NFPA® 780

Standard for the Installation of Lightning Protection Systems

2008 Edition

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NFPA® 780

Standard for the

Installation of Lightning Protection Systems

2008 Edition

This edition of NFPA 780, *Standard for the Installation of Lightning Protection Systems*, was prepared by the Technical Committee on Lightning Protection and acted on by NFPA at its June Association Meeting held June 3–7, 2007, in Boston, MA. It was issued by the Standards Council on July 26, 2007, with an effective date of August 15, 2007, and supersedes all previous editions.

This edition of NFPA 780 was approved as an American National Standard on August 15, 2007.

Origin and Development of NFPA 780

NFPA first adopted *Specifications for Protection of Buildings Against Lightning* in 1904. Revised standards were adopted in 1905, 1906, 1925, 1932, and 1937. In 1945, the NFPA Committee and the parallel ASA Committee on Protection Against Lightning were reorganized and combined under the sponsorship of NFPA, the National Bureau of Standards, and the American Institute of Electrical Engineers (now the IEEE). In 1946, NFPA acted to adopt Part III and in 1947 published a revised edition incorporating this part. Further revisions recommended by the Committee were adopted by NFPA in 1949, 1950, 1951, 1952, 1957, 1959, 1963, 1965, 1968, 1975, 1977, 1980, 1983, 1986, 1989, and 1992.

Commencing with the 1992 edition of the *Lightning Protection Code*, the NFPA numerical designation of the document was changed from NFPA 78 to NFPA 780.

With the issuance of the 1995 edition, the name of the document was changed from *Lightning Protection Code* to *Standard for the Installation of Lightning Protection Systems*. This change was directed by the Standards Council in order to make the title more accurately reflect the document's content. In addition, the Council directed certain changes to the scope of the document in order to clarify that the document did not cover lightning protection installation requirements for early streamer emission systems or lightning dissipater array systems.

The 1997 edition of NFPA 780 incorporated editorial changes to make the document more user friendly.

In issuing this document, the Standards Council has noted that lightning is a stochastic, if not capricious, natural process. Its behavior is not yet completely understood. This standard is intended to provide requirements, within the limits of the current state of knowledge, for the installation of those lightning protection systems covered by the standard.

The 2000 edition of NFPA 780 was amended to provide requirements for open structures such as those found on golf courses. A 1998 lightning flash density chart replaced the 1972 lightning frequency isoceraunic chart.

The 2004 edition of NFPA 780 reflected an extensive editorial revision of the standard to comply with the concurrent edition of the *NFPA Manual of Style for Technical Committee Documents*. These revisions included the addition of three administrative chapters at the beginning of the standard: "Administration," "Referenced Publications," and "Definitions." Five technical chapters followed the administrative chapters in the same sequence as in the 2000 edition. Other editorial revisions included the breakout of paragraphs with multiple requirements to individually numbered paragraphs for each requirement, the minimization of use of exceptions, the use of consistent headings for sections and section subdivisions, and reorganization to limit paragraph numbering to six digits. The International System of Units, commonly known as SI or metric, was used throughout the document. The appendixes were renamed annexes and reordered in a more logical sequence.

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The 2004 edition also contained a number of technical revisions throughout the standard. These included the following: a main conductor, solid strip, was added for Class II material requirements for ordinary structures exceeding 75 ft in height; handrails could be used as a substitute for down conductors; additional separation between ground rods was required where multiple ground rods are used; additional guidance was provided for those instances where it is necessary to install the grounding conductor directly on bedrock; the section entitled "Surge Suppression" was entirely rewritten; titanium strike termination devices were permitted to be used; and in Annex K the term *Faraday cage* was replaced with *metallic cage*.

The 2008 edition provides requirements for surge protective devices to be installed at all power service entrances, at the entrance of conductive communications systems and antenna systems, and where an electrical or electronic system conductor leaves the structure.

A new definition for Lightning Protection System is provided, which now includes "conductive structural members." Clarification is provided relative to the use of ancillary metal parts that cannot be substituted for the main conductor. Strike termination devices include air terminals, metal masts, certain permanent metal parts of structures, and elevated conductors. Revisions now clarify that metal masts and overhead ground wires are included in the requirements of Chapter 4.

Significant changes have been made to the requirements for the use of bimetallic clamps and aluminum in proximity to earth. The standard has long required grounding electrodes be located near the outside perimeter of the structure, and in the 2008 edition additional guidance is provided to assist the system designer. Changes have also been made to better address the requirements for grounding electrodes in shallow topsoil applications.

The requirements for the use of multiple ground rods have been revised. Revisions have also been made in numerous areas of the standard for clarity and to enhance its usability. Revisions to the graphs and formulas for the rolling sphere method have been made to facilitate their use in metric units.

Requirements have been added to address proper installation of lightning protection equipment on large rooftop mechanical units. The installation of air terminals and main-size conductors in these applications are quantified and detailed.

Revisions have been made to enhance and clarify the requirements for bonding together of all grounded media and underground metallic piping. The intent is to provide for potential equalization and not to use the metallic piping as a lightning protection system grounding electrode. All grounding media and buried metallic conductors that may assist in providing a path for lightning currents in or on a structure must be interconnected to provide a common ground potential. Guidance is provided on the use of isolating spark gaps.

Significant changes have been made to the requirements pertaining to the conductors and other lightning protection system hardware used near the top of a heavy-duty stack.

Other significant changes include a complete rewrite of Chapter 8, Protection for Watercraft, providing a number of technical revisions; more user information has been added in Annex B, Principles of Lightning Protection; and Annex F, Protection for Trees, has been revised.

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Committee Scope: This Committee shall have primary responsibility for documents on the protection from lightning of buildings and structures, recreation and sports areas, and any other situations involving danger from lightning to people or property, except those concepts utilizing early streamer emission air terminals. The protection of electric generating, transmission, and distribution systems is not within the scope of this Committee.

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Information on referenced publications can be found in Chapter 2 and Annex O.

Chapter 1 Administration

1.1 Scope.

1.1.1 This document shall cover traditional lightning protection system installation requirements for the following:

(1) Ordinary structures
(2) Miscellaneous structures and special occupancies
(3) Heavy-duty stacks
(4) Watercraft
(5) Structures containing flammable vapors, flammable gases, or liquids that give off flammable vapors

1.1.2* This document shall not cover lightning protection system installation requirements for the following:

(1) Explosives manufacturing buildings and magazines
(2) Electric generating, transmission, and distribution systems

1.1.3 This document shall not cover lightning protection system installation requirements for early streamer emission systems or charge dissipation systems.

1.2 Purpose. The purpose of this standard shall be to provide for the safeguarding of persons and property from hazards arising from exposure to lightning.

1.3 Listed, Labeled, or Approved Components. Where fittings, devices, or other components required by this standard are available as listed or labeled, such components shall be used.

1.4 Mechanical Execution of Work. Lightning protection systems shall be installed in a neat and workmanlike manner.

1.5* Maintenance. Recommended guidelines for the maintenance of the lightning protection system shall be provided to the owner at the completion of installation.

1.6 Metric Units of Measurement. Metric units of measurement in this standard shall be in accordance with the modernized metric system known as the International System of Units (SI).

1.6.1 If a value for measurement as given in this standard is followed by an equivalent value in other units, the first stated value shall be the requirement.

1.6.2 A given equivalent value shall be approximate.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 70, *National Electrical Code®*, 2008 edition.

2.3 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA 70, *National Electrical Code®*, 2008 edition.
NFPA 115, *Standard for Laser Fire Protection*, 2003 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

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3.2.3 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

3.2.4* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.5 Shall. Indicates a mandatory requirement.

3.2.6 Should. Indicates a recommendation or that which is advised but not required.

3.2.7 Standard. A document, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and which is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions shall be located in an appendix or annex, footnote, or fine-print note and are not to be considered a part of the requirements of a standard.

3.3 General Definitions.

3.3.1* Air Terminal. A strike termination device that is a receptor for attachment of flashes to the lightning protection system and is listed for the purpose.

3.3.2 Bonding. An electrical connection between an electrically conductive object and a component of a lightning protection system that is intended to significantly reduce potential differences created by lightning currents.

3.3.3* Cable. A conductor formed of a number of wires stranded together.

3.3.4 Catenary Lightning Protection System. A lightning protection system consisting of one or more overhead ground wires.

3.3.5 Chimney. A construction containing one or more flues that does not meet the criteria defined for heavy-duty stack.

3.3.6* Combination Waveform Generator. A surge generator with a 2-ohm internal impedance producing a 1.2/50 µs open circuit voltage and an 8/20 µs short-circuit current waveshape.

3.3.7 Conductor.

3.3.7.1 ***Bonding Conductor.*** A conductor used for potential equalization between grounded metal bodies or electrically conductive objects and a lightning protection system.

3.3.7.2 ***Loop Conductor.*** A conductor encircling a structure that is used to interconnect grounding electrodes, main conductors, or other electrically conductive bodies.

3.3.7.3* ***Main Conductor.*** A conductor intended to be used to carry lightning currents between strike termination devices and grounding electrodes.

3.3.8 Copper-Clad Steel. Steel with a coating of copper bonded to it.

3.3.9 Discharge Current.

3.3.9.1 ***Maximum Discharge Current (I_{max}).*** The maximum instantaneous value of the current through the SPD having an 8/20 µs waveform.

3.3.9.2 ***Nominal Discharge Current (I_n).*** Peak value of 8/20 µs current waveform selected by the manufacturer for which an SPD remains functional after 15 surges.

3.3.10 Fastener. An attachment device used to secure the conductor to the structure.

3.3.11 Flame Protection. Self-closing gauge hatches, vapor seals, pressure-vacuum breather valves, flame arresters, or other effective means to minimize the possibility of flame entering the vapor space of a tank.

3.3.12* Flammable Air–Vapor Mixtures. Flammable vapors mixed with air in proportions that will cause the mixture to burn rapidly when ignited.

3.3.13 Flammable Vapors. A concentration of constituents in air that exceeds 10 percent of its lower flammable limit (LFL). [**115,** 2003]

3.3.14 Flash Point. The minimum temperature at which a liquid or a solid emits vapor sufficient to form an ignitible mixture with air near the surface of the liquid or the solid.

3.3.15 Gastight. Describes a structure so constructed that gas or air cannot enter or leave the structure except through vents or piping provided for the purpose.

3.3.16 Grounded (Grounding). Connected (connecting) to ground or to a conductive body that extends the ground connection. [**70:** Article 100]

3.3.17 Grounding Electrode. The portion of a lightning protection system, such as a ground rod, ground plate electrode, or ground conductor, that is installed for the purpose of providing electrical contact with the earth.

3.3.18 Heavy-Duty Stack. A smoke or vent stack with a flue that has a cross-sectional area of the flue greater than 0.3 m^2 (500 $in.^2$) and a height greater than 23 m (75 ft).

3.3.19* Lightning Protection System. A complete system of strike termination devices, conductors (which could include conductive structural members), grounding electrodes, interconnecting conductors, surge protective devices, and other connectors and fittings required to complete the system.

3.3.20 Liquid.

3.3.20.1 ***Class I Flammable Liquid.*** Any liquid that has a closed-cup flash point below 37.8°C (100°F) and a Reid vapor pressure not exceeding an absolute pressure of 276 kPa (40 psi) at 37.8°C (100°F).

3.3.20.2 ***Combustible Liquid.*** Any liquid that has a closed-cup flash point at or above 37.8°C (100°F).

3.3.21 Materials.

3.3.21.1* ***Class I Materials.*** Lightning conductors, air terminals, grounding electrodes, and associated fittings required for the protection of structures not exceeding 23 m (75 ft) in height.

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3.3.21.2* ***Class II Materials.*** Lightning conductors, air terminals, grounding electrodes, and associated fittings required for the protection of structures exceeding 23 m (75 ft) in height.

3.3.21.3 ***Explosive Materials.*** Materials, including explosives, blasting agents, and detonators, that are authorized for transportation by the Department of Transportation or the Department of Defense as explosive materials.

3.3.22 Sideflash. An electrical spark, caused by differences of potential, that occurs between conductive metal bodies or between conductive metal bodies and a component of a lightning protection system or ground.

3.3.23 Spark Gap. Any short air space between two conductors that are electrically insulated from or remotely electrically connected to each other.

3.3.24 Strike Termination Device. A component of a lightning protection system that intercepts lightning flashes and connects them to a path to ground. Strike termination devices include air terminals, metal masts, permanent metal parts of structures as described in Section 4.9, and overhead ground wires installed in catenary lightning protection systems.

3.3.25 Striking Distance. The distance over which the final breakdown of the initial lightning stroke to ground or to a grounded object occurs.

3.3.26 Structure.

3.3.26.1 ***Metal-Clad Structure.*** A structure with sides or roof, or both, covered with metal.

3.3.26.2 ***Metal-Framed Structure.*** A structure with electrically continuous structural members of sufficient size to provide an electrical path equivalent to that of lightning conductors.

3.3.27* Suppressed Voltage Rating (SVR). A specific measured limiting voltage rating assigned to a surge protective device (SPD).

3.3.28 Surge. A transient wave of current, potential, or power in an electric circuit. Surges do not include longer duration temporary overvoltages (TOV) consisting of an increase in the power frequency voltage for several cycles.

3.3.29 Surge Arrester. A protective device for limiting surge voltages by discharging or bypassing surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions. [**70:** Article 100]

3.3.30 Surge Protective Device (SPD). A device composed of any combination of linear or nonlinear circuit elements intended for limiting surge voltages on equipment by diverting or limiting surge current.

3.3.31 Transient. A subcycle disturbance in the ac waveform that is evidenced by a sharp, brief discontinuity of the waveform. It can be of either polarity and can be additive to, or subtractive from, the nominal waveform.

3.3.32 Transient Voltage Surge Suppressor (TVSS). A protective device for limiting transient voltages by diverting or limiting surge current; it also prevents continued flow of follow current while remaining capable of repeating these functions.

3.3.33 Vapor Opening. An opening through a tank shell or roof that is above the surface of the stored liquid and that is provided for tank breathing, tank gauging, fire fighting, or other operating purposes.

3.3.34 Voltage.

3.3.34.1 ***Maximum Continuous Operating Voltage (MCOV).*** The maximum designated rms value of the power frequency voltage that can be continuously applied to the mode of protection of a surge protective device (SPD).

3.3.34.2 ***Measured Limiting Voltage (MLV).*** Maximum magnitude of voltage that is measured across the terminals of the surge protective device (SPD) during the application of impulses of specified waveshape and amplitude.

3.3.34.3 ***Nominal System Voltage.*** The nominal voltage (rms) of the power frequency supply.

3.3.34.4 ***Normal Operating Voltage.*** The normal ac power frequency voltage rating, as specified by the manufacturer, to which the SPD may be connected.

3.3.35 Voltage Protection Rating (VPR). A rating (or ratings) selected by the manufacturer based on the measured limiting voltage determined when the SPD is subjected to a combination waveform with an open circuit voltage of 6 kV and a short-circuit current of 3 kA . The value is rounded up to the next highest 100 V level.

3.3.36 Watercraft. All forms of boats and vessels up to 272 metric tons (300 gross tons) used for pleasure or commercial purposes, but excluding seaplanes, hovercraft, vessels with a cargo of flammable liquids, and submersible vessels.

3.3.37 Zone of Protection. The space adjacent to a lightning protection system that is substantially immune to direct lightning flashes.

Chapter 4 Protection for Ordinary Structures

4.1 General.

4.1.1 Ordinary Structures. An ordinary structure shall be any structure that is used for ordinary purposes, whether commercial, industrial, farm, institutional, or residential.

4.1.1.1 Ordinary structures shall be protected according to 4.1.1.1(A) or 4.1.1.1(B).

(A) Ordinary structures not exceeding 23 m (75 ft) in height shall be protected with Class I materials as shown in Table 4.1.1.1(A).

(B) Ordinary structures exceeding 23 m (75 ft) in height shall be protected with Class II materials as shown in Table 4.1.1.1(B).

4.1.1.2 If part of a structure exceeds 23 m (75 ft) in height (e.g., a steeple) and the remaining portion does not exceed 23 m (75 ft) in height, the requirements for Class II air terminals and conductors shall apply only to that portion exceeding 23 m (75 ft) in height.

4.1.1.3 Class II conductors from the higher portion shall be extended to ground and shall be interconnected with the balance of the system.

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Table 4.1.1.1(A) Minimum Class I Material Requirements

		Copper		Aluminum	
Type of Conductor	**Parameter**	**SI**	**U.S.**	**SI**	**U.S.**
Air terminal, solid	Diameter	9.5 mm	⅜ in.	12.7 mm	½ in.
Air terminal, tubular	Diameter	15.9 mm	⅝ in.	15.9 mm	⅝ in.
	Wall thickness	0.8 mm	0.033 in.	1.63 mm	0.064 in.
Main conductor, cable	Size each strand		17 AWG		14 AWG
	Weight per length	278 g/m	187 lb/1000 ft	141 g/m	95 lb/1000 ft
	Cross section area	29 mm^2	57,400 cir. mils	50 mm^2	98,600 cir. mils
Bonding conductor, cable (solid or stranded)	Size each strand		17 AWG		14 AWG
	Cross section area		26,240 cir. mils		41,100 cir. mils
Bonding conductor, solid strip	Thickness	1.30 mm	0.051 in.	1.63 mm	0.064 in.
	Width	12.7 mm	½ in.	12.7 mm	½ in.
Main conductor, solid strip	Thickness	1.30 mm	0.051 in.	1.63 mm	0.064 in.
	Cross section area	29 mm^2	57,400 cir. mils	50 mm^2	98,600 cir. mils

Table 4.1.1.1(B) Minimum Class II Material Requirements

		Copper		Aluminum	
Type of Conductor	**Parameter**	**SI**	**U.S.**	**SI**	**U.S.**
Air terminal, solid	Diameter	12.7 mm	½ in.	15.9 mm	⅝ in.
Main conductor, cable	Size each strand		15 AWG		13 AWG
	Weight per length	558 g/m	375 lb/1000 ft	283 g/m	190 lb/1000 ft
	Cross section area	58 mm^2	115,000 cir. mils	97 mm^2	192,000 cir. mils
Bonding conductor, cable (solid or stranded)	Size each strand		17 AWG		14 AWG
	Cross section area		26,240 cir. mils		41, 100 cir. mils
Bonding conductor, solid strip	Thickness	1.30 mm	0.051 in.	1.63 mm	0.064 in.
	Width	12.7 mm	½ in.	12.7 mm	½ in.
Main conductor, solid strip	Thickness	1.63 mm	0.064 in.	2.61 mm	0.1026 in.
	Cross section area	58 mm^2	115,000 cir. mils	97 mm^2	192,000 cir. mils

4.1.2 Roof Types and Pitch. For the purpose of this standard, protection for the various roof types shall be as shown in Figure 4.1.2.

4.1.2.1 Protection for a shed roof shall be as illustrated for the gable method in Figure 4.1.2.

4.1.2.2 For purposes of this standard, roof pitches shall be as shown in Figure 4.1.2.2.

4.2 Materials. Protection systems shall be made of materials that are resistant to corrosion or protected against corrosion.

4.2.1 Combinations of materials that form electrolytic couples of such a nature that, in the presence of moisture, corrosion is accelerated shall not be used.

4.2.2 One or more of the materials in 4.2.2.1 through 4.2.2.3 shall be used.

4.2.2.1 Copper. Copper shall be of the grade required for commercial electrical work and shall be of 95 percent conductivity when annealed.

4.2.2.2 Copper Alloys. Copper alloy shall be as resistant to corrosion as copper.

4.2.2.3 Aluminum.

(A) Aluminum shall not be used where contact with the earth is possible or where rapid deterioration is possible.

(B) Conductors shall be of electrical grade aluminum.

4.2.3 Copper lightning protection materials shall not be installed on or in contact with aluminum roofing, aluminum siding, or other aluminum surfaces.

4.2.4 Aluminum lightning protection materials shall not be installed on or in contact with copper surfaces.

4.3 Corrosion Protection.

4.3.1 Protection shall be provided against deterioration of lightning protection components due to local conditions.

4.3.2 Copper components installed within 600 mm (24 in.) of the top of a chimney or vent emitting corrosive gases shall be protected by a hot-dipped lead or tin coating.

4.3.3 Connectors and Fittings.

4.3.3.1 Connectors and fittings shall be compatible for use with the conductor and the surfaces on which they are installed.

4.3.3.2 Bimetallic connectors and fittings shall be used for splicing or bonding dissimilar metals.

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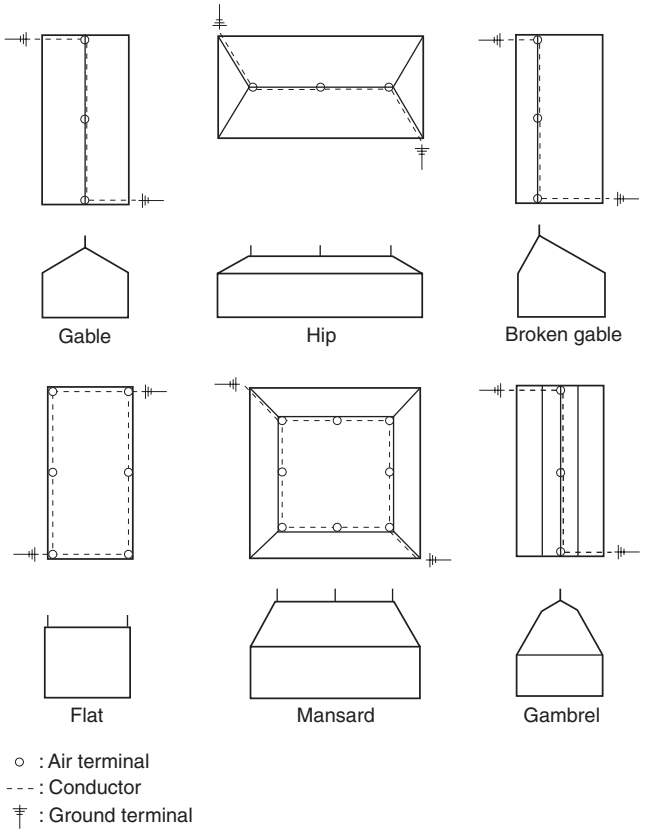
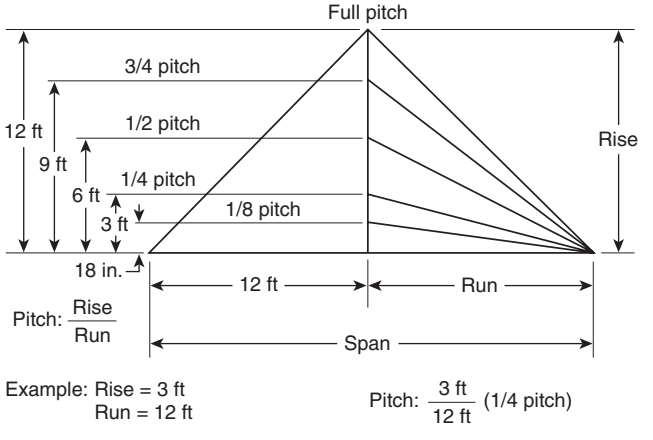


FIGURE 4.1.2 Roof Types: Protection Methods. (Drawings are top and end views of each roof type.)



For SI units, 1 in. = 25.4 mm; 1 ft = 0.305 m.

FIGURE 4.1.2.2 Roof Pitch.

4.4 Mechanical Damage or Displacement.

4.4.1 Any part of a lightning protection system that is subject to mechanical damage or displacement shall be protected with a protective molding or covering.

4.4.2 Where metal pipe or tubing is used around the conductor, the conductor shall be bonded to the pipe or tubing at both ends.

4.5 Use of Aluminum. Aluminum systems shall be installed in accordance with other applicable sections and 4.5.1 through 4.5.3.

4.5.1 Aluminum lightning protection equipment shall not be installed on or in direct contact with copper roofing materials or other copper surfaces, or where exposed to runoff from copper surfaces.

4.5.2 Aluminum materials shall not be used within 460 mm (18 in.) of the point where the lightning protection system conductor comes into contact with the earth.

4.5.2.1 Fittings used for the connection of aluminum down conductors to copper or copper-clad grounding equipment shall be of the bimetallic type.

4.5.2.2 Bimetallic connectors shall be installed not less than 460 mm (18 in.) above earth level.

4.5.3 An aluminum conductor shall not be attached to a surface coated with alkaline-base paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture.

4.6 Strike Termination Devices.

4.6.1 General.

4.6.1.1 Strike termination devices include air terminals, metal masts, permanent metal parts of structures as described in Section 4.9, and overhead ground wires. Combination of these strike termination devices shall be permitted.

4.6.1.2 Strike termination devices shall be provided where required by other sections of this standard.

4.6.1.3 Metal parts of a structure that are exposed to direct lightning flashes and that have a metal thickness of 4.8 mm ($^3/_{16}$ in.) or greater shall require only connection to the lightning protection system.

4.6.1.4 Such connections shall provide a minimum of two paths to ground.

4.6.1.5 Strike termination devices shall not be required for those parts of a structure located within a zone of protection.

4.6.2* Air Terminal Height. The tip of an air terminal shall be not less than 254 mm (10 in.) above the object or area it is to protect, as shown in Figure 4.6.2.

4.6.3 Air Terminal Support.

4.6.3.1 Air terminals shall be secured against overturning or displacement by one of the following methods:

(1) Attachment to the object to be protected
(2) Braces that are permanently and rigidly attached to the structure

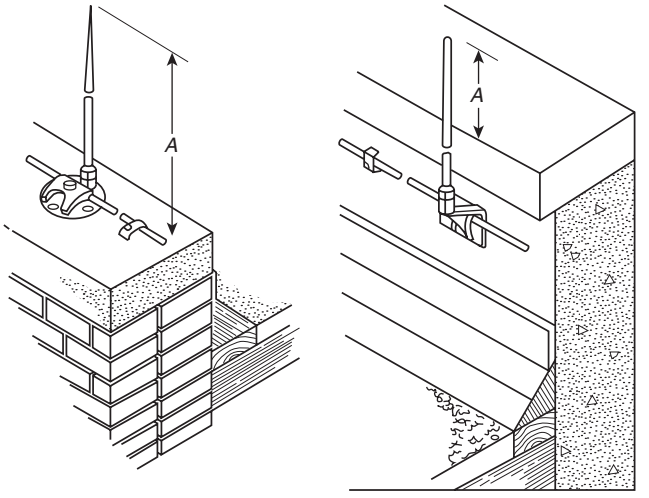
4.6.3.2 Air terminals exceeding 600 mm (24 in.) in height above the area or object they are to protect shall be supported at a point not less than one-half their height, as shown in Figure 4.6.3.2.

4.6.4 Ornaments.

4.6.4.1 An ornament or decoration on a freestanding, unbraced air terminal shall not present, in any plane, a wind-resistance area in excess of 0.01 m^2 (20 $in.^2$).

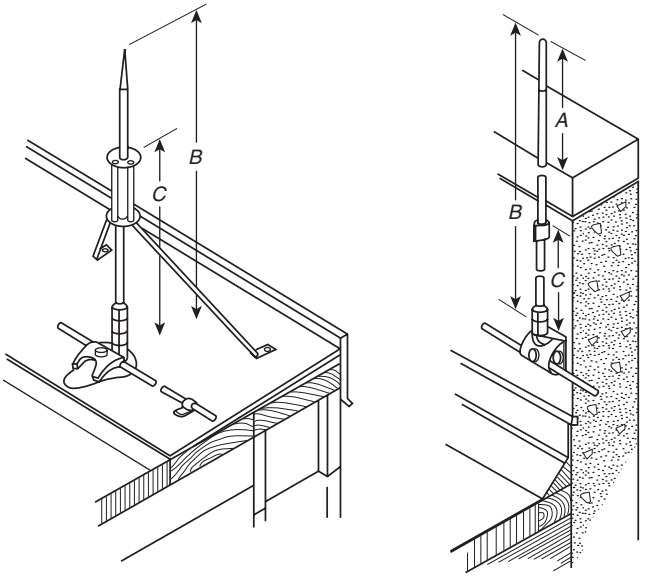
4.6.4.2 The requirement of 4.6.4.1 shall permit the use of an ornamental ball 127 mm (5 in.) or less in diameter.

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A: 254 mm (10 in.)
Note: Air terminal tip configurations can be sharp or blunt.

FIGURE 4.6.2 Air Terminal Height.



A: 600 mm (24 in.)
B: Air terminals over 600 mm (24 in.) high are supported
C: Air terminal supports are located at a point not less than one-half the height of the air terminal
Note: Air terminal tip configurations can be sharp or blunt.

FIGURE 4.6.3.2 Air Terminal Support.

4.7 Zones of Protection. The geometry of the structure shall determine the zone of protection. One or more methods, as described in 4.7.1 through 4.7.3.4.2, shall be used to determine the overall zone of protection.

4.7.1 Roof Types. The zone of protection for the following roof types shall include the roof and appurtenances where protected in accordance with Section 4.8:

(1) Flat or gently sloping roofs
(2) Dormers
(3) Domed roofs
(4) Roofs with ridges, wells, chimneys, or vents

4.7.2 Multiple-Level Roofs.

4.7.2.1 For structures with multiple-level roofs no more than 15 m (50 ft) in height, the zone of protection shall include areas as identified in 4.7.2.3 and 4.7.2.4.

4.7.2.2 The zone of protection is a cone with the apex located at the highest point of the strike termination device, with its surface formed by a 45-degree or 63-degree angle from the vertical.

4.7.2.3 Structures that do not exceed 7.6 m (25 ft) above earth shall be considered to protect lower portions of a structure located within a one-to-two zone of protection as shown in Figure 4.7.2.3(a) and Figure 4.7.2.3(b).

