

Australian/New Zealand Standard™

Lightning protection



AS/NZS 1768:2007

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Australian/New Zealand Standard™

Lightning protection

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-024, Protection against Lightning, to supersede AS/NZS 1768(Int):2003, *Lightning protection*.

This Standard is intended to provide authoritative guidance on the principles and practices of lightning protection for a wide range of structures and systems. It is not intended for mandatory application but, if called up in a contractual situation, compliance with this Standard requires compliance with all relevant clauses of the Standard such that the level of protection will be sufficient to achieve a tolerable level of risk as determined by the risk calculation.

In general, it is not economically possible to provide total protection against all the possible damaging effects of lightning, but the recommendations in this Standard will reduce the probability of damage to a calculated acceptable level, and will minimize any lightning damage that does occur. Guidance is given on methods of enhancing the level of protection against lightning damage, if this is required in a particular situation.

Where a new structure is to be erected, the matter of lightning protection should be considered in the planning stage, as the necessary measures can often be affected in the architectural features without detracting from the appearance of the building. In addition to the aesthetic considerations, it is usually less expensive to install a lightning protection system during construction than afterwards.

The decision to provide lightning protection may be taken without carrying out a risk assessment or regardless of the outcome of any risk assessment, for example, where there is a desire that there be no avoidable risk. Any decision not to provide lightning protection should only be made after considering the advice provided in this Standard. Where doubt exists as to the need for lightning protection, further advice should be sought from a lightning protection designer or installer.

Unless it has been specified that lightning protection must be provided, the first decision to make is whether the lightning protection is needed. Section 2 provides guidance to assist in this decision. Section 3 provides advice on the protection of persons from lightning, mainly relating to the behaviour of persons when not inside substantial buildings. Once a decision is made that lightning protection is necessary, Section 4 provides details on interception lightning protection for the building or structure. This includes information on the size, material, and form of conductors, the positioning of air terminals and downconductors, and the requirements for earth terminations. Persons and equipment within buildings can be at risk from the indirect effects of lightning and Section 5 gives recommendations for the protection of persons and equipment within buildings from the effects of lightning.

Section 6 describes methods of lightning protection of various items not covered in earlier sections, such as communications antennas, chimneys, boats, fences, and trees. A clause is included on methods for protecting domestic dwellings and assorted structures in public places, where a complete protection system may not be justified, but some protection is considered desirable.

Section 7 sets out recommendations for the protection of structures with explosive or highly-flammable contents. Section 8 gives advice on precautions to be taken during installation, inspecting, testing, and maintaining lightning protection systems.

A number of appendices are included that provide additional information and advice. The appendices form an integral part of this Standard unless specifically stated otherwise. i.e. appendices identified as 'informative' only provide supportive or background information and are therefore not an integral part of this Standard.

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STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard Lightning protection

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out guidelines for the protection of persons and property from hazards arising from exposure to lightning. The recommendations specifically cover the following applications:

- (a) The protection of persons, both outdoors, where they may be at risk from the direct effects of a lightning strike, and indoors, where they may be at risk indirectly as a consequence of lightning currents being conducted into the building.
- (b) The protection of a variety of buildings or structures, including those with explosive or highly-flammable contents, and mines.
- (c) The protection of sensitive electronic equipment (e.g. facsimile machines, modems, computers) from overvoltages resulting from a lightning strike to the building or its associated services.

The nature of lightning and the principles of lightning protection are discussed and guidance is given to assist in a determination of whether protective measures should be taken.

This Standard is applicable to conventional lightning protection systems (LPSs) that comprise air terminals, downconductors, earth termination networks and surge protective devices (SPDs). Nothing contained within this Standard either endorses or implies the endorsement of non-conventional LPSs that comprise air terminals that claim enhanced performance or downconductors that claim enhanced magnetic screening over conventional systems.

The performance of such systems is outside the scope of this Standard. Irrespective of claimed performance, air terminals shall be placed in accordance with Section 4 to comply with this Standard.

1.2 APPLICATION

This Standard does not override any statutory requirements but may be used in conjunction with such requirements.

Compliance with the recommendations of this Standard will not necessarily prevent damage or personal injury due to lightning but will reduce the probability of such damage or injury occurring.

1.3 INTRODUCTION

Thunderstorms are natural phenomena and there are no proven devices and methods capable of preventing lightning flashes. Direct and nearby cloud-to-ground lightning discharges can be hazardous to persons, structures, installations and many other things in or on them. Consideration should always be given to the application of lightning protection measures.

Realization that it is possible to provide effective protection against lightning began with Franklin and for over a hundred years national and international manuals and standards have been developed to provide guidance on the principles and practice of lightning protection. Until about ten years ago, risk assessment was used to determine if there was a need to provide lightning protection. However, the modern approach is that of risk management, which integrates the determination of the need for protection with the selection of adequate protection measures to reduce the risk to a tolerable level. This selection takes into account both the efficiency of the measures and the cost of their provision. In the risk management approach, the lightning threats that create risk are identified, the frequencies of all risk events are estimated, the consequences of the risk events are determined, and if these are above a tolerable level of risk, protection measures are applied to reduce the risk (R) to below the tolerable level (R_a). This involves a choice from a range of protection level efficiencies for protection against direct (d) strikes to the structure and decisions about the extent of other measures for protecting low-voltage and electronic equipment against indirect (i) lightning stresses incident from nearby strikes. In summary—

$$R = \sum R_x = \sum R_d + \sum R_i$$

$$R_x = N_x P_x \delta_x$$

$$P_x = k_x p_x$$

$$R \leq R_a$$

where N_x is the frequency of dangerous events, P_x is the probability of damage or injury, δ_x is the relative amount of damage or injury with any consequential effects, and k_x is a reduction factor associated with the protection measure adopted and which equals 1 in the absence of protection measures when $P_x = p_x$.

The lightning protection measures include an LPS for the structure and its occupants, protection against the lightning electromagnetic pulse (LEMP) caused by direct and nearby strikes, and transient protection (TP) of incoming services. The LPS for the structure comprises an air terminal network to intercept the lightning strike, a downconductor system to conduct the discharge current safely to earth and an earth termination network to dissipate the current into the earth. The LEMP protection includes a number of measures to protect sensitive electronic equipment such as the use of a mesh of downconductors to minimize the internal magnetic field, the selection of lightning protection zones, equipotential bonding and earthing, and the installation of SPDs. The TP for incoming services includes the use of isolation devices, the shielding of cables and the installation and coordination of SPDs.

1.4 REFERENCED DOCUMENTS

The documents referred to in this Standard are listed in Appendix G.

1.5 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.5.1 Air terminal

A vertical or horizontal conductor of an LPS, positioned so as to intercept a lightning discharge, which establishes a zone of protection.

1.5.2 Air terminal network

A network of air terminals and interconnecting conductors, which forms the part of an LPS that is intended to intercept lightning discharges.

1.5.3 Base conductors

Conductors placed around the perimeter of a structure near ground level interconnected to a number of earth terminations to distribute the lightning currents amongst them.

1.5.4 Bond (bonding conductor)

A conductor intended to provide electrical connection between the LPS and other metalwork and between various metal parts of a structure or between earthing systems.

1.5.5 Damage (δ)

Mean relative amount of loss consequent to a specified type of damage due to a lightning event, when damage factors are not taken into account.

1.5.6 Direct lightning flash

A lightning discharge, composed of one or more strokes, that strikes the structure or its LPS directly.

1.5.7 Downconductor

A conductor that connects an air terminal network with an earth termination.

1.5.8 Earth impedance (Z)

The electrical impedance of an earthing electrode or structure to earth, derived from the earth potential rise divided by the impulse current to earth causing that rise. It is a relatively complex function and depends on—

- (a) the resistance component (R) as measured by an earth tester;
- (b) the reactance component (X), depending on the circuit path to the general body of earth; and
- (c) a modifying (reducing) time-related component depending on soil ionization caused by high current and fast rise times.

1.5.9 Earth potential rise (EPR)

The increase in electrical potential of an earthing electrode, body of soil or earthed structure, with respect to distant earth, caused by the discharge of current to the general body of earth through the impedance of that earthing electrode or structure.

1.5.10 Earthing boss (terminal lug)

A metal boss specially designed and welded to process plant, storage tanks, or steelwork to which earthing conductors are attached by means of removable studs or nuts and bolts.

1.5.11 Earthing conductor

The conductor by which the final connection to an earthing electrode is made.

1.5.12 Earthing electrodes (earth rods or ground rods)

Those portions of the earth termination that make direct low resistance electrical contact with the earth.

1.5.13 Earthing resistance

The resistance of the LPS to the general mass of earth, as measured from a test point.

1.5.14 Earth termination (earth termination network)

That part of an LPS intended to discharge lightning currents into the general mass of the earth. All parts below the lowest test link in a downconductor are included.

1.5.15 Electricity supply service earthing electrode

An earthing electrode installed for the purposes of providing the connection of the electrical installation earthing system to the general mass of earth.

1.5.16 Explosive gas atmosphere

A mixture of flammable gas, vapour or mist with air in atmospheric conditions in which, after ignition, combustion spreads throughout the unconsumed mixture that is between the upper and lower explosive limits.

NOTE: The term refers exclusively to the danger arising from ignition. Where danger from other causes such as toxicity, asphyxiation, and radioactivity may arise this is specifically mentioned.

1.5.17 Finial

A term not used in this Standard owing to its confusion with architectural application but occasionally used elsewhere in other Standards as referring to short vertical air terminals.

1.5.18 Frequency of lightning flashes direct to a service (N_c)

Expected annual number of lightning flashes directly striking an incoming service.

1.5.19 Frequency of lightning flashes direct to a structure (N_d)

Expected annual number of lightning flashes directly striking the structure.

1.5.20 Frequency of lightning flashes to ground near a service (N_l)

Expected annual number of lightning flashes striking the ground surface near an incoming service.

1.5.21 Frequency of lightning flashes to ground near a structure (N_m)

Expected annual number of lightning flashes striking the ground surface near the structure.

1.5.22 Hazardous area

An area where an explosive atmosphere is, or may be expected to be present continuously, intermittently or due to an abnormal or transient condition (see AS/NZS 2430 series).

1.5.23 Incoming service

A service entering a structure (e.g. electricity supply service lines, telecommunications service lines or other services).

1.5.24 Indirect lightning flash

A lightning discharge, composed of one or more strokes, that strikes the incoming services or the ground near the structure or near the incoming services.

1.5.25 Internal installation

An installation or the part of an incoming service that is located inside the structure.

1.5.26 Joint

A mechanical and electrical junction between two or more sections of an LPS.

1.5.27 Lightning flash (lightning discharge)

An electrical discharge in the atmosphere involving one or more electrically charged regions, most commonly in a cumulonimbus cloud, taking either of the following forms:

- (a) *Ground flash (earth discharge)* A lightning flash in which at least one lightning discharge channel reaches the ground.
- (b) *Cloud flash* A lightning flash in which the lightning discharge channels do not reach the earth.

1.5.28 Lightning flash density (N_g)

The number of lightning flashes of the specified type occurring on or over unit area in unit time. This is commonly expressed as per square kilometre per year ($\text{km}^{-2} \text{ year}^{-1}$). The ground flash density is the number of ground flashes per unit area and per unit time, preferably expressed as a long-term (>10 years) average value.

1.5.29 LPS (LPS Type I to IV)

Complete system used to reduce the danger of physical damages and of injuries due to direct flashes to the structure. It consists of both external and internal LPSs and is defined as a set of construction rules, based on corresponding protection level.

1.5.30 Lightning protection zone (LPZ)

With respect to the lightning threat, a zone may be defined, inside of which is sensitive equipment. Extra protection is applied at the zone boundary to minimize the risk of damage to equipment inside the zone.

1.5.31 Lightning strike

A term used to describe the lightning flash when the attention is centred on the effects of the flash at the lightning strike attachment point, rather than on the complete lightning discharge.

1.5.32 Lightning strike attachment point

The point on the ground or on a structure where the lower end of the lightning discharge channel connects with the ground or structure.

1.5.33 Lightning stroke

A term used to describe an individual current impulse in a complete ground flash.

1.5.34 Loss

Due to lightning strike, the loss can be of human life, loss of service to the public or economic loss.

1.5.35 Multiple earthed neutral (MEN) system

A system of earthing in which the parts of an electrical installation are connected to the general mass of earth and in addition are connected within the electrical installation to the neutral conductor of the supply system.

1.5.36 Partial probability of damage (p)

Probability of a lightning flash causing a specified type of damage to the structure, depending on one characteristic of the structure or of an incoming service.

1.5.37 Probability of damage (P)

Probability of a lightning flash causing a specified type of damage to the structure. It may be composed of one or more simple probabilities of damage.

1.5.38 Protection level (I to IV)

Four levels of lightning protection. For each protection level, a set of maximum (sizing criteria) and minimum (interception criteria) lightning current parameters is fixed, together with the corresponding rolling sphere radius.

1.5.39 Protection measures

Protection measures taken to reduce the probability of damage. These may include an LPS on the building, isolation transformers and/or surge protection on incoming services (primary protection) and internal equipment (secondary protection).

1.5.40 Resistibility

Ability of equipment to withstand an overvoltage or an overcurrent without damage.

1.5.41 Risk (R)

Probable average annual loss (humans and goods) in a structure due to lightning flashes.

1.5.42 Risk assessment

The process of designing an LPS to achieve a probable frequency of damage and injury. It is based on determining the likely number of lightning discharges and also estimates the probability and consequences. A range of protection measures can be selected to reduce the risk to less than a target value. This process is also known as risk management.

1.5.43 Risk component

Partial risk assessed according to the source of damage and the type of damage.

1.5.44 Side-flash

A discharge occurring between nearby objects or from such objects to the LPS or to earth.

1.5.45 Special damage factors (k_n)

Factors affecting the value of the damage δ , with respect to the existing peculiar conditions in the structure, that may decrease or increase the loss.

1.5.46 Striking distance (d_s)

The distance between the tip of the downward leader and the eventual lightning strike attachment point at the moment of initiation of an upward intercepting streamer.

1.5.47 Structure or object

Any building or construction, process plant, storage tank, tree, or similar, on or in the ground.

1.5.48 Surge protective device (SPD)

A device that is intended to mitigate surge overvoltages and overcurrents.

1.5.49 Test link

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

1.5.50 Thunderday

A calendar day during which thunder is heard at a given location. Thunderstorm occurrence at a particular location is usually expressed in terms of the number of calendar days in a year when thunder was heard at the location, averaged over several years.

1.5.51 Tolerable risk (R_a)

Maximum value of the risk that can be tolerated in the structure to be protected. Also referred to as acceptable risk, being the maximum value of risk acceptable based on community expectations.

1.5.52 Zone of protection

The portion of space within which an object or structure is considered to be protected from a direct strike by an LPS.

