

Code of practice for protection of structures against lightning

ICS 91.120.40

Committees responsible for this British Standard

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BEAMA Electrical Cable and Conductor Accessory Manufacturers' Association
British Telecommunications plc
Council for the Care of Churches
Department of the Environment, Transport and the Regions
Electricity Association
Engineering Equipment and Materials Users Association
ERA Technology Ltd.
National Federation of Master Steeplejacks and Lightning Conductor Engineers
Ministry of Defence

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National foreword

This British Standard has been prepared by Technical Committee GEL/81 and supersedes BS 6651:1992, which is withdrawn.

Some of the changes introduced since the publication of the previous edition include:

- the provision of a new lightning flash density map (Figure 1), compiled from data accumulated over the last ten years;
- a simple calculation, based on IEC findings, relating to buildings with cantilevered upper floors and the risk of side flashing from external down conductors to persons standing under the overhang;
- modifications to Figure 13 to clarify the positioning of air terminals on buildings with sloping roofs;
- modifications to Figure 28 to give additional information relating to flashover voltage through cracks in mortar and brickwork.

Corrigendum No. 1 (September 2000) makes corrections to the following:

- Figure 1; Table 1, last row; Table 9, row 3;
- Table 10, title and heading of column 1; Table 13, rows a) and f);
- Figure 13, diagram 3; **19.2.1.4** equation in example of use of equation (6); **19.3.9** (deletion of last three paragraphs; **27.7** item a).

Amendment 1 introduces changes required in order to remove provisions conflicting with those contained in BS EN 50164-1:2000, *Lightning protection components (LPC) — Part 1: Requirements for connection components*, and BS EN 50164-2:2002, *Lightning protection components (LPC) — Part 2: Requirements for conductors and earth electrodes*.

The principle informing all the provisions of this British Standard is that of the “Faraday cage” form of lightning protection. The Technical Committee is aware of development and research on other technologies in the field of lightning protection that has been taking place in recent years, but it is the Committee’s considered opinion that the materials, extent and dimensions of the air terminations, down conductors, earth terminations, bonding, components, etc. as laid down in this code of practice be adhered to in full, irrespective of any devices or systems employed which are claimed to provide enhanced protection.

This standard is intended to provide 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. Guidance is also provided on the need for protection for structures in general and for specific structures that are considered to be most at risk; these recommendations are an economic compromise between absolute protection and the cost of the installation.

The protection of electronic equipment against lightning continues to be the subject of standardization work in the international and European Standards fora. However, until definitive European Standards are available for adoption as British Standards, the Technical Committee maintains the general advice on the subject which is given in Annex C.

As a code of practice, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

WARNING Attention is drawn to the danger of installing or carrying out maintenance work on lightning protection systems or surge protection devices during a storm.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and vi, pages 1 to 131 and a back cover.

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Introduction

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 lightning flashes 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 **10.3**).

This British Standard outlines the general technical aspects of lightning, illustrating its principal electrical, thermal and mechanical effects. Guidance is given on how to assess the risk of being struck and how to compile an index figure as an aid to deciding whether a particular structure is in need of protection. The guidance given is of a general nature and its application to specific lightning protection installations has to take into account the particular conditions pertaining to those installations. 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 the risk of damage to the structure.

NOTE 1 Some explanatory information about the recommendations of this standard is given in Annex A.

NOTE 2 All structures shown in figures are “typical” only and are not intended as designs.

NOTE 3 Guidance on the application of the standard is given in Annex B.

NOTE 4 General advice on the protection of electronic equipment against lightning is given in Annex C.

1 Scope

This British Standard provides 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. Guidance is also given on the protection of electronically stored data.

The principle informing all the provisions of this British Standard is that of the “Faraday cage” form of lightning protection, and installations employing alternative technologies fall outside the scope of this British Standard.

Protection of offshore oil and gas installations does not fall within the scope of this British Standard.

NOTE Where current-carrying conductors are directly associated with structures lying within the scope of this code of practice, 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.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 729, *Specification for hot dip galvanized coatings on iron and steel articles*.

BS 5970, *Code of practice for thermal insulation of pipework and equipment in the temperature range $-100\text{ }^{\circ}\text{C}$ to $+870\text{ }^{\circ}\text{C}$* .

BS 6330, *Code of practice for reception of sound and television broadcasting*.

BS 7430, *Code of practice for earthing*.

BS 7671, *Requirements for electrical installations — IEE Wiring regulations — Sixteenth edition*.

BS EN 50020, *Electrical apparatus for potentially explosive atmospheres — Intrinsic safety “i”*.

BS EN 50164-1, *Lightning protection components (LPC) — Part 1: Requirements for connection components*.

BS EN 50164-2, *Lightning protection components (LPC) — Part 2: Requirements for conductors and earth electrodes*.

3 Definitions and abbreviations

3.1 Definitions

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

3.1.1

lightning flash

electrical discharge between cloud and earth, of atmospheric origin, comprising one or more impulses of many kiloamps

3.1.2

lightning stroke

one of the single distinguishable current impulses of a lightning flash

3.1.3

lightning strike

lightning flash attaching to a structure

3.1.4

lightning protection system

whole system of conductors used to protect a structure from the effects of lightning

3.1.5

air termination network

that part of a lightning protection system which is intended to intercept lightning discharges

NOTE The term "air termination" may be used in an equivalent sense.

3.1.6

down conductor

conductor that connects an air termination with an earth termination (see **3.1.10**)

3.1.7

bond

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

3.1.8

joint

mechanical and/or electrical junction between two or more portions of a lightning protection system

3.1.9

test joint

joint designed and situated so as to enable resistance or continuity measurements to be made

3.1.10

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

NOTE 2 The term "earth termination" may be used in an equivalent sense.

3.1.11

earth electrode

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.

3.1.12**ring earth electrode**

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

NOTE A ring earth electrode may be used to interconnect other earth electrodes.

3.1.13**indicating plate**

plate detailing the number and position of earth electrodes

3.1.14**reference earth electrode**

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

3.1.15**isolation**

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

3.1.16**log book**

record of tests and inspections of a lightning conductor installation

3.1.17**electronic equipment**

communications equipment, telemetry, computer, control and instrumentation systems and power electronic installations and similar equipment incorporating electronic components

3.1.18**equipment transient design level (ETDL)**

level of transients to which a piece of equipment has been satisfactorily tested

NOTE ETDL is sometimes known as “immunity level”.

3.1.19**transient control level (TCL)**

maximum level of transients occurring in a protected system, achieved by design of protection (screening etc.) or by use of surge suppressors

3.1.20**self-inductance**

property of a wire or circuit which causes a back e.m.f. to be generated when a changing current flows through it

NOTE 1 The self-inductance of a wire or circuit produces a back e.m.f. which is given by:

$$V = L \cdot \frac{di}{dt}$$

where

V is the back e.m.f in volts (V);

L is the self-inductance in henries (H);

$\frac{di}{dt}$ is the rate of change of current in amperes per second (A/s).

NOTE 2 See C.9.2.

3.1.21**mutual inductance**

property of a circuit whereby a voltage is induced in a loop by a changing current in a separate conductor

NOTE 1 The mutual inductance of a loop produces an induced voltage given by:

$$V = M \cdot \frac{di}{dt}$$

where

V is the induced voltage in a loop in volts (V);

M is the mutual inductance in henries (H);

$\frac{di}{dt}$ is the rate of change of current in a separator conductor in amperes per second (A/s).

NOTE 2 See C.9.2.

3.1.22**transfer inductance**

property of a circuit whereby a voltage is induced in a loop by a changing current in another circuit, some part of which is included in the loop

NOTE 1 The transfer inductance of a loop produces an induced voltage given by:

$$V = M_T \cdot \frac{di}{dt}$$

where

V is the induced voltage in a loop in volts (V);

M_T is the transfer inductance in henries (H);

$\frac{di}{dt}$ is the rate of change of current in another circuit in amperes per second (A/s).

NOTE 2 See C.9.2.

3.1.23**lightning electromagnetic pulse (LEMP)**

voltages or currents induced into cables and other conductors by the radiated field from a lightning flash some distance away

NOTE LEMPs may be undesirable in electronic systems, but rarely cause transients of high voltage or high energy.

3.1.24**common mode (CM)**

voltage common to all conductors of a group as measured between that group at a given location and an arbitrary reference (usually earth)

NOTE Common mode is sometimes known as “longitudinal mode”.

3.1.25**differential mode (DM)**

voltage at a given location between two conductors of a group

NOTE Differential mode is sometimes known as “transverse mode”.

3.1.26**local area network (LAN)**

data communications system supporting layers 1 and 2 of the ISO Reference Model for Open Systems Interconnections, having a geographic coverage up to 1 km end-to-end and possessing sufficient performance to support the aggregate data throughput required by the stations (data terminal equipment) being used

3.1.27**let-through voltage**

maximum peak voltage occurring within 100 µs of application of the test wave

3.1.28**data line**

cable carrying information as distinct from power

NOTE Examples of data lines are telephone lines, telemetry control and signal lines.

