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NFPA 780
Lightning Protection Code
1992 Edition

NFPA

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Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

Statement on NFPA Procedures

This material has been developed under the published procedures of the National Fire Protection Association, which are designed to assure the appointment of technically competent Committees having balanced representation. While these procedures assure the highest degree of care, neither the National Fire Protection Association, its members, nor those participating in its activities accepts any liability resulting from compliance or noncompliance with the provisions given herein, for any restrictions imposed on materials or processes, or for the completeness of the text.

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NFPA 780

Lightning Protection Code

1992 Edition

This edition of NFPA 780, *Lightning Protection Code*, was prepared by the Technical Committee on Lightning Protection and acted on by the National Fire Protection Association, Inc. at its Annual Meeting held May 18-21, 1992 in New Orleans, LA. It was issued by the Standards Council on July 17, 1992, with an effective date of August 14, 1992, and supersedes all previous editions.

The 1992 edition of this document has been approved by the American National Standards Institute.

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.

Origin and Development of NFPA 780

The National Fire Protection Association 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 the NFPA, the National Bureau of Standards, and the American Institute of Electrical Engineers (now the IEEE). In 1946, the 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 the 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*, NFPA 78 will be identified as NFPA 780.

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This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time changes in the membership may have occurred.

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.

Contents

NFPA 780

Lightning Protection Code

1992 Edition

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

Information on referenced publications can be found in Appendix N.

Chapter 1 Introduction

1-1 Scope.

1-1.1 This code covers lightning protection requirements for ordinary structures, miscellaneous structures and special occupancies, heavy-duty stacks, and structures containing flammable vapors, flammable gases, or liquids that can give off flammable vapors.

1-1.2* This code does not cover lightning protection requirements for explosives manufacturing buildings and magazines or electric generating, transmission, and distribution systems. (*See Appendix L regarding information on the protection of structures housing explosive materials.*)

1-2 Purpose. The purpose of this code is 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 code 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.

Chapter 2 Terms and Definitions

2-1 General Terminology. General terms commonly used in describing lightning protection methods and devices are defined or redefined to conform to recent trends:

Lightning Protection System. This term refers to systems as described and detailed in this code. A lightning protection system is a complete system of air terminals, conductors, ground terminals, interconnecting conductors, surge suppression devices, and other connectors or fittings required to complete the system.

2-2* Definitions.

Air Terminal. An air terminal is that component of a lightning protection system that is intended to intercept lightning flashes. [*See Figure A-2-2(a).*]

Approved. Acceptable to the "authority having jurisdiction."

NOTE: 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 or 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 concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

Authority Having Jurisdiction. The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

NOTE: 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, 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 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."

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. [*See Figure A-2-2(b).*]

Cable. A conductor formed of a number of wires stranded together. [*See Figure A-2-2(c) and Tables 3-4 and 3-5.*]

Chimney. A smoke or vent stack having a flue with a cross-sectional area less than 500 sq in. (0.3 m^2) and a total height less than 75 ft (23 m). [*See Figure A-2-2(d).*]

Class I Materials. Lightning conductors, air terminals, ground terminals, and associated fittings required by this code for the protection of structures not exceeding 75 ft (23 m) in height. [*See Figure A-2-2(e) and Table 3-4.*]

Class II Materials. Lightning conductors, air terminals, ground terminals, and associated fittings required by this code for the protection of structures exceeding 75 ft (23 m) in height. [*See Figure A-2-2(e) and Table 3-5.*]

Combustible Liquid. A liquid having a flash point at or above 100°F (37.8°C).

Combustible liquids shall be subdivided as follows:

Class II liquids shall include those having flash points at or above 100°F (37.8°C) and below 140°F (60°C).

Class IIIA liquids shall include those having flash points at or above 140°F (60°C) and below 200°F (93°C).

Class IIIB liquids shall include those having flash points at or above 200°F (93°C).

Conductor, Bonding. A conductor intended to be used for potential equalization between grounded metal bodies and the lightning protection system.

Conductor, Main. A conductor intended to be used to carry lightning currents between air terminations and ground terminals.

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

Explosive Materials. These include explosives, blasting agents, and detonators as authorized for transportation by the Department of Transportation or the Department of Defense.

Fastener. An attachment to secure the conductor to the structure.

Flame Protection. Self-closing gage 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.

Flammable Air-Vapor Mixtures. When flammable vapors are mixed with air in certain proportions, the mixture will burn rapidly when ignited. The combustion range for ordinary petroleum products, such as gasoline, is from about 1½ to 7½ percent of vapor by volume, the remainder being air.

Flammable Liquid. A liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 psia (275 kPa) at 100°F (37.8°C) shall be known as a Class I liquid.

Class I liquids shall be subdivided as follows:

Class IA shall include those having flash points below 73°F (22.8°C) and having a boiling point below 100°F (37.8°C).

Class IB shall include those having flash points below 73°F (22.8°C) and having a boiling point at or above 100°F (37.8°C).

Class IC shall include those having flash points at or above 73°F (22.8°C) and below 100°F (37.8°C).

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

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

Gastight. Structures so constructed that gas or air can neither enter nor leave the structure except through vents or piping provided for the purpose.

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. [*See Figure A-2-2(f).*]

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

High-Rise Building. For the purposes of this code a high-rise building is a structure exceeding 75 ft (23 m) in height.

Labeled. Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization 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.

Listed. Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which 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.

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

Metal-clad Structure. A structure with sides or roof or both covered with metal.

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

Shall. Indicates a mandatory requirement.

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

Sideflash. An electrical spark, caused by differences of potential, occurring between conductive metal bodies or between such metal bodies and a component of the lightning protection system or ground. [*See Figure A-2-2(g).*]

Spark Gap. As used in this code, the term spark gap means any short air space between two conductors electrically insulated from or remotely electrically connected to each other.

Stack, Heavy-duty. A smoke or vent stack is classified as heavy-duty if the cross-sectional area of the flue is greater than 500 sq in. (0.3 m^2) or the height is greater than 75 ft (23 m).

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

Surge Arrester. A protective device for limiting surge voltages by discharging or bypassing surge current. It also prevents continued flow of follow current while remaining capable of repeating these functions.

Vapor Openings. Openings through a tank shell or roof above the surface of the stored liquid. Such openings may be provided for tank breathing, tank gaging, fire fighting, or other operating purposes.

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

2-3 Metric Units of Measurement. Metric units of measurement in this code 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 code is followed by an equivalent value in other units, the first stated is to be regarded as the requirement. A given equivalent value may be approximate.

Chapter 3 Protection for Ordinary Structures

3-1 General. An ordinary structure is one that is used for ordinary purposes whether commercial, industrial, farm, institutional, or residential. Ordinary structures not exceeding 75 ft (23 m) in height shall be protected with Class I materials as shown in Table 3-4. Ordinary structures greater than 75 ft (23 m) in height shall be protected with Class II materials as shown in Table 3-5.

3-1.1 Roof Types and Pitch. For the purpose of this code, roof types and pitches are as shown in Figures 3-1.1(a) and 3-1.1(b).

3-2 Materials. The materials of which protection systems are made shall be resistant to corrosion or shall be acceptably protected against corrosion. No combination of materials shall be used that forms an electrolytic couple of such nature that in the presence of moisture corrosion is accelerated. One or more of the following materials shall be used:

(a) *Copper.* Where copper is used it shall be of the grade ordinarily required for commercial electrical work, generally designated as being of 95 percent conductivity when annealed.

(b) *Copper Alloys.* Where alloys of copper are used they shall be substantially as resistant to corrosion as copper under similar conditions.

(c) *Aluminum.* Where aluminum is used, care shall be taken not to use it in contact with the earth or elsewhere where it will rapidly deteriorate. Conductors shall be of electrical grade aluminum.

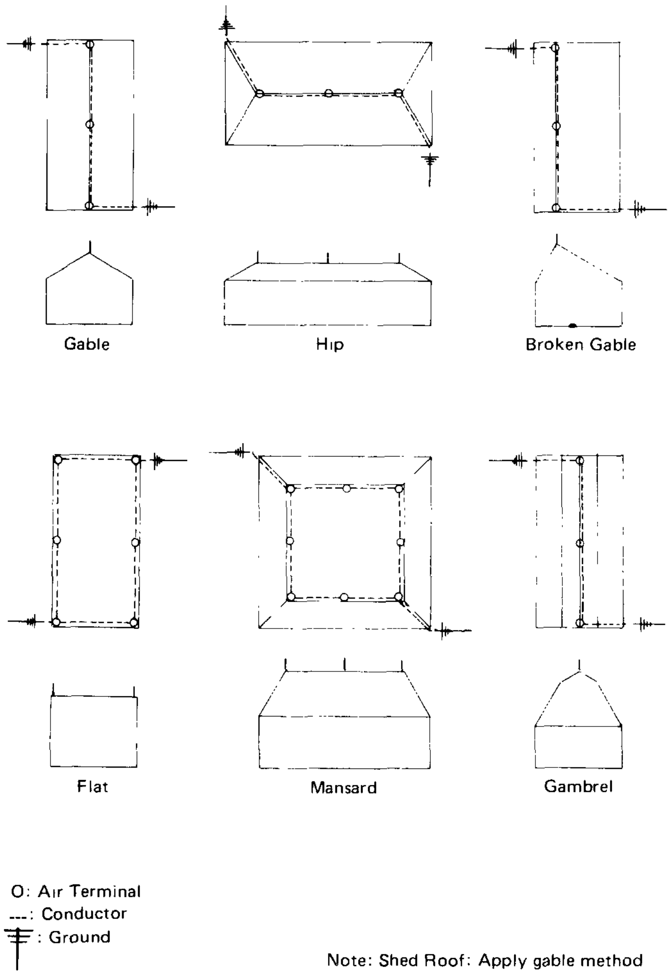


Figure 3-1.1(a) Roof types: protection methods (drawings are top and end views of each roof type).

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

(e) Aluminum lightning protection materials shall not be installed on copper surfaces.

3-3 Form and Size. Air terminals shall be made of solid or tubular rods. Conductors shall be in the form of multiple strand cables, single wires or rods, or flat strips, sized as shown in Tables 3-4 and 3-5. Ground terminals shall be made of rods, plates, or stranded cables.

3-4 Materials, Class I. Table 3-4 gives minimum sizes and weights for air terminals and conductors for use on ordinary buildings and structures not exceeding 75 ft (23 m) in height.

3-5 Materials, Class II. Table 3-5 gives minimum sizes and weights for air terminals and conductors for use on ordinary buildings and structures exceeding 75 ft (23 m) in height. If part of a structure is over 75 ft (23 m) in height (as a steeple), and the remaining portion is less than 75 ft (23 m) in height, the requirements for Class II air terminals and conductors shall apply only to that portion over

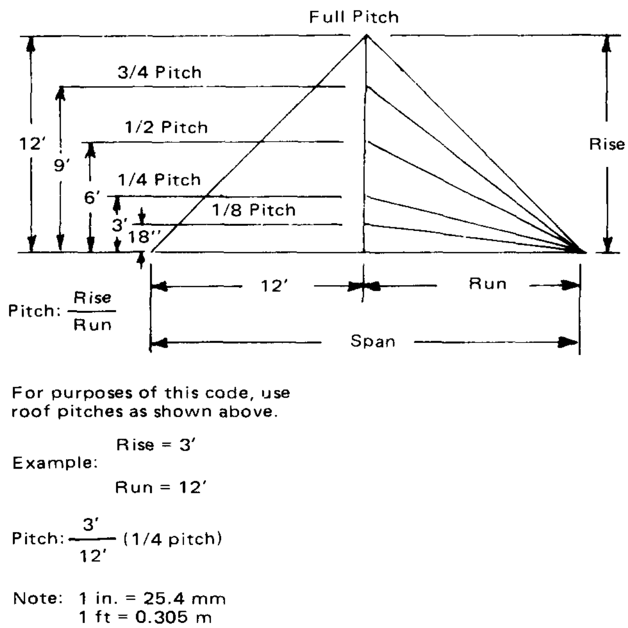


Figure 3-1.1(b) Roof pitch.

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.

3-6 Corrosion Protection. Precautions shall be taken to provide the necessary protection against any tendency towards deterioration of any lightning protection component 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.

3-7 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. If metal pipe or tubing is used around the conductor, the conductor shall be electrically connected to the pipe or tubing at both ends.

3-8 Use of Aluminum. Aluminum systems shall be installed in accordance with other applicable sections and with the following:

(a) Aluminum lightning protection equipment shall not be installed on copper roofing materials or other copper surfaces or where exposed to the runoff from copper surfaces.

(b) 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.

(c) 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.

(d) 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.

3-9 Air Terminals. Air terminals shall be provided for all parts of a structure that are likely to be damaged by direct lightning flashes. 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 only require connection to the lightning protection system. Such connections shall provide a two-way path to ground as is required for air terminals. Air terminals shall not be required for those parts of a structure located within a zone of protection.

Table 3-4 Class I Material Requirements

Type of Conductor		Copper Standard	Copper Metric	Aluminum Standard	Aluminum Metric
Air Terminal, Solid	Min. Diameter	3/8 in.	9.5 mm	1/2 in.	12.7 mm
Air Terminal, Tubular	Min. Diameter	5/8 in.	15.9 mm	5/8 in.	15.9 mm
	Min. Wall Thickness	0.033 in.	0.8 mm	0.064 in.	1.6 mm
Main Conductor, Cable	Min. 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)	Min. 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 3-5 Class II Material Requirements

Type of Conductor		Copper Standard	Copper Metric	Aluminum Standard	Aluminum Metric
Air Terminal, Solid	Min. Diameter	½ in.	12.7 mm	⅝ in.	15.9 mm
Main Conductor, Cable	Min. Size ea. Strand Wgt. per Length Cross Sect. Area	15 AWG 375 lb/1000 ft 115,000 CM	 558 g/m 58 mm^2	13 AWG 190 lb/1000 ft 192,000 CM	 283 g/m 97 mm^2
Bonding Conductor, Cable (solid or stranded)	Min. Size ea. Strand Cross Sect. Area	17 AWG 26,240 CM		14 AWG 41,100 CM	
Bonding Conductor, Solid Strip	Thickness Width	0.051 in. ½ in.	1.30 mm 12.7 mm	0.064 in. ½ in.	1.63 mm 12.7 mm

3-9.1 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 except as permitted by Section 3-11. (*See Figure 3-9.1.*)

3-9.2 Support. Air terminals shall be secured against overturning either by attachment to the object to be protected or by means of braces that shall be permanently and rigidly attached to the building. An air terminal exceeding 24 in. (600 mm) in height shall be supported at a point not less than one-half its height.

3-9.3 Ornaments. An ornament or decoration on a free-standing, unbraced air terminal shall not present, in any plane, a wind-resistance area in excess of 20 sq in. (0.01 m^2). This permits the use of an ornamental ball 5 in. (127 mm) in diameter.

