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Lightning Conduction System: Design Concepts & Components For Trees

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Trees have great value. The architectural, ecological, aesthetic, engineering, and cultural assets trees represent to a homeowner or a community is large. A small portion of asset value must be reinvested in sustaining health and structural integrity. Installation of lightning conduction systems in trees is a significant investment. System installation is a professional specialty within arboriculture. Only historic, socially significant, and high value trees usually merit the attention and expense of a lightning conduction system. As more recreational activities are impacted by liability risks associated with weather, many more average trees (but critically positioned) are candidates for protection.

Storms have great forces which load a tree -- ice, wind, rain, snow, hail, etc. Trees adjust to average wind conditions over time with specialized structural materials positioned in key locations, plus a variable safety factor. Lightning events cannot be prepared for by a tree's growth system, only responded to. Lightning can heat, burn, blow apart, kill, and shatter tree structures. In one flash, a one-hundred-year-old tree can be destroyed and lost. More people are realizing the values in their trees and are taking active steps to defend trees from most lightning impacts.

Candidate Trees

Installation of a properly designed and grounded conduction system made of the proper materials can minimize lightning damage to trees. Some considerations for installation of a lightning conductance systems in trees are:

-- Rare, valuable, and specimen trees, especially when centers of landscapes;
-- Trees which shade or frame recreational areas like golf courses, pools, ball diamonds, bleachers, boat houses, and patio areas;
-- Of special significance, like historical or culturally important trees;
-- In high lightning risk areas or presenting strong ground streamer potentials (enhanced field effects);
-- Large or important trees around and along parks, streets, and public buildings in order to minimize liability risks;
-- Closer than 30 feet to, or a crown overhanging, unprotected structures or buildings;
-- Within 30 feet of a metal well casing, metal water or gas lines, or metal irrigation systems;
-- Representing a significant appraised value in a landscape.

There are many reasons for a tree to be a candidate for a lightning conduction system. Protecting the current and future benefits generated by and flowing from a tree with installation of a lightning conduction system is good management and a good investment.

Protection Concepts

Tree lightning conductance systems are a health care option to consider in especially valuable or vulnerable trees. Lightning conductance systems have a number of unique components which tree health care professionals need to understand. What follows is a brief review of definitions. It is critical to understand coverage here is not meant as an installation guide. Always seek assistance of professional lightning conductance and tree protection specialists. You must seek out and consult the most current national standards, industrial installation guidelines, and best management practices for installing lightning systems in trees. Review Figure 1 for system terms and positions.

Functional System Name

The hardware placed in a tree to effectively conduct lightning between cloud and ground is termed a "lightning conduction system." Installation of a lightning conduction system in a tree is to minimize damage to trees for a large proportion of lightning strikes, and is termed "tree protection." Lightning conduction systems in trees do not significantly attract more lightning. The probability of a lightning strike is marginally increased by installation of a lightning conduction system, but preventing tree damage is greatly reduced. (Uman 2008)

System Purpose

The purpose of a lightning conduction and tree protection system is to effectively conduct electrical charge potential between cloud and ground in a way which minimizes tree damage. Trees are not good conductors of electricity, but can act as a better conduit than air. Lightning conduction systems do not prevent all tree damage, just minimize injury. Extremely large (>250kA) and extremely small (<3kA) lightning discharges can not be completely handled by most lightning conduction systems in trees

Cost-Effectiveness

Tree lightning conductance systems are relatively expensive in labor and materials. Not all trees are candidates for installation of a protection system. Lightning conduction systems must be installed properly with correct materials to insure long term protection. For example, aluminum should not be used for any component or link in a system. It is essential to consult with a trained arborist or urban forester, and a lightning conductance system installer, before designing a protection system for a tree. Use lightning strike risk assessments on candidate trees to help determine the need for installation.