3.1.29**return stroke**

part of the flash in which a charge cell in a thundercloud is discharged to earth

3.1.30**zone of protection**

volume within which a lightning conductor gives protection against a direct lightning strike by directing the strike to itself

3.2**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.

4 Technical aspects of lightning**4.1 General**

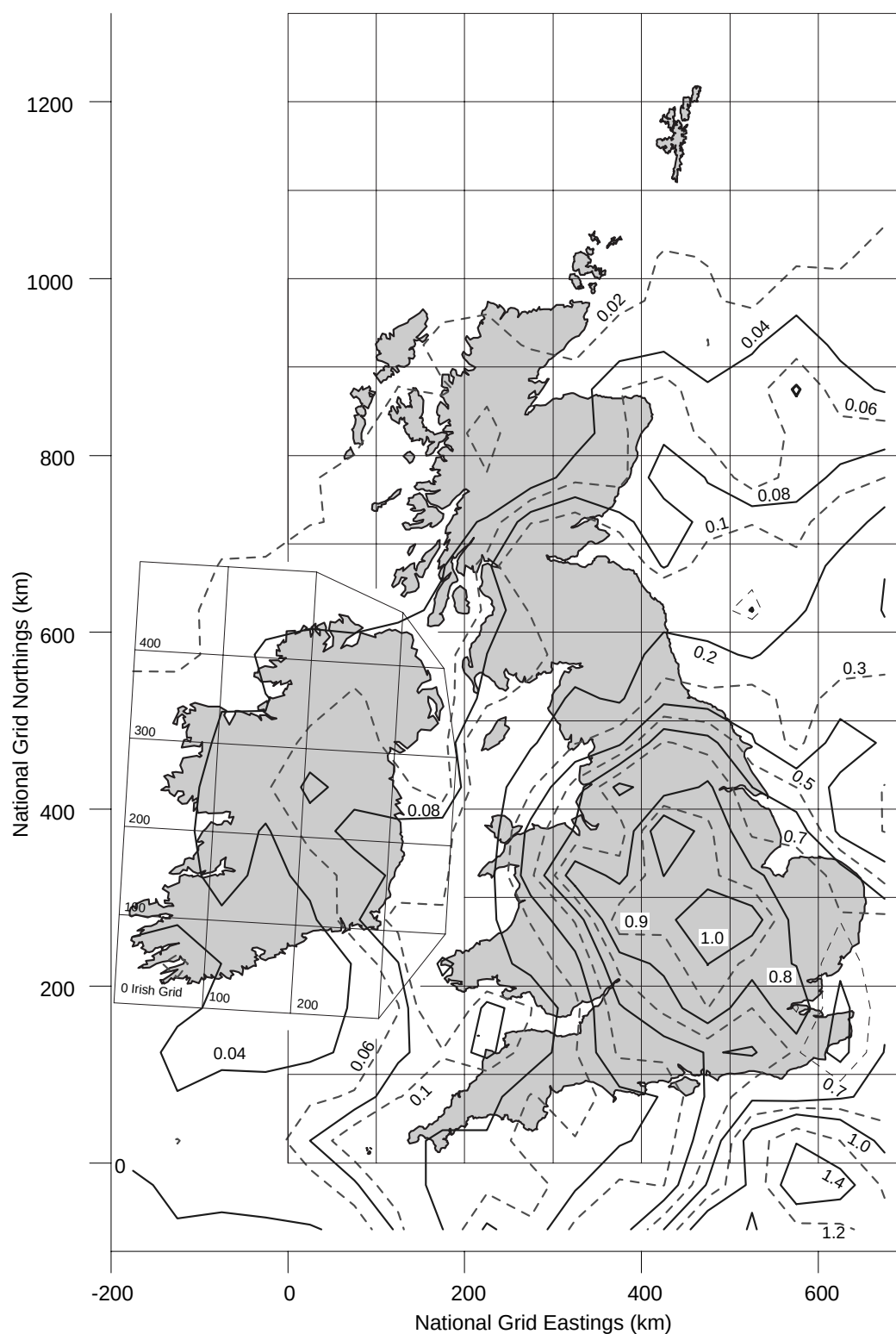
Lightning activity varies over the UK with more flashes in the East than in the West and more in the South than in the North. Furthermore, there is a variation of roughly 2:1 over a period of about 11 years, which corresponds with the sunspot cycle. A diagrammatic representation of the density of lightning flashes to ground is shown in Figure 1.

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 4.2.

4.2 Characteristics of lightning**4.2.1 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. The current in this return stroke ranges from about 2 000 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	8 000 A;
99 % of strokes exceed	3 000 A.



NOTE 1 This lightning density map was compiled by E.A. Technology Ltd. from data accumulated over 10 years.

NOTE 2 A linear interpolation should be used to determine the value of the lightning flash density, N_g , for a location between two contour lines.

Figure 1 — Lightning flash density to ground (N_g) per square kilometre per year for the British Isles

The current in most ground flashes is from the negatively charged cells in the thundercloud 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. Rare multi-stroke flashes, which have more than 10 strokes, may therefore last for up to 1 s.

For the purposes of lightning protection system design, the following values of peak lightning current (i_{max}) are considered to be the most severe:

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

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

4.2.2 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 value is high enough to ensure that the potential of whatever is struck will be controlled by the product of current and impedance, because this 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 is preceded by a downward leader which makes a step-by-step descent of some tens of metres at a time from the cloud. When the last step brings the tip of the leader sufficiently close to earth, an upward leader leaves the earth to join the tip of the downward leader, so establishing a conductive channel for the main current to flow.

The initiation of this upward leader 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 leader will be greater for greater charges and hence high current flashes will start preferentially from high structures for which the field enhancement is high.

5 Effects of lightning strike

5.1 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 also has 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.

5.2 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 therefore constitutes a risk to the occupants and the fabric of the structure.

5.3 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 on initial installation.

In general, the cross-sectional area of a lightning conductor is chosen primarily to satisfy the requirements for 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.

5.4 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 can readily dislodge tiles from a roof.

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

6 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.

Table 1 — Recommended fixing centres for conductors

Arrangement	Fixing centres mm
Horizontal conductors on horizontal surfaces	1 000
Horizontal conductors on vertical surfaces	500
Vertical conductors from the ground to 20 m	1 000
Vertical conductors from 20 m and thereafter	500
NOTE 1 This table does not apply to built-in type fixings which may require special consideration.	
NOTE 2 Assessment of environmental conditions should be undertaken and fixing centres different from those recommended may be found to be necessary.	

7 Materials

All materials chosen for use in the manufacture of the component parts of lightning protection systems should fully meet the requirements of BS EN 50164-1, where the application of the component is to clamp or bridge conductors. Additionally all conductors and earth electrodes should meet the requirements of BS EN 50164-2.

NOTE 1 The future publication of BS EN 50164-4, *Fasteners* will cover the requirements for all fastener/clip arrangements.

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 should be given to protective coatings to prevent corrosion in less-favourable environments, as in the following examples.

a) Covering the conductor 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) Where possible, for maximum effectiveness, air terminations should be formed from bare conductors. Where this is not possible, for example for aesthetic reasons or because corrosion of unprotected metal (particularly aluminium) is expected, a thin (1 mm thick) PVC coating or paint may be used.