SECTION 2 ASSESSMENT AND MANAGEMENT OF RISK DUE TO LIGHTNING — ANALYSIS OF NEED FOR PROTECTION

2.1 INTRODUCTION

Cloud-to-ground lightning discharges can be hazardous to structures, people and installations or equipment in, on or connected to the structure. Lightning can cause damage to all or part of a structure or to the contents of a structure, especially to electrical and electronic systems. Consequential effects of lightning damage may extend to the surroundings of a structure.

To reduce lightning damage and its consequential effects, lightning protection measures may be required. The need for protection and the level of protection applied should be considered in terms of the assessment of risk due to lightning, and management of that risk to an acceptable level.

The approach outlined in this section is based on the principles of the management of risk due to lightning outlined in initial work by IEC Committee TC 81 on this subject. The approach has been simplified by reducing the number of variables and options requiring selection to a minimum (based on assumptions for general conditions in Australia and New Zealand) and providing a Microsoft® Excel calculation tool as an integral part of this Standard.

The Microsoft® Excel calculation tool provides only an estimate of the lightning risk. The risk assessment calculator is a simplified tool for the more common structure types. For specialized structures (e.g. telecommunication exchanges, substations), a detailed lightning risk assessment may be undertaken. This may involve the application of industry specific Standards. Where other information exists, such as the damage/hazard history of existing similar structures in the nearby area, then this should be taken into account when deciding whether or not to install lightning protection and the appropriate level of lightning protection required. A decision to provide lightning protection may be taken regardless of the outcome of any risk assessment, for example, where there is a desire that there be **no avoidable risk**. In such cases, the required protection level for the structure (Level I, II, III or IV – as defined in Section 4) should be specified. It may also be important to specify other protection measures such as SPDs on incoming conductive electrical service lines and internal equipment. Risk assessment for protection of specific conductive electrical services may also be undertaken in isolation based on specific Standards and performance criteria. For telecommunication overvoltages, AS 4262.1 deals with protection of persons, AS 4262.2 deals with protection of equipment and the ITU-T K series of recommendations provide requirements for protecting telecommunication networks.

Before any decision is made not to install lightning protection to a structure, consideration should be given to the factors outlined in other sections of this Standard.

2.2 SCOPE OF SECTION

This Section is applicable to the management of risk caused by lightning discharges to earth.

The object of this Section is to give a procedure for evaluation of the risk to a structure, people and installations or equipment in, on or connected to the structure. This evaluation considers mechanical damage of the structure and contents, damage and failure of equipment, potential differences causing deaths of people and livestock from step and touch voltages, and fire damage that may result from the lightning discharge.

The procedure involves the comparison of the evaluated risk to the tolerable or acceptable limit of the risk and allows for the selection of appropriate protective measures to reduce the risk to below the tolerable limit.

This Standard does not consider the risk of personal injury when using telecommunication equipment during a lightning storm.

2.3 CONCEPT OF RISK

2.3.1 General considerations

In this Standard, risk R is defined as the probable annual loss due to lightning. Expressed as a number, it represents the probability of loss occurring over the period of a year. Thus a risk of 10^{-3} represents a chance of 1 in 1000 of a loss occurring during a year.

To increase understanding of the risk concept, some risks associated with everyday living are provided in Table 2.1. Many human activities imply a judgement that the benefits outweigh the related risks. Table 2.1 gives a scale of risk of loss of human life associated with different activities.

TABLE 2.1
COMPARATIVE PROBABILITY OF DEATH FOR AN INDIVIDUAL PER YEAR
OF EXPOSURE (ORDER OF MAGNITUDE ONLY)*

Risk		Activity
Chance of occurrence	Probability per year	
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 (80 km) by road [†]
1 in 2 000 000	5×10^{-7}	Being struck by lightning

* The source of this table is BS 6651:1999.

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

2.3.2 Types of risk due to lightning

The types of risk due to lightning for a particular structure or facility may include one or more of the following:

- (a) R_1 —risk of loss of human life.
- (b) R_2 —risk of loss of service to the public.

NOTE: Only applicable to structures involved in the provision of public service utilities (e.g. water, electricity, gas, telecommunications, rail).

- (c) R_3 —risk of loss of cultural heritage.
- (d) R_4 —risk of loss of economic value.

2.3.3 Tolerable values of risk

In order to manage risk, a judgement must be made of what is an acceptable or tolerable upper limit for the risk.

In relation to human fatalities, various societal risk guidelines or criteria have been proposed. Generally for a single human fatality, risks of greater than 10^{-3} per year (i.e. chance of 1 in 1000 of occurrence in a year) are considered unacceptable. Public money would normally be spent to try to eliminate (or reduce to a level as low as reasonably practical) the causes of risks greater than 10^{-4} per year (i.e. chance of 1 in 10 000 of occurrence). Risks less than 10^{-5} per year (i.e. chance of 1 in 100 000 of occurrence) are generally considered tolerable although public money may still be spent on an education campaign to reduce those risks regarded as avoidable.

In terms of the risk of various types of losses due to lightning, a value of the tolerable risk, R_a needs to be specified. For each type of loss due to lightning, R_a represents the tolerable probability of that loss occurring over the period of a year. Regarding the potential types of risk due to lightning listed in Clause 2.3.2, typical values of the tolerable or acceptable risk, R_a are given in Table 2.2.

TABLE 2.2
TYPICAL VALUES OF TOLERABLE RISK, R_a

Type of loss	Tolerable risk per year, R_a
Loss of human life	10^{-5}
Loss of service to the public	10^{-3}
Loss of cultural heritage	10^{-3}

For a loss of economic value, the tolerable risk, R_a may be fixed by the facility owner or user, often in consultation with the designer of the protection measures, based on economic or cost/benefit considerations.

For example, at a particular facility, it may be considered that a chance of 1 in 1000 of economic loss due to lightning occurring over a period of a year is tolerable. Alternatively, this would mean that it is considered acceptable for such a loss to occur, on average, once every 1000 years. In such a case the tolerable risk, R_a for loss of economic value would be set at 10^{-3} . Similarly, if it were considered acceptable for such a loss to occur, on average, once every 100 years, R_a for loss of economic value would be set at 10^{-2} .

2.4 DAMAGE DUE TO LIGHTNING

2.4.1 Sources of damage

The current in the lightning discharge is the potential source of damage. In this Section, the following sources of damage, relating to the proximity of the lightning strike, are taken into account (see Table 2.3):

- (a) S1—direct strike to the structure.
- (b) S2—strike to the ground near the structure.
- (c) S3—direct strike to a conductive electrical service line.
- (d) S4—strike to ground near a conductive electrical service line.

Conductive electrical service lines include electricity supply service lines (underground or overhead) and telecommunications service lines.

The number of lightning strikes influencing the structure depends on—

- (i) the dimensions and the characteristics of the structure;
- (ii) the dimensions and characteristics of the incoming conductive electrical service lines;
- (iii) the environment around the structure; and
- (iv) the density of lightning strikes in the region where the structure is located.

The greater the height and collection area, the more lightning strikes will influence the structure. Tall trees and surrounding buildings may shield a structure from lightning strikes. Incoming conductive electrical service lines add to the lightning collection area as they can conduct lightning current into the building.

2.4.2 Types of damage

The type of damage that a lightning strike may cause depends on structure or facility characteristics such as—

- (a) type of construction;
- (b) contents and application;
- (c) incoming conductive electrical service lines; and
- (d) measures taken for limiting the risk.

The damage may be limited to a part of the structure or may extend to the whole structure. Damage may also extend to the surrounding environment (e.g. contamination caused by consequential chemical spills or radioactive emissions).

Direct strikes to the structure or to incoming conductive electrical service lines may cause mechanical damage, injury to people and animals and may cause fire and/or explosion. Indirect strikes as well as direct strikes may cause failure of electrical and electronic equipment due to overvoltages resulting from coupling of the lightning current.

For practical applications of risk assessment, it is useful to distinguish between three basic types of damage that can appear as the consequence of a lightning strike. They are as follows:

- (i) D1—Injury to people (shock of living beings) due to step and touch voltages and side-flash contact.
- (ii) D2—Fire, explosion, mechanical destruction, chemical release due to physical effects of the lightning channel (including dangerous sparking).
- (iii) D3—Failure of electrical and electronic systems due to overvoltages.

2.4.3 Consequences of damage (types of loss)

The value amount of damage caused by the consequential effects of lightning depends on factors such as—

- (a) the number of people and the time they are in the facility;
- (b) the type and importance of the service provided to the public; and
- (c) the value of goods and/or services affected by the damage.

Some special hazard factors also need to be considered. For example, in theatres and halls there can be a significant risk of panic if a lightning strike causes loss of electricity supply or other mechanical or fire-related damage. As a result, people may be injured in the panic to evacuate the building.

Museums and heritage listed buildings have a cultural value. There may be significant loss of revenue (economic loss) associated with damage to computer centres and communication nodes.

For a particular facility or structure, the following consequences of damage due to lightning or types of loss should be taken into account.

(i) L1—Loss of human life.

(ii) L2—Loss of services to the public.

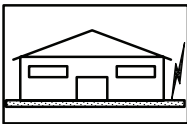
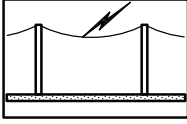
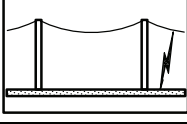
NOTE: Only applicable to structures involved in the provision of public service utilities (e.g. water, electricity, gas, telecommunications, rail).

(iii) L3—Loss of cultural heritage.

(iv) L4—Loss of economic value (structure, content and loss of activity).

Table 2.3 illustrates the relationship between the ‘sources of damage’, ‘types of damage’ and ‘types of loss’ selected according to the point of strike.

TABLE 2.3
SOURCES OF DAMAGES (S1, S2, S3, S4), TYPES OF DAMAGES
(D1, D2, D3) AND TYPES OF LOSS (L1, L2, L3, L4)
SELECTED ACCORDING TO THE POINT OF STRIKE

Point of strike	Source of damage	Structure		Service	
		Type of damage	Type of loss	Type of damage	Type of loss
	S1	D1	L1, L4 ¹⁾		
		D2	L1, L2, L3, L4	D2	L1 ²⁾ , L2, L4
		D3	L1, L2, L4	D3	L2, L4
	S2	D3	L1 ³⁾ , L2, L4		
	S3	D1	L1, L4 ¹⁾		
		D2	L1, L2, L3, L4	D2	L1 ²⁾ , L2, L4
		D3	L1, L2, L4	D3	D2, D4
	S4	D3	L1 ³⁾ , L2, L4	D3	L2, L4

¹⁾ In the case of agricultural properties (loss of animals).

²⁾ In the case of pipelines, with no metallic gasket on flanges, conveying explosive fluid.

³⁾ In the case of hospitals and of structures with risk of explosion.

Figure 2.1 illustrates the relationship between the ‘types of loss’, ‘types of damage’ and ‘components of risk’ (discussed in Clause 2.5.1) that can be associated with lightning discharges to earth.

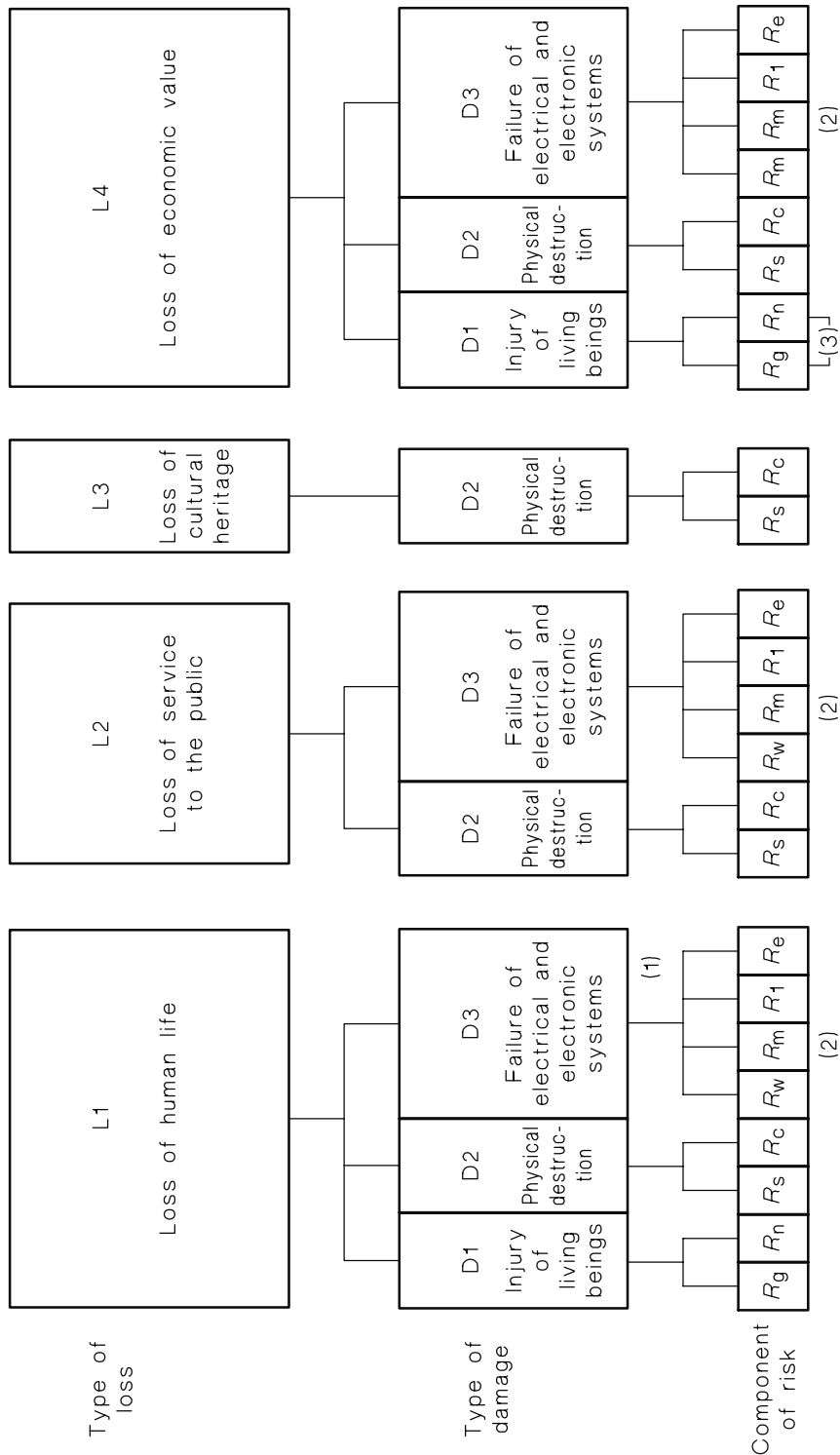


FIGURE 2.1 LOSSES, DAMAGES AND RISK COMPONENTS

2.5 RISKS DUE TO LIGHTNING

2.5.1 Risk components

For **each type** of loss relevant to the structure or facility, the total risk due to lightning, R , is the probability of that loss occurring over the period of a year. The total risk, R , is made up of the sum of a number of risk components associated with the four possible sources of damage (according to the point of strike) as listed below:

(a) *S1 Lightning strikes directly to the structure*

These may generate:

- (i) Component R_h due to step and touch voltages outside the structure (mainly around downconductors) causing shock to living beings (D1).
- (ii) Component R_s due to mechanical and thermal effects of the lightning current or by dangerous sparking causing fire, explosion, mechanical and chemical effects inside the structure (D2).
- (iii) Component R_w due to overvoltages on internal installations and incoming services causing failure of electrical and electronic systems (D3).