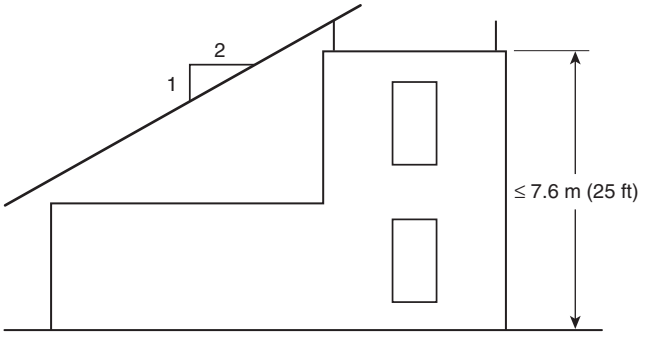


FIGURE 4.7.2.3(a) Lower Roof Protection for Flat Roof Buildings 7.6 m (25 ft) or Less in Height.

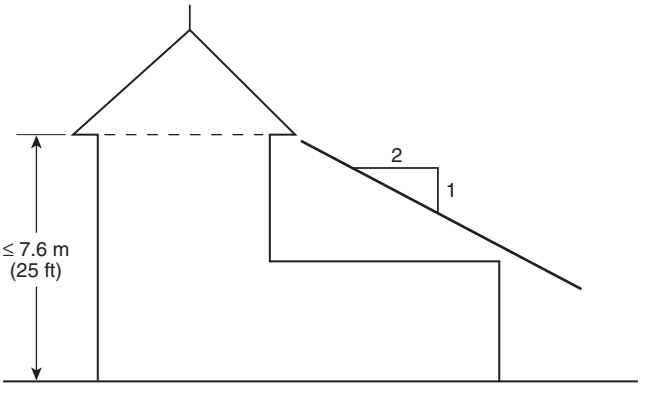


FIGURE 4.7.2.3(b) Lower Roof Protection Provided by Pitched Roof Buildings 7.6 m (25 ft) or Less in Height.

4.7.2.4 Structures that do not exceed 15 m (50 ft) above earth shall be considered to protect lower portions of a structure located within a one-to-one zone of protection as shown in Figure 4.7.2.4(a) and Figure 4.7.2.4(b).

4.7.3 Rolling Sphere Method.

4.7.3.1 The zone of protection shall include the space not intruded by a rolling sphere having a radius of 46 m (150 ft).

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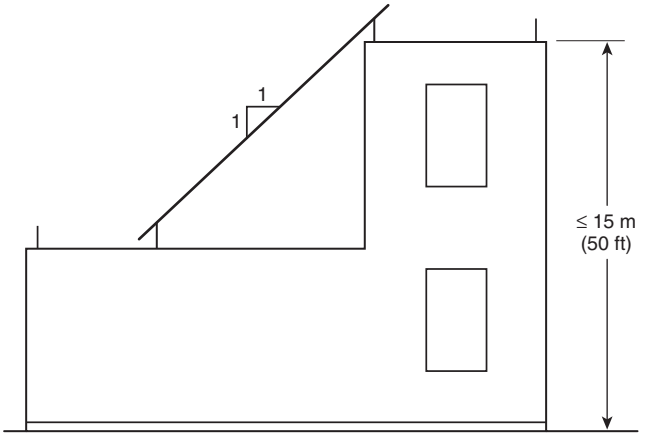


FIGURE 4.7.2.4(a) Lower Roof Protection for Buildings 15 m (50 ft) or Less in Height.

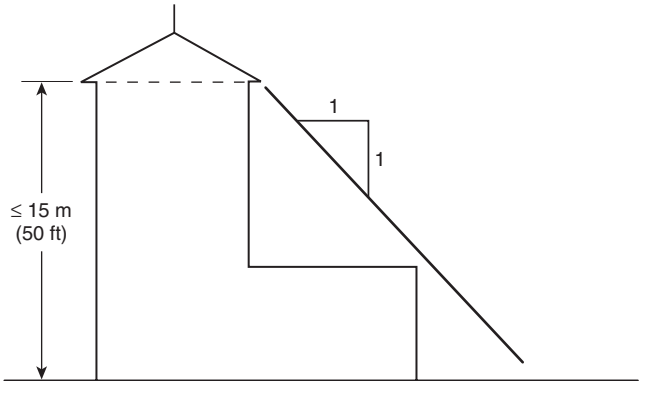


FIGURE 4.7.2.4(b) Lower Roof Protection Provided by Pitched Roof Buildings 15 m (50 ft) or Less in Height.

(A) Where the sphere is tangent to earth and resting against a strike termination device, all space in the vertical plane between the two points of contact and under the sphere shall be considered to be in the zone of protection.

(B) A zone of protection shall also be formed where such a sphere is resting on two or more strike termination devices and shall include the space in the vertical plane under the sphere and between those devices, as shown in Figure 4.7.3.1(B).

(C) All possible placements of the sphere shall be considered when determining the overall zone of protection using the rolling sphere method.

4.7.3.2* For structure heights exceeding 46 m (150 ft) above earth or above a lower strike termination device, the zone of protection shall be the space in the vertical plane between the points of contact, and also under the sphere where the sphere is resting against a vertical surface of the structure and the lower strike termination device(s) or earth.

4.7.3.3 Figure 4.7.3.3 depicts the 46 m (150 ft) rolling sphere method for structures of selected heights up to 46 m (150 ft). Based on the height of the strike termination device for a protected structure being 7.6 m (25 ft), 15 m (50 ft), 23 m (75 ft), 30 m (100 ft), or 46 m (150 ft) above ground, reference to the appropriate curve shows the anticipated zone of protection for objects and roofs at lower elevations.

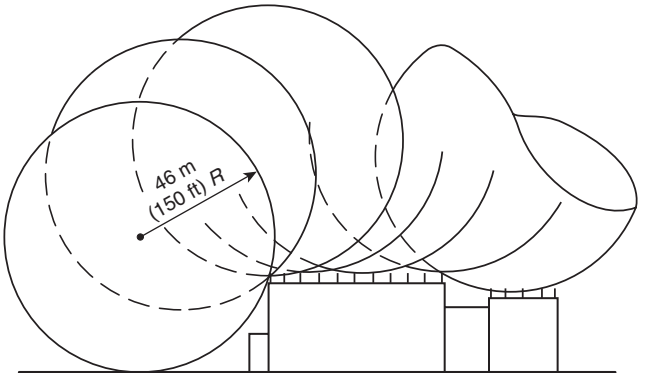


FIGURE 4.7.3.1(B) Zone of Protection Depicting a Rolling Sphere.

(A) The graph shows the protected distance ("horizontal distance") as measured radially from the protected structure.

(B) The horizontal distance thus determined shall apply only at the horizontal plane of the "height protected."

4.7.3.4 Under the rolling sphere method, the horizontal protected distance found geometrically by Figure 4.7.3.3 ("horizontal protected distance, m" or "horizontal protected distance, ft") also shall be permitted to be calculated using the following formula (units shall be consistent, m or ft):

$$d = \sqrt{h_1(2R - h_1)} - \sqrt{h_2(2R - h_2)}$$

where:
d = horizontal protected distance
h_1 = height of the higher roof
R = rolling sphere radius [46 m (150 ft)]
h_2 = height of the lower roof (top of the object)

4.7.3.4.1 Use of this formula shall be based on a 46 m (150 ft) striking distance.

4.7.3.4.2 For the formula to be valid, the sphere shall be either tangent to the lower roof or in contact with the earth, and in contact with the vertical side of the higher portion of the structure.

(A) In addition, the difference in heights between the upper and lower roofs or earth shall be 46 m (150 ft) or less.

4.8 Strike Termination Devices on Roofs.

4.8.1 Pitched Roofs.

(A) Pitched roofs shall be defined as roofs having a span of 12 m (40 ft) or less and a pitch 1/8 or greater, and roofs having a span of more than 12 m (40 ft) and a pitch 1/4 or greater.

(B) All other roofs shall be considered gently sloping and are to be treated as flat.

4.8.2* Location of Devices. As shown in Figure 4.8.2, the distance between strike termination devices and ridge ends on pitched roofs, or edges and outside corners of flat or gently sloping roofs, shall not exceed 0.6 m (2 ft).

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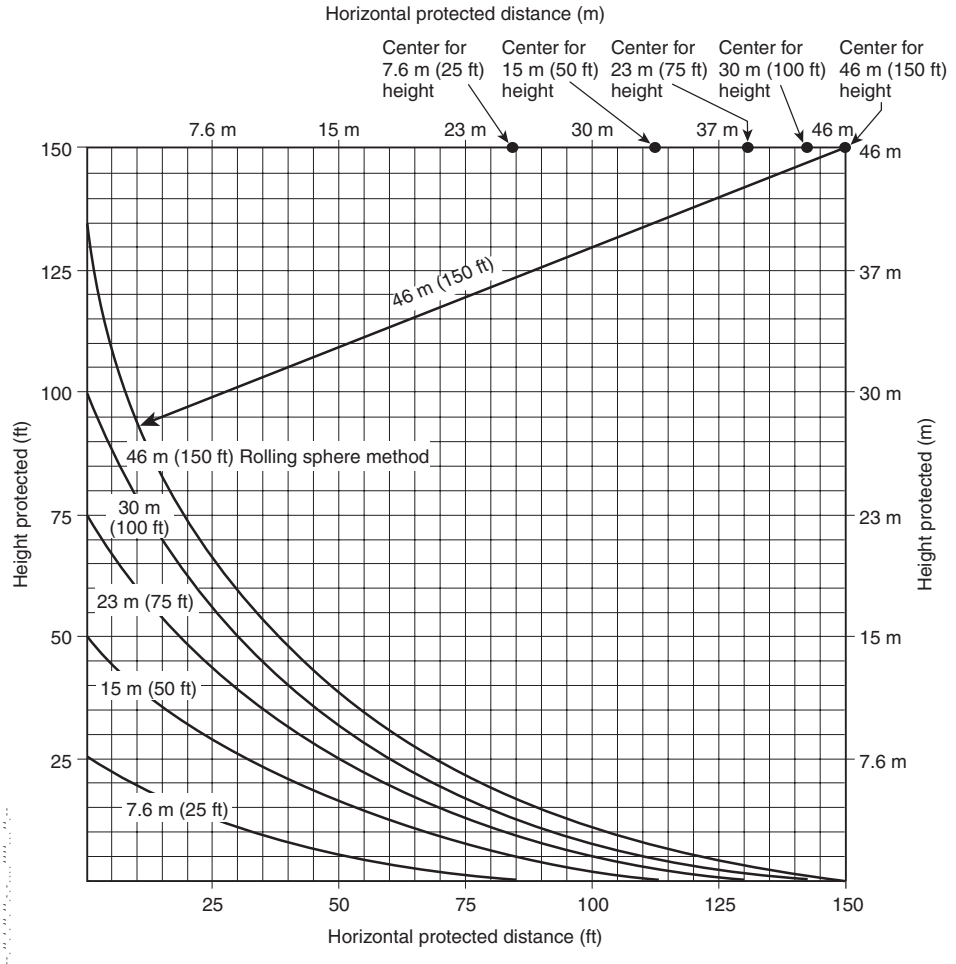


FIGURE 4.7.3.3 Zone of Protection Utilizing Rolling Sphere Method.

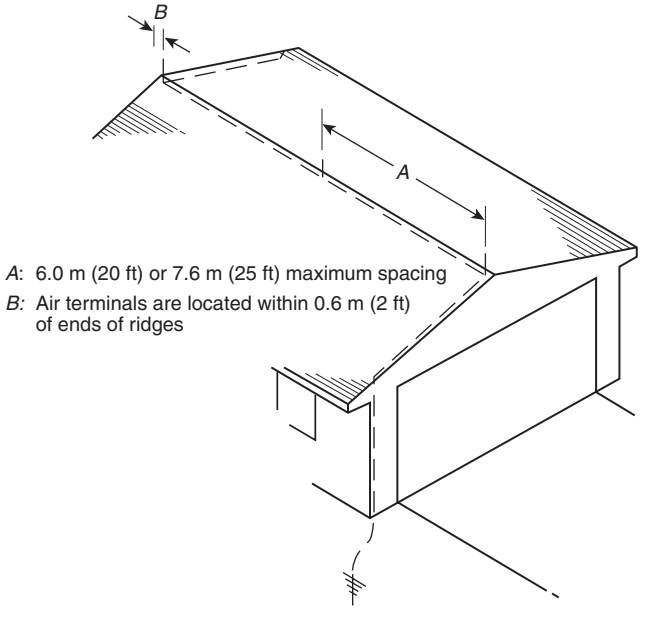


FIGURE 4.8.2 Air Terminals on a Pitched Roof.

4.8.2.1 Strike termination devices shall be placed on ridges of pitched roofs, and around the perimeter of flat or gently sloping roofs, at intervals not exceeding 6 m (20 ft).

4.8.2.2 Strike termination devices 0.6 m (2 ft) or more above the object or area to be protected shall be permitted to be placed at intervals not exceeding 7.6 m (25 ft).

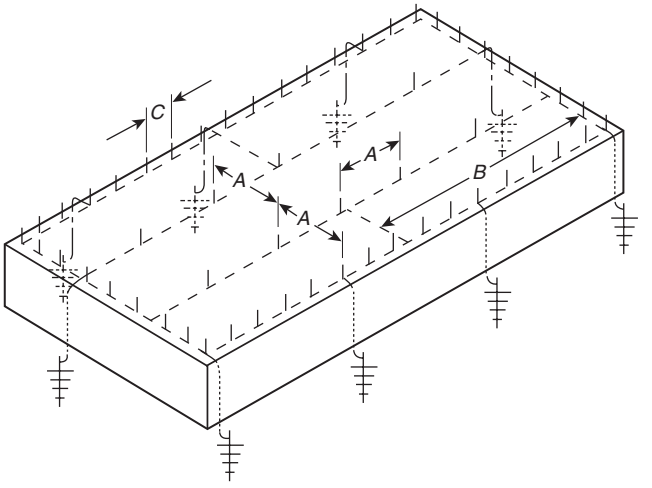
4.8.2.3 Pitched Roof Area.

(A) A pitched roof with eave heights of 15 m (50 ft) or less above grade shall require protection for the ridge only where there is no horizontal portion of the building that extends beyond the eaves, other than a gutter.

(B) Pitched roofs with eave heights more than 15 m (50 ft) shall have strike termination devices located according to the 46 m (150 ft) rolling sphere method. *[See Figure 4.7.3.1(B) and Figure 4.7.3.3.]*

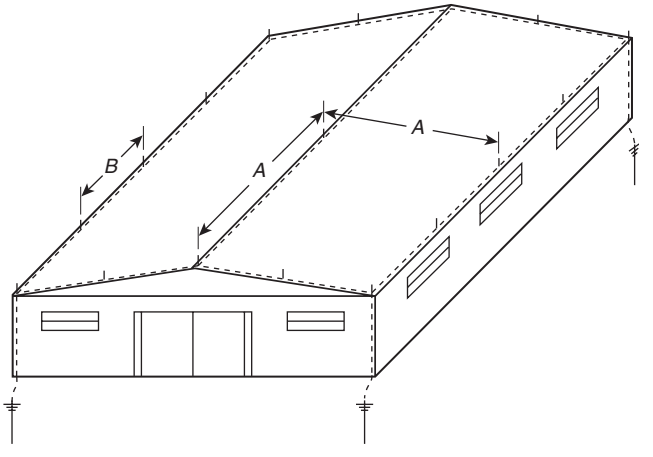
4.8.2.4 Flat or Gently Sloping Roof Area. Flat or gently sloping roofs that exceed 15 m (50 ft) in width or length shall have additional strike termination devices located at intervals not to exceed 15 m (50 ft) on the flat or gently sloping areas, as shown in Figure 4.8.2.4(a) and Figure 4.8.2.4(b), or such area can also be protected using taller air terminals that create zones of protection using the rolling sphere method so the sphere does not contact the flat or gently sloping roof area.

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A: 15 m (50 ft) maximum spacing between air terminals
B: 45 m (150 ft) maximum length of cross run conductor permitted without a connection from the cross run conductor to the main perimeter or down conductor
C: 6 m (20 ft) or 7.6 m (25 ft) maximum spacings between air terminals along edge

FIGURE 4.8.2.4(a) Air Terminals on a Flat Roof.



A: 15 m (50 ft) maximum spacing
B: 6 m (20 ft) or 7.6 m (25 ft) maximum spacing

FIGURE 4.8.2.4(b) Air Terminals on a Gently Sloping Roof.

4.8.3* Dormers.

4.8.3.1 Dormers as high as or higher than the main roof ridge shall be protected with strike termination devices, conductors, and grounds, where required.

4.8.3.2 Dormers and projections below the main ridge shall require protection only on those areas extending outside a zone of protection.

4.8.4 Roofs with Intermediate Ridges. Strike termination devices shall be located along the outermost ridges of buildings that have a series of intermediate ridges at the same intervals as required by 4.8.2.

4.8.4.1 Strike termination devices shall be located on the intermediate ridges in accordance with the requirements for the spacing of strike termination devices on flat or gently sloping roofs.

4.8.4.2 If any intermediate ridge is higher than the outermost ridges, it shall be treated as a main ridge and protected according to 4.8.2.

4.8.5 Flat or Gently Sloping Roofs with Irregular Perimeters. Structures that have exterior wall designs that result in irregular roof perimeters shall be treated on an individual basis.

4.8.5.1 The outermost projections form an imaginary roof edge that shall be used to locate the strike termination devices in accordance with 4.8.2.

4.8.5.2 In all cases, however, strike termination devices shall be located in accordance with Section 4.8, as shown in Figure 4.8.5.2.

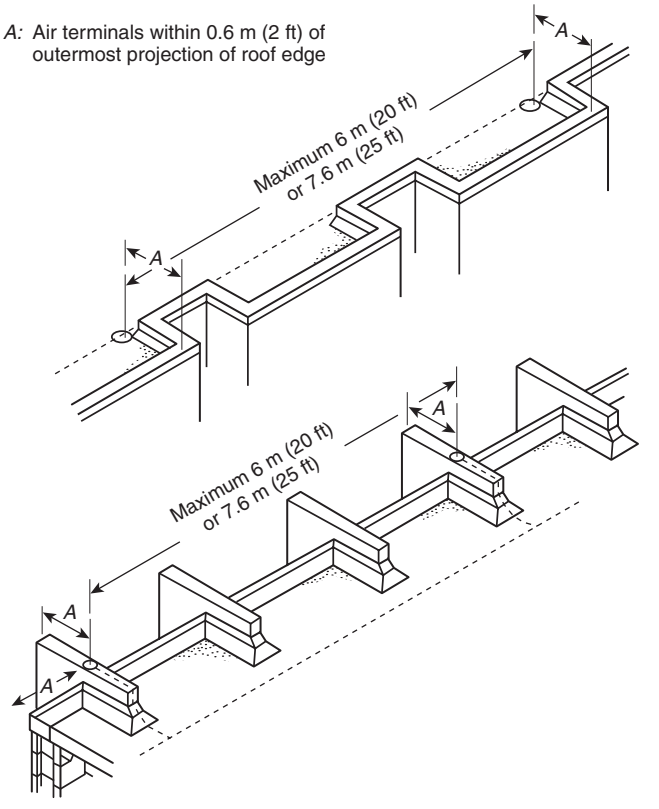


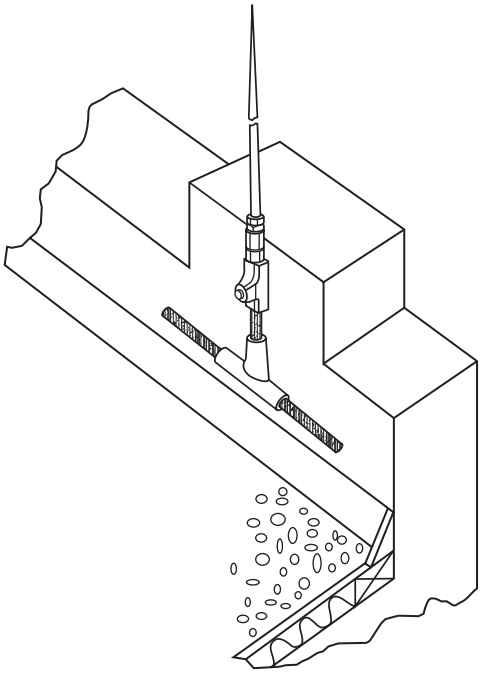
FIGURE 4.8.5.2 Flat or Gently Sloping Roof with an Irregular Perimeter.

4.8.5.3 Strike termination devices installed on vertical roof members shall be permitted to use a single main-size cable to connect to a main roof conductor.

4.8.5.4 The main roof conductor shall be run adjacent to the vertical roof members so that the single cable from the strike termination device is as short as possible and in no case longer than 4.9 m (16 ft).

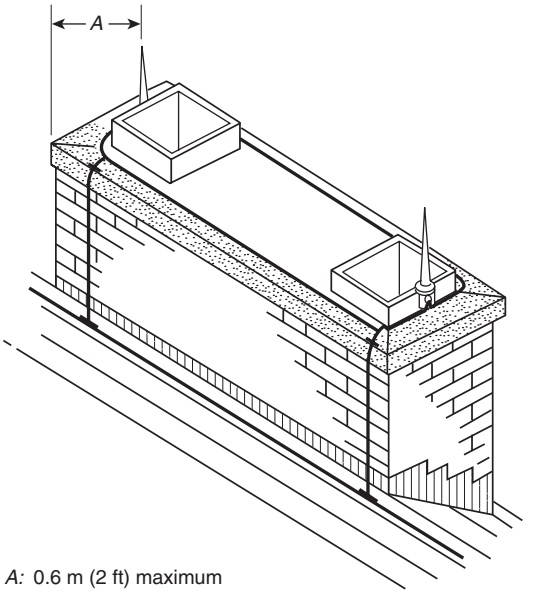
4.8.5.5 The connection of the single cable to the down conductor shall be made with a tee splice, as shown in Figure 4.8.5.5.

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Note: Air terminal tip configurations can be sharp or blunt.

FIGURE 4.8.5.5 Irregular Roof Perimeter.



A: 0.6 m (2 ft) maximum

Note: Air terminal tip configurations can be sharp or blunt.

FIGURE 4.8.8.3 Air Terminals on a Chimney.

4.8.6 Open Areas in Flat Roofs. The perimeter of open areas, such as light or mechanical wells, shall be protected if the open area perimeter exceeds 92 m (300 ft), provided both rectangular dimensions exceed 15 m (50 ft).

4.8.7 Domed or Rounded Roofs. Strike termination devices shall be located so that no portion of the structure is located outside a zone of protection, as set forth in Section 4.7.

4.8.8 Chimneys and Vents. Strike termination devices shall be required on all chimneys and vents that are not located within a zone of protection, including metal chimneys having a metal thickness of less than 4.8 mm (3⁄16 in.).

4.8.8.1 Chimneys or vents with a metal thickness of 4.8 mm (3⁄16 in.) or more shall require only a connection to the lightning protection system.

4.8.8.2 The connection for 4.8.8.1 shall be made using a main-size lightning conductor and a bonding device that has a surface contact area of not less than 1940 mm^2 (3 $in.^2$) and shall provide two or more paths to ground, as is required for strike termination devices.

4.8.8.3* Required strike termination devices shall be installed on chimneys and vents, as shown in Figure 4.8.8.3, so that the distance from a strike termination device to an outside corner or the distance perpendicular to an outside edge shall be not greater than 0.6 m (2 ft).

4.8.8.4 Where only one strike termination device is required on a chimney or vent, at least one main-size conductor shall connect the strike termination device to a main conductor at the location where the chimney or vent meets the roof surface and provides two or more paths to ground from that location in accordance with Section 4.9 and 4.9.2.

4.8.9 Metal Roof Top Units. Roof top mechanical units with continuous metal housings less than 4.8 mm (3⁄16 in.) thick such as air-conditioning/heating units, metal air intake/exhaust housings, cooling towers, and so forth, shall be protected by 4.8.9.1 through 4.8.9.2.2.

4.8.9.1 Air terminals shall be installed in accordance with 4.8.1 and 4.8.2.

4.8.9.1.1 These shall be mounted on bases having a minimum contact area of 1940 mm^2 (3 $in.^2$) each secured to bare metal of the housing or mounted by drilling and tapping to the unit's frame per 4.16.3.2 and 4.16.3.3.

4.8.9.2 At least two main-size conductors shall be installed.

4.8.9.2.1 The connection shall be made to bare metal at the base or lower edges of the unit using main-size lightning conductors and bonding devices that have a surface contact area of not less than 1940 mm^2 (3 $in.^2$) and shall provide two or more paths to ground, as is required for strike termination devices.

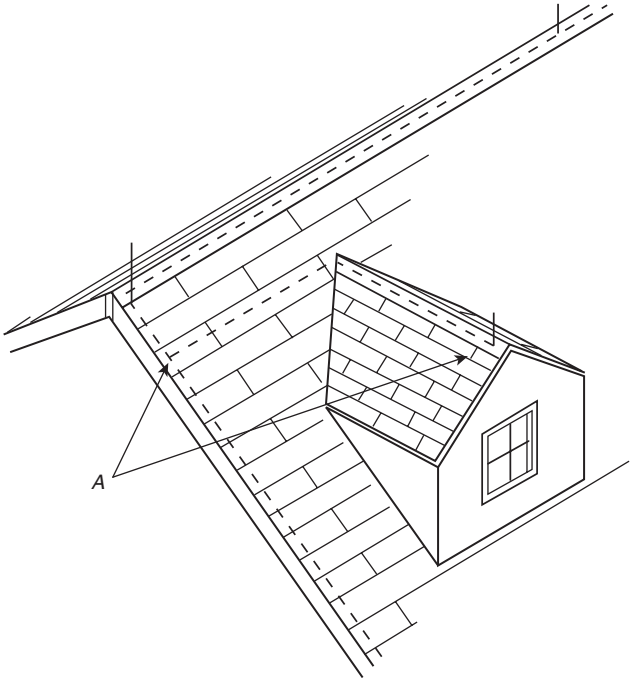
4.8.9.2.2 These two main bonding plates shall be located as far apart as practicable at the base or lower edges of the unit's electrically continuous metal housing and connected to the lightning protection system.

4.9 Conductors. Main conductors shall interconnect all strike termination devices and shall form two or more paths from each strike termination device downward, horizontally, or rising at no more than 1/4 pitch to connections with grounding electrodes, except as permitted by 4.9.1 and 4.9.2.

4.9.1 One-Way Path. Strike termination devices on a lower roof level that are interconnected by a conductor run from a higher roof level shall require only one horizontal or downward path to ground, provided the lower level roof conductor run does not exceed 12 m (40 ft).

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4.9.2 Dead Ends. Strike termination devices shall be permitted to be "dead ended," as shown in Figure 4.9.2, with only one path to a main conductor on roofs below the main protected level, provided the conductor run from the strike termination device to a main conductor is not more than 4.9 m (16 ft) in total length and maintains a horizontal or downward coursing.



A: Permissible dead-end total conductor length not over 4.9 m (16 ft)

FIGURE 4.9.2 Dead End.

4.9.3 Substitution of Main Conductor.

4.9.3.1 Ancillary metal parts of a structure, such as eave troughs, downspouts, ladders, chutes, or other metal parts except as permitted in 4.16.1, shall not be substituted for the main conductor.

4.9.3.2 Permanent exterior metal handrails and ladders that are subject to direct lightning strikes (e.g., on roofs or between roofs) and are electrically continuous shall be permitted to be used as main conductors where the minimum thickness is 1.63 mm (0.064 in.).

4.9.3.3 Likewise, metal roofing or siding having a thickness of less than 4.8 mm (3⁄16 in.) shall not be substituted for main conductors.

4.9.4 "U" or "V" Pockets.

4.9.4.1 Conductors shall maintain a horizontal or downward coursing free from "U" or "V" (down and up) pockets.

4.9.4.2 Such pockets, often formed at low-positioned chimneys, dormers, or other projections on sloped roofs or at parapet walls, shall be provided with a down conductor from the base of the pocket to ground or to an adjacent downlead conductor, as shown in Figure 4.9.4.2.

4.9.5 Conductor Bends. No bend of a conductor shall form an included angle of less than 90 degrees, nor shall it have a radius of bend less than 203 mm (8 in.), as shown in Figure 4.9.5.

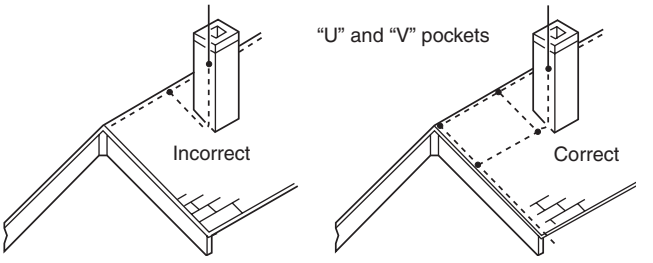


FIGURE 4.9.4.2 Pockets.

4.9.6 Conductor Supports.

4.9.6.1 Conductors shall be permitted to be coursed through air without support for a distance of 0.9 m (3 ft) or less.

4.9.6.2 Conductors that must be coursed through air for distances longer than those of 4.9.6.1 shall be provided with a positive means of support that will prevent damage or displacement of the conductor.