3-10 Zones of Protection. To determine the zone of protection, the geometry of the structure shall be considered. The zone of protection is described in 3-10.1 through 3-10.3.

3-10.1 For flat or gently sloping roofs, dormers, domed roofs, and roofs with ridges, wells, chimneys, or vents, the zone of protection includes the roof and appurtenances where protected in accordance with Section 3-11.

3-10.2 For structures with multiple level roofs no more than 50 ft (15 m) in height, the zone of protection includes areas as identified in 3-10.2.1 and 3-10.2.2. The zone of protection forms a cone having an apex at the highest point of the air terminal, with walls forming approximately a 45- or 63-degree angle from the vertical.

3-10.2.1 Structures that do not exceed 25 ft (7.6 m) above earth are considered to protect lower portions of a structure located in a one-to-two zone of protection as shown in Figure 3-10.2.1.

3-10.2.2 Structures that do not exceed 50 ft (15 m) above earth are considered to protect lower portions of a structure located within a one-to-one zone of protection as shown in Figure 3-10.2.2.

3-10.3 Rolling Sphere Concept.

3-10.3.1 The zone of protection includes the space not intruded by a rolling sphere having a radius of 150 ft (46 m). When tangent to earth and resting against a lightning protection air termination, all space between the two

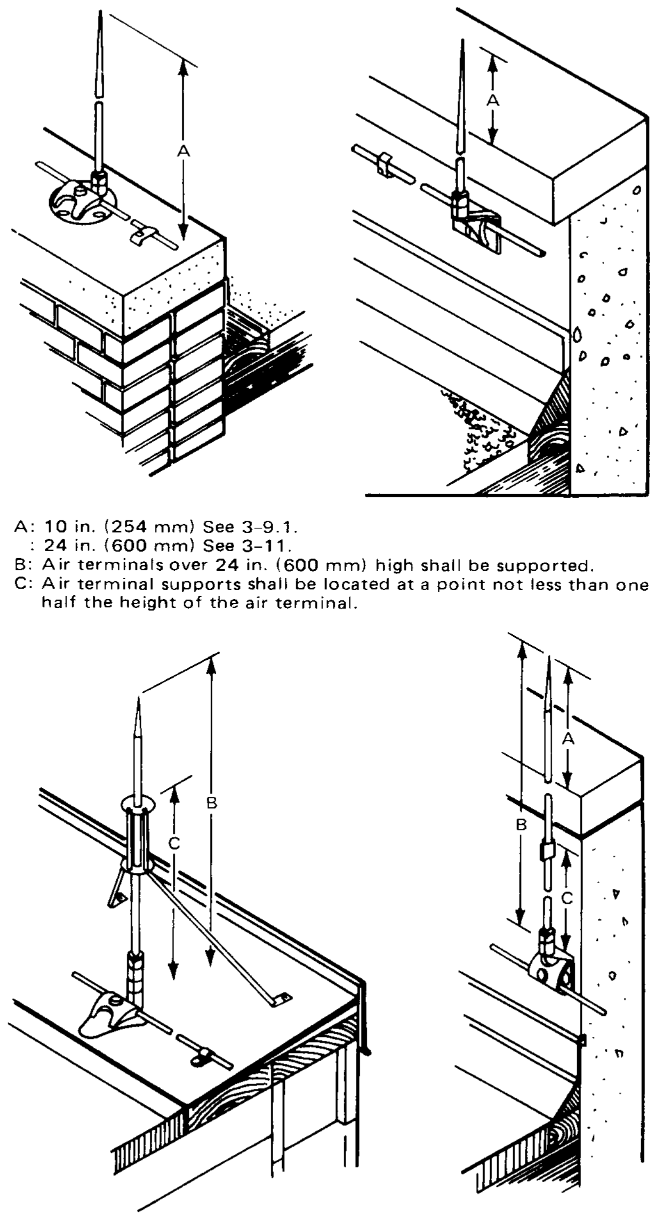


Figure 3-9.1 Air terminal height.

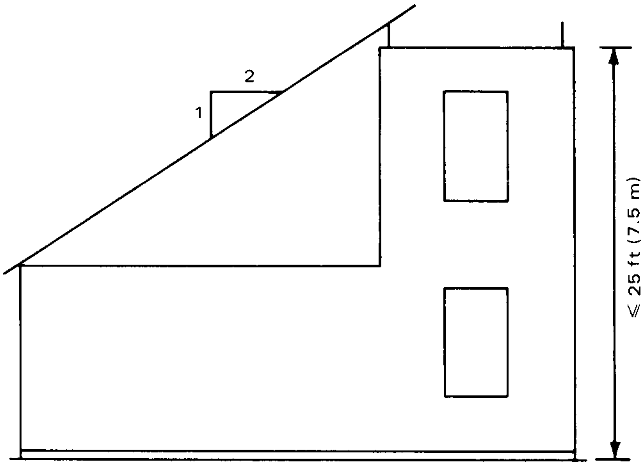


Figure 3-10.2.1 Lower roof protection for buildings 25 ft or less in height.

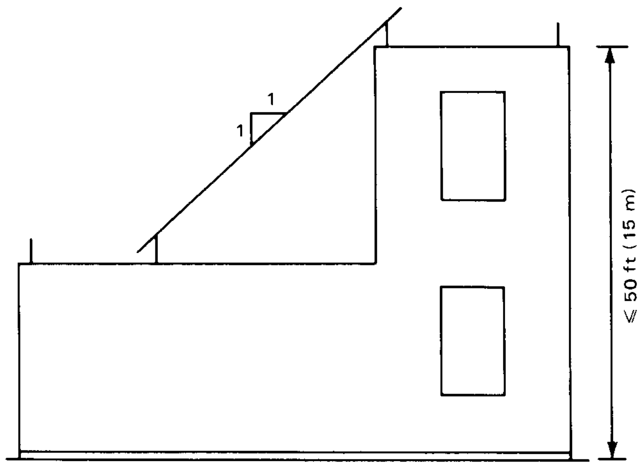


Figure 3-10.2.2 Lower roof protection for buildings 50 ft or less in height.

points of contact and under the sphere are in the zone of protection. A zone of protection is also formed when such a sphere is resting on two or more air terminals and includes the space under the sphere between those terminals as shown in Figure 3-10.3.1. All possible placements of the sphere must be considered when determining the zone of protection using the rolling sphere concept.

3-10.3.2 For structure heights exceeding 150 ft (46 m) above earth or above a lower air terminal, the zone of protection is considered to be the space between the points of contact and under the sphere, when it is resting against a vertical surface of the structure and the lower air terminal or earth. The zone of protection is 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.

3-10.3.3 Figure 3-10.3.3 provides a graphic representation of the 150 ft (46 m) geometric concept for structures of selected heights up to 150 ft (46 m). Based on the height of the air terminal on a protected structure being 25, 50, 75, 100, or 150 ft above ground, reference to the appropriate curve shows the anticipated zone of protection for

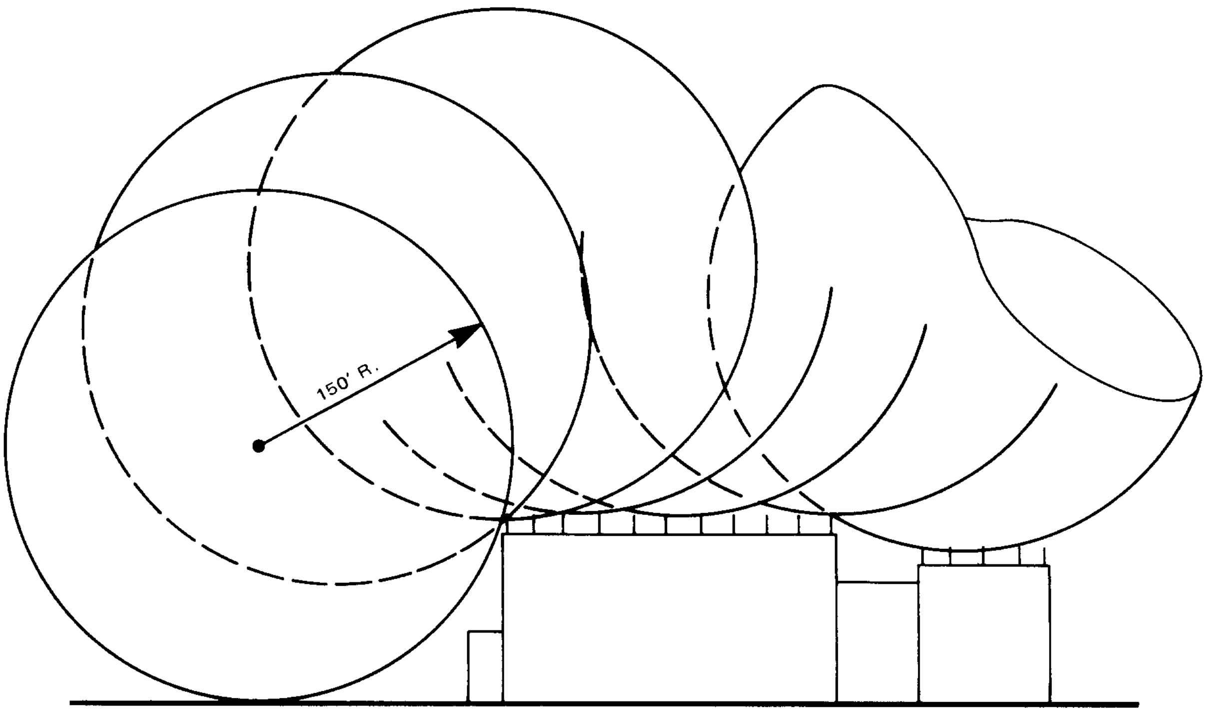


Figure 3-10.3.1.

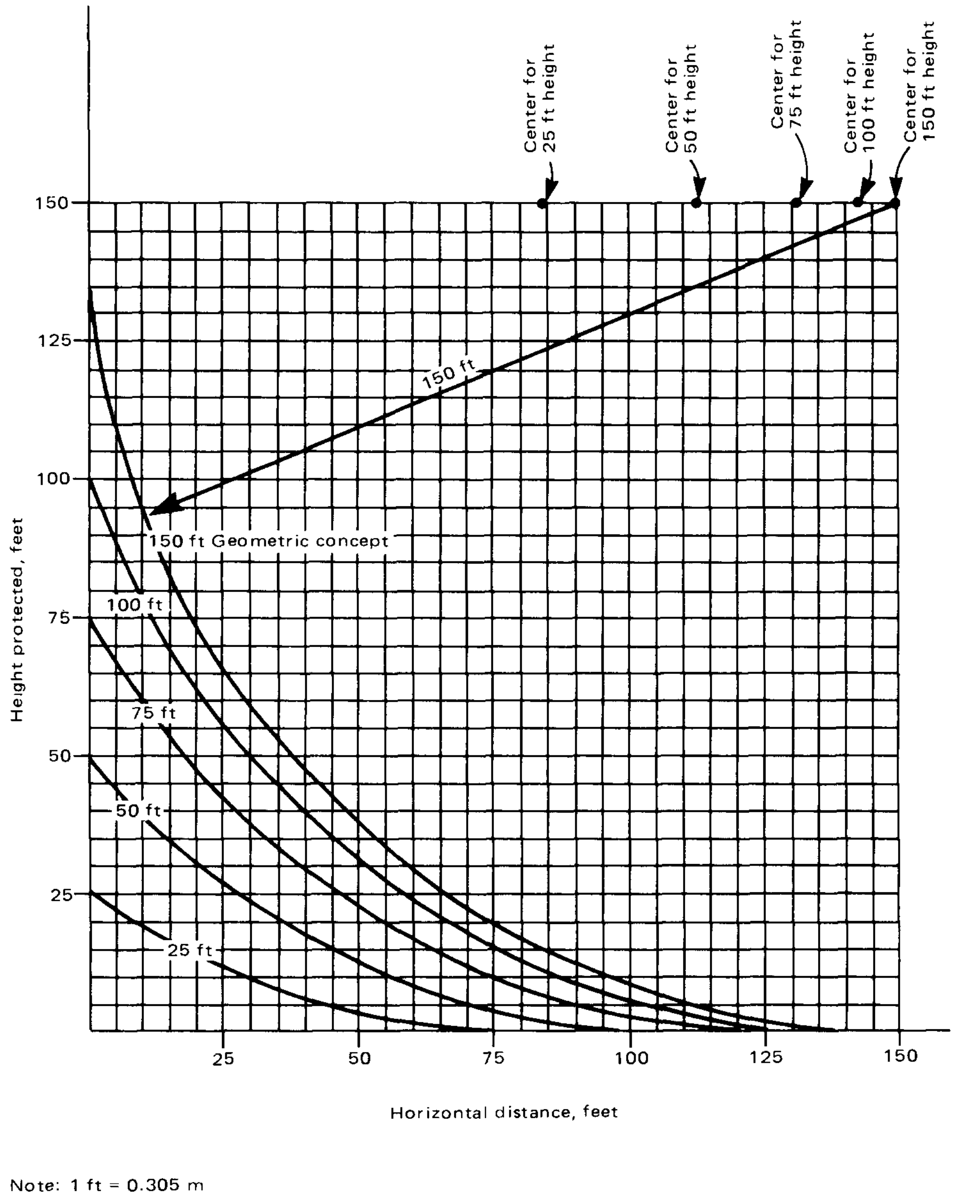


Figure 3-10.3.3 Zone of protection.

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 applies only at the horizontal plane of the "height protected."

3-10.3.4 Under the rolling sphere concept, the horizontal protected distance found geometrically by Figure 3-10.3.3 ("horizontal distance, feet") can also be calculated using the formula:

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

Where:

d = horizontal distance in feet
h_1 = height of the higher roof in feet
h_2 = height of the lower roof (top of the object) in feet.

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

For the formula to be valid, the sphere must be tangent to either 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 must be 150 ft (46 m) or less.

3-11 Air Terminals on Roofs. Air terminals 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) except that air terminals 24 in. (600 mm) or higher may be placed at intervals not exceeding 25 ft (7.6 m). Air terminals shall be placed at or within 2 ft (0.6 m) of the ends of ridges or edges and corners of roofs. (*See Figure 3-11.*)

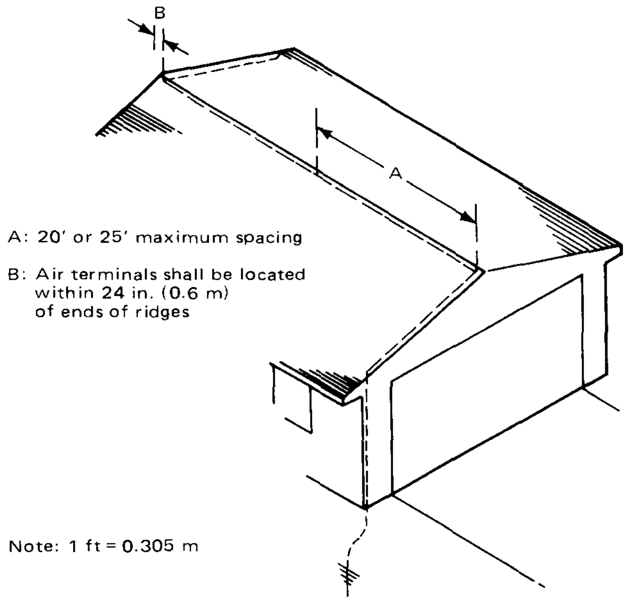


Figure 3-11 Air terminals on peaked roof.