(b) *S2 Lightning strikes to ground near the structure*

These may generate component R_m due to overvoltages on internal installations and equipment (mainly induced by the magnetic field associated with the lightning current) causing failure of electrical and electronic systems (D3).

(c) *S3 Lightning strikes directly to conductive electrical service lines*

These may generate:

- (i) Component R_g due to touch overvoltages transmitted through incoming lines causing shock of living beings inside the structure (D1).
- (ii) Component R_c due to mechanical and thermal effects including dangerous sparking between external installation and metallic parts (generally at the point-of-entry of the incoming line into the structure) causing fire, explosion, mechanical and chemical effects on the structure and/or its content (D2).
- (iii) Component R_e due to overvoltages, transmitted through incoming lines to the structure, causing failure of electrical and electronic systems (D3).

(d) *S4 Lightning strikes to ground near conductive electrical service line conductors*

These may generate component R_l due to induced overvoltages, transmitted through incoming lines to the structure, causing failure of electrical and electronic systems (D3).

Figure 2.1 illustrates the relationship between the ‘types of loss’, ‘types of damage’ and ‘risk components’ that can be associated with lightning discharges to earth. Table 2.4 summarizes the various risk components and the ways that these can be summed to give the total risk.

For **each type** of loss, the total value of the risk due to lightning, R , may be expressed in the following ways:

- (i) With reference to the type of lightning strike—

$$R = R_d + R_i \quad \dots 2.5.1(1)$$

where

$$\begin{aligned} R_d &= R_h + R_s + R_w && \text{risk due to direct strikes to the structure} \\ R_i &= R_g + R_c + R_m + R_e + R_l && \text{risk due to indirect strikes to the structure} \\ &&& \text{(including direct and indirect strikes to} \\ &&& \text{conductive electrical service lines)} \end{aligned}$$

- (ii) With reference to the types of damage—

$$R = R_t + R_f + R_o \quad \dots 2.5.1(2)$$

where

$$\begin{aligned} R_t &= R_h + R_g && \text{risk due to shock to living beings (D1)} \\ R_f &= R_s + R_c && \text{risk due to fire, explosion, mechanical} \\ &&& \text{destruction and chemical release (D2)} \\ R_o &= R_w + R_m + R_e + R_l && \text{risk due to the failure of electrical and} \\ &&& \text{electronic systems due to overvoltages (D3)} \end{aligned}$$

2.5.2 Calculation of risk components

Each component of the risk R_x depends on the number of dangerous events N_x , the probability of damage P_x and the damage factor δ_x . The value of each component of risk R_x may be calculated using an expression similar to that shown below:

$$R_x = N_x P_x \delta_x$$

NOTE: Details of the parameters, factors and equations required to calculate each of the risk components are given in Appendix A.

For each risk component, the damage factor, δ_x , represents the mean damage and takes into account the type of damage, its extent, and the consequential effects that may occur as the result of a lightning strike. Typical values of the damage factors for each type of loss are given in Appendix A and in the risk management calculation tool.

NOTE: Where specific information is known regarding the function or use of a particular structure, alternative damage factor values may be selected based on these relations.

The damage factors are related to the structure's function or use and may be determined from the following approximate relations below:

Loss of human life (L1)

$$\delta_x = \frac{n}{n_t} \times \frac{t}{8760} \quad (\text{relative number of victims}) \quad \dots 2.5.2(1)$$

where

$$\begin{aligned} n &= \text{the number of possible victims from a lightning strike} \\ n_t &= \text{the expected total number of people associated with the structure} \\ t &= \text{the time, in hours per year, for which the people are present in a} \\ &\quad \text{dangerous place} \end{aligned}$$

Unacceptable loss of service to the public (L2)

$$\delta_x = \frac{n}{n_t} \times \frac{t}{8760} \quad (\text{relative amount of possible loss}) \quad \dots 2.5.2(2)$$

where

- n = the mean number of users not served
 n_t = the total number of users served
 t = the annual period of loss of service, in hours.

Loss of cultural heritage (L3)

$$\delta_x = \frac{c}{c_t} \quad (\text{relative amount of possible loss}) \quad \dots 2.5.2(3)$$

where

- c = the insured value of possible loss of goods (monetary amount)
 c_t = the total insured value of all goods present in the structure (monetary amount)

Economic loss (L4)

$$\delta_x = \frac{c}{c_t} \quad (\text{relative amount of possible loss}) \quad \dots 2.5.2(4)$$

where

- c = the mean value of the possible loss of the structure, its contents and associated activities (monetary amount)
 c_t = the total value of the structure, its content and associated activities (monetary amount)

TABLE 2.4
POSSIBLE RISK COMPONENTS CAUSED BY DIFFERENT EFFECTS

Cause of damage Type of damage	Lightning			
	Indirect			
	Direct S1 Strike to the structure	S2 Strike to ground near the structure	S3 Strike to incoming conductive electrical service line	S4 Strike to ground near incoming conductive electrical service line
D1 Injury of living beings	R_h Component due to step and touch voltages or side-flash arc from EPR outside the structure causing shock to living beings		R_g Component due to touch voltages transmitted through incoming conductive electrical service lines causing shock to living beings inside the structure	$R_t = R_h + R_g$ Risk due to shock to living beings
D2 Physical destruction	R_s Component due to mechanical and thermal effects or dangerous sparking causing fire or physical damage		R_c Component due to mechanical and thermal effects or dangerous sparking from incoming conductive electrical service lines (mainly at the point-of-entry to the structure) causing fire or physical damage	$R_f = R_s + R_c$ Risk due to fire or physical damage
D3 Failure of electrical and electronic systems	R_w Component due to overvoltages on internal installations and incoming services causing failure of electrical and electronic systems	R_m Component due to overvoltages on internal installations and equipment (induced by the magnetic field associated with the lightning current) causing failure of electrical and electronic systems	R_e Component due to overvoltages transmitted through incoming conductive electrical service lines to the structure causing failure of electrical and electronic systems	$R_o = R_w + R_m + R_e + R_1$ Risk due to the failure of electrical and electronic systems from overvoltages
$R_d = R_h + R_s + R_w$ Risk due to direct strikes to the structure				$R = R_t + R_f + R_o$ Total risk due to lightning
$R_i = R_g + R_c + R_m + R_e + R_1$ Risk due to indirect strikes to the structure (including direct and indirect strikes to the conductive electrical service lines)				$R = R_d + R_i$ Total risk due to lightning

2.6 PROCEDURE FOR RISK ASSESSMENT AND MANAGEMENT

The procedure for risk assessment and the subsequent selection of protection is outlined in flow chart form in Figure 2.2.

2.6.1 Procedure for risk assessment

The procedure for the assessment of the risk requires:

- (a) Identification of the structure or facility to be protected.

This involves defining the extent of the facility or structure being assessed. In most cases the structure or facility will be a stand-alone building. The structure may encompass a building and its associated outbuildings or equipment supports.

Under certain conditions, a facility that is a part of a building may be considered as 'the structure' for risk assessment purposes. An example of this might be a communications installation at the top of an office building. This segregation of a part of a building is only valid under the following conditions:

- (i) There is no risk of explosion in the remainder of the building.
- (ii) Suitable fire barriers exist around the structure being considered (fire rating of not less than 120 min).
- (iii) Overvoltage (SPD) protection is provided on all conductive electrical service lines at their point-of-entry to the structure being considered.

- (b) Determination of all the relevant physical, environmental and service installation factors applicable to the structure.

- (c) Identification of all the types of loss relevant for the structure or facility.

For most structures, only L1 and L4 will need to be considered. L3 will apply to museums, galleries, libraries and heritage listed buildings while L2 applies to structures involved in the provision of public service utilities such as water, gas, electricity and telecommunications.

- (d) For each type of loss relevant to the structure, determine the relevant damage factors δ_x and special hazard factors.

- (e) For each type of loss relevant to the structure, determine the maximum tolerable risk, R_a .

- (f) For each type of loss relevant to the structure, calculate the risk due to lightning by—

- (i) identifying the components R_x that make up the risk (see Figure 2.1);
- (ii) calculating the identified risk components R_x ; and
- (iii) calculating the total risk due to lightning, R .

- (g) Compare the total risk R with the tolerable value R_a for each type of loss relevant to the structure.

If $R \leq R_a$ (for each type of loss relevant to the structure) lightning protection is not necessary.

If $R > R_a$ (for any type of loss relevant to the structure) the structure shall be equipped with protection measures against lightning.

The selection of the most suitable protection measures shall be made by the designer according to the contribution of each risk component to the total risk, and according to the technical and economic aspects of the different protection measures available. Technical considerations include addressing the highest risk components while economic considerations involve minimizing the total cost to achieve a suitable level of protection.

It is appropriate to consider separately the risk R_d due to direct lightning strikes and the risk R_i due to indirect lightning strikes.

2.6.2 Protection against direct lightning strikes if $R_d > R_a$

When the risk due to direct lightning strikes is greater than the acceptable risk ($R_d > R_a$), then the structure shall be protected against direct lightning strikes with an LPS designed and installed in accordance with the recommendations given in Section 4.

In Section 4, four protection levels (I, II, III, IV) with corresponding interception efficiencies (99%, 97%, 91%, 84%) and resulting LPS efficiencies, E (98%, 95%, 90%, 80%) are defined.

To determine the required protection level, the final calculation for the protected structure may be repeated successively for the protection levels IV, III, II, I until the condition $R_d \leq R_a$ is fulfilled.

NOTE: A previous edition, AS 1768—1991, specified LPSs with protection equivalent to IEC Level III (interception efficiency $\approx 91\%$)—Rolling sphere with $a = 45$ m)

If an LPS of protection level I cannot fulfil this condition, consider surge protection on all incoming conductive electrical service lines at the point-of-entry to the structure or other specific protection measures according to the values of the risk components (refer to detailed calculations and assumptions in Appendix E). These may include—

- (a) measures limiting step and touch voltages;
- (b) measures limiting fire propagation;
- (c) measures to mitigate the effects of lightning-induced overvoltages (e.g. additional, coordinated surge protection or isolation transformers); and
- (d) measures to reduce the incidence of dangerous discharges (e.g. bonding of structural elements).

2.6.3 Protection against indirect lightning strikes if $R_d \leq R_a$ but $R_i > R_a$

When $R_d \leq R_a$, then the structure is protected against direct lightning strikes. However, if the risk due to indirect strikes is greater than the acceptable risk ($R_i > R_a$), then the structure must be protected against the effects of indirect lightning strikes.

Possible protection measures include—

- (a) suitable application of SPDs on all external conductive electrical service lines at the point-of-entry to the structure (primary or point-of-entry surge protection); and
- (b) suitable application of SPDs on all internal equipment (secondary surge protection at the equipment).

NOTE: Suitable application of surge protection requires correct installation, earthing and coordination of appropriately rated SPDs.

To determine the required protection, the final calculation for the protected structure shall be repeated with one or both of these protection measures in place until the condition $R_i \leq R_a$ is fulfilled.

If the application of these protection measures cannot fulfil this condition, specific protection measures shall be provided according to the values of the risk components (refer to detailed calculations and assumptions in Appendix A). These may include magnetic shielding of the structure and/or of the equipment and/or of cable ways and/or by using cable screening. It may also be appropriate to have extra zones of protection around sensitive areas with an extra level of SPD protection at the boundary of that zone.

2.6.4 Final check if $R_d + R_i > R_a$

When $R_d \leq R_a$ and $R_i \leq R_a$ it is still possible that the total risk $R = R_d + R_i > R_a$.

In this case, the structure does not require any specific protection against direct lightning strikes or against overvoltages due to nearby strikes or transmitted through the incoming conductive electrical service lines.

However, since $R > R_a$, protection measures shall be taken to reduce one or more risk components to reduce the risk to $R \leq R_a$. Critical parameters have to be identified to determine the most efficient measure to reduce the risk R .

For each type of loss, there are a number of protection measures that, individually or in combination, may make the condition $R \leq R_a$.

Those measures that make $R \leq R_a$ for all the types of loss must be identified and adopted with due consideration of the associated technical and economic issues.

2.7 RISK MANAGEMENT CALCULATION TOOL

A Microsoft® Excel spreadsheet file has been included as a risk management calculation tool. This file (LIGHTNING RISK.XLS) is provided as an integral part of the Standard and is designed to operate using Microsoft® Excel 97 (or later versions).

The spreadsheet implements the risk calculations detailed in Appendix A with the required inputs and outputs presented on a single page for ease of use. The risk calculations implemented represent a simplification of the approach outlined in initial work by IEC Committee TC 81 with the number of variables and options requiring selection reduced to a minimum based on assumptions for general conditions in Australia and New Zealand.

In addition, a simplified form of the equation for risk component R_s (risk related to physical destruction) has been used, and the classification descriptions for fire risks based on structure type and content (p_s) have been modified, in order to reduce the fire risk sensitivity of the draft IEC model. These modifications have been made to give more practical values based on experience in Australia and New Zealand.

2.7.1 General operation

When the file is opened using Microsoft® Excel, a front page spreadsheet is displayed. This front page presents all of the inputs and final calculation outputs required in the risk management process. Other work sheets showing the calculated values of all of the individual risk components for each type of risk are also accessible if a more in depth analysis is required.

On the front page, the required inputs are subdivided into various categories with input cells highlighted with a border. The possible input options are explained in a comment box, which is displayed when the cursor is positioned over the input cell.

For most input cells, the input option is selected from a pull-down menu of key words that are defined in the associated comment box. Some inputs require numerical values (e.g. structure dimensions), which should be entered in the usual way from the keyboard.

When all of the inputs have been entered, the output values in the 'Risk' section represent the calculated risk components and overall risk for the particular set of structure parameters and conditions specified.

2.7.2 Using the calculation tool in the risk management procedure

The calculation tool can be used in the following way to implement the risk assessment and management procedure outlined in Clause 2.6.

- (a) Identify the structure and input the *structure dimensions*.
- (b) Input the *structure attributes* relating to fire risk, screening effectiveness and internal wiring.
- (c) Determine the average annual lightning ground flash density (N_g) for the structure location from the appropriate Ground Flash Density map (Figure 2.3 or 2.4) and input the value in the *environment* section.