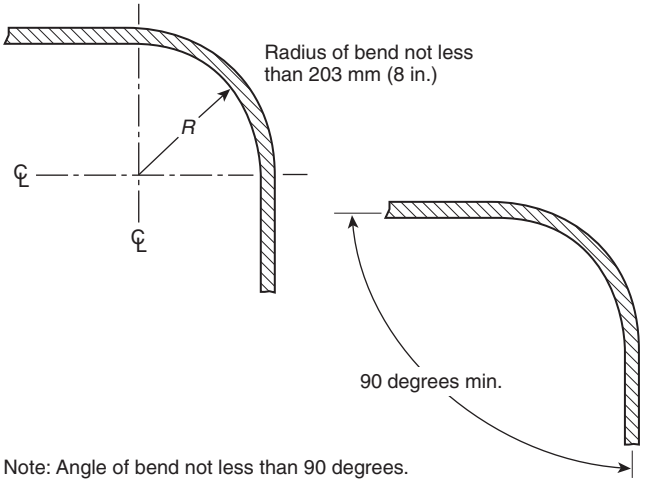
4.9.7 Roof Conductors.

4.9.7.1 Roof conductors shall be coursed along ridges of gable, gambrel, and hip roofs; around the perimeter of flat roofs; behind or on top of parapets; and across flat or gently sloping roof areas as required to interconnect all strike termination devices.

4.9.7.2 Conductors shall be coursed through or around obstructions (e.g., cupolas and ventilators) in a horizontal plane with the main conductor.

4.9.8 Cross-Run Conductors. Cross-run conductors (main conductors) shall be required to interconnect the strike termination devices on flat or gently sloping roofs that exceed 15 m (50 ft) in width.

4.9.8.1 For example, roofs from 15 m to 30 m (50 ft to 100 ft) in width shall require one cross-run conductor, roofs 30 m to 46 m (100 ft to 150 ft) in width shall require two cross-run conductors, and so on.



Note: Angle of bend not less than 90 degrees.

FIGURE 4.9.5 Conductor Bends.

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4.9.8.2 Cross-run conductors shall be connected to the main perimeter cable at intervals not exceeding 46 m (150 ft), as shown in Figure 4.8.2.4(a).

4.9.9 Down Conductors.

4.9.9.1 Down conductors shall be as widely separated as practicable.

4.9.9.2 The location of down conductors shall depend on considerations such as the following:

(1) Placement of strike termination devices
(2) Most direct coursing of conductors
(3) Earth conditions
(4) Security against displacement
(5) Location of large metallic bodies
(6) Location of underground metallic piping systems

4.9.10 Number of Down Conductors. At least two down conductors shall be provided on any kind of structure, including steeples.

4.9.10.1 Structures exceeding 76 m (250 ft) in perimeter shall have a down conductor for every 30 m (100 ft) of perimeter or fraction thereof.

4.9.10.2 The total number of down conductors on structures having flat or gently sloping roofs shall be such that the average distance between all down conductors does not exceed 30 m (100 ft).

4.9.10.3 Irregular-shaped structures shall have additional down conductors as necessary to provide a two-way path from each strike termination device.

4.9.10.4 For a flat or gently sloping roof structure, only the perimeter of the roof areas requiring protection shall be measured.

4.9.10.5 When determining the perimeter of a pitched roof structure, the horizontal projection (footprint) of the protected roof shall be measured as shown in Figure 4.9.10.5.

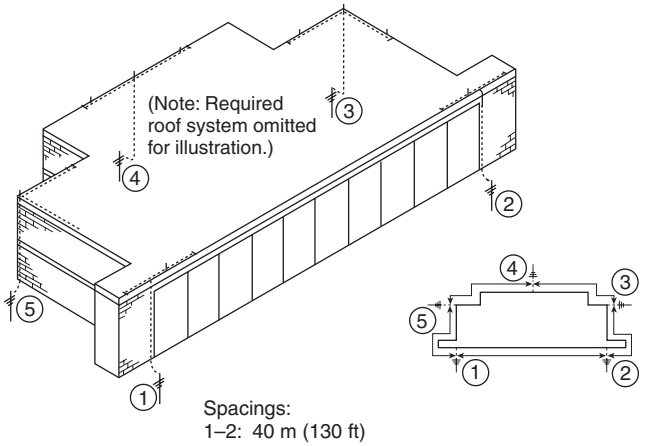


FIGURE 4.9.10.5 Quantity of Down Conductors.

4.9.10.6 Lower roofs or projections that are located within a zone of protection shall not be required to be included in the perimeter measurement.

4.9.11 Protecting Down Conductors. Down conductors located in runways, driveways, school playgrounds, cattle yards, public walks, or other locations subject to physical damage or displacement shall be guarded.

4.9.11.1 Metallic guards shall be bonded at each end.

4.9.11.2 The down conductor shall be protected for a minimum distance of 1.8 m (6 ft) above grade level.

4.9.12 Down Conductors Entering Corrosive Soil. Down conductors entering corrosive soil shall be protected against corrosion by a protective covering beginning at a point 0.9 m (3 ft) above grade level and extending for their entire length below grade.

4.9.13 Down Conductors and Structural Columns. Down conductors coursed on or in reinforced concrete columns or on structural steel columns shall be connected to the reinforcing steel or the structural steel member at their upper and lower extremities.

4.9.13.1 In the case of long vertical members, an additional connection shall be made at intervals not exceeding 60 m (200 ft).

4.9.13.2 The connections for 4.9.13.1 shall be made using listed clamps or listed bonding plates or by welding or brazing.

4.9.13.3 Where the bonding requirements of 4.9.13.1 and 4.9.13.2 are not satisfied, provisions shall be made to ensure the required interconnection of these parallel vertical paths.

4.9.14 Down Conductors in Nonmetallic Enclosures. The use of PVC conduit or other nonmetallic chase shall not eliminate the need to satisfy the bonding requirements of Sections 4.19, 4.20, and 4.21.

4.10 Conductor Fasteners. Conductors shall be fastened to the structure upon which they are placed at intervals not exceeding 0.9 m (3 ft).

4.10.1 Attached by nails, screws, bolts, or adhesives as necessary, the fasteners shall not be subject to breakage and shall be of the same material as the conductor or of a material equally resistant to corrosion as that of the conductor.

4.10.2 No combination of materials shall be used that will form an electrolytic couple of such a nature that, in the presence of moisture, corrosion will be accelerated.

4.11 Masonry Anchors. Masonry anchors used to attach lightning protection materials shall have a minimum outside diameter of 6.4 mm (¼ in.).

4.11.1 Holes made to receive the body of the anchor shall be of the correct size, made in the brick, stone, or other masonry unit rather than in mortar joints.

4.11.2 Where the anchors are installed, the fit shall be tight against moisture, thus reducing the possibility of damage due to freezing.

4.12 Connector Fittings. Connector fittings shall be used at all "end-to-end," "tee," or "Y" splices of lightning conductors.

4.12.1 Fittings shall be attached so as to withstand a pull test of 890 N (200 lb).

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4.12.2 Fittings used for required connections to metal bodies in or on a structure shall be secured to the metal body by bolting, brazing, welding, or using high-compression connectors listed for the purpose.

4.12.3 Conductor connections shall be of the bolted, welded, high compression, or crimp type.

4.12.4 Crimp-type connections shall not be used with Class II conductors.

4.13 Grounding Electrodes.

4.13.1 General.

4.13.1.1 Each down conductor shall terminate at a grounding electrode dedicated to the lightning protection system.

4.13.1.2 The design, size, depth, and number of grounding electrodes used shall comply with 4.13.2 through 4.13.8.

4.13.1.3 Underground metallic piping, electrical system and telecommunication grounding electrodes shall not be used in lieu of lightning ground electrodes; this provision shall not prohibit the required bonding together of these items as required by 4.14.1.

4.13.1.4 The down conductor(s) shall be attached permanently to the grounding electrode system by bolting, brazing, welding, or high-compression connectors listed for the purpose, and clamps shall be suitable for direct burial.

4.13.1.5 Grounding electrodes shall be copper-clad steel, solid copper, or stainless steel.

4.13.1.6 Grounding electrodes shall be installed below the frost line where possible (excluding shallow topsoil conditions).

4.13.2* Ground Rods.

4.13.2.1 Ground rods shall be not less than 12.7 mm (½ in.) in diameter and 2.4 m (8 ft) long.

4.13.2.2 Rods shall be free of paint or other nonconductive coatings.

4.13.2.3 Ground Rod Depth.

(A) The ground rods shall extend vertically not less than 3 m (10 ft) into the earth.

(B) The earth shall be compacted and made tight against the length of the conductor and ground rod, as illustrated in Figure 4.13.2.3(B).

4.13.2.4* Multiple Ground Rods. Where multiple connected ground rods are used, the separation between any two ground rods shall be at least the sum of their driven depths where practicable.

4.13.3 Concrete-Encased Electrodes. Concrete-encased electrodes shall be used only in new construction.

4.13.3.1 The electrode shall be located near the bottom of a concrete foundation or footing that is in direct contact with the earth and shall be encased by not less than 50 mm (2 in.) of concrete.

4.13.3.2 The encased electrode shall consist of one of the following:

(1) Not less than 6 m (20 ft) of bare copper main-size conductor
(2) At least 6 m (20 ft) of one or more steel reinforcing bars or rods not less than 12.7 mm (½ in.) in diameter that have been effectively bonded together by either welding or overlapping 20 diameters and wire tying

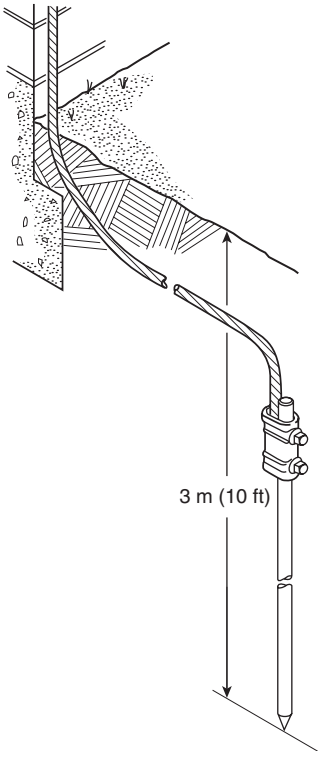


FIGURE 4.13.2.3(B) Typical Single Ground Rod Installation.

4.13.4 Ground Ring Electrode. A ground ring electrode encircling a structure shall be as shown in Figure 4.13.4, in direct contact with earth at a depth of not less than 460 mm (18 in.) or encased in a concrete footing in accordance with 4.13.3.

4.13.4.1 The encased electrode shall consist of not less than 6 continuous m (20 continuous ft) of bare copper main-size conductor.

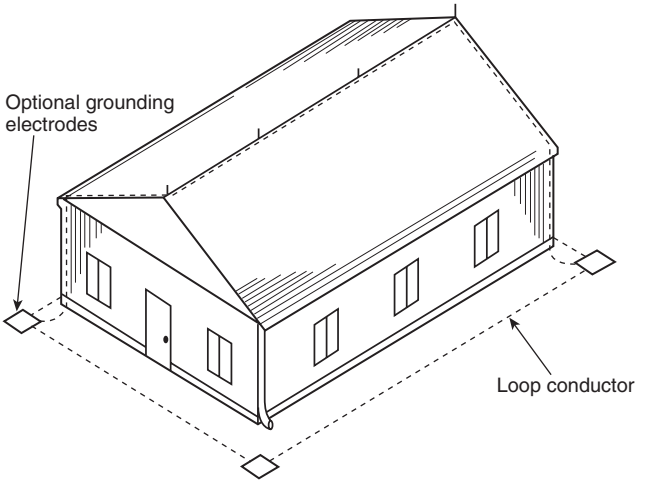


FIGURE 4.13.4 Typical Ground Ring Electrode Installation.

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4.13.4.2 The ground ring electrode shall be a main-size lightning conductor.

4.13.5* Radials.

4.13.5.1 A radial electrode system shall consist of one or more main-size conductors, each in a separate trench extending outward from the location of each down conductor.

4.13.5.2 Each radial electrode shall be not less than 3.6 m (12 ft) in length and not less than 460 mm (18 in.) below grade and shall diverge at an angle not greater than 90 degrees.

4.13.6* Plate Electrode or Ground Plate Electrode.

4.13.6.1 A ground plate or plate electrode shall have a minimum thickness of 0.8 mm (0.032 in.) and a minimum surface area of 0.18 m^2 (2 ft^2).

4.13.6.2 The ground plate electrode shall be buried not less than 460 mm (18 in.) below grade.

4.13.7 Combinations. Combinations of the grounding electrodes in Section 4.13 shall be permitted.

4.13.8 Grounding Electrode Selection Criteria. The site limitations and soil conditions shall determine the selection of the type or combinations of types of grounding electrodes used.

4.13.8.1* Shallow Topsoil. The methods in 4.13.3 through 4.13.7 shall be used in shallow topsoil conditions where practicable.

4.13.8.1.1 Where the methods described in 4.13.3 through 4.13.6 are found to be impractical due to topsoil depth less than 460 mm (18 in.), it shall be permitted to provide a ground terminal buried at the maximum depth of topsoil available.

4.13.8.1.2 The ground terminal for shallow topsoil shall be either a ground ring electrode in accordance with 4.13.4 a minimum distance of 0.6 m (2 ft) from the foundation or exterior footing, radial(s) in accordance with 4.13.5, or a plate electrode in accordance with 4.13.6 a minimum distance of 0.6 m (2 ft) from the foundation or exterior footing. The ground ring electrode, radial(s), or plate electrode shall be buried at maximum depth of topsoil available.

4.13.8.1.3 Where a method of 4.13.8.1.2 is impossible, radial(s) shall be permitted to be laid directly on bedrock a minimum distance of 3.6 m (12 ft) from the foundation or exterior footing. A ground ring electrode encircling the structure shall be permitted to be laid directly on bedrock a minimum distance of 0.6 m (2 ft) from the foundation or exterior footing.

4.13.8.1.4 In those cases where the grounding conductor is laid directly on bedrock, the conductor shall be secured to the bedrock every 0.9 m (3 ft) by nailing, conductive cement, or a conductive adhesive to ensure electrical contact and protect against movement.

4.13.8.2 Sandy Soil Conditions. Because sandy or gravelly soil conditions are characterized by high soil resistivity, multiple grounding electrodes shall be used to augment the lightning grounding electrode system.

4.14 Common Grounding.

4.14.1* General. All grounding media and buried metallic conductors that can assist in providing a path for lightning currents in or on a structure shall be interconnected to provide a common ground potential.

4.14.1.1 This interconnection shall include lightning protection, electric service, communications, and antenna system grounds, as well as underground metallic piping systems.

4.14.1.2 Underground metallic piping systems shall include water service, well casings located within 7.6 m (25 ft) of the structure, gas piping, underground conduits, underground liquefied petroleum gas piping systems, and so on.

4.14.1.3 Interconnection to a gas line shall be made on the customer's side of the meter.

4.14.1.4 Main-size lightning conductors shall be used for interconnecting these grounding systems to the lightning protection system.

4.14.2 Common Ground Bondings.

4.14.2.1 Where electric, community antenna television (CATV), data, communications, or other systems are bonded to a metallic water pipe, only one connection from the lightning protection system to the water pipe system shall be required, provided the water pipe is electrically continuous between all systems.

4.14.2.2 If the water pipe is not electrically continuous due to the use of plastic pipe sections or other reasons, the nonconductive sections shall be bridged with main-size conductors, or the connection shall be made at a point where electrical continuity is ensured.

4.15 Concealed Systems.

4.15.1 General.

4.15.1.1 Requirements covering exposed systems also shall apply to concealed systems, except conductors shall be permitted to be coursed under roofing materials, under roof framing, behind exterior wall facing, between wall studding, in conduit chases, or embedded directly in concrete or masonry construction.

4.15.1.2 Where a conductor is run in metal conduit, it shall be bonded to the conduit at the point where it enters the conduit, at the point where it emerges from the conduit, and at all locations where the conduit is not electrically continuous.

4.15.2 Masonry Chimneys. Chimney strike termination devices and conductors shall be permitted to be concealed within masonry chimneys or to be attached to the exterior of masonry chimneys and routed through the structure to concealed main conductors.

4.15.3 Concealment in Steel-Reinforced Concrete. Conductors or other components of the lightning protection system concealed in steel-reinforced concrete units shall be connected to the reinforcing steel.

4.15.3.1 Concealed down conductors shall be connected to the vertical reinforcing steel in accordance with 4.9.13.

4.15.3.2 Roof conductors or other concealed horizontal conductor runs shall be connected to the reinforcing steel at intervals not exceeding 30 m (100 ft).

4.15.4 Grounding Electrodes. Grounding electrodes for concealed systems shall comply with Section 4.13.

4.15.4.1* Grounding electrodes located under basement slabs or in crawl spaces shall be installed as near as practicable to the outside perimeter of the structure.

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4.15.4.2 Where rod or cable conductors are used for grounding electrodes, they shall be in contact with the earth for a minimum of 3 m (10 ft) and shall extend to a depth of not less than 3 m (10 ft) below finished grade, except as permitted by 4.13.4 and 4.13.5.

4.16 Structural Steel Systems.

4.16.1 General. The structural steel framework of a structure shall be permitted to be utilized as the main conductor of a lightning protection system if it is electrically continuous or is made electrically continuous.

4.16.2 Strike Termination Devices.

4.16.2.1 Strike termination devices shall be connected to the structural steel framing by direct connection, by use of individual conductors routed through the roof or parapet walls to the steel framework, or by use of an exterior conductor that interconnects all strike termination devices and that is connected to the steel framework.

4.16.2.2 Where such an exterior conductor is used, it shall be connected to the steel framework of the structure at intervals not exceeding 30 m (100 ft).

4.16.3 Connections to Framework. Conductors shall be connected to areas of the structural steel framework that have been cleaned to base metal, by use of bonding plates having a surface contact area of not less than 5200 mm^2 (8 $in.^2$) or by welding or brazing.

4.16.3.1 Drilling and tapping the steel column to accept a threaded connector also shall be permitted.

4.16.3.2 The threaded device shall be installed with at least five threads fully engaged and secured with at least a jam nut.

4.16.3.3 The threaded portion of the connector shall be not less than 12.7 mm (½ in.) in diameter.

4.16.3.4 Bonding plates shall have bolt-pressure cable connectors and shall be bolted, welded, or brazed to the structural steel framework so as to maintain electrical continuity.

4.16.3.5 Where rust-protective paint or coating is removed, the base steel shall be protected with a conductive, corrosion-inhibiting coating.

4.16.4 Grounding Electrodes.

4.16.4.1 Grounding electrodes shall be connected to steel columns around the perimeter of the structure at intervals averaging not more than 18 m (60 ft).

4.16.4.2 Connections shall be made near the base of the column in accordance with the requirements in 4.16.3.

4.16.5 Bonding Connections. Where metal bodies located within a steel-framed structure are inherently bonded to the structure through the construction, separate bonding connections shall not be required.

4.17 Metal Antenna Masts and Supports. Metal antenna masts or supports located on a protected structure shall be connected to the lightning protection system using main-size conductors and listed fittings unless they are within a zone of protection.

4.18 Surge Protection.

4.18.1* General. This section provides requirements for surge protection systems installed for the electrical, communications (including but not limited to CATV, alarm, and data) or antenna systems, or other electrical system hardware. The requirements included within this standard are limited to permanently installed surge protective devices (SPDs).

4.18.2* Surge Protection Requirements.

4.18.2.1 SPDs shall be installed at all power service entrances.

4.18.2.2* SPDs shall be installed at entrances of conductive communications systems (including but not limited to CATV, alarm, and data) and antenna systems.

4.18.2.3 SPDs shall be installed at all points where an electrical or electronic system conductor leaves a structure to supply another structure if the conductors or cables are run over 30 m (100 ft).

4.18.2.4 Surge protection shall be permitted for installation at subpanels or branch panels and at the point of utilization (outlet or signal termination; also termed *supplementary protection*).

4.18.2.5* SPDs shall not be required where, under engineering supervision, it is determined that surge threat is negligible or the lines are equivalently protected or where installation compromises safety.

4.18.3 Surge Threat Levels.

4.18.3.1* Electrical Power Circuits.

4.18.3.1.1 The SPD shall protect against a surge produced by a 1.2/50 μs, 8/20 μs combination waveform generator.

4.18.3.1.2 SPDs at the service entrance shall have an I_{max} rating of at least 40 kA 8/20 μs per phase or a nominal discharge current (I_n) rating of at least 20 kA 8/20 μs per phase.

4.18.3.2 Signal, Data, and Communication Protection. SPDs shall be listed for the protection of signal, data, and communications systems and shall have an I_{max} rating of at least 10 kA 8/20 μs or greater when installed at the entrance.

4.18.4* SPD's Measured Limiting Voltage. Where an SPD has been listed as a transient voltage surge suppressor (TVSS), the published suppressed voltage rating (SVR) for each mode of protection shall be selected to be no greater than those given in Table 4.18.4 for the different power distribution systems to which they can be connected.

4.18.5* Facility ac Surge Protection.

4.18.5.1 The short circuit current rating of the SPD shall be coordinated with the available fault current rating of the supply (panel) to which it is connected, in accordance with NFPA 70, *National Electrical Code*.

4.18.5.2 The maximum continuous operating voltage (MCOV) of the SPD shall be selected to ensure that it is greater than the upper tolerance of the utility power system to which it is connected.

4.18.5.3 The SPD shall be listed for the protection of service entrances.

4.18.5.4 SPDs at grounded service entrances shall be wired in a line-to-ground (L–G) or line-to-neutral (L–N) configuration.

4.18.5.4.1 Additional modes, line-to-line (L–L), or neutral-to-ground (N–G) shall be permitted at the service entrance.

4.18.5.4.2 For services without a neutral, SPD elements shall be connected line-to-ground (L–G). Additional line-to-line (L–L) connections shall also be permitted.

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Table 4.18.4 Maximum Allowed Suppressed Voltage Ratings per Mode of Protection Provided for Different Power Distribution Systems to Which the SPD May Be Connected

Power Distribution System	Line-to-Neutral	Line-to-Ground	Neutral-to-Ground	Line-to-Line
120 2W + ground	500	500	500	
240 2W + ground		1000		1000
120/240 3W + ground	500	500	500	1000
120/208 WYE 4W + ground	500	500	500	1000
277/480 WYE 4W + ground	1000	1000	1000	1500
277/480 WYE 4W + HRG (high resistance ground)				1500
347/600 WYE 4W + ground	1500	1500	1500	2000
240 DELTA 3W (ungrounded)				1000
480 DELTA 3W (ungrounded)				1500
240 DELTA 3W + ground (corner grounded)		1000		1000
480 DELTA 3W + ground (corner grounded)		1500		1500

4.18.6 Communications Surge Protection.

4.18.6.1* SPDs shall be provided for all communications systems (including but not limited to CATV, alarm, and data) and antenna systems at facility entrances.

4.18.6.2 SPDs shall be selected taking into consideration aspects such as the frequency, bandwidth, and voltage. Losses (such as returns loss, insertion loss, impedance mismatch, or other attenuation) introduced by the SPD(s) shall be within acceptable operational limits.

4.18.6.3 SPDs protecting communications systems shall be grounded.

4.18.6.3.1* The SPD shall also be bonded to the point of grounding of the electrical service.

4.18.6.3.2 If the point of grounding in 4.18.6.3.1 is greater than 6 m (20 ft) away, a supplementary earth electrode or electrode system shall be installed at the SPD location.

4.18.6.3.3 Where provided, a supplementary earth electrode or electrode system shall be electrically bonded to the facility's main ground electrode system in compliance with NFPA 70, *National Electrical Code*.

4.18.6.3.4 SPDs shall not be grounded through a down conductor of the lightning protection system.

4.18.6.3.5* SPDs for data and signal line protection shall provide common mode protection.

4.18.7 Installation.

4.18.7.1 Installation of surge suppression hardware shall conform to the requirements of NFPA 70, *National Electrical Code*.

4.18.7.2* SPDs shall be located and installed so as to minimize lead length. Interconnecting leads shall be routed so as to avoid sharp bends or kinks.

4.18.7.3 The SPD grounding conductor shall be installed in accordance with the manufacturer's instructions.

4.18.7.4* All SPD components shall be accessible for inspection and maintenance.

4.18.8* Earth Grounding Electrode. Resistance of the earth electrode system used in the grounding of SPDs shall comply with NFPA 70, *National Electrical Code*.

4.18.9 Physical Characteristics.

4.18.9.1 The SPDs shall be protected with consideration for the operational environment and according to the manufacturer's instructions.

4.18.9.2 Enclosures and other ancillary equipment shall be listed for the purpose.

4.19* Metal Bodies. Metal bodies located outside or inside a structure that contribute to lightning hazards because they are grounded or assist in providing a path to ground for lightning currents shall be bonded to the lightning protection system in accordance with Sections 4.19, 4.20, and 4.21.

4.19.1 General. The factors in 4.19.1.1 through 4.19.1.4 shall determine the necessity of bonding a metal body to a lightning protection system.

4.19.1.1 Bonding shall be required if there is likely to be a sideflash between the lightning protection system and another grounded metal body.

4.19.1.2 The influence of a nongrounded metal body, such as a metal window frame in a nonconductive medium, is limited to its effectiveness as a short-circuit conductor if a sideflash occurs and, therefore, shall not necessarily require bonding to the lightning protection system.

4.19.1.3 Bonding distance requirements shall be determined by a technical evaluation of the number of down conductors and their location, the interconnection of other grounded systems, the proximity of grounded metal bodies to the down conductors, and the flashover medium (i.e., air or solid materials).

4.19.1.4 Metal bodies located in a steel-framed structure that are inherently bonded through construction shall not require further bonding.

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4.19.2 Materials.

4.19.2.1 Horizontal loop conductors used for the interconnection of lightning protection system downlead conductors, grounding electrodes, or other grounded media shall be sized no smaller than the size required for the main conductor, as listed in Table 4.1.1.1(A) and Table 4.1.1.1(B).

4.19.2.2 Conductors used for the bonding of grounded metal bodies or isolated metal bodies requiring connection to the lightning protection system shall be sized in accordance with bonding conductor requirements in Table 4.1.1.1(A) and Table 4.1.1.1(B).

4.20 Potential Equalization.

4.20.1* Ground-Level Potential Equalization.

4.20.1.1 All grounded media and buried metallic conductors that can assist in providing a path for lightning currents in and on a structure shall be connected to the lightning protection system within 3.6 m (12 ft) of the base of the structure in accordance with Section 4.14.

4.20.1.2 For structures exceeding 18 m (60 ft) in height, the interconnection of the lightning protection system grounding electrodes and other grounded media shall be in the form of a ground loop conductor.

4.20.2* Roof-Level Potential Equalization. For structures exceeding 18 m (60 ft) in height, all grounded media in or on the structure shall be interconnected within 3.6 m (12 ft) of the main roof level.

4.20.3 Intermediate-Level Potential Equalization. Intermediate-level potential equalization shall be accomplished by the interconnection of the lightning protection system down conductors and other grounded media at the intermediate levels between the roof and the base of a structure in accordance with 4.20.3(A) through 4.20.3(C).

(A) Steel-Framed Structures. Intermediate-loop conductors shall not be required for steel-framed structures where the framing is electrically continuous.

(B) Reinforced Concrete Structures Where the Reinforcement Is Interconnected and Grounded in Accordance with 4.15.3. The lightning protection system down conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 60 m (200 ft).

(C) Other Structures. The lightning protection down conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 18 m (60 ft).

4.21 Bonding of Metal Bodies.

4.21.1 Long, Vertical Metal Bodies. Long, vertical metal bodies shall be bonded in accordance with 4.21.1(A) through 4.21.1(C).

(A) Steel-Framed Structures. Grounded and ungrounded metal bodies exceeding 18 m (60 ft) in vertical length shall be bonded to structural steel members as near as practicable to their extremities unless inherently bonded through construction at these locations.

(B) Reinforced Concrete Structures Where the Reinforcement Is Interconnected and Grounded in Accordance with 4.15.3. Grounded and ungrounded metal bodies exceeding 18 m (60 ft) in vertical length shall be bonded to the lightning protection system as near as practicable to their extremities unless inherently bonded through construction at these locations.

(C) Other Structures. Bonding of grounded or ungrounded long, vertical metal bodies shall be determined by 4.21.2 and 4.21.3, respectively.

4.21.2 Grounded Metal Bodies. This subsection shall cover the bonding of grounded metal bodies not covered in 4.21.1.

4.21.2.1 Where grounded metal bodies have been connected to the lightning protection system at only one extremity, the formula shown in 4.21.2.4 or 4.21.2.5 shall be used to determine whether additional bonding is required.

4.21.2.2 Branches of grounded metal bodies connected to the lightning protection system at their extremities shall require bonding to the lightning protection system in accordance with the formula shown in 4.21.2.4 or 4.21.2.5 if they change vertical direction more than 3.6 m (12 ft).

4.21.2.3 Where such bonding has been accomplished either inherently through construction or by physical contact between electrically conductive materials, no additional bonding connection shall be required.

4.21.2.4 Structures More Than 12 m (40 ft) in Height.

(A) Grounded metal bodies shall be bonded to the lightning protection system where located within a calculated bonding distance, *D*, as determined by the following formula:

$$D = \frac{h}{6n} \times K_m$$

where:

D = calculated bonding distance
h = vertical distance between the bond being considered and the nearest lightning protection system bond
n = a value related to the number of down conductors that are spaced at least 7.6 m (25 ft) apart, located within a zone of 30 m (100 ft) from the bond in question, and where bonding is required within 18 m (60 ft) from the top of any structure
K_m = 1 if the flashover is through air, or 0.50 if through dense material such as concrete, brick, wood, and so forth

(B) The value n shall be calculated as follows: $n = 1$ where there is only one down conductor in this zone; $n = 1.5$ where there are only two down conductors in this zone; $n = 2.25$ where there are three or more down conductors in this zone.

