NFPA 780

Standard for the Installation of Lightning Protection Systems

2000 Edition

NFPA, 1 Batterymarch Park, PO Box 9101, Quincy, MA 02269-9101
An International Codes and Standards Organization

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NFPA 780

Standard for the Installation of

Lightning Protection Systems

2000 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 the National Fire Protection Association, Inc., at its World Fire Safety Congress and Exposition™ held May 14–17, 2000, in Denver, CO. It was issued by the Standards Council on October 4, 2001, with an effective date of October 24, 2001, and supersedes all previous editions.

This edition of NFPA 780 was approved as an American National Standard on October 4, 2001.

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

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NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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.

Contents

NFPA 780

Standard for the Installation of

Lightning Protection Systems

2000 Edition

NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Appendix A.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Information on referenced publications can be found in Chapter 8 and Appendix M.

Chapter 1 Introduction

1.1 Scope.

1.1.1 This document covers 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 does 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 is to provide for the practical 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. Otherwise, such components shall be approved by the authority having jurisdiction.

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 should be provided to the owner at the completion of installation.

1.6 Metric Units of Measurement. Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). If a value for measurement as given in this standard is followed by an equivalent value in other units, the first stated value is the requirement. A given equivalent value is approximate.

Chapter 2 Terms and Definitions

2.1 Definitions.

2.1.1* 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.

2.1.2* Approved. Acceptable to the authority having jurisdiction.

2.1.3* Authority Having Jurisdiction. The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

2.1.4 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.

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

2.1.6 Chimney. A smoke or vent stack having a flue with a cross-sectional area less than 500 in.^{2} (0.3 m^2) and a total height of 75 ft (23 m) or less.

2.1.7* Class I Materials. Lightning conductors, air terminals, ground terminals, and associated fittings required by this standard for the protection of structures not exceeding 75 ft (23 m) in height.

2.1.8* Class II Materials. Lightning conductors, air terminals, ground terminals, and associated fittings required by this standard for the protection of structures exceeding 75 ft (23 m) in height.

2.1.9 Combustible Liquid. Any liquid that has a closed-cup flash point at or above 100°F (37.8°C), as determined by the test procedures and apparatus set forth in NFPA 30, *Flammable and Combustible Liquids Code,* 1.7.4. Combustible liquids are classified as Class II or Class III as follows: (a) *Class II Liquid* — any liquid that has a flash point at or above 100°F (37.8°C) and below 140°F (60°C); (b) *Class IIIA* — any liquid that has a flash point at or above 140°F (60°C), but below 200°F (93°C); (c) *Class IIIB* — any liquid that has a flash point at or above 200°F (93°C).

2.1.10 Conductor.

2.1.10.1 Bonding Conductor. A conductor used for potential equalization between grounded metal bodies and a lightning protection system.

2.1.10.2 Main Conductor. A conductor intended to be used to carry lightning currents between strike termination devices and ground terminals. The main conductor also serves as a strike termination device for catenary lightning protection systems.

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

2.1.12 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.

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

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

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

2.1.16 Flammable Liquid. Any liquid that has a closed-cup flash point below 100°F (37.8°C), as determined by the test procedures and apparatus set forth in NFPA 30, *Flammable and Combustible Liquids Code*, 1.7.4. Flammable liquids are classified as Class I as follows: *Class I Liquid* — any liquid that has a closed-cup flash point below 100°F (37.8°C) and a Reid vapor pressure not exceeding 40 psia (2068.6 mm Hg) at 100°F (37.8°C), as determined by ASTM D 323, *Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)*. Class I liquids are further classified as follows: (1) Class IA liquids — those liquids that have flash points below 73°F (22.8°C) and boiling points below 100°F (37.8°C); (2) Class IB liquids — those liquids that have flash points below 73°F (22.8°C) and boiling points at or above 100°F (37.8°C); (3) Class IC liquids — those liquids that have flash points at or above 73°F (22.8°C), but below 100°F (37.8°C).

2.1.17 Flammable Vapors. The vapors given off from a flammable or combustible liquid at or above its flash point.

2.1.18 Flash Point. The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitible mixture with air that is near the surface of the liquid within the vessel, as specified by appropriate test procedure and apparatus.

2.1.19 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.

2.1.20 Ground Terminal. The portion of a lightning protection system, such as a ground rod, ground plate, or ground conductor, that is installed for the purpose of providing electrical contact with the earth.

2.1.21 Grounded. Connected to earth or to some conducting body that is connected to earth.

2.1.22 High-Rise Building. A structure exceeding 75 ft (23 m) in height.

2.1.23 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.

2.1.24* Lightning Protection System. A lightning protection system is a complete system of strike termination devices, conductors, ground terminals, interconnecting conductors, surge suppression devices, and other connectors or fittings required to complete the system.

2.1.24.1 Catenary Lightning Protection System. A lightning protection system consisting of one or more overhead ground wires meeting the requirements of Chapter 6. Each overhead ground wire forms a catenary between masts and serves the functions of both a strike termination device and a main conductor.

2.1.25* 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.

2.1.26 Loop Conductor. A conductor encircling a structure that is used to interconnect ground terminals, main conductors, or other grounded bodies.

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

2.1.28 Metal-Framed Structure. A structure with electrically continuous structural members of sufficient size to provide an electrical path equivalent to that of lightning conductors covered in this standard.

2.1.29 Shall. Indicates a mandatory requirement.

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

2.1.31 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.

2.1.32 Spark Gap. As used in this standard, any short air space between two conductors that are electrically insulated from or remotely electrically connected to each other.

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

2.1.34 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 3.9, and overhead ground wires installed in catenary lightning protection systems.

2.1.35 Striking Distance. The distance over which the final breakdown of the initial lightning stroke occurs.

2.1.36 Surge Arrester. A protective device used for limiting surge voltages by discharging or bypassing surge current that can also prevent continued flow of follow current while remaining capable of discharging or bypassing surge current.

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

2.1.38 Watercraft. For the purpose of this document, all forms of boats and vessels up to 300 gross tons (272 metric tons) used for pleasure or commercial purposes, but excluding seaplanes, hovercraft, vessels with a cargo of flammable liquids, and submersible vessels.

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

Chapter 3 Protection for Ordinary Structures

3.1 General.

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

Ordinary structures shall be protected as follows:

(1) Ordinary structures not exceeding 75 ft (23 m) in height shall be protected with Class I materials as shown in Table 3.1.1(a).
(2) Ordinary structures exceeding 75 ft (23 m) in height shall be protected with Class II materials as shown in Table 3.1.1(b).

If part of a structure exceeds 75 ft (23 m) in height (e.g., a steeple) and the remaining portion does not exceed 75 ft (23 m) in height, the requirements for Class II air terminals and conductors shall apply only to that portion exceeding 75 ft (23 m) in height. Class II conductors from the higher portion shall be extended to ground and shall be interconnected with the balance of the system.

3.1.2 Roof Types and Pitch. For the purpose of this standard, protection for the various roof types shall be as shown in Figure 3.1.2(a). Protection for a shed roof shall be as illustrated for gable method in Figure 3.1.2(a). For purposes of this standard, roof pitches shall be as shown in Figure 3.1.2(b).

3.2 Materials. Protection systems shall be made of materials that are resistant to corrosion or protected against corrosion. Combinations of materials that form electrolytic couples of such a nature that in the presence of moisture corrosion is accelerated shall not be used. One or more of the following materials shall be used.

(a) *Copper.* Copper shall be of the grade required for commercial electrical work and shall be of 95-percent conductivity when annealed.

(b) *Copper Alloys.* Copper alloy shall be as resistant to corrosion as copper.

(c) *Aluminum.* Aluminum shall not be used where contact with the earth is possible or where rapid deterioration is possible. Conductors shall be of electrical grade aluminum.

3.2.1 Copper lightning protection materials shall not be installed on aluminum roofing, siding, or other aluminum surfaces.

3.2.2 Aluminum lightning protection materials shall not be installed on copper surfaces.

3.3 Corrosion Protection. Protection shall be provided against deterioration of lightning protection components due to local conditions. Copper components installed within 24 in. (600 mm) of the top of a chimney or vent emitting corrosive gases shall be protected by a hot-dipped lead coating or equivalent.

Table 3.1.1(a) Minimum Class I Material Requirements

		Copper		Aluminum	
Type of Conductor	**Parameter**	**English**	**Metric**	**English**	**Metric**
Air terminal, solid	Diameter	$^3/_8$ in.	9.5 mm	$^1/_2$ in.	12.7 mm
Air terminal, tubular	Diameter	$^5/_8$ in.	15.9 mm	$^5/_8$ in.	15.9 mm
	Wall thickness	0.033 in.	0.8 mm	0.064 in.	1.6 mm
Main conductor, cable	Size ea. strand	17 AWG		14 AWG	
	Wgt. per length	187 lb/1000 ft	278 g/m	95 lb/1000 ft	141 g/m
	Cross sect. area	57,400 CM	29 mm^2	98,600 CM	50 mm^2
Main conductor, solid strip	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
	Width	1 in.	25.4 mm	1 in.	25.4 mm
Bonding conductor, cable (solid or stranded)	Size ea. strand	17 AWG		14 AWG	
	Cross sect. area	26,240 CM		41,100 CM	
Bonding conductor, solid strip	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
	Width	$^1/_2$ in.	12.7 mm	$^1/_2$ in.	12.7 mm

Table 3.1.1(b) Minimum Class II Material Requirements

		Copper		Aluminum	
Type of Conductor	**Parameter**	**English**	**Metric**	**English**	**Metric**
Air terminal, solid	Diameter	$^1/_2$ in.	12.7 mm	$^5/_8$ in.	15.9 mm
Main conductor, cable	Size ea. strand	15 AWG		13 AWG	
	Wgt. per length	375 lb/1000 ft	558 g/m	190 lb/1000 ft	283 g/m
	Cross sect. area	115,000 CM	58 mm^2	192,000 CM	97 mm^2
Bonding conductor, cable (solid or stranded)	Size ea. strand	17 AWG		14 AWG	
	Cross sect. area	26,240 CM		41,100 CM	
Bonding conductor, solid strip	Thickness	0.051 in.	1.30 mm	0.064 in.	1.63 mm
	Width	$^1/_2$ in.	12.7 mm	$^1/_2$ in.	12.7 mm

FIGURE 3.1.2(a) Roof types: protection methods (drawings are top and end views of each roof type).

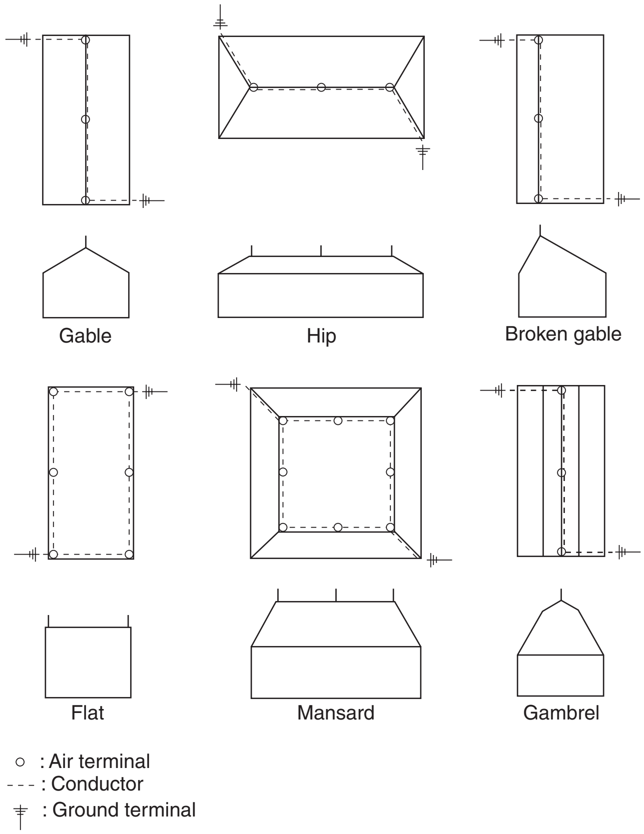
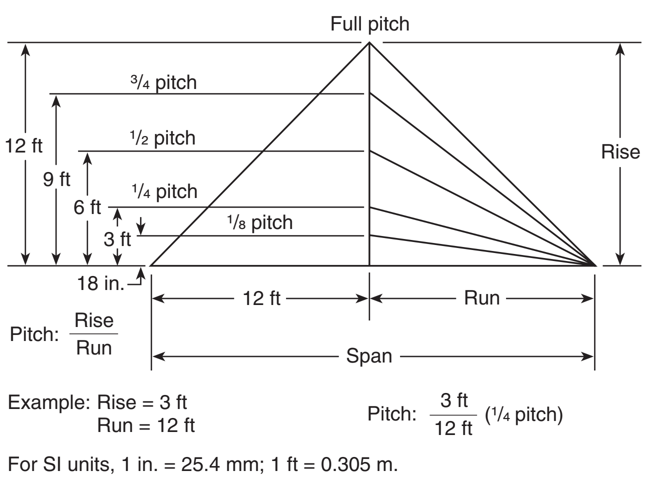


FIGURE 3.1.2(b) Roof pitch.



3.4 Mechanical Damage or Displacement. Any part of a lightning protection system that is subject to mechanical damage or displacement shall be protected with a protective molding or covering. Where metal pipe or tubing is used around the conductor, the conductor shall be electrically connected to the pipe or tubing at both ends.

3.5 Use of Aluminum. Aluminum systems shall be installed in accordance with other applicable sections and with the following.

3.5.1 Aluminum lightning protection equipment shall not be installed on copper roofing materials or other copper surfaces, or where exposed to runoff from copper surfaces.

3.5.2 Aluminum materials shall not be used where they come into direct contact with earth. Fittings used for the connection of aluminum down conductors to copper or copper-clad grounding equipment shall be of the bimetallic type. Bimetallic connectors shall be installed not less than 18 in. (457 mm) above earth level.

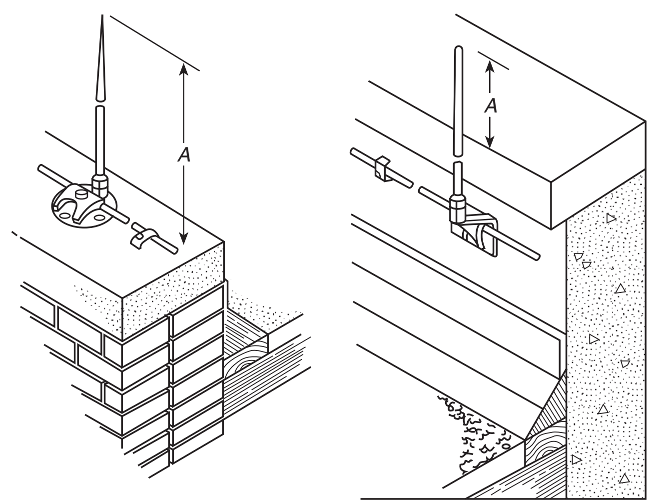
3.5.3 Connectors and fittings shall be suitable for use with the conductor and the surfaces on which they are installed. Bimetallic connectors and fittings shall be used for splicing or bonding dissimilar metals.

3.5.4 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.

3.6 Strike Termination Devices. Strike termination devices shall be provided where required by other sections of this standard. Metal parts of a structure that are exposed to direct lightning flashes and that have a metal thickness of $^{3}/_{16}$ in. (4.8 mm) or greater shall require only connection to the lightning protection system. Such connections shall provide a minimum of two paths to ground. Strike termination devices shall not be required for those parts of a structure located within a zone of protection.