NOTES:

- 1 Earlier editions of AS/NZS 1768 provided thunderday maps, refer Appendix B2.3.
- 2 An approximate relationship between ground flash density (N_g) and thunderdays (T_d) for Australia is $N_g = 0.012 T_d^{1.4}$.

- (d) Input the other *environment* attributes relating to surrounding feature height and service density.
- (e) Specify the details of the *conductive electrical service lines* associated with the structure in the following way:
 - (i) Input the type of electricity supply service line and identify whether or not a transformer is installed on this service line at the structure.
 - (ii) Input the number and type of other overhead or underground conductive electrical service lines connected to the structure **via divergent routes**.

NOTES:

- 1 Different service lines that follow the same physical route from the nearest distribution node to the structure should be considered as one service line connection.
- 2 Typically a structure will have one electricity supply service connection (overhead or underground) and one telecommunications service connection (overhead or underground) that could be considered as being connected via divergent routes.

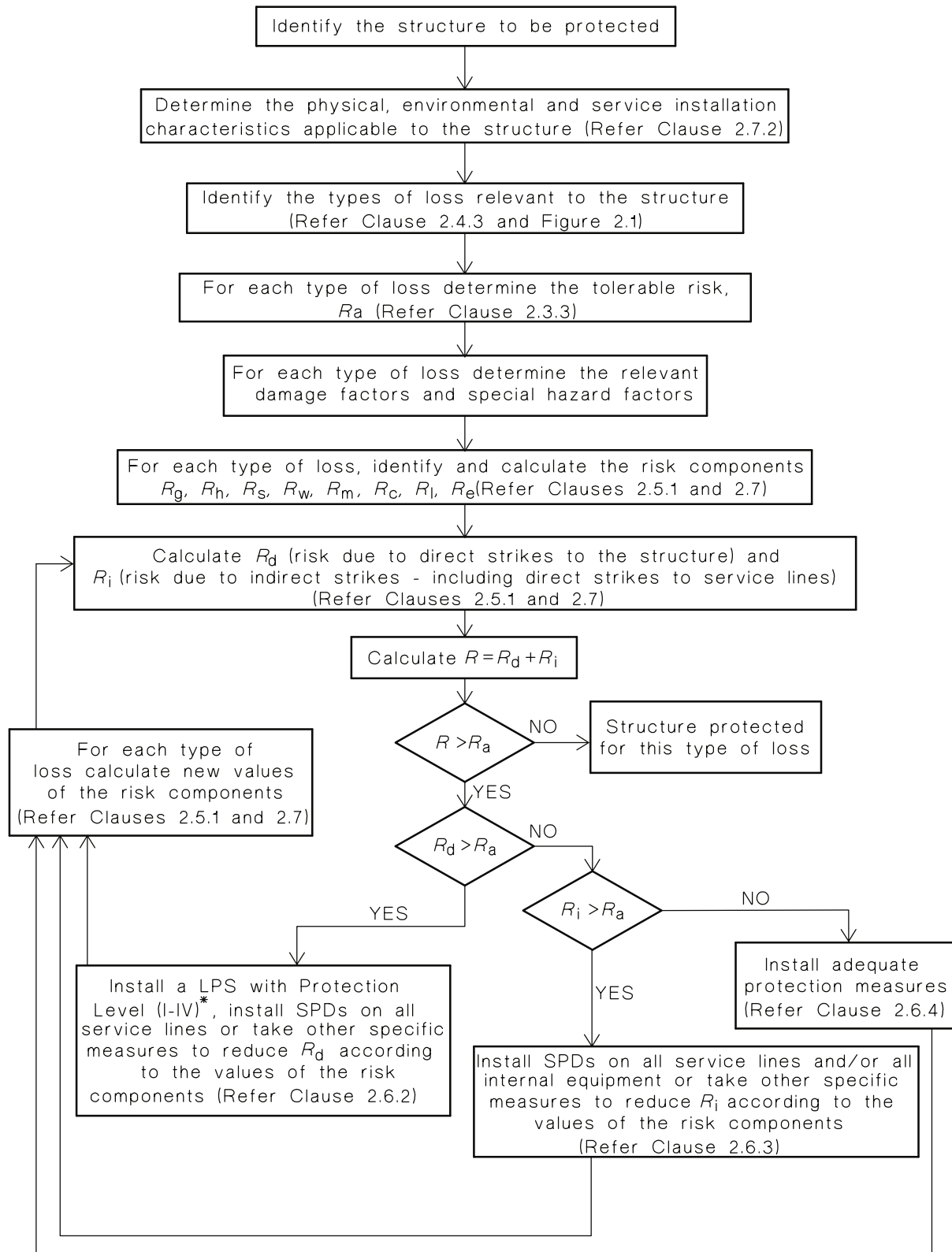
- (f) Identify the *loss types* relevant to the structure and for each type input the *damage factors* and *special hazard factors* as appropriate.
- (g) Determine and input an appropriate value for the acceptable risk of loss of economic value as it applies to the structure.
- (h) Input details of any *protection measures* installed. The surge protection options offered are for:
 - (i) Suitable application of SPDs on all external conductive electrical service lines at the point-of-entry to the structure (primary or point-of-entry surge protection).
 - (ii) Suitable application of SPDs on all electrical equipment inside the structure (secondary surge protection at the equipment).

NOTE: Suitable application of surge protection requires correct installation, earthing and coordination of appropriately rated SPDs.

For each type of loss relevant to the structure, compare the acceptable risk with the total risk calculated. Review the risk components and follow the Risk Management procedure detailed in Clause 2.6 and Figure 2.2.

Use the spreadsheet to recalculate the risk components and total risk figures for any *protection measures* proposed. Successive calculations can be performed to observe the effects of various protection measures.

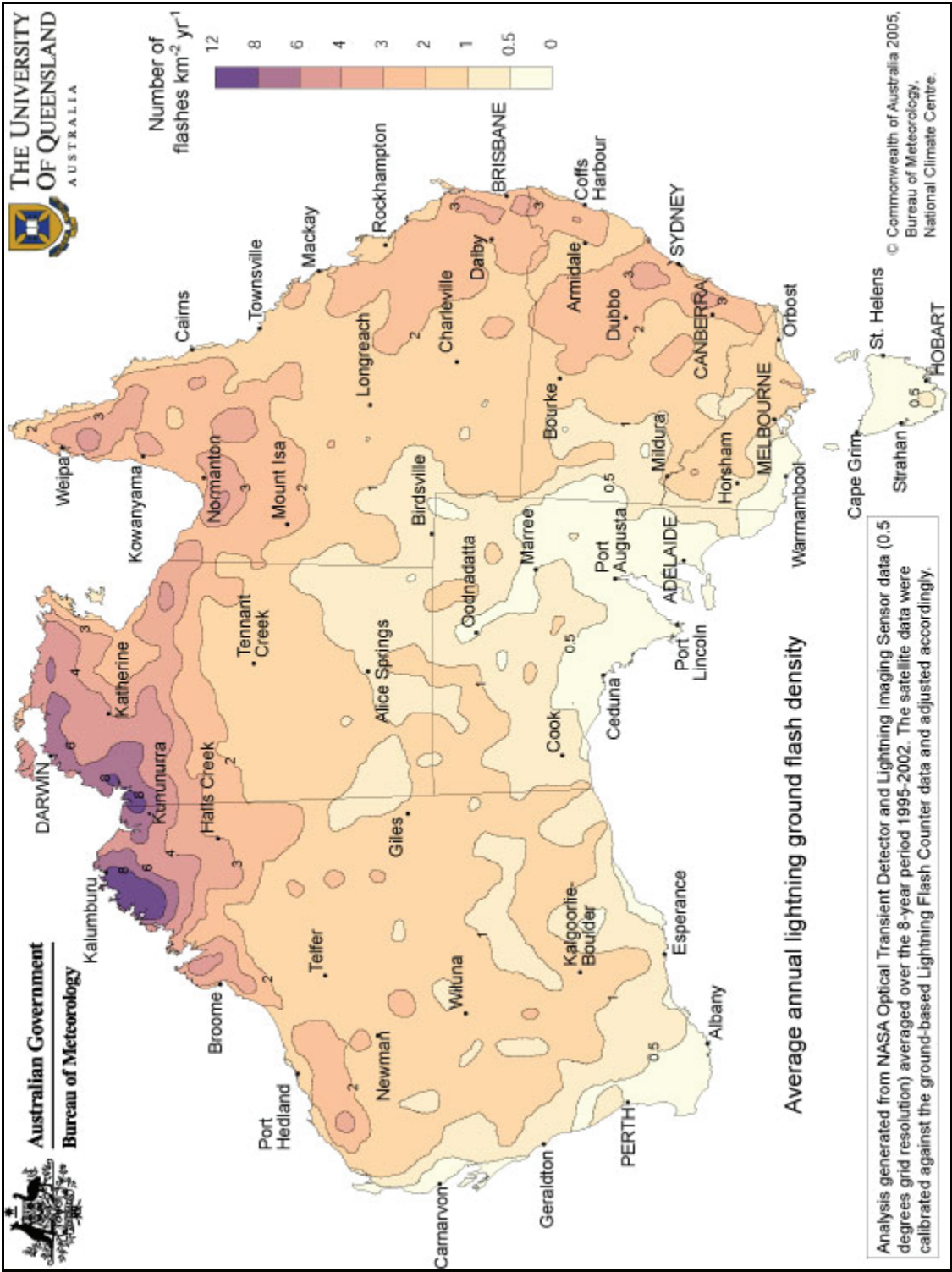
A number of completed spreadsheet examples are provided for information in Appendix A.



* Refer to Section 4.

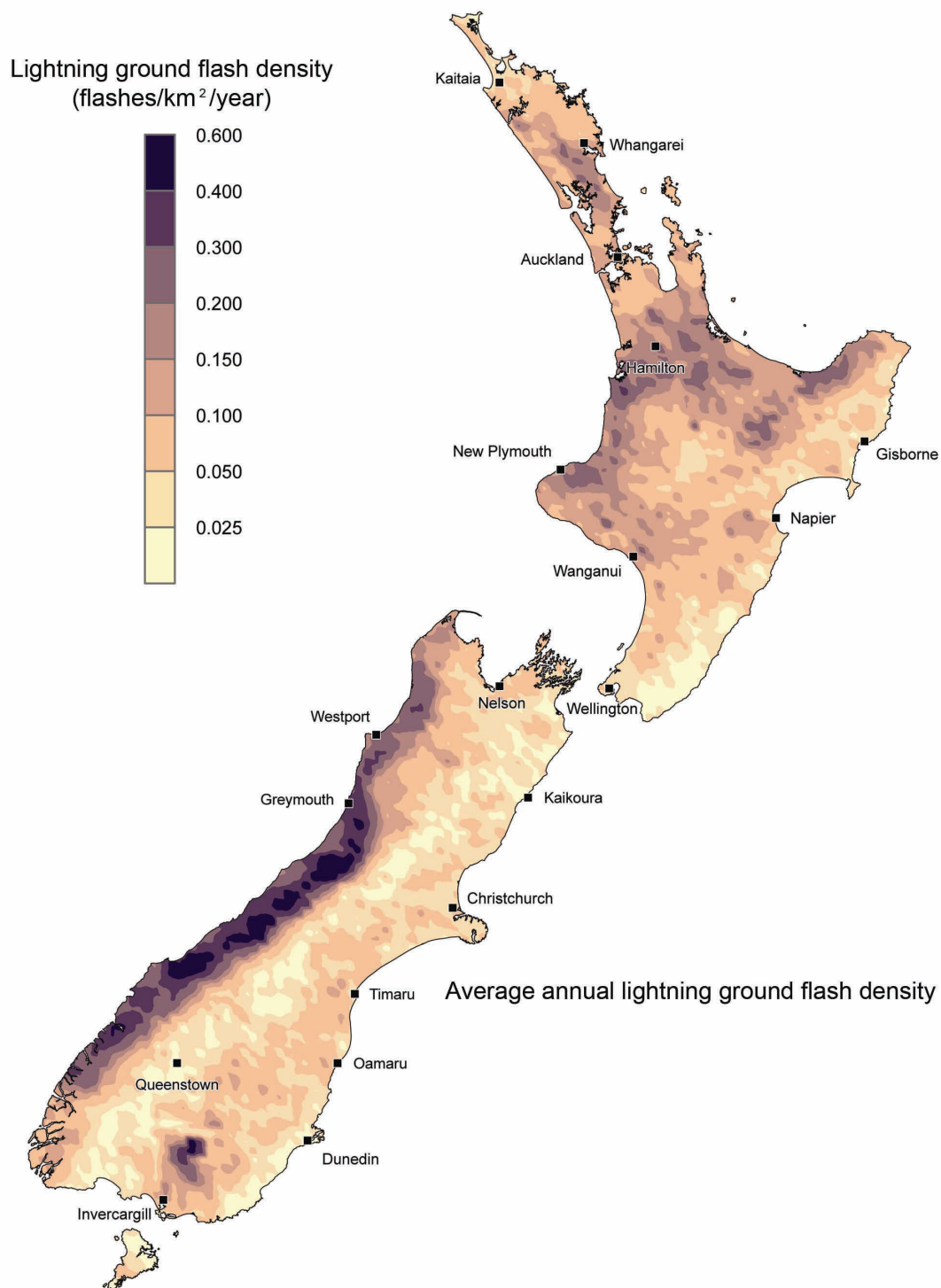
NOTE: A previous edition, AS 1768—1991, specified an LPS with protection equivalent to Level III—Rolling sphere with $a=45$ m.

FIGURE 2.2 RISK MANAGEMENT PROCEDURE FOR SELECTION OF LIGHTNING PROTECTION MEASURES



NOTE: The Australian Ground Flash Density map has been compiled and kindly supplied by the Australian Bureau of Meteorology and the University of Queensland.

FIGURE 2.3 AVERAGE ANNUAL LIGHTNING GROUND FLASH DENSITY MAP OF AUSTRALIA



NOTE: This figure has been derived from ground flash density data obtained from the Lightning Detection Network of New Zealand for the period January 1, 2001 through February 9, 2006. Data supplied by Transpower New Zealand Ltd and the Meteorological Service of New Zealand Ltd (MetService).

FIGURE 2.4 AVERAGE ANNUAL LIGHTNING GROUND FLASH DENSITY MAP OF NEW ZEALAND

SECTION 3 PRECAUTIONS FOR PERSONAL SAFETY

3.1 SCOPE OF SECTION

This Section provides guidance for personal safety during thunderstorms.

Measures for the protection of persons, which should be incorporated in LPSs for buildings and structures, are outlined in other sections.

For shelters designed for the protection of persons during storm activity, reference should be made to Clause 6.9.1.

3.2 NEED FOR PERSONAL PROTECTION

A hazard to persons exists during a thunderstorm. Each year a number of persons are struck by lightning, particularly when outdoors in open space such as an exposed location on a golf course, or when out on the water. Between six and ten people are killed by lightning in Australia each year. This is equivalent to a probability of about 5×10^{-7} per year for an individual being killed by lightning in Australia.