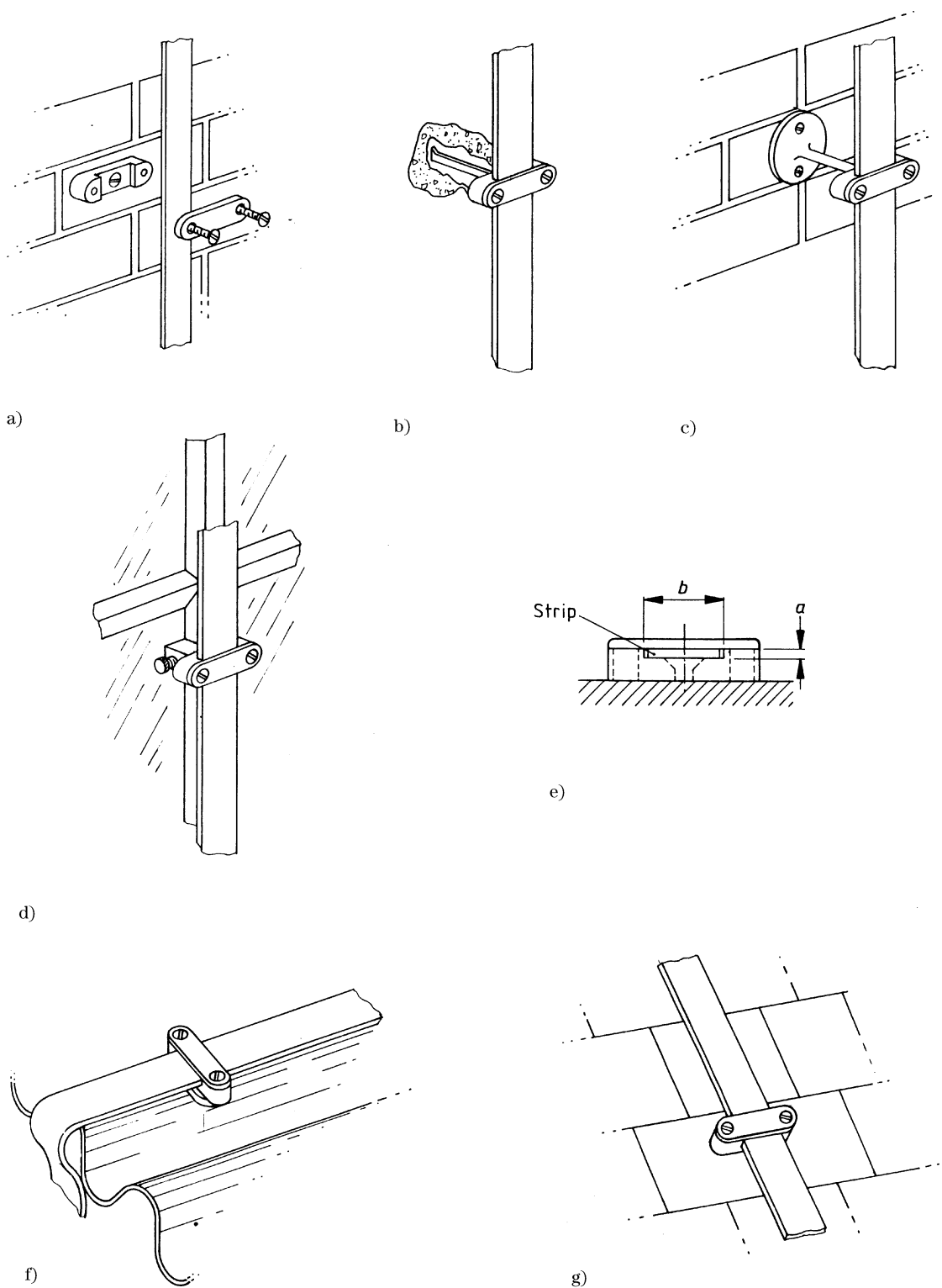
When non-metallic fixing materials are used, their possible degradation due to ultraviolet light, frost, etc., should be borne in mind and the advantages of easy installation and absence of electrogalvanic corrosion set alongside the possible need to replace the fixings more frequently.

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

Internal bonds may have approximately half the cross-sectional area of external bonds (see 16.10.2). Flexible bonds may be used and should then conform to the requirements of BS 6360.

NOTE 2 Stainless steel in contact with aluminium or aluminium alloys is likely to cause additional corrosion to the latter materials (see PD 6484). It is therefore important to take protective measures such as the use of inhibitors.

NOTE 3 Copper alloys are permissible as long as they have a minimum copper content of 75 % and are suitable for the environment and application where they will be used. (This note will be superseded with the publication of BS EN 50164-4, *Fasteners*.)



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 dimension 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

Table 2 *deleted by Amendment No. 1.*

8 Dimensions

Dimensions of component parts of lightning protection systems should be in accordance with BS EN 50164-2:2002. Dimensions of sheet metal used for roofing that forms part of an air termination network should be in accordance with Table 5.

Table 3 *deleted by Amendment No. 1.*

Table 4 *deleted by Amendment No. 1.*

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 roof forms 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)	

9 Basic considerations

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 special considerations, if any, should be taken into account (see Clauses 10 and 11).
- 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.

10 Need for protection

10.1 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 22.

For all other structures, the standard of protection recommended in the remainder of this code of practice 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 with 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 10.2, 10.3, 10.4, 10.5, 10.6, 10.7 and 10.8 where the various factors affecting the risk of being struck and the consequent 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:

- 1) the use to which the structure is put;
- 2) the nature of its construction;
- 3) the 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).

10.2 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 square kilometre per year. Values of N_g vary significantly; estimates of the average annual density calculated from observations over a period of many years are shown in Figure 1 and corresponding information for overseas countries can be obtained by reference to 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 (all in metres), 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 metres). This gives a collection area, A_c (in square metres), of:

$$A_c = LW + 2LH + 2WH + \pi H^2 \quad (1)$$

This is shown in Figure 29.

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

$$p = A_c \times N_g \times 10^{-6} \quad (2)$$

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 square kilometre per year

Thunderstorm days per year	Flashes per square kilometre 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 Conference Internationale des Grands Réseaux Electriques (CIGRE), *Lightning Parameters for Engineering Application* [1].

10.3 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 the UK Government Royal Commission on Environmental Pollution [2]. 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 allows an appreciation of the scale of risk associated with different activities. Generally, risks greater than 10^{-3} (1 in 1 000) per year are considered unacceptable. With risks of 10^{-4} (1 in 10 000) per year, it is 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.

10.4 Suggested acceptable risk

On the basis of 10.3, the acceptable risk figure has been taken as 10^{-5} per year, i.e. 1 in 100 000 per year.

10.5 Overall assessment of risk

Having established the value of p , the probable number of strikes to the structure per year (see 10.2), the next step is to apply the “weighting factors”, as given in Table 8, Table 9, Table 10, Table 11 and Table 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 $p_o = 10^{-5}$ per year.

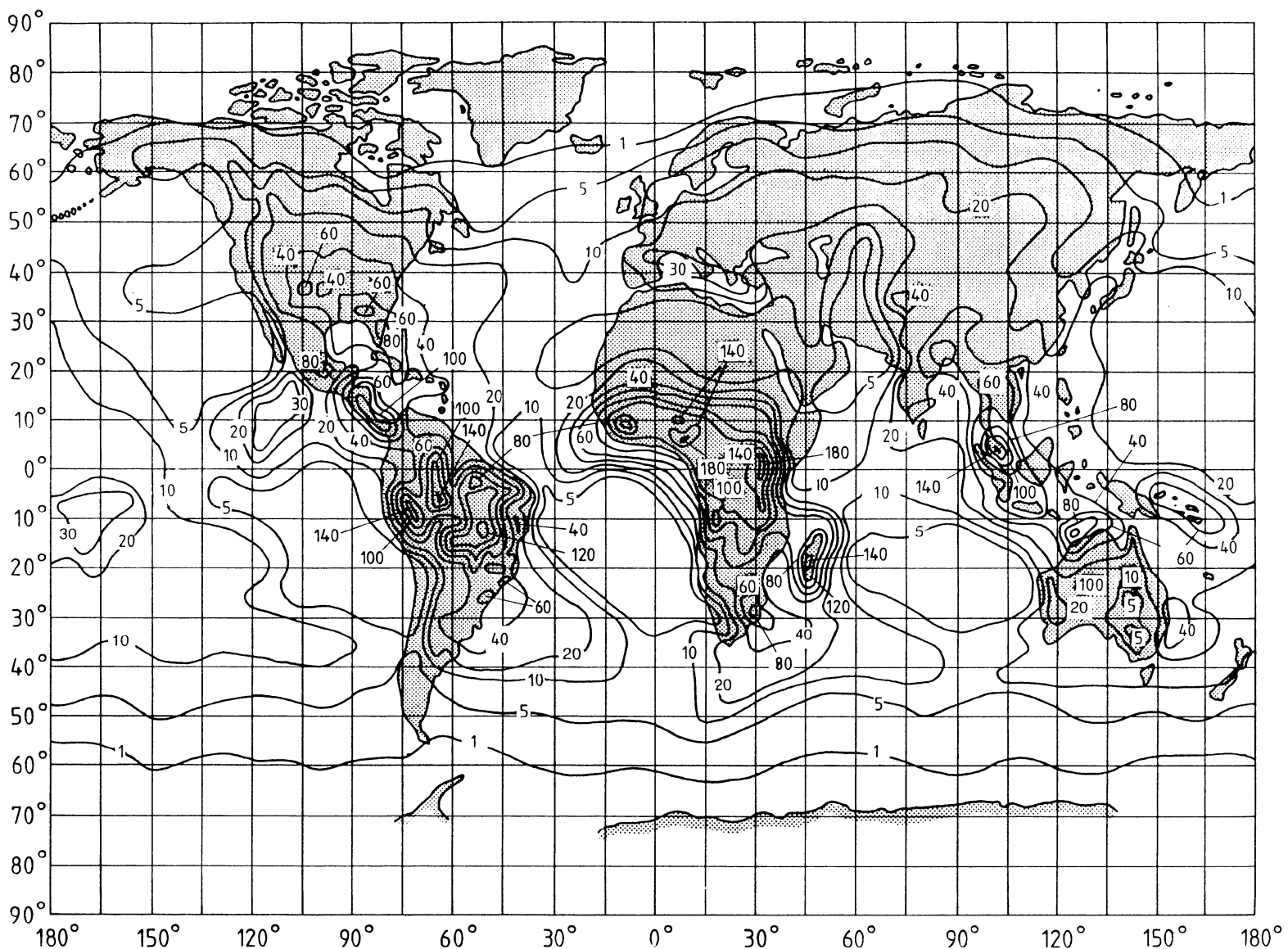
10.6 Weighting factors

In Table 8, Table 9, Table 10, Table 11 and Table 12, the weighting factor values are given under the headings *A* to *E* and denote the relative degree of importance or risk in each case.

