see also clause 19) to protect against strikes on the side of the building.

10.2 Protective angle

For structures not exceeding 20 m in height, the angle between the side of the cone and the vertical at the apex of the cone is known as the protective angle, as shown in figure 6. Because it depends upon the severity of the stroke and the presence within the protective zone of conductive objects providing independent paths to earth, the magnitude of the protective angle cannot be precisely stated. All that can be stated is that the protection afforded by a lightning conductor increases as the assumed protective angle decreases. For structures exceeding 20 m in height, the protective angle of any conductors up to the height of 20 m would be similar to that for lower structures. However, for structures above 20 m, where there is a possibility of such buildings being struck on the side, it is recommended that the protected volume should be determined using the rolling sphere method (see A.5).

For the practical purpose of providing an acceptable degree of protection for an ordinary structure up to 20 m high and up to a height of 20 m for a higher structure, the protective angle of any single component part of an air termination network, namely either one vertical or one horizontal conductor, is considered to be 45° (see figure 6(a) and (b)). Between two or more vertical conductors, spaced at a distance not exceeding twice their height, the equivalent protective angle may, as an exception be taken as 60° to the vertical; an example is shown in figure 6(c). For a flat roof, the area between parallel horizontal conductors is deemed to be effectively protected if the air termination network is arranged as recommended in 14.2 and 14.3. For structures requiring a higher degree of protection, other protective angles are recommended (see clause 21).

10.3 Structures of exceptional vulnerability

For structures of exceptional vulnerability, by reason of explosive or highly flammable contents, every possible protection may need to be provided, even against the rare occurrence of a lightning discharge striking within the protected zone defined in 10.1 and 10.2. For this reason, a reduced zone of protection, and various other special measures, should be taken as recommended in clause 21.

Table 13. Examples of calculations for evaluating the need for protection

1	2	3	4	5	6	7	8	9	10	11	12	13
Ref. in figure 4	Description of structure	Risk of being struck, P			Weighting factors					Overall multiplying factor (product of columns 6 to 10)	Overall risk factor (product of columns 5 and 11)	Recommendation
		Collection area, A_c	Flash density, N_g	$P = A_c \times N_g \times 10^{-6}$	A Use of structure (table 8)	B Type of construction (table 9)	C Contents or consequential effects (table 10)	D Degree of isolation (table 11)	E Type of country (table 12)			
(a)	Maisonette, reinforced concrete and brick built, non-metallic roof, Canterbury, Kent	3327	0.6	2×10^{-3}	1.2	0.4	0.3	0.4	0.3	0.02	4×10^{-5}	Protection recommended
(b)	Office building, reinforced concrete construction, non-metallic roof, West Bromwich	4296	0.6	2.6×10^{-3}	1.2	0.4	0.3	0.4	0.3	0.02	5.2×10^{-5}	Protection recommended
(c)	School, brick built, in Kingston-on-Thames	1456	0.7	1×10^{-3}	1.7	1.0	1.7	0.4	0.3	0.3	3×10^{-4}	Protection required
(d)	Three bedroom detached dwelling house, brick built, Bournemouth area	405	0.4	1.6×10^{-4}	0.3	1.0	0.3	0.4	0.3	0.01	1.6×10^{-6}	No protection required
(e)	Village church in Lincolnshire	5027	0.6	3×10^{-3}	1.3	1.0	1.7	2.0	0.3	1.3	3.9×10^{-3}	Protection required
(f)	Office building, reinforced concrete construction, non-metallic roof, Glasgow	4090	0.2	8.2×10^{-4}	1.2	0.4	0.3	0.4	0.3	0.02	1.6×10^{-5}	Need for protection marginal, consider other factors, e.g. future life or operational importance of building
(g)	Factory, steel framed encased, non-metallic roof, Aberystwyth	3675	0.2	7.4×10^{-4}	1.2	0.2	0.3	0.4	0.3	0.01	7.4×10^{-6}	No protection required
(h)	Shop, brick built, tiled roof, Carlisle	1070	0.3	3.3×10^{-4}	0.3	1.0	0.6	0.4	0.3	0.02	6.6×10^{-6}	No protection required

NOTE. The risk of being struck, P (column 5), is multiplied by the product of the weighting factors (columns 6 to 10) to yield an overall risk factor (column 12). This should be compared with the acceptable risk (10^{-5}) for guidance on whether or not to protect. Risks less than 10^{-5} do not generally require protection; risks greater than 10^{-4} require protection; for risks between 10^{-5} and 10^{-4} protection is recommended (see 9.3 to 9.8).