3-11.1 Flat or Gently Sloping Roofs. Flat or gently sloping roofs that exceed 50 ft (15 m) in width or length shall have additional air terminals located at intervals not to exceed 50 ft (15 m) on the flat or gently sloping areas. Gently sloping roofs are defined as: (1) those roofs having a span of 40 ft (12 m) or less and a pitch of less than 1/8; and (2) those roofs having a span of more than 40 ft (12 m) and a pitch of less than 1/4 [*See Figures 3-11.1(a) and 3-11.1(b).*]

3-11.2* Dormers. Dormers as high or higher than the main roof shall be protected with air terminals, cable, down conductors, and grounds as normally specified. Dormers and projections below the main ridge require protection only on those areas extending outside a zone of protection.

3-11.3 Roofs with Intermediate Ridges. Air terminals shall be located along the outermost ridges of buildings that have a series of intermediate ridges at the same intervals as required by Section 3-11. Air terminals shall be located on the intermediate ridges in accordance with the requirements for the spacing of air terminals 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 Section 3-11. (*See Figure 3-11.3.*)

3-11.4 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 terminals in accordance with Section 3-11. In all cases, however, air terminals shall be located in accordance with Section 3-11 through 3-11.7. (*See Figure 3-11.4.*)

3-11.5 Open Areas in Flat Roofs. The perimeter of open areas, such as light or mechanical wells, that are located in large flat-roofed structures shall be protected if their perimeter exceeds 300 ft (92 m) provided both rectangular dimensions exceed 50 ft (15 m).

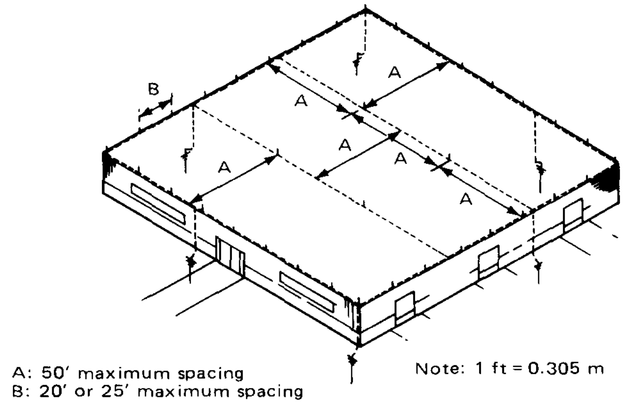


Figure 3-11.1(a) Air terminals on flat roof.

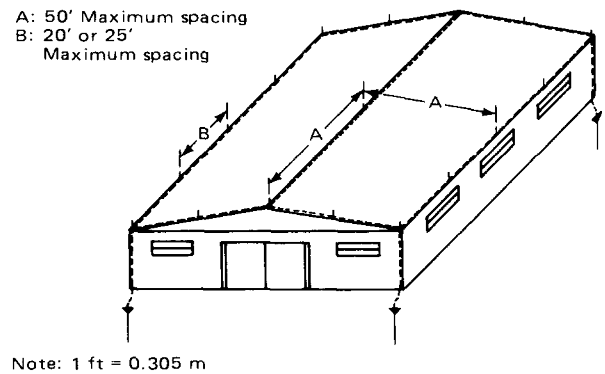


Figure 3-11.1(b) Air terminals on gently sloping roof.

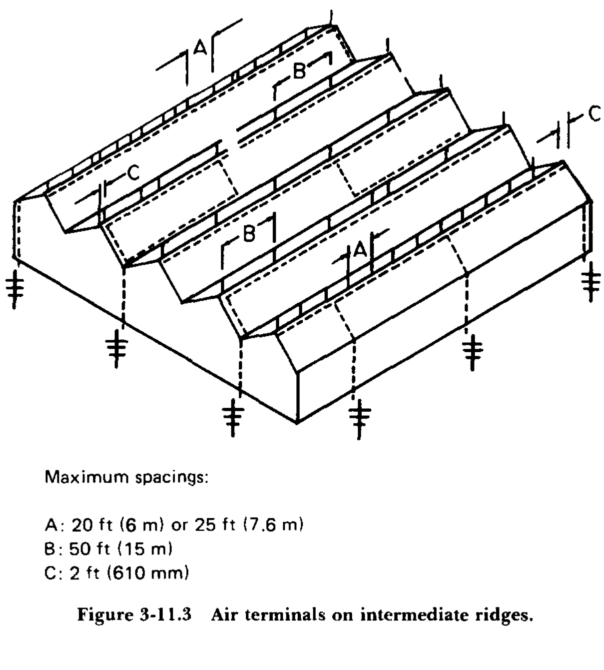


Figure 3-11.3 Air terminals on intermediate ridges.

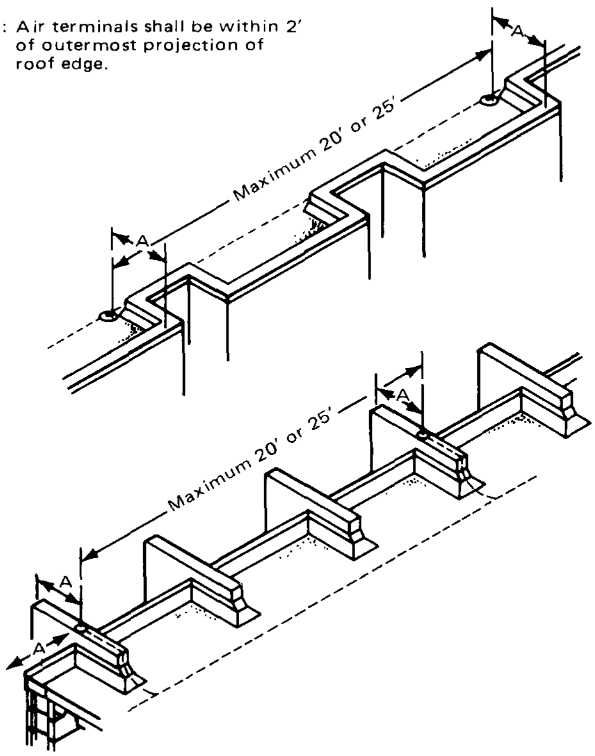


Figure 3-11.4 Flat or gently sloping roof with irregular perimeter.

3-11.6 Domed or Rounded Roofs. Air terminals shall be located as required 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 3-11.

3-11.7 Chimneys and Vents. Air terminals are required on all chimneys and vents, including metal chimneys having a metal thickness of less than $^3/_{16}$ in. (4.8 mm), where such chimneys or vents are not located within a zone of protection. If the metal thickness is $^3/_{16}$ in. (4.8 mm) or more, only a connection to the lightning protection system is required. Such a connection shall be made using a main size lightning conductor, a bonding device having a surface contact area of not less than 3 sq in. (1940 mm^2) and shall provide a two-way path to ground as is required for air terminals. Required air terminals shall be installed on chimneys and vents so that the distance from an air terminal to an outside corner or the distance perpendicular to an outside edge shall be not greater than 2 ft (0.6 m). (*See Figure 3-11.7.*) Where only one air terminal is required on a chimney or vent, at least one main sized conductor shall connect the air terminal to a main conductor at the location where the chimney or vent meets the roof surface and provides a two-way path to ground from that location in accordance with Section 3-12 and 3-12.2.

3-12 Conductors. Conductors shall interconnect all air terminals and shall form a two-way path from each air terminal horizontally, downward, or rising at a rate not exceeding 3 in. per ft (76.2 mm) to connections with ground terminals except as permitted by 3-12.1 and 3-12.2.

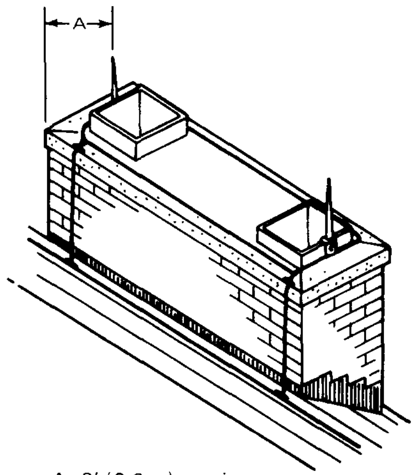


Figure 3-11.7 Air terminals on chimney.

3-12.1 One-Way Path. Air terminals on a lower roof level that are interconnected by a conductor run from a higher roof level only require one horizontal or downward path to ground provided the lower level roof conductor run does not exceed 40 ft (12 m).

3-12.2 Dead Ends. Air terminals may be "dead ended" with only one path to a main conductor on roofs below the main protected level provided the conductor run from the air terminal to a main conductor is not more than 16 ft (4.9 m) in total length and maintains a horizontal or downward coursing. (*See Figure 3-12.2.*)

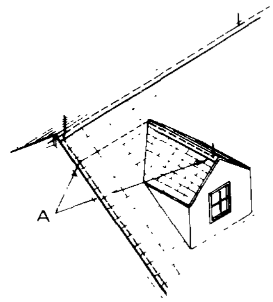


Figure 3-12.2 Dead end.

3-12.3 Substitution of Metals. Metal parts of a structure such as eave troughs, down spouts, 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.

3-12.4 "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 down lead conductor. (*See Figure 3-12.4.*)

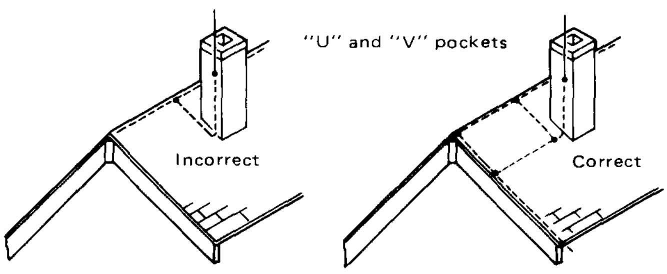


Figure 3-12.4 Pockets.

3-12.5 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). (*See Figure 3-12.5.*)

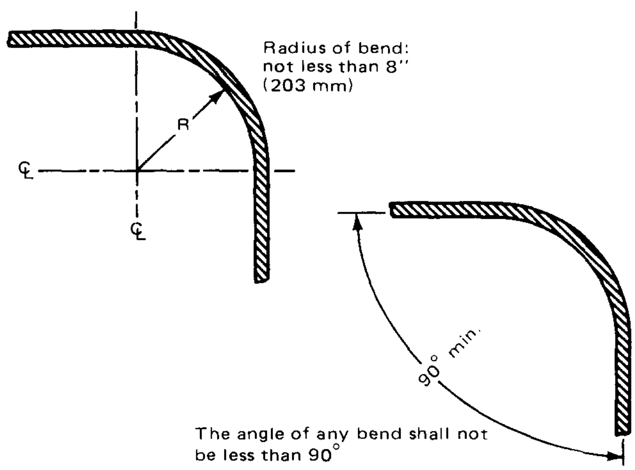


Figure 3-12.5 Conductor bends.

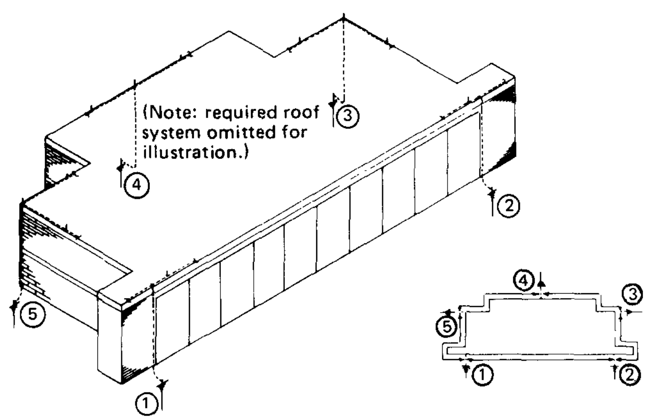
3-12.6 Conductor Supports. Conductors may be coursed through air without support for a distance of 3 ft (0.9 m) or less. Conductors that must be coursed through air for longer distances shall be provided with a positive means of support that will prevent damage or displacement of the conductor.

3-12.7 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 air terminals. Conductors shall be coursed through or around obstructions (such as cupolas, ventilators, etc.) in a horizontal plane with the main conductor.

3-12.8 Cross-Run Conductors. Cross-run conductors (main conductors) are required to interconnect the air terminals on flat or gently sloping roofs that exceed 50 ft (15 m) in width. For example, roofs from 50 ft (15 m) to 100 ft (30 m) in width require one cross run, roofs 100 ft (30 m) to 150 ft (46 m) in width require two cross runs, etc. Cross-run conductors shall be connected to the main perimeter cable at intervals not exceeding 150 ft (46 m).

3-12.9 Down Conductors. Down conductors shall be as widely separated as practicable. Their location depends on such considerations as: the placement of air terminals, the most direct coursing of conductors, earth conditions, security against displacement, the location of large metallic bodies, and the location of underground metallic piping systems.

3-12.10 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 may require additional down conductors in order to provide a two-way path from each air terminal. When determining the perimeter of a structure, measure only the perimeter of the roof area requiring protection. Lower roofs or projections that are located within a zone of protection shall be excluded. (*See Figure 3-12.10.*)



Spacings:

1–2–130′	(40 m)
2–3–85′	(26 m)
3–4–85′	(26 m)
4–5–85′	(26 m)
5–1–85′	(26 m)

Total perimeter: 470′ (144 m)
Required grounds: 5

Figure 3-12.10 Quantity of down conductors.

3-12.11 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. If the conductor is run through ferrous metal tubing, the conductor shall be bonded to the top and bottom of the tubing. The down conductor shall be protected for a minimum distance of 6 ft (1.8 m) above grade level.

3-12.12 Down Conductor 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 its entire length below grade.

3-12.13 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 its 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. The use of PVC conduit or other nonmetallic chase does not negate the need for these interconnections unless sufficient separation is provided to satisfy the bonding requirements of Sections 3-22, 3-23, and 3-24. Where such is not the case, provisions shall be made to assure the required interconnection of these parallel vertical paths.

