62305-3. The 15-degree angle from vertical falls well within the limits specified for a Class IV lightning protection system at a height of 60 m (200 ft).

A.4.6.7 Figure A.4.6.7 illustrates dormer protection.

A.4.6.11.2 Strike termination devices should be placed as close as practicable to an outside corner.

A.4.6.13 Examples include windsocks, cranes, window washing davits, and weathervanes where connection of the supporting masts or sockets to the lightning protection system complies with the requirements of Chapter 4 and arcing within the metal object will not damage the protected structure. When lightning attaches to metallic objects with movable parts, there is a possibility that arcing could occur at the point of articulation between the component parts, which could possibly fuse the parts together.

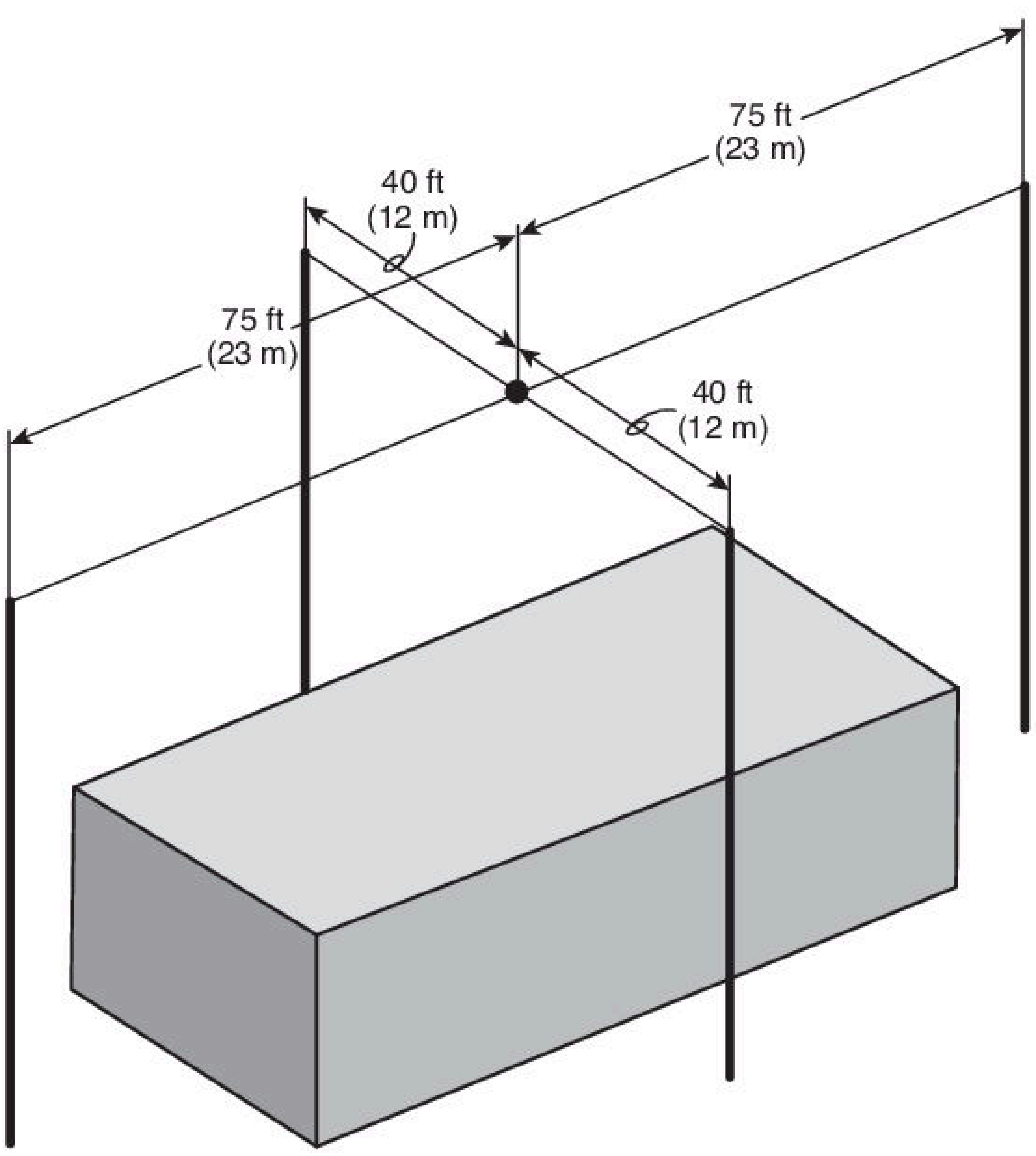
N **A.4.7.2.3** The purpose of Figure 4.7.2.4(b) is to provide a graphical representation of the area protected by the upper roof. The reference point is the eave because the criteria in 4.7.3 have been met and, thus, air terminals are not required on the ridge. It has been determined that this area is not susceptible to a direct strike.

N **A.4.7.2.4** The purpose of Figure 4.7.2.4(b) is to provide a graphical representation of the area protected by the upper roof. The reference point is the eave because the criteria in 4.7.3 have been met and, thus, air terminals are not required on the eave. It has been determined that this area is not susceptible to a direct strike.

A.4.7.3.1 Figure A.4.7.3.1 depicts the 150 ft (45 m) rolling sphere method for structures of selected heights up to 150 ft (45 m). Based on the height of the strike termination device for a protected structure being 25 ft (7.6 m), 50 ft (15 m), 75 ft (23 m), 100 ft (30 m), or 150 ft (45 m) aboveground, reference to the appropriate curve shows the anticipated zone of protection for objects and roofs at lower elevations.

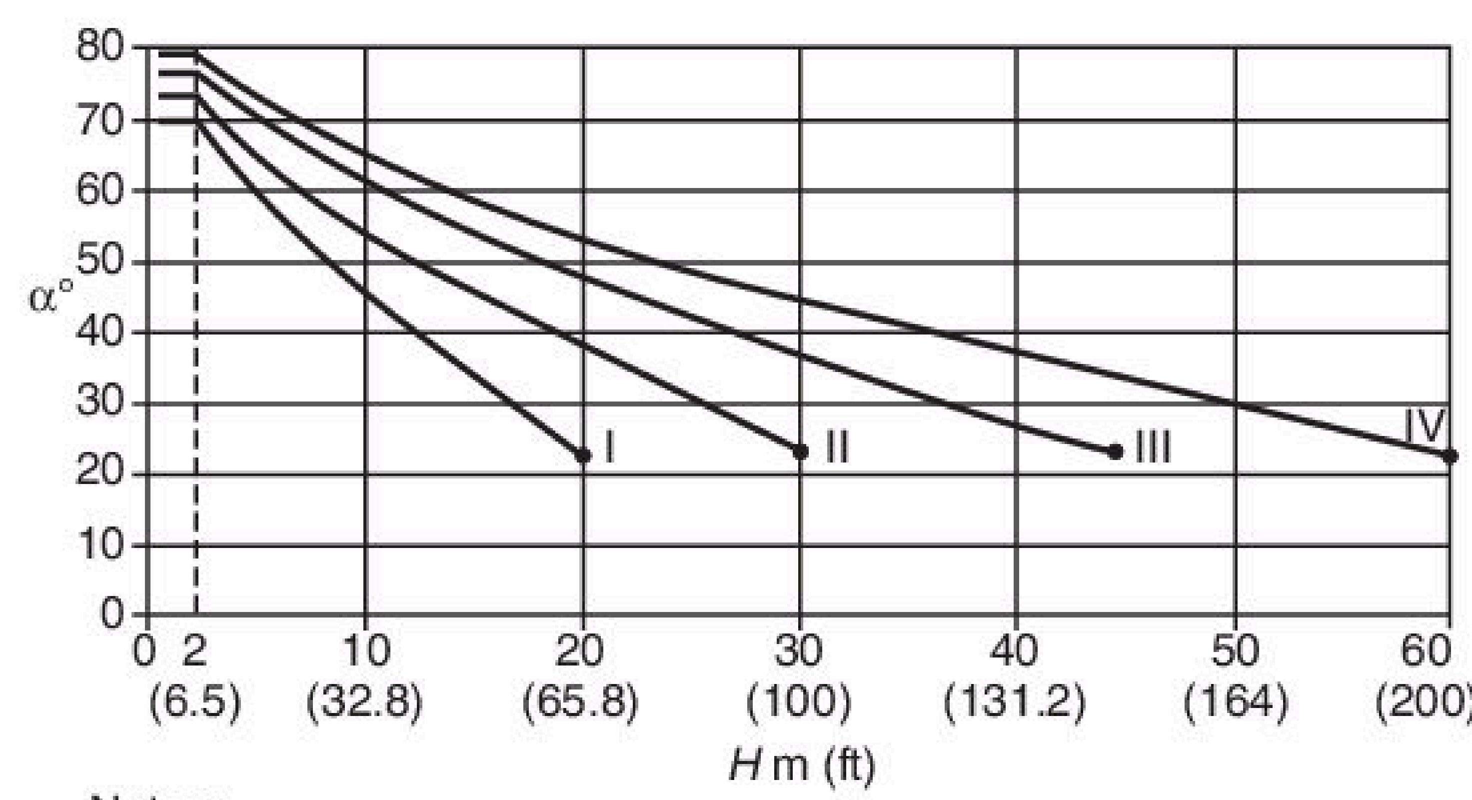
A.4.7.3.2 It is recognized that the sides of tall structures are subject to direct lightning strikes. Due to the low risk of strikes to the sides of tall structures and the minimal damage caused by these typically low current–level discharges, the cost of protection for the sides of tall structures normally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

A.4.8.1 See Figure A.4.8.1 for an example of an additional path for conductor runs over 40 ft (12 m).