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Reference	General arrangement	Collection area and method of calculation
(a)		$A_c = 14 \times 50 + 2(15 \times 50) + 2(15 \times 14) + \pi 15^2$ $A_c = 3327 \text{ m}^2$
(b)		$A_c = 15 \times 40 + 2(21 \times 40) + 2(21 \times 15) + \pi 21^2$ $A_c = 4296 \text{ m}^2$
(c)		$A_c = \pi 14^2 + 2(14 \times 30)$ $A_c = 1456 \text{ m}^2$
(d)		$A_c = 7 \times 8 + 2(6 \times 7) + \pi 9^2 + 10 \text{ (approx.) for areas in black}$ $A_c = 405 \text{ m}^2$
(e)		$A_c = \pi 40^2$ $A_c = 5027 \text{ m}^2$
(f)		$A_c = 12 \times 55 + 2(18 \times 55) + 2(18 \times 12) + \pi 18^2$ $A_c = 4090 \text{ m}^2$
(g)		$A_c = 25 \times 60 + 25 \times 30 + 6 \times 60 + 6 \times 50 + 6 \times 25 + 6 \times 25 + 6 \times 30 + 6 \times 24 + \frac{5}{4} \pi 6^2$ $A_c = 3675 \text{ m}^2$
(h)		$A_c = 20 \times 30 + 2(4 \times 30) + 2(4 \times 20) + \pi 4^2 + 20 \text{ (approx.) for area in black}$ $A_c = 1070 \text{ m}^2$

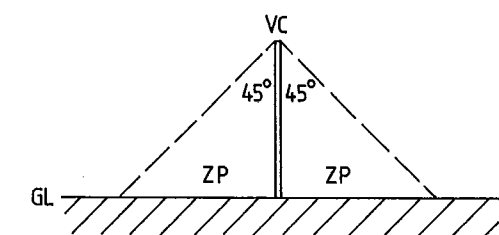
All dimensions are in metres.

NOTE. This figure should be used in conjunction with table 13.

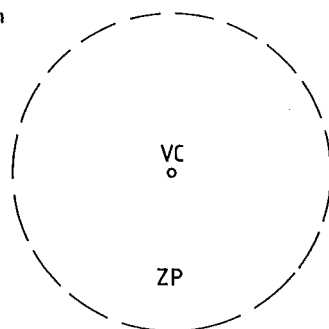
Figure 4. Details of structures and collection areas



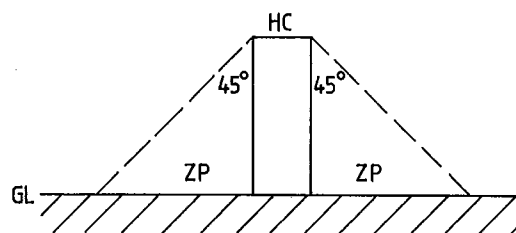
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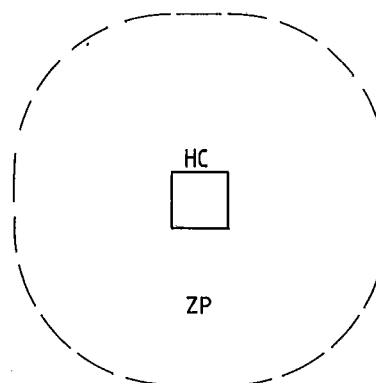
Plan view
of zone of
protection
at ground
level