3-13 Conductor Fasteners. Conductors shall be securely fastened to the structure upon which they are placed, at intervals not exceeding 3 ft (1 m). The fasteners, attached by nails, screws, bolts, or adhesives as necessary, 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 forms an electrolytic couple of such nature that, in the presence of moisture, corrosion will be accelerated.

3-14 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. When the anchors are installed the fit shall be tight against moisture thus reducing the possibility of damage due to freezing.

3-15 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 under bolt tension. Conductor connections shall be of the bolted, welded, high compression, or crimp-type except that crimp-type connections shall not be used with Class II conductors.

3-16 Ground Terminals. Each down conductor shall terminate at a ground terminal. The design, size, depth, and number of ground terminals used shall comply with 3-16.1 through 3-16.4.

3-16.1 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 copper-clad steel, solid copper, hot dipped galvanized steel, or stainless steel. Rods shall be free of paint or other nonconductive coatings.

NOTE: 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 when this type of rod is used.

Electrical system (grounding electrodes) shall not be used in lieu of lightning ground rods. This provision shall not prohibit the required bonding together of grounding electrodes of different systems.

NOTE: For further information, see NFPA 70, *National Electrical Code*, which contains detailed information on the grounding of electrical systems.

3-16.1.1 Ground Rod Terminations. The down conductor shall be attached to the ground rod by welding (including exothermic), brazing, or clamping. Clamps shall be suitable for direct soil burial.

3-16.1.2 Deep Moist Clay Soil. The lightning conductors or 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. (*See Figure 3-16.1.2.*)

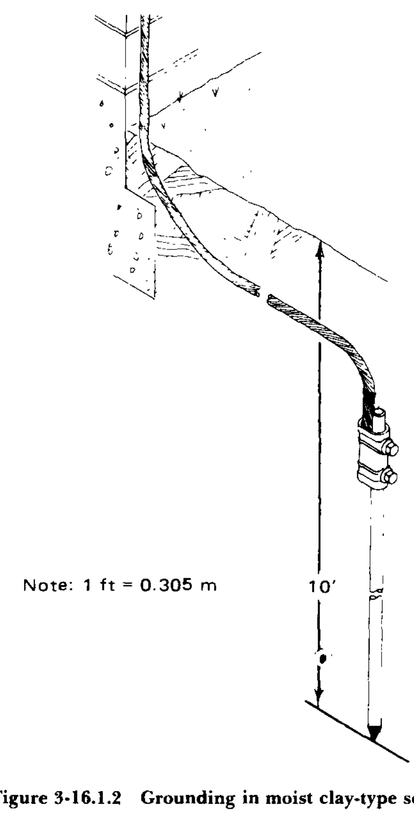


Figure 3-16.1.2 Grounding in moist clay-type soil.

3-16.1.3 Sandy or Gravelly Soil. In sand or gravel, two or more ground rods, at not less than 10 ft (3 m) spacings, shall be driven vertically to a minimum depth of 10 ft (3 m) below grade. (*See Figure 3-16.1.3.*)

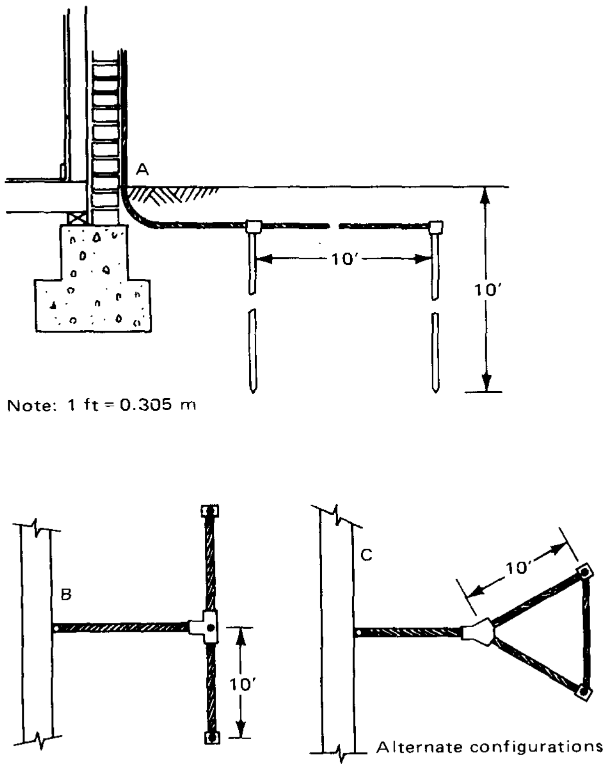


Figure 3-16.1.3 Grounding in sandy or gravelly soils.

3-16.1.4 Shallow Topsoil. Where bedrock is near the surface, the conductor shall be laid in trenches extending away from the building at each down conductor. These trenches shall be not less than 12 ft (3.7 m) in length and from 1 to 2 ft (0.3 to 0.6 m) in depth in clay soil. In sandy or gravelly soil, the trench shall be not less than 24 ft (7.5 m) in length and 2 ft (0.6 m) in depth. If these methods should prove impractical, an acceptable alternative would be to carry the lightning protection cable in trenches of a depth specified above or, if this is impossible, directly on bedrock a minimum distance of 2 ft (0.6 m) from the foundation or exterior footing and 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 sq ft (0.18 m^2).

3-16.1.5 Soil Less than 1 ft (0.3 m) Deep. If the soil is less than 1 ft (0.3 m) in depth, down conductors shall be connected to a loop conductor installed in a trench or in rock crevices around the structure. The loop conductor shall be not smaller than the equivalent of a main size lightning conductor. Optional plate electrodes may be attached to the loop conductor to enhance its earth contact where the measured grounding resistance is found to be too high to provide effective grounding. (*See Figure 3-16.1.5.*)

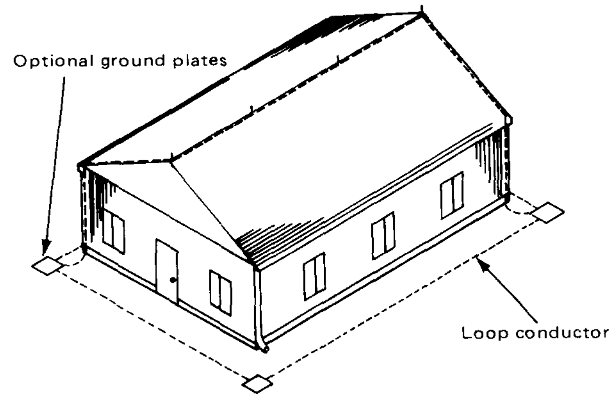


Figure 3-16.1.5 Grounding in soil less than 1 ft (0.3 m) deep.

3-16.2 Concrete Encased Electrodes. Concrete encased electrodes shall only be used 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:

(a) Not less than 20 ft (6.1 m) of No. 2 AWG bare copper conductor.

(b) An electrode consisting of at least 20 ft (6.1 m) of one or more steel reinforcing bars or rods not less than ½ in. (12.7 mm) in diameter that have been effectively bonded together by either welding or overlapping 20 diameters and securely wire-tying.

3-16.2.1 Concrete Encased Electrode Terminations. The down conductor(s) shall be permanently attached to the concrete encased electrode system by welding (including exothermic), brazing, or clamps.

3-16.3 Ground Ring Electrode. A ground ring electrode encircling a structure shall be in direct contact with earth at a depth of not less than 2½ ft (762 mm) or encased in a concrete footing in accordance with 3-16.2. It shall consist of not less than 20 continuous ft (6.1 m) of No. 2 AWG bare copper conductor.

3-16.3.1 Ground Ring Electrode Terminations. The down conductor(s) shall be permanently attached to the ground ring electrode by welding (including exothermic), brazing, or clamps. Clamps shall be suitable for direct burial.

3-16.4 Combinations. Combinations of the above grounding terminals are permitted.

3-17 Common Grounding. 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. Such piping systems 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, etc. 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.

3-17.1 Common Ground Bondings. If electric, telephone, or other systems are bonded to a metallic water pipe, only one connection from the lightning protection system to the water pipe system is required provided that the water pipe is electrically continuous between all systems. If it is not electrically continuous due to the use of plastic pipe sections or for 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 assured.

3-18 Concealed Systems.

3-18.1 General. Requirements covering exposed systems shall also apply to concealed systems, except conductors may 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. If a conductor is run in metal conduit, it shall be bonded to the conduit at the points where it enters and where it emerges from the conduit.

3-18.2 Masonry Chimneys. Chimney air terminals 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.

3-18.3 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 3-12.13. Roof conductors or other concealed horizontal conductor runs shall be connected to the reinforcing steel at intervals not exceeding 100 ft (30 m).

3-18.4 Ground Terminals. Ground terminals for concealed systems shall comply with Section 3-16. 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 3-16.3 and 3-16.4.

3-19 Structural Steel Systems.

3-19.1 General. The structural steel framework of a structure may be utilized as the main conductor of a lightning protection system if it is electrically continuous or is made so.

3-19.2 Air Terminals. Air terminals 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 air terminals 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).

3-19.3 Connections to Framework. Conductors shall be connected to cleaned areas of the structural steel framework by use of bonding plates having a surface contact area of not less than 8 sq in. (5200 mm^2) or by welding or brazing. 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.

3-19.4 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 with a surface contact area of not less than 8 sq in. (5200 mm^2), or by welding or brazing the ground terminal conductor directly to the column. Bonding plates shall have bolt tension cable connectors and shall be bolted, welded, or brazed securely to the column so as to maintain electrical continuity.

3-19.5 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.

3-20 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.

3-21 Surge Suppression. Devices suitable for protection of the structure shall be installed on electric and telephone service entrances and on radio and television antenna lead-ins.

NOTE: Electrical systems and utilization equipment within the structure may require further surge suppression. Such protection is not part of this code. Documents such as ANSI/IEEE C-62.1, NFPA 70, and UL 1449 provide additional information.

3-22 Metal Bodies. Certain metal bodies located outside or inside a structure contribute to lightning hazards because they are grounded or assist in providing a path to ground for lightning currents. Such metal bodies shall be bonded to the lightning protection system in accordance with Sections 3-22, 3-23, and 3-24. (*See Appendix K for a technical discussion of lightning-protection potential-equalization bonding.*)

3-22.1 General. In determining the necessity of bonding a metal body to a lightning protection system, the following factors shall be considered.

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

(b) 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 should a sideflash occur and therefore does not necessarily require bonding to the lightning protection system.

(c) Bonding distance requirements depend on 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).

(d) Metal bodies located in a steel-framed structure may be inherently bonded through construction and further bonding would not be required.

3-22.2 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. See Tables 3-4 and 3-5.

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 3-4 and 3-5.

3-23 Potential Equalization.

3-23.1 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 3-17.

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.

NOTE: 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 ground ring electrode as a ground loop conductor. A ground ring electrode conforming to 3-16.3 may be utilized for the ground loop conductor.

3-23.2 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.

NOTE: In the case of flat or gently sloping roofs, the roof conductors required by 3-12.7 may 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.

3-23.3 Intermediate Level Potential Equalization. Intermediate level potential equalization is accomplished by the interconnection of the lightning protection system downlead 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 are not 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 3-18.3.* The lightning protection system downlead 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 downlead conductors and other grounded media shall be interconnected with a loop conductor at intermediate levels not exceeding 60 ft (18 m).

3-24 Bonding of Metal Bodies.

3-24.1 Long, Vertical Metal Bodies.

(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 3-18.3.* 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 3-24.2 and 3-24.3, respectively.

3-24.2 Grounded Metal Bodies. This section covers the bonding of grounded metal bodies not covered in 3-24.1. 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).

NOTE: Where such bonding has been accomplished either inherently through construction or by physical contact between electrically conductive materials, no additional bonding connection is 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 distance "D" as determined by the formula:

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

Where "h" is the vertical distance between the bond being considered and the nearest lightning protection system bond.

The value of "n" is 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 and is calculated as follows:

1. Where bonding is required within 60 ft (18 m) from the top of any structure:

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.

K_m = 1.0 if the flashover is through air or 0.50 if through dense material such as concrete, brick, wood, etc.

2. Where bonding is required below a level 60 ft (18 m) from the top of a structure "n" is 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 distance "D" as determined by the formula:

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

Where "h" is 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.

The value of "n" is 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 and is 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.

K_m = 1.0 if the flashover is through air or 0.50 if through dense material such as concrete, brick, wood, etc.

3-24.3 Isolated (Nongrounded) Metallic Bodies. An isolated metallic body, such as a metal window frame in a nonconducting medium, which 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. (*See Figure 3-24.3.*)

A bonding connection is required when 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 3-24.2. Bondings shall be made between the

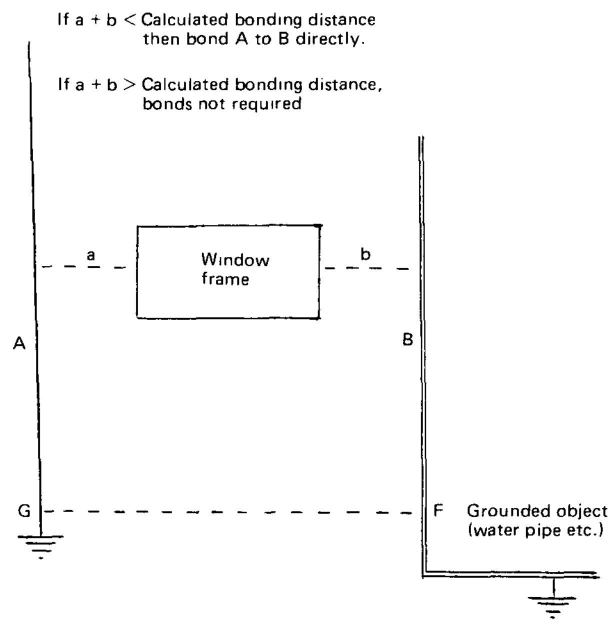


Figure 3-24.3 Effect of isolated (grounded) metallic bodies, such as window frame, in nonconductive media.

lightning protection system and the grounded metal body and need not run through or be connected to the isolated metal body.

NOTE: 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 K for a discussion of bonding and an understanding of problems often encountered.

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 require one air terminal, down conductor, and ground terminal. Electrically continuous metal structures do not require air terminals or down conductors but do require ground terminals.

4-3 Grain, Coal, and Coke Handling and Processing Structures. On wood frame elevators, provision shall be made to allow for the settling and rising of the structure as grain 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 need 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 overhead ground wire-type 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, 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 Chapter 3 or 6.

Chapter 5 Protection for Heavy-Duty Stacks

5-1 General. A smoke or vent stack is classified as heavy-duty if the cross-sectional area of the flue is greater than 500 sq in. (0.3 m^2) and the height is greater than 75 ft (23 m). (*See Figure 5-1.*)

5-2 Materials. Materials shall be Class II as shown in Table 3-5 and as described in this chapter.