(C) Where bonding is required below a level 18 m (60 ft) from the top of a structure, n shall be the total number of down conductors in the lightning protection system.

4.21.2.5 Structures 12 m (40 ft) and Less in Height.

(A) Grounded metal bodies shall be bonded to the lightning protection system where located within a calculated bonding distance, *D*, as determined by the following formula:

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$$D = \frac{h}{6n} \times K_m$$

where:

D = calculated bonding distance
h = either the height of the building or the vertical distance from the nearest bonding connection from the grounded metal body to the lightning protection system and the point on the down conductor where the bonding connection is being considered
n = a value related to the number of down conductors that are spaced at least 7.6 m (25 ft) apart and located within a zone of 30 m (100 ft) from the bond in question
K_m = 1 if the flashover is through air, or 0.50 if through dense material such as concrete, brick, wood, and so forth

(B) The value n shall be calculated as follows: $n = 1$ where there is only one down conductor in this zone; $n = 1.5$ where there are only two down conductors in this zone; $n = 2.25$ where there are three or more down conductors in this zone.

4.21.3* Isolated (Nongrounded) Metallic Bodies. An isolated metallic body, such as a metal window frame in a nonconducting medium, that is located close to a lightning conductor and to a grounded metal body will influence bonding requirements only if the total of the isolated distances between the lightning conductor and the isolated metal body and between the isolated metal body and the grounded metal body is equal to or less than the calculated bonding distance. The effect shall be determined by 4.21.3.1.

4.21.3.1 The effect shall be determined by using Figure 4.21.3.1 according to either 4.21.3.1(A) or 4.21.3.1(B).

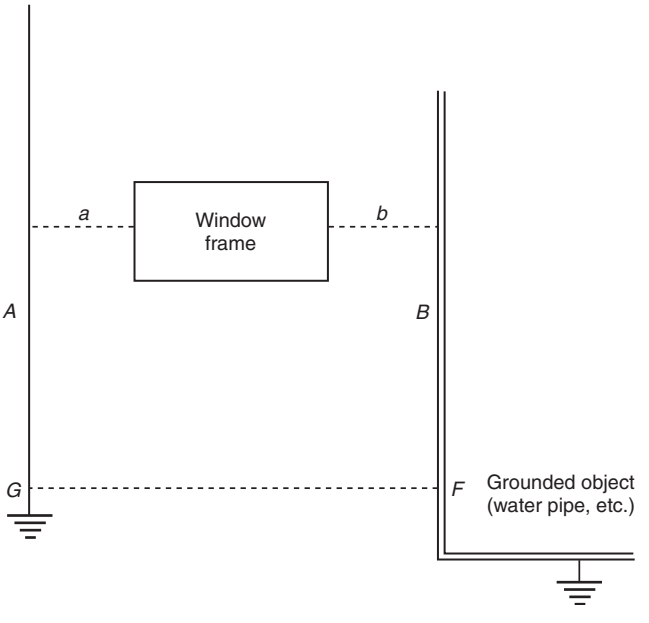


FIGURE 4.21.3.1 Effect of Isolated (Nongrounded) Metallic Bodies, Such as a Window Frame, in Nonconductive Media.

(A) If $a + b$ is less than the calculated bonding distance, then A shall be bonded to B directly.

(B) If $a + b$ is greater than the calculated bonding distance, bonds shall not be required.

4.21.3.2 A bonding connection shall be required where the total of the shortest distance between the lightning conductor and the isolated metal body and the shortest distance between the isolated metal body and the grounded metal body is equal to or less than the bonding distance as calculated in accordance with 4.21.2.

4.21.3.3 Bondings shall be made between the lightning protection system and the grounded metal body and shall not be required to run through or be connected to the isolated metal body.

Chapter 5 Protection for Miscellaneous Structures and Special Occupancies

5.1 General. All requirements of Chapter 4 shall apply except as modified by this chapter.

5.2 Masts, Spires, Flagpoles.

5.2.1 These slender structures shall require one strike termination device, down conductor, and grounding electrode.

5.2.2 Electrically continuous metal structures shall require only bonding to grounding electrode(s).

5.3 Grain-, Coal-, and Coke-Handling and Processing Structures. Provisions shall be made for the settling and rising of wood frame elevators as grain, coal, and coke are loaded and unloaded.

5.4 Metal Towers and Tanks. Metal towers and tanks constructed so as to receive a stroke of lightning without damage shall require only bonding to grounding electrodes as required in Chapter 4, except as provided in Chapter 7.

5.5 Air-Inflated Structures. Air-inflated structures shall be protected with a mast-type or catenary lightning protection system in accordance with Chapter 7 or with a lightning protection system in accordance with Chapter 4.

5.6 Concrete Tanks and Silos. Lightning protection systems for concrete (including prestressed concrete) tanks containing flammable vapors, flammable gases, and liquids that produce flammable vapors and for concrete silos containing materials susceptible to dust explosions shall be provided with either external conductors or with conductors embedded in the concrete in accordance with Chapter 4 or Chapter 7.

5.7 Guyed Structures. Each metal guy cable shall be bonded at its lower end with a main-size conductor to all other guy cables sharing a common anchor point, and grounded at the anchor point.

5.7.1 Anchor plates shall be bonded to the anchor ground point.

5.7.2 Multiple guy cables shall be permitted to be connected to a common point with a single continuous conductor to the ground and the anchor plate bonding conductor attached to that main conductor.

5.7.3 Each metal guy cable shall be bonded at its upper end to the structure it supports if it is constructed of a conductive

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material, and to the lightning protection system loop conductor or down conductors.

5.8 Wind Turbines. Where a lightning protection system is provided for wind turbines, zones of protection shall include the supporting structure and overall blade rotation perimeter. *(See Annex N.)*

Chapter 6 Protection for Heavy-Duty Stacks

6.1 General. A smoke or vent stack as shown in Figure 6.1 shall be classified as heavy duty if the cross-sectional area of the flue is greater than 0.3 m^2 (500 $in.^2$) and the height is greater than 23 m (75 ft).

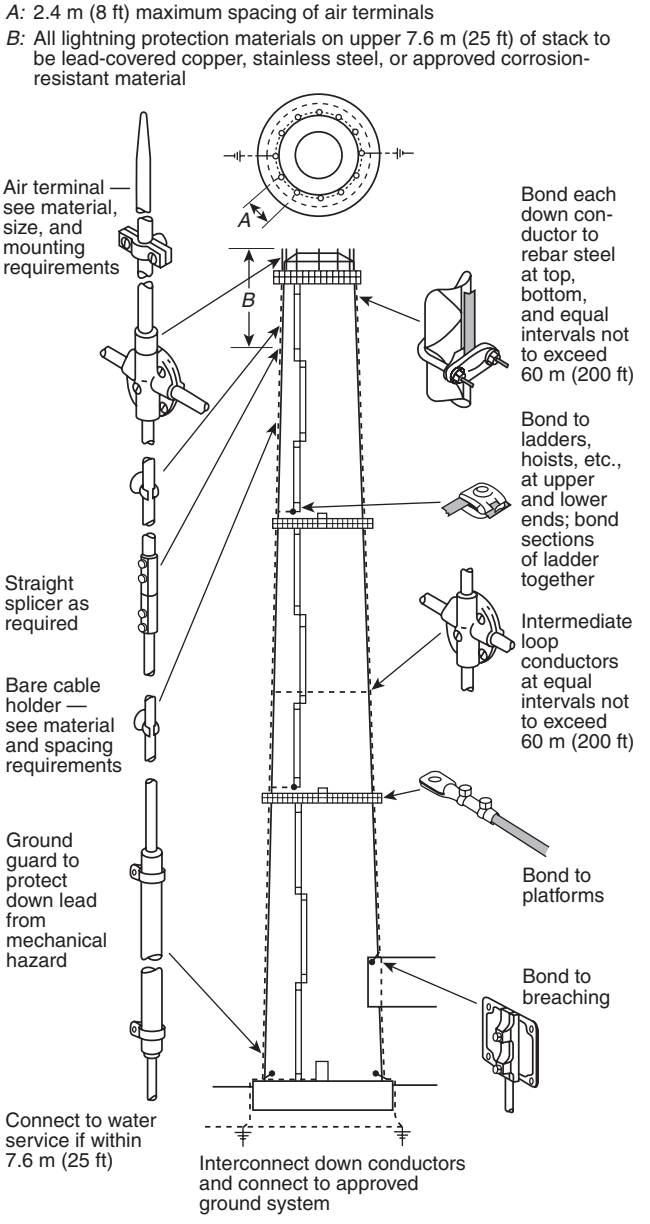


FIGURE 6.1 Heavy-Duty Stack.

6.2 Materials.

6.2.1 General. Materials shall be Class II as shown in Table 4.1.1.1(B) and as described in this chapter.

6.2.2 Corrosion Protection. Copper and bronze materials used on the upper 7.6 m (25 ft) of a stack shall have a continuous covering of lead having minimum thickness of 1.6 mm (1/16 in.) to resist corrosion by flue gases.

6.2.2.1 Such materials shall include conductors, strike termination devices, connectors, splicers, and cable holders.

6.2.2.2 Stacks that extend through a roof less than 7.6 m (25 ft) shall have a lead covering only on those materials above the roof level.

6.3 Strike Termination Devices. Strike termination devices shall be made of solid copper, stainless steel, titanium, or Monel® metal.

6.3.1 They shall be located uniformly around the top of cylindrical stacks at intervals not exceeding 2.4 m (8 ft).

6.3.2 On square or rectangular stacks, strike termination devices shall be located not more than 600 mm (24 in.) from the corners and shall be spaced not more than 2.4 m (8 ft) apart around the perimeter.

6.3.3 Air Terminal Heights. The height of air terminals above the stacks shall be not less than 460 mm (18 in.) nor more than 760 mm (30 in.).

6.3.3.1 They shall be at least 15 mm (5/8 in.) in diameter, exclusive of the corrosion protection.

6.3.3.2 Top-mounted air terminals shall not extend more than 460 mm (18 in.) above the top of the stack.

6.3.4 Air Terminal Mountings.

6.3.4.1 Air terminals shall be secured to the stack and shall be connected together at their lower end with a conductor forming a closed loop around the stack.

6.3.4.2 Side-mounted air terminals shall be secured to the stack at not less than two locations.

6.3.4.3 An anchored base connector shall be considered as one location.

6.3.5 Steel Hoods.

6.3.5.1 An electrically continuous steel hood covering the stack lining and column, having a metal thickness of not less than 4.8 mm (3/16 in.), shall be permitted to serve as the strike termination device.

6.3.5.2 The hood serves as a top loop conductor and shall be connected to each down conductor using a connection plate of not less than 5200 mm^2 (8 $in.^2$) bolted or welded to the hood.

6.4 Conductors.

6.4.1 General.

6.4.1.1 Conductors shall be copper, weighing not less than 558 g per m (375 lb per 1000 ft) without the lead coating, or approved corrosion-resistant material or coating.

6.4.1.2 The size of any wire in the conductor shall be not less than 15 AWG.

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6.4.2 Down Conductors.

6.4.2.1 No fewer than two down conductors shall be provided.

6.4.2.2 Down conductors shall be as equally spaced as practicable around the stack and shall lead from the loop conductor at the top to grounding electrodes.

6.4.2.3 Down conductors shall be interconnected within 3.6 m (12 ft) of the base by a loop conductor, preferably below grade.

6.4.2.4 The down conductor also shall be interconnected with a loop conductor at intervals not exceeding 60 m (200 ft).

6.4.2.5 Down conductors shall be protected from physical damage or displacement for a distance of not less than 2.4 m (8 ft) above grade.

6.5 Fasteners.

6.5.1 Fasteners shall be of copper, bronze, or stainless steel.

6.5.2 They shall be anchored to the stack by masonry anchors or lay-in attachments.

6.5.3 The threaded shank of fasteners shall be not less than 12.7 mm (½ in.) diameter for air terminals and 10 mm (⅜ in.) diameter for conductors.

6.5.4 Vertical conductors shall be fastened at intervals not exceeding 1.2 m (4 ft), and horizontal conductors shall be fastened at intervals not exceeding 0.6 m (2 ft).

6.6 Splices. Splices in conductors shall be as few as practicable and shall be attached so as to withstand a pull test of 890 N (200 lb).

6.6.1 All connections and splices shall be by bolting, brazing, welding, or high-compression connectors listed for the purpose.

6.6.2 All connectors and splicers shall make contact with the conductor for a distance not less than 38 mm (1½ in.), measured parallel to the axis of the conductor.

6.7 Reinforced Concrete Stacks.

6.7.1 All reinforcing steel shall be made electrically continuous and bonded to each down conductor within 3.6 m (12 ft) of the top and base of the stack and at intervals not to exceed 60 m (200 ft).

6.7.2 Tying or clipping of reinforcing steel shall be a permitted means of ensuring continuity.

6.7.3 Clamps or welding shall be used for all connections to the reinforcing steel and to the down conductors.

6.8 Bonding of Metal Bodies. Bonding of metal bodies on a heavy-duty stack shall comply with the requirements of Sections 4.19, 4.20, and 4.21, and as described in this section.

6.8.1 Potential Equalization. Potential equalization shall be accomplished by 6.8.1.1 through 6.8.1.3.

6.8.1.1 Ground Level of Stack.

(A) All interior and exterior grounded media shall be interconnected by a loop conductor within 3.6 m (12 ft) of the base of the stack.

(B) This interconnection shall include, but not be limited to, lightning protection down conductors, conduit, piping, elevators, ladders, and breeching steel and reinforcing steel.

6.8.1.2 Top Level of Stack. All interior and exterior grounded media shall be interconnected within 3.6 m (12 ft) of the top of the stack.

6.8.1.3 Intermediate Levels of Stack. All interior and exterior vertical grounded media shall be interconnected at intervals not to exceed 60 m (200 ft).

6.8.2 Isolated (Nongrounded) Protruding Metal Bodies. Isolated (nongrounded) protruding metal bodies shall be bonded in accordance with 6.8.2.1 through 6.8.2.2.

6.8.2.1 Exterior. Isolated protruding metal bodies 46 m (150 ft) or more above the base and on the exterior of a stack are subject to a direct strike and shall be interconnected to the lightning protection system.

6.8.2.1.1 Isolated protruding metal bodies shall include, but not be limited to, rest platforms, jib hoists, and other metal bodies protruding 460 mm (18 in.) or more from the column wall.

6.8.2.2 Interior. Isolated metal bodies on the interior of a reinforced steel stack or within the zone of protection on the exterior shall not be required to be connected to the lightning protection system.

6.9* Grounding.

6.9.1 A grounding electrode suitable for the soil conditions encountered shall be provided for each down conductor.

6.9.2 Grounding electrodes shall be in accordance with Section 4.13, except ground rods shall be a copper-clad or stainless steel rod having a diameter of not less than 15 mm (⅝ in.) and shall be at least 3 m (10 ft) in length.

6.10 Metal Stacks.

6.10.1 Heavy-duty metal stacks having a metal thickness of 4.8 mm (3⁄16 in.) or greater shall not require air terminals or down conductors.

6.10.2 The metal stacks of 6.10.1 shall be grounded by at least two grounding electrodes as equally spaced as practicable around the stack.

6.10.3 If the stack is an adjunct of a building or located within the sideflash distance, as determined by Sections 4.19, 4.20, and 4.21, it shall be interconnected to the lightning protection system on the building.

6.10.4 If the stack is located within the perimeter of a protected building, two connections shall be made between the stack conductors and the nearest main building lightning conductors at or about the roof level.

6.11 Metal Guy Wires and Cables. Metal guy wires and cables used to support stacks shall be grounded at their lower ends.

Chapter 7 Protection for Structures Containing Flammable Vapors, Flammable Gases, or Liquids That Can Give Off Flammable Vapors

7.1 Reduction of Damage.

7.1.1* Application.

7.1.1.1 This chapter shall apply to the protection of structures containing flammable vapors, flammable gases, or liquids that give off flammable vapors.

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7.1.1.2 For the purpose of this chapter, the term *structure* shall apply to any outdoor vessel, tank, or other container where this material is contained.

7.1.2 Certain types of structures used for the storage of liquids that produce flammable vapors or used to store flammable gases are essentially self-protecting against damage from lightning strokes and shall need no additional protection.

7.1.2.1 Metallic structures that are electrically continuous; tightly sealed to prevent the escape of liquids, vapors, or gases; and of 4.8 mm (3⁄16 in.) thickness or greater to withstand direct strikes in accordance with 7.3.2 shall be considered to be inherently self-protecting.

7.1.2.2 Protection of other structures shall be achieved by the use of strike termination devices.

7.1.3* Because of the nature of the contents of the structures considered in this chapter, extra precautions shall be taken.

7.1.4 In the structures covered in Chapter 7, a spark that would otherwise cause little or no damage might ignite the flammable contents and result in a fire or explosion.

7.2 Fundamental Principles of Protection. Protection of these structures and their contents from lightning damage shall require adherence to the principles of 7.2.1 through 7.2.5.

7.2.1 Liquids that give off flammable vapors shall be stored in essentially gastight structures.

7.2.2 Openings where flammable concentrations of vapor or gas escape to the atmosphere shall be closed or otherwise protected against the entrance of flame.

7.2.3 Structures and all appurtenances (e.g., gauge hatches, vent valves) shall be maintained in operating condition.

7.2.4 Flammable air–vapor mixtures shall be prevented, to the greatest possible extent, from accumulating outside such structures.

7.2.5 Potential spark gaps between conductive surfaces shall not be allowed at points where flammable vapors escape or accumulate.

7.3 Protective Measures.

7.3.1 Materials and Installation.

7.3.1.1 Conductors, strike termination devices, surge protection, and grounding connections shall be selected and installed in accordance with the requirements of Chapter 4 and as described in this chapter.

7.3.1.2 Overhead ground wire material shall be chosen to minimize corrosion from conditions at the site.

7.3.1.3 The overhead ground wire selected shall be sized in cross-sectional area to a main conductor and shall be self-supporting with minimum sag under all conditions.

7.3.1.4 The overhead ground wire shall be constructed of aluminum, copper, stainless steel, or protected steel such as copper-clad, aluminum-clad, lead-clad, or galvanized steel.

7.3.2 Sheet Steel. Sheet steel less than 4.8 mm (3⁄16 in.) in thickness shall not be relied upon as protection from direct lightning strokes.

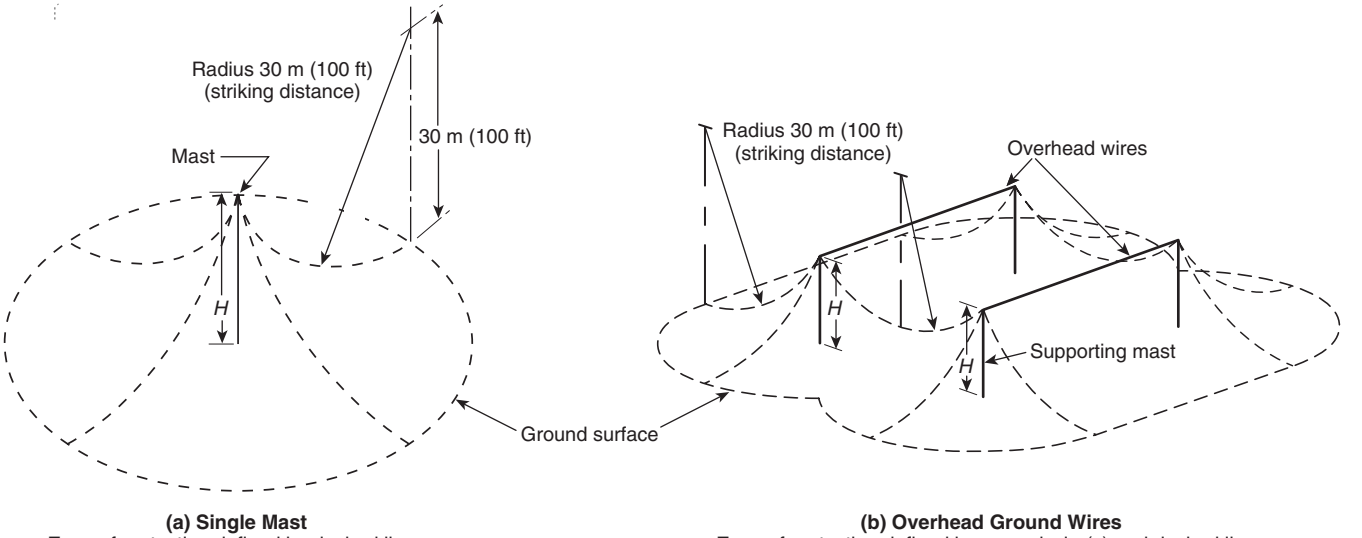
7.3.3 Rods, Masts, and Overhead Ground Wires.

7.3.3.1 The zone of protection of a lightning protection mast shall be based on the striking distance of the lightning stroke.

7.3.3.2 Since the lightning stroke can strike any grounded object within the striking distance of the point from which final breakdown to ground occurs, the zone of protection shall be defined by a circular arc concave upward, shown in part (a) of Figure 7.3.3.2.

7.3.3.3 The radius of the arc is the striking distance, and the arc shall pass through the tip of the mast and be tangent to the ground.

7.3.3.4 Where more than one mast is used, the arc shall pass through the tips of adjacent masts, as shown in part (b) of Figure 7.3.3.2 and in Figure 7.3.3.4. The distance can be determined analytically for a 30 m (100 ft) striking distance with the following equation (units shall be consistent, m or ft):



(a) Single Mast
Zone of protection defined by dashed lines

(b) Overhead Ground Wires
Zone of protection defined by ground wire(s) and dashed lines

FIGURE 7.3.3.2 Single Mast Zone of Protection (a) and Overhead Ground Wires Zone of Protection (b).

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$$d = \sqrt{h_1(2R - h_1)} - \sqrt{h_2(2R - h_2)}$$

where:
d = horizontal protected distance
h_1 = height of the higher mast
R = rolling sphere radius [30 m (100 ft)]
h_2 = height of the lower mast

7.3.3.5 The striking distance is related to the peak stroke current and thus to the severity of the lightning stroke; the greater the severity of the stroke, the greater the striking distance.

(A) In the vast majority of cases, the striking distance exceeds 30 m (100 ft).

(B) Accordingly, the zone based on a striking distance of 30 m (100 ft) is protected.

7.3.3.6 The zone of protection afforded by any configuration of masts or other elevated, conductive grounded objects shall be determined.

7.3.3.7 Overhead Ground Wire.

(A) The zone of protection of an overhead ground wire shall be based on a striking distance of 30 m (100 ft) and defined by 30 m (100 ft) radius arcs concave upward. *[See part (b) of Figure 7.3.3.2.]*

(B) The supporting masts shall have a clearance from the protected structure in accordance with 7.3.3.8.

7.3.3.8* To prevent sideflashes, the minimum distance between a mast or overhead ground wire and the structure to be protected shall be not less than the bonding distance or sideflash distance.

(A) Sideflash distance from a mast shall be calculated from the following formula:

$$D = \frac{h}{6}$$

where:
D = sideflash distance from a mast
h = height of structure (or object being calculated)

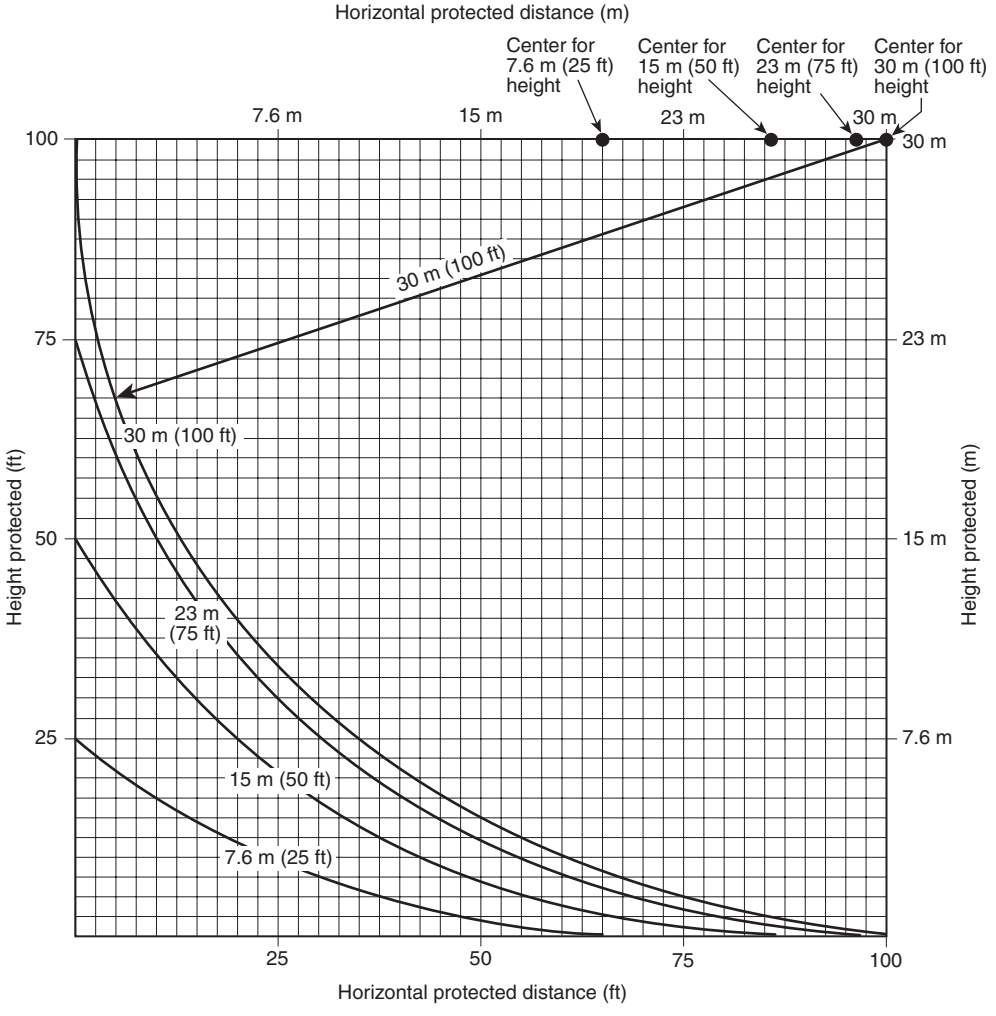


FIGURE 7.3.3.4 Zone of Protection — 30 m (100 ft) Utilizing Rolling Sphere Method.

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(B) Sideflash distance from a catenary shall be calculated as

$$D = \frac{l}{6n}$$

where:
D = sideflash distance from a catenary
l = length of lightning protection conductor between its grounded point and the point being calculated
n = 1 where there is a single overhead ground wire that exceeds 60 m (200 ft) in horizontal length
n = 1.5 where there is a single overhead wire or more than one wire interconnected above the structure to be protected, such that only two down conductors are located greater than 6 m (20 ft) and less than 30 m (100 ft) apart
n = 2.25 where there are more than two down conductors spaced more than 7.6 m (25 ft) apart within a 30 m (100 ft) wide area that are interconnected above the structure being protected

(C) The masts or overhead ground wires shall be grounded and interconnected with the grounding system of the structure to be protected.

(D) The grounding requirements of Chapter 4 shall apply.

7.3.3.9 Alternate Grounding Methods.

(A) Masts of wood, used either separately or with ground wires, shall have an air terminal extending at least 0.6 m (2 ft) above the top of the pole, attached to the pole as in Figure 7.3.3.9(A), and connected to the grounding system.

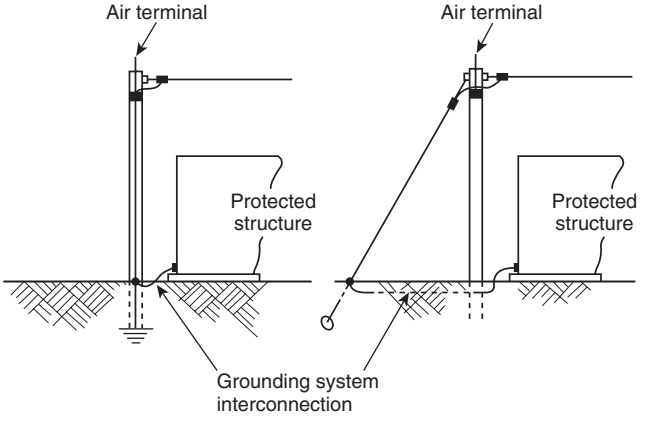


FIGURE 7.3.3.9(A) Alternate Grounding Methods for Overhead Ground Wire Protection.

(B) As an alternative, an overhead ground wire or a down conductor, extending above or across the top of the pole, shall be permitted to be used.

(C) In the case of an overhead ground wire system, the pole guy wire shall be permitted to be used as the down conductor, provided the guy meets the requirement of 7.3.1.

(D) For grounded metallic masts, the air terminal and the down conductor shall not be required.

7.4 Protection of Specific Classes of Structures.

7.4.1 Aboveground Tanks at Atmospheric Pressure Containing Flammable Vapors or Liquids That Give Off Flammable Vapors.

7.4.1.1 Fixed-Roof Tanks. Metallic tanks with steel roofs of riveted, bolted, or welded construction, with or without supporting members, that are used for the storage of liquids that give off flammable vapors at atmospheric pressure shall be considered protected against lightning (inherently self-protecting) if the requirements of 7.4.1.1(A) through 7.4.1.1(E) are met.

(A) All joints between metallic plates shall be riveted, bolted, or welded.

(B) All pipes entering the tank shall be metallically connected to the tank at the point of entrance.

(C) All vapor or gas openings shall be closed or provided with flame protection in locations where the stored stock produces a flammable air–vapor mixture under storage conditions.