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.



NOTE This map is based on information from the World Meteorological Organization records for 1955.

Figure 3 — Map showing thunderstorm days per year throughout the world

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 2 000	(5×10^{-4})	All accidents
1 in 8 000	(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 ^a Driving 50 miles by road ^a
1 in 2 000 000	(5×10^{-7})	Being struck by lightning ^a
NOTE The source of this table is Royal Commission on Environmental Pollution, Chairman Sir Brian Flowers, Sixth Report, <i>Nuclear Power and the Environment</i> (Cmd 6618) [2].		
^a These risks are conventionally expressed in this form rather than in terms of exposure for a year.		

Table 8 — Weighting factor *A* (use of structure)

Use to which structure is put	Value of factor <i>A</i>
Houses and other buildings of comparable size	0.3
Houses and other buildings of comparable size with an outside aerial	0.7
Factories, workshops and laboratories	1.0
Office blocks, hotels, blocks of flats and other residential buildings other than those 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 <i>B</i>
Steel framed encased or reinforced concrete with metal roof	0.1
Steel framed encased with any roof other than metal ^a	0.2
Reinforced concrete with any roof other than metal	0.4
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 Structures of exposed metal which are continuous down to ground level are excluded from the table as lightning protection beyond adequate earthing is not needed.	

Table 10 — Weighting factor *C* (contents or consequential effects)

Contents or consequential effects	Value of factor <i>C</i>
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents ^a	0.3
Industrial and agricultural buildings with specially susceptible contents ^a	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
^a Specially valuable plant or materials vulnerable to fire or the results of fire.	

Table 11 — Weighting factor *D* (degree of isolation)

Degree of isolation	Value of factor <i>D</i>
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 terrain)

Type of country	Value of factor <i>E</i>
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

10.7 Interpretation of overall risk factor

The risk factor method given in this code of practice 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), in the absence of other overriding considerations, protection does not appear necessary; if the result is greater than 10^{-5} , for example 10^{-4} (1 in 10 000), sound reasons would be needed to support a decision not to provide 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 and to accept the risk. Even if this decision has been made, it is recommended that the calculation is still performed in order to give 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 whether protection is necessary may have to exercise their 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.

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, protection is necessary 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 considerations (see Clause 22 and 11.3).

Results of calculations for different structures are given in Table 13 and a specific case is worked through in 10.8.

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

10.8 Sample calculation of overall risk factor

A hospital in the Thames Valley is 10 m high and covers an area of 70 m × 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 square kilometre per year.* The map in Figure 1 gives a value for N_g of 0.6 flashes per square kilometre per year.

b) *Collection area.* Using equation (1) in 10.2, the collection area, A_c in square metres, is given by:

$$\begin{aligned} A_c &= LW + 2LH + 2WH + \pi H^2 \\ &= (70 \times 12) + 2(70 \times 10) + 2(12 \times 10) + (\pi \times 100) \\ &= 840 + 1\,400 + 240 + 314 \\ &= 2\,794 \text{ m}^2. \end{aligned}$$

c) *Probability of being struck.* Using equation (2) in 10.2, the probable number of strikes per year, p , is given by:

$$\begin{aligned} p &= A_c \times N_g \times 10^{-6} \\ &= 2\,794 \times 0.6 \times 10^{-6} \\ &= 1.7 \times 10^{-3} \text{ approximately.} \end{aligned}$$

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

factor $A = 1.7$

factor $B = 1.0$

factor $C = 1.7$

factor $D = 2.0$

factor $E = 0.3$

The overall multiplying factor $= A \times B \times C \times D \times E = 1.7$

Therefore, the overall risk factor $= 1.7 \times 1.7 \times 10^{-3} = 2.9 \times 10^{-3}$

The conclusion is, therefore, that protection is necessary.

11 Zone of protection

11.1 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 is 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 is 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 20) to protect against strikes on the side of the building.

11.2 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. The magnitude of the protective angle cannot be precisely stated because it depends upon the severity of the stroke and the presence within the protective zone of conductive objects providing independent paths to earth. 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 is 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 6a) and Figure 6b)]. 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 6c). 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 15.2 and 15.3. For structures requiring a higher degree of protection, other protective angles are recommended (see Clause 22).

11.3 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 11.1 and 11.2. For this reason, a reduced zone of protection, and various other special measures should be taken as in Clause 22.

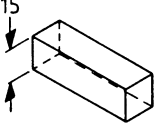
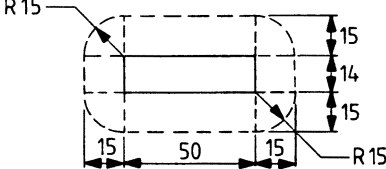
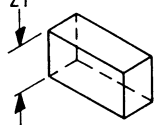
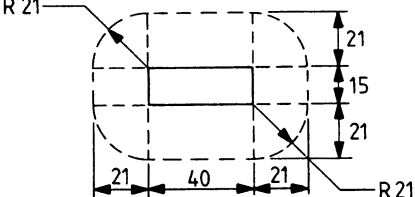
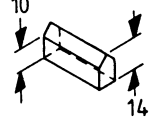
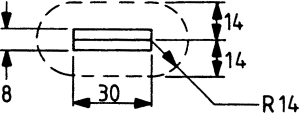
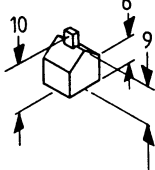
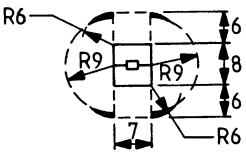
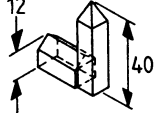
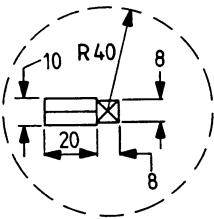
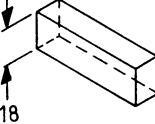
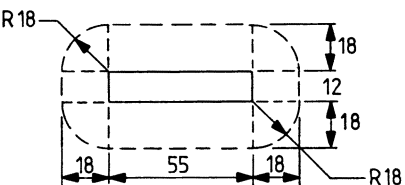
Table 13 — Examples of calculations for evaluating the need for protection

1	2	3	4	5	6	7	8	9	10	11	12	13
Reference 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)	Recommendations
		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	3 327	0.7	2.3×10^{-3}	1.2	0.4	0.3	0.4	0.3	0.02	4.6×10^{-5}	Protection recommended
b)	Office building, reinforced concrete construction, non-metallic roof, West Bromwich	4 296	0.8	3.4×10^{-3}	1.2	0.4	0.3	0.4	0.3	0.02	6.8×10^{-5}	Protection recommended
c)	School, brick-built, in Kingston-on-Thames	1 456	0.6	8.7×10^{-4}	1.7	1.0	1.7	0.4	0.3	0.3	2.6×10^{-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	5 027	0.7	3.5×10^{-3}	1.3	1.0	1.7	2.0	0.3	1.3	4.6×10^{-3}	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 10.3, 10.4, 10.5, 10.6, 10.7 and 10.8).

Table 13 — Examples of calculations for evaluating the need for protection (continued)

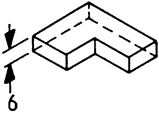
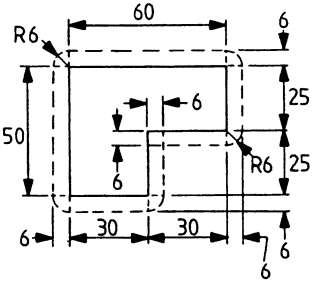
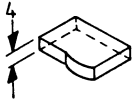
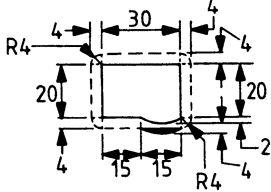
1	2	3	4	5	6	7	8	9	10	11	12	13
Reference in Figure 4	Description of structure	Risk of being struck, p			Weighting factors					Overall multiplying factor (product of columns 6 to 10)	Overall risk factor (product of columns 5 and 11)	Recommen- dations
		Collection area, A_c	Flash density, N_g	$p =$ $A_c \times N_g \times 10^{-6}$	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)			
e)	Village church in Lincolnshire	5 027	0.7	3.5×10^{-3}	1.3	1.0	1.7	2.0	0.3	1.3	4.6×10^{-3}	Protection required
f)	Theatre, reinforced concrete construction, metallic roof, Glasgow	4 090	0.1	4.1×10^{-4}	1.3	0.1	1.7	0.4	0.3	0.026	1.06×10^{-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	3 675	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	1 070	0.2	2.1×10^{-4}	0.3	1.0	0.6	0.4	0.3	0.02	4.2×10^{-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 10.3, 10.4, 10.5, 10.6, 10.7 and 10.8).												