Note: Four down conductors are within 100 ft (30 m) of intersection of overhead ground wires; $n = 2.25$ at that location.

FIGURE A.4.5.5.2(b) Overhead Wire Lightning Protection System Using Multiple Overhead Ground Wires Interconnected Above the Structure.



Notes:
1. H is the height of air-termination above the reference plane of the area to be protected.
2. The angle will not change for values of H below 1.8 m (6 ft).
3. The figure is based on data from IEC 62305–3, which uses metric values as normative.

FIGURE A.4.6.3.2.3 Maximum Values of Protection Angle Corresponding to the Class of Lightning Protection System. ***(Source: IEC 62305-3, Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard, Section 5.2.2.)***

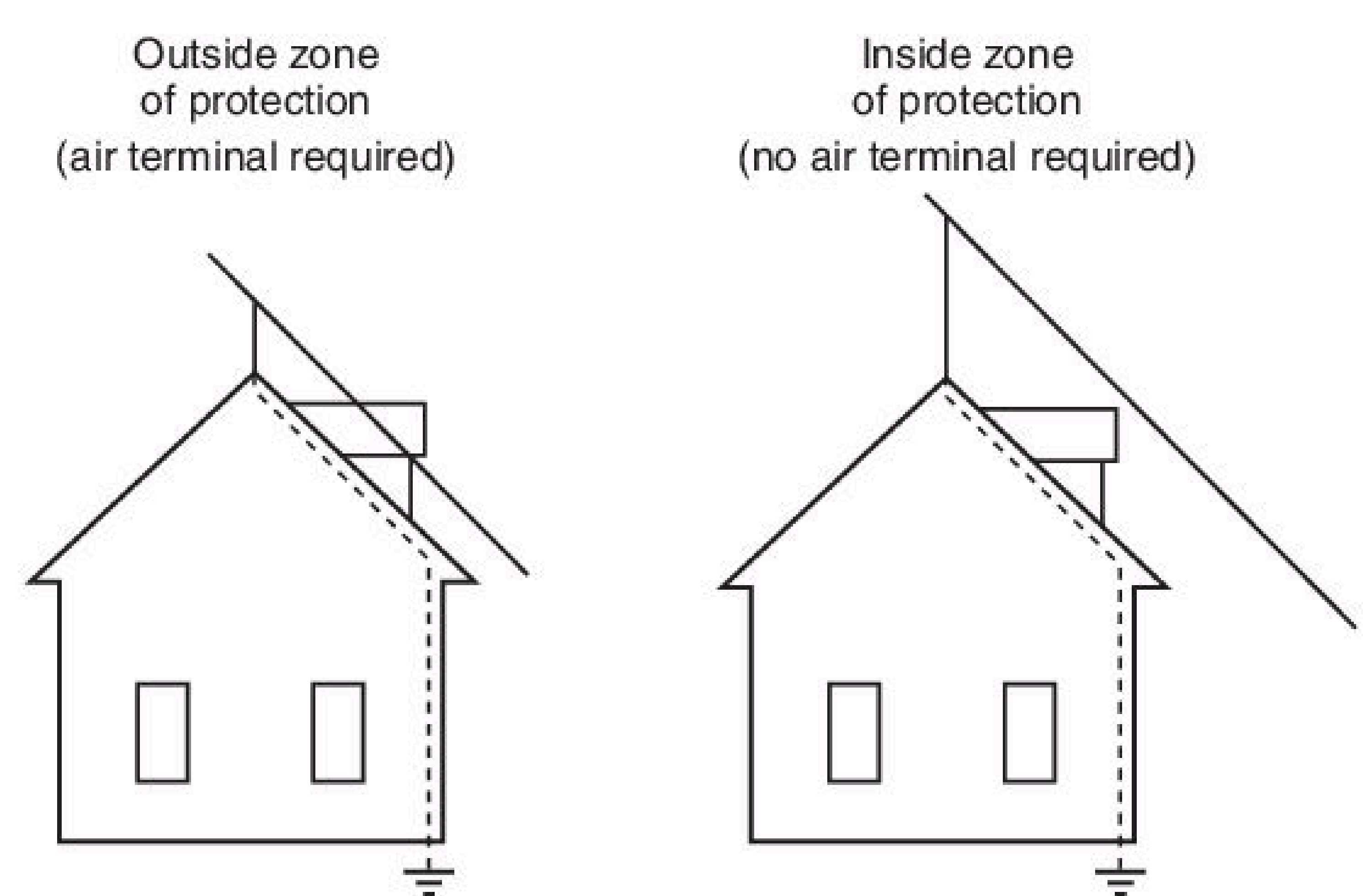
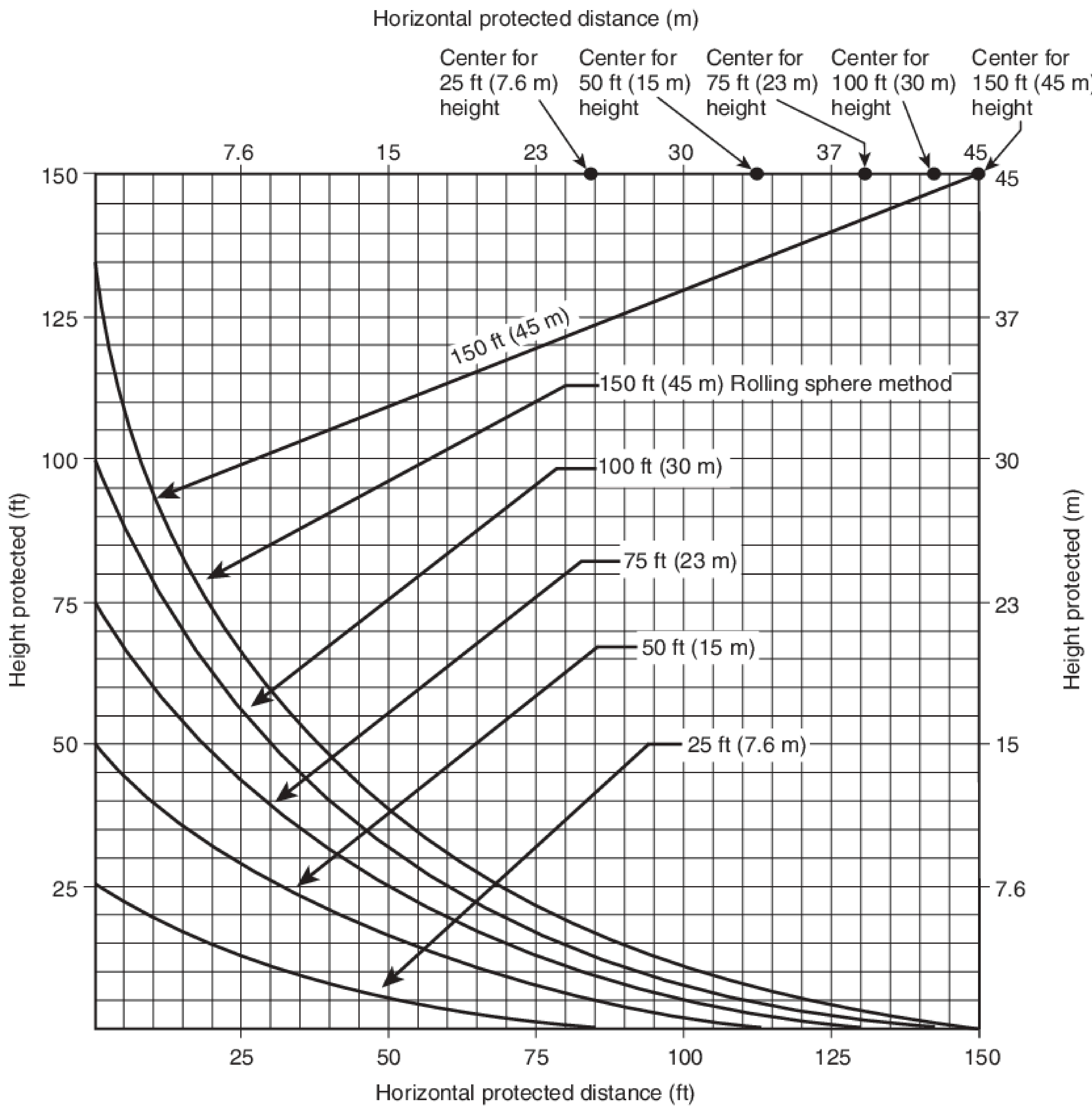


FIGURE A.4.6.7 Dormer Protection.