(D) The roof shall have a minimum thickness of 4.8 mm (3⁄16 in.).

(E) The roof shall be welded, bolted, or riveted to the shell.

7.4.1.2* Floating-Roof Tanks. Where floating roofs utilize hangers located within a vapor space, the roof shall be electrically bonded to the shoes of the seal through a direct electrical path at intervals not greater than 3 m (10 ft) on the circumference of the tank.

(A) These shunts shall consist of flexible Type 302, 28-gauge [0.4 mm × 50 mm (1⁄64 in. × 2 in.)] wide stainless steel straps or the equivalent in current-carrying capacity and corrosion resistance.

(B) The metallic shoe shall be maintained in contact with the shell and without openings (such as corrosion holes) through the shoe.

(C) Tanks without a vapor space at the seal shall not require shunts at the seal.

(D) Where metallic weather shields cover the seal, they shall maintain contact with the shell.

(E) Where a floating roof is equipped with both primary and secondary seals, the space between the two seals could contain a vapor–air mixture within the flammable range; therefore, if the design of such a seal system incorporates electrically conductive materials and a spark gap exists within that space or could be created by roof movement, shunts shall be installed so that they directly contact the tank shell above the secondary seal.

(F) The shunts shall be spaced at intervals not greater than 3 m (10 ft) and shall be constructed so that metallic contact is maintained between the floating roof and the tank shell in all operational positions of the floating roof.

7.4.1.3 Metallic Tanks with Nonmetallic Roofs. Metallic tanks with wooden or other nonmetallic roofs shall not be self-protecting, even if the roof is essentially gastight and sheathed with thin metal and with all gas openings provided with flame protection.

(A) Such tanks shall be provided with strike termination devices.

(B) Such strike termination devices shall be bonded to each other, to the metallic sheathing, if any, and to the tank shell.

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(C) Isolated metal parts shall be bonded as required by Section 4.19.

(D) Any of the following strike termination devices shall be permitted to be used: conducting masts, overhead ground wires, or a combination of masts and overhead ground wires.

7.4.1.4 Grounding Tanks.

7.4.1.4.1 Tanks shall be grounded to conduct away the current of direct strokes and the buildup and potential that causes sparks to ground.

7.4.1.4.2 A metal tank shall be grounded by one of the following methods:

(1) A tank shall be connected without insulated joints to a grounded metallic piping system.
(2) A vertical cylindrical tank shall rest on earth or concrete and shall be at least 6 m (20 ft) in diameter, or shall rest on bituminous pavement and shall be at least 15 m (50 ft) in diameter.
(3) A tank shall be bonded to ground through a minimum of two grounding electrodes, as described in Section 4.13, at maximum 30 m (100 ft) intervals along the perimeter of the tank.
(4) A tank installation using an insulating membrane beneath for environmental or other reasons shall be grounded as in (3).

7.4.2 Earthen Containers at Atmospheric Pressure Containing Flammable Vapors or Liquids That Give Off Flammable Vapors.

7.4.2.1 Lined or unlined earthen containers with combustible roofs that enclose flammable vapors or liquids that can give off flammable vapors shall be protected by air terminals, separate masts, overhead ground wires, or a combination of these devices.

7.4.2.2 Aboveground nonmetallic tanks shall be protected as described in 7.3.3.

Chapter 8 Protection for Watercraft

8.1 General. The intent of this chapter shall be to provide lightning protection requirements for watercraft while in water.

8.1.1* Lightning protection systems installed on watercraft shall be installed in accordance with the provisions of this chapter.

8.2 Materials.

8.2.1 Corrosion.

8.2.1.1 The materials used in the lightning protection system shall be resistant to corrosion in a marine environment.

8.2.1.2 The use of combinations of metals that form detrimental galvanic couples shall be prohibited where they are likely to be in contact with water.

8.2.2 Dissimilar Metals.

8.2.2.1 Copper conductors shall be tinned.

8.2.2.2 All copper conductors shall be of the grade required for commercial electrical work and shall have at least 95 percent of the conductivity of pure copper.

8.2.2.3 The use of conducting materials other than copper, such as aluminum, stainless steel, and bronze, shall be permitted provided they meet all requirements in this chapter.

8.2.2.4* Carbon fiber composite (CFC) is not permitted to be used as a conductor in a lightning protection system.

8.3 Strike Termination.

8.3.1* Zone of Protection.

8.3.1.1 The zone of protection for watercraft shall be based on a striking distance of 30 m (100 ft).

8.3.1.2 The zone of protection afforded by any configuration of masts or other elevated conductive objects shall be determined graphically or mathematically, as shown in Figure 7.3.3.4 and Figure 8.3.1.2. The distance can be determined analytically for a 30 m (100 ft) striking distance with the following equation (units shall be consistent, m or ft):

$$d = \sqrt{h_1(2R - h_1)} - \sqrt{h_2(2R - h_2)}$$

where:
d = horizontal protected distance
h_1 = height of strike termination device
R = rolling sphere radius [30 m (100 ft)]
h_2 = height of object to be protected

8.3.2 Strike Termination Devices.

8.3.2.1* Strike termination devices shall meet the requirements of Section 4.6 and Table 4.1.1.1(A) and shall be so located and high enough to provide a zone of protection that covers the entire watercraft.

8.3.2.2 The devices shall be mechanically strong to withstand the roll and pitching action of the hull, as well as heavy weather.

8.3.2.3 Metallic fittings such as masts, handrails, stanchions, bimini tops, outriggers, flybridges, and dinghy davits shall be permitted as strike termination devices providing they meet the requirements of 8.3.2.1.

8.3.3 Nonmetallic Masts. A nonmetallic mast not within the zone of protection of a strike termination device shall be provided with at least one air terminal that meets the requirements of a strike termination device.

8.3.3.1 An air terminal shall extend a minimum of 254 mm (10 in.) above the mast.

8.3.3.2 The top of an air terminal shall be sufficiently high that all masthead fittings are below the surface of a 90 degree inverted cone with its apex at the top of the air terminal.

8.3.3.3 Multiple air terminals shall be permitted to give the required zone of protection comprising overlapping zones of protection as described in 8.3.3.2.

8.3.3.4 An air terminal shall be securely fastened to the mast and connected to a main conductor as described in 8.4.1.

8.4 Conductors.

8.4.1 Main Conductor.

8.4.1.1* A main conductor made of copper shall have a cross-sectional area of at least 21 mm^2 (0.033 $in.^2$).

8.4.1.2 A main conductor made of aluminum shall have a cross-sectional area of at least 40 mm^2 (0.062 $in.^2$).

8.4.1.3* A conducting fitting constructed of metal other than copper or aluminum that neither contains electrical wiring nor connects conductors containing electrical wiring shall be

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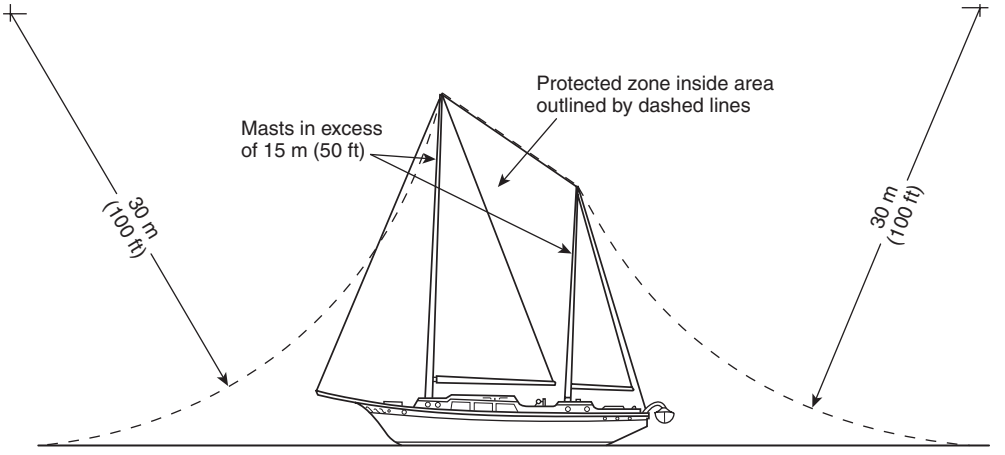


FIGURE 8.3.1.2 Diagram of a Boat with Masts in Excess of 15 m (50 ft) Above the Water. [Protection based on lightning strike distance of 30 m (100 ft).]

permitted to be used as a main conductor if it has at least the cross-sectional area given by the following formula:

$$A = 9.7 \times 10^{9} \sqrt{\frac{\rho}{C_p D(MP - 298)}} \text{mm}^2$$

where:
A = cross-sectional area
ρ = resistivity in Ω m
C_p = specific heat capacity in J kg^{-2} K^{-1}
D = density in kg m^{-3}
MP = melting point in degrees Kelvin

8.4.1.4* A conducting fitting constructed of metal other than copper or aluminum that either contains electrical wiring or connects conductors containing electrical wiring shall be permitted to be used as a main conductor if it has the same or smaller dc resistance per unit length as a copper conductor with a cross-sectional area of 21 mm^2 (0.033 in.^{2}).

8.4.1.5 Metallic fittings, including masts, handrails, toe rails, stanchions, through bolts, bimini tops, outriggers, flybridges, and dinghy davits, shall be permitted to be used as main conductors providing they meet the requirements of 8.4.1.

8.4.1.6* Each main conductor shall be routed either directly to a grounding electrode, described in Section 8.5, or outboard of crewed areas, wiring, and electronics.

8.4.1.7* No main conductor shall pass within 150 mm (6 in.) of the unheeled waterline unless it is terminated in a grounding electrode *(see 8.5.4)* within 600 mm (24 in.).

8.4.1.8 An air gap shall be permitted to break the path of a main conductor, subject to the conditions in 8.5.5.

8.4.2 Bonding Conductor.

8.4.2.1 A bonding conductor made of copper shall have a cross-sectional area of at least 8.3 mm^2 (0.013 in.^{2}).

8.4.2.2 A bonding conductor made of aluminum shall have a cross-sectional area of at least 16 mm^2 (0.025 in.^{2}).

8.4.2.3* A conducting fitting constructed of metal other than copper or aluminum that neither contains electrical wiring nor connects conductors containing electrical wiring shall be permitted to be used as a bonding conductor if it meets the minimum cross-sectional area given by the following formula:

$$A = 3.8 \times 10^{9} \sqrt{\frac{\rho}{C_p D(MP - 298)}} \text{mm}^2$$

where:
A = cross-sectional area
ρ = resistivity in Ω m
C_p = specific heat capacity in J kg^{-2} K^{-1}
D = density in kg m^{-3}
MP = melting point in degrees Kelvin

8.4.2.4* A conducting fitting constructed of metal other than copper or aluminum that either contains electrical wiring or connects conductors containing electrical wiring shall be permitted to be used as a bonding conductor if it has the same or smaller dc resistance per unit length as a copper conductor with a cross-sectional area of 8.3 mm^2 (0.013 in.^{2}).

8.4.2.5 Metallic fittings, including masts, handrails, toe rails, stanchions, through bolts, bimini tops, outriggers, flybridges, and dinghy davits, shall be permitted to be used as bonding conductors providing they meet the requirements of 8.4.2.

8.4.2.6 No bonding conductor shall pass within 150 mm (6 in.) of the unheeled waterline unless it is within 600 mm (24 in.) of a grounding electrode *(see 8.5.4)*.

8.4.2.7* Large metallic masses shall be connected to the loop conductor, a bonding conductor, or a main conductor with at least one bonding conductor.

8.4.2.8 The lower end of each metallic shroud or stay shall be bonded horizontally to the loop conductor.

8.4.2.9 The connection to the shroud or its chainplate shall be permitted to be made near deck level.

8.4.3 Loop Conductor.

8.4.3.1 A main size loop conductor shall be routed horizontally at either deck level or cabin top level or at least 2 m (6 ft) above the waterline, to form a continuous conducting loop outboard of crewed areas, wiring, and electronics.

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8.4.3.2 The loop conductor shall be connected to at least one main conductor by means of a main conductor.

8.4.4 Conductor System.

8.4.4.1* All main conductors, bonding conductors, and loop conductors shall be interconnected to form the lightning conductor system.

8.4.4.2 Each interconnection shall consist of a conductor no smaller than a bonding conductor as described in 8.4.2, or a connecting fitting satisfying the requirements in 8.4.6.

8.4.4.3 Each joint between conductors shall satisfy the requirements in 8.4.5.

8.4.4.4 The path between each strike termination device and each grounding electrode *(see 8.5.4)* shall be connected by at least one main conductor.

8.4.4.5 The thickness of any copper ribbon, strip, or hollow conductor in the system shall be not less than 1.3 mm (0.052 in.).

8.4.4.6 The thickness of any aluminum ribbon, strip, or hollow conductor in the system shall be not less than 1.6 mm (0.064 in.).

8.4.4.7 The lightning conductor system shall be connected to both the dc and ac electric grounds using a bonding conductor.

8.4.5 Joints.

8.4.5.1 Joints shall be mechanically strong and able to withstand any torque, force, or tension to be expected during normal operation.

8.4.5.2 When a joint is made between conductors of the same material, the contact area shall be at least as large as the cross-sectional area of the conductor. Depending on the material, the contact minimum area for a joint in a main conductor shall be given by 8.4.1.1(for copper), 8.4.1.2 (for aluminum), or 8.4.1.3 (for other metals). For a joint in a bonding conductor, or between a bonding conductor and main conductor, the contact minimum area shall be given by 8.4.2.1(for copper), 8.4.2.2 (for aluminum), or 8.4.2.3 (for other metals).

8.4.5.3 When a joint is made between two different metals, the minimum contact area shall be that required in 8.4.1.3 for a main conductor and 8.4.2.3 for a bonding conductor.

8.4.5.4 With the exception of bimetallic connectors, direct contact between metals whose galvanic potential differs by more than 0.5 V shall not be permitted.

8.4.5.5 For plated metals, the galvanic potential shall be that of the plating.

8.4.5.6 No joint between metals whose galvanic potential differs by more than 0.5 V shall be permitted in locations where immersion is likely, such as the bilge, unless the joint is encapsulated in a waterproof enclosure.

8.4.5.7 In those cases where it is impractical to avoid a junction of dissimilar metals, the corrosion effect shall be reduced by the use of plating or special connectors, such as stainless steel connectors used between aluminum and copper or copper alloys.

8.4.6 Connecting Fittings.

8.4.6.1 Fittings of any length that are made of aluminum shall be permitted to join two conductors if the minimum cross-sectional area meets the requirements of 8.4.1 for main conductors or 8.4.2 for bonding conductors.

8.4.6.2* Connecting fittings made of metals other than aluminum or copper shall meet either of the following criteria:

(1) Have the same resistance per unit length as the corresponding type of conductor (that is, main or bonding)
(2) Have a cross-sectional area at least as large as that given in 8.4.1.3 for a main conductor or 8.4.2.3 for a bonding conductor, and have a resistance that is not more than the resistance of 0.6 m (2 ft) of the corresponding copper conductor

8.5 Grounding.

8.5.1 Watercraft with Metal Hulls. Where an electrical connection exists between a metallic hull and a lightning air terminal or other metallic superstructure of sufficient height to provide the zone of protection specified in Section 8.3, no further protection shall be necessary.

8.5.2 Watercraft with Nonmetallic Hulls.

8.5.2.1* Grounding electrodes shall be installed on the nonmetallic hull of a watercraft to provide multiple paths for the lightning current to exit into the water.

8.5.2.2 Each grounding electrode shall be connected either directly to a main conductor or to a main conductor through an air gap that satisfies all conditions in 8.5.5.

8.5.2.3* Rudders, struts, seacocks, through-hull fittings, or any other metallic fittings that meet the requirements of either 8.5.4.1 or 8.5.4.2 shall be permitted to be used as grounding electrodes.

8.5.2.4 Through-hull connectors to a grounding electrode shall be metallic and have a cross-sectional area equivalent to a main conductor.

8.5.3 Main Grounding Electrode.

8.5.3.1 At least one grounding electrode shall comprise an immersed solid conductor that has a contact area with the water of at least 0.09 m^2 (1 ft^2), a thickness of at least 5 mm (3⁄16 in.), and a width of at least 19 mm (3⁄4 in.).

8.5.3.2 The area of a main grounding electrode shall be determined as the outward-facing area of the surface that is in contact with the water.

8.5.3.3 A main grounding electrode shall be immersed during all normal modes of vessel operation.

8.5.4 Supplemental Grounding Electrode.

8.5.4.1* Supplemental grounding electrodes shall be permitted that have less than 0.09 m^2 (1 ft^2) in contact with the water.

8.5.4.2 The outboard surface of the grounding electrode shall be less than 1 mm (0.04 in.) inside the outer finished surface of the hull, including coatings and paint.

8.5.5* Galvanic Corrosion Protection.

8.5.5.1 An air gap or SPD (such as a gas discharge tube) shall be permitted to break the path of a main conductor within 200 mm (8 in.) of a grounding electrode.

8.5.5.2 The breakdown voltage of an air gap or SPD (such as a gas discharge tube) shall be not less than 600 V and not greater than 15 kV.

8.5.5.3 With the exception of the gap itself, all components in and connections to an air gap device shall have a cross-sectional area meeting the requirements for a main conductor.

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Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1.2 Electric generating facilities whose primary purpose is to generate electric power are excluded from this standard with regard to generation, transmission, and distribution of power. Most electrical utilities have standards covering the protection of their facilities and equipment. Installations not directly related to those areas and structures housing such installations can be protected against lightning by the provisions of this standard.

Lightning protection systems for structures used for production or storage of explosive materials require special consideration because the contents of such structures are sensitive to arc or spark ignition. Annex K provides guidance for protection of structures housing explosive materials. Other standards and handbooks that provide guidance for military applications are found in Annex O.

A.1.5 Guidance on an effective maintenance program is provided in Annex D.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.2.4 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.3.1 Air Terminal. Typical air terminals are formed of a tube or solid rod. Air terminals are sometimes called *lightning rods*.

A.3.3.3 Cable. See Table 4.1.1.1(A) and Table 4.1.1.1(B).

A.3.3.6 Combination Waveform Generator. For the open-circuit waveform, the front time = 1.67(t90 – t30), where t90 and t30 are times to the 90 percent and the 30 percent amplitude points on the leading edge of the waveform. The duration of this waveform will be the time between virtual origin and time to the 50 percent point on the tail. (Virtual origin is the intersection of the line connecting t90 and t30, with V = 0.)

For the short-circuit waveform, the front time = 1.25 (t90 – t10), where t90 and t10 are times to the 90 percent and the 10 percent amplitude points on the leading edge of the waveform. The duration will be the time between virtual origin and time to the 50 percent point on the tail. (Virtual origin is the intersection of the line connecting t90 and t10, with I = 0.)

A.3.3.7.3 Main Conductor. The main conductor also serves as a strike termination device for catenary lightning protection systems.

A.3.3.12 Flammable Air–Vapor Mixtures. The combustion range for ordinary petroleum products, such as gasoline, is from about 1½ percent to 7½ percent of vapor by volume, the remainder being air.

A.3.3.19 Lightning Protection System. The term refers to systems as described and detailed in this standard. A traditional lightning protection system used for ordinary structures is described in Chapter 4. Mast and catenary-type systems typically used for special occupancies and constructions are described in Chapter 7.

A.3.3.21.1 Class I Materials. See Table 4.1.1.1(A).

A.3.3.21.2 Class II Materials. See Table 4.1.1.1(B).

A.3.3.27 Suppressed Voltage Rating (SVR). The SVR is a rating (or ratings) selected by the manufacturer based on the measured limiting voltage determined during the transient voltage surge suppression test specified in UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors*. This rating is the maximum voltage developed when the SPD is exposed to a 500 A, 8/20 µs current limited waveform through the device. It is a specific measured limiting voltage rating assigned to a TVSS by testing done in accordance with UL 1449 . Nominal SVR values include 330 V, 400 V, 500 V, 600 V, 700 V, and so forth.

Devices rated in accordance with UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors,* Edition 3, will reflect a Voltage Protection Rating (VPR) in place of the SVR. This is to reflect the difference that the voltage rating test will utilize a 3 kA peak current instead of the 500 A current level used in the SVR test of UL 1449, Edition 2.

A.4.6.2 Recent experiments described by Moore et al. in the *Journal of Applied Meteorology* suggest that the optimal air terminal tip radius of curvature for interception of lightning strikes is 4.8 mm (3⁄16 in.) minimum to 12.7 mm (½ in.) maximum.

A.4.7.3.2 It is recognized that the sides of tall structures are subject to direct lightning strikes. Due to the low risk of strikes to the sides of tall structures and the minimal damage caused by these typically low current level discharges, the cost of protection for the sides of tall structures is not normally justified.

A.4.8.2 Strike termination devices should be placed as close as practicable to roof edges and outside corners.

A.4.8.3 Figure A.4.8.3 illustrates dormer protection.

A.4.8.8.3 Strike termination devices should be placed as close as practicable to an outside corner.

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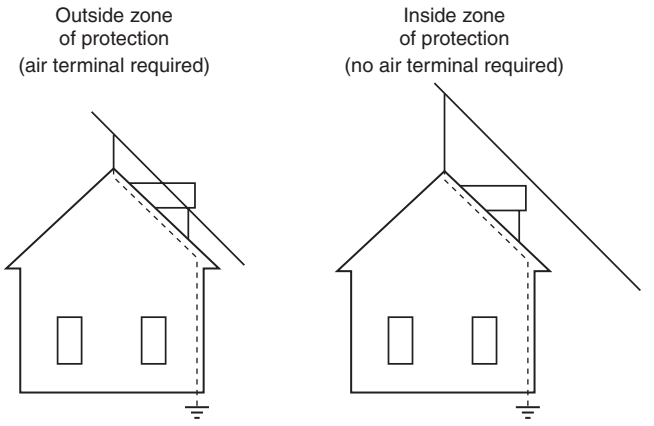


FIGURE A.4.8.3 Dormer Protection.

A.4.13.2 Research has been presented that warns that stainless steel is very susceptible to corrosion in many soil conditions. Extreme caution should be used with proper soil analysis where this type of rod is used. For further information, see NFPA 70, *National Electrical Code®*, which contains detailed information on the grounding of electrical systems.

A.4.13.2.4 Minimal benefit is gained from the second ground rod if placed closer than the sum of the driven depth of both rods.

A.4.13.5 Radial augmentation of the grounding system specified in 4.13.5 and 4.13.8.2 by the use of one or more radial conductors is recommended. Radial conductors should be sized in accordance with the requirements for main conductors and installed in accordance with 4.13.8.1.

A.4.13.6 The 0.18 m^2 (2 ft^2) surface area requirement can be accomplished by using a 0.09 m^2 (1 ft^2) plate with both sides in contact with the earth.

A.4.13.8.1 For those instances in which it is necessary to install the grounding conductor directly on bedrock, it is recommended that main conductor solid strips be utilized. If there are locations along the length of the radial conductor in which there is sufficient soil available for the installation of an earth electrode, the installation of an additional earth electrode is encouraged. When a ground ring electrode is used in an application with insufficient soil cover, radial(s) should be considered to supplement the ground ring electrode to direct the lightning away from the protected area for all locations where property boundaries allow their addition.

A.4.14.1 Isolating spark gaps can be used to provide the required bond in those cases where galvanic corrosion is a concern or where a direct bond is not allowed by local code. The use of isolating spark gaps is not recommended for those applications where significant follow current can be expected. It is recommended that isolating spark gaps used in this application be installed in accordance with the manufacturer's instructions and be rated for the environment in which they are to be installed (hazardous classified location, direct burial, etc. as applicable). The devices used in these applications should be rated at a maximum discharge current no less than 100 kA, 8/20 µs [2.5 kV spark over voltage (U_p)], have an isolating resistance no less than 10^8 Ω and a maximum dc spark over voltage of 500 V.

A.4.15.4.1 It is preferable that grounding electrodes be located no closer than 0.6 m (2 ft) from foundation walls to minimize the probability of damage to the foundation, although this is not always practicable for all applications. For reference, IEC 62305, *Protection Against Lightning*, Part 3, *Physical Damage to Structures and Life Hazard*, requires that ring earth electrodes be buried at a depth of at least 0.5 m (18 in.) and a distance of approximately 1 m (3 ft) around external walls.

A.4.18.1 Surge protection alone is not intended to prevent or limit physical damage from a direct lightning strike to a facility or structure. Rather, it is intended to defend against indirect lightning effects imposed upon the electrical services to a structure as part of a coordinated lightning protection system installed in accordance with the requirements of this standard.

Surge currents and their corresponding overvoltage transients can be coupled onto electrical utility feeders in a number of ways. These mechanisms include magnetic or capacitive coupling of a nearby strike or the more dramatic but much less frequent conductive coupling of a direct cloud-to-ground discharge. These overvoltage transients pose a significant threat to modern electrical and electronic equipment.

A.4.18.2 The SPD responds to surges by lowering its internal impedance so as to divert surge current to limit the voltage to its protective level — the measured limiting voltage. After the occurrence of surges, the SPD recovers to a high-impedance-state line-to-ground and extinguishes current to ground through the device when line voltage returns to normal. The SPD achieves these functions under normal service conditions. The normal service conditions are specified by the frequency of the system, voltage, load current, altitude (i.e., air pressure), humidity, and ambient air temperature.

A.4.18.2.2 Antennas are considered a part of conductive signal, data, and communication services.

A.4.18.2.5 Most services to facilities will require discrete surge suppression devices installed to protect against damaging surges. Occasionally, services will be located in an area or manner where the threat from lightning-induced surges and overvoltage transients might be negligible. For example, the requirements in 4.18.2.3 *(also see A.4.18.6.1)* exempt services less than 30 m (100 ft) in length that are run in grounded metal conduit between buildings requiring surge protection. Other examples where surge protective devices might not be required to be installed at each service entrance are those applications where fiber optic transmission lines (with no conducting members) are used. The standard recognizes that there can be acceptable exceptions and consequently allows for such exceptions to the requirements for surge suppression on electrical utility, data, and other signal lines, provided a competent engineering authority has determined that the threat is negligible or that the system is protected in a manner equivalent to surge suppression.

Allowance in this standard for the exemption of surge suppression at specific locations is not intended as a means to provide a broad exemption simply because surge suppression might be considered inconvenient to install. Rather, this allowance recognizes that all possible circumstances and configurations, particularly those in specialized industries, cannot be covered by this standard.

Determinations made by an engineering authority for exempting installation of SPDs should focus on the likelihood of lightning activity in the region, the level of damage that might be incurred, and the potential loss to human life or essential services due to inadequate overvoltage protection.

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Three methods of analysis are commonly used for this determination, although other equivalent analysis can be used. The three methods are the following:

(1) The *lightning flash density/risk analysis* is an analysis to determine the frequency of lightning activity in the geographic area of the facility. As a rule of thumb, if the flash density exceeds one flash per square kilometer per year, surge suppression or other physical protection should be considered. Lightning energy can indirectly couple to services at ranges greater than 1 km (0.6 mi) to create potentially damaging overvoltages.
(2) *Plant/facility statistical or maintenance records* can also be used as a risk analysis. If these records can demonstrate the lack of damage on a service due to surges, it can be used to justify low risk of surge damage to a particular system or facility.
(3) The *lightning electromagnetic environment analysis* starts with a threat electromagnetic field from a nearby lightning strike and computes the magnitude and rise-time characteristics of transients coupled into services feeding a structure or facility. Based on the computed threat, SPDs can be sized appropriately or omitted, as warranted. This analysis is typically performed for critical communications facilities and in military applications. Electromagnetic environments for such an analysis can be found in MIL-STD-464, *Interface Standard Electromagnetic Environmental Effects Requirements for Systems*, and IEC 61312-1, *Protection Against Lightning Electromagnetic Impulse*.

In all cases, the criticality of continued operation, potential life hazard to persons and essential services, and the consequence of facility damage or shutdown should be factors in the analysis. If a hazardous condition results from a surge causing temporary shutdown without permanent damage (e.g., through the disabling of a computer or communication system), then the requirements for surge suppression as articulated by Section 4.18 should not be exempted.

A.4.18.3.1 SPDs are typically sized significantly larger than the expected challenge level. At service entries, it is generally agreed that a maximum discharge current *(I_{max})* between 40 kA and 60 kA will provide adequate protection. However, larger ratings that protect against less probable but more powerful lightning events will usually provide a better capability to handle multiple strikes and will usually provide a longer service life. Rating the SPD's I_{max} higher than the minimums in this document is recommended in areas with frequent lightning.

Where installed, SPDs at branch panels or subpanels should have an I_{max} rating of 20 kA 8/20 μs or greater per phase.

Where installed, supplementary protection (also called point of utilization) SPDs should have an I_{max} rating of 10 kA 8/20 μs or greater per phase.

A.4.18.4 The measured limiting voltages of the SPD should be selected to limit damage to the service or equipment protected.

Devices rated in accordance with UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors*, Edition 3, will reflect a VPR in place of the SVR. This is to reflect that the voltage rating test in Edition 3 will utilize a 3 kA peak current instead of the 500 A current level used in the SVR test of UL 1449, Edition 2.

A.4.18.5 Surges can be induced upon any line entering a structure.

Where installed, branch panels over 30 m (100 ft) from the service entrance should have L–G or L–N and N–G modes of protection. Additionally, L–L protection is also permitted (although this is usually achieved by the L–N modes across two phases). L–L protection is achieved by the L–N modes across two phases.