Air Terminals

A primary component of a tree lightning conduction system is an air terminal (air point). Figure 2. The top of the down-cable should be attached firmly to an air terminal. This is either a rounded or pointed solid copper alloy object which provides an effective ground streamer anchor point near the top of a tree. The air terminal is held away from the stem several inches by metal pylons. The air terminal is shallowly but firmly screwed into the stem. Air terminals should not be attached using any type of bands running around the circumference of the stem.

Air terminals or points should be firmly attached as high into the tree crown center as can be safely accessed. Ideally air terminals should be placed in the crown at least 80% of the height of the tree. Air terminals are acceptable as low in the tree crown as just above major branch attachment points, understanding the tree portion above the air terminal can be severely damaged by any lightning strike. Blunt or rounded air terminal tips are more effective than sharp points. Figure 3.

Down-Cables

Another one of the primary components of a tree lightning protection system is the down-cable. A down-cable should run between the highest accessible part of a tree, along the stem, into the ground, and away from the tree. The top-most terminal end of the down-cable should be tightly fastened to the tree and to a solid copper or copper-bronze air terminal. The bottom-most terminal end should be tightly fastened to a solid copper or copper-bronze ground rod.

A multi-strand, woven, hollow-core copper or copper alloy cable can be used for the down-cable. Figure 4. Any bends in the cable should be minimized and then be gently sweeping, not abrupt and sharp. Down-cables are attached to the tree and held several inches away from periderm by metal pylons spaced about three feet apart and shallowly screwed or tacked into the tree. Down cables should not be painted.

As the cable is attached to hold-off pylons along a tree stem, the tree should be divided into three segments based upon stem movement. The lower third should not significantly sway and will only wobble up and down across the root plate no more than about 3/4 inch. The middle third of the tree is subject to significant bending, twist, and swaying in the wind. The upper third or outer third of the tree is subject to large deflections approaching 70-80 degrees. The down cable must be installed in such a way to allow for these normal tree movements and not pull out connectors or pylons. The amount of cable slack must be progressively increased with height.

In extremely large stemmed or widespreading trees with large crown volumes, two down cables with separate but connected grounds on opposite sides can be installed. The above ground portions of this double system should be interconnected at least every 30 feet.

Approaching Ground

As a down-cable is placed running down the stem and installation approaches the soil surface, a gentle curve should be installed to allow the cable to run away from the tree horizontally 1.5-2 feet below ground parallel to the soil surface. The curve should not exceed an 12 inch radius, or reach or exceed a 80^{o} angle.

A neutral, soil, or bark colored, loose open conduit or casing (i.e. 3mm thick polyethylene pipe) should surround the down cable from about 1-2 feet above the soil surface to well below the soil surface and away from the tree base. The open lower end of the conduit must provide drainage of any accumulated precipitation or irrigation water. This conduit should be anchored below ground along with the down cable. In special circumstances, conduit 3-10 feet above the soil surface attached to the stem may be used if animals, humans, or machines could damage the integrity of the system, or have touch contact in a storm. The chances of side flash, surface arcing, and step voltage disipation will not be significantly changed.

Cable Lay-Out

The down-cable runs along a tree stem and into the ground at a tree base. The down-cable is gently bent in a wide curve from the stem base into the ground. The down-cable is then put into a soil trench at least

1.5-2 feet deep in soil and extended away from a tree. The distance away from a tree depends upon grounding efficiency / electrical resistance, potential tree damage, and other site features. The down-cable should be gently curved or turned down at its far end (ground rod end) and ran downward to connect with the vertical ground rod driven 1.5-2 feet below the soil surface. This is a connection at greatest risk of failure and needs periodic visual inspections.

Ground Rods

Another primary component of a tree lightning conduction system is the grounding rod. Lightning conduction systems must be properly grounded in order to provide for a low resistance charge exchange pathway. Vertically driven, solid ground rods should be at least 1/2 inch in diameter and 8 feet long. Buried wire or woven cable should not be substituted for solid rods. Always test the ground system for actual electrical resistance. Ground rods are usually copper or copper bronze. They are driven into the soil and below the surface 1.5 - 2 feet. (Uman 2008). Ground rod resistance should always be measured, never assumed.