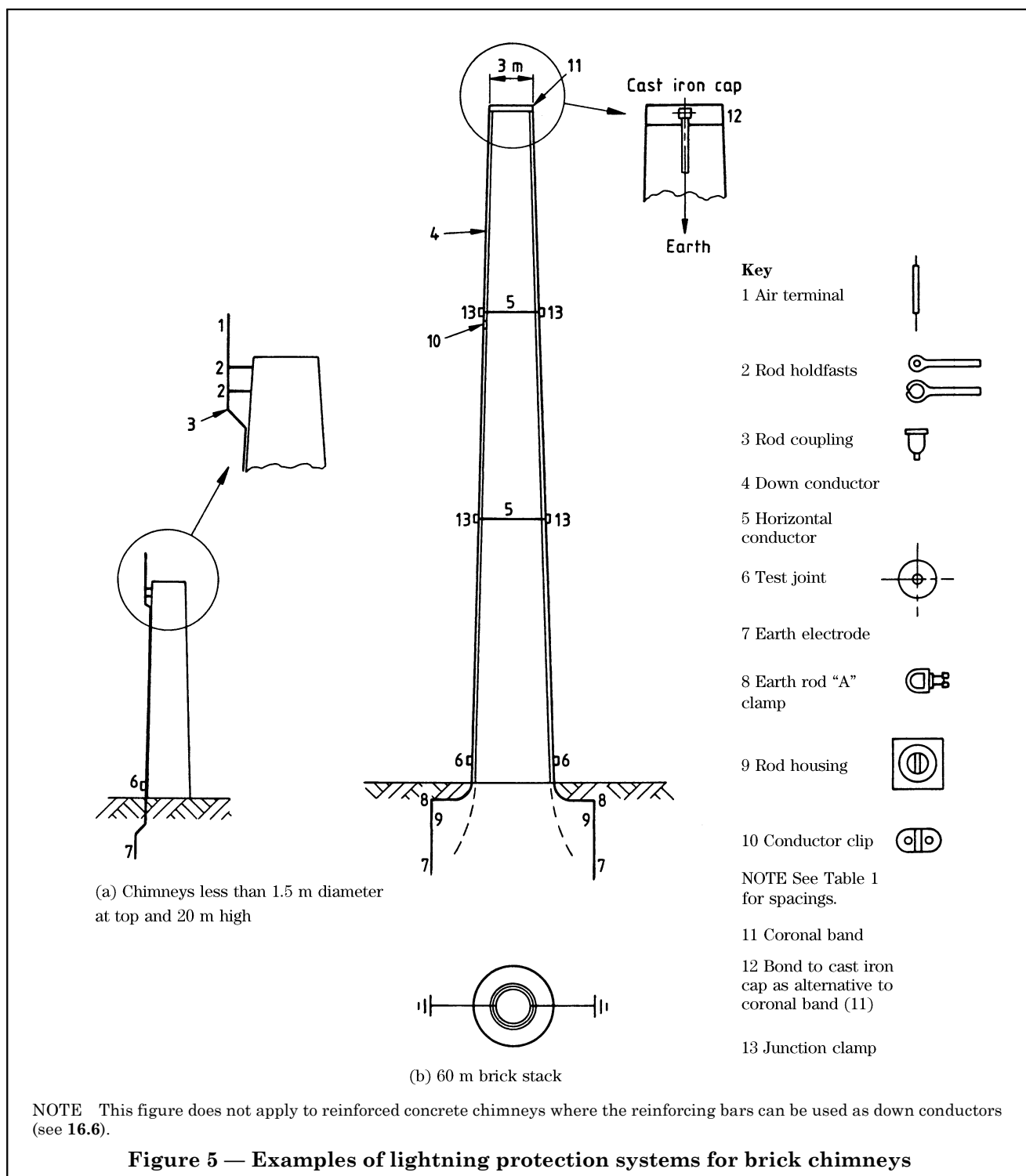
Reference	General arrangement	Collection area and method of calculation	
(a)			$A_c = 14 \times 50 + 2(15 \times 50)$ $+ 2(15 \times 14) + \pi \times 15^2$ $A_c = 3\,327 \text{ m}^2$
(b)			$A_c = 15 \times 40 + 2(21 \times 40)$ $+ 2(21 \times 15) + \pi \times 21^2$ $A_c = 4\,296 \text{ m}^2$
(c)			$A_c = \pi \times 14^2 + 2(14 \times 30)$ $A_c = 1\,456 \text{ m}^2$
(d)			$A_c = 7 \times 8 + 2(6 \times 7) + \pi \times 9^2$ $+ 10 \text{ (approx.) for areas in black}$ $A_c = 405 \text{ m}^2$
(e)			$A_c = \pi \times 40^2$ $A_c = 5\,027 \text{ m}^2$
(f)			$A_c = 12 \times 55 + 2(18 \times 55)$ $+ 2(18 \times 12) + \pi \times 18^2$ $A_c = 4\,090 \text{ m}^2$

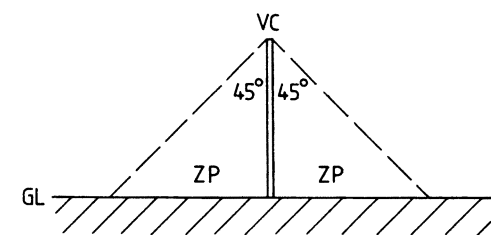
All dimensions are in metres

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

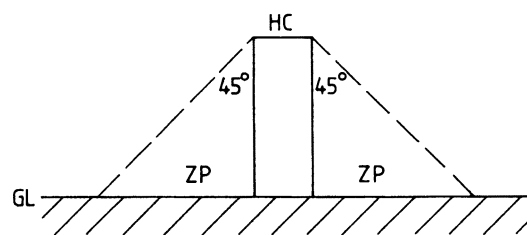
Figure 4 — Details of structures and collection areas

Reference	General arrangement	Collection area and method of calculation	
(g)			$A_c = 25 \times 60 + 25 \times 30 + 6 \times 60$ $+ 6 \times 50 + 6 \times 25 + 6 \times 25$ $+ 6 \times 30 + 6 \times 24 + \frac{5}{4} \times \pi \times 6^2$ $A_c = 3\,675 \text{ m}^2$
(h)			$A_c = 20 \times 30 + 2(4 \times 30)$ $+ 2(4 \times 20) + \pi \times 4^2$ $+ 20 \text{ (approx.) for area in black}$ $A_c = 1\,070 \text{ m}^2$
All dimensions are in metres			
NOTE This figure should be used in conjunction with Table 13.			
Figure 4 — Details of structures and collection areas <i>(continued)</i>			

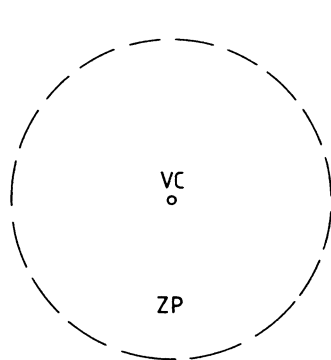




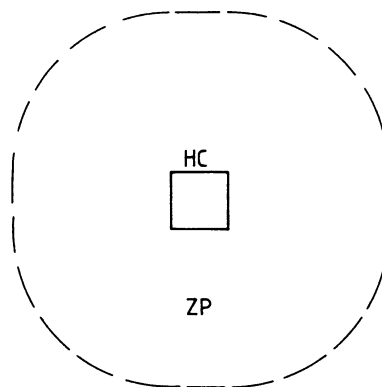
Plan view of zone of protection at ground level



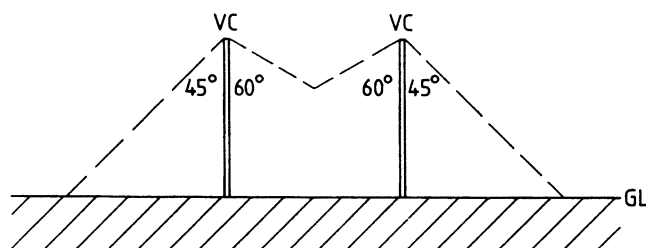
Plan view of zone of protection at ground level



(a) One vertical conductor

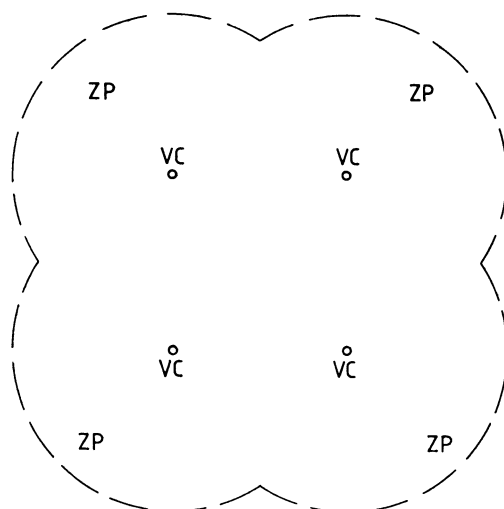


(b) Horizontal air termination



Plan view of zone of protection at ground level

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

12 General considerations for system design

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

In the case of structures having no suitable metallic members, it is important to consider the positioning of all the component parts of the 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 is 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 use of 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.