5-2.1 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 include conductors, air terminals, 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 Air Terminals. Air terminals 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, air terminals 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. Stacks that have electrically continuous steel hoods covering the lining and column, and having a metal thickness of not less than $^3/_{16}$ in. (4.8 mm), shall not require air terminals. 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 sq in. (5200 mm^2) securely bolted or welded to the hood.

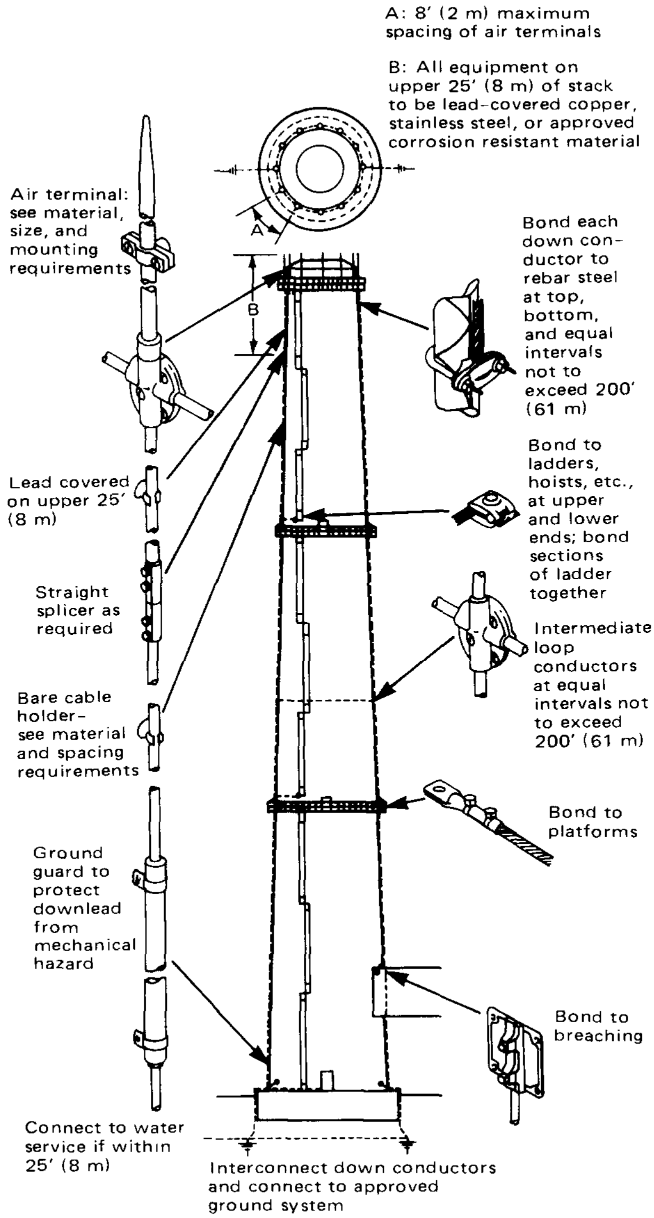


Figure 5-1 Heavy-duty stack.

5-4 Conductors. 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.

5-4.1 Down Conductors. Not less than two down conductors shall be provided. They shall be located on opposite sides of the stack and 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 shall also 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 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 connectors and splicers shall be bolt tension type and 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 3-22, 3-23, and 3-24 and as described herein.

5-8.1 Potential Equalization.

(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.

(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. These 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 3-16 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 do 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 3-22, 3-23, and 3-24, 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.

5-10.1 Metal Guy Wires and Cables. Metal guy wires and cables used to support metal stacks shall be grounded at their lower ends if anchored in concrete or to a building or other nonconductive support.

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 applies 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 in which 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 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 are inherently self-protecting. Protection of other structures may be achieved by the use of air terminals, masts, overhead ground wires, or other types of protective devices.

6-1.3 Chapters 3 through 5 of this code give requirements for the protection of buildings and miscellaneous property against lightning damage. Because of the nature of the contents of the structures considered in this chapter, extra precautions shall be taken. In these structures, 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 requires adherence to the following principles:

(a) Liquids that can give off flammable vapors shall be stored in essentially gastight structures.

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

(c) Structures and all appurtenances (e.g., gage hatches, vent valves) shall be maintained in good operating condition.

(d) Flammable air-vapor mixtures shall be prevented, to the greatest possible extent, from accumulating outside of such structures.

(e) Potential spark gaps between metallic conductors shall be avoided at points where flammable vapors may escape or accumulate.

6-3 Protective Measures.

6-3.1 Materials and Installation. Conductors, air terminals, 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. It shall be constructed of materials such as aluminum, copper, copper- or aluminum-clad steel, lead or galvanized steel, or stainless steel.

6-3.2 Sheet Steel. Sheet steel less than 3/16 in. (4.8 mm) in thickness may 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 is based on the striking distance of the lightning stroke (the distance over which final breakdown of the initial stroke to ground, or to a grounded object, occurs). Since the lightning stroke may strike any grounded object within the striking distance of the point from which final breakdown to ground occurs, the zone of protection is defined by a circular arc concave upward. [*See Figure 6-3.3.1(a).*] The radius of the arc is the striking distance, and the arc passes through the tip of the mast and is tangent to the ground. Where more than one mast is used, the arc passes through the tips of adjacent masts. [*See Figures 6-3.3.1(b) and 6-3.3.1(c).*]

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) is 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 is based on a striking distance of 100 ft (30 m) and is defined by 100-ft (30-m) radius arcs concave upward. [*See Figure 6-3.3.1(b).*] The supporting masts shall have a clearance from the protected structure as under 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 can be calculated from the formula

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

Where:

h = height of structure (or object under consideration).

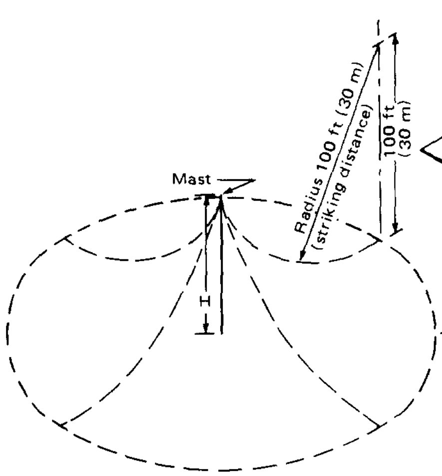


Figure 6-3.3.1(a) Single mast zone of protection.

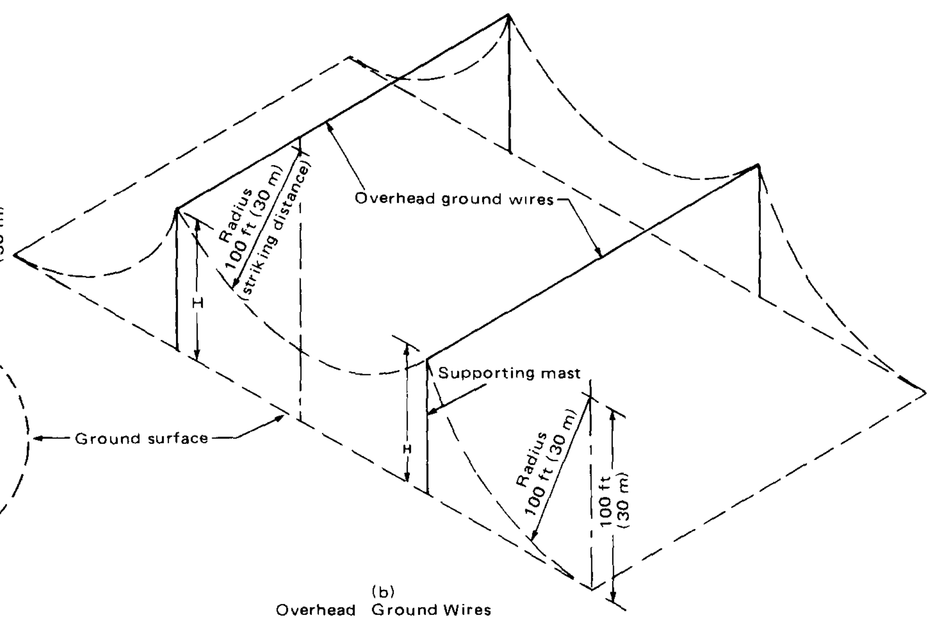
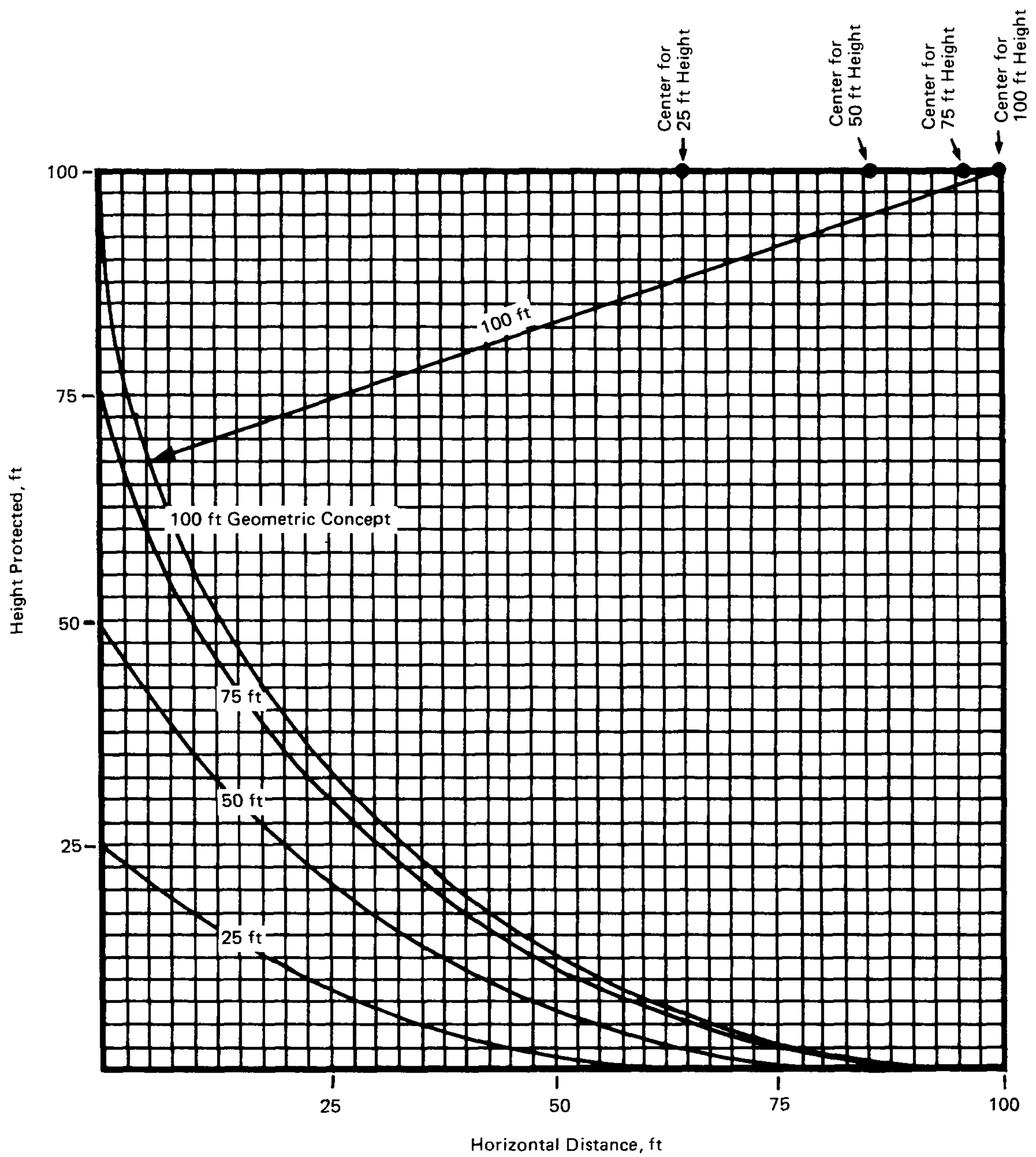


Figure 6-3.3.1(b) Overhead ground wires.



NOTE: The distance may 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 roof, ft
h_2 = height of lower roof, ft

For SI Units: 1 ft = 0.305 m

Figure 6-3.3.1(c) Zone of protection—100 ft (30 m) striking distance.

Sideflash distance from a catenary may be calculated as

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

Where: l = length of lightning protection cable between its grounded point and the point under consideration.

n = 1 where there is a single overhead conductor that exceeds 200 ft in horizontal length.

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

n = 2.25 where there are more than two down conductors spaced more than 25 ft apart within a 100-ft 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 (*see 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, may be used as the air terminal. In case of an overhead ground-wire system, the pole guy wire may 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.

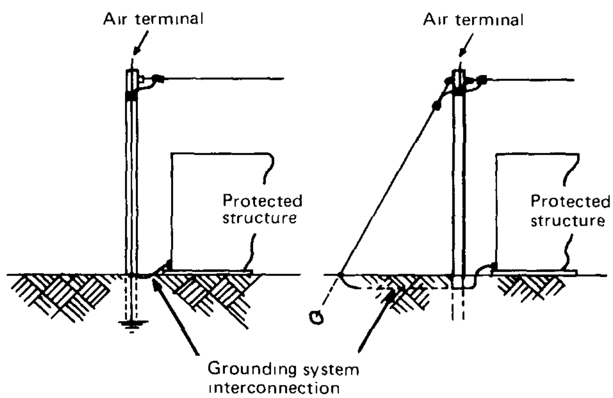


Figure 6-3.3.4 Alternate grounding method for overhead ground-wire protection.

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, used for the storage of liquids that give off flammable vapors at atmospheric pressure are considered to be protected against lightning (inherently self-protecting) if the following requirements are met:

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

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

(c) All vapor or gas openings shall be closed or provided with flame protection when the stored stock may produce a flammable air-vapor mixture under storage conditions.

(d) The roof shall have a minimum thickness of $^3/_{16}$ in. (4.8 mm).

(e) 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 lightning-caused discharges. 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 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-gage [$^1/_{64}$-in. (0.4-mm) × 2-in. (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 do 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 may contain a vapor-air mixture within the flammable range. 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 are not 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 air terminals. Such air terminals shall be bonded to each other, to the metallic sheathing, if any, and to the tank shell. Isolated metal parts shall be bonded as provided in Section 3-22. In lieu of air terminals, any of the following may 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 may cause sparks to ground. A metal tank shall be grounded by one of the following methods:

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

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

(c) By bonding the tank to ground through a minimum of two ground terminals as described in Section 3-16 at maximum 100-ft (30-m) intervals along the perimeter of the tank. This also applies 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. Earthen containers enclosing flammable vapors or liquids that can give off flammable vapors, lined or unlined, having combustible roofs 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.