3.6.1* Air Terminal Height. The tip of an air terminal shall be not less than 10 in. (254 mm) above the object or area it is to protect, as shown in Figure 3.6.1.

FIGURE 3.6.1 Air terminal height.



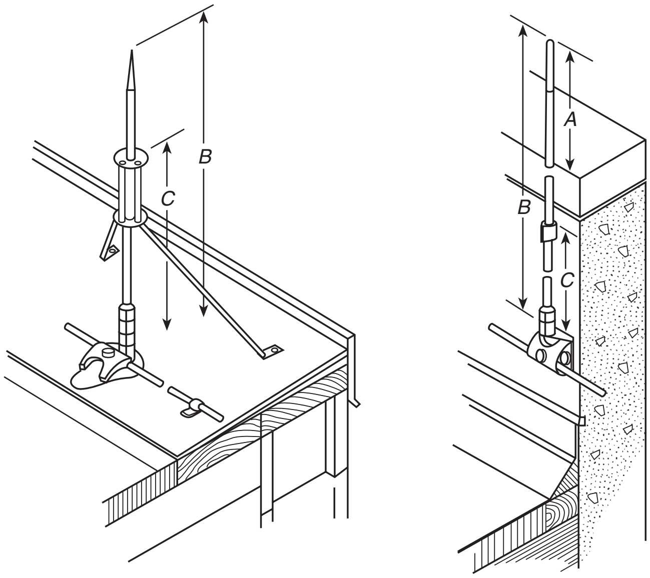
A: 10 in. (254 mm)
Note: Air terminal tip configurations can be sharp or blunt.

3.6.2 Air Terminal Support. Air terminals shall be secured against overturning by one of the following methods:

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

Air terminals exceeding 24 in. (600 mm) 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 3.6.2.

FIGURE 3.6.2 Air terminal support.



A: 24 in. (600 mm).
B: Air terminals over 24 in. (600 mm) 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.

3.6.3 Ornaments. An ornament or decoration on a freestanding, unbraced air terminal shall not present, in any plane, a wind-resistance area in excess of 20 in.^{2} (0.01 m^2). This requirement shall permit the use of an ornamental ball 5 in. (127 mm) in diameter.

3.7 Zones of Protection. To determine the zone of protection, the geometry of the structure shall be considered.

3.7.1 Roof Types. The zone of protection for the following roof types shall include the roof and appurtenances where protected in accordance with Section 3.8:

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

3.7.2 Multiple-Level Roofs. For structures with multiple-level roofs no more than 50 ft (15 m) in height, the zone of protection shall include areas as identified in 3.7.2.1 and 3.7.2.2. The zone of protection shall form a cone whose apex is located at the highest point of the strike termination device, with walls forming approximately a 45-degree or 63-degree angle from the vertical.

3.7.2.1 Structures that do not exceed 25 ft (7.6 m) above earth shall be considered to protect lower portions of a structure located in a one-to-two zone of protection as shown in Figures 3.7.2.1(a) and 3.7.2.1(b).

FIGURE 3.7.2.1(a) Lower roof protection for flat roof buildings 25 ft (7.6 m) or less in height.

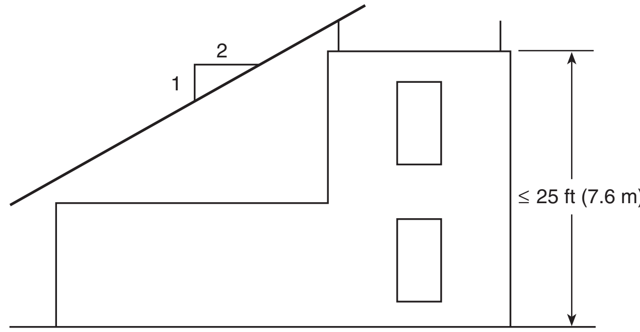
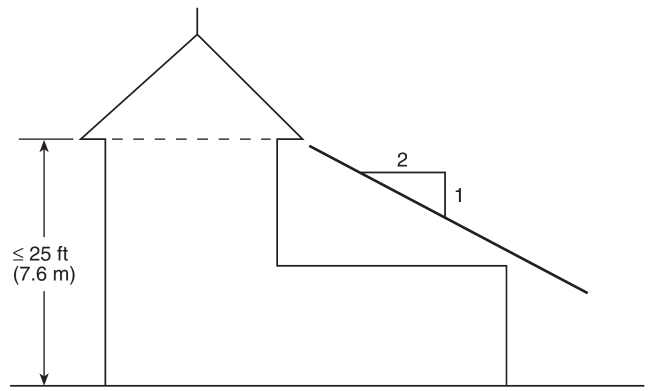


FIGURE 3.7.2.1(b) Lower roof protection provided by pitched roof buildings 25 ft (7.6 m) or less in height.



3.7.2.2 Structures that do not exceed 50 ft (15.24 m) above earth shall be considered to protect lower portions of a structure located within a one-to-one zone of protection as shown in Figures 3.7.2.2(a) and 3.7.2.2(b).

FIGURE 3.7.2.2(a) Lower roof protection for buildings 50 ft (15.24 m) or less in height.

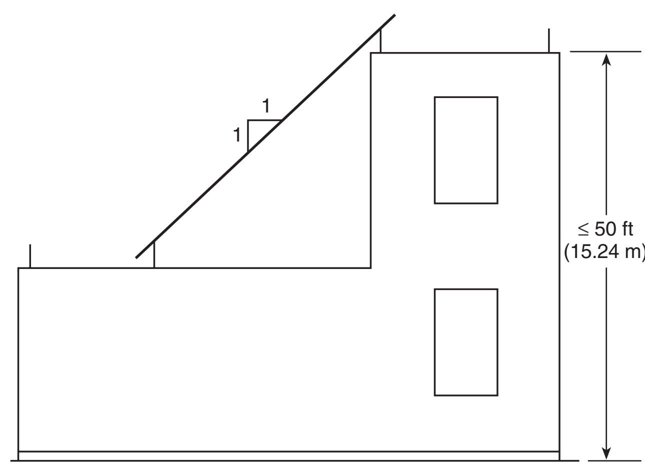
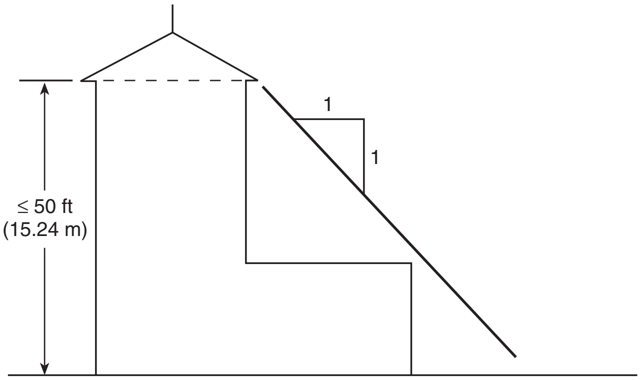


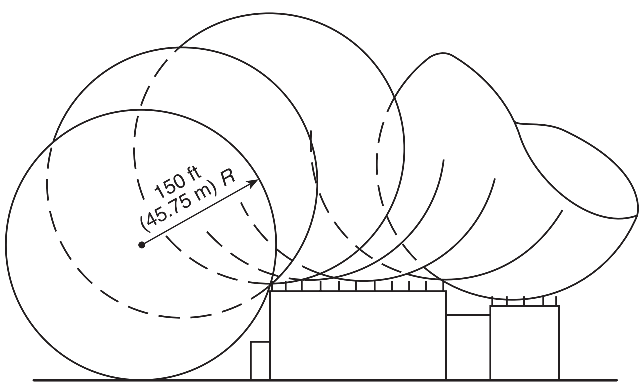
FIGURE 3.7.2.2(b) Lower roof protection provided by pitched roof buildings 50 ft (15.24 m) or less in height.



3.7.3 Rolling Sphere Model.

3.7.3.1 The zone of protection shall include the space not intruded by a rolling sphere having a radius of 150 ft (46 m). 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. 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 3.7.3.1. All possible placements of the sphere shall be considered when determining the zone of protection using the rolling sphere model.

FIGURE 3.7.3.1 Zone of protection.



3.7.3.2 For structure heights exceeding 150 ft (46 m) above earth or above a lower strike termination device, the zone of protection shall be considered to be the space in the vertical plane between the points of contact and under the sphere where the sphere is resting against a vertical surface of the structure and the lower strike termination device or earth. The zone of protection shall be limited to the space above the horizontal plane of the lowest terminal unless it can be extended by further analysis, such as in rolling the sphere to be tangent to earth.

3.7.3.3 Figure 3.7.3.3 provides a graphic representation of the 150-ft (46-m) geometric model for structures of selected heights up to 150 ft (46 m). Based on the height of the strike termination device for a protected structure being 25 ft (7.6 m), 50 ft (15 m), 75 ft (23 m), 100 ft (30 m), or 150 ft (46 m) aboveground, reference to the appropriate curve shows the anticipated zone of protection for objects and roofs at lower elevations. The graph shows the protected distance ("horizontal distance") as measured radially from the protected structure. The horizontal distance thus determined shall apply only at the horizontal plane of the "height protected."

3.7.3.4 Under the rolling sphere model, the horizontal protected distance found geometrically by Figure 3.7.3.3 ("horizontal distance, ft") also shall be permitted to be calculated using the following formula:

$$d = \sqrt{h_1(300 - h_1)} - \sqrt{h_2(300 - h_2)}$$

where:

d = horizontal distance (ft)

h_1 = height of the higher roof (ft)

h_2 = height of the lower roof (top of the object) (ft)

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

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

3.8 Strike Termination Devices on Roofs. Pitched roofs shall be defined as roofs having a span of 40 ft (12 m) or less and a pitch $^1/_8$ or greater and roofs having a span of more than 40 ft (12 m) and a pitch $^1/_4$ or greater. All other roofs shall be considered flat or gently sloping.

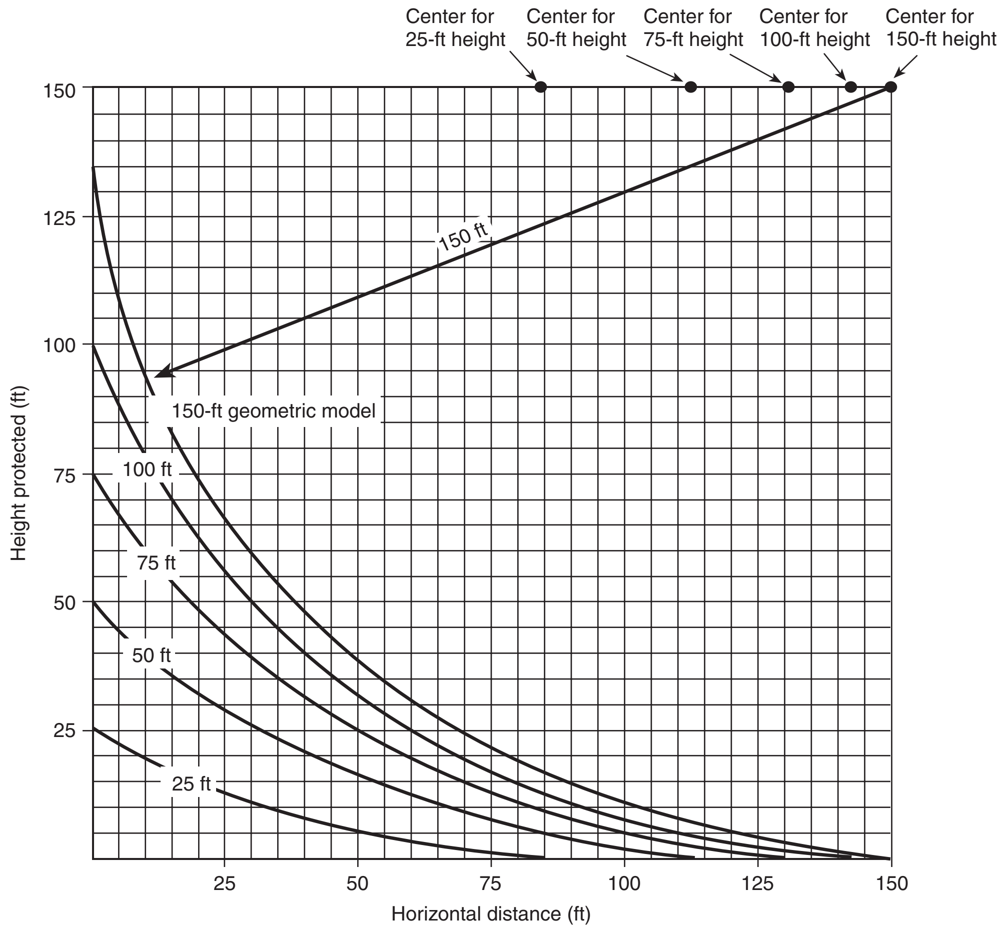
3.8.1 Location of Devices. As shown in Figure 3.8.1, strike termination devices shall be placed at or within 2 ft (0.6 m) of ridge ends on pitched roofs or at edges and outside corners of flat or gently sloping roofs. Strike termination devices shall be placed on ridges of pitched roofs and around the perimeter of flat or gently sloping roofs at intervals not exceeding 20 ft (6 m). Strike termination devices 24 in. (600 mm) or more above the object or area to be protected shall be permitted to be placed at intervals not exceeding 25 ft (7.6 m).

3.8.1.1 Pitched Roof Area. A pitched roof with eaves height of 50 ft (15 m) 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. Pitched roofs with eaves height over 50 ft (15 m) shall have strike termination devices located according to the 150-ft (46-m) geometric model. *(See Figures 3.7.3.1 and 3.7.3.3.)*

3.8.1.2 Flat or Gently Sloping Roof Area. Flat or gently sloping roofs that exceed 50 ft (15 m) in width or length shall have additional strike termination devices located at intervals not to exceed 50 ft (15 m) on the flat or gently sloping areas, as shown in Figures 3.8.1.2(a) and 3.8.1.2(b).

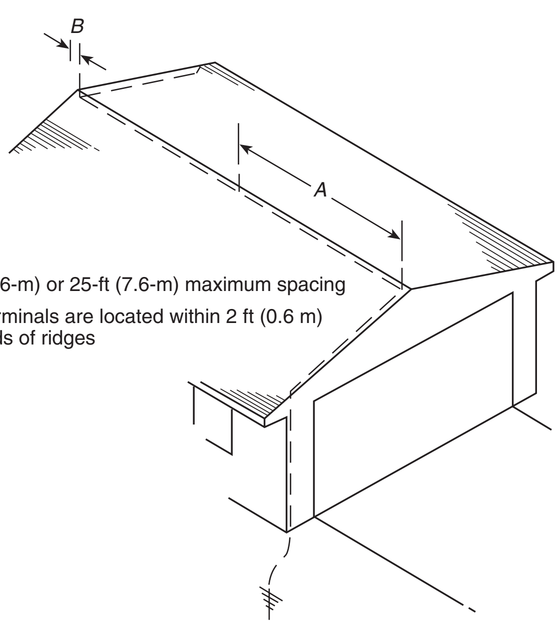
3.8.2* Dormers. Dormers as high or higher than the main roof shall be protected with strike termination devices, conductors, and grounds where required. Dormers and projections below the main ridge shall require protection only on those areas extending outside a zone of protection.

FIGURE 3.7.3.3 Zone of protection.