The following modes of protection are possible to minimize voltage differences between the individual conductors:

(1) Line-to-line (L–L) protection places the SPD between the current-carrying conductors in a power system.
(2) Line-to-neutral (L–N) protection places the SPD between the current-carrying conductors and the grounded conductor (neutral) in a power system.
(3) Line-to-ground (L–G) protection places the SPD between the current-carrying conductors and the grounding conductor (ground) in a power system.
(4) Neutral-to-ground (N–G) protection places an SPD between the grounded conductor (neutral) and the grounding conductor (ground) in a power system. This mode of protection is not required at the service entrance (primary service panel board) if the neutral-to-ground bond is implemented at this location or within proximity of this point of installation. Thus, in general, an SPD with only L–L and L–N modes of protection might be required at the service entrance.
(5) *Common mode* is a term used for a mode of protecting telecommunications, data lines, and so forth. This mode places the SPD between the signal conductor and ground. It is analogous to L–G mode in power systems.
(6) *Differential mode* is a term used for a mode of protecting telecommunications, data lines, and so forth. In this mode, an SPD is placed between the individual signal lines, analogous to the L–L mode of protection in power systems.

A.4.18.6.1 SPDs should be placed on both ends of external signal, data, and communication lines longer than 30 m (100 ft) connecting pieces of equipment or facilities, to protect against surges coupled into the wiring or caused by ground potential differences.

A.4.18.6.3.1 The purpose of the SPD is to equalize L–L, L–N, L–G, and N–G potentials. While a good ground is important, a good bond is imperative to minimize damage due to lightning and/or power contact or induction.

A.4.18.6.3.5 Differential mode protection should also be provided where practicable.

A.4.18.7.2 Longer, or looped, SPD line and ground conductors increase the impedance of the SPD ground circuit. Increasing the lead length serves to increase pass-through voltage at the point where the SPD is wired into service equipment or a branch panelboard. Consequently, it is essential to minimize lead length impedance in this circuit.

A.4.18.7.4 Some SPD units are provided with a failure indicator. This feature is recommended since it facilitates maintenance or test procedures. Where used, this indicator should be visible. Building maintenance should consider periodic inspection or test of SPDs.

A.4.18.8 The SPD earth ground resistance is part of the total impedance of the SPD ground circuit. The ability of the SPD to discharge current to ground is affected by this impedance. Also, a lower ground resistance minimizes voltage differences of conductors attached to SPDs near the service entrance and reduce the chance of arcing or insulation breach. Consequently, it is essential to minimize impedance in this circuit.

A.4.19 See Annex C for a technical discussion of lightning protection potential-equalization bonding.

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A.4.20.1 For structures 18 m (60 ft) or less in height, a loop conductor should be provided for the interconnection of all grounding electrodes and other grounded media. Regardless of the building height, ground loop conductors should be installed underground in contact with earth. Ground-level potential equalization allows use of a ground ring electrode as a ground loop conductor. A ground ring electrode conforming to 4.13.4 can be utilized for the ground loop conductor.

A.4.20.2 In the case of flat or gently sloping roofs, the roof conductors required by 4.9.7 can be used for achieving roof-level potential equalization. In the case of pitched roofs, the interconnection should be a loop placed at the eave level.

A.4.21.3 In addition to the bonding of metal bodies, surge suppression should be provided to protect power, communication, and data lines from dangerous overvoltages and sparks caused by the lightning strikes. *(See Annex C for a discussion of bonding and an understanding of problems often encountered.)*

A.6.9 A ground grid located within 15 m (50 ft) of the foundation of a stack and constructed of wires meeting the requirements of this standard for main conductors is a permitted grounding electrode. If the stack is located within 15 m (50 ft) of the grid in all directions, the grid can also serve as the bottom loop conductor required by 6.4.2.

A.7.1.1 Flammable vapors can emanate from a flammable liquid [flash point below 37.8°C (100°F)] or a combustible liquid [flash point at or above 37.8°C (100°F)] when the temperature of the liquid is at or above its flash point. Chapter 7 applies to these liquids when they are stored at atmospheric pressure and ambient temperature. Provided that the temperature of the liquid remains below the flash point, combustible liquids stored under these conditions will not normally release significant vapors since their flash point is defined to be at or above 37.8°C (100°F).

Metallic tanks, vessels, and process equipment that contain flammable or combustible liquids or flammable gases under pressure normally do not require lightning protection since this equipment is well shielded from lightning strikes. Equipment of this type is normally well grounded and is thick enough not to be punctured by a direct strike.

This chapter applies to flammable or combustible liquids such as gasoline, diesel, jet fuel, fuel oil, or crude oil stored at atmospheric pressure. It does not apply to liquids or gases stored under pressure, such as liquefied natural gases or liquefied petroleum gases.

A.7.1.3 Chapters 4, 5, and 6 of this standard give requirements for the protection of buildings and miscellaneous property against lightning damage.

A.7.3.3.8 The sideflash formulas are based on the impedance of main-size copper conductors. Other ground wire materials can require additional separation distance.

A.7.4.1.2 Fires have occurred when lightning has struck the rims of open-top floating-roof tanks where the roofs were quite high and the contents volatile. Above-the-seal fires have occurred when direct lightning strokes to the rims of floating-roof tanks have ignited flammable vapors within the open shells. These have occurred where roofs were low. The resulting seal fires have been at small leakage points in the seal. An effective defense against ignition by a direct stroke is a tight seal.

Fires have also occurred in the seal space of open-top floating-roof tanks as a result of discharges caused by lightning. These have occurred most frequently in tanks having floating roofs and seals with vapor spaces below the flexible membranes. Vapor spaces will be formed where tanks are fitted with secondary seals in compliance with environmental regulations. Ignition can be from a direct stroke or from the sudden discharge of an induced (bound) charge on the floating roof, released when the charge on a cloud discharges to ground or to another cloud.

A.8.1.1 A lightning protection system does not afford protection if any part of the watercraft contacts a power line or other voltage source while in water or on shore. A lightning protection system lowers but does not eliminate risk to watercraft and its occupants.

A.8.2.2.4 Carbon fiber fittings, including masts, should be isolated electrically from the lightning conductor system. Since carbon fiber is a conductor, sideflash risk is increased in the vicinity of CFC structures, especially near the water. The use of CFC reinforcement in areas such as chainplates is to be avoided.

A.8.3.1 The techniques described in Chapter 8 should also be applied to watercraft for the placement of strike termination devices and determining the zone of protection.

A.8.3.2.1 Where a standing person is not covered by the zone of protection, a warning to this effect should be included in the owner's manual.

For retrofit applications and those applications where a sufficient zone of protection cannot be provided, the zone of protection of the lightning protection system should be identified and provided to the user of the watercraft.

A.8.4.1.1 See Table 9.12.5(a) of NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft*, for minimum strand sizes for watercraft conductors. Main conductors of greater cross sectional area as discussed in Section 4.9 provide a greater degree of safety.

A.8.4.1.3 If a metal with the area given by the equation in 8.4.1.3 is subject to the lightning heating (action integral) required to raise the temperature of a copper conductor with 21 mm^2 (0.033 $in.^2$) from a nominal temperature of 298 K to the melting point of copper, then its temperature would be raised to the melting point of the metal. Values for silicon bronze and stainless steel are given in Table A.8.4.1.3.

A.8.4.1.4 The area of a conductor of uniform cross section that has the same resistance as a copper conductor of area A_{Cu} is given by:

Table A.8.4.1.3 Areas for Main Conductor Not Containing Electrical Wiring

Metal	C_p ($J\ kg^{-2}\ K^{-1}$)	D ($kg\ m^{-3}$)	ρ (Ω m)	MP (K)	Area (mm^2)
Silicon bronze	360	8800	2.55×10^{-7}	1356	85
Stainless steel	510	7930	9.6×10^{-7}	1800	125

Note: Conductors with these areas have a larger resistance per unit length than a main conductor made of copper and so should not be used where potential equalization is required.

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$$A = \frac{\rho}{\rho_{Cu}} A_{Cu}$$

where:
A = cross-sectional area
ρ = resistivity of alternate metal (Ω m)
ρ_{Cu} = 1.7×10^{-8} Ω m = resistivity of copper
A_{Cu} = 21 mm^2 for a main conductor

Using the same parameters in Table A.8.4.1.3, the areas are 315 mm^2 (0.49 in.^{2}) for silicon bronze and 1200 mm^2 (1.8 in.^{2}) for stainless steel.

A.8.4.1.6 Routing lightning conductors near the outer surface of the hull lowers the risk of internal side flashes forming between the lightning conductors and other conducting fittings and of external sideflashes forming between conducting fittings and the water. Routing lightning conductors externally is also more consistent with the layout recommended for buildings wherein air terminals, down conductors, and grounding electrodes are located on the outside of the building. However, in the case of internal conducting fittings being very close to the water, such as a keel-stepped mast, a grounding electrode should be provided as close as is practicable to the portion of the fitting that is closest to the water.

A.8.4.1.7 All lightning conductors should be routed as far as possible from the water, and especially the waterline, to minimize the risk of an external sideflash forming between the lightning conductor and the water. Similarly, conducting fittings, electronic equipment, and electrical wiring should be located as far as possible from the water.

A.8.4.2.3 Using the same parameters as in Table A.8.4.1.3, the required areas are 33 mm^2 (0.052 in.^{2}) for silicon bronze and 48 mm^2 (0.075 in.^{2}) for stainless steel.

A.8.4.2.4 Using the same equation as in A.8.4.1.4 with the area for a copper bonding conductor, A_{Cu} = 8.3 mm^2 (0.013 in.^{2}), the required areas are 125 mm^2 (0.19 in.^{2}) for silicon bronze and 470 mm^2 (0.73 in.^{2}) for stainless steel.

A.8.4.2.7 Large metallic masses include metal cabinets that enclose electronic equipment, tanks, handrails, lifeline stanchions, engines, generators, steering cables, steering wheels or tillers, engine controls, metallic arches, and bow and stern pulpits.

A.8.4.4.1 A main conductor is designed to conduct an appreciable fraction of the lightning current, typically in a vertical direction. Close to the water, and especially inside the hull below the waterline, the optimum direction for a main conductor is perpendicular to the hull directly inboard of the grounding electrode in contact with the water. A bonding conductor is intended to conduct the relatively small currents required to equalize potentials between conducting fittings and the lightning protection system. The optimum orientation for bonding conductors is parallel to the water surface and the best location is as far from the water surface as is practicable.

A.8.4.6.2 The area of a conductor of uniform cross section that has the same resistance per unit length as a main conductor is given by the equation in A.8.4.1.4. For connecting a main conductor, the areas are 315 mm^2 (0.49 in.^{2}) for silicon bronze and 1200 mm^2 (1.8 in.^{2}) for stainless steel. For connecting a bonding conductor the required areas are 125 mm^2 (0.19 in.^{2}) for silicon bronze and 470 mm^2 (0.73 in.^{2}) for stainless steel.

Equating resistances for a copper conductor of area A_{Cu}, resistivity ρ_{Cu}, and length L_{Cu} and a metal connector of area A, resistivity ρ, and length L gives a maximum allowable length for the metal connector of:

$$L = L_{Cu} \frac{A}{A_{Cu}} \frac{\rho_{Cu}}{\rho}$$

where:
L = length of metal connector
L_{Cu} = length of copper conductor
A = area of metal connector
A_{Cu} = area of copper conductor
ρ = resistivity of metal connector
ρ_{Cu} = resistivity of copper conductor

The length is the same for both main and bonding conductors and is 165 mm (6.5 in.) for silicon bronze and 63.5 mm (2.5 in.) for stainless steel when L_{Cu} = 0.6 m (2 ft).

A.8.5.2.1 In order to allow for main conductors to be routed externally to vulnerable areas (as described in 8.4.1.6) and to reduce the risk of external side flashes from the lightning conductors, grounding electrodes should be located as close to the waterline as is practicable. Where an onboard fitting is below the waterline and close to the water, an additional supplemental grounding electrode is advisable in the vicinity of the fitting.

A.8.5.2.3 Seacocks are particularly susceptible to damage and leaking after a strike and should be inspected after all suspected strikes.

A.8.5.4.1 A supplemental grounding electrode can be painted or covered with a thin coating (<1 mm or 0.04 in.) but should not be encapsulated in fiberglass.

A.8.5.5 An air gap or SPD (such as a gas discharge tube) might be desirable to reduce corrosion in the presence of leakage currents in the water and could reduce galvanic corrosion. However, using an air gap to isolate an immersed conductor from the water can increase the risk of a ground fault current bypassing any ground fault protection device. Hence a hazardous current can be inadvertently introduced into the water. For this reason, measures should be taken to ensure that loose electrical connections cannot contact any part of the isolated grounding electrode. A spark gap should not be used where there is the possibility of ignitible vapors or personal hazards.

Annex B Principles of Lightning Protection

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

B.1 Fundamental Principles of Lightning Protection.

B.1.1 The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or leave the earth without resulting damage or loss. A low impedance path that the discharge current will follow in preference to all alternative high impedance paths offered by building materials such as wood, brick, tile, stone, or concrete should be offered. When lightning follows the higher impedance paths, damage can be caused by the heat and mechanical forces generated during the passage of the discharge. Most metals, being good electrical conductors, are virtually unaffected by either the heat or the mechanical forces if they are of sufficient size to carry the current that

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can be expected. The metallic path should be continuous from the grounding electrode to the strike termination device. Care should be exercised in the selection of metal conductors to ensure the integrity of the lightning conductor for an extended period. A nonferrous metal such as copper or aluminum will provide, in most atmospheres, a lasting conductor free of the effects of rust or corrosion.

B.1.2 Parts of structures most likely to be struck by lightning are those that project above surrounding parts, such as chimneys, ventilators, flagpoles, towers, water tanks, spires, steeples, deck railings, shafthouses, gables, skylights, dormers, ridges, and parapets. The edges and corners of the roof are the parts most likely to be struck on flat or gently sloping roofed buildings.

B.2 Lightning Protection Systems.

B.2.1 Lightning protection systems consist of the following three basic parts that provide the low impedance metal path required:

(1) A system of strike termination devices on the roof and other elevated locations
(2) A system of grounding electrodes
(3) A conductor system connecting the strike termination devices to the grounding electrodes

Properly located and installed, these basic components improve the likelihood that the lightning discharge will be conducted harmlessly between the strike termination devices and the grounding electrodes.

B.2.2 While intercepting, conducting, and dissipating the main discharge, the three basic protection system components do not ensure safety from possible secondary effects of a lightning strike. Therefore, secondary conductors are provided to interconnect metal bodies to ensure that such metal bodies are maintained at the same electrical potential so as to prevent sideflashes or sparkover. Surge suppression devices are also provided to protect power lines and associated equipment from both direct discharges and induced currents.

B.2.3 Metal parts of a structure can be used as part of the lightning protection system in some cases. For example, the structural metal framing, which has sufficient cross-sectional area to equal the conductivity of main conductors, and which is electrically continuous, can be used in lieu of separate down conductors. In such cases, air terminals can be bonded to the framework at the top, and grounding electrodes can be provided at the bottom, as described elsewhere in this standard. Structures with 4.8 mm (3⁄16 in.) thick, or thicker, metal shells or skins that are electrically continuous might not require a system of air terminals and down conductors.

B.2.4 The structure should be examined, and installation of air terminals should be planned for all areas or parts likely to receive a lightning discharge. The object is to intercept the discharge immediately above the parts liable to be struck and to provide a direct path to earth, rather than to attempt to divert the discharge in a direction it would not be likely to take. The air terminals should be placed high enough above the structure to obviate danger of fire from the arc.

B.3 Positioning of Air Terminals. Positioning of air terminals depends upon the physical lightning model used to describe the behavior of lightning. The development of these models has been ongoing for 250 years, and models have a basis in physical observations of lightning. While the models tend to be simplified compared to actual details of lightning development and propagation, empirical observations over hundreds of years have proven their effectiveness.

Air terminals are intended to intercept the lightning event by providing a preferred attachment point for lightning's electrical discharge. They operate by actually providing an upward propagating leader of ionized air to intercept a downward lightning leader. Since these leaders are ionized air of opposite charge, they attract and provide the electrical channel to earth for lightning when they connect. Air terminals placed upon a structure do not substantially increase the probability of the structure being struck by lightning. If the downward progressing lightning leader is close to the structure, it will probably attach to that structure anyway. Thus, air terminals are designed to provide a preferential attachment point on structures that already provide a likely lightning attachment point. Once lightning connects to the air terminal, it is easier to control the lightning current and direct it to earth, as opposed to it taking a random, uncontrolled (and usually damaging) path through the structure otherwise.

B.3.1 Physics of Lightning Attachment. The first stroke of a ground flash is normally preceded by a downward-progressing, low-current leader discharge that commences in the negatively charged region of the cloud and progresses toward the earth, depositing negative charges in the air surrounding the leader discharge channel. (Occasionally, the downward leader can be positive in charge but this does not affect its behavior in terms of attachment.) When the lower end of the downward leader is 100 m to 300 m (330 ft to 1000 ft) from the earth or grounded objects, upward leaders are likely to be initiated from prominent points on grounded objects and to propagate towards the downward leader. Several upward leaders may start, but usually only one is successful in reaching the downward leader.

The high current phase (return stroke) commences at the moment the upward leader connects with the downward leader. The position in space of the lower portion of the lightning discharge channel is therefore determined by the path of the successful leader (i.e. the one that succeeded in reaching the downward leader). The primary task in protecting a structure is to ensure a high probability that the successful leader originates from the air terminals and not from a part of the structure that would be adversely affected by the lightning current that subsequently flows.

As the path of the successful leader can have a large horizontal component as well as a vertical component, an elevated air terminal will provide protection for objects spread out below it. It is therefore possible to provide protection for a large volume with correctly positioned air terminals. This is the basis for the concept of a "zone of protection" and provides the basic principle underlying lightning protection.

Therefore, the function of an air terminal in a lightning protection system (LPS) is to divert to itself the lightning discharge that might otherwise strike a vulnerable part of the object to be protected. It is generally accepted that the range over which an air terminal can intercept a lightning discharge is not constant, but increases with the severity of the discharge.

The upper outer edges and corners of buildings or structures, and especially protruding parts, are likely to have higher local electric fields than elsewhere, and are therefore likely places for the initiation of upward leaders. Consequently, the most probable strike attachment point on a building is the edge, corner, or other protruding part in the vicinity of the downward leader. Hence, if air terminals are placed at all locations where high electric fields and leader initiation are likely, there will be a high probability that the discharge will be intercepted successfully.

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These fields are not as strong on flat surfaces as they are on edges and corners and consequently are less likely to be struck.

B.3.2 Overview of Methods. A "design method" is used to identify the most suitable locations for placing strike termination devices, based on the area of protection afforded by each one. There are two categories of "placement methods" as used in NFPA 780:

(1) Purely geometrical constructions, such as the "cone of protection" or "protection angle" method.
(2) Electrogeometric models (EGMs), in which empirical relationships for striking distance and lightning peak current are invoked. The most common example is the "rolling sphere method," which is also partly a geometric construction.

B.3.2.1 Cone of Protection Protection Angle Method. This method is based on the assumption that an air terminal or an elevated, grounded object creates an adjacent, conical space that is essentially immune to lightning. The concept of a cone of sufficient angle to define the protected zone has its roots in the very beginning of lightning protection studies. Although Franklin recognized a limit as to the range of the air terminal in the late 1700s, the concept was first formally proposed by the French Academy of Sciences in 1823 and initially used a base of twice the height (i.e., an angle of 63 degrees). By 1855, this angle was changed to 45 degrees due to field reports that the method was failing. Generally, this angle was preserved in standards for more than 100 years. In some standards today, a variable angle depending on the height of the structure is used. In addition, this protective angle can be increased when considering the placement of air terminals on the interior of large flat surfaces, due to the reduced electric field strength.

A cone of protection is limited; this is articulated by the requirements in Chapter 4.

B.3.2.2 Rolling Sphere Method. The rolling sphere method was incorporated into NFPA 780 in the 1980 edition. It originated from the electric power transmission industry (lightning strike attachment to phase and shield wires of lines) and is based on the simple electrogeometric model. To apply the method, an imaginary sphere is rolled over the structure. All surface contact points are deemed to require protection, while the unaffected surfaces and volumes are deemed to be protected, as shown in Figure B.3.2.2.

The physical basis for the rolling sphere method is the electrogeometric model. Consider a particular peak lightning current I_p (kA) and the corresponding striking distance d_s (m), where $d_s = 10\ I_p^{0.65}$. For a typical peak current of 10 kA, the striking distance is approximately 45 m (150 ft). This is the distance at which a downward leader results in the initiation of an upward leader from the structure.

Note that a smaller striking distance (implying a lower peak current of the lightning event) results in a smaller sphere that can intrude upon the standard 45 m (150 ft) zone of protection. Thus, a more conservative design is to size the sphere using a lower lightning peak current. Lightning peak currents below 5 kA to 7 kA are not common. Ten kA peak current represents 91 percent of all lightning events.

The advantage of the rolling sphere method (RSM) is that it is relatively easy to apply, even to buildings with complicated shapes. However, since it is a simplification of the physical process of lightning attachment to a structure, it has some limitations. The main limitation is that it assigns an equal leader initiation ability to all contact points on the structure; no account is taken of the influence of electric fields in initiating return streamers, so it does not distinguish between likely and unlikely lightning strike attachment points. In other words, for a given prospective peak stroke current, the striking distance d_s is a *constant value*. This simplification stems from the RSM's origins in the electrical power transmission industry, where there is considerable uniformity in the parameters of transmission lines (diameters, heights, etc.). In reality, lightning could preferentially strike the corner of a building rather than the vertical flat surface halfway down the side of the building. The same claims apply to the flat roof of a structure.

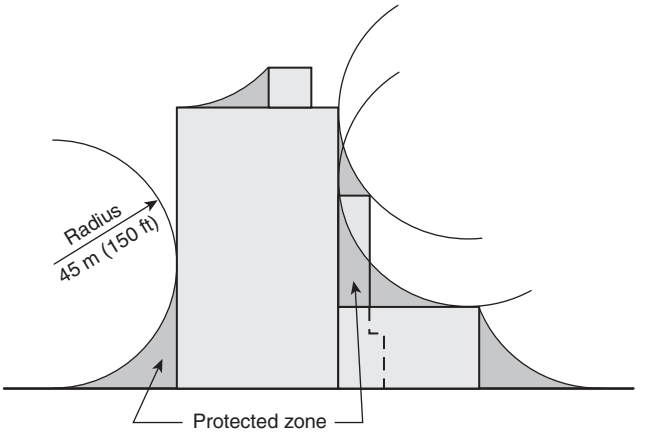


FIGURE B.3.2.2 Lightning Protection Design Using the Rolling Sphere Method.

Some qualitative indication of the probability of strike attachment to any particular point can be obtained if the sphere is supposed to be rolled over the building in such a manner that its center moves at constant speed. Then the length of time that the sphere dwells on any point of the building gives a qualitative indication of the probability of that point being struck. Thus, for a simple rectangular building with a flat roof, the dwell time would be large at the corners and edges and small at any point on the flat part of the roof, correctly indicating a higher probability of the corners or edges being struck and a low probability that a point on the flat part of the roof will be struck.

Where the RSM is applied to a building of height greater than the selected sphere radius, the sphere touches the vertical edges on the sides of the building at all points above a height equal to the sphere radius. This indicates the possibility of strikes to the sides of the building and raises the question of the need for an air terminal network in these locations. Studies show that strikes to vertical edges on the sides of tall buildings do occur but are not very common. There are theoretical reasons for believing that only flashes with low I_p and consequently low d_s values are likely to be able to penetrate below the level of the roof of a building and strike the sides. Hence, the consequences of a strike to the sides of a building could result in damage of a minor nature. Unless there are specific reasons for side protection, as would be the case of a structure containing explosives, it is considered that the cost of side protection would not normally be justified.

B.4 Items to Consider When Planning Protection.

B.4.1 The best time to design a lightning protection system for a structure is during the structure's design phase, and the best time to install the system can be during construction. Sys-

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tem components can be built in so as to be protected from mechanical displacement and environmental effects. In addition, aesthetic advantages can be gained by such concealment. Generally, it is less expensive to meet lightning protection requirements during construction.

B.4.2 Conductors should be installed to offer the least impedance to the passage of stroke current between the strike termination devices and earth. The most direct path, without sharp bends or narrow loops, is best. The impedance of the conductor system is practically inversely proportional to the number of widely separated paths. Accordingly, there should be at least two paths to ground and more, if practicable, from each strike termination device. The number of paths is increased and the impedance decreased by connecting the conductors to form a cage enclosing the building.

B.4.3 Properly made ground connections are essential to the effective functioning of a lightning protection system, and every effort should be made to provide ample contact with the earth. This does not necessarily mean that the resistance of the ground connection should be low, but rather that the distribution of metal in the earth or upon its surface in extreme cases should be such as to permit the dissipation of a stroke of lightning without damage.

B.4.4 Low resistance is desirable, but not essential, as shown by the extreme case on the one hand of a building resting on moist clay soil, and on the other by a building resting on bare solid rock.

B.4.4.1 In the first case, if the soil is of normal resistivity of from 4,000 ohm-centimeters to 50,000 ohm-centimeters, the resistance of a ground connection made by extending the conductor 3 m (10 ft) into the ground will be from about 15 Ω to 200 Ω, and two such ground connections on a small rectangular building have been found by experience to be sufficient. Under these favorable conditions, providing adequate means for collecting and dissipating the energy of a flash without serious chance of damage is a simple and comparatively inexpensive matter.

B.4.4.2 In the second case, it would be impossible to make a ground connection in the ordinary sense of the term because most kinds of rocks are insulating, or at least of high resistivity, and in order to obtain effective grounding other more elaborate means are necessary. The most effective means would be an extensive wire network laid on the surface of the rock surrounding the building to which the down conductors could be connected. The resistance to earth at some distant point of such an arrangement would be high, but at the same time the potential distribution about the building would be substantially the same, as though the building were resting on conducting soil, and the resulting protective effect also would be substantially the same.

B.4.5 In general, the extent of the grounding arrangements depends on the character of the soil, ranging from simple extension of the conductor into the ground where the soil is deep and of high conductivity to an elaborate buried network where the soil is very dry or of very poor conductivity. Where a network is required, it should be buried if there is soil enough to permit burial, as this adds to its effectiveness. Its extent will be determined largely by the judgment of the person planning the installation with due regard to the following rule: The more extensive the underground metal available, the more effective the protection.

B.4.6 Where practicable, each grounding electrode connection should extend or have a branch that extends below and at least 0.6 m (2 ft) away from the foundation walls of the building in order to minimize the likelihood of damage to foundation walls, footings, and stemwalls.

B.4.7 When a lightning conductor system is placed on a building, within or about which there are metal objects of considerable size within a few feet of a conductor, there will be a tendency for sparks or sideflashes to jump between the metal object and the conductor. To prevent damage, interconnecting conductors should be provided at all places where sideflashes are likely to occur.

B.4.8 Lightning currents entering protected buildings on overhead or underground power lines, telephone conductors, or television or radio antennas are not necessarily restricted to associated wiring systems and appliances. Therefore, such systems should be equipped with appropriate protective devices and bonded to ensure a common potential.

B.4.9 Because a lightning protection system is expected to remain in working condition for long periods with minimum attention, the mechanical construction should be strong, and the materials used should offer resistance to corrosion and mechanical injury.

B.5 Inspection and Maintenance of Lightning Protection Systems. It has been shown that, in cases where damage has occurred to a protected structure, the damage was due to additions or repairs to the building or to deterioration or mechanical damage that was allowed to go undetected and unrepaired, or both. Therefore, it is recommended that an annual visual inspection be made and that the system be thoroughly inspected every five years.

B.6 Indirect Losses. In addition to direct losses such as destruction of buildings by lightning, fire resulting from lightning, and the killing of livestock, indirect losses sometimes accompany the destruction or damage of buildings and their contents. An interruption to business or farming operations, especially at certain times of the year, might involve losses quite distinct from, and in addition to, the losses arising from the direct destruction of material property. There are cases where whole communities depend on the integrity of a single structure for their safety and comfort. For example, a community might depend on a water-pumping plant, a telephone relay station, a police station, or a fire station. A stroke of lightning to the unprotected chimney of a pumping plant might have serious consequences such as a lack of sanitary drinking water, irrigating water, or water for fire protection. Additional information on this topic is available in the documents identified in Annex O.

Annex C Explanation of Bonding Principles

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

C.1 General. Lightning strikes can give rise to harmful potential differences in and on a building. The major concern in the protection of a building is the occurrence of potential differences between the conductors of the lightning protection system and other grounded metal bodies and wires belonging to the building. These potential differences are caused by resistive and inductive effects and can be of such a magnitude that dangerous sparking can occur. In order to reduce the possibility of sparking, it is

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necessary to equalize potentials by bonding grounded metal bodies to the lightning protection system.

Where installing (or modifying) lightning protection systems on existing structures, bonding of certain grounded metal bodies can present difficult installation problems due to the inaccessibility of building systems. Placement of conductors to avoid grounded metal bodies or increasing the number of down conductors to shorten the required bonding distances are options to overcome these problems.

C.2 Potential Differences. Figure C.2 illustrates the generation of potential differences between conductors of the lightning protection system and other grounded metal bodies and wires.