Appendix A

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

A-1-1.2 Electric generating facilities whose primary purpose is to generate electric power are excluded from this code 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 may be protected against lightning by the provisions of this code.

Lightning protection systems for structures used for production of storage of explosive materials require special consideration because of the sensitivity to arc or spark ignition of the structures' contents. Appendix L provides guidance for protection of structures housing explosive materials. Other standards and handbooks that provide guidance for military applications are found in Appendix N.

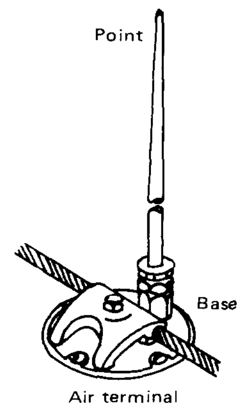


Figure A-2-2(a).

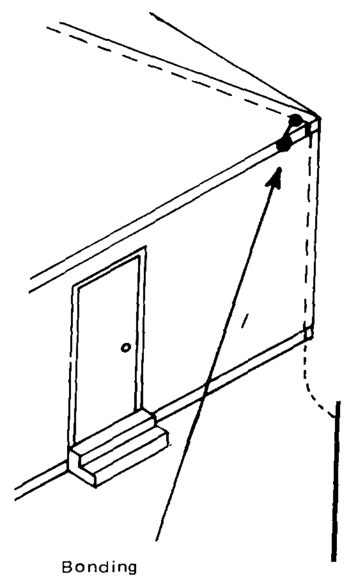


Figure A-2-2(b).

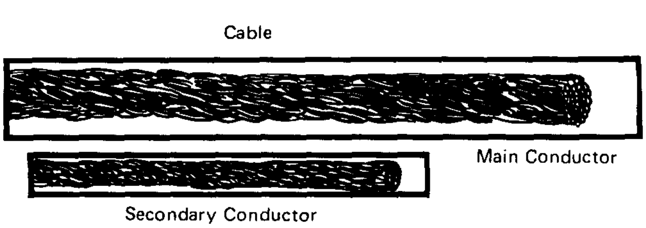


Figure A-2-2(c).

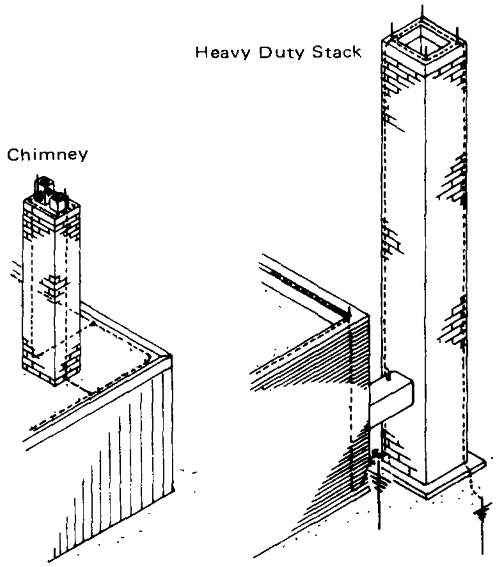


Figure A-2-2(d).

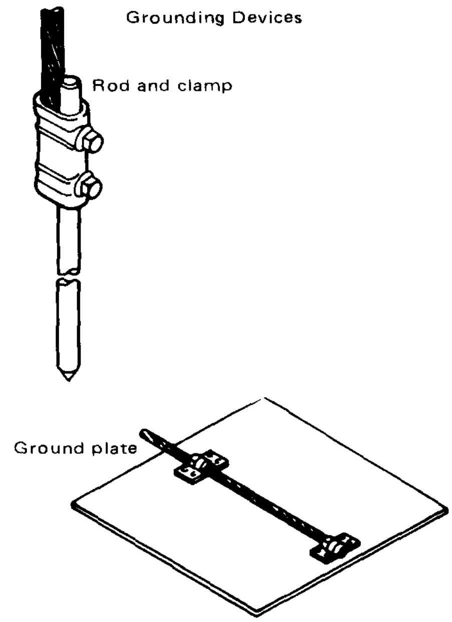


Figure A-2-2(f).

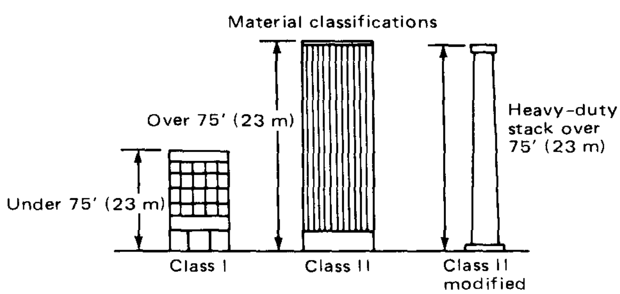


Figure A-2-2(e).

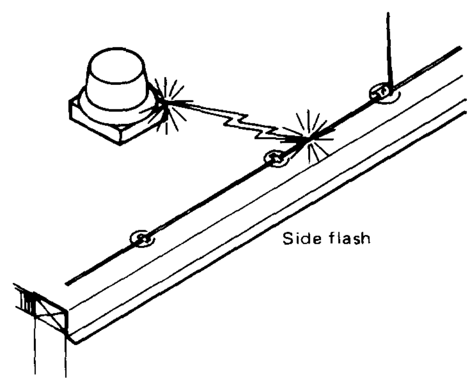


Figure A-2-2(g).

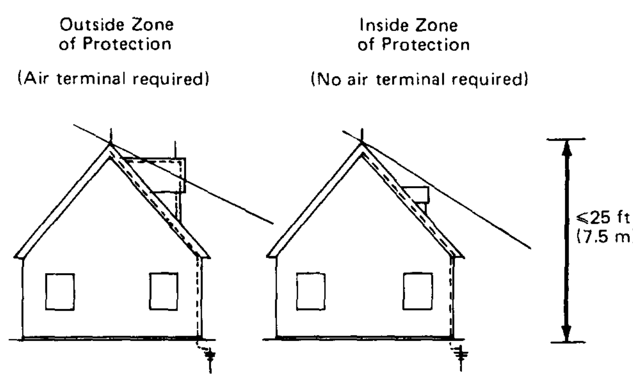


Figure A-3-11.2.

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 code for main conductors is an acceptable ground terminal and, if the stack is located within 50 ft (15.2 m) of the grid in all directions, may also serve as the bottom loop conductor required by 5-4.1.

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. Providing 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 under pressure 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 liquified natural gases or liquefied petroleum gases.

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 information 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 inspection should be determined by such factors as:

(a) Classification of structure or area protected.

(b) Level of protection afforded by the system.

(c) Immediate environment (corrosive atmospheres).

(d) Materials from which components are made.

(e) The type of surface to which the lightning protection components are attached.

B-1.1.1 In addition to the above, 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 so inspected every one to three years depending on occupancy or the environment in which 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:

(a) The system is in good repair.

(b) There are no loose connections that might result in high resistance joints.

(c) No part of the system has been weakened by corrosion or vibration.

(d) All down conductors and ground terminals are intact (non-severed).

(e) All conductors and system components are securely fastened to their mounting surfaces and are protected against accidental mechanical displacement as required.

(f) There have not been additions or alterations to the protected structure that would require additional protection.

(g) There has been no visual indication of damage to surge suppression (over voltage) devices.

(h) The system complies in all respects with the current edition of NFPA 780, *Lightning Protection Code*.

B-1.3 Complete Testing and Inspection. Such testing and inspection includes the visual inspections described above in addition to the following:

(a) Perform 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) Conduct 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) Perform 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:

(a) The general condition of air terminals, conductors, and other components.

(b) The general condition of corrosion protection measures.

(c) The security of attachment of conductors and components.

(d) Resistance measurements of various parts of the ground terminal system.

(e) Any variations from the requirements contained in this *Lightning Protection Code*.

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:

(a) Weather related degradation.

(b) Frequency of stroke damage.

(c) Protection level required.

(d) 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 may serve as a check list so that a definite maintenance procedure 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:

(a) Inspection of all conductors and system components.

(b) Tightening of all clamps and splicers.

(c) Measurement of lightning protection system resistance.

(d) Measurement of resistance of ground terminals.

(e) Inspection or testing, or both, of surge suppression devices to determine their effectiveness compared with similar new devices.

(f) Refastening and tightening of components and conductors as required.

(g) 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 during Thunderstorms

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

C-1 The purpose of this appendix is to furnish a guide for personal safety during thunderstorms.

C-2 Personal Conduct.

C-2.1 Do not go out-of-doors or remain out during thunderstorms unless it is necessary. Seek shelter as follows:

(a) Dwellings or other buildings that are protected against lightning.

(b) Underground shelters such as subways, tunnels, and caves.

(c) Large metal-frame buildings.

(d) Large unprotected buildings.

(e) Enclosed automobiles, buses, and other vehicles with metal tops and bodies.

(f) Enclosed metal trains and street cars.

(g) Enclosed metal boats or ships.

(h) Boats that are protected against lightning.

(i) City streets that may be shielded by nearby buildings.

C-2.2 If possible, avoid the following places, which offer little or no protection from lightning:

(a) Small, unprotected buildings, barns, sheds, etc.

(b) Tents and temporary shelters.

(c) Automobiles (nonmetal top or open).

(d) 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 storms are in the immediate vicinity:

(a) Hilltops and ridges.

(b) Areas on top of buildings.

(c) Open fields, athletic fields, golf courses.

(d) Parking lots and tennis courts.

(e) Swimming pools, lakes, and seashores.

(f) Near wire fences, clotheslines, overhead wires, and railroad tracks.

(g) Under isolated trees.

(h) Avoid use of or contact with electrical appliances, telephones, and plumbing fixtures.

C-2.4 In the above locations, it is especially hazardous to be riding in or on any of the following during thunderstorms:

(a) Open tractors or other farm machinery operated in open fields.

(b) Golf carts, scooters, bicycles, or motorcycles.

(c) Open boats (without masts) and Hovercraft.

(d) Automobiles (nonmetal top or open).

C-2.5 It may not always be possible to choose a location that offers good protection from lightning. Follow these rules when there is a choice in selecting locations:

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

(b) Seek dense woods—avoid isolated trees.

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

(d) If you are hopelessly isolated in an exposed area and you feel your hair stand on end, indicating that lightning is about to strike, drop to your knees and bend forward, putting your hands on your knees. Do not lie flat on the ground or place your hands on the ground.

Appendix D Protection for Sailboats, Power Boats, Small Boats, and Ships

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

D-1 General Principles.

D-1.1 Successful protection of persons and watercraft from lightning is dependent upon a combination of proper design and maintenance of equipment and on personnel behavior. Proper design is covered in this and following sections. Maintenance of equipment is covered in Section D-12 and personnel behavior in D-11. In view of the wide variation in structural design of boats, specific recommendations cannot be made for all cases. However, the basic guides contained in Appendix D should be considered and used in designing and installing a lightning protection system for any given craft. A lightning protection system offers no protection when the boat is out of water and is not intended to afford protection if any part of the boat comes in contact with power lines or other high voltage sources while afloat or ashore.

D-1.2 A grounded conductor, or lightning protective mast, will generally divert to itself direct hits that might otherwise fall within a cone-shaped space, the apex of which is the top of the conductor or lightning protective mast and the base a circle at the surface of the water having a radius related to the height. For a mast height not exceeding 50 ft (15 m) above the water, this radius is approximately equal to the mast height. For mast heights in excess of 50 ft (15 m), see 6-3.3.1.

D-1.3 For metallic masts, the bond from the mast to the ground should have conductivity equivalent to #4 AWG copper.

Where a nonmetallic mast with an air termination point or cap is used, the down conductor should have conductivity equivalent to #4 AWG copper. Where multiple shrouds are used in lieu of a single down conductor, the aggregate conductivity should be not less than #4 AWG copper. No single shroud should be less than the equivalent of #6 AWG copper.

D-1.4 If there are metal objects of considerable size within a few feet of the grounding conductor, there will be a strong tendency for sparks or sideflashes to jump from the grounding conductor to the metal object at the closest point. To prevent damage from such sideflashes, an interconnecting conductor at least equal to No. 8 AWG copper should be provided at all places where they are likely to occur. Large metallic objects that are not part of the electrical system of the boat and that are not already grounded due to their own functional or other requirements may be grounded directly to the ground plate, provided that it is not practical to interconnect with the lightning conductor or bonding systems. (*See Section D-4.*)

D-1.5 Lightning protection provisions are quite likely to receive scant attention after installation, and therefore their composition and assembly should be strong and materials used should be highly resistant to corrosion.

D-2 Installation Recommendations.

D-2.1 Lightning Protective Mast.

D-2.1.1 A lightning protective mast should be of adequate height and should be mechanically strong in order to withstand exposure to use and weather (*see D-1.2*). If the mast is of nonconducting material, the associated lightning or grounding conductor should be essentially straight and securely fastened to the mast, should extend at least 6 in. (150 mm) above the mast, should preferably terminate in a receiving point, should be led as directly as practicable to the grounding connection (*see Section D-5*), and should meet the recommendations of Section D-3.

D-2.1.2 For small open boats, a means should be provided for the insertion of a metal air terminal (such as a long reach boat hook) that will allow secure bonding. The mounting means should be bonded to the potential equalization bus using a conductor having a conductivity of not less than a #4 AWG copper.

The terminal should be positioned in proximity to the main passenger compartment. (*See Figure D-2.1.2.*)

D-2.2 Radio Antenna. A radio antenna may serve as a lightning protective mast provided it has conductivity equivalent to No. 4 AWG copper and is equipped with surge suppression and means for grounding during electrical storms. The grounding of metal rod-type radio antennas constitutes sufficient protection for wooden boats, without masts and spars, provided the following conditions are met:

D-2.2.1 The antenna and all conductors in the grounding circuit of the antenna have a conductivity equivalent to No. 4 AWG copper.

D-2.2.2 The top of the antenna is not more than 50 ft (15 m) above the water, and a line drawn from the top of the antenna downward toward the water at an angle of 45 degrees to the vertical does not intercept any part of the boat. (*See D-1.2.*)

D-2.2.3 Because a loading coil presents a high impedance to the flow of lightning current, the portion of an antenna above the bottom of a loading coil is not effective as a lightning protective mast unless the coil is provided with a suitable surge suppression device for bypassing the lightning current.