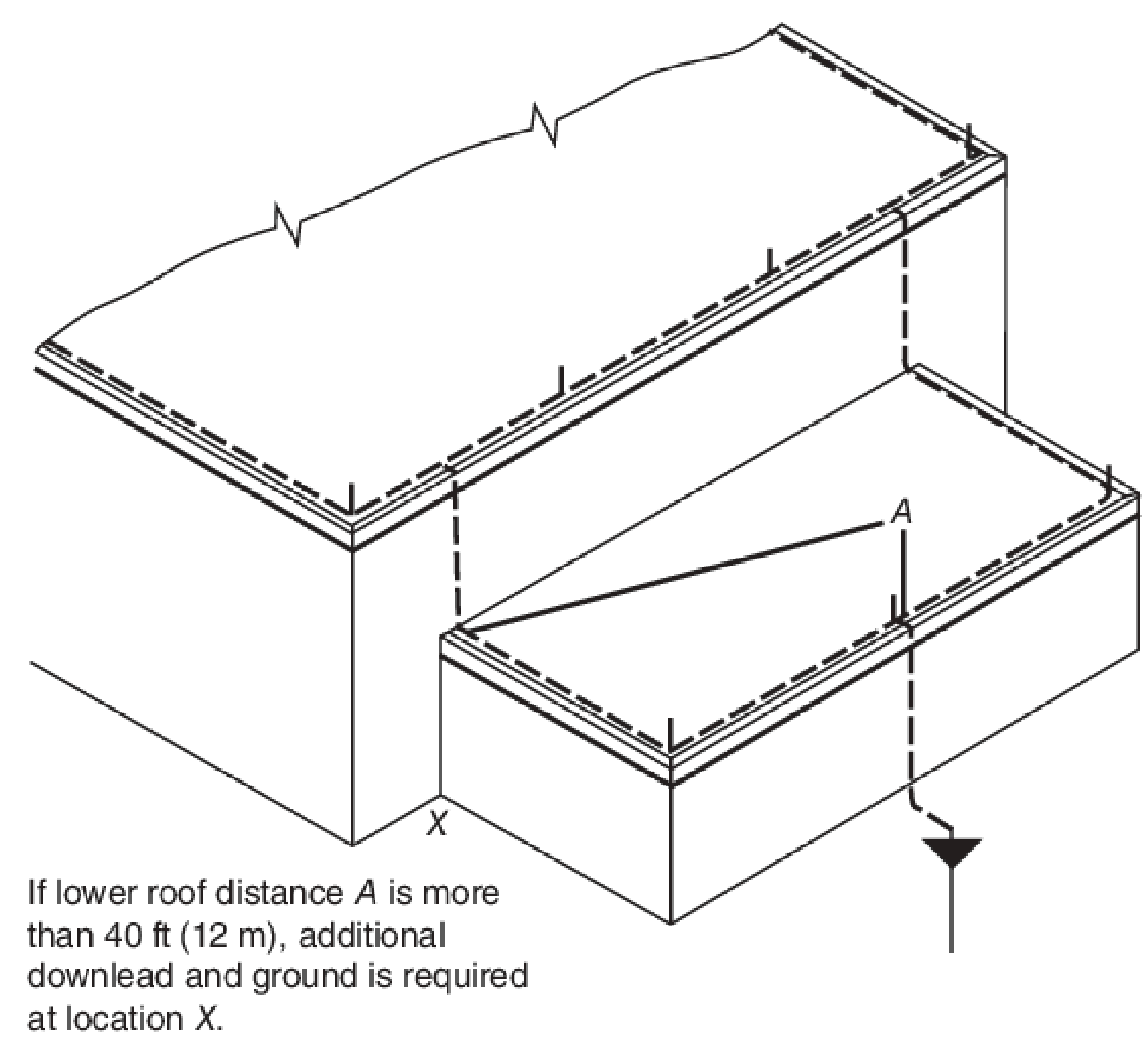
Δ **FIGURE A.4.7.3.1 Zone of Protection Utilizing Rolling Sphere Method.**

A.4.8.4 "U" and "V" pockets often form at low-positioned chimneys, dormers, or other projections on sloped roofs or at parapet walls and typically have conductor bends with less than a 90-degree interior angle. Additional conductors with downward or horizontal paths eliminate the acute angle and provide the two-way path.

A.4.8.8.1 For example, roofs from 50 ft to 100 ft (15 m to 30 m) in width will require one cross-run conductor, roofs 100 ft to 150 ft (30 m to 45 m) in width will require two cross-run conductors, and so on.

N **A.4.8.13** When it is necessary to install down conductors on or within the required bonding distance of steel-reinforced concrete columns in an existing structure, engineering consultation should be sought before piercing the column to access the rebar. Disturbing the concrete could impact the structural integrity of the steel-reinforced concrete column. If the engineer denies the alteration of the concrete column, coursing the down conductor on the column can be used as a means of last resort at the direction of the AHJ.

It is highly recommended that no attempt be made to bond steel-reinforcing cables in post-tensioned concrete.



Δ **FIGURE A.4.8.1 Additional Path for Conductor Runs Over 40 ft (12 m).**

A.4.12.1 Grounding electrodes that will not be accessible after installation should be provided with access wells, hand-holes, or similar means to allow for future inspection, testing, or maintenance of the down conductors and grounding electrodes. *(See Annex D and Annex E for further information on inspection, testing, and maintenance of lightning protection systems.)*

A.4.12.1.1 A grid grounding electrode system meeting the requirements of 4.12.4 is considered equivalent to a ground ring electrode.

N **A.4.12.1.1(2)** For lightning protection, a single integrated (interconnected) grounding system including lightning protection, power systems, communications systems, and other grounded systems is preferable.

A.4.12.1.6 Consideration of the corrosive environment is necessary for the selection of the appropriate stainless-steel alloy material for the grounding electrode. Research has been presented that warns that stainless steel is very susceptible to corrosion in many soil conditions. Extreme caution should be used and proper soil analysis should be performed where this type of rod is used. which contains detailed information on the grounding of electrical systems.

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N **A.4.12.2.1** IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*, states that the effect of the ground rod diameter on the resistance of the connection to earth is small and that ground rod diameter is more a function of mechanical strength and rigidity. Driving a ½ in. (12.7 mm) diameter 8 ft (2.4 m) ground rod into sandy soil is easily accomplished. However, driving the same 8 ft (2.4 m) ground rod into rocky soil or 80 ft (24 m) ground rod into sandy soil could require the mechanical strength of a ¾ in. (19 mm) diameter ground rod. The designer should select a ground rod diameter based on sound engineering practices and the success of the selected diameter in previous installations.

A.4.12.2.5 Minimal benefit is gained from the second ground rod if placed closer than the sum of the driven depth of both rods.

N **A.4.12.3** Concrete-encased electrodes used in the grounding of lightning protection systems should be limited to those specifically designed for that purpose. The AHJ or its designated representative should confirm and document that the concrete-encased electrode meets the requirements of 4.12.3.

A.4.12.3.2 Field experience has demonstrated that a copper conductor could experience accelerated corrosion at the point where the copper conductor exits the concrete. Concrete and soil composition could have a direct impact on the amount of corrosion, if any. Investigation of existing installations at the proposed site or chemical analysis of the concrete and soil composition would provide a basis to determine if additional corrosion protection is warranted. Each installation should be evaluated to determine the need for any additional corrosion protection. Tinned copper conductors or installation of a nonmetallic sleeve over the conductor where the conductor exits the concrete are two methods that could mitigate corrosion. The nonmetallic sleeve should extend 6 in. (150 mm) on each side of the transition from concrete to soil. See Sections 4.2 and 4.3 for additional requirements.

N **A.4.12.4.1** Soil and climate conditions could, due to a lack of moisture or reduction of surface area contact, create high resistance between the local earth and grounding electrode(s), as well as the associated conductor(s). Where such conditions exist, additional measures should be considered to reduce the resistance of the lightning protection system to remote earth. Some examples are using ground enhancing materials or, where practicable, embedding the ground ring and grounding electrodes below the permanent moisture level of earth at the site.

A.4.12.5 Augmentation of the grounding system specified in 4.12.5 and 4.12.8.2 by the use of one or more radial conductors is recommended. Radial conductors should be sized in accordance with the requirements for main conductors and installed in accordance with 4.12.8.1.

N **A.4.12.5.3** Soil and climate conditions could, due to a lack of moisture or reduction of surface area contact, create high resistance between the local earth and radial electrode(s), as well as the associated conductor(s). Where such conditions exist, additional measures should be considered to reduce the resistance of the lightning protection system to remote earth. Some examples are using ground enhancing materials or, where practicable, embedding the radial electrode(s) below the permanent moisture level of earth at the site.