13 Consultation

13.1 General

Consultation should take place between the designer of the lightning protection system and the interested parties indicated in 13.2, 13.3, 13.4, 13.5 and 13.6 before and during all stages of design.

13.2 Architect

As far as practicable, the following should be determined:

- a) the routeing of all conductors;
- b) the general areas available for earth termination networks and reference earth electrodes;
- c) the material(s) for conductors;
- d) the 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) the material(s) to be used in the structure, especially for any continuous metal, e.g. stanchions or reinforcing;
- f) the use to which the structure is to be put;
- g) the details of all metallic service pipes, rainwater systems, rails and the like entering or leaving the structure or within the structure which may need to be bonded to the lightning protection system;
- h) the 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 need to be bonded to the lightning protection system.

13.3 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.

13.4 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) the 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.

13.5 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 26 and also BS 6330).

13.6 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;
- 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.

14 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 15, 16, 17 and 18 and typical designs of various fixings are shown in Figure 2, Figure 8 and Figure 9.

15 Air terminations

15.1 General

Basic guidelines on the design of air terminations are given in 15.2 and explanatory notes on the various forms that are commonly used follow in 15.3.

15.2 Basic rules

Air termination networks may consist of vertical or horizontal conductors or combinations of both (see, for example, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15).

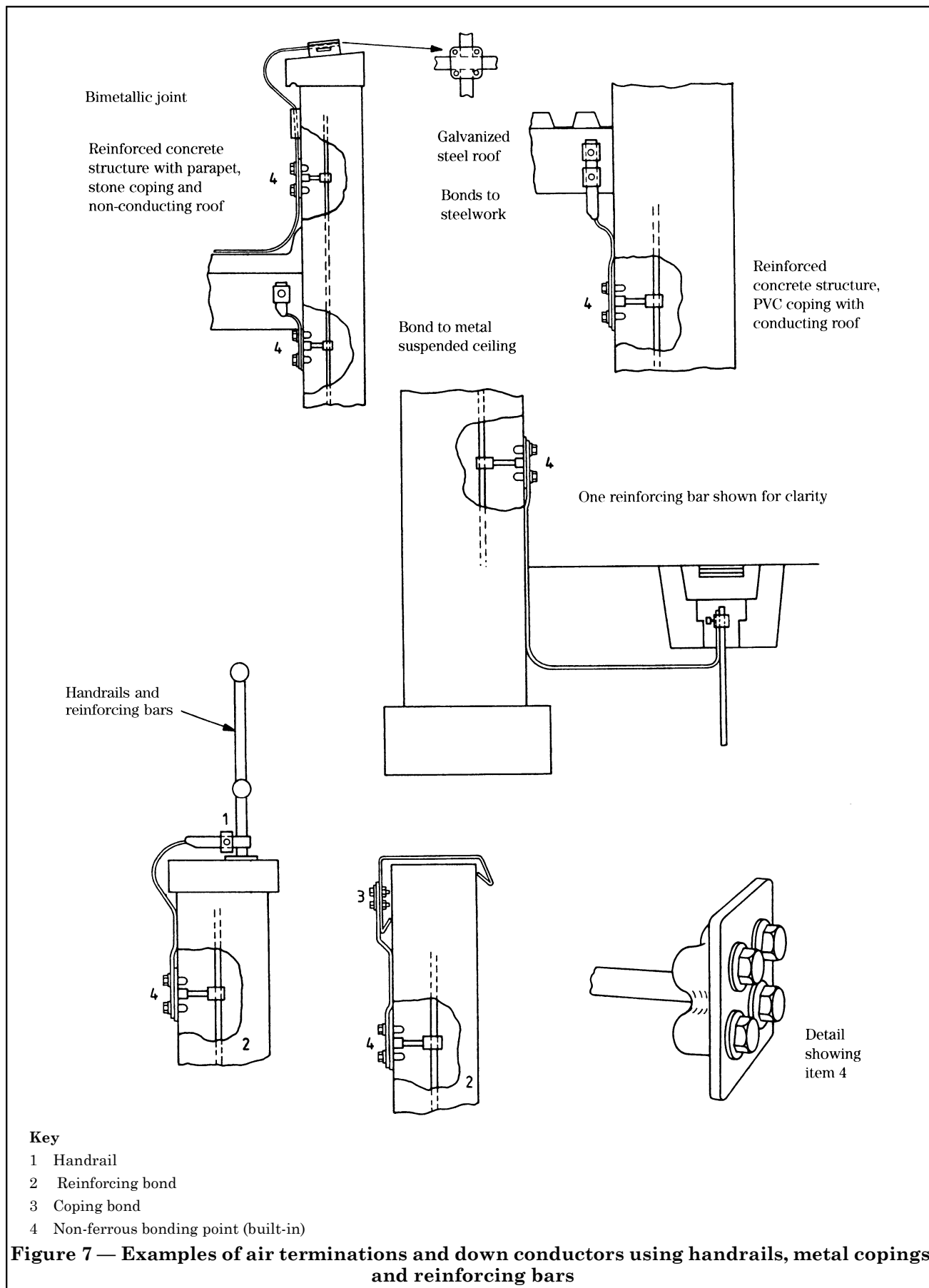
No part of the roof should be more than 5 m from the nearest horizontal conductor (but see notes 1 and 2 on Figure 11). For large flat roofs, this is achieved typically by use of an air termination network mesh of approximately 10 m × 20 m. On multiple ridge roofs, additional conductors are necessary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

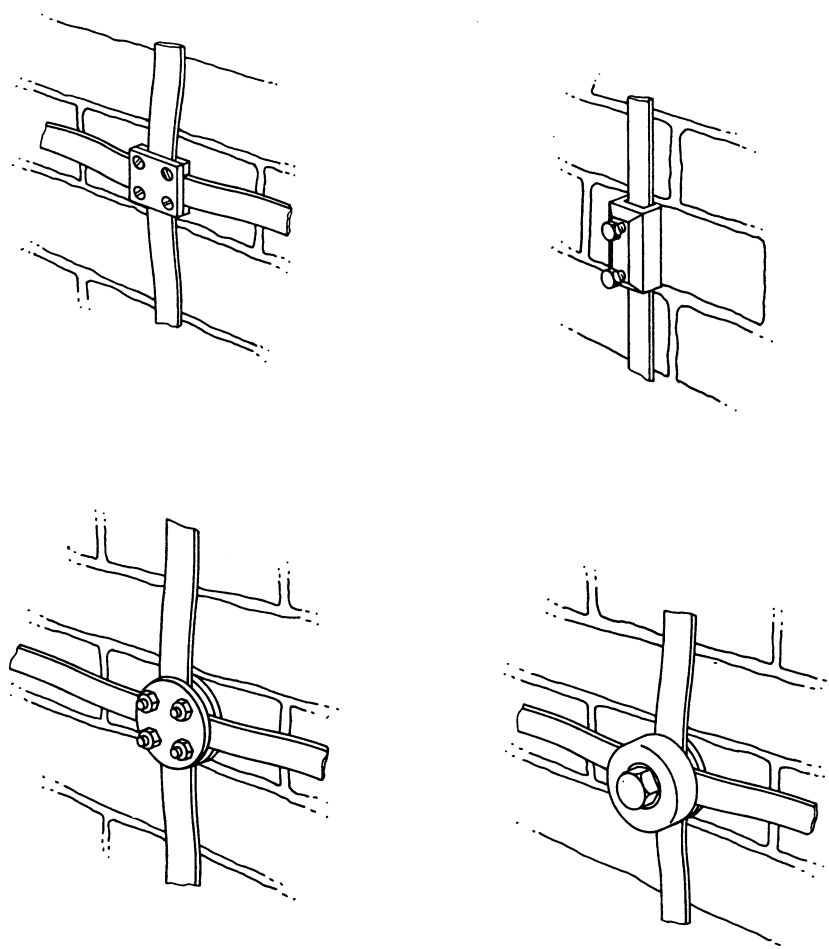
On a reinforced concrete structure, the air termination should be connected to the reinforcing bars in the number of positions needed for down conductors.

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, Figure 5 and Figure 7 and also refer to Figure 16).

Metallic coping, roof coverings, handrails (see Clause 12), window washing equipment and metallic screens around play areas should be considered for inclusion as part of the air termination network (see Figure 5, Figure 7 and Figure 17).

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.





NOTE A corrosion inhibitor should be used on all joints and bonds.