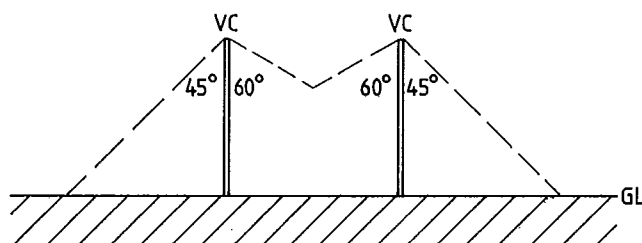
(a) One vertical conductor



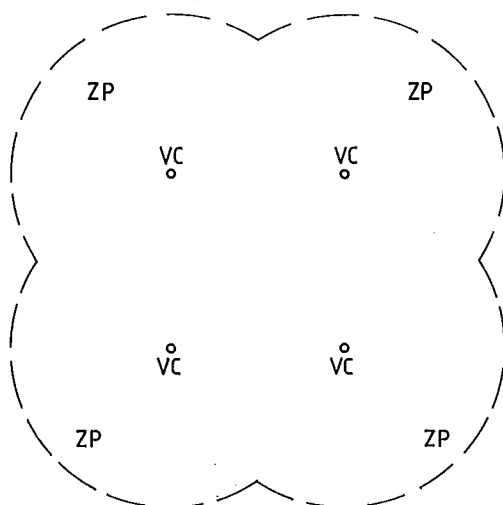
Plan view
of zone of
protection
at ground
level



(b) Horizontal air termination



Plan view
of zone of
protection
at ground
level



(c) Four vertical conductors showing protective angles
and associated zones of protection

Figure 6. Protective angles and zones of protection for various forms of air termination

Section three. System design

11 General considerations

'The structure or, if it has not been built, the drawings and specifications should be examined taking into account the recommendations of this code.

In the case of structures having no suitable metallic members it is important to consider the positioning of all the component parts of a lightning protection system so that they perform their function without detracting from the appearance of the structure.

Modern buildings use metal extensively in their structure and there is considerable benefit in utilizing such metal parts to maximize the number of parallel conducting paths. Often the lightning protection will be improved, worthwhile cost savings may result and the aesthetic appearance of the structure preserved. However, it should be borne in mind that a lightning strike to such a metal part, especially if it is beneath the surface, may damage the covering and cause masonry to fall. This risk can be reduced, but not eliminated, by a surface-mounted lightning protection system.

Examples of metal parts which should be incorporated into lightning protection systems are steel frames, concrete reinforcing bars, metal in or on a roof, window cleaning rails and handrails. Some metal within a structure may be used as a component of the lightning protection system; for example sheet piling being in contact with the general mass of earth may be used as an earth electrode and is unlikely to be improved upon by the addition of rods or tapes.

The whole structure should be provided with a fully interconnected lightning protection system, i.e. no part of the structure should be protected in isolation.'

12 Consultation

12.1 General

Consultation should take place between the designer of the lightning protection system and the interested parties indicated in 12.2 to 12.6 before and during all stages of design.

12.2 Architect

As far as practicable, the following should be determined:

- (a) routing of all conductors;
- (b) general areas available for earth termination networks and reference earth electrodes;
- (c) material(s) for conductors;
- (d) extent of the work and the division of responsibility for primary fixings to the structure, especially those affecting the watertightness of the fabric, chiefly roofing;
- (e) material(s) to be used in the structure, especially for any continuous metal, e.g. stanchions or reinforcing;
- (f) use to which the structure is to be put;

(g) details of all metallic service pipes, rain-water systems, rails and the like entering or leaving the structure or within the structure which may require bonding to the lightning protection system;

(h) extent of any buried services which could affect the siting of the earth termination network(s);

(i) details of any equipment, apparatus, plant or the like to be installed within or near the building and which would require bonding to the lightning protection system.

12.3 Public utilities

Agreement should be reached on the bonding of services to the lightning protection system. Because of the introduction of new materials and practices, reliance should not be placed on agreements reached for other structures.

12.4 Fire and safety officers

Agreement should be reached on:

- (a) the need for a lightning protection system on structures containing flammable or explosive materials;
- (b) routes and material(s) for construction of ducts and sealing at floors if internal conductors are being considered;
- (c) the method of lightning protection to be adopted in the unlikely event of a structure having a flammable roof.

12.5 Television and radio installers

Agreement should be reached on the need to bond aerial supports and screens of cables to the lightning protection system (see clause 25 and also BS 6330).