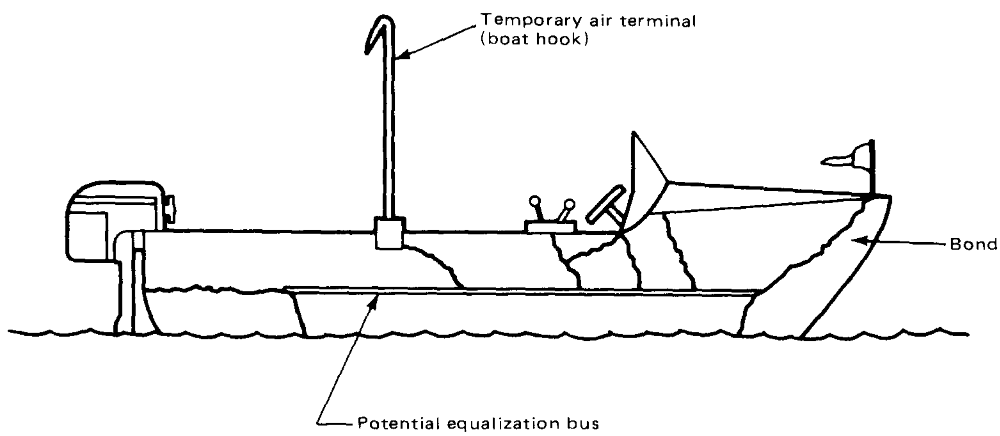


Figure D-2.1.2.

D-2.2.4 Nonconducting antenna masts with spirally wrapped conductors are not considered suitable for lightning protection purposes.

D-2.2.5 For those pieces of equipment in close proximity to each other where persons may come in contact with two or more objects at the same time, a bonding conductor having a conductivity equivalent to #8 AWG copper.

D-2.2.6 Connections between the potential equalization bus and the exterior grounding plate should be made fore and aft using as a minimum the equivalent of #4 AWG copper connectors through the hull.

D-2.2.7 An exterior grounding plate of copper, copper alloys, stainless steel, or aluminum should be provided. This grounding plate should be a strip of minimum thickness of $1/8$ in. and a minimum width of $3/4$ in. The length should extend as far as necessary to permit direct connection to the primary down conductor and primary metal bodies, but not less than 4 ft. As a minimum, one grounding strip should be provided.

The positioning of the grounding plate should be made under or near primary metal bodies such as fuel and water tanks, engine, etc. It should be located under water during normal operation.

D-2.3 The potential equalization bus is a common attachment point for the bonding of all metal bodies and grounding of all electrical and electronic equipment.

D-3 Materials.

D-3.1 The materials used in the making of a protective system should be resistant to corrosion. The use of combinations of metals that form galvanic or electrolytic couples should be avoided.

D-3.2 In those cases where it is impractical to avoid a junction of dissimilar metals, the corrosion effects can be reduced by the use of suitable platings or special connectors available for such purposes. Except for the use of conducting materials that are otherwise part of the structure of the boat, only copper should be used as the conductor. Where copper is used, it should be of the grade ordinarily required for commercial electrical work, generally designated as being of 98 percent conductivity when annealed.

D-3.3 Copper Conductor. Copper cable conductors should be of a diameter not less than No. 8 AWG. The size of any strand of a cable should be not less than No. 17 AWG. The thickness of any copper ribbon or strip should be not less than No. 20 AWG. Where other materials are used the gage should be such as to give conductivity equal to or greater than No. 8 AWG stranded copper cable.

D-3.4 Joints. Joints should be mechanically strong and should be so made that they have an electrical resistance not in excess of that of 2 ft (0.6 m) of conductor.

D-4 Interconnection of Metallic Masses.

D-4.1 Metallic masses aboard boats that are a permanent part of the boat or are permanently installed within or about it and whose function would not be seriously affected by grounding should, with the exception of those of comparatively small size, be made a part of the lightning-conductor system by interconnection with a potential equalization bus.

Metallic through-hull fittings and sea cocks should not be connected directly to a down conductor. Connections should be made to a potential equalization bus.

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

D-4.2 The object of interconnecting the metal parts of a boat with the conductor is to prevent damage from sideflashes, especially in the case of rather extensive metal objects that are nearby. The main principle to be observed in the prevention of such damage is to identify on a boat the places where sideflashes are most likely to occur and to provide metallic paths for them.

D-4.3 To minimize flow of lightning discharge current through engine bearings, it may be preferable to bond engine blocks directly to the ground plate rather than to an intermediate point on the lightning conductor.

D-4.4 Exterior Bodies of Metal.

D-4.4.1 Metal situated wholly on the exterior of boats should be electrically connected to the grounding conductor.

D-4.4.2 Exterior metal bodies on boats include any large masses such as horizontal handrails on cabin tops, smokestacks from galley stoves, davits, or metal signal masts.

D-4.4.3 Shrouds should be bonded. All standing rigging should be bonded together at the top and at their lower ends to the potential equalization bus in the most direct path, using a minimum #6 AWG copper bond.

D-4.5 Interior Bodies of Metal.

D-4.5.1 Metal situated wholly in the interior of boats and that at any point comes within 6 ft (1.8 m) of a lightning conductor should be electrically interconnected with this lightning conductor.

D-4.5.2 Interior bodies of metal include engines, water and gasoline tanks, and control rods for steering gear or reversing gear. It is not intended that small metal objects such as compasses, clocks, galley stoves, medicine chests, and other parts of the boat's hardware be grounded.

D-4.6 Metal that projects through cabin tops, decks, or sides of boats above the sheer should be bonded to the nearest lightning conductor at the point where the metal emerges from the boat and should be grounded at its lower or extreme end within the boat.

D-4.7 Protection of Equipment. Wherever possible, electronic equipment should be enclosed in metal cabinets or boxes and the enclosure or box bonded to the potential equalization bus with a minimum #8 AWG copper conductor or equivalent. Where equipment is not so encased, it should be surrounded with copper wire mesh or another type of metal envelope bonded to the potential equalization bus with #8 AWG copper conductor or equivalent.

D-4.8 Surge suppression devices should be installed on all wiring entering or leaving electronic equipment, usually power data or communication wiring.

D-5 Ground Connection. A ground connection for a boat may consist of any metal surface that is normally submerged in the water and that has an area of at least 1 sq ft (0.093 m^2). Propellers and metallic rudder surfaces may be used for this purpose. The ground plate as required by the Federal Communications Commission for radio transmitters should be considered adequate. A metal hull itself constitutes an adequate ground.

Grounding plates should be mounted on the hull or hulls as necessary. On sail boats, multiple strips may be necessary considering one may be completely out of the water when the boat is heeled over.

D-6 Vessels with Metal Hulls. If there is an electrical contact between metal hulls and metal masts or other metallic superstructure of adequate height to meet the recommendations of Section D-2, no further protection against lightning is necessary; however, surge suppression in accordance with D-4.8 should be provided. Boats with ungrounded or nonconducting objects projecting above the metal masts or superstructure should have these objects grounded or protected with a grounded conductor, respectively, in order to protect them.

D-7 Protection of Sailboats (Nonmetallic).

D-7.1 Sailboats. Sailboats with metallic standing rigging will be adequately protected provided that all rigging is grounded, so that the mast and rigging meet the recommendations of Sections D-2 and D-3.

D-7.2 Open Day-Sailers. Open sailboats will be adequately protected if any shrouds, backstays, or preventors and any continuous metallic track on the mast and boom are grounded. These should be electrically connected at the lower or forward end and grounded to a copper plate on the hull or to a metal rudder, centerboard, or keel.

D-7.3 Cruising Sailboats. All stays and all sail tracks should be grounded on cruising sailboats since it is assumed that persons will be in proximity of fore-stays as well as after-stays. Grounding of other objects on cruising boats should be in accordance with the foregoing subsections.

D-8 Protection of Power Boats (Nonmetallic).

D-8.1 Power boats may be adequately protected by a grounded radio antenna or other suitable grounded lightning protective mast as recommended in Section D-2, provided the height of the mast meets the recommendations for the zone of protection in D-1.2. Interconnection and grounding of metallic masses should be in accordance with D-2.2.2.

D-8.2 Where the size of the boat is such as to render the use of a single mast impractical, additional lightning protective masts should be erected to form overlapping zones of protection.

D-9 Protection of Small Boats. Small boats may be protected by means of a temporary lightning protective mast that may be erected when lightning conditions are observed in the distance. Grounding provisions may be made by means of flexible copper wire and a submerged ground plate of at least 1 sq ft (0.093 m^2) in area.

D-10 Protection of Ships.

D-10.1 Ships almost invariably are constructed with steel masts, spars, superstructures, hulls, smokestacks, and shrouds, and the array of masts, stacks, and radio antennas usually provide the zones of protection recommended in D-1.2. Therefore, ships and personnel aboard them are usually inherently protected against the effects of lightning. In those cases where adequate zones of protection are lacking, they should be corrected in accordance with D-1.2, if accomplished by changes in number or height of masts, or in accordance with 6-3.3 if by shielding wires suspended between masts.

D-10.2 Fiberglass or wooden hulled sailing ships should be protected in accordance with Sections D-1 through D-7.

D-11 Precautions for Personnel.

D-11.1 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 Appendix C.

D-11.2 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.

D-11.3 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.

D-11.4 No one should be in the water during a lightning storm.

D-12 Maintenance Suggestions.

D-12.1 One should not have a whip-type radio antenna tied down during a lightning storm if it has been designed as a part of the lightning protective system.

D-12.2 If a boat has been struck by lightning, compasses and electrical gear should be checked to determine whether damage or change in calibration has taken place.

Appendix E Protection for Livestock in Fields

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

E-1 General.

E-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 Appendix E should minimize the hazard.

E-1.2 The loss of livestock by 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.

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

E-1.4 Fences built with metal posts set in 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 it can if the stroke is direct and the fence continuous, even though grounded. The fences that give rise to the most trouble are those constructed with posts of poorly conducting material, such as wood.

E-2 Grounding of Wire Fences.

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

E-2.2 Iron Posts. Ground connections may be made by inserting at intervals galvanized-iron posts, such as are ordinarily used for farm fencing, and attaching in electrical contact all of the wires of the fence, or 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 they may be placed up to about 300 ft (92 m) apart.

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

E-3 Breaking Continuity of Fence.

E-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 may 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 may consist of strips of wood about 2 × 2 × 24 in. (50 × 50 × 600 mm), or their equivalent as far as insulating properties and mechanical strength are concerned.

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

Appendix F 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 information purposes only.

F-1 Picnic Grounds and Playgrounds. Protection from lightning may be provided by the methods indicated in F-1.1 or F-1.2.

F-1.1 Shelters with Lightning Protection Systems. Provide shelters with closed or open sides that are equipped with lightning protection systems. Down conductors should be shielded with nonconductive material, resistant to impact and climate conditions, to at least an 8-ft (2.4-m) height. Shelters with earthen floors should have: (1) ground terminals interconnected by an encircling, buried, bare copper conductor, or (2) ground terminals provided with buried radial conductors run out at least 10 ft (3 m) from the ground terminal away from the shelter.

F-1.2 Masts and Overhead Ground Wires. Erect masts (poles) on opposite sides of the grounds and near the edges. 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 copper or equivalent. If 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) and (b) in Chapter 6 for illustration.*]

F-2 Ball Parks and Racetracks.

F-2.1 Roofed Grandstands. Roofed grandstands are included within the scope of this code.

F-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 F-1.2.

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

F-4 Piers.

F-4.1 Covered Piers. Covered piers are included within the scope of this code.

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

Appendix G Protection for Trees

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

G-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, a fire, or from the superheating of the moisture in the tree resulting in splintering of the tree. It may be desirable to equip other trees with a lightning protection system because of particular value to the owner.

G-2 Methods and Materials.

G-2.1 Conductors. Conductors should conform to the requirements of Chapter 3.

G-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.

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

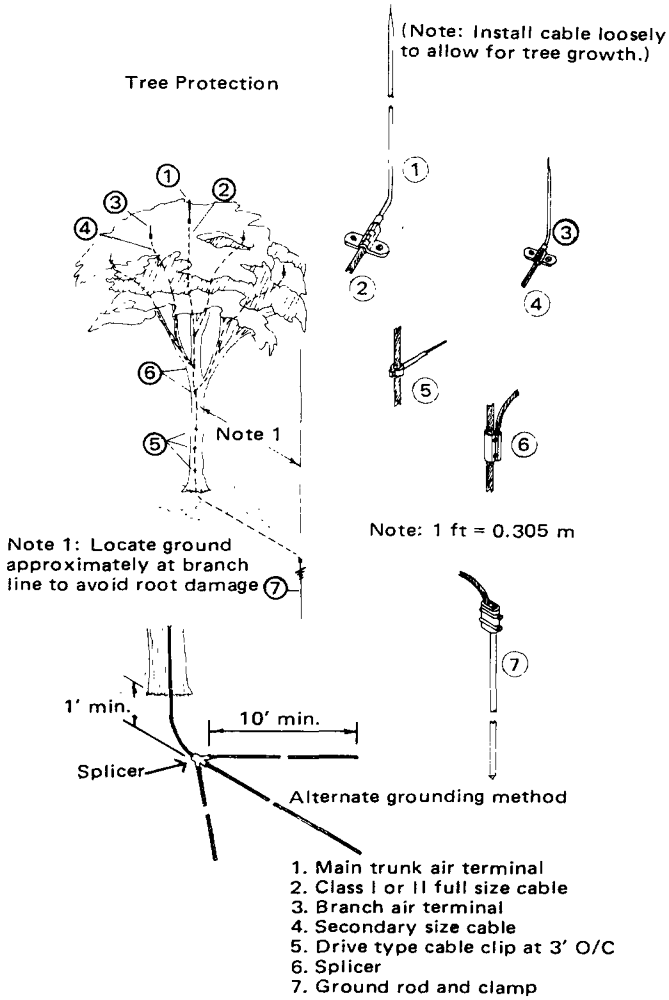


Figure G-1 Protection for trees.

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

G-2.5 Ground Terminals. Ground terminals for conductors should:

(a) Be made from each conductor, 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);

(b) Have the radial conductors extended to the branch line not less than 25 ft (7.6 m);

(c) 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); and

(d) Be bonded to an underground metallic water pipe where available within 25 ft (7.6 m) of the branch line.

Appendix H Protection for Parked Aircraft

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

H-1 General Principles.

H-1.1 Aircraft includes airplanes, helicopters, and lighter-than-air craft. They 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.

H-1.2 All metal airplanes parked outside hangars should be grounded. This grounding may 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 may be provided. The height should be in accordance with the zones of protection described in Chapter 3.

H-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, radiocommunication, and radar equipment can help to minimize these effects. Suitable equipment and electrical wiring layout can also aid in reducing lightning-induced problems.

H-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.

H-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*.

H-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.

H-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 I Risk Assessment Guide

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

I-1 General.

I-1.1 This lightning risk assessment guide is prepared to assist in the analysis of various criteria to determine the risk of loss due to lightning. As a guide, it is not possible to cover each special design element that may render a structure more or less susceptible to lightning damage. In special cases personal and economic factors may be very important and should be considered in addition to the assessment obtained by use of this guide.

I-1.2 If the structure is in a high risk situation, a risk index (R) should be computed for a wide range of structures in the environment concerned. The structure's index is then compared to the index of these other structures so that a judgment of local risk weighting can be made.