A.4.12.6.1 The 2 ft^2 (0.18 m^2) surface area requirement can be met using a 1 ft^2 (0.09 m^2) plate with both sides in contact with the earth.

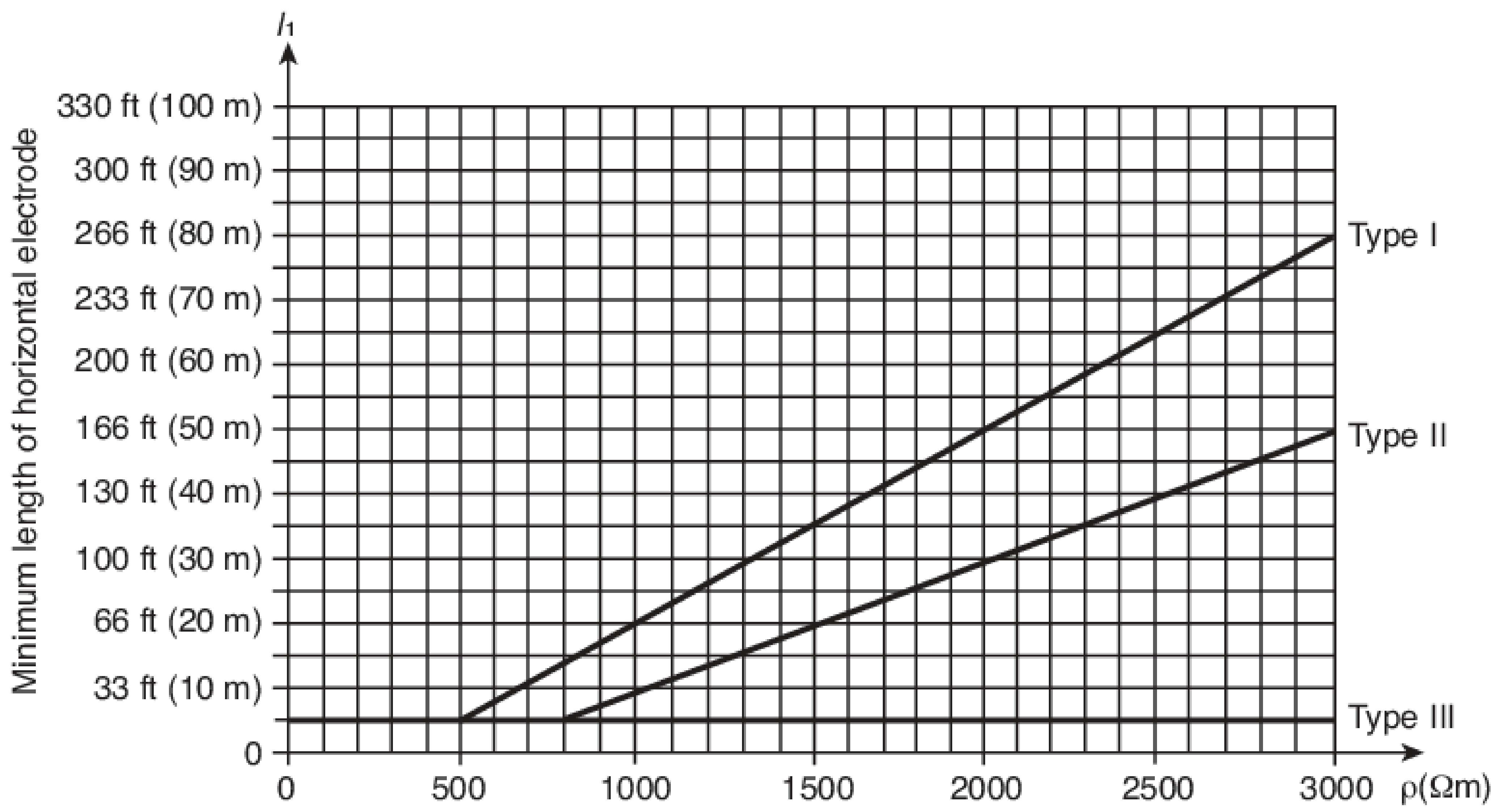
N **A.4.12.6.2** Soil and climate conditions could, due to a lack of moisture or reduction of surface area contact, create high resistance between the local earth and ground plate electrode(s), as well as the associated conductor(s). Where such conditions exist, additional measures should be considered to reduce the resistance of the lightning protection system to remote earth. Some examples are using ground enhancing materials or, where practicable, embedding the ground plate electrode(s) below the permanent moisture level of earth at the site.

A.4.12.8.1 For those instances in which it is necessary to install the grounding conductor directly on bedrock, it is recommended that main conductor solid strips be utilized. If there are locations along the length of the radial conductor in which there is sufficient soil available for the installation of an earth electrode, the installation of an additional earth electrode is encouraged. When a ground ring electrode is used in an application with insufficient soil cover, radial(s) should be considered to supplement the ground ring electrode to direct the lightning away from the protected area for all locations where property boundaries allow their addition.

A.4.12.8.1.2 For applications involving shallow or no topsoil, the overall earth resistivity could be high, leading to a correspondingly high grounding system resistance. In such applications, the use of radials extending from the structure is encouraged. Where high earth resistivity is encountered, a greater radial length than that specified in 4.12.5 is recommended. It is also recommended that the length of radials used in these applications meet the criteria for Type II lightning protection systems (as defined in IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*) as shown in Figure A.4.12.8.1.2.

A.4.12.8.3.1 It is preferable that grounding electrodes be located no closer than 24 in. (600 mm) from foundation walls to minimize the probability of damage to the foundation, although this is not always practicable for all applications. For

 Shaded text = Revisions. Δ = Text deletions and figure/table revisions. • = Section deletions. *N* = New material.



Note: Minimum length of horizontal electrode denotes the combined total length of all conductors that each electrode comprises.

FIGURE A.4.12.8.1.2 Minimum Length of Each Grounding Electrode Based on Earth Resistivity. *(Source: IEC 62305-3, Edition 2, Figure 3.)*

reference, IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*, requires that ring earth electrodes be buried at a depth of at least 18 in. (450 mm) and a distance of approximately 3 ft (1 m) around external walls. Note: The metric equivalent values given in this paragraph are the values cited in the IEC standard.

A.4.13.1 The interconnection of incoming services to the lightning protection system should be performed as near the service entry as reasonable and as direct as practicable through the structure before its interconnection. For larger structures with services entering the structure at different locations, multiple equipotential ground bus bars (EGB) should be considered. In these cases, the interconnection of the multiple EGBs is best accomplished through interconnection with a ground ring electrode.

A.4.13.2 A ground ring electrode conforming to 4.12.4 will be the most efficient method to meet the ground loop conductor requirement.

Δ **A.4.13.3** The definitions in *NFPA 70(NEC)* and in this standard for *bonded (bonding), grounded, grounding,* and *grounding electrode* are similar. The actual sections in the *NEC* and in this standard that define what constitutes these various items point to differences in application, equipment, and requirements.

Section 250.50 of the *NEC* requires that all electrodes present at each building or structure be bonded together to form the grounding electrode system, which coordinates with the requirements of Section 4.13 of this standard. The differences occur in 250.52 of the *NEC*, which describes grounding electrode devices not shown in Section 4.12. Grounding electrode devices described in 250.52 of the *NEC* but not referenced in this document include the following:

(1) 250.52(A)(1): 10 ft (3 m) of metallic underground water pipe that extends from the structure in contact with earth.
(2) 250.52(A)(2): The metal in-ground support structure that is in contact with earth.
(3) 250.52(A)(3)(2): The concrete-encased electrode described as #4 AWG, which would need to be a main-size conductor per 4.12.3.2.
(4) 250.52(A)(4): The ground ring electrode not smaller than 2 AWG that is acceptable for Class I but would not be acceptable for Class II *(see Table 4.1.1.1.2)*.
(5) 250.52(A)(5): Pipe electrodes described in item (a), which are not included, and rod electrodes described in item (b) as zinc-coated steel, which are not covered *(see 4.12.2.2)*.
(6) 250.52(A)(6): Other listed electrodes, which would need to comply with the various paragraphs of Section 4.12.
(7) 250.52(A)(7): Plate electrodes, which would need to comply with 4.12.6.
(8) 250.52(A)(8): “Other local metal underground systems or structures,” which are not referenced as grounding electrodes in this standard.

The lightning protection system designer must be familiar with these differences to coordinate interconnection with other building grounding electrodes or the structural grounding electrode system as required by 4.13.3.

Where separate but adjacent buildings or facilities are interconnected directly (not through a utility) by electric, CATV, CCTV, data, or communications wiring, the grounding systems of those buildings should be directly interconnected with a main-size conductor. The need for this interconnection can be eliminated with the use of fiber-optic cable, shielded wire, wire run in grounded metallic conduit, or cascading surge protection [surge arresters, surge protective devices (SPDs), or surge protectors installed at the entrance(s) and exit(s) of buildings or facilities].