Lightning strikes to a person, or close by, may cause death or serious injury. A person touching or close to an object struck by lightning may be affected by a side-flash, or receive a shock due to step, touch or transferred potentials. There is a significant risk of side-flash for people in small, public structures such as picnic shelters, particularly those with unearthed metallic roofs. In built-up areas protection is frequently provided by nearby buildings, electricity supply service lines or street lighting poles.

Persons within a substantial structure are normally protected from direct strikes, but may be exposed to a hazard from conductive electrical services entering the structure or from conductive objects within the structure that may attain different potentials.

The first recorded 'electrical accident' involving the use of a telephone occurred in 1860 and was caused by lightning being conducted through the telephone system. Telephone related injuries include acoustic and/or electric shock. About 10% of injuries are severe. No telephone related deaths have been reported in Australia. This is probably because of warnings not to use the telephone, except in an emergency, during a lightning storm and the use of SPDs on telephone installations in lightning prone areas. Around 80% of incidents involve a lightning strike to or close to a building or a strike to the electricity supply service line all of which result in a rise of the local earth potential rather than surges on the telecommunications service line. This rise in local earth potential can result in a breakdown between the person and the telephone, (which is connected to a nominal remote earth via the telecommunications service line).

In some workplaces employees who work within larger buildings may be unaware of the changing outside weather conditions, and may not be aware that it may be unsafe to use telephone systems. Where modern fixed line telephonist headsets are used, this increases the risk of human injury through external transients being conducted through to those wearing the headsets.

When moderate to loud thunder is heard, persons out of doors should avoid exposed locations and should seek adequate shelter. Persons indoors should avoid using the telephone and contacting metallic structures. These warnings apply particularly if thunder follows within 15 s of a lightning flash (corresponding to a distance of less than 5 km).

3.3 PERSONAL CONDUCT

3.3.1 General

The threat to personal safety is greatest if a person is out of doors when the thunderstorm is local. In the absence of specific information from weather radar, a lightning location system or a specialized lightning warning device, the '30/30' safety guideline (Paragraph G2, Ref. 1) should be used. An approaching thunderstorm is treated as local when the time interval between seeing a lightning flash and hearing the thunder is less than 30 s and then the appropriate safety measures described in Clause 3.3.2 should be implemented. A receding local thunderstorm is no longer a threat when more than 30 min have elapsed after the last thunder is heard.

3.3.2 Outdoors

When outdoors, some of the measures for reducing the risk of injury that may be caused by lightning strikes to ground during a local thunderstorm are as follows:

- (a) Seek shelter in a substantial building with at least normal headroom or within a totally enclosed, metal-bodied vehicle such as car or truck with metallic roof. If in a car, close the windows and avoid contact with metallic parts and remove any hands-free mobile telephone attachments from the body. Avoid driving the car as a strike to the car may blow out the tyres. Do not stay in open vehicles such as tractors, beach buggies, or any other type of open or enclosed vehicle without a metallic roof. Conventional fabric tents offer no protection; small sheds offer uncertain protection.
- (b) Do not ride or sit on horses, bicycles or motorcycles, or otherwise elevate the body above the surroundings.
- (c) Do not shelter under trees, particularly an isolated tree. If surrounded by trees, seek a position outside the foliage and crouch, keeping the feet together.
- (d) Do not shelter in small sheds, pagodas, walkways etc. with low unearthed metallic roofs supported on wooden or other electrically insulating materials.
- (e) Do not touch or stand close to any metallic structures, including wire fences and clothes lines. Do not stand on or under bridges or other elevated structures. Do not carry metallic objects such as umbrellas or golf clubs and remove metallic chains and other jewellery, particularly from the head and upper parts of the body.
- (f) If on open field or on the beach and remote from any shelters, keep as low and as small a profile as possible, i.e. crouch keeping the feet together and do not touch any objects or people near you. A dry ditch, valley or any depression in the ground is safer than an elevated or flat terrain. Do not lie on the ground as this could cause dangerous voltage to develop across the body by earth currents generated by a nearby strike. Footwear or a layer of non-absorbing, insulating material, such as plastic sheets, can offer some protection against earth voltages.
- (g) Do not swim or wade in the sea, lake, river, pool or any other body of water.
Exit the water and move to a safe place.
- (h) If on a boat deck, keep a low profile and avoid contacts with or being close to masts, rails, stay wires or any other metallic objects. Avoid unnecessary contacts with communication or navigation equipment. Do not enter the water, and in general avoid contact with water. Additional protection may be gained by anchoring under relatively high objects such as jetties and bridges, provided that direct contact is not made with them. Isolated buoys and pylons should be avoided.

In addition, the following checks should be made when planning outdoor activities:

- (i) Check weather reports for likely thunderstorms.
- (ii) When engaged in outdoor activities, monitor the surroundings for indications of the onset of thunderstorms. These checks are particularly important when planning and undertaking activities involving groups and large numbers of people.

3.3.3 Indoor and outdoor swimming pools

Certain locations are extremely hazardous during thunderstorms and should be avoided if at all possible. Statistics show that more than 10% of lightning-related injuries and deaths are water related (e.g. fishing, boating and swimming). Swimming pool facilities are connected to a large surface area via underground water pipes, gas lines, electric and telephone wiring, etc. Hence, lightning strikes to the ground anywhere on this metallic network may cause shocks elsewhere. Indoor and outdoor pools are treated the same with regard to lightning dangers.

The following swimming pool safety procedures are recommended:

- (a) A person should be designated as the pool's weather safety lookout. That person should keep an eye on the weather and use the appropriate means to obtain localized, advanced weather information.
- (b) Identify in advance safe/not safe places—
 - (i) Safe—dry areas inside large permanent buildings.
 - (ii) Not safe—near electrical conductors, electrical equipment, metal objects (lifeguard stands, ladders, diving board stanchions) and water, including showers.
- (c) When thunder and/or lightning are first noticed, use the '30/30 method' described in Clause 3.3.1. The pool should be evacuated in a time interval of less than 30 s and people should be directed to a safe shelter nearby.

3.3.4 Indoors

When indoors, some of the measures for reducing the risk of injury that may be caused by lightning strikes to ground during a local thunderstorm are as follows:

- (a) Avoid unnecessary use of telephones particularly in suburban and rural dwellings during local thunderstorms. If unavoidable, keep it brief and try not to touch electrical appliances, personal computers, metal pipes, stoves, sinks, and any other metallic objects at the same time. Mobile and cordless telephones are safe to use indoors. Where headsets are used for a large percentage of the time, or where operators may be unaware of local lightning storms, the risk of injury from lightning can be dramatically reduced by the use of wireless headsets.
- (b) Do not take a bath or a shower and do not wash hands or dishes. Do not use personal computers and other electronic and electrical equipment, and avoid contacts with sinks, stoves, refrigerators, metallic pipes and other large metallic objects in the house.
- (c) Disconnect television sets, personal computers, video recorders and other electronic and electrical appliances from antennas, conductive telecommunication connections and electricity supply outlets to avoid damage to them. This should be done before the storm is local to minimize risk of personal injury.

NOTES:

- 1 Switching off an appliance does not disconnect neutral and earth wiring.
- 2 Switching off the electricity supply at the switchboard may also reduce the chances of damage to the electrical wiring and to permanently wired electrical appliances.

3.4 EFFECT ON PERSONS AND TREATMENT FOR INJURY BY LIGHTNING

The severity of the injuries inflicted on a person by a lightning strike will depend upon the intensity of the strike and for any given strike, on the fraction of the current that flows over the skin outside the body and the fraction that flows through the body, and its path. The worst situation would arise when a person is struck on the head, in which case the current through the body could cause fatal injuries to the brain, the heart and the lungs. A less dangerous situation is where the person is subjected to step or touch potentials, and only a small fraction of the total current passes through the body, although the pathway taken by this fraction is still important.

The effects of lightning include burns to the skin, which are usually superficial, damage to various bodily organs and systems, unconsciousness and, most dangerously, cessation of breathing and cessation of heart beat. Independently of these electrically-related effects, temporary or permanent hearing impairment may be experienced as a consequence of the extremely high sound pressure levels associated with a nearby lightning strike.

In the first aid treatment of a patient injured by lightning, it is essential that breathing be restored by artificial respiration and blood circulation be restored by external cardiac massage, if appropriate. These procedures should be continued until breathing and heart beat are restored, or it can be medically confirmed that the patient is dead. It should also be noted that the usual neurological criteria for death may be unreliable in this situation. There is no danger in touching a person who has been struck by lightning.

Lightning strike victims are sometimes thrown violently against an object, or are hit by flying fragments of a shattered tree, so first aid treatment may have to include treatment for traumatic injury.

Subsequent treatment of a lightning strike patient is a specialized area with important differences from the treatment of injuries inflicted by electric power current. For example, the nature of the burns and the extent of damage to underlying muscle tissue tend to be severe with electric power current, but mild with lightning current. Neurological and cardiac injuries also are different, and follow different courses.

NOTE: For a more comprehensive treatment of the subject covered by this Clause—see Paragraph G2, Ref. 2.

SECTION 4 PROTECTION OF STRUCTURES

4.1 SCOPE OF SECTION

This Section sets out recommendations for installation practices and for the selection of equipment to prevent or to minimize damage or injury that may be caused by a lightning discharge. The recommendations apply generally to the protection of structures using LPSs comprising air terminals, downconductors, equipotential bonding and earth terminations.

If, after completing the LPS risk assessment, it is evident that surge protection is required to protect internal systems within the building and services at entry to the buildings then the requirements of Section 5 shall be applied.

4.2 PROTECTION LEVEL

Four protection levels (PL) I, II, III, IV are used to define the efficiency with which the LPS is designed to protect the structure against physical damage and life hazard. The protection level efficiency (η) has two components—interception protection efficiency (η_I), which characterizes the effectiveness of the air terminals, and sizing protection efficiency (η_S), which characterizes the effectiveness of the downconductors and the earth terminations. Each is determined independently—by the minimum lightning current (I , kA) that will be intercepted, and by the maximum sizes of lightning current, charge (Q , C) and current steepness (di/dt , kA/ μ s) that will be discharged safely. The four protection levels are based on IEC TC 81 documents and are defined in Table 4.1.

TABLE 4.1
PROTECTION LEVELS

Protection level PL	Interception efficiency η_I	Sizing efficiency η_S	LPS efficiency η
I	0.99	0.99	0.98
II	0.97	0.98	0.95
III	0.91	0.97	0.90
IV	0.84	0.97	0.80

4.3 LPS DESIGN RULES

4.3.1 General

The following Clauses provide the details of the recommendations for the design and installation of all the LPS elements. This Clause lists the **overriding design rules** that shall normally be observed to provide **minimum requirements** for air terminals, downconductors and earth terminations. Observance of these rules will ensure that appropriate interception protection is provided by air terminals for the parts of structures most likely to be damaged by direct lightning strikes, that the conduction of the lightning current by the downconductors is adequate and that it is dissipated into the earth by the earth terminations.

These rules are the first step in the process of the design of a complete LPS. The remaining steps are referred to in the design rules and their application is referred to in subsequent sections.

NOTE: These design rules may not apply to some small structures.

Field data of damage caused by lightning flashes terminating on structures (See Paragraph G2, Refs. 3 and 4) identify the parts that are vulnerable to strikes. The most vulnerable, associated with over 90% of observed lightning damage, are nearly always located on the upper parts of structures, such as—

- (a) pointed apex roofs, spires and protrusions;
- (b) gable roof ridge ends; and
- (c) outer roof corners.

Other areas of vulnerability, in decreasing order, are—

- (d) the exposed edges of horizontal roofs, and the slanting and horizontal edge of gable roofs (<10%);
- (e) lower horizontal edges and vertical edges on outer-sides just below corners (<5%);
- (f) flat surfaces near points and corners (<3%); and
- (g) intruding surfaces and other surfaces, particularly flat surfaces (<1%).

As discussed in later Sections, the vulnerability is caused mainly by the electric field intensification associated with exposed points and corners on the upper surfaces of structures. It is obvious that air terminals must be installed to provide interception for the most vulnerable parts.

As well as providing conductive paths for the lightning current from the air terminals to the earth terminals, the downconductors should assist in preventing side-flashes to nearby metal elements (including reinforcing bars). This is best done by locating downconductors immediately below the air terminals used to protect the most vulnerable parts.

4.3.2 Rules for air terminals

- (a) First, provide air terminals to protect the most vulnerable parts (points and corners); second, use the rolling sphere method (RSM) to check if the less vulnerable parts (edges) are protected and, if not, add more terminals to protect them; third, also check if the least vulnerable parts (such as flat surfaces) are protected and, if not, add more terminals.
- (b) Air terminals shall be placed on or close to the most vulnerable parts; if a strip conductor is used, it shall be directly on the part it is to protect; if a vertical rod is used, its length shall be not less than 500 mm, and it shall preferably be mounted on the part it is to protect or within 1 m or 1/2 its length, whichever is the smaller (this rule is supported by recent research – see Paragraph G2, Ref. 5). The maximum allowable length of a rod terminal is 6 m.
- (c) If the structure has horizontal or gently sloping upper parts that are essentially cylindrical or oval in shape, then the edges are the vulnerable parts and shall be protected by air terminals; if a strip conductor is used, it shall be run along the edge(s); if vertical rods are used, there shall be a minimum of two evenly spaced terminals.
- (d) Non-conventional LPS using air terminals that claim enhanced performance are outside the scope of this Standard. To comply with this Standard and irrespective of claimed performance, air terminals shall be placed in accordance with the relevant clauses of this Section.

4.3.3 Rules for downconductors

- (a) Main conductors shall interconnect all air terminals and shall form one or more paths to earth via downconductors, such that the spacing between the downconductors does not exceed 20 m.

- (b) A downconductor shall be connected directly below an air terminal used to protect the most vulnerable parts; if the air terminal is on an exposed roof corner, its downconductor will also act as a continuation of the air terminal to protect the vertical edge below it, as is required for tall structures.

4.3.4 Rules for earth terminations

- (a) Low earth resistance is desirable and all practical measures should be taken to achieve $10\ \Omega$ or less for the whole interconnected LPS earth termination network. There shall be equipotential bonding at ground level for all metallic surfaces.

If the risk assessment indicates a need for SPDs, these shall be installed and bonded in accordance with Section 5.

- (b) There shall be one earth termination per downconductor.

4.4 ZONES OF PROTECTION FOR LIGHTNING INTERCEPTION

4.4.1 Basis of recommendations

The selected interception protection efficiency against direct lightning strikes is achieved by installing an LPS in such a way that its air terminals establish zones of protection enclosing the whole structure. For the calculation of these zones of protection, the RSM, with a modification for large flat surfaces, is used.

The RSM generally ensures that for lightning striking distances determined by the radius of the rolling sphere, the shortest distance between a lightning leader tip and any part of the structure is an air terminal.