I-2 Determining the Risk. The assessment of risk index (R) is given in Table I-2. The risk index (R) is obtained by dividing the sum of the values given in Tables I-2(a) through I-2(e) by the lightning frequency index value obtained from Table I-2(f).

The risk index (R) is:

$$R = \frac{A + B + C + D + E}{F}$$

Table I-2 Assessment of Risk, R

R Value	Risk Value
0-2	Light
2-3	Light to Moderate
3-4	Moderate
4-7	Moderate to Severe
Over 7	Severe

The computed "R" values for the eastern United States should be multiplied by a factor varying from 1.5 in the northeast to 0.5 in the southeast. This factor is due to the differences in storm characteristics in these regions.

Table I-2(a) Index "A" — Type of Structure

Structure	Index Value
Single family residence less than 5,000 sq ft (465 m^2)	1
Single family residence over 5,000 sq ft (465 m^2)	2
Residential, office, or factory building less than 50 ft (15 m) in height:	
Covering less than 25,000 sq ft (2323 m^2) of ground area	3
Covering over 25,000 sq ft (2323 m^2) of ground area	5
Residential, office, or factory building from 50 to 75 ft (15 to 23 m) high	4
Residential, office, or factory building from 75 to 150 ft (23 to 46 m) high	5
Residential, office, or factory building from 150 ft (46 m) or higher	8
Municipal services buildings, fire, police, water, sewer, etc.	7
Hangars	7
Power generating stations, central telephone exchanges	8
Water towers and cooling towers	8
Libraries, museums, historical structures	8
Farm buildings	9
Golf shelters and other recreational shelters	9
Places of public assembly such as schools, churches, theaters, stadiums	9
Slender structures such as smokestacks, church steeples and spires, control towers, lighthouses, etc.	10
Hospitals, nursing homes, housing for the elderly or handicapped	10
Buildings housing the manufacture, handling, or storage of hazardous materials	10

Table I-2(b) Index "B" — Type of Construction

Structural Framework	Roof Type	Index Value
Nonmetallic	Wood	5
(Other than wood)	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	1
Wood	Wood	5
	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	2
Reinforced Concrete	Wood	5
	Composition	3
	Metal — not continuous	4
	Metal — electrically continuous	1
Structural Steel	Wood	4
	Composition	3
	Metal — not continuous	3
	Metal — electrically continuous	1

NOTE: Composition roofs include asphalt, tar, tile, slate, etc.

Table I-2(c) Index "C" — Relative Location

Location	Index Value
Structures in areas of higher structures:	
Small structures — covering ground area of less than 10,000 sq ft (929 m^2)	1
Large structures — covering ground area of more than 10,000 sq ft (929 m^2)	2
Structures in areas of lower structures:	
Small structures — covering ground area of less than 10,000 sq ft (929 m^2)	4
Large structures — covering ground area of more than 10,000 sq ft (929 m^2)	5
Structures extending up to 50 ft (15.2 m) above adjacent structures or terrain	7
Structures extending more than 50 ft (15.2 m) above adjacent structures or terrain	10

Table I-2(d) Index "D" — Topography

Location	Index Value
On flat land	1
On hillside	2
On hill top	4
On mountain top	5

Table I-2(e) Index "E" — Occupancy and Contents

	Index Value
Noncombustible materials — unoccupied	1
Residential furnishings	2
Ordinary furnishings or equipment	2
Cattle and livestock	3
Small assembly of people — less than 50	4
Combustible materials	5
Large assembly of people — 50 or more	6
High value materials or equipment	7
Essential services — police, fire, etc.	8
Immobile or bedfast persons	8
Flammable liquids or gases — gasoline, hydrogen, etc.	8
Critical operating equipment	9
Historic contents	10
Explosives and explosive ingredients	10

Table I-2(f) Index "F" — Lightning Frequency Isoceraunic Level [See Figure I-2(f)(a) or I-2(f)(b)]

	Index Value
0-5	9
6-10	8
11-20	7
21-30	6
31-40	5
41-50	4
51-60	3
61-70	2
Over 70	1

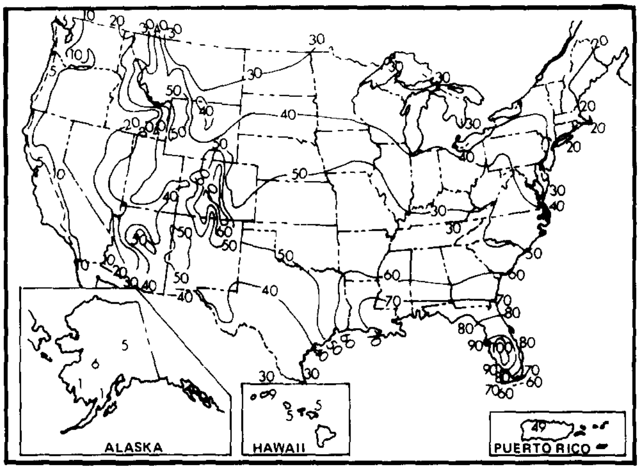


Figure I-2(f)(a) Statistics for continental United States showing mean annual number of days with thunderstorms. The highest frequency is encountered in south-central Florida. Since 1894, the recording of thunderstorms has been defined as the local calendar day during which thunder was heard. A day with thunderstorms is so recorded regardless of the number occurring on that day. The occurrence of lightning without thunder is not recorded as a thunderstorm. (Data supplied by Environmental Science Service Administration, U.S. Department of Commerce.)

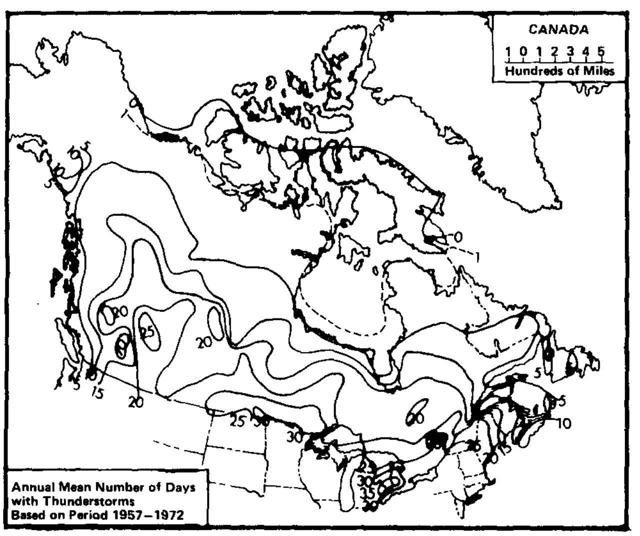


Figure I-2(f)(b) Canadian statistics showing annual average number of days with thunderstorms. Data based on the period 1957-1972. (Meteorological Division, Department of Transportation, Canada.)

Appendix J Ground Measurement Techniques

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

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

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

The principle of ground resistance measurement is shown in Figure J. L is the lightning ground rod or ground rod system, P is a test probe, and A an auxiliary current probe. M is the standard AC measuring equipment for three-point technique ground resistance measurements. Convenient distances for LP and LA are 75 ft (22 m) and 120 ft (36 m), respectively. In general P should be at 62 percent of the distance from L to A. If 120 ft (36 m) is not convenient, it could be increased significantly [or reduced to no less than 50 ft (15.2 m)] provided LP is increased proportionately.

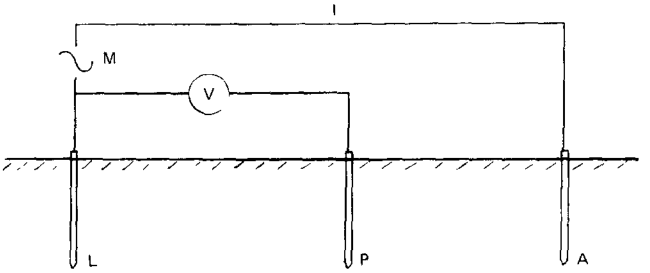


Figure J Measurement of ground resistance.

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

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

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

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

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

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

Appendix K Explanation of Bonding Principles

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

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

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

Figure K illustrates the generation of these potential differences.

(a) *Resistive Effect.* In the situation where conductor C is connected only to a ground terminal and the water pipe is independently grounded, a large potential may exist between B and F. Assuming a resistance of 20 ohms between C and ground and a lightning current of 100,000 amps, then Ohm's law (voltage = current × resistance) indicates that a potential of 2 million volts exists on conductor ABC. Because no current initially is passing through the water pipe its potential is zero volts. The difference of potential of 2 million volts between B and F is sufficient for a sideflash of over 6 ft (2 m). In order to reduce this potential difference to zero the code requires equalization of potentials at ground level in accordance with 3-23.1. Such a bond is shown as CD in Figure K.

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

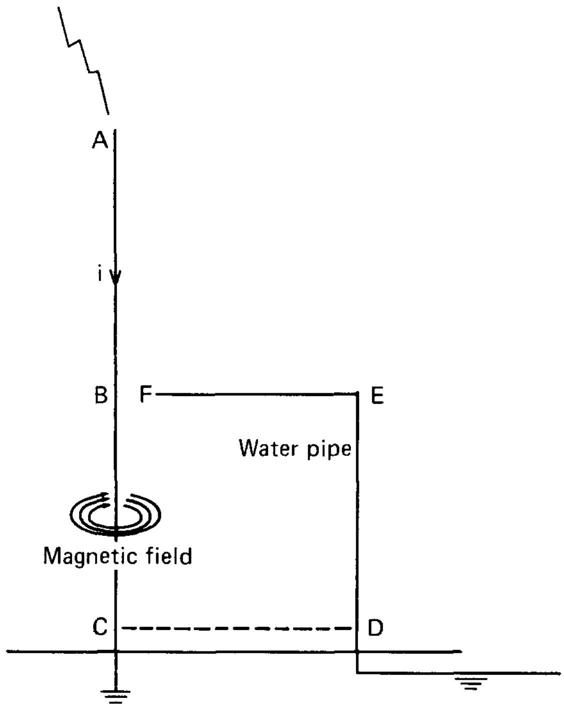


Figure K The magnetic field around a conductor.

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

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

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

The voltage across the gap BF is related to the size of the loop BCDEF but dominantly to the height BC rather than CD; hence the height "h" term in the formulas of 3-24.2. Equalizing the potentials at frequent heights in accordance with Section 3-23 also reduces the size of the loop BCDEF, thereby keeping the gap voltage to a controllable value that can be removed by simple bonding.

One factor that is difficult to control is the problem related to power and communication lines entering the building. For all intents, such lines are at ground potential relative to the extremely high induced voltages. If the line

DEF was such an electrical, telephone, power, or data line not bonded at ground, the voltage across the loop would be enhanced by the resistive effect described by Ohm's law as well as by the inductive effect, and hence BF could soon approach breakdown. This would lead to sparks causing fire as well as the obvious electrical, electronic, and human life problems. All such lines entering the building should have electrical bonding through surge protection as specified in Section 3-21, thereby reducing the resistive component and controlling dangerous sparking and damage. If just one wire, however, does not have such suppression devices the dangers described above still exist, even to the protected building and the electrical equipment. Table K shows sample calculations.

In order to reduce the voltage across the gap BF so as to make bonding less necessary, it is possible to provide more down conductors. This code requires down conductors every 100 ft (30 m) (*see 3-12.10*), but the number of down conductors, "n," required in the bonding formula of 3-24.2 is restricted. It can be shown theoretically for structures less than 60 ft (18 m) in height that for a series of planar down conductors spaced 50 ft (15 m) apart "n" can be no bigger than 1.5, and for a similar three-dimensional situation "n" can be no bigger than 2.25. These values of "n" also apply to the upper 60 ft (18 m) of a tall structure. As the lightning current passes into the lower portion of a tall structure, however, the value of "n" must be calculated on the assumption that the current flow down the structure is much more symmetrical through the down conductors. This implies that for all but the upper 60 ft (18 m) of a structure the bonding distance can be calculated from a formula involving a larger value of "n," as shown in 3-24.2.

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

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

Table K Sample Calculations of Bonding Distances

		n = 1.0	n = 1.5	n = 2.25
h	**K_m**	**D**		
10	1.0	1 in. 8 ft	1 ft 1⅜ in.	9 in.
	0.5	10 in.	6¾ in.	4½ in.
20	1.0	3 ft 4 in.	2 ft 2¾ in.	1 ft 6 in.
	0.5	1 ft 8 in.	1 ft 1⅜ in.	9 in.
30	1.0	5 ft 0 in.	3 ft 4 in.	2 ft 2¾ in.
	0.5	2 ft 6 in.	1 ft 8 in.	1 ft 1⅜ in.
40	1.0	6 ft 8 in.	4 ft 6 in.	3 ft
	0.5	3 ft 4 in.	2 ft 3 in.	1 ft 6 in.

Appendix L Protection of Structures Housing Explosive Materials

This Appendix is not a part of the requirements of this NFPA document, but is included for information purposes only.

L-1 General. This appendix provides the minimum technical requirements for lightning protection of structures housing explosive materials.

L-1.1 Due to the possibility of danger to the surrounding area, an increased level of protection efficiency as defined herein is necessary for such structures. The decision of when to protect these structures should be left to the authority having jurisdiction.

L-1.2 The protection of the contents contained in structures housing explosives must take into account the packages used to contain these materials as well as bonding or grounding requirements specified by the authority having jurisdiction.

L-2 Design Considerations. Lightning protection systems designed to protect structures housing explosives and energetic materials should be based on a striking distance of 100 ft (33 m) as discussed in 6-3.3.

NOTE: When the effects of electromagnetic coupling are of concern a mast of overhead wire (catenary) systems may be preferred over integral systems unless a Faraday cage or shield is required. The removal (isolation) of the down conductors will reduce the magnetic field strength in the structure and reduce the probability of a sideflash from a down conductor.

L-3 Types of Systems.

L-3.1 Mast-type Systems. Mast-type systems should be designed as specified in 6-3.3.2.

L-3.2 Overhead Wire (Catenary) Systems. Catenary systems should be designed as specified in 6-3.3.2.

L-3.3 Integral Systems. An integral lightning protection system is a system that utilizes air terminals mounted directly on the structure to be protected. These types of air termination systems are as described in Chapter 3. Air terminal spacing should be modified as necessary to provide a zone of protection defined by a 100-ft (33-m) striking distance.

When an integral lightning protection system is used to protect the structures covered by this chapter, it is critical that the bonding requirements of Chapter 3 be met. It is also critical that a rigorous maintenance schedule be maintained for this type of system.

L-3.4 Faraday Cage. The optimum scheme for protecting extremely sensitive operations from all forms of electromagnetic radiation is to enclose the operation(s) or facility inside a Faraday cage. A true Faraday cage is difficult to construct and economically justified only for critical facilities or where extremely sensitive operations warrant this level of protection.