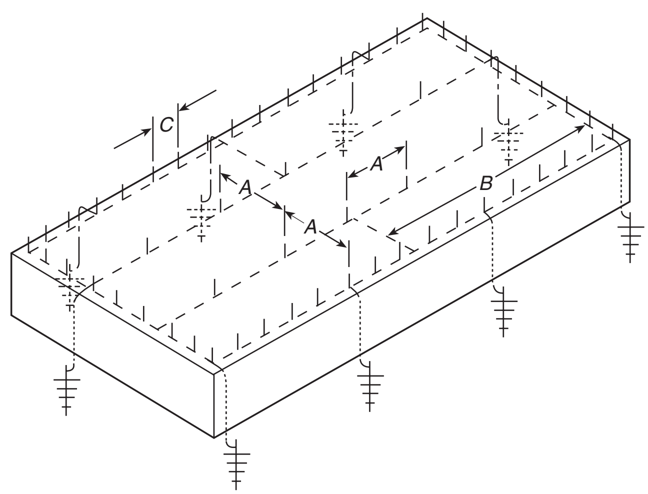
For SI units, 1 ft = 0.305 m.

FIGURE 3.8.1 Air terminals on pitched roof.



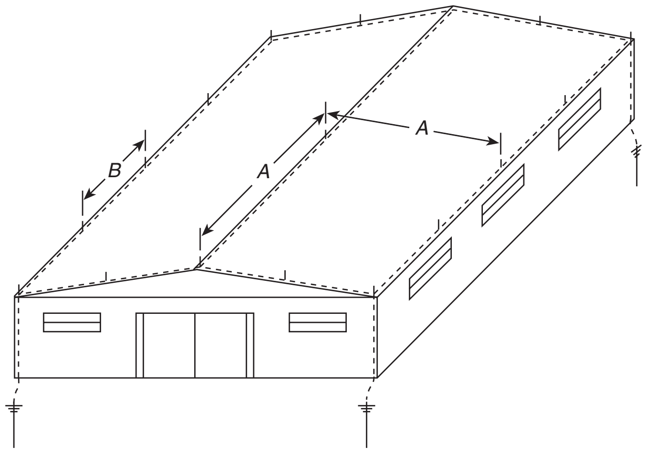
A: 20-ft (6-m) or 25-ft (7.6-m) maximum spacing
B: Air terminals are located within 2 ft (0.6 m) of ends of ridges

FIGURE 3.8.1.2(a) Air terminals on flat roof.



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

FIGURE 3.8.1.2(b) Air terminals on gently sloping roof.



3.8.3 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 3.8.1. 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. If any intermediate ridge is higher than the outermost ridges, it shall be treated as a main ridge and protected according to 3.8.1.

3.8.4 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. In many cases, the outermost projections form an imaginary roof edge that is used to locate the strike termination devices in accordance with 3.8.1. In all cases, however, strike termination devices shall be located in accordance with Section 3.8, as shown in Figure 3.8.4(a).

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. 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 16 ft (4.9 m). The connection of the single cable to the down conductor shall be made with a tee splice, as shown in Figure 3.8.4(b).

3.8.5 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 300 ft (92 m), provided both rectangular dimensions exceed 50 ft (15 m).

3.8.6 Domed or Rounded Roofs. Strike termination devices shall be located so that no portion of the structure is located outside a zone of protection, based on a striking distance of 150 ft (45 m), as set forth in Section 3.8.

FIGURE 3.8.4(a) Flat or gently sloping roof with irregular perimeter.

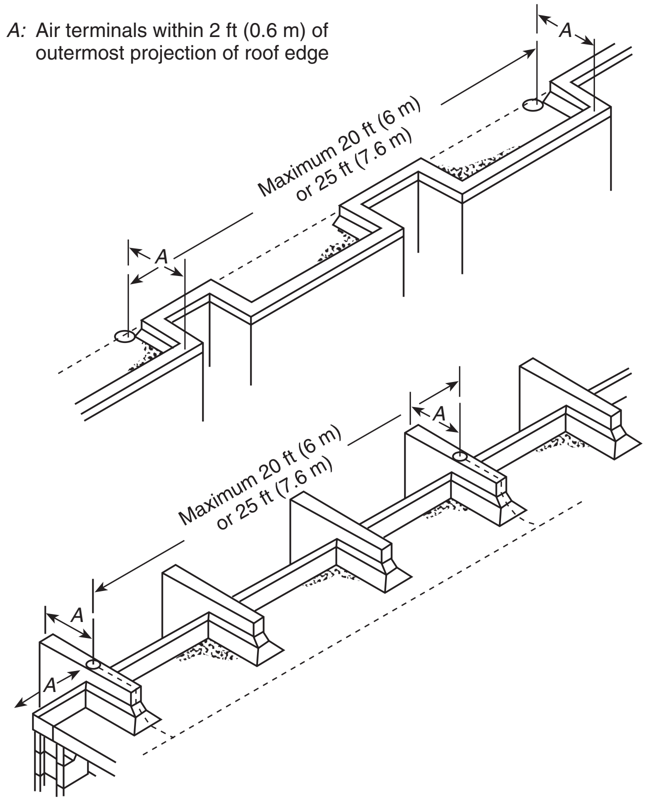
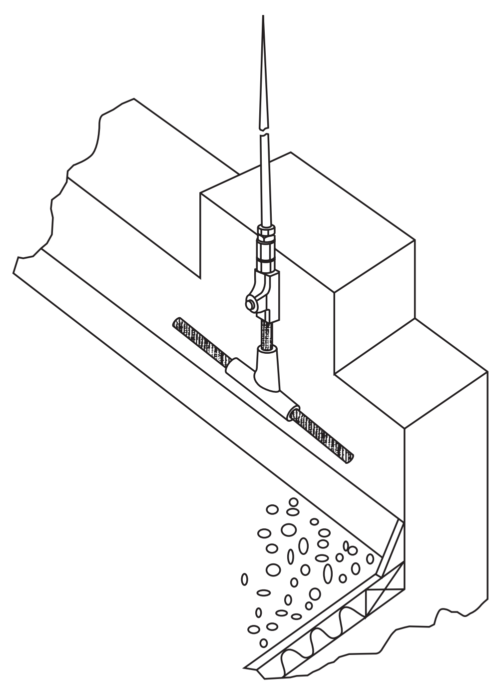


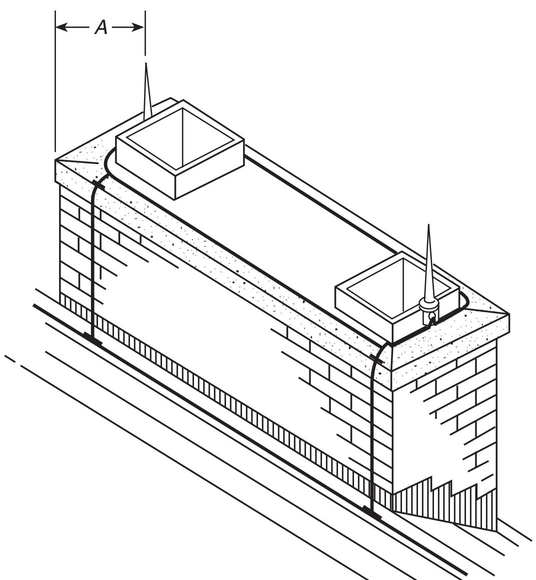
FIGURE 3.8.4(b) Irregular roof perimeter.



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

3.8.7 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 $^3/_{16}$ in. (4.8 mm). Chimneys or vents with a metal thickness of $^3/_{16}$ in. (4.8 mm) or more shall require only a connection to the lightning protection system. Such a connection shall be made using a main-size lightning conductor and a bonding device having a surface contact area of not less than 3 in.^{2} (1940 mm^2), and shall provide two or more paths to ground as is required for strike termination devices. Required strike termination devices shall be installed on chimneys and vents, as shown in Figure 3.8.7, 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 2 ft (0.6 m). 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 3.9 and 3.9.2.

FIGURE 3.8.7 Air terminals on chimney.



A: 2 ft (0.6 m) maximum

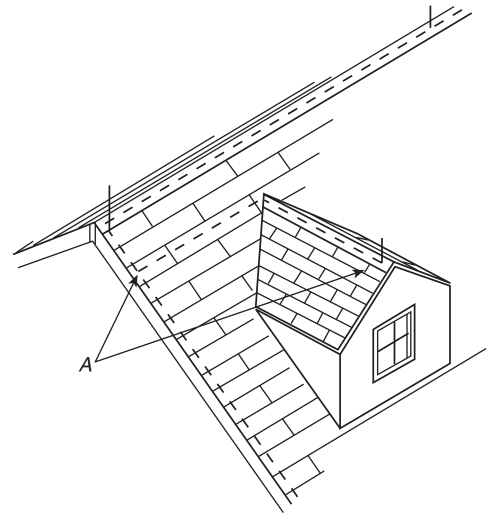
Note: Air terminal tip configurations can be sharp or blunt.

3.9 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 ground terminals, except as permitted by 3.9.1 and 3.9.2.

3.9.1 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 40 ft (12 m).

3.9.2 Dead Ends. Strike termination devices shall be permitted to be "dead ended," as shown in Figure 3.9.2, 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 16 ft (4.9 m) in total length and maintains a horizontal or downward coursing.

FIGURE 3.9.2 Dead end.

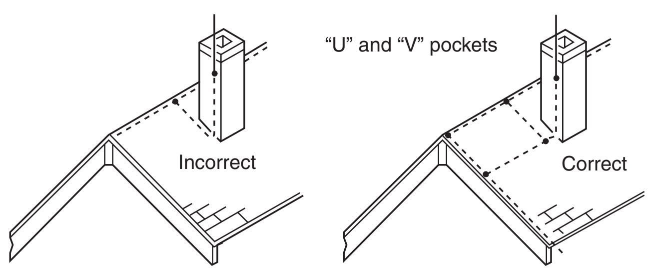


A: Permissible dead-end total conductor length not over 16 ft (5 m)

3.9.3 Substitution of Metals. Metal parts of a structure, such as eave troughs, downspouts, ladders, chutes, or other metal parts, shall not be substituted for the main lightning conductor. Likewise, metal roofing or siding having a thickness of less than $^3/_{16}$ in. (4.8 mm) shall not be substituted for main lightning conductors.

3.9.4 "U" or "V" Pockets. Conductors shall maintain a horizontal or downward coursing free from "U" or "V" (down and up) pockets. 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 3.9.4.

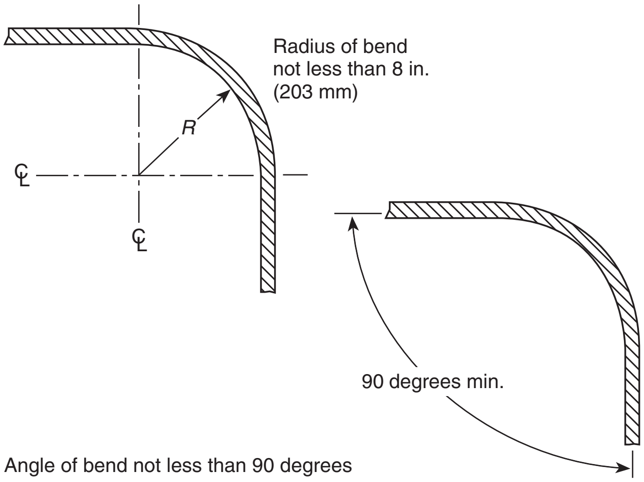
FIGURE 3.9.4 Pockets.



3.9.5 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 8 in. (203 mm), as shown in Figure 3.9.5.

3.9.6 Conductor Supports. Conductors shall be permitted to be coursed through air without support for a distance of 3 ft (0.9 m) or less. Conductors that must be coursed through air for longer distances shall be provided with a positive means of support that will prevent damage or displacement of the conductor.

FIGURE 3.9.5 Conductor bends.



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

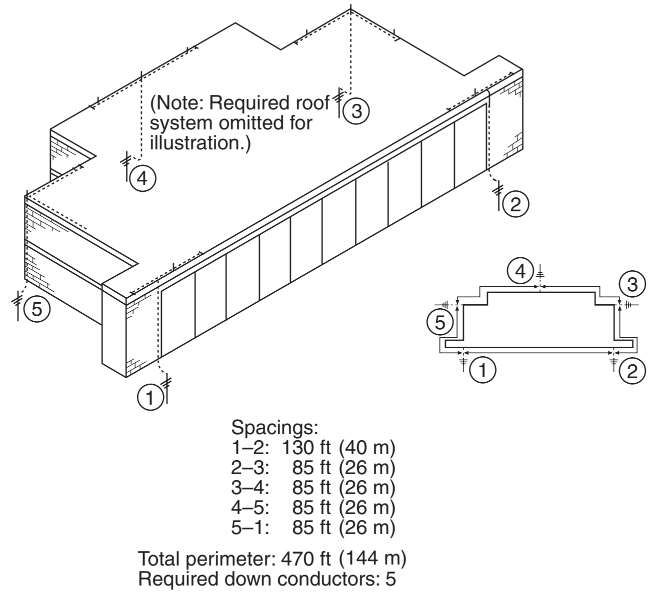
3.9.8 Cross-Run Conductors. Cross-run conductors (main conductors) shall be required to interconnect the strike termination devices on flat or gently sloping roofs that exceed 50 ft (15 m) in width. For example, roofs from 50 ft to 100 ft (15 m to 30 m) in width shall require one cross-run conductor, roofs 100 ft to 150 ft (30 m to 46 m) in width shall require two cross-run conductors, and so on. Cross-run conductors shall be connected to the main perimeter cable at intervals not exceeding 150 ft (46 m), as shown in Figure 3.8.1.2(a).

3.9.9 Down Conductors. Down conductors shall be as widely separated as practicable. Their location shall depend on such considerations 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

3.9.10 Number of Down Conductors. At least two down conductors shall be provided on any kind of structure, including steeples. Structures exceeding 250 ft (76 m) in perimeter shall have a down conductor for every 100 ft (30 m) of perimeter or fraction thereof. 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 100 ft (30 m). Irregular-shaped structures shall have additional down conductors as necessary to provide a two-way path from each strike termination device. For a flat or gently sloping roof structure, only the perimeter of the roof areas requiring protection shall be measured. When determining the perimeter of a pitched roof structure, the horizontal projection (footprint) of the protected roof shall be measured as shown in Figure 3.9.10. Lower roofs or projections that are located within a zone of protection shall not be required to be included in the perimeter measurement.

FIGURE 3.9.10 Quantity of down conductors.



3.9.11 Protecting Down Conductors. Down conductors located in runways, driveways, school playgrounds, cattle yards, public walks, or other similar locations shall be guarded to prevent physical damage or displacement. Metallic guards shall be bonded at each end. The down conductor shall be protected for a minimum distance of 6 ft (1.8 m) above grade level.

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

3.9.13 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. In the case of long vertical members, an additional connection shall be made at intervals not exceeding 200 ft (60 m). Such connections shall be made using listed clamps or listed bonding plates or by welding or brazing. Where these bonding requirements are not satisfied, provisions shall be made to ensure the required interconnection of these parallel vertical paths.

3.9.14 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 3.19, 3.20, and 3.21.

3.10 Conductor Fasteners. Conductors shall be fastened securely to the structure upon which they are placed at intervals not exceeding 3 ft (1 m). 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. 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.