Rod Installation

It is essential ground rods be driven vertically until they are at least 1.5-2 feet below the soil surface and then fastened tightly to the down-cable end. Rods must be driven into the soil to assure a firm contact. Do not dig out soil and bury rods unless the soil can be firmly tamped around the full length of the rod. If soil depth is limited, long horizontal rods packed into trenches or many shorter vertical rods are viable alternatives. The more connections required, the more expensive and more prone to failure over time grounding components become.

Rod ends must be driven into soil to be below any expected soil freeze level, as well as into and below soil water levels, if possible. The top of vertical ground rods should be a minimum of 1.5 feet below grade, but must be placed to remain accessible for inspection. The location of the rod top and the down cable connection point should be recorded or marked for ease of visual inspection and tightening of bolt connectors over time. If multiple vertical rods are required, the distance between rods should be a minimum of two times (2X) rod length, or two times (2X) lowest rod depth reached for vertical rods..

Rod Placement

Grounding methods differ in different soils. Normally, driving a rod vertically into soil producing lengthwise soil and soil-water contact is sufficient. Where soil space is limited or soils are shallow, forking the cable and burying (tamped in firmly!) several rods in separate trenches as deep as possible is acceptable.

Grounding rods should be placed at some distance from the stem base, depending upon a number of soil, site, and tree features. Minimizing significant root damage is one aspect of effective ground rod placement. Ground rod depth, distance between rods, and the amount of moist soil contact are critical for proper grounding.

If soil depth is limited, horizontal buried rods arranged in several configurations within trenches are viable alternatives. The coarser the soil texture, and the more gravel, rocks, or cobbles present, the longer the trench and number of interconnected rods required. Shallow soils with large components of sand and gravel should have a minimum 25 feet long rod buried horizontally at least 2 feet deep. Shallow soils composed primarily of clay should have a minimum 15 feet long rod buried horizontally at least 2 feet deep.

Ground Effectiveness

The effectiveness of grounding rods is dependant primarily upon soil water contents. Dry soil problems (high resistance values) occur around foundations, basements, or tunnels where soils have been modified or materials added to prevent water movement. These areas should be avoided for ground rod installation.

Soil amendments, organic material, or mulch which lighten or protect soils can have a high resistance when dry. These materials have moisture levels which fluctuate greatly through wet and dry cycles. Artificial soils and soils mixed for a variety of landscape purposes may not provide good contact or effective grounding volumes, and so, should be avoided for rod installation. Remember, large soil ground volume is more critical than meeting simple resistance values.

For most grounding, an electrical resistance of less than 25 ohms is minimally acceptable and less than 10 ohms is desirable. Measure electrical ground resistance of tree lightning conduction systems. If large resistance values are measured, installation of extra ground rods will be necessary. The whole system is worthless if not adequately grounded. When measuring electrical resistance in a tree lightning conduction system, any noticeable increase in resistance over time would suggest impending system component failures (usually connectors), corrosion of surfaces and connectors, or long-term or short-term soil water changes.

Coder Grounding Distance

The down cable should be buried in a radial trench running away from the tree base and end with a rod connection a minimum of 16 feet away from the tree base. Under normal, non-soil limiting conditions, the minimum distance away from a tree where the grounding rod (or first grounding rod in a multi-rod system) should be driven is calculated using the Coder Tree Grounding Distance formula as follows:

Minimum Distance in feet from Tree Base for Driving First Ground Rod =

(0.45 X tree diameter in inches) + (1.6 X grounding rod length in feet)

Figure 5 provides the minimum distance in feet away from a tree stem base for inserting a vertical grounding rod which is 8 feet long. The objective in using the Coder Tree Grounding Distance formula is to minimize and avoid major tree root impacts.