A.4.13.5 Section 250.64(F) of the *NEC* identifies locations where grounding electrode conductors and bonding jumpers might be located for common system grounding or bonding. Section 250.104 of the *NEC* details the interconnection of metallic piping, the structural frame, and all separately derived grounding systems. Subsection 4.13.5 requires one connection to other building grounded systems.

Much like a ground bus bar, the common grounding point for the lightning protection system to other building grounded systems could be distinguishable as located in the first 5 ft (1.52 m) of water pipe, but it could include the entire water pipe system. A common connection point on the structural metallic frame could be apparent, or it could be the extent of the building framework. There is no qualifier (size of pipe or structural metal) in the *NEC*, which is different from this standard. NFPA 780 qualifies the structural metallic frame as a current-carrying part of the system if it meets or exceeds the $^{3}/_{16}$ in. (4.8 mm) thickness requirement *(see 4.18.1)*.

Where installation of the electrical grounding system is made in full compliance with the *NEC*, it would be necessary to connect to the lightning protection ground system only once to comply with 4.13.5. The location must be identified by the method used in the *NEC*. In cases where the building structural metallic frame is a part of the lightning protection system or is bonded as required by 4.8.13, it would generally be expected that no additional bonding runs at grade level between systems would be required.

The lightning protection system designer could consider simplification of the system interconnection requirement by specifying one connection to the metallic water pipe system, but in certain cases the use of plastic pipe sections makes this not a part of the building grounding system. In other instances, the building structural frame cannot be exposed for connection of derived systems, so this could not be the method for interconnection of grounded systems, or there might be no metallic frame. The designer could also specify connection of the lightning protection ground system to the electrical grounding electrode, but in the case of buildings served by feeders of branch circuits *[see 250.104(A)(3) in the NEC]*, there may or may not be a grounding electrode at a separate building.

Knowledge of the requirements or acceptable allowances in the *NEC* is necessary to determine common bonding of the lightning protection system to other building grounded systems at a single point. If the installed building grounded systems are not in compliance with current *NEC* requirements, common ground bonding must include the interconnection of all building-grounded systems to the lightning protection grounding system. If there is no problem with multiple bonds between various systems or loops, then multiple connections from the lightning protection system will simply improve the overall grounding system quality for the structure.

A.4.13.6.1(2) A method to determine whether grounded media and buried metallic conductors are inherently bonded through construction is to perform a bonding test using test equipment suitable for the purpose. The measured bonding resistance for inherently bonded conductors should typically be in the range of tens of milliohms but should not exceed 200 milliohms.

A.4.13.6.1(6) There could be installations where multiple sections of piping and associated junctions exist between the gas meter/regulator and the entrance of the line to the structure. Such junctions can create increased impedances at frequencies that are associated with overvoltages. Where there is internal piping that could be susceptible to overvoltages, care should be taken to ensure that the interconnection of the lightning protection grounding system is made to pipe sections that will not increase the impedance between the pipe and the grounding section. This could be accomplished by connection to the last section of the pipe entering the structure. This interconnection could be made either external or internal to the structure.

Where lightning protection is installed on a structure containing corrugated stainless-steel tubing (CSST), the CSST should be bonded to the lightning protection system in more than one location to lower the probability of arcing. The CSST should be bonded as close to the gas service entrance as possible, at any appliance supplied by the CSST, and at any manifold present in the gas piping system. In addition, the length of any bonding conductor between the CSST gas piping system and the lightning protection grounding system should be as short as possible.

Shorter bonding lengths limit the voltage drop between CSST and other metal components, lowering the probability of the development of an electric arc. Shorter bonding lengths conduct a larger amount of current to ground and reduce voltage differences between the CSST and other metallic components. A bonding length of 25 ft (7.6 m) or less is likely to be effective in preventing arcing due to induced currents.

Bonding clamps should not be installed directly on the CSST or its jacket. The means of bonding the CSST should be installed in accordance with the CSST manufacturer's instructions.

Maintaining a separation between metal bodies (except appliances and bonding connections) and CSST piping could also mitigate arcing. A separation distance of 6 in. (150 mm) or more is recommended.

A.4.13.6.2 Isolating spark gaps can be used to provide the required bond in those cases where galvanic corrosion is a concern or where a direct bond is not allowed by local code. The use of isolating spark gaps is not recommended for those applications where significant follow current can be expected. It is recommended that isolating spark gaps used in this application be installed in accordance with the manufacturer's instructions and be rated for the environment in which they are to be installed (e.g., hazardous classified location, direct burial, as applicable). The devices used in the applications should be rated at a maximum discharge current no less than 100 kA, 8/20 μs [2.5 kV spark overvoltage (U_p)], have an isolating resistance no less than 10^8 ohms, and have a maximum dc spark overvoltage of 500 V.

A.4.14.2 In the case of flat or gently sloping roofs, the roof conductors required by 4.8.7 can be used for achieving roof-level potential equalization. In the case of pitched roofs, the interconnection should be a loop placed at the eave level.

A.4.15 See Annex C for a technical discussion of lightning protection potential-equalization bonding and isolation.

In addition to the bonding of metal bodies, surge protection should be provided to protect power, communication, signal, and data lines from dangerous overvoltages and sparks caused by lightning strikes.

A.4.15.4 An ungrounded metallic body, such as a metal window frame in a nonconducting medium, that is located close to a lightning conductor and to a grounded metal body will influence bonding requirements only if the total of the distances between the lightning conductor and the ungrounded metal body and between the ungrounded metal body and the grounded metal body is equal to or less than the calculated bonding distance.

Δ **A.4.16** Metallic antenna masts or supports should not be used as strike termination devices. Thin metallic supports could be damaged and damage to the antenna lead-in conductors will most likely occur. Antenna should be placed in a zone of protection and isolated from the lightning protection system. Communications conductors should not be located near lightning conductors. *(See Section 4.19 for surge protection requirements.)*

A.4.18.3.4 Protecting the base metal with a conductive, corrosion-inhibiting coating, coating the entire bond with a corrosion-inhibiting coating, or other equivalent methods can be utilized.

A.4.19.1 Surge protection alone is not intended to prevent or limit physical damage caused by a direct lightning strike to a facility or structure. Rather, it is intended to defend against the indirect lightning effects imposed upon the electrical services of a structure as part of a coordinated lightning protection system installed in accordance with the requirements of this standard.

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

A.4.19.2 An SPD responds to surges by lowering its internal impedance so as to divert a surge current to limit the voltage to its protective level — the measured limiting voltage. After the occurrence of surges, the SPD recovers to a high-impedance-state line-to-ground and extinguishes the current-to-ground through the device when the line voltage returns to normal. The SPD performs these functions under normal service conditions, which are specific to the frequency of the system, voltage, load current, altitude (i.e., air pressure), humidity, and ambient air temperature.

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Δ **A.4.19.2.3** Permanent failure of electrical and electronic systems can result from conducted and induced surges transmitted to an apparatus via connecting wiring, as well as from the effects of radiated electromagnetic fields impinging directly onto the apparatus itself. Protection of the service equipment and downstream equipment (cascading SPD system) is recommended to reduce such effects.

To reduce the probability of failure of mission-critical equipment or equipment that is critical to life safety, surge protection should also be considered for the branch distribution equipment powering the equipment. IEC 62305-4, *Protection Against Lightning — Part 4: Electrical and Electronic Systems Within Structures*, recommends that the length of system wiring between the point at which the SPD is installed and the equipment being protected be no greater than 30 ft (10 m). Induced voltages can be reintroduced onto long lengths of system wiring, which can add to the protection level (U_p) of the SPD. If the protection level exceeds the withstand voltage level (U_w) of the equipment being protected, the protection afforded by the SPD might not be adequate. In such a case, the installer should locate an SPD closer to the point of utilization of the equipment. This philosophy extends to the protection of service equipment.

Depending on the presence of other protective measures (e.g., shielding), SPDs should be considered for branch distribution equipment as close as 30 ft (10 m) or more from the service equipment where the electrical equipment fed by the panel equipment is susceptible to overvoltage. Inductive coupling of electrical and magnetic fields can result in surges that can cause damage to susceptible electrical equipment.

Δ **A.4.19.2.4** Most services to facilities require discrete surge suppression devices to protect against damaging surges. Occasionally, services might be located in an area or manner for which the threat from lightning-induced surges and overvoltage transients is negligible. For example, the requirement in 4.19.2.2*(see also A.4.19.4.2)* exempts services less than 100 ft (30 m) in length that are run in grounded metal conduit between buildings requiring surge protection. Other examples where SPDs might not be required at each service entrance are those applications for which fiber optic transmission lines (with no conducting members) are used. The standard recognizes that there might be some exceptions. Consequently, the standard allows for such exceptions to the requirements for surge suppression on electrical utility, data, and other signal lines provided a competent engineering authority determines that the threat is negligible or that the system is protected in a manner equivalent to surge suppression protection.