Figure 8 — Test joints

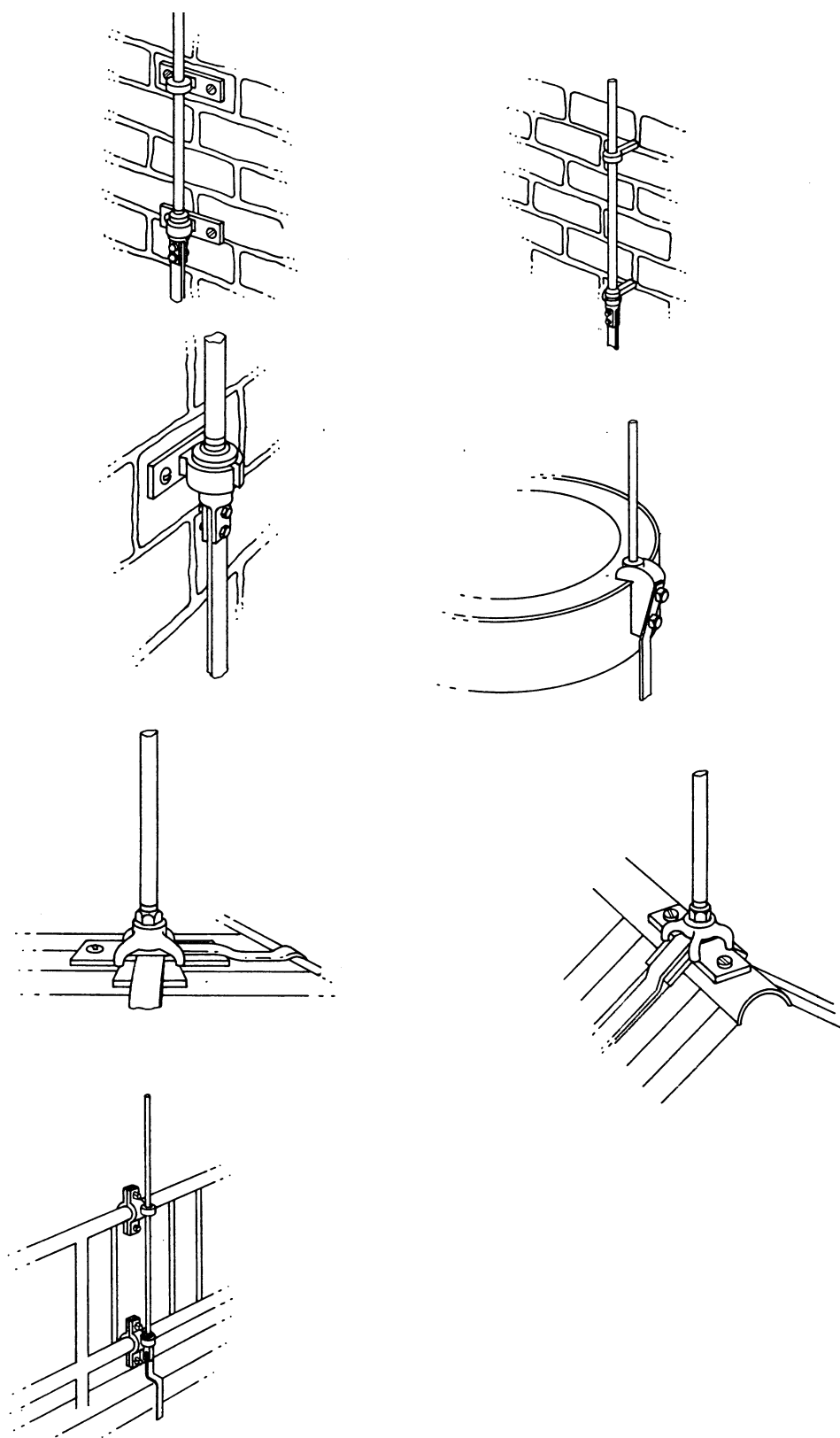


Figure 9 — Typical forms of vertical air terminations

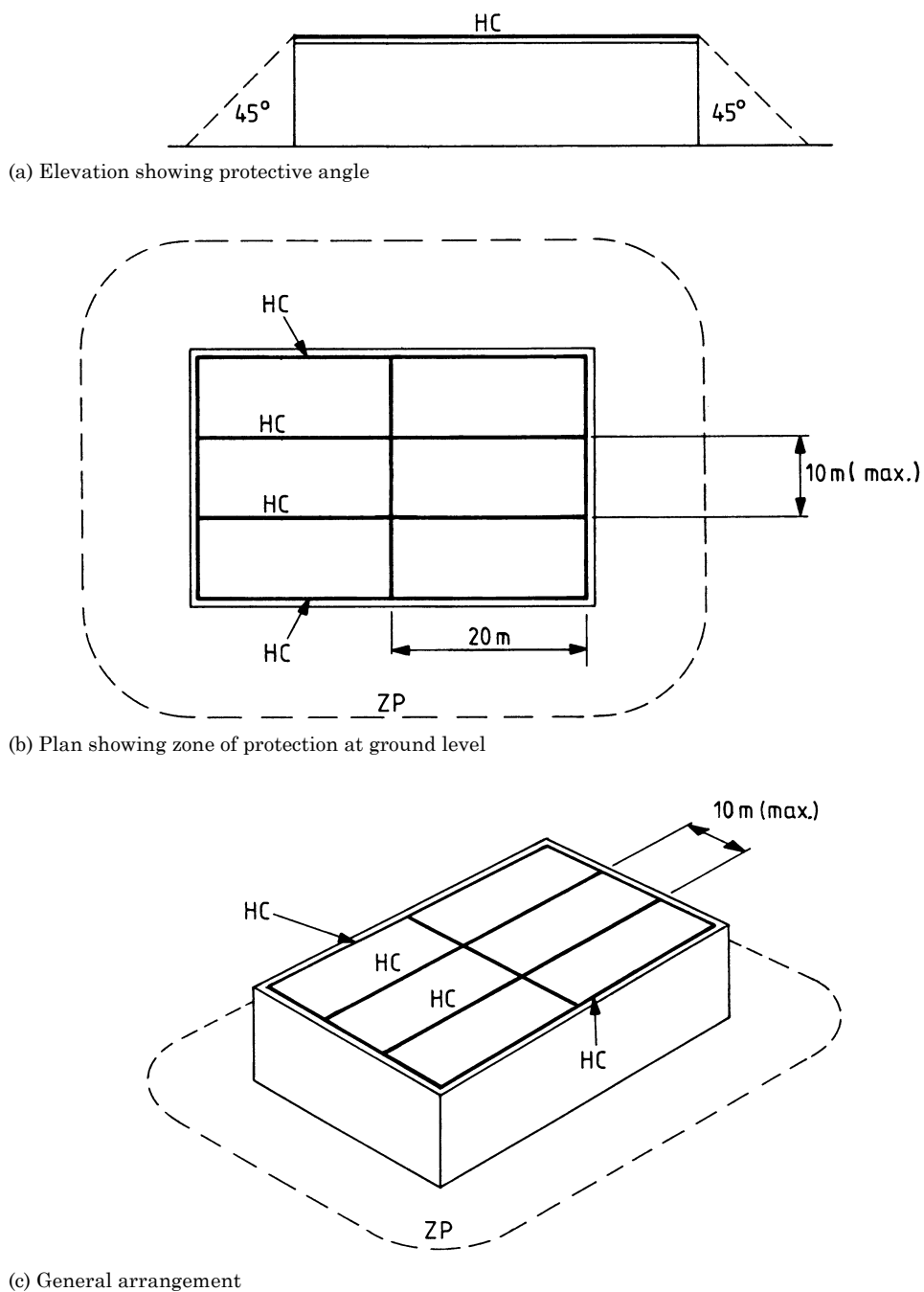
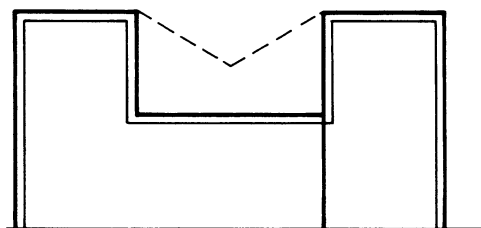
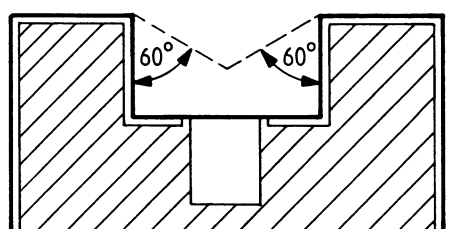


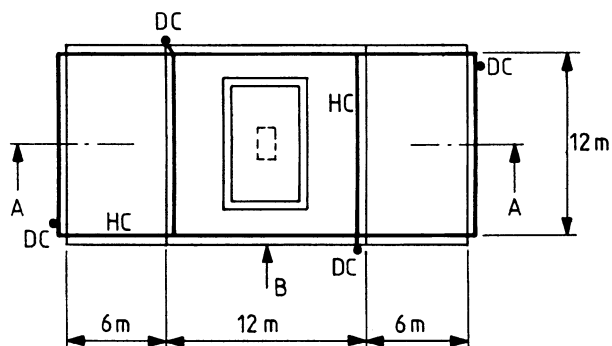
Figure 10 — Air terminations for a flat roof



View from B



Section A-A

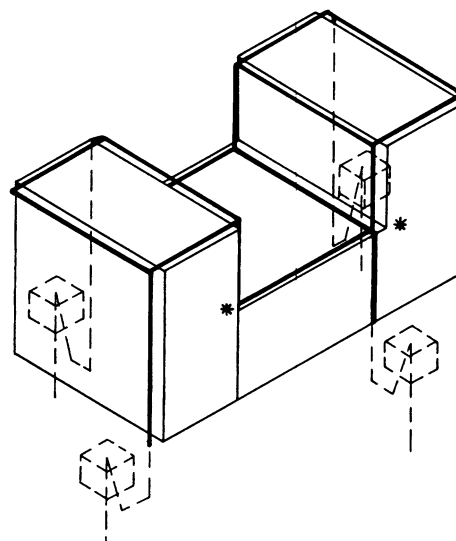


NOTE 1 An air termination along the outer perimeter of the roof is required and no part should be more than 5 m from the nearest horizontal conductor, except that an additional 1 m may be allowed for each metre by which the part to be protected is below the nearest conductor.