3.11 Masonry Anchors. Masonry anchors used to secure lightning protection materials shall have a minimum outside diameter of $^1/_4$ in. (6.4 mm) and shall be set with care. Holes made to receive the body of the anchor shall be of the correct size, made with the proper tools, and preferably made in the brick, stone, or other masonry unit rather than in mortar joints. Where the anchors are installed, the fit shall be tight against moisture, thus reducing the possibility of damage due to freezing.

3.12 Connector Fittings. Connector fittings shall be used at all "end-to-end," "tee," or "Y" splices of lightning conductors. They shall be attached so as to withstand a pull test of 200 lb (890 N). 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. Conductor connections shall be of the bolted, welded, high compression, or crimp type. Crimp-type connections shall not be used with Class II conductors.

3.13 Ground Terminals. Each down conductor shall terminate at a ground terminal dedicated to the lightning protection system. The design, size, depth, and number of ground terminals used shall comply with 3.13.1 through 3.13.4.

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 grounding electrodes of different systems.

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.

Ground terminals shall be copper-clad steel, solid copper, hot-dipped galvanized steel, or stainless steel.

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

3.13.1* Ground Rods. Ground rods shall be not less than $^1/_2$ in. (12.7 mm) in diameter and 8 ft (2.4 m) long. Rods shall be free of paint or other nonconductive coatings.

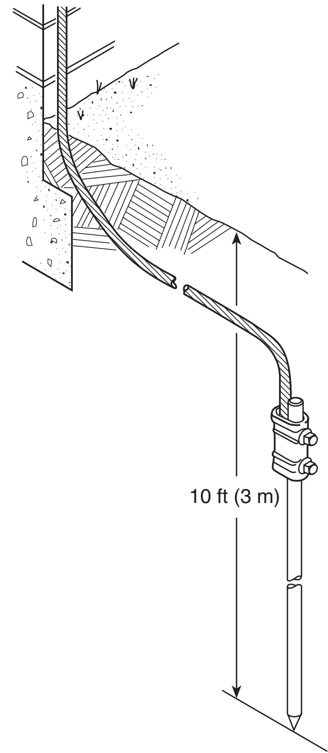
3.13.1.1 Ground Rod Depth. The ground rods shall extend vertically not less than 10 ft (3 m) into the earth. The earth shall be compacted and made tight against the length of the conductor or ground rod, as illustrated in Figure 3.13.1.1.

3.13.1.2* Multiple Ground Rods. Where multiple ground rods are used, the separation between any two ground rods shall be at least the length of the longer of two adjacent rods where practicable.

3.13.2 Concrete-Encased Electrodes. Concrete-encased electrodes shall be used only in new construction. 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 2 in. (50.8 mm) of concrete. The encased electrode shall consist of one of the following:

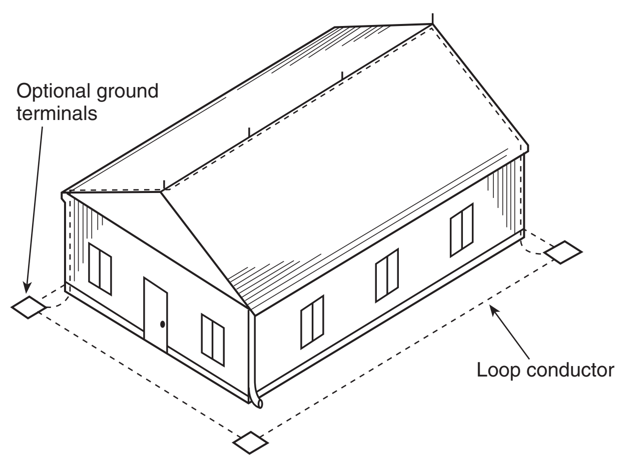
(1) Not less than 20 ft (6.1 m) of bare copper main-size conductor
(2) An electrode consisting of at least 20 ft (6.1 m) of one or more steel reinforcing bars or rods not less than $^1/_2$ in. (12.7 mm) in diameter that have been effectively bonded together by either welding or overlapping 20 diameters and securely wire-tying

FIGURE 3.13.1.1 Typical single ground rod installation.



3.13.3 Ground Ring Electrode. A ground ring electrode encircling a structure shall be as shown in Figure 3.13.3, in direct contact with earth at a depth of not less than 18 in. (457 mm) or encased in a concrete footing in accordance with 3.13.2. The encased electrode shall consist of not less than 20 continuous ft (6.1 m) of bare copper main-size conductor. The ground ring electrode shall be not smaller than the equivalent of a main-size lightning conductor.

FIGURE 3.13.3 Typical ground ring electrode installation.



3.13.4* Radials. 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. Each radial electrode shall be not less than 12 ft (3.7 m) in length and not less than 18 in. (0.5 m) below grade, and shall diverge at an angle not greater than 90 degrees.

3.13.5 Plate Electrode or Ground Plate. A ground plate or plate electrode shall have a minimum thickness of 0.032 in. (0.8 mm) and a minimum surface area of 2 ft^2 (0.18 m^2). The plate shall be buried not less than 18 in. (0.5 m) below grade.

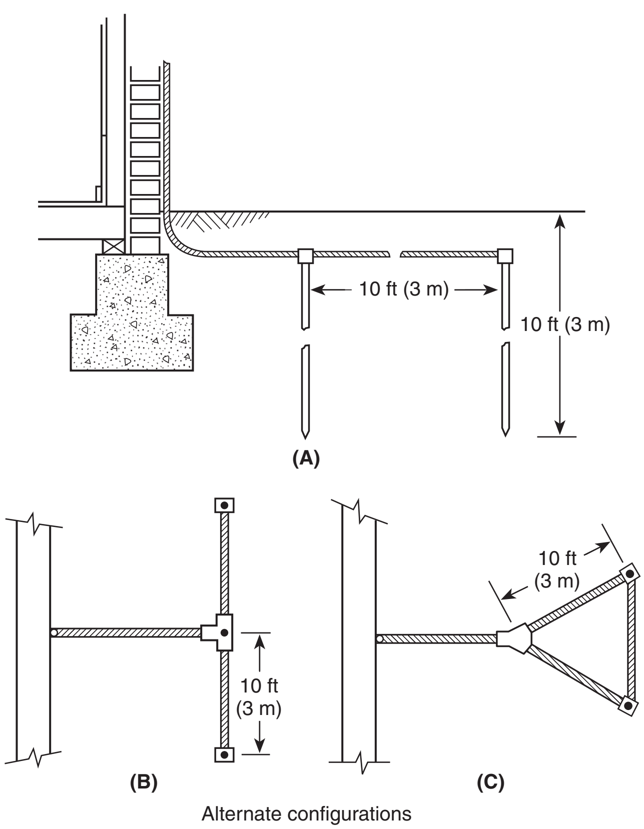
3.13.6 Combinations. Combinations of the grounding terminals in Section 3.13 shall be permitted.

3.13.7 Ground Terminal Selection Criteria. The site limitations and soil conditions shall determine the selection of the type or combinations of types of ground terminals used.

3.13.7.1 Shallow Topsoil. Methods of 3.13.2 through 3.13.5 shall be used in shallow topsoil conditions. Where the methods described in 3.13.2 or 3.13.5 are found to be impractical, due to topsoil depth less than 1 ft (0.3 m), it shall be permitted to carry the lightning protection cable in trenches of a depth of 1 ft (0.3 m) to 2 ft (0.6 m) in clay soil or 2 ft (0.6 m) in sandy or gravelly soil. Where this protection is impossible, the conductor shall be permitted to be laid directly on bedrock a minimum distance of 2 ft (0.6 m) from the foundation or exterior footing. The cable shall terminate by attachment to a buried copper ground plate at least 0.032 in. (0.8 mm) thick and having a minimum surface area of 2 ft^2 (0.18 m^2).

3.13.7.2 Sandy Soil Conditions. Because sandy or gravelly soil conditions are characterized by poor soil resistivity, multiple ground electrodes shall be used to augment the lightning grounding terminal system, as shown in Figure 3.13.7.2.

FIGURE 3.13.7.2 Grounding in a sandy or gravelly soil.



3.14 Common Grounding.

3.14.1 General. All grounding media in or on a structure shall be interconnected to provide a common ground potential. This shall include lightning protection, electric service, telephone and antenna system grounds, as well as underground metallic piping systems. Underground metallic piping systems shall include water service, well casings located within 25 ft (7.6 m) of the structure, gas piping, underground conduits, underground liquefied petroleum gas piping systems, and so on. Interconnection to a gas line shall be made on the customer's side of the meter. Main-size lightning conductors shall be used for interconnecting these grounding systems to the lightning protection system.

3.14.2 Common Ground Bondings. Where electric, Community Antenna Television (CATV), data, telephone, 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 that the water pipe is electrically continuous between all systems. 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.

3.15 Concealed Systems.

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

3.15.2 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.

3.15.3 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. Concealed down conductors shall be connected to the vertical reinforcing steel in accordance with 3.9.13. Roof conductors or other concealed horizontal conductor runs shall be connected to the reinforcing steel at intervals not exceeding 100 ft (30 m).

3.15.4 Ground Terminals. Ground terminals for concealed systems shall comply with Section 3.13. Ground terminals located under basement slabs or in crawl spaces shall be installed as near as practicable to the outside perimeter of the structure. Where rod or cable conductors are used for ground terminals, they shall be in contact with the earth for a minimum of 10 ft (3 m) and shall extend to a depth of not less than 10 ft (3 m) below finished grade, except as permitted by 3.13.3 and 3.13.4.

3.16 Structural Steel Systems.

3.16.1 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.

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

3.16.3 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 8 in.^{2} (5200 mm^2) or by welding or brazing. Drilling and tapping the steel column to accept a threaded connector also shall be an acceptable method. The threaded device shall be installed with five threads fully engaged and secured with a jam nut. The threaded portion of the connector shall be not less than $^1/_2$ in. (12.7 mm) in diameter. Bonding plates shall have bolt-pressure cable connectors and shall be bolted, welded, or brazed securely to the structural steel framework so as to maintain electrical continuity. Where rust-protective paint or coating is removed, the base steel shall be protected with a conductive, corrosion-inhibiting coating.

3.16.4 Ground Terminals. Ground terminals shall be connected to approximately every other steel column around the perimeter of the structure at intervals averaging not more than 60 ft (18 m). Connections shall be made near the base of the column in accordance with the requirements in 3.16.3.

3.16.5 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.

3.17 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.

3.18* Surge Suppression. Devices suitable for the protection of the structure shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins.

3.19* 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 3.19, 3.20, and 3.21.

3.19.1 General. In determining the necessity of bonding a metal body to a lightning protection system, the following factors shall be considered:

(1) Bonding shall be required only if there is likely to be a sideflash between the lightning protection system and another grounded metal body.
(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.
(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) Metal bodies located in a steel-framed structure that are inherently bonded through construction shall not require further bonding.

3.19.2 Materials. Horizontal loop conductors used for the interconnection of lightning protection system downlead conductors, ground terminals, or other grounded media shall be sized no smaller than that required for the main lightning conductor, as listed in Tables 3.1.1(a) and 3.1.1(b).

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 Tables 3.1.1(a) and 3.1.1(b).

3.20 Potential Equalization.

3.20.1* Ground-Level Potential Equalization. All grounded media in and on a structure shall be connected to the lightning protection system within 12 ft (3.6 m) of the base of the structure in accordance with Section 3.14.

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

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

3.20.3 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 the following.

(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 3.15.3.* The lightning protection system down conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 200 ft (60 m).

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

3.21 Bonding of Metal Bodies.

3.21.1 Long, Vertical Metal Bodies. Long, vertical metal bodies shall be bonded in accordance with the following.

(a) *Steel-Framed Structures.* Grounded and ungrounded metal bodies exceeding 60 ft (18 m) in vertical length shall be bonded to structural steel members as near as practical 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 3.15.3.* Grounded and ungrounded metal bodies exceeding 60 ft (18 m) in vertical length shall be bonded to the lightning protection system as near as practical 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 3.21.2 and 3.21.3, respectively.

3.21.2 Grounded Metal Bodies. This subsection shall cover the bonding of grounded metal bodies not covered in 3.21.1. Where grounded metal bodies have been connected to the lightning protection system at only one extremity, the following formula shall be used to determine if additional bonding is required. 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 following formula if they change vertical direction more than 12 ft (3.6 m). 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.

(a) *Structures over 40 ft (12 m) in Height.* 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.

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

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 25 ft (7.6 m) apart; located within a zone of 100 ft (30 m) from the bond in question; and where bonding is required within 60 ft (18 m) 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

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

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

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

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

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 25 ft (7.6 m) apart and located within a zone of 100 ft (30 m) 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

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

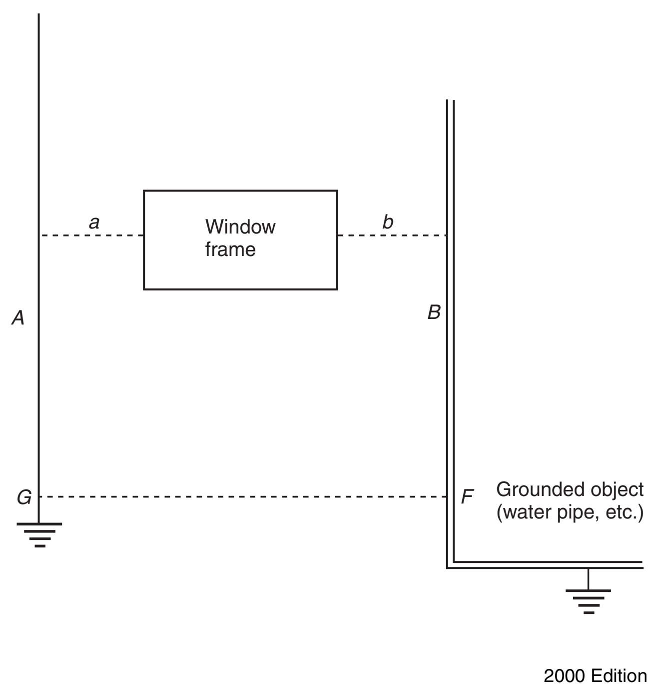
n = 2.25 where there are three or more down conductors in this zone

3.21.3* 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 using Figure 3.21.3 as follows.

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

(b) If $a + b >$ the calculated bonding distance, bonds shall not be required.

FIGURE 3.21.3 Effect of isolated (nongrounded) metallic bodies, such as a window frame, in nonconductive media.



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

Chapter 4 Protection for Miscellaneous Structures and Special Occupancies

4.1 General. Special consideration shall be given to the miscellaneous structures and special occupancies covered in this chapter. All requirements of Chapter 3 shall apply except as modified.

4.2 Masts, Spires, Flagpoles. These slender structures shall require one strike termination device, down conductor, and ground terminal. Electrically continuous metal structures shall require only bonding to ground terminals.

4.3 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 is loaded and unloaded.

4.4 Metal Towers and Tanks. Metal towers and tanks constructed so as to receive a stroke of lightning without damage shall require only bonding to ground terminals as required in Chapter 3, except as provided in Chapter 6.

4.5 Air-Inflated Structures. Air-inflated structures shall be protected with a mast-type or catenary lightning protection system in accordance with Chapter 6, or with a lightning protection system in accordance with Chapter 3.

4.6 Concrete Tanks and Silos. Lightning protection systems for concrete (including prestressed concrete) tanks containing flammable vapors, flammable gases, and liquids that can produce flammable vapors; and 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 Chapters 3 or 6.