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

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

The following four methods of analysis are commonly used for this determination, although other equivalent analysis can be used:

(1) A *risk assessment* can be performed in accordance with IEC 62305-2, *Protection Against Lightning — Part 2: Risk Management*, and surge protection requirements can be waived if justified by the assessment.
(2) A *lightning flash density/risk analysis* can be performed to determine the frequency of lightning activity in the geographic area of a facility. As a rule of thumb, if the flash density exceeds one flash per square kilometer per year, surge suppression or other physical protection should be considered. Lightning energy can indirectly couple to services at ranges greater than 0.6 mi (1 km) to create potentially damaging overvoltage.
(3) *Plant/facility statistical or maintenance records* can be used for risk analysis, if they demonstrate the lack of damage on a service caused by surges, as well as to justify low risk of surge damage in particular systems or facilities.
(4) A *lightning electromagnetic environment analysis* can take the threat of an electromagnetic field from a nearby lightning strike and compute the magnitude and rise-time characteristics of transients coupled into services feeding

a structure or facility. Based on the computed threat, SPDs can be sized appropriately or omitted, as warranted. This analysis is typically performed in critical communications facilities and for military applications. Electromagnetic environments for such an analysis can be found in MIL-STD-464C, *Interface Standard Electromagnetic Environmental Effects Requirements for Systems*, and IEC 62305-4, *Protection Against Lightning — Part 4: Electrical and Electronic Systems Within Structures.*

In all cases, the criticality of continued operation, potential hazard to persons and essential services, and consequences of facility damage or shutdown should be considered. If a hazardous condition results from a surge causing temporary shutdown without permanent damage (e.g., due to the disabling of a computer or communication system), then the requirements for surge suppression as articulated by Section 4.19 should not be exempted.

Δ **A.4.19.2.6** SPDs are typically sized significantly larger than the expected surge level. With service equipment, it is generally agreed that a nominal discharge current (I_n) of 20 kA will provide adequate protection. However, higher ratings that protect against less probable but more powerful lightning events usually provide a better capability to handle multiple strikes and have a longer service life.

Rating the SPD's I_n higher than the minimums in this document is recommended in areas with frequent lightning.

Where installed, SPDs on downstream equipment should have an I_n rating of 10 kA 8/20 µs or greater per mode.

Where installed, supplementary protection (also called *point of utilization protection*) SPDs should have an I_n rating of 5 kA 8/20 µs or greater per mode.

Δ **A.4.19.2.7** The measured limiting voltages of the SPD should be selected to limit damage to the service or equipment protected.

Devices rated in accordance with UL 1449, *Safety for Surge Protective Devices*, reflect that the voltage rating test in this edition utilizes a 3 kA peak current.

Δ **A.4.19.2.12** Surges can be induced upon any line entering a structure.

Where installed, downstream equipment over 100 ft (30 m) from the service equipment should have L–G or L–N and N–G modes of protection. Additionally, L–L protection is permitted — although this is usually achieved with the L–N modes across two phases.

The following modes of protection can be used to minimize the voltage differences between the individual conductors:

(1) Line-to-line (L–L) protection places the SPD between the current-carrying conductors in a power system.
(2) Line-to-neutral (L–N) protection places the SPD between the current-carrying conductors and the grounded conductor (neutral) in a power system.
(3) Line-to-ground (L–G) protection places the SPD between the current-carrying conductors and the grounding conductor (ground) in a power system.
(4) Neutral-to-ground (N–G) protection places the SPD between the grounded conductor (neutral) and the grounding conductor (ground) in a power system. This mode of protection is not required at the service equipment if the neutral-to-ground bond is implemented at this location or within proximity of the point of installation. Thus, in general, an SPD with only L–L and L–N modes of protection might be required at the service equipment.

A.4.19.2.13 The effectiveness of an SPD is based on the impedance of the path to ground. A lower impedance minimizes the voltage differences of conductors attached to SPDs near the service entrance and reduces the chance of arcing or insulation breach. Consequently, it is essential to minimize impedance in this circuit.

N **A.4.19.2.14.2** For information on enclosure environmental ratings, see NEMA 250, *Enclosures for Electrical Equipment (1,000 Volts Maximum)*, and Section 110.28 of *NFPA 70 (NEC)*.

N **A.4.19.3** For further information on surge arresters, see IEEE C62.11-2012, *Standard for Metal-Oxide Surge Arresters for Alternating-Current Power Circuits (>1 kV)*, and IEEE C62.22-2009, *Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.*

N **A.4.19.3.2** The selection of a properly rated metal arrester should be based on the maximum continuous operating voltage and the magnitude and duration of overvoltage at the arrester location as affected by phase-to-ground faults, system grounding techniques, switching surges, and other causes. A surge arrester should never be installed where the rating of the surge arrester is equal to or less than the maximum continuous phase-to-ground voltage at the power frequency available at the point of application. See the manufacturer's application rules to select the specific arrester for a particular location.

N **A.4.19.4.1** Antennas are considered part of conductive signal, data, and communication services.

Δ **A.4.19.4.2** Surge protectors should be placed on both ends of external signal, data, and communication lines longer than 100 ft (30 m) that connect pieces of equipment or facilities to protect against surges coupled into the wiring or caused by ground potential differences.

N **A.4.19.4.3** Where surge protectors having a rating of 10 kA 8/20 µs do not exist, devices complying with the requirements of Section 1.3 should be installed.

N **A.4.19.4.5** Additional information on the surge parameters of isolating transformers can be found in IEEE C62.69-2016, *Standard for the Surge Parameters of Isolating Transformers Used in Networking Devices and Equipment*; IEEE C62.36-2016, *Standard Test Methods for Surge Protectors and Protective Circuits Used in Information and Communications Technology (ICT) Circuits, and Smart Grid Data Circuits*; and IEEE C62.43-2005, *Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 Vrms or 1200 Vdc) Data, Communications, and Signaling Circuits.*

A.4.19.4.5.2 The purpose of a surge protector is to equalize conductor-to-conductor and conductor-to-ground potential. While a good ground is important, a good bond is imperative to minimize the damage caused by lightning and power contact or induction. Common mode is a mode of protecting telecommunications lines, data lines, and so forth. This mode places the protector between the signal conductor and the ground. It is analogous to L–G mode in power systems. Differential mode is a mode of protecting telecommunications lines, data lines, and so forth. In this mode, a protector is placed between the

 Shaded text = Revisions. Δ = Text deletions and figure/table revisions. • = Section deletions. *N* = New material.

individual signal lines, analogous to the L–L mode of protection in power systems.

A.4.19.4.8 Longer or looped surge protector conductors increase the impedance of the protector circuit. Increasing the lead length serves to increase the pass-through voltage at the point where the protector is wired into signal, data, or communications equipment. Consequently, it is essential to minimize lead length impedance in this circuit.

A.4.19.4.10 Some SPD units are provided with a failure indicator. This feature is recommended because it facilitates maintenance or test procedures. Where used, this indicator should be visible. Periodic inspection or testing of SPDs should be considered as part of building maintenance. *(See NFPA 70B.)*

A.4.19.5.2.1 Differential mode protection should also be provided where practicable.

A.5.8.1 The metal thickness could be less than the dimensions required in Chapter 4. On a nonmetal helipad, a flat metal plate should be permitted to serve as a strike termination device in the landing area if the landing area exceeds 50 ft (15 m) in both dimensions. The minimum exposed area of the plate should be 3 in.^{2} (1950 mm^2). The minimum thickness of the plate should be $\frac{3}{16}$ in. (4.8 mm). The plate should be installed flush with the helipad surface and exposed to the air. The plate should be connected to the roof lightning protection system with a two-way horizontal or downward path. Conductors connecting the plate to the lightning protection system should be installed flush with or below the helipad surface. Refer to 4.17.3.2 for the bonding requirements.

A.5.8.6 The connection does not provide lightning protection for the parked aircraft. Consideration should be given to relocate the helicopter to a safer location.

A.5.9.4.2 Refer to G.1.1.3 for guidance on installation criteria.

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

A.7.1 In the structures covered in Chapter 7, a spark that would otherwise cause little or no damage could ignite the flammable contents and result in a fire or explosion. The requirements of this chapter should be considered the minimum acceptable and the authority having jurisdiction (AHJ) could find it necessary to supplement these requirements to address specific risks. It is also up to the AHJ as to when any upgrades to existing lightning protection systems are to be accomplished. 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. Provided the temperature of the liquid remains below the flash point, combustible liquids stored at atmospheric pressure will not normally release significant vapors; since their flash point is defined to be at or above 100°F (37.8°C).

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N **A.7.1.1** This chapter applies to structures that might contain a Class I hazardous (classified) location in all or only portions of a structure. See Article 500 in *NFPA 70* for information on classified locations.