12.6 Builder

Agreement should be reached on:

- (a) the form, positions and numbers of primary fixings to be provided by the builder;
- (b) any fixings provided by the lightning protection system contractor to be installed by the builder;
- (c) the positions of conductors to be placed beneath the structure;
- (d) whether any components of the lightning protection system are to be used during the construction phase, e.g. the permanent earth termination network could be used for earthing cranes, railway lines, scaffolding, hoists and the like during construction;
- (e) for steel framed structures, the numbers and positions of stanchions and the form of fixing to be made for the connection of earth terminations;
- (f) whether metallic roof coverings, where used, are suitable as part of the lightning protection system and the method of attachment of conductors to earth;

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Bimetallic joint

Reinforced concrete structure with parapet, stone coping and non-conducting roof

Galvanized steel roof

Bonds to steelwork

Reinforced concrete structure, PVC coping with conducting roof

Bond to metal suspended ceiling

One reinforcing bar shown for clarity

Handrails and reinforcing bars

Detail showing item 4

Key

- 1 Handrail bond
- 2 Reinforcing bond
- 3 Coping bond
- 4 Non-ferrous bonding point (built-in)

Figure 7. Examples of air terminations and down conductors using handrails, metal copings and reinforcing bars

(g) the nature and location of services entering the structure above and below ground including railway lines, crane rails, wire ropeways, conveyor systems, television and radio aerials and their metal supports, metal flues, flue-liners, window cleaning gear and dry risers;

(h) the position and number of flag-masts, roof level plant rooms (e.g. lift motor rooms, ventilating, heating and air-conditioning plant rooms), water tanks and other salient features;

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

(j) possible penetration of a waterproofing membrane where earth terminations have to be sited beneath the structure, especially in 'urban' situations and in confined spaces on industrial sites;

NOTE. The same general consideration applies to the reference earth electrode for use in initial and periodic testing.

(k) the provision of holes through the structure, parapets, cornices, etc. to allow for the free passage of the down conductor;

(l) the provision of bonding connections to a steel frame, reinforcement bars and other metal;

(m) the most suitable choice of metal for the conductors taking account of corrosion, especially at bimetallic contacts;

(n) the accessibility of test joints, protection by non-metallic casings from mechanical damage or pilferage, lowering of flag-masts or other removable objects, facilities for periodic inspection, especially on chimneys;

(o) the preparation of a drawing incorporating the above details and showing the positions of all conductors and of the main components.

13 Component parts

The principal components of a lightning protection system are as follows:

- (a) air terminations;
- (b) down conductors;
- (c) joints and bonds;
- (d) test joints;
- (e) earth terminations;
- (f) earth electrodes.

These are dealt with in detail in clauses 14 to 17 and typical designs of various fixings are shown in figures 2, 8 and 9.

14 Air terminations

14.1 General

The basic guidelines on the design of air terminations are given in 14.2 and explanatory notes on the various forms commonly used follow in 14.3.

14.2 Basic rules

Air termination networks may consist of vertical or horizontal conductors or combinations of both (see, for example, figures 10 to 15).

No part of the roof should be more than 5 m from the nearest horizontal conductor (but see notes 1 and 2 on figure 11). For large flat roofs, this will be achieved typically by an air termination network mesh of approximately 10 m x 20 m. On multiple ridge roofs, additional conductors will be required if the separation, S (in m), of the ridges is greater than $10 + 2H$, where H is the height of the ridge (in m) (see figure 12).

On a reinforced concrete structure, the air termination should be connected to the reinforcing bars in the number of positions required for down conductors.

All metallic projections on or above the main surface of the roof which are connected, intentionally or fortuitously, to the general mass of the earth should be bonded to, and form part of, the air termination network (see, for example, figures 5 and 7 and also refer to figure 16).

Metallic coping, roof coverings, handrails (see clause 11), window washing equipment and metallic screens around play areas should be considered for inclusion as part of the air termination network (see figures 5, 7 and 17).

In general, parts of a structure falling within the zone of protection of a protected higher part do not require air terminations.

If portions of a structure vary considerably in height, any necessary air terminations or air termination networks for the lower portions should be joined to the down conductors of the taller portions in addition to being joined to their own down conductors.