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

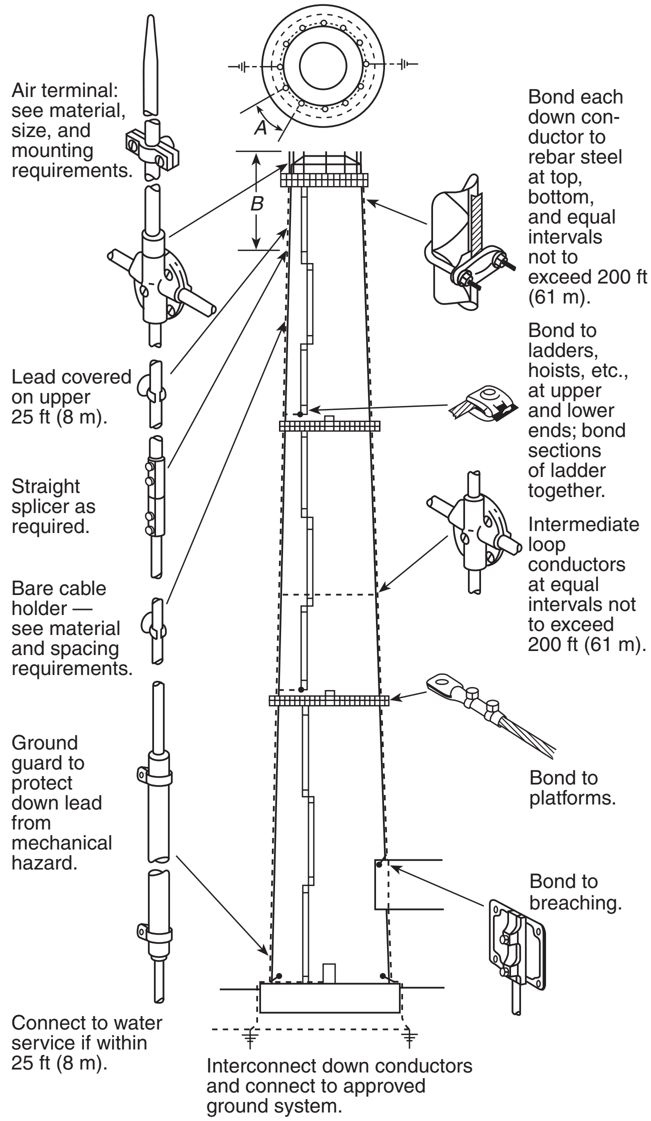
Each metal guy cable shall be bonded at its upper end to the structure it supports if it is constructed of a conductive material, and to the lightning protection system loop conductor or down conductors.

Chapter 5 Protection for Heavy-Duty Stacks

5.1 General. A smoke or vent stack shall be classified as heavy duty if the cross-sectional area of the flue is greater than 500 in.^{2} (0.3 m^2) and the height is greater than 75 ft (23 m), as shown in Figure 5.1.

FIGURE 5.1 Heavy-duty stack.

A: 8 ft (2 m) maximum spacing of air terminals.
B: All equipment on upper 25 ft (8 m) of stack to be lead-covered copper, stainless steel, or approved corrosion-resistant material.



5.2 Materials.

5.2.1 General. Materials shall be Class II as shown in Table 3.1.1(b) and as described in this chapter.

5.2.2 Corrosion Protection. Copper and bronze materials used on the upper 25 ft (7.6 m) of a stack shall have a continuous covering of lead having minimum thickness of $^1/_{16}$ in. (1.6 mm) to resist corrosion by flue gases. Such materials shall include conductors, strike termination devices, connectors, splicers, and cable holders. Stacks that extend through a roof less than 25 ft (7.6 m) shall have a lead covering only on those materials above the roof level.

5.3 Strike Termination Devices. Strike termination devices shall be made of solid copper, stainless steel, or Monel Metal™. They shall be located uniformly around the top of cylindrical stacks at intervals not exceeding 8 ft (2.4 m). On square or rectangular stacks, strike termination devices shall be located not more than 24 in. (600 mm) from the corners and shall be spaced not more than 8 ft (2.4 m) apart around the perimeter.

5.3.1 Air Terminal Heights. The height of air terminals above the stacks shall be not less than 18 in. (460 mm) nor more than 30 in. (760 mm). They shall be at least $^5/_8$ in. (15 mm) in diameter, exclusive of the corrosion protection. Top-mounted air terminals shall not extend more than 18 in. (460 mm) above the top of the stack.

5.3.2 Air Terminal Mountings. Air terminals shall be properly secured to the stack and shall be connected together at their lower end with a conductor forming a closed loop around the stack. Side-mounted air terminals shall be secured to the stack at not less than two locations. An anchored base connector shall be considered as one location.

5.3.3 Steel Hoods. An electrically continuous steel hood covering the stack lining and column, having a metal thickness of not less than $^3/_{16}$ in. (4.8 mm), shall be permitted to serve as the strike termination device. The hood serves as a top loop conductor and shall be connected to each down conductor using a connection plate of not less than 8 in.^{2} (5200 mm^2) securely bolted or welded to the hood.

5.4 Conductors.

5.4.1 General. Conductors shall be copper, weighing not less than 375 lb per 1000 ft (558 g per m) without the lead covering. The size of any wire in the conductor shall be not less than 15 AWG.

5.4.2 Down Conductors. Not less than two down conductors shall be provided. They shall be located on opposite sides of the stack and shall lead from the loop conductor at the top to ground terminals. Down conductors shall be interconnected within 12 ft (3.6 m) of the base by a loop conductor, preferably below grade. The down conductor also shall be interconnected with a loop conductor at approximately equal intervals not to exceed 200 ft (67 m). Down conductors shall be protected from physical damage or displacement for a distance of not less than 8 ft (2.4 m) above grade.

5.5 Fasteners. Fasteners shall be of copper, bronze, or stainless steel. They shall be anchored firmly to the stack by masonry anchors or lay-in attachments. The threaded shank of fasteners shall be not less than $^1/_2$-in. (13-mm) diameter for air terminals and $^3/_8$-in. (10-mm) diameter for conductors. Vertical conductors shall be fastened at intervals not exceeding 4 ft (1.2 m), and horizontal conductors shall be fastened at intervals not exceeding 2 ft (0.6 m).

5.6 Splices. Splices in conductors shall be as few as practicable and shall be attached so as to withstand a pull test of 200 lb (890 N). All connections and splices shall be by bolting, brazing, welding, or high-compression connectors listed for the purpose. All connectors and splicers shall make contact with the conductor for a distance not less than $1^1/_2$ in. (38 mm), measured parallel to the axis of the conductor.

5.7 Reinforced Concrete Stacks. All reinforcing steel shall be made electrically continuous and bonded to each down conductor within 12 ft (3.6 m) of the top and base of the stack, and at approximately equal intervals not to exceed 200 ft (67 m). Tying or clipping of reinforcing steel shall be an acceptable means of ensuring continuity. Clamps or welding shall be used for all connections to the reinforcing steel and to the down conductors.

5.8 Bonding of Metal Bodies. Bonding of metal bodies on a heavy-duty stack shall comply with the requirements of Sections 3.19, 3.20, and 3.21, and as described in this section.

5.8.1 Potential Equalization. Potential equalization shall be accomplished by the following.

(a) *Ground Level of Stack.* All interior and exterior grounded media shall be interconnected by a loop conductor within 12 ft (3.6 m) of the base of the stack. This shall include, but not be limited to, lightning protection down conductors, conduit, piping, elevators, ladders, and breeching steel and reinforcing steel.

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

(c) *Intermediate Levels of Stack.* All interior and exterior vertical grounded media shall be interconnected at approximately equal intervals not to exceed 200 ft (67 m).

5.8.2 Isolated (Nongrounded) Protruding Metal Bodies. Isolated (nongrounded) protruding metal bodies shall be bonded in accordance with the following.

(a) Isolated protruding metal bodies 150 ft (50 m) 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. Isolated protruding metal bodies shall include, but not be limited to, rest platforms, jib hoists, and other metal bodies protruding 18 in. (460 mm) or more from the column wall.

(b) 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.

5.9* Grounding. A ground terminal suitable for the soil conditions encountered shall be provided for each down conductor. Ground terminals shall be in accordance with Section 3.13, except ground rods shall be a copper-clad or stainless steel rod having a diameter of not less than $^5/_8$ in. (15.9 mm) and shall be at least 10 ft (3 m) in length.

5.10 Metal Stacks. Heavy-duty metal stacks having a metal thickness of $^3/_{16}$ in. (4.8 mm) or greater shall not require air terminals or down conductors. They shall be grounded by means of at least two ground terminals located on opposite sides of the stack. If the stack is an adjunct of a building or located within the sideflash distance, as determined by Sections 3.19, 3.20, and 3.21, it shall be interconnected to the lightning protection on the building. 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.

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

Chapter 6 Protection for Structures Containing Flammable Vapors, Flammable Gases, or Liquids That Can Give Off Flammable Vapors

6.1 Reduction of Damage.

6.1.1* This chapter shall apply to the protection of structures containing flammable vapors, flammable gases, or liquids that can give off flammable vapors. For the purpose of this chapter, the term *structure* shall apply to the vessel, tank, or other container where this material is contained.

6.1.2 Certain types of structures used for the storage of liquids that can produce flammable vapors or used to store flammable gases are essentially self-protecting against damage from lightning strokes and shall need no additional protection. Metallic structures that are electrically continuous, tightly sealed to prevent the escape of liquids, vapors, or gases, and of adequate thickness to withstand direct strokes in accordance with 6.3.2 shall be considered to be inherently self-protecting. Protection of other structures shall be achieved by the use of air terminals, masts, overhead ground wires, or other types of protective devices.

6.1.3* Because of the nature of the contents of the structures considered in this chapter, extra precautions shall be taken. In the structures covered in Chapter 6, a spark that would otherwise cause little or no damage might ignite the flammable contents and result in a fire or explosion.

6.2 Fundamental Principles of Protection. Protection of these structures and their contents from lightning damage shall require adherence to the following principles:

(1) Liquids that can give off flammable vapors shall be stored in essentially gastight structures.
(2) Openings where flammable concentrations of vapor or gas can escape to the atmosphere shall be closed or otherwise protected against the entrance of flame.
(3) Structures and all appurtenances (e.g., gauge hatches, vent valves) shall be maintained in good operating condition.
(4) Flammable air–vapor mixtures shall be prevented, to the greatest possible extent, from accumulating outside of such structures.
(5) Potential spark gaps between metallic conductors shall be avoided at points where flammable vapors can escape or accumulate.

6.3 Protective Measures.

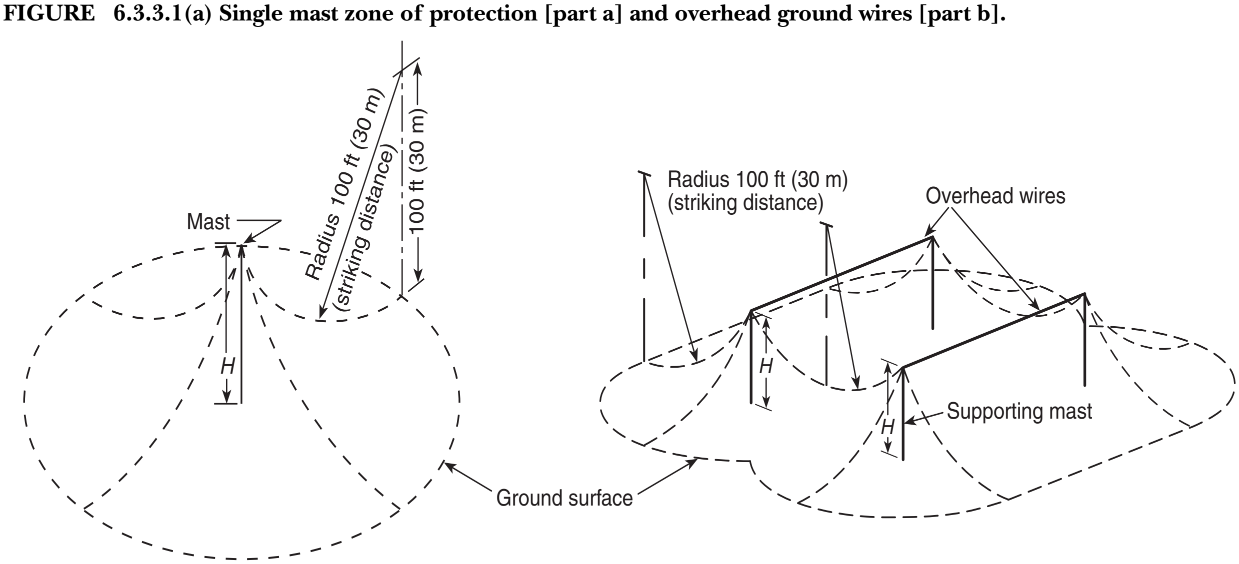
6.3.1 Materials and Installation. Conductors, strike termination devices, and grounding connections shall be selected and installed in accordance with the requirements of Chapter 3 and as described in this chapter. Overhead ground wires shall be noncorrosive for the conditions existing at the site. The overhead ground wire selected shall be sized to be equivalent in cross-sectional area to a main conductor and shall be self-supporting with minimum sag under all conditions. 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.

6.3.2 Sheet Steel. Sheet steel less than $^3/_{16}$ in. (4.8 mm) in thickness might be punctured by severe strokes and shall not be relied upon as protection from direct lightning strokes.

6.3.3 Rods, Masts, and Overhead Ground Wires.

6.3.3.1 The zone of protection of a lightning protection mast shall be based on the striking distance of the lightning stroke, that is, the distance over which final breakdown of the initial stroke to ground, or to a grounded object, occurs. 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 Figure 6.3.3.1(a), part (a). 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. Where more than one mast is used, the arc shall pass through the tips of adjacent masts, as shown in Figure 6.3.3.1(a), part (b) and Figure 6.3.3.1(b).

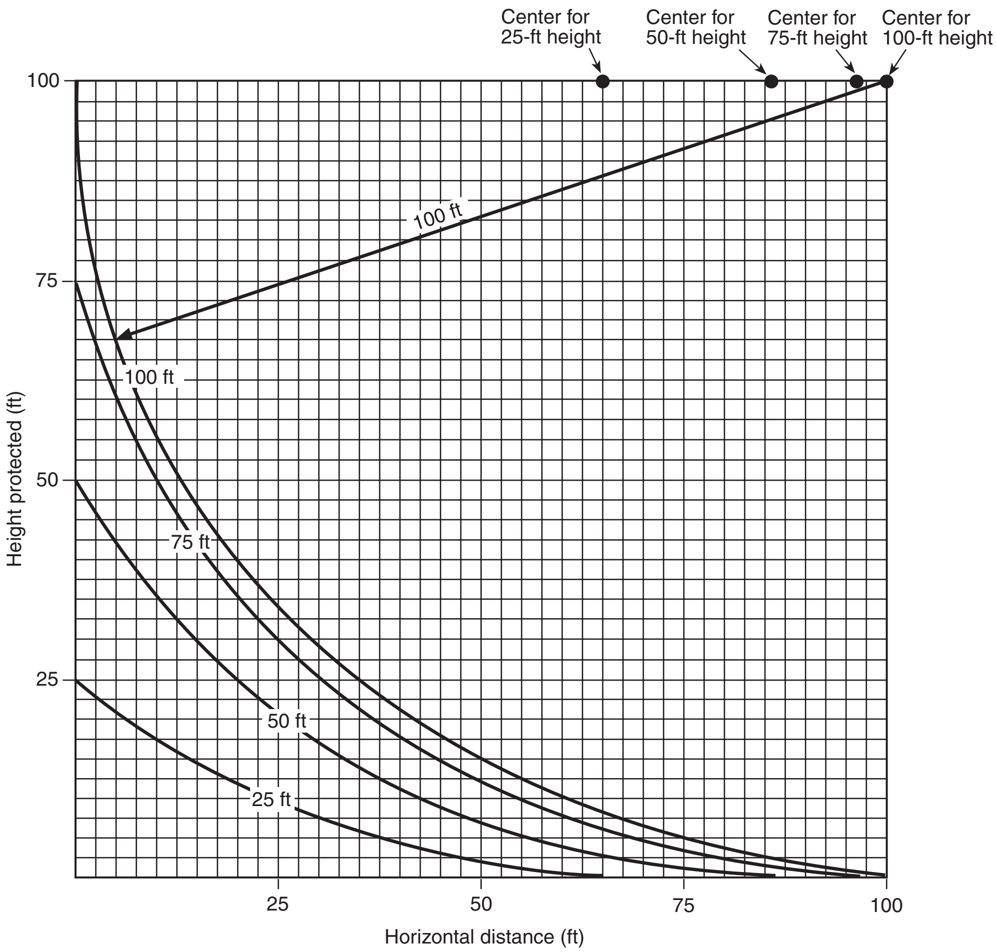
FIGURE 6.3.3.1(a) Single mast zone of protection [part a] and overhead ground wires [part b].