Connectors

Everywhere component touch and are connected, they must securely overlap by 2-3 inches. Clamps, bolts, and heat / arc bonding should be used. Brazing and welding overlapping connectors are considered excellent bonding. Each connection should test less than 10 milliohms resistance. Bolts and clamps of overlapping components are considered good or acceptable. Crimped connections should not be used. All connectors should be made of copper / copper-bronze. Figure 6.

The value of all parts of a tree lightning conduction system lies in how each is connected. The tree protection system is only as good as its poorest connection. Down-cables and associated connectors are impacted with thousands of foot pounds of mechanical and magnetic force, plus rapid heat expansion forces, with each lightning stroke. Connectors and any curves in the down-cable are where these forces can be concentrated.

All connection hardware must be easily located for visible inspections. Connectors that cannot be readily inspected put systems at risk of failure over time. Cable connectors which tightly hold and overlap cable ends can be used along the down-cable, but should be minimized above ground and never used below ground. Any connector in the system must hold at least two inches of cable overlap and be able to accept more than 250 lbs of tension and compression force. Bolt connectors between cables and rods are always preferable to any crimped connectors.

Stand-Off Pylons

Pylons are short metal pegs which keep the down-cable at least 2 inches away from the periderm surface. Figure 7. The are positioned every 3-5 feet along the down cable and firmly attached to the tree. Some have shallow nail points and others use small screws for attachment.

Set-Backs

When a tree with a lightning conduction system grows near a structure / building, lightning behavior suggests a set-back or gap between the protected tree and structure be installed. Figure 8 shows the set-back space needed around a tree with a lightning conducting system installed. The air gap is much larger than the soil gap. For average lightning strikes, the tree grounding system should be separated by at least 8 feet from the structure's foundation and underground services, and by at least 14 feet between air terminal and down cable components of the tree system and above ground structures.

Figure 9 provides an image of the setbacks between the tree system and the structure both above and below ground. The separation between soil metal, utility services, metal well casing, and various pipes and wires is shown. These values are minimum distances. If tree system grounding is going to be closer, a firmly attached and large surface area electrical connection between the tree system and any underground metal service should be made. This figure also provides the ratio between above and below ground set-back distances.

Interconnections

Because peak lightning currents are determined by probability only, a few traditional installation guidelines have been developed over many years. If a tree lightning conduction system is within 30 feet of other lightning conduction systems, metal water pipes, or metal well casings, bonded interconnections should be made. Trees with crown or root base lighting, wiring, metal cables, or other hardware should have all hardware interconnected with the lightning conduction system. Interconnect tree lightning protection system with all metal (like cable and bracing) within the tree growing area.

Trees do not protect adjacent or shaded structures from lightning. Trees within 30 feet of a shorter building, or with branches overhanging a building, should be protected. All lightning systems within 30 feet of each other, like a system on a building and a tree system, should be interconnected. In multiple rod, horizontal or vertical ground systems, the grounding system center and edge should be located. In these cases, the edge of the system should be a minimum of 16 feet away from the tree stem, and moved out away from a tree using the Coder Tree Grounding Distance formula.

Historical Grounding Concerns

In the past, solid or mesh grounding plates or metal sheets were used to lower electrical resistance under severe soil limitation conditions. The use of grounding plates is an expensive and high maintenance system for any reduction in electrical resistance gained, and is not recommended.

In the past, salts were added to help the short term effectiveness of a ground, and would generate false resistance measures. Do not use salts to lower resistance in systems as this leads to temporary changes only, and corrodes system effectiveness. Any surrounding metal objects in a salt laced soil will also be affected.

Never mix different types of metals in below ground parts of a tree lightning conduction system. Different metals in a moist soil environment will react together leading to corrosion. Managerial notice should be issued for accelerated corrosion of other metal parts in the soil area, even if not connected directly to the grounding system. For example, nearby iron water or gas pipes can corrode more quickly near a copper cable, rod, or connector. Aluminum and bare iron should not be present in soil near a tree lightning conduction system.