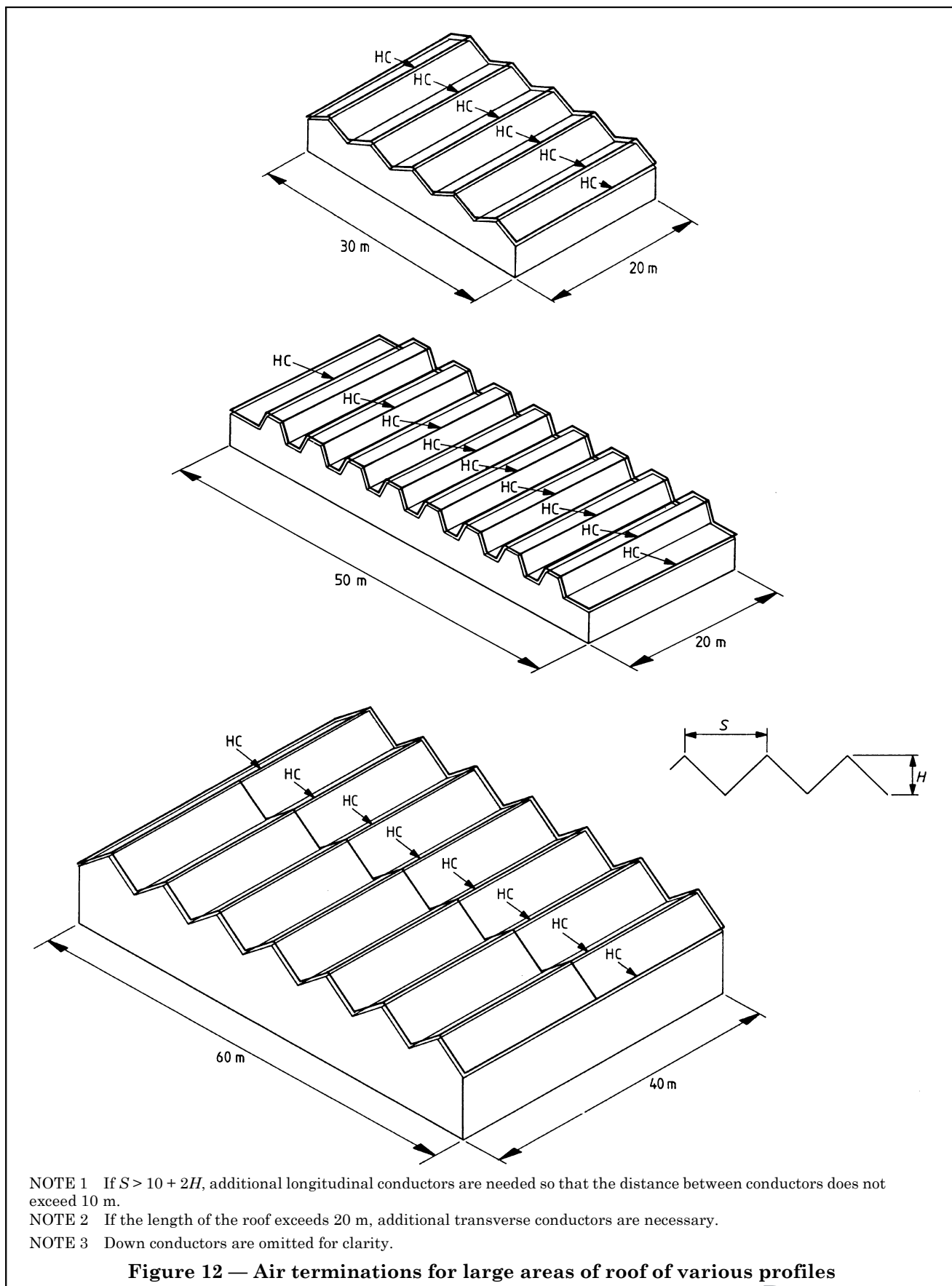
Perimeter = $24 + 24 + 12 + 12 = 72$ m
 Number of down conductors required
 (see 16.3) = $72/20 = 4$.

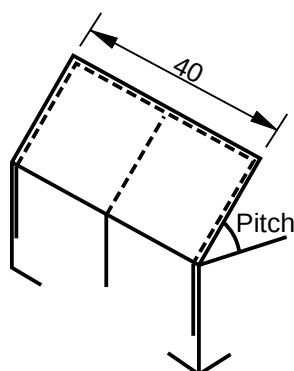
NOTE 2 Horizontal conductors are not necessary on the parapets of the light well; a zone of protection of 60° is provided by the two adjacent horizontal conductors for structures less than 20 m high. This principle does not apply to taller structures.

Figure 11 — Air terminations for flat roofs at different levels

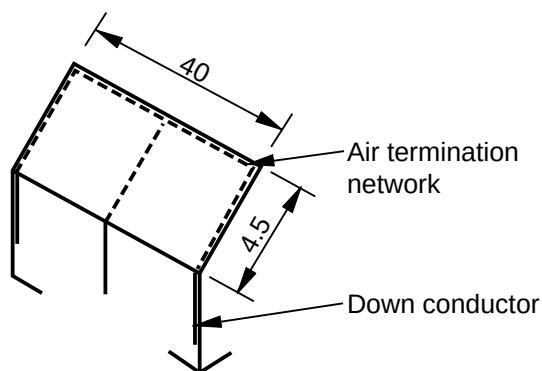


* Join down conductors and horizontal conductors on lower parapet.

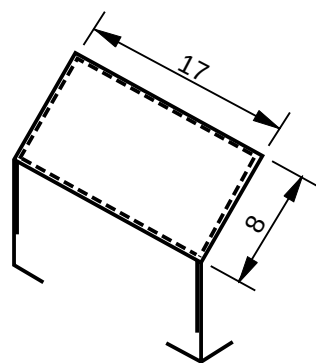




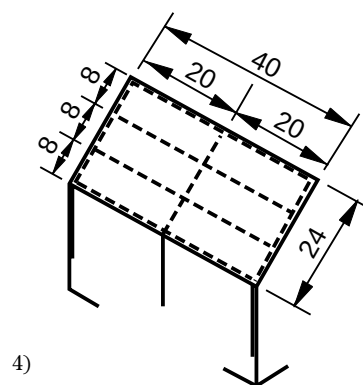
1) For roofs of pitch 45° and above, only a ridge conductor is required



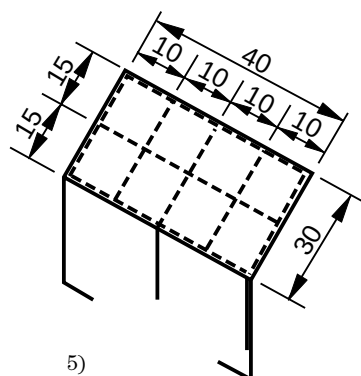
2) For roofs where the eaves are within 5 m of the ridge, only a ridge conductor is required



3)



4)



5)

Dimensions are in millimetres

For pitched roofs where cases 1) and 2) do not apply, ridge and eaves conductors are to be installed, with any intermediate transverse and longitudinal conductors being added to form a maximum $20\text{ m} \times 10\text{ m}$ mesh (see 15.2) as detailed in 3), 4) and 5).

NOTE 1 If there are items of metalwork which are electrically continuous and are in accordance with Table 5, they may be utilized as part of the air termination network (e.g. metal guttering in place of the eaves conductor).

NOTE 2 These examples of air terminations for various sizes of roof, but the criteria to be met when designing the roof network are:

- no part of the roof should be greater than 5 m from the nearest conductor;
- a $20\text{ m} \times 10\text{ m}$ mesh should be maintained.

a) Air terminations and down conductors

Figure 13 — Air terminations and concealed conductors for buildings less than 20 m high with sloping roofs