This method of analysis is suitable for conventional lightning terminals, which may be vertical rods, horizontal wires or strip conductors, railings, metal sheets, fascias and so on.

4.4.2 Rolling sphere method (with a modification for large flat surfaces)

In the 'rolling sphere' technique of determining zones of protection, a sphere of specified radius (a) is theoretically brought up to and rolled over the total structure. All sections of the structure that the sphere touches are considered to be exposed to direct lightning strokes and would need to be protected by air terminals. In general, air terminals need to be installed so that the sphere only touches their interception surfaces. This is illustrated in Figure 4.1, which shows that the top corner/edge of the structure requires protection by an air terminal but the sides and lower section do not. The values of the rolling sphere radius (a) for the four protection levels (PL) I, II, III, IV are given in Table 4.2 together with the corresponding minimum lightning current ($I_{\min}$) that will be intercepted.

TABLE 4.2
ROLLING SPHERE RADIUS FOR EACH PROTECTION LEVEL

Protection level	Sphere radius	Interception current [†]
PL	$a, \text{ m } (a_i)^*$	$I_{\min}, \text{ kA}$
I	20 (60)	2.9
II	30 (60)	5.4
III	45 (90)	10.1
IV	60 (120)	15.7

* The values in brackets are for increased radius (a_i), see below.

† Values from IEC documents, which use distributions of lightning current parameters that differ slightly from those in Table B1 of Appendix B.

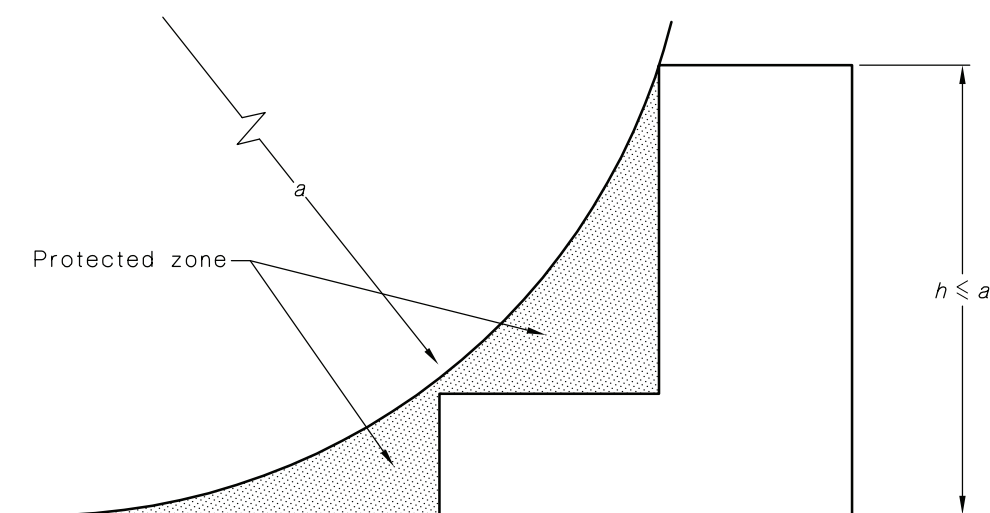


FIGURE 4.1 ZONE OF PROTECTION ON A STRUCTURE ESTABLISHED BY A ROLLING SPHERE OF RADIUS a

It is common to consider that PL III using a sphere of radius a , 45 m provides ‘standard’ protection (as in AS/NZS 1768(Int):2003 and NFPA 780—2004). PL I and II with a , 20 and 30 m provide higher degrees of protection and should be used if required by the risk management calculations of Section 2 and Appendix A. Conversely, PL IV with a , 60 m provides a lower degree of protection. For PL III, the protection ensures that, for striking distances of 45 m or more, the shortest distance to the structure is to an air terminal. From Tables 4.1 and 4.2, such striking distances correspond from empirical observations to peak currents of 10 kA or more, and an interception efficiency of 91%, there being only of the order of 9% of strikes having a lower current. In the RSM, lightning is considered most likely to follow the path of shortest distance. This path will have the highest average electric field produced by the potential difference between the tip of the lightning leader (likely to be at more than 10 MV) and the structure (approximately at earth potential).

The RSM produces a conservative design since it makes no allowance for field intensification at the edges and corners of structures. Using a constant radius for the rolling sphere the sides and tops of structures are assigned an equal probability of lightning strike to the corners and edges.

In particular, the ‘rolling sphere’ method is unduly conservative for large flat surfaces, such as on the roof of a structure and on the sides of tall structures, both of which are unlikely to be struck by lightning. Further advice on the protection of roofs is given in Clause 4.11.2.

A simple modification to the RSM can overcome the former problem (See Paragraph G2, Ref. 6). The basis of the modification is that the application of the RSM will be a two-step process in which—

- (a) the air terminal network is first selected and positioned to provide interception protection for points, corners and edge surfaces using a rolling sphere of radius (a) selected from Table 4.2; and
- (b) the selected and positioned air terminal network is then used to determine if protection is provided to all plane (flat) surfaces using a rolling sphere with the corresponding increased radius (a_i) in Table 4.2; if not, more air terminals are added to protect the exposed plane surface(s) still using the rolling sphere of radius (a_i).

For the purposes of this modification to the RSM, a plane surface is defined as any large flat surface that has no projection from it exceeding 300 mm. Any flat surface is considered to be large if, after step (b), it is apparent that more air terminals are required to protect it.

According to the RSM, an air terminal of height h above the edge of a flat roof or horizontal plane is considered to protect the edge of that roof or plane up to a horizontal distance r from a vertical rod or a horizontal conductor, where r is given by:

$$r = \sqrt{(2ah - h^2)} \quad \dots 4.4.2(1)$$

in which a is the sphere radius from Table 4.2 and r , a and h are in metres.

For points on the flat surface, according to the modification to the RSM, the protection extends to a distance r_i from the air terminal, given by:

$$r_i = \sqrt{(2a_i h - h^2)} \quad \dots 4.4.2(2)$$

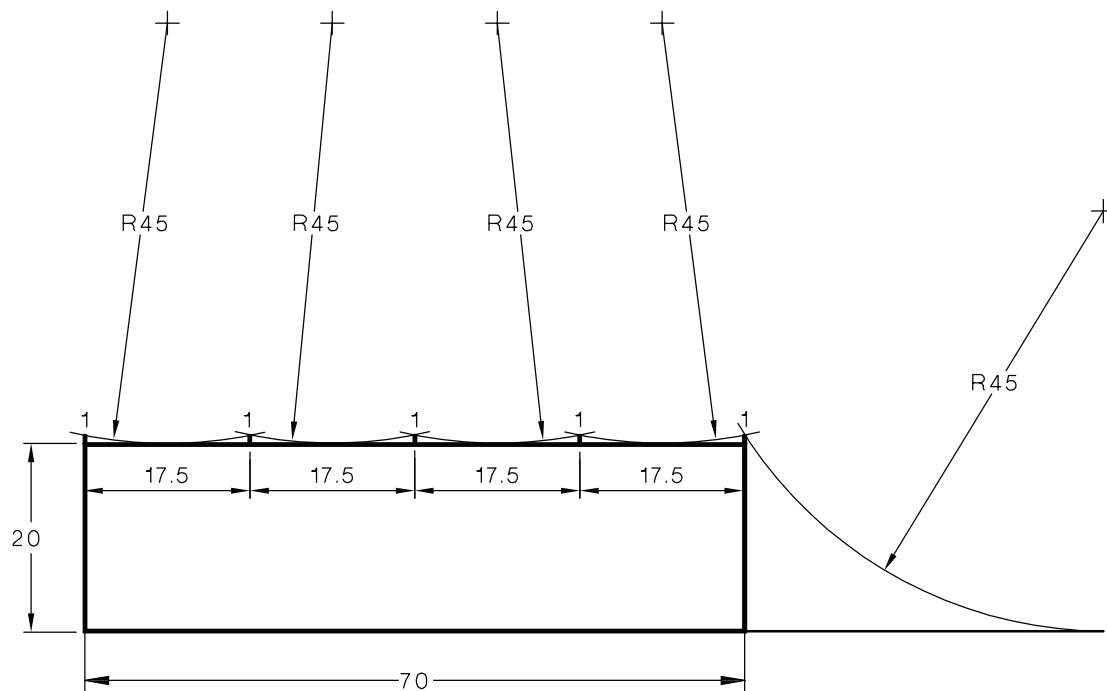
in which a_i is the increased radius from Table 4.2. For all but small horizontal surfaces, an array of air terminals is required at spacing distances that ensure that no parts of the surface are unprotected. If the array is a square grid, the spacings must not exceed d_{vr} for vertical rods and d_{hc} for horizontal conductors, given by:

$$d_{vr} \leq r_i \sqrt{2} \quad \text{and} \quad d_{hc} \leq 2 r_i \quad \dots 4.4.2(3)$$

Some numerical values are given to illustrate the magnitudes; for protection level III, a is 45 m and a_i is 90 m, then when the air terminal of height h is 1 m, r is 9.4 m, r_i is 13.4 m, d_{vr} is 19 m and d_{hc} is 26.8 m. Table 4.3 provides information on the spacings of air terminals required to protect roofs at each of protection levels I to IV for the three most common heights of air terminals used in Australia and New Zealand.

Figures 4.2 and 4.3 illustrate the application of the RSM (with the modification for flat surfaces) to a rectangular structure using either vertical rods or horizontal conductors. Figure 4.2 (Step (a)) deals with the interception protection for the vulnerable corners and horizontal edges and Figure 4.3 (Step (b)) shows how Equations 4.4.2(2) and 4.4.2(3) are used for the flat roof.

For more complex structures, the technique of rolling the sphere must be used directly to determine the required configuration of air terminals needed to achieve the interception protection efficiency that has been selected.



BUILDING ELEVATION SHOWING CORNERS AND EDGES

Step (a): Protect corner and edge surfaces

Either,

Place vertical rods at 4 corners, try $h = 1$ m (shown).

Using Equation 4.4.2(1) $r = \sqrt{(2ah - h^2)} = 9.4$ m

Max spacing along edge = $2 \times 9.4 = 18.6$ m

Therefore, 3 additional rods are needed along each edge

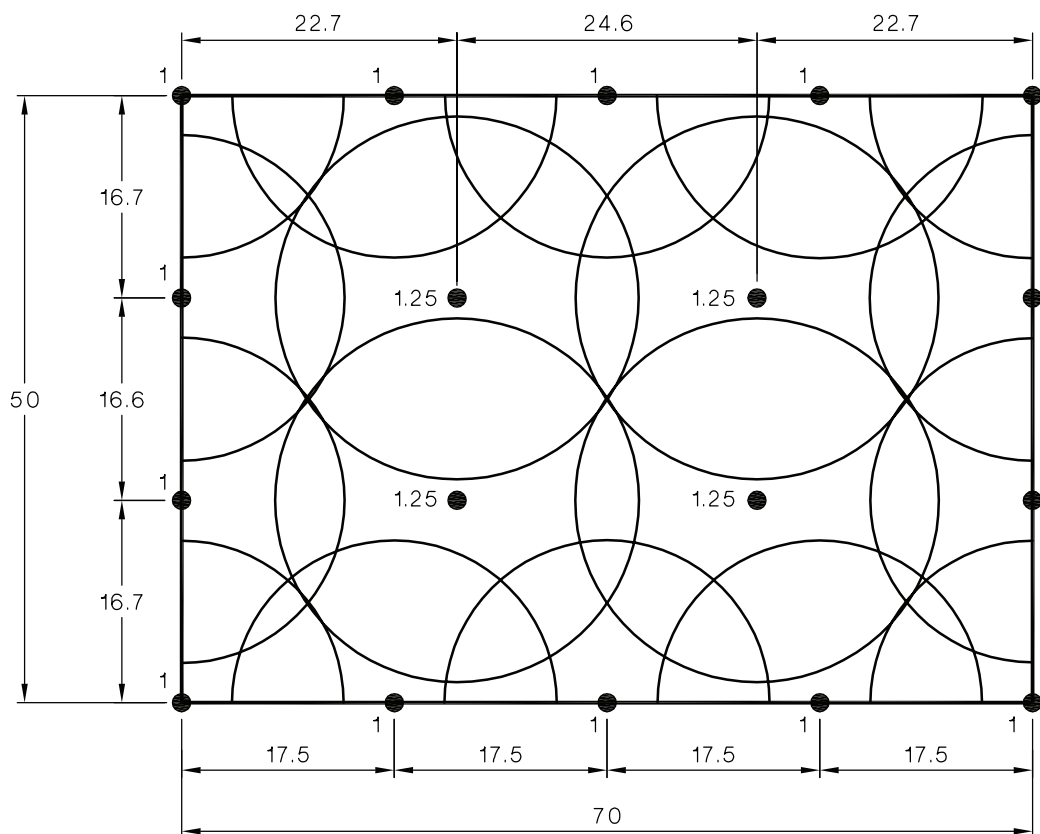
Check with rolling sphere of radius 45 m, okay (shown)

or

Place metal railings $h = 1$ m along the 4 edges (not shown)

This protects all 4 corners and 4 edges

FIGURE 4.2 APPLICATION OF STEP (a) OF RSM (WITH THE MODIFICATION FOR FLAT SURFACES) FOR PROTECTION LEVEL III FOR A RECTANGULAR STRUCTURE OF DIMENSIONS 70 X 50 X 20 m USING EITHER VERTICAL ROD OR RAISED HORIZONTAL CONDUCTOR AIR TERMINALS



PLAN VIEW

Step (b): Using increased sphere radius a_i to determine if more terminals are required