System Identification

All tree lightning conduction systems should have an identification tag attached with the installer's contact information or unique code number. Maintenance is required to check and reattach connections, and prevent damage to the down cable especially where it enters the soil. All system components should be inspected at least every year, and in particularly valuable trees, after every major storm event.

Side Flash

Because of tree resistance to current flow, side-flash from a tree to objects near them has a strong probability. Trees should be maintained with a minimum of 16 feet clear horizontal crown clearance from any structures. (Uman 2008) Trees taller than a structure should have a horizontal clearance from that structure amounting to 40% of structure height. Any lightning system components on the structure (like a down cable) should be open and facing the tree to facilitate conductivity of side-flashes. Trees with lightning conduction systems can also sideflash. Interconnect (i.e. bond) other system down cables within 16 feet of the tree down cable. More down cables minimize side flash (Uman 2008)

Standards & Practices

There are a number of lightning conduction and tree protection system standards, specifications, and information sets available to assist a tree health care providers understand installation procedures. These materials usually have a creation date and sometimes have a sunset date attached. Use only the most recent approved information. Note a number of building, structural, utility, and communication protection specifications may have a small section on tree protection. Remember, lightning conduction systems for communication towers and tall buildings are not biologically nor structurally designed for living trees.

Citation:

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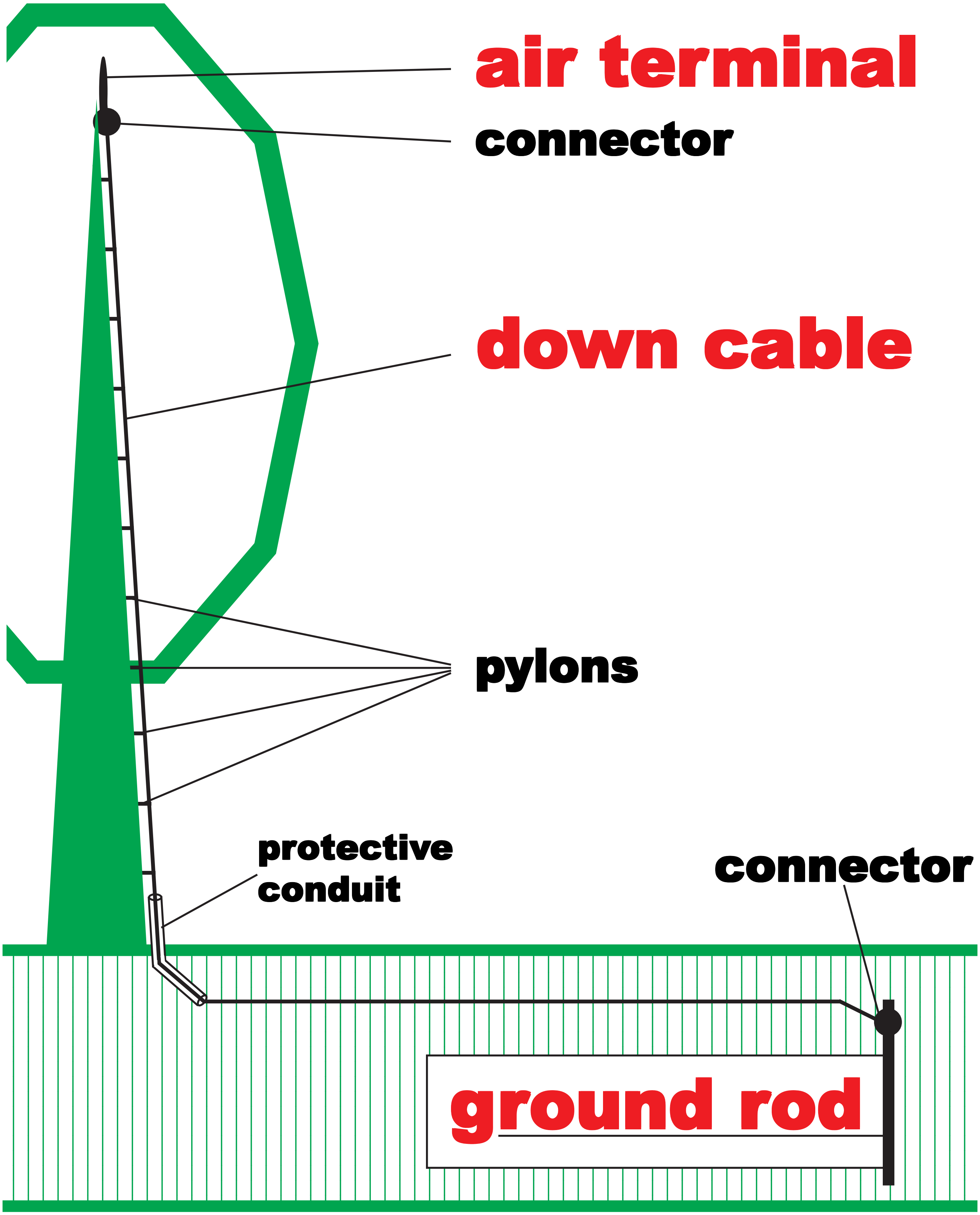