(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 6.3.3.1(b) Zone of protection — 100-ft (30-m) striking distance.



Note: The distance can be determined analytically for a 100-ft (30-m) striking distance with the following equation:

$$d = \sqrt{h_1 (200 - h_1)} - \sqrt{h_2 (200 - h_2)}$$

where:
d = horizontal distance (ft)
h_1 = height of higher mast (ft)
h_2 = height of lower mast (ft)
For SI units, 1 ft = 0.305 m.

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. In the vast majority of cases, the striking distance exceeds 100 ft (30 m). Accordingly, the zone based on a striking distance of 100 ft (30 m) shall be considered to be adequately protected.

The zone of protection afforded by any configuration of masts or other elevated, conductive grounded objects can readily be determined graphically. Increasing the height of a mast above the striking distance will not increase the zone of protection.

6.3.3.2 The zone of protection of an overhead ground wire shall be based on a striking distance of 100 ft (30 m) and defined by 100-ft (30-m) radius arcs concave upward. *[See Figure 6.3.3.1(a), part (b).]* The supporting masts shall have a clearance from the protected structure in accordance with 6.3.3.3.

6.3.3.3* 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. 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 under consideration)

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 under consideration

n = 1 where there is a single overhead ground wire that exceeds 200 ft (67 m) in horizontal length

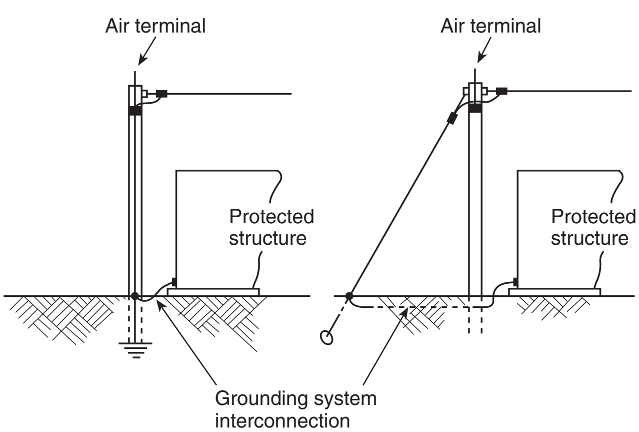
n = 1.5 where there is a single overhead wire or more than one wire interconnected above the structure to be protected, such that only two down conductors are located greater than 20 ft (6 m) and less than 100 ft (30 m) apart

n = 2.25 where there are more than two down conductors spaced more than 25 ft (7.6 m) apart within a 100-ft (30-m) wide area that are interconnected above the structure being protected

The masts or overhead ground wires shall be grounded and interconnected with the grounding system of the structure to be protected. The grounding requirements of Chapter 3 shall apply.

6.3.3.4 Masts of wood, used either separately or with ground wires, shall have an air terminal extending at least 2 ft (0.6 m) above the top of the pole, securely attached to the pole, as in Figure 6.3.3.4, and connected to the grounding system. 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. In the case of an overhead ground-wire system, the pole guy wire shall be permitted to be used as the down conductor. *(See Figure 6.3.3.4.)* For metallic masts, the air terminal and the down conductor shall not be required.

FIGURE 6.3.3.4 Alternate grounding methods for overhead ground-wire protection.



6.4 Protection of Specific Classes of Structures.

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

6.4.1.1 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 to be protected against lightning (inherently self-protecting) if the following requirements are met:

(1) All joints between metallic plates shall be riveted, bolted, or welded.
(2) All pipes entering the tank shall be metallically connected to the tank at the point of entrance.
(3) All vapor or gas openings shall be closed or provided with flame protection in locations where the stored stock might produce a flammable air–vapor mixture under storage conditions.
(4) The roof shall have a minimum thickness of $^3/_{16}$ in. (4.8 mm).
(5) The roof shall be welded, bolted, or riveted to the shell.

6.4.1.2 Floating Roof Tanks.

(a) *General.* 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. Similar 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. Similar 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.

(b) *Protection.* Where floating roofs utilize hangers located within a vapor space, the roof shall be electrically bonded to the shoes of the seal through the most direct electrical path at intervals not greater than 10 ft (3 m) on the circumference of the tank. These shunts shall consist of flexible Type 302, 28-gauge [$^1/_{64}$ in. × 2 in. (0.4 mm × 51 mm)] wide stainless steel straps or the equivalent in current-carrying capacity and corrosion resistance. The metallic shoe shall be maintained in contact with the shell and without openings (such as corrosion holes) through the shoe. Tanks without a vapor space at the seal shall not require shunts at the seal. Where metallic weather shields cover the seal, they shall maintain contact with the shell.

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. The shunts shall be spaced at intervals not greater than 10 ft (3 m) 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.

6.4.1.3 Metallic Tanks with Nonmetallic Roofs. Metallic tanks with wooden or other nonmetallic roofs shall not be considered to be self-protecting, even if the roof is essentially gastight and sheathed with thin metal and with all gas openings provided with flame protection. Such tanks shall be provided with strike termination devices. Such strike termination devices shall be bonded to each other, to the metallic sheathing, if any, and to the tank shell. Isolated metal parts shall be bonded as required by Section 3.19. 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.

6.4.1.4 Grounding Tanks. Tanks shall be grounded to conduct away the current of direct strokes and to avoid the buildup and potential that can cause sparks to ground. A metal tank shall be grounded by one of the following methods.

(a) A tank shall be connected without insulated joints to a grounded metallic piping system.

(b) A vertical cylindrical tank shall rest on earth or concrete and shall be at least 20 ft (6 m) in diameter, or shall rest on bituminous pavement and shall be at least 50 ft (15 m) in diameter.

(c) A tank shall be bonded to ground through a minimum of two ground terminals, as described in Section 3.13, at maximum 100-ft (30-m) intervals along the perimeter of the tank. This also shall apply to tanks with an insulating membrane beneath the tank.

6.4.2 Earthen Containers at Atmospheric Pressure Containing Flammable Vapors or Liquids that Can Give Off Flammable Vapors. 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.

6.4.3 Aboveground nonmetallic tanks shall be protected as described in 6.3.3.

Chapter 7 Protection for Watercraft

7.1 General. The intent of this chapter shall be to provide lightning protection requirements for watercraft while in water. Lightning protection systems installed on watercraft shall be installed in accordance with the provisions of this chapter.

7.1.1 A lightning protection system installed in accordance with the requirements of this chapter shall offer no protection for a watercraft that is out of the water.

7.1.2* Personnel on small watercraft shall exit the water as quickly as practical when an approaching thunderstorm is noticed.

7.1.3 A lightning protection system shall not be considered to afford protection if any part of the watercraft contacts a power line or other voltage source while in water or on shore.

7.2 Materials.

7.2.1 Corrosion. The materials used in the lightning protection system shall be resistant to corrosion. The use of combinations of metals that form detrimental galvanic couples shall be avoided.

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

Exception: Except for the use of conducting materials that are part of the structure of the watercraft, such as aluminum masts, only copper shall be used in a lightning conductor system. All copper conductors shall be the grade ordinarily required for commercial electrical work, which generally is designated as providing 98-percent conductivity where annealed.

7.2.3* Copper Conductors. Copper cable conductors shall be of a diameter not less than No. 4 AWG (41,740 CM) for the main down conductor, not less than No. 6 AWG (13 mm^2) for two parallel paths, or No. 8 AWG (8 mm^2) for more than two paths (such as those to shrouds and stay connections on sailboats). The thickness of any copper ribbon or strip (except for grounding plates and strips as discussed in 7.5.1) shall not be less than No. 20 AWG. Where other materials are used, the gauge shall be such as to provide conductivity equal to or greater than the required conductor size.

7.2.4 Joints. Joints shall be mechanically strong and shall be made so that they do not have an electrical resistance in excess of 2 ft (0.610 m) of conductor.

7.3 Antennas and Masts.

7.3.1 General. The zone of protection for watercraft is based on a striking distance of 100 ft (30 m). The zone of protection afforded by any configuration of masts or other elevated conductive objects can be readily determined graphically or mathematically as shown in Figure 7.3.1(a). Figure 7.3.1(b) provides an example of how the zone of protection is to be determined for a watercraft with multiple masts.

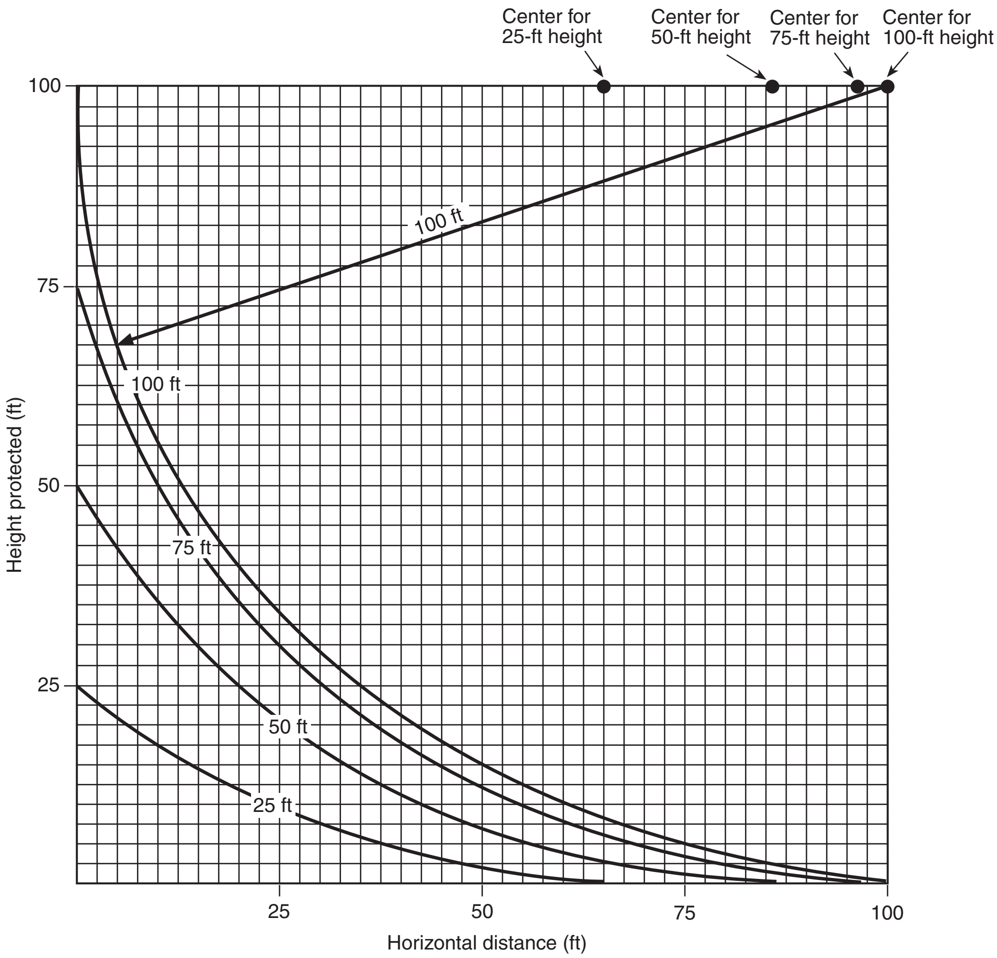
7.3.2 Strike Termination Devices. Strike termination devices (including conductive masts, etc.) meeting the requirements of Section 3.6 shall be so located and of sufficient height to provide a zone of protection that covers the entire watercraft. They shall be mechanically strong to withstand the roll and pitching action of the hull as well as heavy weather. The strike termination device shall be permitted to be raked at an angle, but shall be substantially vertical.

7.3.3 Metallic Masts. A metallic mast used as a strike termination device shall have a conductivity equivalent to a No. 4 AWG (21 mm^2) copper conductor. It shall be grounded in accordance with the requirements provided in Sections 7.4 and 7.5.

7.3.4 Nonmetallic Masts. A nonmetallic mast not within the zone of protection of a strike termination device shall be provided with an air terminal as described in Section 3.6. The air terminal shall extend a minimum of 6 in. (152 mm) above the mast. The air terminal shall be provided with a copper conductor or strip securely fastened to the mast. The down conductor shall have a conductivity equivalent to a No. 4 AWG (21 mm^2) copper conductor. A grounding system meeting the requirements of Section 7.5 also shall be provided.

7.3.5 Radio Antennas. A solid metal vertical radio antenna shall be permitted to serve as a strike termination device for small nonmetallic watercraft, provided a provision is made to ground the metal antenna with a conductor equivalent to a No. 4 AWG (21 mm^2) copper conductor. The conductor shall be routed vertically to the maximum extent practical (minimizing bends, etc.) to the lightning grounding plate, the lightning grounding strip under the watercraft, or to an equalization bus. The height of the antenna shall be sufficient to provide the required zone of protection for the watercraft and its occupants.

FIGURE 7.3.1(a) Zone of protection—100-ft (30-m) striking distance.



Note: The distance can be determined analytically for a 100-ft (30-m) striking distance with the following equation:

$$d = \sqrt{h_1 (200 - h_1)} - \sqrt{h_2 (200 - h_2)}$$

where:
d = horizontal distance (ft)
h_1 = height of strike termination device (ft)
h_2 = height of object to be protected (ft)

For SI units, 1 ft = 0.305 m.

Because a loading coil presents a high impedance to the flow of lightning currents, the coil shall be shorted, equipped with a surge suppression device (lightning arrester) for bypassing the lightning current, or grounded above the coil.

Nonmetallic radio antennas with spirally wrapped conductors shall not be used for lightning protection.

7.3.6 Temporary Strike Termination Device. On small watercraft that cannot be equipped with a permanent strike termination device, a temporary strike termination device shall be permitted. The temporary strike termination device shall be located so as to provide a zone of protection covering the entire watercraft and its occupants when installed. Temporary strike termination devices shall have a conductivity equivalent to a No. 4 AWG (21 mm^2) copper conductor.