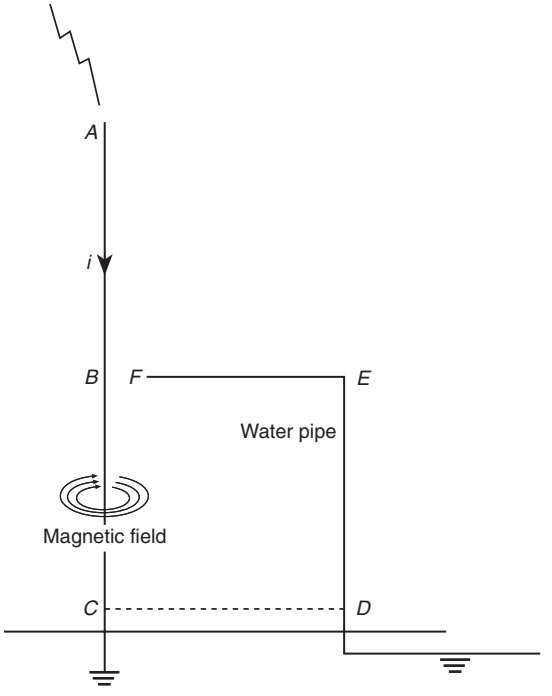


FIGURE C.2 The Magnetic Field Around a Conductor.

C.2.1 Resistive Effect. In the situation where conductor *C* is connected only to a grounding electrode and the water pipe is independently grounded, a large potential can exist between *B* and *F*. Assuming a resistance of 20 Ω between *C* and ground and a lightning current of 100,000 A, then Ohm's law (voltage = current × resistance) indicates that a potential of 2 million volts exists on conductor *ABC*. Because no current is initially passing through the water pipe, its potential is zero volts. The difference of potential of 2 million volts between *B* and *F* is sufficient for a sideflash of over 1.8 m (6 ft). In order to reduce this potential to essentially zero, this standard requires equalization of potentials at ground level in accordance with 4.20.1. Such a bond is shown as *CD* in Figure C.2.

With bond *CD* in position, the resistance between *B* and *F* is essentially zero; hence during a lightning strike the potential at *B* due to the resistive effect is similar to that at *F*. Therefore, the resistive effect can be neglected for bonding purposes.

C.2.2 Inductive Effect. When a large current passes down the lightning conductor *ABC*, a magnetic field is generated in circular motion around the conductor as shown in Figure C.2. The higher the lightning current, the higher the magnetic field. These magnetic field lines can be referred to as *magnetic flux*.

The loop *BCDEF* is intercepted by these lines of magnetic flux. The rate of change of the flux passing through this loop induces a voltage in the loop, creating a potential difference between *B* and *F*. This potential difference can be in the order of a few million volts, again causing a sideflash.

The bonding techniques described in this standard call for bonding the gaps over which high potentials exist, such as *BF*, in order to remove the spark and provide a safe path to ground for the current. The bonding-distance formulas are calculated from the laws of physics, making assumptions on the relevant lightning characteristics that influence the induced voltage. The assumptions for this standard are based on an extremely severe lightning current, thereby providing a bonding distance that is almost totally protective.

The voltage across the gap *BF* is related to the size of the loop *BCDEF* but dominantly to the height *BC* rather than the horizontal measure *CD*; hence the height *h* term is used in the formulas of 4.21.2. Equalizing the potentials at frequent heights in accordance with Section 4.20 also reduces the size of the loop *BCDEF*, thereby keeping the gap voltage to a controllable value that can be removed by simple bonding.

C.2.3 Power and Communications Services. One factor that is difficult to control is the problem related to power and communication lines entering the building. For all intents, such lines are at ground potential relative to the extremely high induced voltages. If the line *DEF* were such an electrical, telephone, power, or data line not bonded at ground, the voltage across the loop would be enhanced by the resistive effect described by Ohm's law as well as by the inductive effect. Hence, *BF* could soon approach breakdown. This would lead to sparks causing fire, as well as the obvious electrical, electronic, and human life problems. All such lines entering the building should have electrical bonding through surge protection as specified in Section 4.18, thereby reducing the resistive component and controlling dangerous sparking and damage. If just one wire, however, does not have such suppression devices, the dangers described still exist to the protected building and the electrical equipment. Table C.2.3 shows sample calculations.

C.2.4 Reduction of Potential Difference. In order to reduce the voltage across the gap *BF* so as to make bonding less necessary, it is possible to provide more down conductors. This standard requires down conductors every 30 m (100 ft) *(see 4.9.10)*, but the number of down conductors, *n*, required in the bonding formulas of 4.21.2 is restricted. It can be shown theoretically for structures less than 18 m (60 ft) in height that for a series of planar down conductors spaced 15 m (50 ft) apart, *n* can be no larger than 1.5, and for a similar three-dimensional situation, *n* can be no larger than 2.25. These values of *n* also apply to the upper 18 m (60 ft) of a tall structure. As the lightning current passes into the lower portion of a tall structure, however, the value of *n* must be calculated on the assumption that the current flow down the structure is much more symmetrical through the down conductors. Using this assumption, for all but the upper 18 m (60 ft) of a structure the bonding distance can be calculated from a formula involving a larger value of *n*, as shown in 4.21.2.

C.2.5 Sideflash. Sideflashing can easily occur to grounded objects within the building. The intensity of the electric field in air is greater than that in concrete by approximately a factor of 2, allowing for a reduction of the sideflash distance through a wall cavity.

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Table C.2.3 Sample Calculations of Bonding Distances

h			*D*					
			n = 1.0		*n* = 1.5		*n* = 2.25	
m	ft	K_m	m	ft	m	ft	m	ft
3.05	10	1	0.50	1 ft 8 in.	0.33	1 ft 1⅜ in.	0.22	9 in.
		0.5	0.25	10 in.	0.17	6¾ in.	0.11	4½ in.
6.10	20	1	1.01	3 ft 4 in.	0.67	2 ft 2¾ in.	0.45	1 ft 6 in.
		0.5	0.50	1 ft 1⅜ in.	0.33	1 ft 1⅜ in.	0.22	9 in.
9.15	30	1	1.52	5 ft 0 in.	1.01	3 ft 4 in.	0.67	2 ft 2¾ in.
		0.5	0.76	2 ft 6 in.	0.50	1 ft 8 in.	0.33	1 ft 1⅜ in.
12.2	40	1	2.03	6 ft 8 in.	1.37	4 ft 6 in.	0.91	3 ft
		0.5	1.01	3 ft 4 in.	0.68	2 ft 3 in.	0.45	1 ft 6 in.

If an individual touches a correctly bonded connection within the building, he or she should suffer no harm. This scenario is similar to that of a bird sitting on a high-voltage wire unaware that the bird's potential is changing from over a thousand volts positive to over a thousand volts negative several times a second.

Annex D Inspection and Maintenance of Lightning Protection Systems

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

D.1 Inspection of Lightning Protection Systems.

D.1.1 Frequency of Inspections. It is understood that all new lightning protection systems must be inspected following completion of their installation. Recommended guidelines for the maintenance of the lightning protection system should be provided to the owner at the completion of installation.

It is important to make periodic inspections of existing systems. The interval between inspections should be determined by factors such as the following:

(1) Classification of the structure or area protected
(2) Level of protection afforded by the system
(3) Immediate environment (corrosive atmospheres)
(4) Materials from which system components are made
(5) Type of surface to which the lightning protection components are attached
(6) Trouble reports or complaints

D.1.1.1 In addition to regular periodic inspections, a lightning protection system should be inspected whenever any alterations or repairs are made to a protected structure, as well as following any known lightning discharge to the system.

D.1.1.2 It is recommended that lightning protection systems be visually inspected at least annually. In some areas where severe climatic changes occur, it might be advisable to visually inspect systems semiannually or following extreme changes in ambient temperatures. Complete, in-depth inspections of all systems should be completed every 3 to 5 years. It is recommended that critical systems be inspected every 1 to 3 years, depending on occupancy or the environment where the protected structure is located.

D.1.1.3 In most geographical areas, and especially in areas that experience extreme seasonal changes in temperature and rainfall, it is advisable to stagger inspections so that earth resistance measurements, for example, are made in the hot, dry months as well as the cool, wet months. Such staggering of inspections and testing is important in assessing the effectiveness of the lightning protection system during the various seasons throughout the year.

D.1.2 Visual Inspection. Visual inspections are made to ascertain the following:

(1) The system is in good repair.
(2) There are no loose connections that might result in high-resistance joints.
(3) No part of the system has been weakened by corrosion or vibration.
(4) All down conductors and grounding electrodes are intact (nonsevered).
(5) All conductors and system components are fastened securely to their mounting surfaces and are protected against accidental mechanical displacement as required.
(6) There have not been additions or alterations to the protected structure that would require additional protection.
(7) There is no visual indication of damage to surge suppression (overvoltage) devices.
(8) The system complies in all respects with the current edition of this standard.

D.1.3 Complete Testing and Inspection. Complete testing and inspection includes the visual inspections described in D.1.2 and the following:

(1) Tests to verify continuity of those parts of the system that were concealed (built in) during the initial installation and that are not now available for visual inspection.
(2) Ground resistance tests of the grounding electrode termination system and its individual grounding electrodes, if adequate disconnecting means have been provided. These test results should be compared with previous or original results or current accepted values, or both, for the soil conditions involved. If it is found that the test values differ substantially from previous values obtained under the same test procedures, additional investigations should be made to determine the reason for the difference.

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(3) Continuity tests to determine if suitable equipotential bonding has been established for any new services or constructions that have been added to the interior of the structure since the last inspection.

D.1.4 Inspection Guides and Records. Inspection guides or forms should be prepared and made available to the authority responsible for conducting inspections of lightning protection systems. These forms should contain sufficient information to guide the inspector through the inspection process so that he or she can document all areas of importance relating to the methods of installation, the type and condition of system components, test methods, and the proper recording of the test data obtained.

D.1.5 Records and Test Data. The inspector or inspection authority should compile and maintain records pertaining to the following:

(1) General condition of air terminals, conductors, and other components
(2) General condition of corrosion-protection measures
(3) Security of attachment of conductors and components
(4) Resistance measurements of various parts of the grounding electrode system
(5) Any variations from the requirements contained in this standard

D.2 Maintenance of Lightning Protection Systems.

D.2.1 General. Maintenance of a lightning protection system is extremely important even though the lightning protection design engineer has taken special precautions to provide corrosion protection and has sized the components according to their particular exposure to lightning damage. Many system components tend to lose their effectiveness over the years because of corrosion factors, weather-related damage, and stroke damage. The physical as well as the electrical characteristics of the lightning protection system must be maintained in order to remain in compliance with design requirements.

D.2.2 Maintenance Procedures.

D.2.2.1 Periodic maintenance programs should be established for all lightning protection systems. The frequency of maintenance procedures is dependent on the following:

(1) Weather-related degradation
(2) Frequency of stroke damage
(3) Protection level required
(4) Exposure to stroke damage

D.2.2.2 Lightning protection system maintenance procedures should be established for each system and should become a part of the overall maintenance program for the structure that it protects.

A maintenance program should contain a list of more or less routine items that can serve as a checklist and can establish a definite maintenance procedure that can be followed regularly. It is the repeatability of the procedures that enhances the effectiveness of a good maintenance program.

A good maintenance program should contain provisions for the following:

(1) Inspection of all conductors and system components
(2) Tightening of all clamps and splicers
(3) Measurement of lightning protection system resistance
(4) Measurement of resistance of grounding electrodes
(5) Inspection, testing, or both of surge suppression devices to determine their effectiveness compared with similar new devices
(6) Refastening and tightening of components and conductors as required
(7) Inspection and testing as required to determine if the effectiveness of the lightning protection system has been altered by additions to or changes in the structure

D.2.3 Maintenance Records. Complete records should be kept of all maintenance procedures and routines and of corrective actions that have been or will be taken. Such records provide a means of evaluating system components and their installation. They also serve as a basis for reviewing maintenance procedures as well as updating preventive maintenance programs.

Annex E Ground Measurement Techniques

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

E.1 General.

E.1.1 In order to determine the ground resistance of a lightning protection system, it is necessary to remove it from any other ground connection. This can prove a virtually impossible task, necessitating certain assumptions. In reality, ground resistance–measuring equipment works at low frequencies relative to the lightning discharge. The resistance it computes is therefore often affected by the resistance of power-system grounding electrodes or a similar ground medium that can be several thousand feet from the structure being protected. The ground resistance to be used to calculate lightning conductor potentials when a high-frequency lightning discharge strikes a building must be the grounds in the immediate area of the building, not the remote ones that ground-measuring equipment probably monitor.

E.1.2 If the building is small and the lightning protection system can be disconnected totally from any other grounding network, the resistance of the system can be measured by the three-point technique described in E.1.3. If the building is large or cannot be disconnected totally from any other grounding network, then the ground resistance of individual isolated lightning protection ground rods should be measured by the three-point technique described in E.1.3 and this resistance multiplied by a factor depending on the number of ground rods.

E.1.3 The principle of ground resistance measurement is shown in Figure E.1.3. *L* is the lightning ground rod or ground rod system, *P* is a test probe, and *A* is an auxiliary current probe. *M* is the standard ac measuring equipment for three-point technique ground resistance measurements. Convenient distances for *LP* and *LA* are 23 m (75 ft) and 36 m (120 ft), respectively. In general, *P* should be at 62 percent of the distance from *L* to *A*. If a distance of 36 m (120 ft) is not convenient, it could be increased significantly [or reduced to no less than 15 m (50 ft)], provided *LP* is increased proportionately.

A current, *I*, is passed through the electrode or electrodes to be tested, *L*, and through an auxiliary probe, *A*. The distance, *LA*, is long compared to the electrode length. The voltage, *V*, between *L* and *P* is measured by the test equipment, which also monitors *I* and calculates the ground resistance, *R*, as *V*/*I*. Alternating current is used to avoid errors due to electrolytic factors in the soil and to remove effects due to stray currents.

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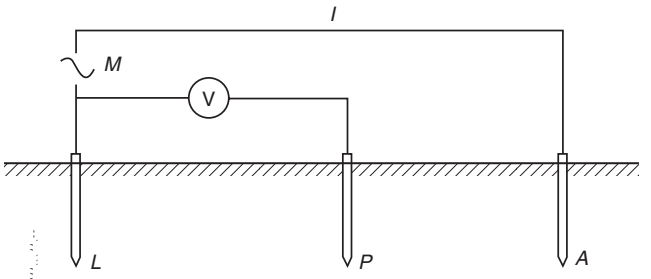


FIGURE E.1.3 Measurement of Ground Resistance.

Three-point ground resistance–measuring equipment using these principles is relatively inexpensive and allows direct reading of *R*.

NOTE: The individual equipment manufacturer's recommended operational procedures should be used.

E.1.4 Variations in soil resistivity due to temperature and moisture fluctuations can affect the measured ground resistance. A good designer will measure ground resistance under average or high resistivity conditions in order to design a lightning protection system to function adequately.

If the building ground is complex in nature, the resistance of single ground rods can be measured and certain assumptions made. The average single ground rod resistance, R_m, must be multiplied by a factor depending on the number of lightning protection ground rods, n, spaced at least 10.7 m (35 ft) apart.

The total system ground resistance, R, can be calculated from the formula:

$$R = 1.1\left(\frac{R_m}{n}\right)$$

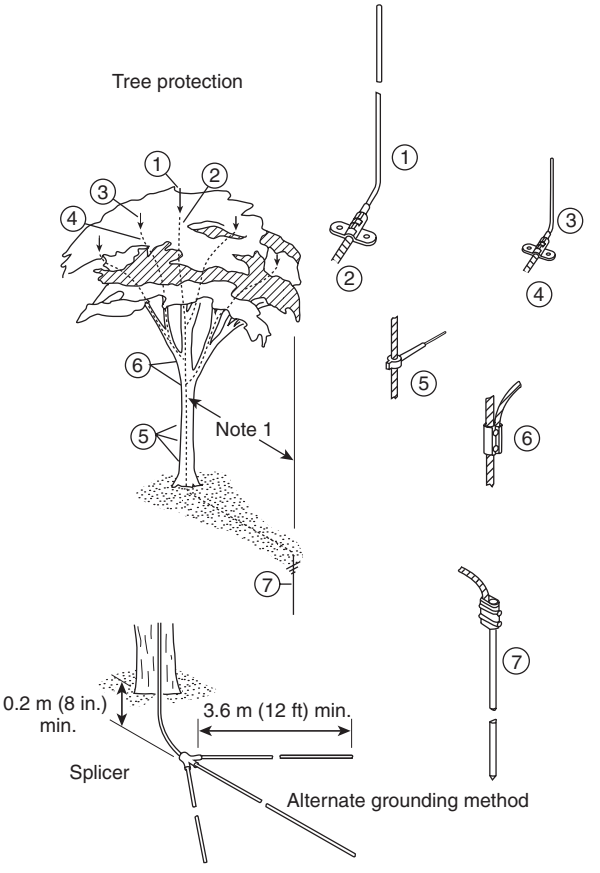
where:
R = total system ground resistance
R_m = average single ground rod resistance
n = number of lightning protection ground rods

Annex F Protection for Trees

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

F.1 General. Trees with trunks within 3 m (10 ft) of a structure or with branches that extend to a height above the structure should be equipped with a lightning protection system because of the danger of sideflash, fire, or superheating of the moisture in the tree, which could result in the splintering of the tree. It might be desirable to equip other trees with a lightning protection system because of a particular tree's value to the owner. Figure F.1 illustrates such protection.

Note that it should not be inferred that adding protection to a tree will ensure the safety of people seeking shelter under the tree during a thunderstorm. Possible sideflashes, step potential, and touch potentials could threaten the safety of people seeking shelter under trees even if the trees are protected.



1. Main trunk air terminal
2. Class I or Class II full-size cable
3. Branch air terminal
4. Branch conductor (bonding size conductor, minimum)
5. Drive-type cable clip at 0.9 m (3 ft) O/C
6. Splicer
7. Ground rod and clamp

Note 1: Locate grounding electrode approximately at branch line to avoid root damage at least 3 m (10 ft) from trunk.
Note 2: Install cable loosely to allow for tree growth.
Note 3: Air terminal tip configurations can be sharp or blunt.

FIGURE F.1 Protection for Trees.

F.2 Methods and Materials.

F.2.1 Conductors. Conductors should conform to the requirements of Section 4.1.

F.2.2 Coursing of Conductors. A single conductor should be run from the highest part of the tree along the trunk to a ground connection. If the tree is forked, branch conductors should be extended to the highest parts of the principal limbs. If the tree trunk is 0.9 m (3 ft) in diameter or larger, two down conductors should be run on opposite sides of the trunk and interconnected.

F.2.3 Air Terminals. The conductors should be extended to the highest part of the tree, terminating with an air terminal.

F.2.4 Attachment of Conductors. Conductors should be attached to the tree securely in such a way as to allow for swaying in the wind and growth without danger of breakage.

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F.2.5 Grounding Electrodes. Grounding electrodes for conductors should be in accordance with the following:

(1) Be connected to all conductors that descend the trunk of the tree, extend one or more radial conductor(s) in trenches 0.2 m (8 in.) deep, and be spaced at equal intervals about the base to a distance of not less than 3 m (10 ft) or a single driven rod installed a distance of not less than 3 m (10 ft) from the trunk of the tree *(See Figure F.1.)*
(2) Have the radial conductor(s) extended to the branch line but not less than 3.6 m (12 ft)
(3) Connect the terminations of the radials to a ground loop conductor that encircles the tree at a depth of not less than 0.2 m (8 in.)
(4) Be bonded to an underground metallic water pipe where available within 7.6 m (25 ft) of the branch line

Annex G Protection for Picnic Grounds, Playgrounds, Ball Parks, and Other Open Places

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

G.1 Picnic Grounds and Playgrounds. Protection from lightning can be provided by the methods indicated in G.1.1 or G.1.2.

G.1.1 Design concerns for lightning protection systems on open shelters include the following:

(1) Step potential
(2) Touch potential
(3) Sideflash to persons and animals

Lightning protection systems for open shelters should conform to the requirements of Chapter 5 with the guidance given in G.1.1.1 through G.1.1.3.

G.1.1.1 Step Potential Reduction. Establishment of an electrically equipotential plane is desired to reduce step potential within the shelter perimeter. This can be accomplished by installation of a grounding grid or other equivalent method, including the following:

(1) Concrete-floor shelters might need no additional enhancement. However, for new construction, it is desirable to establish a grid below the surface of the concrete that should be bonded to the down-conductor system and the grounding system.
(2) Wood floors, or other essentially insulating flooring materials, should also have a grid installed as described in G.1.1.3.
(3) Earth-floored shelters should also have a grid installed as described in G.1.1.3.

G.1.1.2 Sideflash and Touch Potential Reduction. Additional measures to reduce the possibility of sideflash and touch potential within the structure include the following:

(1) Providing down conductors at each corner of a structure (four for a typical rectangular structure). Structures of irregular shape or with many sides should use no fewer than four down conductors if it is impractical to install one at each corner.
(2) Shielding down conductors to at least 2.4 m (8 ft) in height with electrically insulating material that is resistant to climatic conditions and impact. Where structural steel framework is used, electrical insulation of the structural steel is less critical due to the typically larger size of the structural steel framework and its lower inductive reactance. Insulation of the structural steel framework will further reduce the probability of sideflash and touch potential hazards.
(3) Bonding structural steel to the grounding electrode.

G.1.1.3 Grounding. Grounding terminations should be installed as specified in Chapter 4, with the following additional guidance:

(1) For existing concrete floors, a ground ring should be installed. As an additional precaution, radial grounding is recommended to be installed at points around the periphery.
(2) The grounding grid should be constructed of main-size interconnected copper conductors at no greater than 1 m (3.3 ft) spacing between conductors. The periphery of the grid should be interconnected. Burial of the grid should be at a depth of no less than 152 mm (6 in.) and no greater than 459 mm (18 in.).
(3) The grid perimeter should be connected to grounding electrodes with radial grounding extensions recommended.

G.1.2 Masts and Overhead Ground Wires. Masts (poles) on opposite sides of the grounds and near the edges should be erected. Overhead wires should be strung between the masts at least 6 m (20 ft) above the ground level. Down conductors should be connected to the overhead wires with grounding electrodes. Down conductors should be shielded to a height of not less than 2.4 m (8 ft) with material resistant to impact and climate conditions. The wires should be not less than 4 AWG copper or equivalent. Where steel masts are used, down leads are not necessary, but the foot of the mast should be grounded. If the area to be protected is extensive, it might be necessary to erect several masts around the perimeter so that the area is covered by a network of wires to form a zone of protection. *[See Figure 7.3.3.2 for an example.]*

G.2 Ball Parks and Racetracks.

G.2.1 Roofed Grandstands. Roofed grandstands are included within the scope of this standard.

G.2.2 Open Grandstands and Open Spectator Areas. Open grandstands and open spectator areas should be provided with masts and overhead ground wires as described in G.1.2.

G.3 Beaches. Beaches should be provided with shelters as described in G.1.1.

G.4 Piers.

G.4.1 Covered Piers. Covered piers are included within the scope of this standard.

G.4.2 Open Piers. Open piers should be provided with masts and overhead ground wires as described in G.1.2.

Annex H Protection for Livestock in Fields

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

H.1 General.

H.1.1 The nature of the exposure of livestock in fields is such that it is not possible to eliminate the hazard entirely. However, application of the recommendations contained in this annex can minimize the hazard.

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H.1.2 The loss of livestock due to lightning during thunderstorms is caused in large measure by herds congregating under isolated trees in open pastures or drifting against ungrounded wire fences and receiving a sufficient discharge to kill them.

H.1.3 In pastures where shelter is available from wooded areas of considerable size, isolated trees should be removed.

H.1.4 Fences built with metal posts set in the earth are as safe from lightning as it is practical to make them, especially if the electrical continuity is broken. Breaking the electrical continuity is very useful in that it reduces the possibility of a lightning stroke affecting the entire length of a fence, as is possible if the stroke is direct and the fence continuous, even though it might be grounded. The fences that give rise to the most trouble are those constructed with posts of poorly conducting material, such as wood.

H.2 Grounding of Wire Fences.

H.2.1 Nonconductive Posts. Where it is desirable or necessary to mitigate the danger from wire fences constructed with posts of nonconducting material, H.2.2 and H.2.3 should be applied.

H.2.2 Iron Posts. Ground connections can be made by inserting galvanized-iron posts, such as are ordinarily used for farm fencing, at intervals and attaching in electrical contact all the wires of the fence. Grounding can also be achieved by driving a length of not less than 12.7 mm (½ in.) in diameter galvanized-iron pipe beside the fence and attaching the wires by ties of galvanized-iron wire. If the ground is normally dry, the intervals between metal posts should not exceed about 46 m (150 ft). If the ground is normally damp, the metal posts can be placed up to about 92 m (300 ft) apart.

H.2.3 Depth of Grounds. Pipes should be extended into the ground at least 0.6 m (2 ft).

H.3 Breaking Continuity of Fence.

H.3.1 In addition to grounding the fence, its electrical continuity should be broken by inserting insulating material in breaks in the wires at intervals of about 150 m (500 ft). These insertions can be in the form of fence panels of wood or lengths of insulating material to the ends of which the wires can be attached. Such lengths of insulating material can consist of strips of wood about 50 mm × 50 mm × 600 mm (2 in. × 2 in. × 24 in.), or their equivalent as far as insulating properties and mechanical strength are concerned.

H.3.2 In areas where herds can congregate along fences, the continuity should be broken at more frequent intervals than described in H.3.1.

Annex I Protection for Parked Aircraft

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

I.1 General Principles.

I.1.1 For the purposes of this annex, aircraft includes airplanes, helicopters, and lighter-than-air craft. Aircraft can best be protected by being placed inside a lightning-protected hangar. Hangar facilities should be provided with grounding receptacles to permit interconnection of metal aircraft with the hangar lightning protection system. It is important that hangar floors, aprons, and aircraft parking areas be kept free of gasoline or other flammable liquids.

I.1.2 All metal airplanes parked outside hangars should be grounded. This grounding can be achieved by the use of grounded metal tie-down cables or the equivalent. An aircraft having fabric or plastic covering materials can be protected by connecting its metal frame to ground. For additional protection of aircraft parked outside hangars, an overhead ground wire or mast-type lightning protection system can be provided. The height should be in accordance with the zones of protection described in Chapter 4.

I.1.3 The effects of lightning strikes to metal and composite aircraft are a matter of continuous study. The use of surge suppression circuitry on critical navigational, radio-communication, and radar equipment can help to minimize these effects. Suitable equipment and electrical wiring layout can also aid in reducing lightning-induced problems.

I.1.4 Commercial aircraft have grown considerably larger in recent years and in many cases are taller than surrounding airport terminal buildings. A review of available lightning-strike injury data indicates that nearly all of the reported personal injuries were the result of lightning-induced static discharge.

I.1.5 The grounding methods used for aircraft undergoing fuel servicing and certain maintenance operations are not necessarily adequate to provide effective lightning protection for aircraft or persons. The installation of additional grounding straps, preferably at the aircraft's extremities, during thunderstorm activity will provide alternative paths to ground for any current flow resulting from the rapid adjustment in the aircraft surface charge. Experience has shown that additional grounding straps offer little protection in the event of a direct strike to the aircraft. Fuel servicing operations and other maintenance operations involving the use of flammable liquids or the release of flammable vapors should be suspended during lightning storms. Refer to NFPA 407, *Standard for Aircraft Fuel Servicing*, and NFPA 410, *Standard on Aircraft Maintenance*, for more information.

I.1.6 Baggage handling, exterior maintenance, and servicing of parked aircraft should be suspended when a thunderstorm is in the vicinity of an airport. Lightning-warning equipment can be utilized to aid in determining when to suspend these operations. There are many detection methods capable of detecting and tracking approaching storms. One such method — atmospherics — is being used to establish lightning-detection networks that now cover approximately half of the United States. While atmospherics equipment can give positional information of distant lightning, it gives no warning of a cloud directly overhead becoming electrified. Devices that measure some property of the electric field can detect the development of a hazardous condition and provide a warning prior to the first discharge.

I.1.7 Cables connected to parked aircraft should not be handled when a thunderstorm is in the vicinity. The use of hand signals, without the use of headsets, is recommended for ground-to-cockpit communications during this period.

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Annex K Protection of Structures Housing Explosive Materials

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

K.1 General. This annex provides the minimum technical recommendations for lightning protection of structures housing explosive materials.

K.1.1 Due to the possibility of danger to the surrounding area, an increased level of protection efficiency as defined herein is necessary for such structures. The decision of when to protect these structures should be left to the authority having jurisdiction.

K.1.2 The protection of the contents contained in structures housing explosives should take into account the packages used to contain these materials as well as bonding or grounding requirements specified by the authority having jurisdiction.

K.2 Design Considerations. Lightning protection systems designed to protect structures housing explosives and energetic materials should be based on a striking distance of 30 m (100 ft), as discussed in 7.3.3.

Where the effects of electromagnetic coupling are of concern, a mast of overhead wire (catenary) systems might be preferred over integral systems unless a metallic cage or shield is required. The removal (isolation) of the down conductors will reduce the magnetic field strength in the structure and reduce the probability of a sideflash from a down conductor.

K.3 Types of Systems.

K.3.1 Mast-Type Systems. Mast-type systems should be designed as specified in 7.3.3.

K.3.2 Overhead Wire (Catenary) Systems. Catenary systems should be designed as specified in 7.3.3.

K.3.3 Integral Systems. An integral lightning protection system is a system that utilizes air terminals mounted directly on the structure to be protected. These types of air termination systems are as described in Chapter 4. Air terminal spacing should be modified as necessary to provide a zone of protection defined by a 30 m (100 ft) striking distance.

Where an integral lightning protection system is used to protect the structures covered by this annex, it is critical that the bonding requirements of Chapter 4 be met. It is also critical that a rigorous maintenance schedule be maintained for this type of system.

K.3.4 Metallic Cage. The optimum protection for structures housing explosives would be to enclose the object to be protected within a grounded continuously conductive enclosure of adequate thickness, and to provide adequate bonding of the services entering the structure at the entrance point. This would prevent the penetration of lightning current and related electromagnetic field into the object to be protected and prevent dangerous thermal and electrodynamic effects of current as well as dangerous sparking and overvoltages for electrical and electronic systems.