Figure 1: Diagram of a lightning conduction system installed in a tree.

Figure 2: Generic image of pointed air terminal hardware.

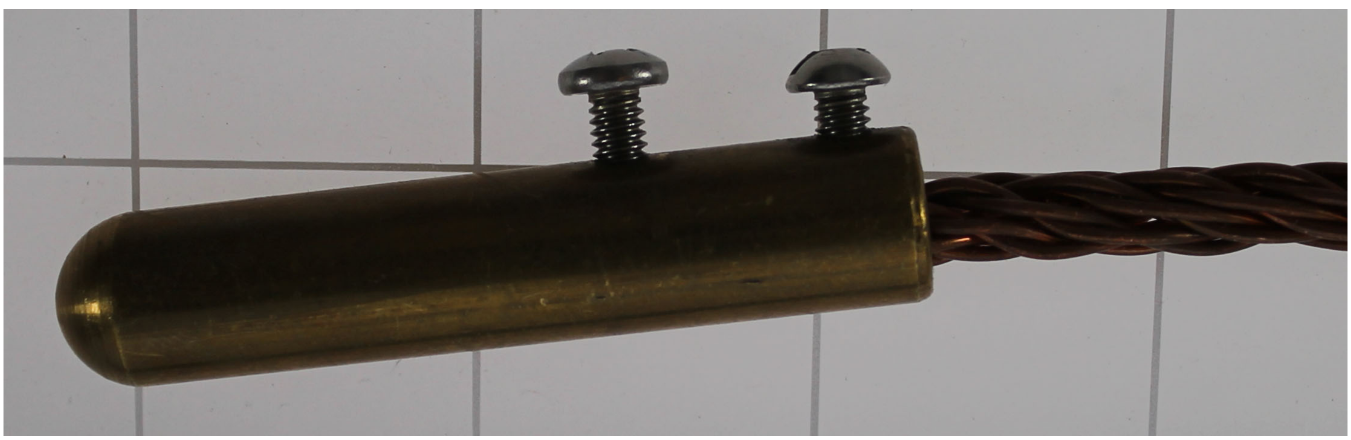

Figure 3: Generic image of rounded air terminal hardware with inserted down-cable.

Figure 4: Generic image of down-cable hardware.

stem diameter (DBH inches)	distance from stem to rod (ft)	stem diameter (DBH inches)	distance from stem to rod (ft)
<8in.	16ft	30	26
		32	27
10	17	34	28
12	18	36	29
14	19	38	30
16	20		
18	21	40	31
		50	35
20	22	60	40
22	23	70	44
24	24	80	49
26	25		
28	25	90	53
		100	58

Figure 5: Minimum distance in feet (rounded values) away from tree stem base for inserting vertical ground rod (8 feet long) in order to avoid major tree root impacts. (Coder Tree Grounding Distance).