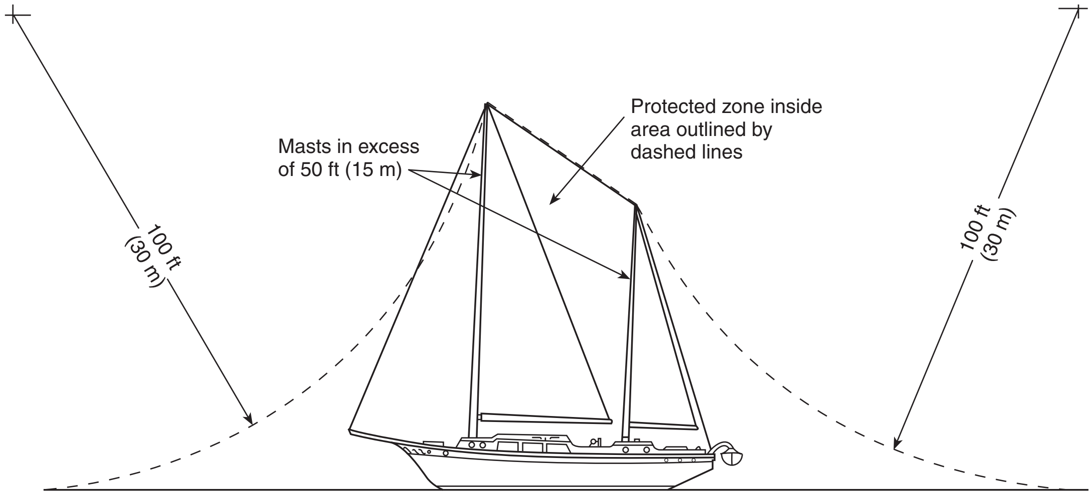
Exception: A solid stainless steel whip antenna or equivalent shall be permitted to be used as a temporary strike termination device.*

The location of the strike termination device base shall be such that persons on the watercraft can avoid physical contact with the strike termination device or its base.

7.4 Conductors.

7.4.1 Lightning Grounding Conductors. Lightning grounding conductors shall be routed directly to a ground, as discussed in Section 7.5, to the maximum extent practicable (minimizing bends, etc.). Lightning grounding conductors also shall be routed as remotely as possible from the watercraft's wiring to minimize sideflashes and to avoid introducing high voltages into the watercraft's wiring system. The watercraft wiring system shall be routed perpendicular to the lightning grounding conductors where practicable.

FIGURE 7.3.1(b) Diagram of boat with masts in excess of 50 ft (15 m) above the water. Protection based on lightning strike distance of 100 ft (30 m).



7.4.2* Interconnecting Conductors. An interconnecting conductor, equivalent to No. 8 AWG (8 mm^2) copper conductor, shall be provided at all locations where sideflashes are likely to occur. Large metallic masses that are subject to sideflashes shall be connected to the lightning grounding plate(s), the lightning grounding strip, or to the equalization bus, if provided, in accordance with Section 7.6.

7.4.3 Metallic Tanks. Metallic tanks shall be connected directly to the lightning ground plate(s), the lightning grounding strip, or to the equalization bus.

7.4.4 Shrouds and Stays. Shrouds and stays shall be permitted as part of the path to ground from the mast (strike termination device) to the lightning grounding plate or strip. The aggregate conductivity and inductance, including the mast, shall be not less than that of a No. 4 AWG (21 mm^2) copper conductor. Where stainless steel shrouds and stays are used in the lightning protection system, every shroud or stay shall be connected at its lower end or at the chainplates directly to the lightning grounding plate or lightning grounding strip with conductors having the minimum size of a No. 8 AWG (8 mm^2) copper conductor.

Stainless steel shrouds of small diameter and stays on small sailboats that are trailered without the required conductivity [less than that of a No. 8 AWG (8 mm^2) copper conductor] shall be grounded at their lower ends in addition to the grounding of the mast.

7.5 Grounding.

7.5.1 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 7.3, no further protection shall be necessary; however, surge suppression in accordance with Section 3.18 shall be provided. Conducting objects projecting above metal masts or superstructures shall be grounded with a grounding conductor connected to the metal hull or superstructure.

7.5.2 Watercraft with Nonmetallic Hulls. Grounding plates or strips shall be installed on the underside of the hull of nonmetallic watercraft to provide a path for the lightning current into the water.

7.5.2.1 Grounding Plate. A grounding plate of copper, copper alloys, or stainless steel shall be provided. The plate shall have a minimum size of 1 $ft^2 \times {}^3/_{16}$-in. (0.09 $m^2 \times$ 4.8-mm) thick. It shall be located as closely as possible below the strike termination device. Through-hull connectors shall be metallic and have a cross-sectional area equivalent to a No. 4 AWG (21 mm^2) copper conductor.

7.5.2.2 Grounding Strip. An external grounding strip of copper, copper alloys, or stainless steel installed under the watercraft running fore and aft shall have a minimum thickness of $^3/_{16}$ in. (4.8 mm) and a minimum width of $^3/_4$ in. (19 mm). The length of the strip shall be permitted to extend from a point located directly below the strike termination device to the aft end of the watercraft where a direct connection shall be made to the engine. The total length of the strip shall be not less than 4 ft (1.2 m).

In a sailboat, the backstay and engine shall be connected electrically to the aft end of the strip. The strip shall be secured to the hull with one, or preferably two, galvanically compatible throughbolts at each end. The bolts shall have a minimum cross-sectional area equivalent to a No. 4 AWG (21 mm^2) copper conductor. The strip shall be located so that it is submerged under all operating conditions. If the single strip is not located so as to be continuously submerged when the vessel is heeled either to port or starboard, then a strip shall be required on both port and starboard sides. Where more than one grounding strip is provided, all of the grounding strips shall be bonded together.

All terminations to the strip shall be made as short and direct as possible.

Additional through-hull connections shall be permitted to be located along the length of the strip for additional connections, such as those on a two-masted sailboat. Because of the possibility of stray current corrosion of the securing bolts, the number of through-hull bolts shall be kept to a minimum. To minimize the number of through-hull bolt connections, an equalization bus shall be permitted to be installed in accordance with Section 7.6.

The aft end of the grounding strip shall be connected directly to the engine negative ground terminal to provide a path inside the hull for any stray dc currents that are imposed on the through-hull bolts from the lightning grounding strip where those bolts contact bilge water.

7.6 Interconnection of Metallic Masses.

7.6.1 Equalization Bus. On watercraft where several connections are made to the lightning grounding strip, an equalization bus shall be permitted to be installed inside the boat to minimize the number of through-hull bolts needed. The equalization bus, if used, shall be installed inside the watercraft parallel to the underwater location of the lightning grounding strip. Permanently installed large metallic masses inside the watercraft shall be connected directly to the equalization bus. The equalization bus shall be connected to the underwater lightning grounding strip at both ends.

7.6.2* Seacocks and Through-Hull Fittings. Seacocks and through-hull fittings shall not be connected to the main down conductor but shall be permitted to be connected to the underwater grounding strip, the lightning grounding plate, or the equalization bus.

7.6.3 Metal Masses. Metal masses such as engines, generators, metallic tanks, steering systems located inside the vessel, and metal life rails shall be connected to the lightning grounding plate, grounding strip, or equalization bus as directly as possible.

7.6.4 Engine Grounding. To minimize the flow of the lightning discharge currents through the engine bearings, the engine block shall be permitted to be grounded directly to the lightning grounding plate or lightning grounding strip rather than to an intermediate point in the system.

7.6.5 Protection of Equipment. Wherever possible, electronic equipment shall be enclosed in metal cabinets that are connected to the lightning grounding system with a minimum of a No. 8 AWG (8 mm^2) copper conductor. Surge suppression devices shall be installed on all wiring entering or leaving electronic equipment.

7.7 Nonmetallic Watercraft.

7.7.1 Sailboats. Sailboats without inboard engines that are equipped with metallic masts and metallic rigging shall be considered to be adequately protected if the mast and the rigging chain plates are all connected to a lightning grounding plate or lightning grounding strip located directly below the mast.

7.7.1.1 Open Day-Sailers. Adequate lightning protection on open day-sailers shall depend on the grounding of the rigging as well as the metal masts or the continuous metallic tracks on nonmetallic masts because stainless steel rigging and preventors usually are not equivalent to No. 8 AWG (8 mm^2) copper conductor. The rigging, metal masts, or metallic tracks on nonmetallic masts shall be connected at the lower ends to a lightning grounding plate or a lightning strip located directly below the mast. Metallic rudders at the aft end of the boat shall not be used as the lightning ground for the mast because of the need for a long, horizontal conductor to be run to the aft end of the boat. The tiller or other connections to metallic rudders with which the operator could come into contact shall be of nonconductive materials. Metallic keels or centerboards shall be connected directly to the lightning grounding plate or strip, or shall be permitted to serve as the lightning grounding means if they provide the l ft^2 (0.09 m^2) area required to be in contact with the water. If a centerboard is used as the lightning grounding means, a warning sign shall be provided that clearly states that the centerboard shall be in the down position in order to function as a lightning ground.

7.7.1.2 Cruising Sailboats. All shrouds, stays, sail tracks, and metallic masts shall be connected to the lightning grounding system, since it is assumed that occupants of the boat will be in proximity of forestays, backstays, and shrouds during the normal operation of the boat. Grounding of all metallic masses on the boat shall be in accordance with all applicable sections of this standard.

7.7.2* Power Boats. Where practicable, lightning protection shall be provided through the use of a metallic radio antenna, as described in 7.3.5, or a temporary strike termination device, as described in 7.3.6.

Chapter 8 Referenced Publications

8.1 The following documents or portions thereof are referenced within this standard as mandatory requirements and shall be considered part of the requirements of this standard. The edition indicated for each referenced mandatory document is the current edition as of the date of the NFPA issuance of this standard. Some of these mandatory documents might also be referenced in this standard for specific informational purposes and, therefore, are also listed in Appendix M.

8.1.1 NFPA Publication. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

NFPA 30, *Flammable and Combustible Liquids Code*, 2000 edition.

8.1.2 Other Publication.

8.1.2.1 ASTM Publication. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959

ASTM D 323, *Standard Method of Test for Vapor Pressure of Petroleum Products (Reid Method)*, 1999.

Appendix A Explanatory Material

Appendix A is not a part of the requirements of this NFPA document but is included for informational purposes only. This appendix 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 need special consideration because the contents of such structures are sensitive to arc or spark ignition. Appendix K provides guidance for protection of structures housing explosive materials. Other standards and handbooks that provide guidance for military applications are found in Appendix M.

A.2.1.1 Air Terminal. Typical air terminals are formed of a tube or solid rod. Air terminals are sometimes called lightning rods.

A.2.1.2 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.2.1.3 Authority Having Jurisdiction. The phrase "authority having jurisdiction" 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.2.1.5 Cable. See Tables 3.1.1(a) and 3.1.1(b).

A.2.1.7 Class I Materials. See Table 3.1.1(a).

A.2.1.8 Class II Materials. See Table 3.1.1(b).

A.2.1.15 Flammable Air–Vapor Mixtures. The combustion range for ordinary petroleum products, such as gasoline, is from about $1^1/_2$ to $7^1/_2$ percent of vapor by volume, the remainder being air.

A.2.1.24 Lightning Protection System. Refers to systems as described and detailed in this standard. A traditional lightning protection system used for ordinary structures is described in Chapter 3. Mast and catenary-type systems typically used for special occupancies and constructions are described in Chapter 6.

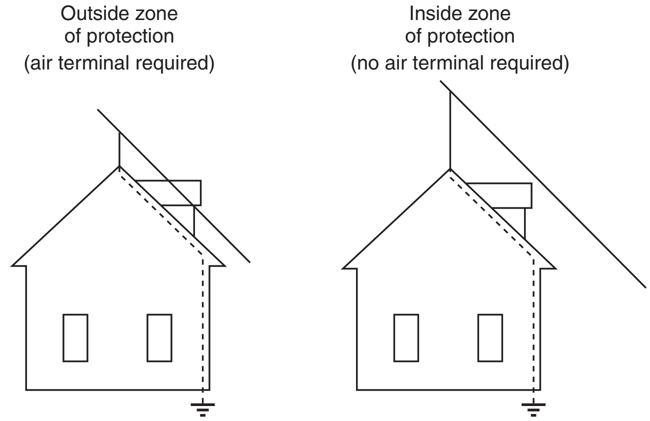
A.2.1.25 Listed. The means for identifying listed equipment may vary for each organization concerned with product evaluation; some organizations do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.

A.3.6.1 Recent experiments, described in the *Journal of Applied Meteorology*, suggest that the optimal air terminal tip radius of curvature for interception of lightning strikes is $^3/_{16}$ in. (4.8 mm) minimum to $^1/_2$ in. (12.7 mm) maximum.

A.3.8.2 Figure A.3.8.2 illustrates dormer protection.

A.3.13.1 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.

FIGURE A.3.8.2 Dormers.



A.3.13.1.2 No benefit is gained from the second ground rod if placed closer than the length of the longer rod. No additional benefit is gained if the second rod is placed over four times the length of the longer rod.

A.3.13.4 Radial augmentation of the grounding system specified in 3.13.4 and 3.13.7.2 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 3.13.7.1.

A.3.18 Electrical systems and utilization equipment within the structure can require further surge suppression. Such protection is not part of this standard. Documents such as ANSI/IEEE C-62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Systems*, NFPA 70, *National Electrical Code*®, and UL 1449, *UL Standard for Safety Transient Voltage Surge Suppressors,* provide additional information.

A.3.19 See Appendix J for a technical discussion of lightning-protection potential-equalization bonding.

A.3.20.1 For structures 60 ft (18 m) or less in height, a loop conductor should be provided for the interconnection of all ground terminals 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 3.13.3 can be utilized for the ground loop conductor.

A.3.20.2 In the case of flat or gently sloping roofs, the roof conductors required by 3.9.7 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.3.21.3 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 Appendix J for a discussion of bonding and an understanding of problems often encountered.)*

A.5.9 A ground grid located within 50 ft (15 m) of the foundation of a stack and constructed of wires meeting the requirements of this standard for main conductors is an acceptable ground terminal and, if the stack is located within 50 ft (15 m) of the grid in all directions, can also serve as the bottom loop conductor required by 5.4.2.

A.6.1.1 Flammable vapors can emanate from a flammable liquid [flash point below 100°F (37.8°C)] or a combustible liquid [flash point at or above 100°F (37.8°C)] when the temperature of the liquid is at or above its flash point. This chapter applies to these liquids when 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 100°F (37.8°C).

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.6.1.3 Chapters 3 through 5 of this standard give requirements for the protection of buildings and miscellaneous property against lightning damage.

A.6.3.3.3 The sideflash formulas are based on the impedance of main-size copper conductors. Other ground wire materials may require additional separation distance.

A.7.1.2 See Appendix C for information on personnel safety.

A.7.2.3 See NFPA 302, *Fire Protection Standard for Pleasure and Commercial Motor Craft,* Table 7.12.5(a) for minimum strand sizes for watercraft conductors.

A.7.3.6 Exception. A solid stainless steel whip antenna or equivalent can be used because of its higher melting temperature, however it does not provide as low a resistance as a No. 4 AWG copper conductor.

A.7.4.2 Sideflash distances can be calculated using the formulas provided in Section 3.21. Sideflashes are more likely to occur if the routing of the lightning conductor is horizontal for some distance and if the metallic object provides a relatively direct path to ground.

A.7.6.2 Seacocks are particularly susceptible to damage and leaking after a strike and should be inspected after all suspected strikes.