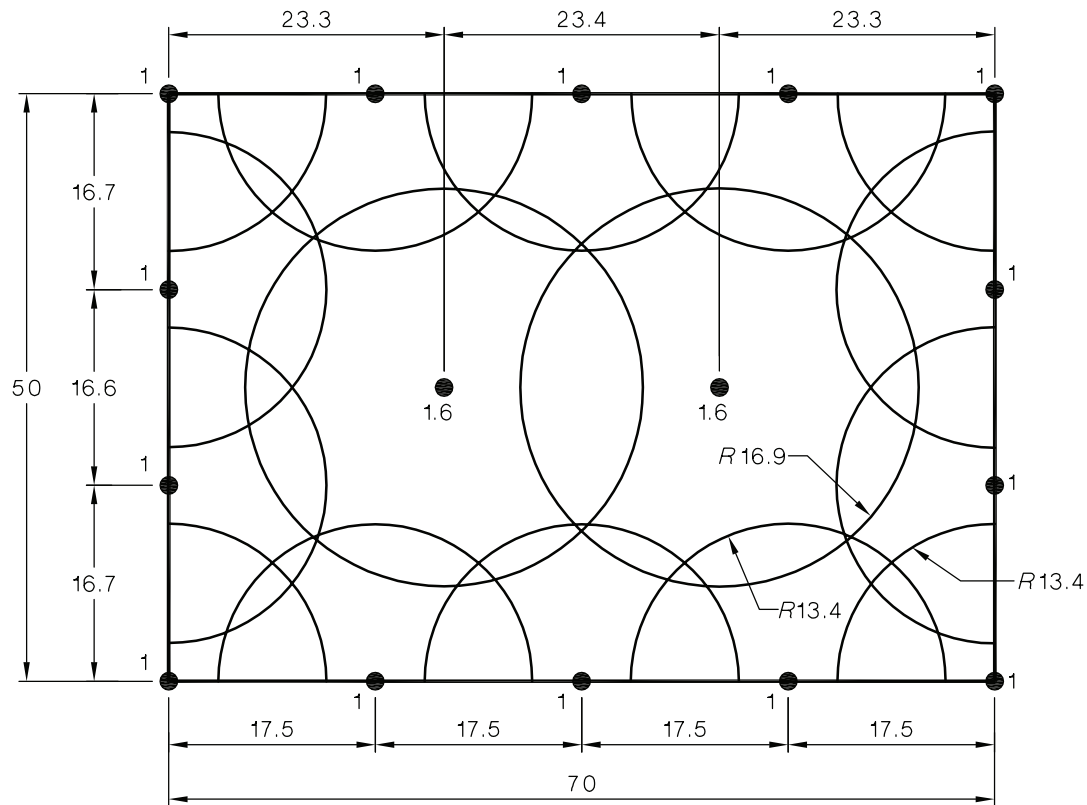
14 × 1 m rods plus 4 × 1.25 m rods

Using Equation 4.4.2(2),

$$r_i = \sqrt{(2a_i h - h^2)} = 15 \text{ m}$$

The building is protected

FIGURE 4.3(a) APPLICATION OF STEP (b) OF RSM (WITH THE MODIFICATION FOR FLAT SURFACES) FOR PROTECTION LEVEL III FOR A RECTANGULAR STRUCTURE OF DIMENSIONS 70 × 50 × 20 m USING 4 × 1.25 m VERTICAL RODS ON THE INTERIOR PLANE SURFACE



PLAN VIEW

Step (b): Using increased sphere radius a_i to determine if more terminals are required

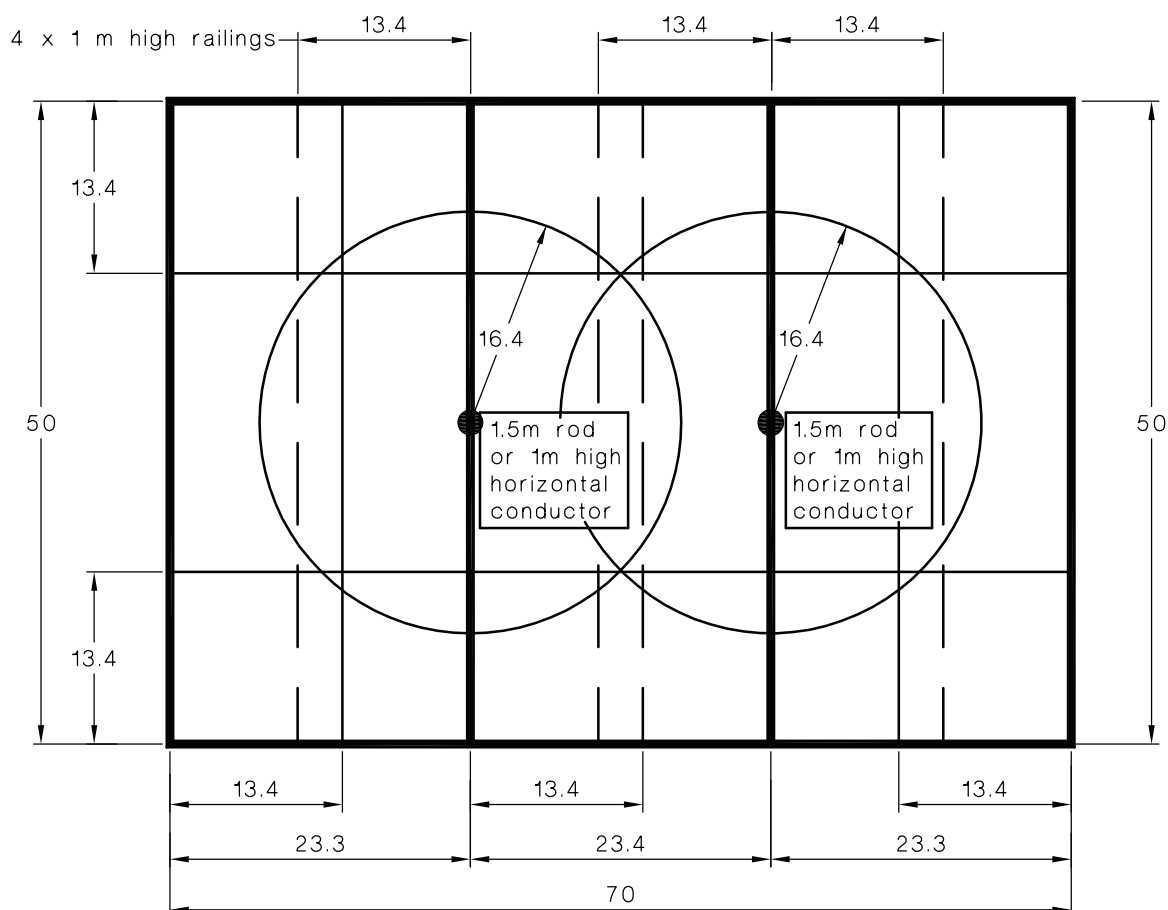
14 × 1 m rods plus 2 × 1.6 m rods

Using Equation 4.4.2(2),

$$r_i = \sqrt{(2a_i h - h^2)} = 16.9 \text{ m}$$

The building is protected

FIGURE 4.3(b) AN ALTERNATIVE APPLICATION OF STEP (b) OF RSM (WITH THE MODIFICATION FOR FLAT SURFACES) FOR PROTECTION LEVEL III FOR A RECTANGULAR STRUCTURE OF DIMENSIONS 70 × 50 × 20 m USING 2 × 1.6 m VERTICAL RODS ON THE INTERIOR PLANE SURFACE



PLAN VIEW

Step (b): Using increased sphere radius a_i to determine if more terminals are required

Either,

1 (or more) additional raised horizontal conductors $h = 1$ m to protect the flat roof

Using Equation 4.2.2(2), $r_i = \sqrt{(2a_i h - h^2)} = 13.4$ m

Using Equation 4.2.2(3), $d_{hc} \leq 2r_i = 26.8$ m, but is $<$ the 70 m between the

edge railings, and so the 4 railings along the edges do not protect all the roof

Add 2 additional raised horizontal conductors $h = 1$ m and all the roof is protected (shown)

So need 4 x 1 m high railings plus 2 additional 1 m high raised horizontal conductors

or

The 2 additional raised horizontal conductors could be replaced by 2 x 1.5 m vertical rods ($r = 16.4$ m) as shown

FIGURE 4.3(c) AN ALTERNATIVE APPLICATION OF RSM (WITH MODIFICATION FOR FLAT SURFACES) FOR PROTECTION LEVEL III FOR A RECTANGULAR STRUCTURE OF DIMENSIONS 70 x 50 x 20 m USING RAISED HORIZONTAL CONDUCTORS ONLY OR RAISED HORIZONTAL CONDUCTORS ON BUILDING CORNERS AND EDGES AND VERTICAL RODS ON THE INTERIOR PLANE SURFACES

TABLE 4.3
HEIGHT AND SPACING OF AIR TERMINALS TO PROTECT ROOFS

dimensions in metres

Protection level	Height of air terminal ¹⁾ h	Edges and corners of roof protected by vertical rod or raised horizontal conductor		Middle of flat roof		
		Horizontal distance for which roof is protected r $(= \sqrt{2ah - h^2})$	Maximum spacing for array d $(= r \cdot 2)$	Horizontal distance for which roof is protected r_i $(= \sqrt{2a_i h - h^2})$	Maximum spacing for an array of vertical rods d_{vr} $(= r_i \sqrt{2})$	Maximum spacing for raised horizontal conductor ²⁾ d_{hc} $(= r_i \cdot 2)$
I ($a = 20$ m, $a_i = 60$ m)	0.5	4.4	8.9	7.7	10.9	15.5
	1	6.2	12.5	10.9	15.4	21.8
	2	8.7	17.4	15.4	21.7	30.7
II ($a = 30$ m, $a_i = 60$ m)	0.5	5.5	10.9	7.7	10.9	15.5
	1	7.7	15.4	10.9	15.4	21.8
	2	10.8	21.5	15.4	21.7	30.7
III ($a = 45$ m, $a_i = 90$ m)	0.5	6.7	13.4	9.5	13.4	18.9
	1	9.4	18.9	13.4	18.9	26.8
	2	13.3	26.5	18.9	26.7	37.7
IV ($a = 60$ m, $a_i = 120$ m)	0.5	7.7	15.5	10.9	15.5	21.9
	1	10.9	21.8	15.5	21.9	30.9
	2	15.4	30.7	21.8	30.9	43.6

¹⁾ For other air terminal heights (h) use equations 4.4.2(1), (2) and (3).

²⁾ For further information on raised horizontal conductors placed on the roof, see Clause 4.11.2.

4.5 METHODS OF PROTECTION

4.5.1 Structural steel-framed buildings

Buildings with structural steel framing may be protected by the installation of metal air terminals at the high parts of the building, the air terminals being connected to the steel framing and the framing earthed in the vicinity of the foundation. A typical LPS is shown in Figure 4.4 (see also Clause 4.16.1).

4.5.2 Buildings without structural steel frames

4.5.2.1 General

The required conditions of protection for non-metallic buildings are generally met by placing metal air terminals on the uppermost parts of the building or its projections, with conductors connecting the air terminals to each other and to earth. By this means a relatively small amount of metal properly positioned and distributed can afford a satisfactory degree of protection and, if desired, the material may be placed so as to give minimum interference to the appearance of the building. A typical LPS is shown in Figure 4.5. Additional methods utilizing the individual characteristics of particular types of building construction are given in Clauses 4.5.2.2 to 4.5.2.4, and in Figure 4.4.

4.5.2.2 Structures with continuous metal

Structures containing continuous metal, e.g. metal within a roof, wall, floor or covering may, if the amount and arrangement of the metal is adequate in terms of the recommendations of Clauses 4.12 to 4.16, utilize such metal as part of the LPS.

4.5.2.3 Metal-roofed buildings

Lightning tends to strike the ridges, corners, parapets and edges of building roofs. Generally these attachment points coincide with the metal roof sheeting, capping or guttering being fixed by multiple screws, rivets or clips directly to the supporting steel purlins, beams and trusses below.

While a direct strike can puncture a hole in thin metal sheeting the instances of such damage are rare (refer to Paragraph B3, Appendix B for more information). For many buildings that are roofed, or roofed and clad, with metal, it may be possible to dispense with some or all air terminals provided the supporting roof steelwork is directly connected to a downconductor network or the earthing system. Any decision on dispensing with use of air terminals should consider the consequences of possible damage to the integrity of the roof and the contents within the building.

4.5.2.4 Reinforced concrete buildings

The following recommendations apply to the use of steel reinforcement in reinforced concrete buildings as part of the LPS (see also Paragraph B5.5.2, Appendix B):

- (a) *General* As far as possible, the steel reinforcement should be made electrically continuous in all concrete elements having a structural purpose, e.g. columns, beams and also in non-structural concrete elements, e.g. concrete wall panels, where the element, or a part of it, if dislodged, could endanger persons below.

Where the steel reinforcement is used as the downconductor system, an effective electrical connection should be made from the air terminal network to the steel reinforcement at the top of the building. Such connections should be made, by means such as welding or clamping to a minimum of four vertical and/or horizontal bars, to ensure a multiplicity of conductive paths for the discharge of lightning current.

NOTE: Steel reinforcement that is overlapped and tied by means of wire is not considered to provide an effective electrical connection for the purpose of air termination connection, however, such joints are acceptable elsewhere as part of the downconductor system where current sharing is assured.

Modern reinforced concrete structures frequently involve several structural techniques including *in situ* reinforced concrete, prestressed reinforced concrete and precast concrete; recommendations for these are listed in Items (b), (c) and (d).

- (b) *In situ reinforced concrete* Reinforcing steel rods are tied together by steel tie wire at splice points where reinforcing steel bars are overlapped for mechanical strength. Despite the fortuitous nature of the metallic connection, the very large number of rods and crossing points assures a subdivision of the total lightning current into a multiplicity of parallel discharge paths. Experience shows that with this splicing technique the rods can also be readily utilized as part of the LPS without thermal or mechanical damage to the structure.

NOTE: Particular recommendations on the size, material or number of tie wires are not given in this Standard, normal building practice being relied upon to provide adequate continuity.

Normal building practice also ensures the multiple conducting paths continue into the building foundations (see Note). The foundations are deep in the mass of earth and the resistivity of concrete is generally comparable with that of clay or other moderately conductive ground. Hence, except in soils of low resistivity, the resistance to earth from the foundation reinforcement is often lower than can be obtained economically with driven rods, because of the much greater surface area. Concrete foundations themselves constitute a satisfactory earth termination network but their use, as such, precludes the inclusion of base conductors. It is desirable, however, that a metallic connection to the reinforcing be installed, in a position suitable for the bonding of metallic services associated with the building.

NOTE: Conductive paths may not be ensured if special building techniques are used, e.g. grouting reinforcing bars into drilled holes in concrete after it has set, using an insulating epoxy-based material.

- (c) *Prestressed reinforced concrete* Prestressed reinforced concrete is used most commonly in the horizontal structural elements in a building, such as the beams and floor slabs, and only rarely in vertical elements such as columns. Consequently, the principal reason for avoiding insulating gaps in prestressed concrete relates to side-flashing rather than to the ability of the reinforcement to carry a lightning discharge to earth. See Clause 4.16.2 for details of the treatment of prestressed concrete in order to avoid side-flashing. These principles should be used in the rare instance where vertical prestressed elements, such as prestressed columns, occur in a building.

Although prestressed concrete affords a large reduction in the cross-sectional area of steel reinforcement compared with conventionally reinforced concrete, calculations indicate that prestressed cables of 10 mm diameter or more, will not be damaged thermally by lightning and that thermal effects become negligible when several cables are connected in parallel.

- (d) *Precast concrete* Where electrical continuity is required through precast concrete elements, the structural connection details, e.g. attachment plates, threaded ferrules, bolt or dowel connections, should be carefully examined from an electrical continuity standpoint. In most cases, the attachment device will be a metallic one and continuity can be achieved by simply welding the attachment device to electrically continuous reinforcement within the precast concrete element.