Sections 7.1 and 7.2 provide administrative information and a discussion on the general principles of the protection of structures containing flammable vapors, flammable gases, or liquids that give off flammable vapors. These are only general principles. Specific requirements for specific applications can be found in the sections that follow.

Section 7.3 provides general protective measures and baseline requirements. These requirements apply to all structures except where specified otherwise for specific structures. It covers all the aspects of protection, but all the requirements might not apply to every structure.

Section 7.4 contains requirements for specific classes of structures. Subsection 7.4.1 provides the requirements for operating facilities and other non-storage applications.

Section 7.5 applies to storage tanks under pressure and Section 7.6 addresses aboveground tanks at atmospheric pressure. Section 7.7 addresses earthen containers at atmospheric pressure.

A.7.1.3 It is recommended that consideration be given to upgrading the lightning protection systems to the current requirements not only during new construction but also for reconstructed tanks and any external floating roof tank that undergoes a major roof repair or that has its entire seal system replaced.

A.7.2.1 Hazardous (classified) locations are defined by Chapter 5 of *NFPA 70.*

N **A.7.2.1.2** Systems should be designed to control the air-to-vapor ratio and maintain that ratio at a level that is not flammable to mitigate ignition.

N **A.7.2.2** A structure is considered inherently self-protected from the effects of lightning if, by construction and perhaps intended design, components of the installation are sufficient to protect against direct strikes, strikes near a structure, strikes to an incoming line, and strikes near an incoming line. In such cases, additional lightning protection is not required.

In practice, such structures are uncommon due to the presence of structural vulnerabilities that undermine the inherent self-protection. These structural vulnerabilities include, but are not limited to, the following:

(1) Vents that compromise the seal
(2) Valves or other appurtenances that provide a location for secondary arcing *(see 7.5.2)*
(3) A floating roof that is not sufficiently bonded to the tank shell
(4) Primary and secondary seals that do not completely prevent the escape of flammable vapors
(5) Any electronic equipment that requires SPDs
(6) Any structure that permits the accumulation of flammable vapors

For structures containing flammable gases or vapors, protection should also include procedures to prevent the accumulation of gases or vapors that would require classification of the location where direct strikes or arcing is likely to occur.

A.7.3.3.2 Sparks or damaging impact at the striking point could also be experienced. This should be taken into consideration in the determination of air-termination device locations. For example, US Army Ammunition and Explosives Safety Standard DA-PAM 385-64, *Ammunition and Explosives Safety*

Standards, requires that air terminals on structures containing explosive materials that are located at vents emitting explosives vapors under natural draft be at least 5 ft (1.52 m) higher than the vent. For vents where explosive gases are emitted under forced draft, the air terminals are required to be at least 15 ft (4.5 m) above the vent.

A.7.3.4.3 Where it is not practicable to install down conductors external to the hazardous locations, the following should be considered:

(1) The down conductor passing through the hazardous location should be continuous (i.e., without splices).
(2) Where the minimum autoignition temperature of the hazardous environment is less than or equal to 160°F (70°C), the down conductor should be installed in a nonmetallic enclosure suitable for the hazardous area.

N **A.7.3.6.3** Additional guidance on the installation of surge protection in hazardous (classified) locations can be found in Sections 501.35 and 502.35 of *NFPA 70 (NEC)*.

A.7.3.7 A 20 ft (6 m) diameter or larger vertical cylindrical tank resting on earth or concrete or 50 ft (15 m) diameter or larger vertical cylindrical tank resting on bituminous pavement can be substituted for the ground ring electrode.

A.7.3.7.3(1) It is possible to ground metal tanks by utilizing buried pipe in direct contact with earth. The shorter the distance from the tank to the point of entry to earth, the greater the efficacy of the ground. For a pipe or piping system to be considered a grounding electrode, it should be electrically continuous and buried in direct contact with the earth for at least 10 ft (3 m). Generally, the more pipe that is in contact with earth, the more effective it will be in serving as a grounding electrode. Multiple grounding electrodes are better for grounding metal tanks. If only one ground entry point is available, additional buried length of pipe should be considered. See 4.12.5 for requirements for length of radials.

A.7.4.1 For structures in which a hazardous (classified) location exists in only one part of the structure, a risk assessment utilizing the lightning protection zone (LPZ) concept in accordance with IEC 62305-2, *Protection Against Lightning — Part 2: Risk Management*, is recommended.

The lightning risk assessment provided in Annex L does not currently incorporate the concept of defining multiple LPZs in a structure, but the methodology for the assessment is given below.

An LPZ is characterized by a common set of lightning risk components and not necessarily by walls or other physical barriers. LPZs are generally used to address risks related to a specific area(s) in or around a structure. They are associated with specific characteristics of susceptibility to lightning-related threats. A structure might be characterized as a single zone or it could be divided into multiple risk zones, where each risk zone is defined by a common set of relevant risk components.

The advantage of using the LPZ concept can be seen where only a portion of a larger structure needs to meet the requirements of Chapter 7 and the cost of protecting the structure as a single zone would be greater than mitigating the risk in that zone. Dividing the structure into lightning protection zones enables each zone to be assessed individually to determine whether measures could be taken within that zone to reduce risk to a tolerable level and not require the measures to be implemented throughout the structure.

In such cases, the characteristics of each zone in the structure must be evaluated, taking into account each risk component relevant to that zone. This enables the most suitable protection measures to be applied to each risk zone, tailoring the protection against lightning for specific applications.

A.7.6.1 For fixed roof tanks (metallic cone or dome) and internal floating roof tanks, there is a possibility of flammable vapors being present at atmospheric vents. If present, flammable vapors can be ignited by a lightning flash. Bonding techniques to prevent discharge between the floating roof and the shell are addressed in API 650, *Welded Steel Tanks for Oil Storage*, Appendix H. Tanks handling low–vapor pressure materials or in-service tanks with properly maintained floating roofs with tight-fitting seals are not likely to have flammable vapors at atmospheric vents unless they are being refilled from empty. In these cases, no further lightning protection is required.

A.7.6.2.1 Sliding contacts between the tank floating roof and tank shell are used to conduct the short and intermediate components of lightning-stroke current.

A.7.6.2.1.2 Refer to API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*. Shunts are used for conduction of fast- and intermediate-duration components of lightning-stroke current.

A.7.6.2.1.2(7) API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*, recommends a minimum service life of 30 years.

A.7.6.2.2 Fixed contacts, such as bypass conductors, are used for conduction of the intermediate- and long-duration component of lightning-stroke current.

A.7.6.2.2.7 API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*, recommends a minimum service life of 30 years.

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N **A.7.8** The requirements of this section are not applicable to nonmetallic tanks. Considerations for nonmetallic tanks are discussed in Annex N and are not within the scope of Chapter 7.

N **A.7.8.3** Consideration should be given to interconnecting the grounding electrode for the site appurtenance discussed in 7.8.3 to the battery grounding system, depending on proximity.

N **A.7.8.5** A method of venting in locations where arcing is likely to occur is to install a vapor recovery system or, at a minimum, a horizontal vent line that terminates at least 50 ft (15.2 m) from the tank battery.

All vents, flame arrestors, and thief hatches should be maintained in operating condition. All thief hatches should be closed during normal tank operations.

N **A.8.1** An AHJ might elect to omit the installation of a lightning protection system when all of the following conditions are met:

(1) The facility is served by an approved local lightning warning system as determined by the AHJ, and the lightning warning system permits explosives operations to be terminated before an approaching thunderstorm is within 10 mi (16 km) of the installation. Data by López and Holle, "Lightning Casualties and Damages in the United

States from 1959 to 1994," suggests that a minimum warning distance of at least 6 mi to 8 mi (9.6 km to 12.8 km) is required to ensure that there is no significant damage from a lightning strike.

(2) All personnel are evacuated to a shelter providing adequate protection.

(3) The resulting damage and loss from a lightning strike are acceptable to the AHJ. Annex L provides guidance for performing a facility risk assessment.

(4) The facility contains only explosive materials that cannot be initiated by lightning and no fire hazard exists, as determined by documented tests and analyses and approved by the AHJ.

(5) Injury to personnel is not expected; there is minimal risk of economic loss in relation to the structure, its contents, or the surrounding facilities; and the potential resulting damage and loss from a lightning strike is acceptable to the AHJ.

A.8.3.2 The best method to protect extremely sensitive operations from all sources of electromagnetic radiation is to enclose the operations or facility inside a metallic, "Faraday-like" cage. A metallic, Faraday-like cage is an enclosure that comprises a continuous grid of conductors, such that the voltage between any two points inside the enclosure is zero when the cage is immersed in an electrostatic field. A metallic cage or Faraday shield lightning protection system is one in which the protected volume is enclosed by a heavy metal screen (i.e., similar to a birdcage) or continuous metallic structure with all metallic penetrations bonded. The lightning current flows on the exterior of the structure, not through the interior. A Faraday-like shield, which is not an ideal Faraday cage, is formed by a continuous conductive matrix that is properly bonded and grounded.