A.7.7.2 At the approach of a thunderstorm, personnel should head for shore and quickly seek a land-based protected structure. There are many methods available by which lightning can be detected. These methods range from listening for static on AM radios, to single-station detection devices, to sophisticated lightning location systems.

Appendix B Inspection and Maintenance of Lightning Protection Systems

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

B.1 Inspection of Lightning Protection Systems.

B.1.1 Frequency of Inspections. It is understood that all new lightning protection systems must be inspected following completion of their installation. However, it is also very important to make periodic inspections of existing systems. The interval between inspections should be determined by such factors as the following:

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

B.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.

B.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 may 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 three to five years. It is recommended that critical systems be inspected every one to three years depending on occupancy or the environment where the protected structure is located.

B.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.

B.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 ground terminals 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 has been no visual indication of damage to surge suppression (overvoltage) devices.
(8) The system complies in all respects with the current edition of this standard.

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

(a) 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.

(b) Ground resistance tests of the ground termination system and its individual ground 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.

(c) 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.

B.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 guides should contain sufficient information to guide the inspector through the inspection process so that he or she may 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.

B.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 ground terminal system
(5) Any variations from the requirements contained in this standard

B.2 Maintenance of Lightning Protection Systems.

B.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 maintain compliance with design requirements.

B.2.2 Maintenance Procedures.

B.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

B.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 establish a definite maintenance procedure that can be followed regularly. It is the repeatability of the procedures that enhance 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 ground terminals
(5) Inspection or 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 due to additions to, or changes in, the structure

B.2.3 Maintenance Records. Complete records should be kept of all maintenance procedures and routines and should include 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.

Appendix C Guide for Personal Safety from Lightning

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

C.1 Scope. The purpose of this appendix is to furnish a guide for personal safety from lightning. Personnel can be at risk prior to any visual or audible indication of a thunderstorm. Any time that conditions that could lead to lightning activity exist, personnel safety should be considered. Lightning warning systems are available to provide early warning of lightning activity.

C.2 Personal Conduct during Lightning Activity.

C.2.1 Do not go out-of-doors or remain out, unless it is necessary. Seek shelter in structures such as the following:

(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

C.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)

C.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, 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

C.2.4 It is especially hazardous to be riding in or on any of the following during thunderstorms while in the locations described in C.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)

C.2.5 It may not always be possible to choose a location that offers good protection from lightning, but the following rules should be observed when a location can be selected.

(a) Seek depressed areas — avoid mountaintops, hilltops, and other high places.

(b) Seek dense woods — avoid isolated trees.

(c) Seek buildings, tents, and shelters in low areas — avoid unprotected buildings.

(d) 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.

C.3 Protection for Personnel in Watercraft. Inasmuch as the basic purpose of protection against lightning is to ensure the safety of personnel, it is appropriate that the following precautions and suggestions be listed in addition to all applicable recommendations in the preceding sections.

C.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.

C.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 and especially in such a way as to bridge between these items. For example, it is undesirable that an operator be in contact with reversing gear levers and spotlight control handle at the same time.

C.3.3 No one should be in the water during a lightning storm.

Appendix D Protection for Livestock in Fields

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

D.1 General.

D.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 appendix can minimize the hazard.

D.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.

D.1.3 In pastures where shelter is available from wooded areas of considerable size, isolated trees should be removed unless protection is provided.

D.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 may be grounded. The fences that give rise to the most trouble are those constructed with posts of poorly conducting material, such as wood.

D.2 Grounding of Wire Fences.

D.2.1 Nonconductive Posts. Where it is desirable or necessary to mitigate the danger from wire fences constructed with posts of nonconducting material, D.2.2 and D.2.3 should be applied.

D.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 of the wires of the fence. Grounding can also be achieved by driving a length of not less than $^1/_2$ in. (12.7 mm) 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 150 ft (46 m). If the ground is normally damp, the metal posts may be placed up to about 300 ft (92 m) apart.

D.2.3 Depth of Grounds. Pipes should be extended into the ground at least 2 ft (0.6 m).

D.3 Breaking Continuity of Fence.

D.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 500 ft (150 m). 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 2 in. × 2 in. × 24 in. (50 mm × 50 mm × 600 mm), or their equivalent as far as insulating properties and mechanical strength are concerned.

D.3.2 In areas where herds can congregate along fences, the continuity should be broken at more frequent intervals than described in D.3.1.

Appendix E Protection for Picnic Grounds, Playgrounds, Ball Parks, and Other Open Places

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

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

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

(1) Step potential
(2) Touch potential
(3) Sideflash to personnel

Lighting protection systems for open shelters should conform to the requirements of Chapter 4 with the following guidance.

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

(a) 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.

(b) Wood floor, or other essentially insulating flooring materials should also have a grid installed as described in E.1.1.3.

(c) Earth-floored shelters should also have a grid installed as described in E.1.1.3.

E.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.

(a) 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.

(b) Shielding down conductors to at least 8 ft (2.4 m) 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.

(c) Bonding structural steel to the ground terminal.

E.1.1.3 Grounding. Grounding terminations should be installed as specified in Chapter 3 with the following additional guidance.

(a) For existing concrete floor, a ground ring should be installed. As an additional precaution, radial grounding should be installed. As an additional precaution, radial grounding is recommended at points around the periphery.

(b) The grounding grid should be constructed of main-size interconnected copper conductors at no greater than 3.3 ft (1 m) spacing between conductors. The periphery of the grid should be interconnected. Burial of the grid should be no less than 6 inches (153 mm) and no greater than 18 inches (459 mm).

(c) The grid perimeter should be connected to appropriate ground terminals with radial grounding extensions recommended.

E.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 20 ft (6.1 m) above the ground level. Down conductors should be connected to the overhead wires with ground terminals. Down conductors should be shielded with material resistant to impact and climate conditions to at least an 8-ft (2.4-m) height. The wires should be not less than No. 4 AWG (21 mm^2) 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 may 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 6.3.3.1(a) for an example.]*

E.2 Ball Parks and Racetracks.

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

E.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 E.1.2.

E.3 Beaches. Beaches should be provided with shelters as described in E.1.1.

E.4 Piers.

E.4.1 Covered Piers. Covered piers are included within the scope of this standard.

E.4.2 Open Piers. Open piers should be provided with masts and overhead ground wires as described in E.1.2.

Appendix F Protection for Trees

This appendix 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 10 ft (3 m) 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 the tree's particular value to the owner. Figure F.1 illustrates such protection.

F.2 Methods and Materials.

F.2.1 Conductors. Conductors should conform to the requirements of Chapter 3.

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 3 ft (0.9 m) 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.

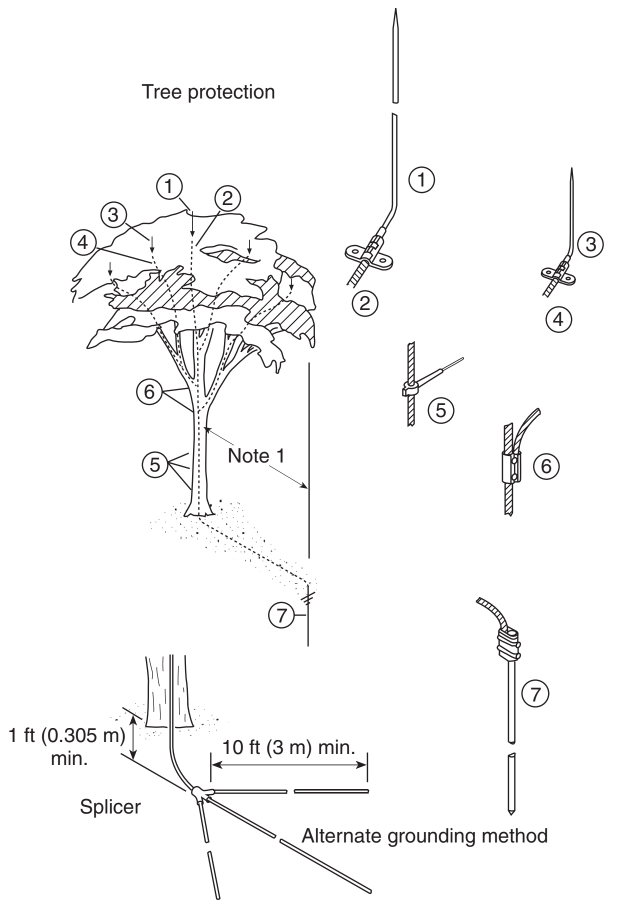
F.2.4 Attachment of Conductors. Conductors should be attached to the tree securely in such a way as to allow for swaying in the wind and growth without danger of breakage.

F.2.5 Ground Terminals. Ground terminals for conductors should be in accordance with the following:

(1) Be connected to all conductors that descend the trunk of the tree, extend three or more radial conductors in trenches 1 ft (0.3 m) deep, and be spaced at equal intervals about the base to a distance of not less than 10 ft (3 m)
(2) Have the radial conductors extended to the branch line not less than 25 ft (7.6 m)

(3) Have the out ends connected to the radial conductors with a conductor that encircles the tree at a depth of not less than 1 ft (0.3 m)
(4) Be bonded to an underground metallic water pipe where available within 25 ft (7.6 m) of the branch line

FIGURE F.1 Protection for trees.



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

Note 1: Locate ground approximately at branch line to avoid root damage.
Note 2: Install cable loosely to allow for tree growth.
Note 3: Air terminal tip configurations can be blunt or sharp.

Appendix G Protection for Parked Aircraft

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

G.1 General Principles.

G.1.1 For the purposes of this appendix, aircraft includes airplanes, helicopters, and lighter-than-air craft. Aircraft can best be protected by being placed inside a properly 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.

G.1.2 All metal airplanes parked outside hangars should be grounded. This grounding can be achieved by the use of adequately grounded metal tie-down cables or the equivalent. 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 3.

G.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.

G.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 personnel injuries were the result of lightning-induced static discharge.

G.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 personnel. 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.

G.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.

G.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.

Appendix H Lightning Risk Assessment

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

H.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.

H.1.1 In most cases, the need for lightning protection is obvious.

Examples are:

(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

H.1.2 Some common types of consequences of lightning strokes to several types of common structures are listed in Table H.1.2.

H.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 times the flash density for the area that the structure is located.

H.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

H.1.5 Lightning risk for a structure is the product of the lightning strike frequency and the consequence of the strike to the structure.

H.2 Lightning Flash Density (N_g). The yearly number of flashes to ground per km^2, lightning flash density is found in Figure H.2.

H.3 Lightning Strike Frequency (N_d). The yearly lightning strike frequency (N_d) to a structure is determined by the following equation.

$$N_d = (N_g)(A_e)(C_1)$$

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 in km^2

C_1 = the environmental coefficient

H.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.

H.4.1 The equivalent collective area A_e of a structure is calculated in accordance with H.4.2(a) through H.4.2(c).

H.4.2 The equivalent collective area of a structure is the area obtained by extending a line with a slope of 1 to 3 from the top of the structure to ground completely around the structure. The total included area is the equivalent collective area (ECA). See Figures H.4.2(a), H.4.2(b), and H.4.2(c) for examples of calculating the ECA.

Table H.1.2 Damage by Occupancy Use

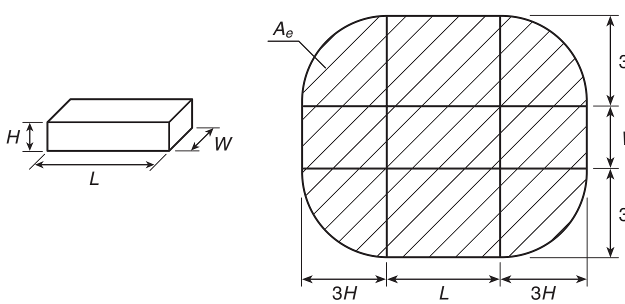
Structure Type	Lightning Consequence
Private homes	Perforation of electrical installations; fire and equipment damage limited to objects close to the lightning strike point or path
Farms	Risk of fire and dangerous sparks Risk consequent to power failure: loss of ventilation for livestock and food distribution Risk of step voltage consequence
Theaters, schools, large retail stores, sports areas	Risk of panic and fire, alarm system and power failures, loss of life
Banks, insurance companies, businesses, hospitals and elderly care	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

FIGURE H.2 1989–1998 average U.S. lightning flash density in flashes/km^2/year. (Courtesy Global Atmospherics, Inc.)

flashes/km²/year

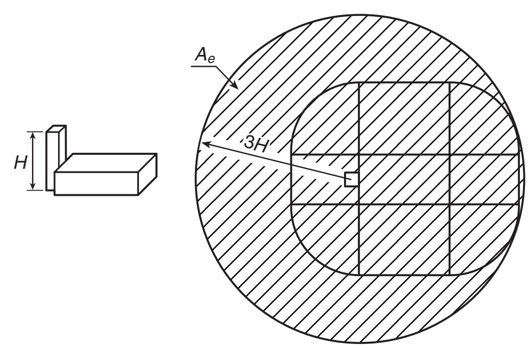
Lightning data provided by the U.S. National Lightning Detection Network™
(Measured lightning flash density corrected for NLDN detection efficiency)

FIGURE H.4.2(a) Calculation of the equivalent collective area for a rectangular structure.



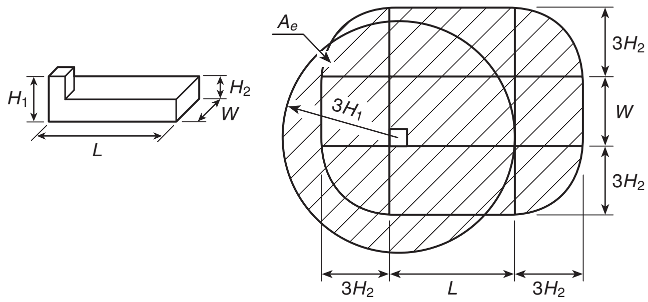
For a rectangular structure, $A_e = LW + 6H(L + W) + \pi 9H^2$.

FIGURE H.4.2(b) Calculation of the equivalent collective area for a structure where a prominent part encompasses all portions of the lower part of the structure.



Note: For a structure where a prominent part encompasses all portions of the lower part, $A_e = \pi 9H^2$

FIGURE H.4.2(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.



H.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 H.4.3.

Table H.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 3*H*	0.25
Structure surrounded by smaller structures within a distance of 3*H*	0.5
Isolated structure, no other structures located within a distance of 3*H*	1
Isolated structure on a hilltop	2

H.4.4 Where the equivalent collective area of a structure totally covers another structure, that structure is disregarded.

H.4.5 When the collective areas of several structures are overlapped, the corresponding common collection area is considered as a single collection area.

H.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 formula

$$N_c = \frac{1.5 \times 10^{-3}}{C}$$

where $C = (C_2)(C_3)(C_4)(C_5)$.

The values for *C* are obtained from Tables H.5(a) through H.5(d); 1.5×10^{-3} is an amount selected to represent the acceptable frequency of property losses.

Table H.5(a) Determination of Structural Coefficient C_2

C_2 — Structural Coefficients			
	Roof		
Structure	Metal	Nonmetallic	Flammable
Metal	0.5	1.0	2.0
Nonmetallic	1.0	1.0	2.5
Flammable	2.0	2.5	3.0

Table H.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 H.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 H.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

H.6 Selection of the Protection Level.

H.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.

H.6.2 When required, an LPS should be installed per the requirements of this standard. Additionally, any statutory and regulatory requirements for the installations of an LPS will take precedence over the results of this assessment.