4.5.3 Structures with flammable or explosive atmosphere

Structures in which very small induced sparks present an appreciable element of danger, such as structures containing explosive atmospheres of flammable vapour or gas and structures in which easily ignitable fibres or materials producing combustible fines are stored, e.g. cotton, grain or explosives, usually require much more than the standard protection. Such structures can be protected by tall conducting masts earthed at the bottom, by bonding as detailed in Clause 4.16.2.2, or by overhead earthed wires (see Section 7).

4.6 MATTERS TO BE CONSIDERED WHEN PLANNING PROTECTION

4.6.1 Structures to be erected

For structures that are to be erected, the matter of lightning protection should be considered in the planning stage, as the necessary measures can often be effected in the architectural features without detracting from the appearance of the building. In addition to the aesthetic considerations, it is usually less expensive to install lightning protection during construction than afterwards.

4.6.2 Design considerations

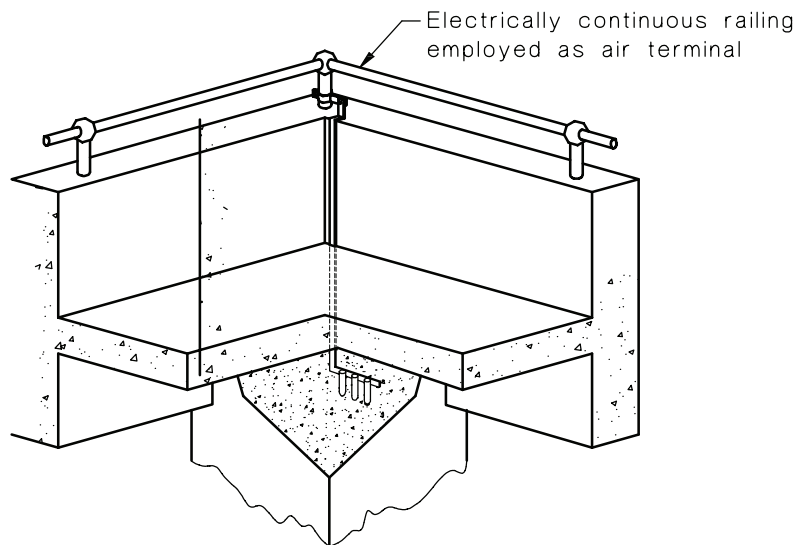
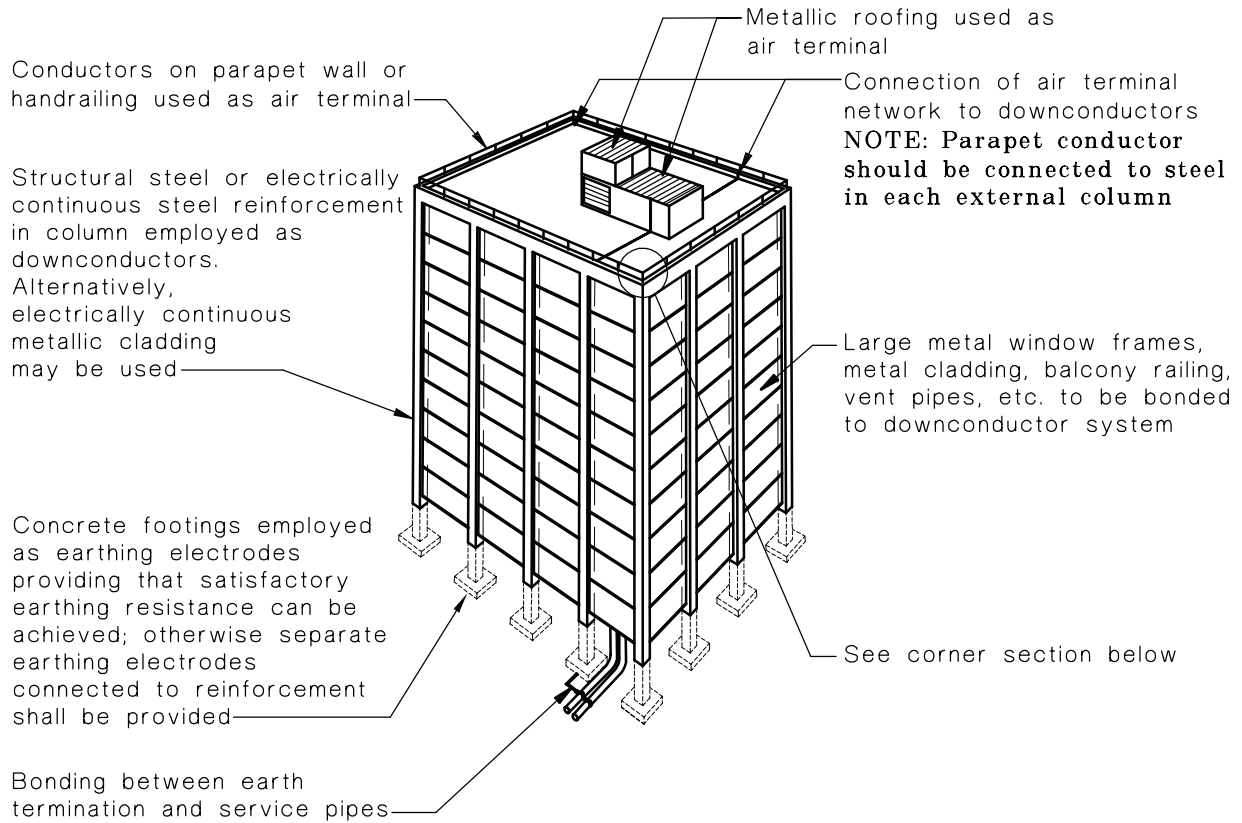
4.6.2.1 General considerations

The structure or, if the structure has not been built, the drawings, should be examined with due regard to all the relevant details of this Standard and in particular to the following:

- (a) Metal used in the roof, walls, framework or reinforcement above or below ground, e.g. sheet piling, to determine the suitability of such metal in place of, or for use as, components of the LPS.

NOTE: For a non-metallic roof, the position of any conduit, piping, water mains or other earthed metal immediately beneath the roof should be noted, as this may inadvertently attract a discharge if not shielded by an adjacent roof or structure, or downconductor on or above the roof.

- (b) Available positions for downconductors providing the required number of low impedance paths from the air terminal network to the earth termination; this is particularly important for internal downconductors.
- (c) The nature and resistivity of the soil as revealed by trial bore holes for foundation purposes or soil resistivity tests with, where economically practicable, the driving and testing of a trial earthing electrode with the object of designing a suitable earth termination.
- (d) Services entering the structure above and below ground.
- (e) Radio and television antennas and microwave communications antennae.
- (f) Flag masts, roof level plant rooms, e.g. lift motor rooms, ventilating plant and boiler rooms, water tanks and other salient features.
- (g) The construction of roofs to determine methods of fixing conductors with special regard to maintaining weatherproofing of the structure.
- (h) Possible penetration of waterproofing membrane where earth terminations are to be sited beneath the structure.
- (i) The provision of holes through, or fixing to, reinforced concrete.
- (j) The provision of bonding connections to steel frame, reinforcement rods or internal metalwork, and for any holes through the structure, parapets, cornices, and the like, to allow for the free passage of the lightning conductor.
- (k) The choice of metal most suitable for the conductor, e.g. aluminium conductors for structures where aluminium is employed externally.
- (l) Accessibility of test joints; protection by non-metallic casing from mechanical damage or pilferage and hazard to persons; lowering of flagmasts or other removable objects; facilities for periodic inspection, especially on tall chimneys.
- (m) The preparation of an outline drawing incorporating the foregoing details and showing the positions of the main components to form a basis for the record drawing recommended in Clause 8.4.
- (n) Requirements for the coordination of the structure's lightning protection earthing and the earthing of electricity supply and telecommunications services.



Corner section of structure giving an example of parapet railing employed as air terminal in reinforced concrete buildings.

FIGURE 4.4 TYPICAL LPS USING METAL IN OR ON A STRUCTURE

Height of air terminations is 1 m.
 Spacings of air terminals
 on roof to be in accordance with
 eqn(s) 4.4.2 in Clause 4.4.2

Shaded areas indicate parts
 of building requiring protection
 (without air terminals installed)

Placement of air terminals is most
 important at exposed corners and
 edges of roof on top
 vertical edges

Downconductors,
 spacing 20 m max.

To other
 downconductor
 test links

Earthing electrode(s)

It is desirable to interconnect
 LPS earth electrodes via a
 ring earth, see Figure E5

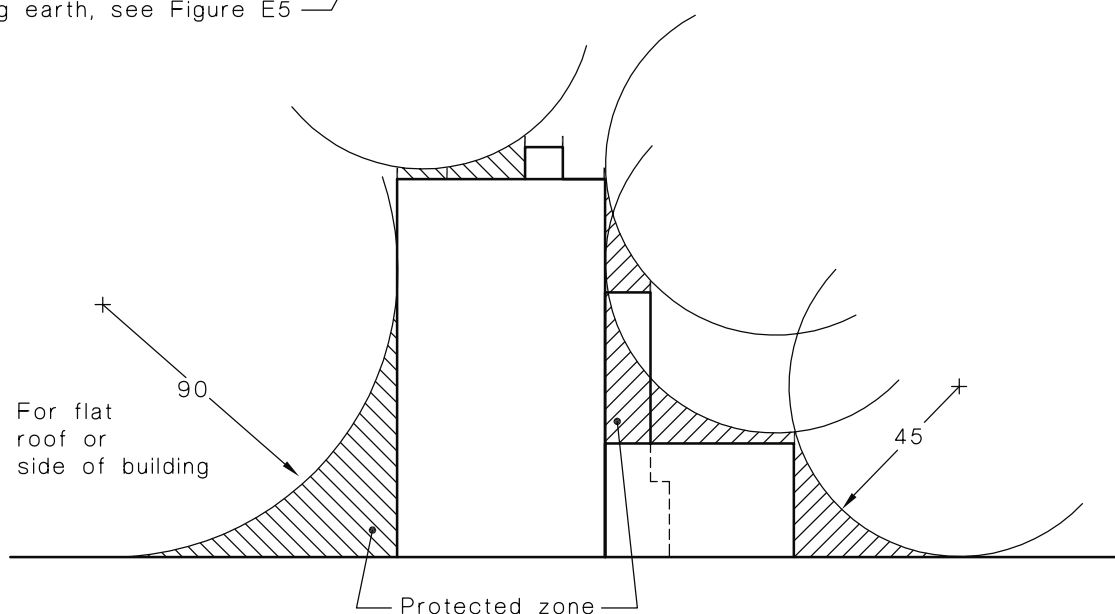


FIGURE 4.5 TYPICAL LPS EMPLOYING VERTICAL AIR TERMINALS, FOR PROTECTION LEVEL III

4.6.2.2 *Route for conductors*

Conductors should be installed with a view to offering the least impedance to the passage of discharge current between the air terminals and earth. The most direct path is the best (see Clause 4.12.2). The impedance to earth is approximately inversely proportional to the number of widely separated paths, so that from each air terminal there should be as many paths to earth as practicable. The number of paths is increased and the impedance decreased by connecting the conductors to form a cage enclosing the building.

4.6.2.3 *Trouble-free installation*

Since an LPS, as a general rule, is expected to remain in working condition for long periods with little attention, the mechanical construction should be strong, and the materials used should offer resistance to corrosion.

4.6.2.4 *Economy of installation*

Economy of installation can be effected by keeping the variety of equipment to a minimum, avoiding the use of unusual air terminal ornaments and similar features, and taking advantage of constructional features as far as practicable.

4.7 MATERIALS

4.7.1 General

Copper is recommended for its conductivity and durability; however, alternative materials may be used if suitable for the environment in which they are installed and are otherwise satisfactory for the purpose (see Clause 4.8). Typical materials from which the current-carrying component parts of LPSs may be chosen are given in Table 4.4 (see also Clause 4.7.2).

Where insulating coatings are used, due regard should be given to their durability and non-flammability.

For the protection of conductors at the tops of chimneys, see Clause 4.7.2.2(a).

4.7.2 Corrosion

4.7.2.1 *Basic considerations*

The materials used in LPSs should be resistant to corrosion resulting from the environment in which they are installed. This includes the effects of atmospheric, soil or water-borne electrolytes or contaminants, and of contact with those metals or alloys that will lead to galvanic corrosion in the presence of moisture.

Corrosion resulting from contact of dissimilar metals can exist where a conductor is held by fixing devices on or against external metal surfaces of a building or structure. Corrosion of this nature can also arise where water passes over a relatively cathodic metal such as copper carrying small amounts of copper corrosion product that is deposited as a fine film of metallic copper on relatively anodic metals such as aluminium, zinc or steel. This causes destructive galvanic corrosion of the latter metals, which are commonly used in building cladding or roofing. The metallic components of the LPS should therefore be compatible with the metals used externally on the structure over which these components pass or with which they may make contact.

The components of LPSs may be constructed from a variety of materials as described in Clauses 4.7.2.2 and 4.7.2.3.

4.7.2.2 *Air terminals and downconductors*

Specific recommendations for air terminals and downconductors are given in Clauses 4.11 and 4.12 respectively. Account should be taken of the principles outlined in Clause 4.7.2.1 in the selection of materials for those components.

Where there is a risk of metallic building elements being contaminated by corrosion products, e.g. from copper conductors, the use of insulated conductors should be considered. Such insulation may need protection against ultraviolet radiation, e.g. by enclosure in conduit or by the application of appropriate paints or coatings.

Where insulated cables are used as downconductors, bonding to the air terminal network should be effected at the specified intervals (see Clause 4.16.2.2) and bonding connections should be sealed against the ingress of moisture.

Where structural steel or reinforcing bars form part of the downconductor system no further corrosion-protection will normally be required.

With the common conductor materials, several specific precautions are necessary as follows:

- (a) *Bare copper* Copper should be of the grade ordinarily used for commercial electrical work.

NOTE: Where any part of a copper conductor used in an LPS is exposed to the direct action of chimney gases or other corrosive gases, it should be protected by a continuous coating of tin, lead or other material suitable for the environment to which it is exposed. Such a coating should extend not less than 500 mm below the top of a chimney or outside the area of exposure. The coating should not be removed at joints.

- (b) *Bare alloys* Galvanized iron or alloys of metals should be substantially as resistant to corrosion as copper under similar conditions. Galvanized iron may be used as part or the whole of the downconductor system provided it has adequate current-carrying capacity and is fastened with fittings having compatible corrosion characteristics. The galvanized iron may comprise the structural or decorative elements of the building subject to these requirements.
- (c) *Bare aluminium or aluminium alloys* Care should be taken not to use aluminium in contact with concrete, mortar, the ground, or in other situations where moisture may be retained causing the aluminium to deteriorate. Precautions should be observed at connections with dissimilar metals.

In aluminium LPSs, copper, copper-covered and copper alloy fixtures and fittings should not be used. Aluminium or aluminium alloy fixtures and fittings or non-metallic components of adequate strength and durability are required. Special arrangements will be needed at any earth terminations for this class of LPS.

Other materials may be used to the extent recommended elsewhere in this Standard.