A freestanding structure that is determined by the AHJ to be a metallic cage or Faraday-like shield might not require either grounding systems or strike termination devices. Use of a strike termination system on these structures provides a preferred attachment point for lightning and could prevent structural damage, such as concrete spall, from direct lightning attachment.

The intent of this type of structure is to prevent the penetration of lightning current and related electromagnetic field into the object to be protected and prevent dangerous thermal and electrodynamic effects of current as well as dangerous sparking and overvoltages for electrical and electronic systems. Effective lightning protection is similarly provided by metallic structures such as those formed by the steel arch or the reinforcing steel in the walls and floors of earth-covered magazines (also referred to as bunkers, huts, or igloos) if the steel reinforcement is bonded together and it meets the bonding resistance of 8.10.7.1.

A.8.3.3 The isolation of the down conductors from the structure will reduce the magnetic field strength in the structure and the probability of a sideflash from a down conductor.

A.8.3.3.2 It is recognized that some partial lightning current will flow on a mast guy.

N **A.8.3.3.5** A significant difference in the resistance to earth of grounding systems can result in a significant difference in current division from an attachment point on the lightning protection system. For lightning protection systems using mast or catenary systems consisting of three or more masts, the use of a ground ring electrode should be considered. The use of a buried grounding conductor interconnecting systems using two masts should also be considered if there is a significant difference between the value of resistance to earth for the two masts.

A.8.3.5 The spacing dimensions of strike termination devices based upon the 100 ft (30 m) rolling sphere method (RSM), with terminals 12 in. (300 mm) tall, are 25 ft (7.6 m) at the center of the roof, 20 ft (6.1 m) at the roof perimeter, and 24 in. (600 mm) set back from the outer end of roof ridges. For terminals 24 in. (600 mm) tall, the dimensions increase to 35 ft (12 m) at the center of the roof, 20 ft (6.1 m) at the roof perimeter, and 24 in. (600 mm) set back from the outer end of roof ridges.

N **A.8.4.2** Section 4.12.2.5 allows for the use of copper-clad steel and stainless-steel ground rods; however, AHJs should understand that installation of these rods in some conditions and locations can greatly affect their serviceability over the expected lifecycle of the lightning protection system. Soil conditions with rocky or larger gravel concentrations can abrade copper cladding, exposing the steel core to corrosive elements that can greatly diminish the performance and effectiveness of the electrode over time. Acidic and corrosive soil conditions can adversely affect the lifespan of stainless-steel grounding electrodes.

N **A.8.4.2.4** A conductor with a cross-sectional area of 105,000 circular mils ensures that cables can remain serviceable over the lifecycle of the system.

N **A.8.4.2.5** The effectiveness of concrete-encased electrodes can be drastically influenced by their design and implementation. It is recommended that AHJs fully understand the design characteristics that influence the effectiveness of concrete-encased electrodes as they pertain to their applicability in conducting lightning energies into the earth. The design requirements of 4.12.3.1 and 4.12.3.2(1) and 4.12.3.2(2) are particularly influential in the effectiveness of the concrete-encased electrode's ability to perform and function and to transfer lightning energies into the earth and should be confirmed.

A.8.5.4 Welding includes exothermic welding.

A.8.5.5.1 All internal metallic door frames (and metallic doors through bonding to the frames) should be considered for bonding to the ground ring electrode.

A.8.5.7 Hazardous arcing can occur between rail cars and structural members, bollards, metallic barricades, etc., where the rail cars are stored or unloaded inside a structure. Bonding of the track to the structure or its grounding system at the entry point to the structure can maximize the safe separation distance between explosive-ladened rail cars and grounded structural components.

N **A.8.7.1.1** The AHJ should determine the necessity of the placement of strike termination devices other than headwalls, ventilators, or other metal bodies. When an earth-covered magazine can provide metallic (Faraday-Like) cage protection, as defined in 8.3.2, non-metal bodies that do not penetrate the structure can be omitted from consideration for strike termination protection.

A.8.7.2 The purpose of the lightning protection system requirements expressed in 8.7.2 is to protect the explosives positioned on these structures from being ignited by direct lightning strikes. Open-air explosives staging areas on a wharf will generally require lightning protection from a mast or catenary system. A ship alongside an explosives-handling wharf is capable of providing a zone of protection for a section of the explosives-handling wharf and could be considered to provide a zone of protection for an explosives staging area.

A.8.7.2.4 The conductors between the deck-level potential equalization network and grounding electrodes should be provided at or near the location of lightning protection masts or catenary cables where practicable.

A.8.7.2.5.3 The grounding electrodes should be submerged below the 100-year drought water level.

Δ **A.8.7.4** ISO containers meeting the requirements of ISO 1496, *Series 1 freight containers — Specification and testing — Part 1: General cargo containers for general purposes*, are sometimes used for temporary storage of various explosives materials, such as small arms in ammo boxes, various weapons system configurations in shipping containers, commercial explosives, fireworks, and so forth. Because the metal frame of a properly maintained ISO container does not meet the metal thickness requirement for strike termination devices, there could be burn-through caused by some strikes. The metal frame will provide some protection from lightning electromagnetic effects and the surface area contact of the superstructure on the local earth will provide some impedance to earth. These provide protection against the effects of lightning for some configurations and sensitivity of contents, but not all. In some cases, it might be necessary to provide strike termination devices, additional bonding, and grounding of the ISO container. Whether the ISO container is to be supplemented by lightning protection is a decision for the AHJ to make based on a risk assessment of the sensitivity of the container's contents.

A.8.9 The effectiveness of any lightning protection system depends on its installation, its maintenance, and the testing methods used. Therefore, all installed lightning protection systems should be properly maintained. Proper records of maintenance and inspections should be maintained on each facility to ensure adequate safety. These records are part of the lightning protection requirements and should be maintained.

N **A.8.10.6.3** The manufacturer's installation instructions or product markings might provide additional criteria or guidance on how and when to inspect, test, and maintain equipment providing surge protection.

A.8.10.7 The instrument used in earth resistance testing should be capable of measuring 0 ohms to 50 ohms, ±10 percent. The instrument used to measure bonding resistance should be capable of measuring 0 ohms to 10 ohms, ±10 percent.

A.8.10.7.8 Assistance in determining a qualified person can be found in *NFPA 70E*.

A.9.1 Modern turbine blades are typically constructed of composite materials such as carbon or glass-reinforced plastic. Some parts and discrete components such as mounting flanges, balancing weights, hinges, bearings, wires, electrical wiring, and springs are made of metal. Lightning strikes blades that have metallic and nonmetallic components. The technical challenge in designing lightning protection of wind turbine blades is to conduct the lightning current safely from the strike attachment point to the hub in such a way that the formation of a lightning arc inside the blade is avoided. This can be achieved by diverting the lightning current from the strike attachment point along the surface to the blade root, using metallic conductors either fixed to the blade surface or inside the blade.

Typically for blades up to 60 ft (18 m) long, receptors at the tip of the blade are adequate. However, it might be necessary for longer blades to have more than one receptor to obtain the desired interception efficiency. Protection of the blades is provided by the blade manufacturer and is typically an integral part of the blade.

Any wiring for sensors placed on or inside blades should be protected via bonding to the down conduction system. Wiring should be either shielded cables or placed in metal tubes. The cable shield or metal tube should be placed as close as possible to the down conductor and bonded to it.

A.9.1.2 This protection is addressed by specific manufacturer product approval standards.

N **A.9.2.5** A hub is also referred to as a spinner.

A.9.2.6 A tubular metal tower, as predominantly used for large wind turbines, usually fulfils the dimensions required for down conductors stated in NFPA 780 and IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*, and can be considered an effective electromagnetic shield.

A.9.4.1 Consideration should be given to design requirements for power generation facility grounding, including sizing of conductors for fault currents and requirements for touch and step potential.

A.9.4.2 Additional vertical or horizontal grounding electrodes could be used in combination with the ground ring electrode.

A.10.1.2 A lightning protection system does not afford protection if any part of the watercraft contacts a power line or other voltage source while in water or on shore. A lightning protection system lowers but does not eliminate risk to watercraft and its occupants.

A.10.2.2.4 Carbon fiber fittings, including masts, should be isolated electrically from the lightning conductor system. Since carbon fiber is a conductor, sideflash risk is increased in the vicinity of carbon fiber composite (CFC) structures, especially near the water. The use of CFC reinforcement in areas such as chainplates is to be avoided.

A.10.3.1 The techniques described in Chapter 10 should also be applied to watercraft for the placement of strike termination devices and determining the zone of protection.

A.10.3.2.1 Where a standing person is not covered by the zone of protection, a warning to this effect should be included in the owner's manual.

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

A.10.4.1.1 See Table 9.12.5(a) of NFPA 302 for minimum strand sizes for watercraft conductors. Main conductors of greater cross-sectional area as discussed in Section 4.8 provide a greater degree of safety.

A.10.4.1.3 If a metal with the area given by the equations in 10.4.1.3 is subject to the lightning heating (action integral)