Effective lightning protection is similarly provided by metallic structures such as those formed by the steel arch or the reinforcing steel in the walls and floors of earth-covered magazines if the steel reinforcement is bonded together and it meets the minimum ground system resistance recommendations of Section K.4.

K.4 Grounding.

K.4.1 General. A ground loop conductor should be required for all lightning protection systems used to protect the subject structures. All down conductors, structural steel, ground rods, and other grounding systems should be connected to the ground loop conductor.

For structures with areas of 46.5 m^2 (500 ft^2) or less or those that can be protected by a single mast or air terminal, the ground loop conductors should not be required.

K.4.2 Metal Portable Magazines. Portable magazines that provide the protection of a metallic cage as described in K.3.4 should be grounded. Main-size conductors should be used to interconnect the portable magazine to the ground system. The lightning protection recommendations in K.4.2.1 and K.4.2.2 for portable magazines are for single and group configurations.

K.4.2.1 Single Portable Magazines. Single portable magazines less than 2.323 m^2 (25 ft^2) (using outside dimensions) need only a single ground rod. Single portable magazines greater than or equal to 2.323 m^2 (25 ft^2) should be grounded by using a minimum of two separate ground rods each placed in a different corner. Connections to existing ground loop conductors can be substituted for ground rods. All earth connections should provide as low as practical resistance to earth.

K.4.2.2 Portable Magazine Groups. A portable magazine group is formed when two or more portable magazines are bonded together above ground. Portable magazine groups should meet the following bonding and grounding recommendations:

(1) Each group should have a minimum of two connections to earth. Groups exceeding 76 m (250 ft) in perimeter should have a connection to earth for every 30 m (100 ft) of perimeter or fraction thereof, such that the average distance between all connections to earth does not exceed 30 m (100 ft).
(2) For small groups requiring only two connections to earth, the connections should be placed at opposite ends of the group, as far apart as is practical.
(3) Connections to existing ground loop conductors can be substituted for ground rods. All earth connections should provide as low as practical resistance to earth.

K.5 Bonding.

K.5.1 General. It is critical that the bonding requirements of Chapter 4 be enforced for the protection of structures housing explosives or other energetic materials. The material used to bond items to the grounding loop conductor should meet the requirements of Section 4.2. Section 4.2 also provides the requirements for the use of dissimilar metals.

K.5.2 Bonding Resistance. The resistance of any object bonded to the lightning protection system should not exceed 1 Ω. For static dissipative systems such as conductive floors, workbenches, and so on, bond resistance of 1 MΩ is acceptable.

K.5.3 Painting. Bonding connections and conductor splices should not be painted. Paint on lightning protection conductors should not exceed a level at which the conductor's physical continuity can be confirmed.

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K.5.4 Magazines.

K.5.4.1 Earth-Covered Magazines. Metal ventilators, steel doors, door frames, and steel reinforcement should be bonded to the structure's grounding system. Incoming power, data, and communication cables should be bonded to the ground loop conductor or steel reinforcement as it enters the structure.

K.5.4.2 Metal Portable Magazines. Portable box-type magazines made of 4.8 mm (3⁄16 in.) steel or equivalent where the walls, floor, and roof are welded together should require bonding of the doors across the hinges. Bonding of services, data lines, and communication lines also should be provided. Additional information on this topic is available in the documents identified in O.1.2.3 and O.2.2.

K.5.5 Fences. Fences should have bonding across gates as well as other discontinuities and should be bonded to the lightning protection system ground loop conductor where they cross or come within the sideflash distance of the structure of a lightning protection system. Bonding across discontinuities in metallic fences should be provided as necessary for electrical continuity.

K.5.6 Railroad Tracks. All railroad tracks that cross or come within the sideflash distance of a structure's lightning protection system should be bonded to the lightning protection system ground loop conductors. If the tracks are used to carry electrical signals, they should have insulated joints immediately external to bond the lightning protection system's ground loop conductor. If these tracks enter a facility, they also should be bonded to the frame of the structure (or equivalent).

K.6 Surge Protection. Surge protection should be required for all power, communication, or data conductors entering or exiting a structure housing explosives. Specific requirements are provided in Section 4.18. The ground reference for the surge protection should be referenced to a ground plane where provided.

K.7 Maintenance and Inspection. The effectiveness of a lightning protection system is best ensured by a quality control program designed to ensure that the system is not degraded by age, mechanical damage, or modifications to the structure. A maintenance and inspection plan should be developed for all protection systems used to protect structures housing explosives.

The initial installation should be inspected by the authority having jurisdiction (or their designated representative). It should be recertified after any work is done on the structure.

K.7.1 General. To ensure that the protection system used to protect structures housing explosives is properly maintained, it should be inspected visually twice a year and inspected electrically approximately once a year. To ensure that the systems are tested during all four seasons over a 6-year period, 7-month and 14-month test cycles are suggested.

K.7.2 Visual (7-Month) Test. The lightning protection system should be inspected visually every 7 months for evidence of corrosion or broken wires/connections. All necessary repairs should be made immediately. Any detected damage to the system should be entered in the test records as recommended in D.1.5.

K.7.3 Electrical (14-Month) Test. The lightning protection system should be tested electrically every 14 months. The test should be conducted in accordance with the appropriate test equipment manufacturer's instructions by personnel familiar with lightning protection system testing.

Surge suppressors should be verified operable once per year or after any suspected lightning strike.

K.7.4 Test Equipment. Only those instruments designed specifically for earth resistance testing are acceptable for use in this application. The instrument used in earth resistance testing should be capable of measuring 0 Ω to 10 Ω ± 10 percent. The instrument used to measure bonding resistance should be capable of measuring 0 Ω to 1 Ω ±10 percent.

Annex L Lightning Risk Assessment

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

L.1 General. The lightning risk assessment methodology is provided to assist the building owner or architect/engineer in determining the risk of damage due to lightning. Once the risk has been determined, deciding on the need for protection measures is much easier. The methodology considers only the damage caused by a direct strike to the building or structure to be protected and the currents flowing through the lightning protection system.

L.1.1 In most cases, the need for lightning protection is obvious. Examples include the following:

(1) Large crowds
(2) Service continuity
(3) Very high lightning flash frequency
(4) Tall isolated structure
(5) Building containing explosive or flammable materials
(6) Building containing irreplaceable cultural heritage

L.1.2 Some common consequences of lightning strokes to several types of common structures are listed in Table L.1.2.

L.1.3 The probability that a structure or object will be struck by lightning is the product of the equivalent collection area of the structure or object and the flash density for the area that the structure is located.

L.1.4 This risk assessment method is a guide that takes into account the lightning and the following factors:

(1) Building environment
(2) Type of construction
(3) Structure occupancy
(4) Structure contents
(5) Lightning stroke consequences

L.1.5 Lightning risk for a structure is the product of the lightning strike frequency and the consequence of the strike to the structure.

L.2 Lightning Flash Density (N_g). The yearly number of flashes to ground per square kilometer, lightning flash density, is found in Figure L.2(a) or Figure L.2(b).

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Table L.1.2 Damage by Occupancy Use

Structure Type	Lightning Consequence
Private homes	Perforation of electrical installations; fire and equipment damage limited to objects close to the lightning strike point or path
Farms	Risk of fire and dangerous sparks Risk consequent to power failure: loss of ventilation for livestock; food distribution Risk of step voltage consequence
Theaters, schools, large retail stores, sports arenas	Risk of panic and fire, alarm system, and power failures; loss of life
Banks, insurance companies, businesses, hospitals, and elder care facilities	Risk of panic, egress problems, alarm failures and power failures, loss of life, handicap egress issues Loss of computer and electronic equipment
Industrial buildings	Loss of production, loss of feed stock, damage to and consequences from flammables, explosive materials Loss of electronic and computer equipment
Museums and cultural sites	Irreplaceable losses of cultural heritage

L.3 Lightning Strike Frequency (N_d). The yearly lightning strike frequency (N_d) to a structure is determined by the following equation:

$$N_d = (N_g)(A_e)(C_1)(10^{-6})$$

where:
N_d = the yearly lightning strike frequency to the structure
N_g = the yearly average flash density in the region where the structure is located
A_e = the equivalent collective area of the structure (m^2)
C_1 = the environmental coefficient

L.4 Equivalent Collective Area (A_e). A_e refers to the ground area having the same yearly direct lightning flash probability as the structure. It is an increased area for the structure that includes the effect of the height and location of the structure.

L.4.1 The equivalent collective area, A_e, of a structure is calculated in accordance with Figure L.4.1(a) through Figure L.4.1(c).

L.4.2 The equivalent collective area of a structure is the area obtained by extending a line with a slope of 1/3 from the top of the structure to ground completely around the structure. The total included area is the equivalent collective area (ECA). *[See Figure L.4.1(a), Figure L.4.1(b), and Figure L.4.1(c) for examples of calculating the ECA.]*

L.4.3 The environmental coefficient accounts for the topography of the site of the structure and any objects located within the distance 3*H* from the structure that can affect the collective area. Environmental coefficients are given in Table L.4.3.

L.4.4 Where the equivalent collective area of a structure totally covers another structure, that structure is disregarded.

L.4.5 When the collective areas of several structures are overlapped, the corresponding common collection area is considered as a single collection area.

L.5 Tolerable Lightning Frequency (N_c). The tolerable lightning frequency (N_c) is a measure of the damage risk to the structure, including factors affecting risks to the structure, environment, and monetary loss.

The tolerable lightning frequency is expressed by the following formula, where $C = (C_2)(C_3)(C_4)(C_5)$.

$$N_c = \frac{1.5 \times 10^{-3}}{C}$$

The values for C are obtained from Table L.5(a) through Table L.5(d); 1.5×10^{-3} is an amount selected to represent the acceptable frequency of property losses.

L.6 Selection of the Protection Level.

L.6.1 The tolerable lightning frequency (N_c) is compared with the expected lightning frequency (N_d). The result of this comparison is used to decide if a lightning protection system is needed. If $N_d \leq N_c$, a lightning protection system (LPS) can be optional. If $N_d > N_c$, a lightning protection system should be installed.

L.6.2 When required, a lightning protection system should be installed per the requirements of this standard. Additionally, any statutory and regulatory requirements for the installation of a lightning protection system will take precedence over the results of this assessment.

L.6.3 When a lightning protection system is installed, the following additional protective measures should also be considered:

(1) Measures limiting step or contact voltage
(2) Measures restricting fire propagation
(3) Measures limiting induced voltages
(4) Measures to reduce the effects of lightning-induced surges to sensitive electronic equipment

L.6.4 Table L.6.4 provides a simple method of calculating and using the assessment methods described in Annex L.

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Lightning data provided by the U.S. National Lightning Detection Network™
(Measured lightning flash density corrected for NLDN detection efficiency)

FIGURE L.2(a) 1989–1998 Average U.S. Lightning Flash Density Map (Flashes per square kilometer per year). ***(Courtesy Global Atmospherics, Inc.)***

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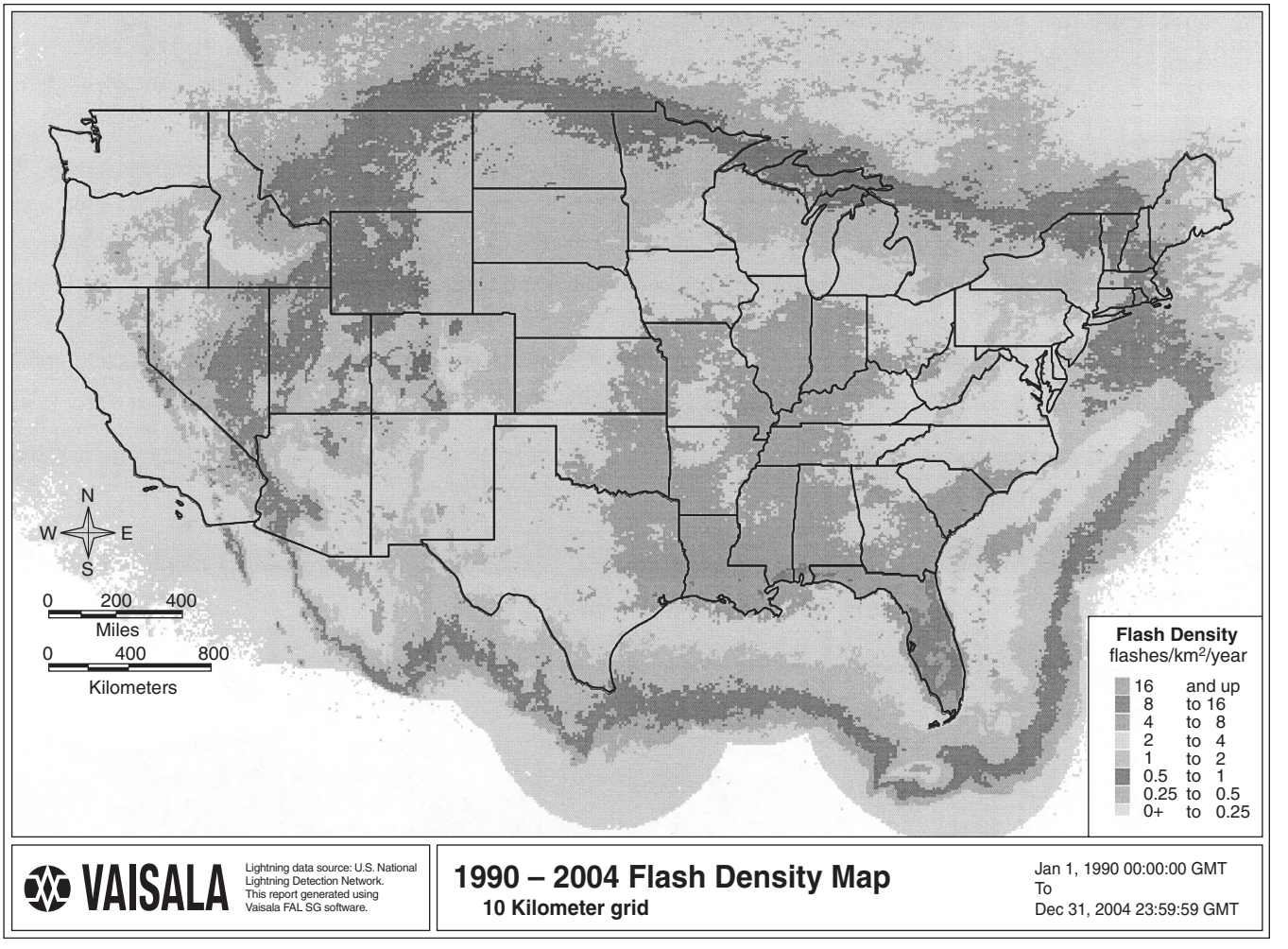
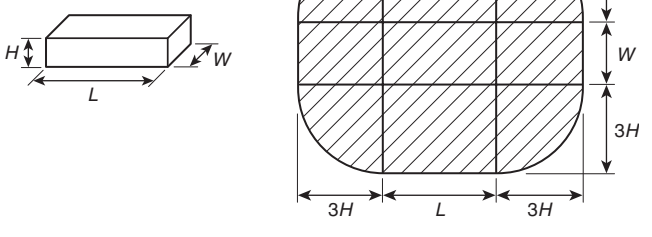
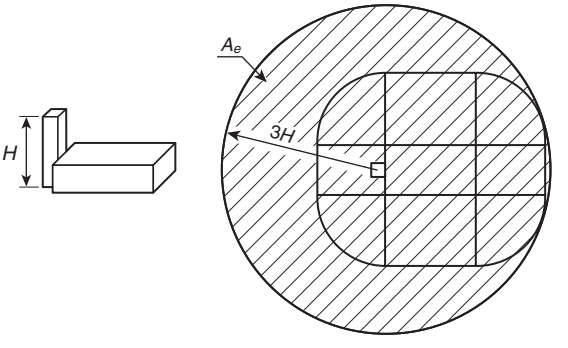


FIGURE L.2(b) 1990–2004 Average U.S. Lightning Flash Density Map (Flashes per square kilometer per year). ***(Courtesy Vaisala, Inc.)***



Note: For a rectangular structure, $A_e = LW + 6H(L + W) + \pi 9H^2$.

FIGURE L.4.1(a) Calculation of the Equivalent Collective Area for a Rectangular Structure.



Note: For a structure where a prominent part encompasses all portions of the lower part, $A_e = \pi 9H^2$.

FIGURE L.4.1(b) Calculation of the Equivalent Collective Area for a Structure Where a Prominent Part Encompasses All Portions of the Lower Part of the Structure.

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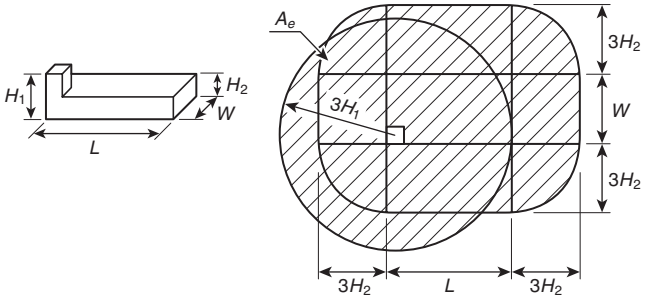


FIGURE L.4.1(c) Alternative Calculation of the Equivalent Collective Area for a Structure Where a Prominent Part Encompasses All Portions of the Lower Part of the Structure.

Table L.4.3 Determination of Environmental Coefficient C_1

Relative Structure Location	C_1
Structure located within a space containing structures or trees of the same height or taller within a distance of $3H$	0.25
Structure surrounded by smaller structures within a distance of $3H$	0.5
Isolated structure, no other structures located within a distance of $3H$	1
Isolated structure on a hilltop	2

Table L.5(a) Determination of Structural Coefficient C_2

	Structural Coefficients C_2		
Structure	Metal Roof	Nonmetallic Roof	Flammable Roof
Metal	0.5	1.0	2.0
Nonmetallic	1.0	1.0	2.5
Flammable	2.0	2.5	3.0

Table L.5(b) Determination of Structure Contents Coefficient C_3

Structure Contents	C_3
Low value and nonflammable	0.5
Standard value and nonflammable	1.0
High value, moderate flammability	2.0
Exceptional value, flammable, computer or electronics	3.0
Exceptional value, irreplaceable cultural items	4.0

Table L.5(c) Determination of Structure Occupancy Coefficient C_4

Structure Occupancy	C_4
Unoccupied	0.5
Normally occupied	1.0
Difficult to evacuate or risk of panic	3.0

Table L.5(d) Determination of Lightning Consequence Coefficient C_5

Lightning Consequence	C_5
Continuity of facility services not required, no environmental impact	1.0
Continuity of facility services required, no environmental impact	5.0
Consequences to the environment	10.0

Table L.6.4 Determination of Protection System Requirement

Data Input Equations	Computation	Results
Equivalent collective area $A_e = LW + 6H(L + W) + \pi 9H^2$ (for a rectangular structure)	$L =$ $W =$ $H =$ $H^2 =$	$A_e =$
Expected lightning strike frequency to the structure $N_d = (N_g)(A_e)(C_1)\ (10^{-6})$	$N_g =$ $A_e =$ $C_1 =$	$N_d =$
Tolerable lightning frequency to the structure $N_c = (1.5 \times 10^{-3})/C$ where $C = (C_2)(C_3)(C_4)(C_5)$	$C_2 =$ $C_3 =$ $C_4 =$ $C_5 =$ $C =$	$N_c =$
If $N_d \le N_c$, an LPS may be optional. If $N_d > N_c$, an LPS should be installed.		

Annex M Guide for Personal Safety from Lightning

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

M.1 Scope. The purpose of this annex is to furnish a guide for personal safety from lightning. Persons can be at risk prior to any visual or audible indication of a thunderstorm. Any time conditions exist that could lead to lightning activity, personal safety should be considered. Lightning warning systems are available to provide early warning of lightning activity.

M.2 Personal Conduct During Lightning Activity.

M.2.1 Do not go out-of-doors or remain out, unless it is necessary. Seek shelter in structures such as the following:

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(1) Dwellings or other buildings that are protected against lightning
(2) Underground shelters such as subways, tunnels, and caves
(3) Large metal-frame buildings
(4) Large unprotected buildings
(5) Enclosed automobiles, buses, and other vehicles with metal tops and bodies
(6) Enclosed metal trains and street cars
(7) Enclosed metal boats or ships
(8) Boats that are protected against lightning
(9) City streets shielded by nearby buildings

M.2.2 If possible, avoid places with little or no protection from lightning such as the following:

(1) Small, unprotected buildings, barns, sheds, and so forth
(2) Tents and temporary shelters
(3) Automobiles (nonmetal top or open)
(4) Trailers (nonmetal or open)

M.2.3 Certain locations are extremely hazardous during thunderstorms and should be avoided if at all possible. Approaching thunderstorms should be anticipated and the following locations avoided when thunderstorms are in the immediate vicinity:

(1) Hilltops and ridges
(2) Areas on top of buildings
(3) Open fields, athletic fields, golf courses
(4) Parking lots and tennis courts
(5) Swimming pools (indoor or outdoor), lakes, and seashores
(6) Near wire fences, clotheslines, overhead wires, and railroad tracks
(7) Under isolated trees
(8) Near electrical appliances, telephones, plumbing fixtures, and metal or electrically conductive objects

M.2.4 It is especially hazardous to be riding in or on any of the following during thunderstorms while in the locations described in M.2.3:

(1) Open tractors or other farm machinery operated in open fields
(2) Golf carts, scooters, bicycles, or motorcycles
(3) Open boats (without masts) and hovercraft
(4) Automobiles (nonmetal top or open)

M.2.5 It is not always possible to choose a location that offers good protection from lightning, but the following rules should be observed when a location can be selected:

(1) Seek depressed areas — avoid mountaintops, hilltops, and other high places.
(2) Seek dense woods — avoid isolated trees.
(3) Seek buildings, tents, and shelters in low areas — avoid unprotected buildings.
(4) If caught in an exposed area, crouch as low as possible, keeping feet together, putting hands on knees. To minimize risk of direct strike, it is necessary to keep as low as possible. To minimize risk of step potential hazards, it is necessary to minimize the area of the body in contact with the ground. Do not lie flat.

M.3 Protection for Persons in Watercraft. Inasmuch as the basic purpose of protection against lightning is to ensure the safety of persons, it is appropriate that the precautions and suggestions in M.3.1 through M.3.3 be listed in addition to all applicable recommendations in the preceding sections.

M.3.1 One should remain inside a closed boat, as far as practical, during a lightning storm and should not dangle arms or legs in the water.

M.3.2 To the extent consistent with safe handling and navigation of the boat during a lightning storm, one should avoid making contact with any items connected to a lightning protection system, especially in such a way as to bridge between these items. For example, it is undesirable for an operator to be in contact with reversing gear levers and spotlight control handle at the same time.

M.3.3 No one should be in the water during a lightning storm.

Annex N Wind Turbine Generator Systems

This annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

N.1 General. Damage to wind turbines from lightning has been recognized as a growing problem due to the increasing number and height of installed turbines. Wind turbines present a unique lightning protection problem due to their physical construction of insulating composite materials, such as glass fiber reinforced plastic or other nonconductive materials. The lightning protection system typically has to be fully integrated into the different parts of the wind turbines to ensure that all parts likely to be lightning attachment points are able to withstand the impact of the lightning, and to ensure that the lightning current can be conducted safely from the attachment points to the ground without experiencing damage or disturbances to the systems. While physical blade damage is the most expensive and disruptive damage caused by lightning, by far the most common is damage to the control system. Unlike lightning damage to wind turbine blades, damage to control systems comes from both direct and indirect sources.

N.1.1 Protection of Wind Turbine Blades. Modern turbine blades are typically constructed of composite materials such as carbon or glass-reinforced plastic. Some parts and discrete components such as mounting flanges, balancing weights, hinges, bearings, wires, electrical wiring, and springs are made of metal. Lightning strikes blades that have metallic and nonmetallic components. The technical challenge in the design of lightning protection of wind turbine blades is to conduct the lightning current safely from the strike attachment point to the hub in such a way that the formation of a lightning arc inside the blade is avoided. This can be achieved by diverting the lightning current from the strike attachment point along the surface to the blade root, using metallic conductors either fixed to the blade surface or inside the blade.

Typically for blades up to 20 m (60 ft) long, receptors at the tip of the blade are adequate. However, it might be necessary for longer blades to have more than one receptor to obtain the desired interception efficiency. Protection of the blades is provided by the blade manufacturer and is typically an integral part of the blade.

Any wiring for sensors placed on or inside blades should be protected via bonding to the down conduction system. Wiring should either be shielded cables or be placed in metal tubes. The cable shield or metal tube should be placed as close as possible to the down conductor and bonded to it.

N.1.2 Protection of Wind Turbine Structures. With the blade being provided with integral protection, the wind turbine should be protected in accordance with the main body of this

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standard. The placement of air terminals on parts of the wind turbine structure other than the blades is to be determined with reference to Chapter 4. Specifically, when determining protection zones, the blades are assumed to be stationary within the "worst case scenario" position (where the blades are oriented so they provide the smallest zone of protection to the structure). The materials used for lightning protection of wind turbine blades should be able to withstand the electric, thermal, and electrodynamic stresses imposed by the lightning current. Minimum dimensions for materials used for air termination and down conduction are provided in Chapter 4.

N.1.3 Protection of Bearings and Gearbox. Arcing between bearing raceways and rolling elements can dissipate sufficient energy to cause severe pitting. Such damage might not be identified as being caused by lightning and can result in a greatly reduced lifetime of the bearing. It is possible that large, heavily loaded bearings and stationary bearings might be able to conduct the lightning current without significant damage. Therefore, lightning protection of the slow-moving pitch bearings and yaw bearings might not be needed.

For additional protection, or in the case of lighter weight bearings, it is recommended that an alternative supplemental current path be provided across the bearings with a flexible conductor, a sliding contact, or similar arrangement.

N.1.4 Protection of Electrical and Control System. Lightning currents can induce transients into circuits through various coupling mechanisms such as conduction and capacitive and magnetic coupling. The following are general recommendations to limit these coupling mechanisms:

(1) Providing preferential, low impedance paths for the lightning current can minimize conductive coupling. Proper separation distances and good bonding techniques, as defined in Chapter 4, can prevent flashovers.
(2) Capacitive coupling between conductors designed to carry the lightning current and a component (cable and/or electrical equipment) can be reduced by the following techniques:
    (a) Shielding (a complete metal enclosure, braided wire sheath, or wire mesh screen)
    (b) Increasing the distance between lightning conductors and such components (moving the wires close to a ground plane, using grounded metallic conduit, wireways, or raceways)
(3) Magnetic coupling to electrical or control cabling and equipment can be reduced by the following techniques:
    (a) Using metal enclosures (raceways, pipes, shields, or a metal box)
    (b) Avoiding forming large-loop areas with electrical or control cabling
    (c) Keeping conductors close to metal components such as gearboxes and generators
    (d) Twisted pairing of cables

Bonding within the wind turbine is required to reduce voltage differences between parts of the wind turbine. This bonding provides protection against touch and step voltages during a lightning strike.

Electrical power equipment such as motors, generators, transformers, and switchgear is designed to withstand high-voltage surges. Insulation of electrical power equipment normally withstands transient voltages in the kilovolt range. It is recommended that a surge protection device (SPD) rated above the operating line voltage and possible temporary over voltages be used. Otherwise, the SPD can conduct current during normal line variations and have greatly reduced service life. Further guidelines for the application of SPDs are found in Section 4.18 of this document, and in ANSI/IEEE C62.41.1, *Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits*, and ANSI/IEEE C62.41.2, *Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits*.

Signal circuits can only withstand transient voltages of some tens of volts, and such circuits are susceptible to transient overvoltages, particularly in the exposed environment of a wind turbine. Depending on the nature of the equipment being protected, the correct array of SPDs should be selected and installed as close as practical to the equipment to be protected.

N.2 Blade-to-Hub Connection. At the base of the blade, the down conductor system is usually either terminated to the blade-mounting flange or to the hub.

Blades could be either pitch regulated or equipped with a tip brake. In such cases, the hydraulic control or pitch bearing is protected using either a sliding contact or a flexible bonding cable with enough slack to allow for motion. This bonding provides a preferred path for the lightning energy from the blade conductor to the hub.

Care must be taken to reduce the slack in such bonding straps, since the inductive voltage drop across the slack can become very high, thus resulting in inefficient protection.

N.3 Grounding. Each wind turbine is to be equipped with its own grounding electrode system and interconnected to a site grounding system, if one is present. The lightning protection system grounding should be designed in accordance with the minimum requirements of this standard. However, consideration should be given to typical factors in a power generation facility, such as sizing conductors for fault currents and touch and step potential requirements. These factors are outside the scope of this annex. The grounding of a wind turbine would then comprise a ground ring electrode external to the structure (defined by the radius of the turbine foundation) in contact with the soil, bonded to the foundation reinforcing bars. Additional vertical and horizontal grounding electrodes could be used in combination with the ring electrode. The ring electrode should be buried to a depth of at least 460 mm (18 in.). Horizontal electrodes can be used to connect the grounding system of one wind turbine to the site grounding system. The lightning protection grounding electrode should always be bonded to the power grounding system.

Annex O Informational References

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- Committee votes by written ballot on Proposals. If two-thirds approve, Report goes forward. Lacking two-thirds approval, Report returns to Committee.
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3.3.78 Effective Ground-Fault Current Path. An intentionally constructed, permanent, low impedance electrically conductive path designed and intended to carry ~~underground~~ electric fault current ~~conditions~~ from the point of a ground fault on a wiring system to the electrical supply source.

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