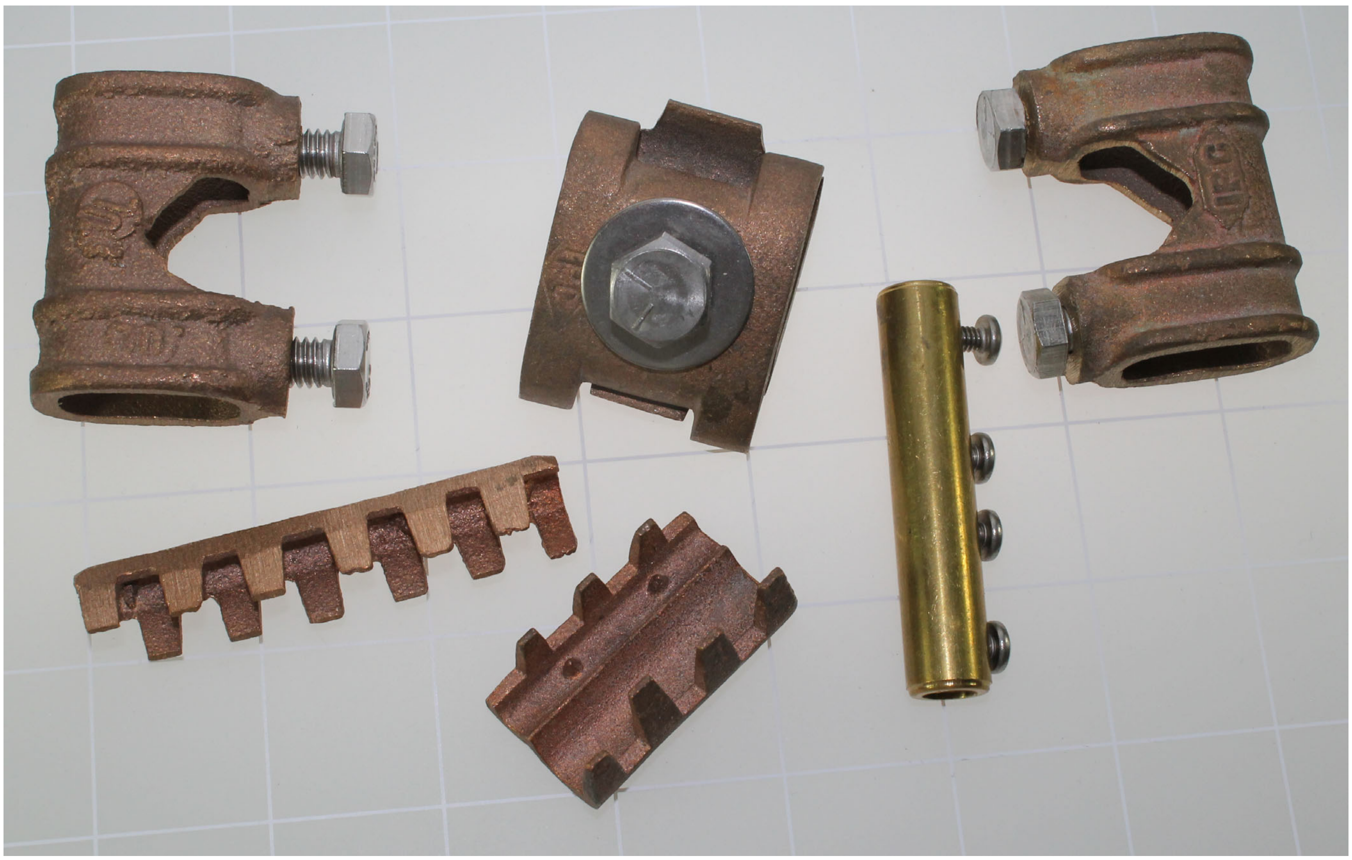

Figure 6: Generic image of various types of connector hardware.

Figure 7: Generic image of stand-off pylon hardware.

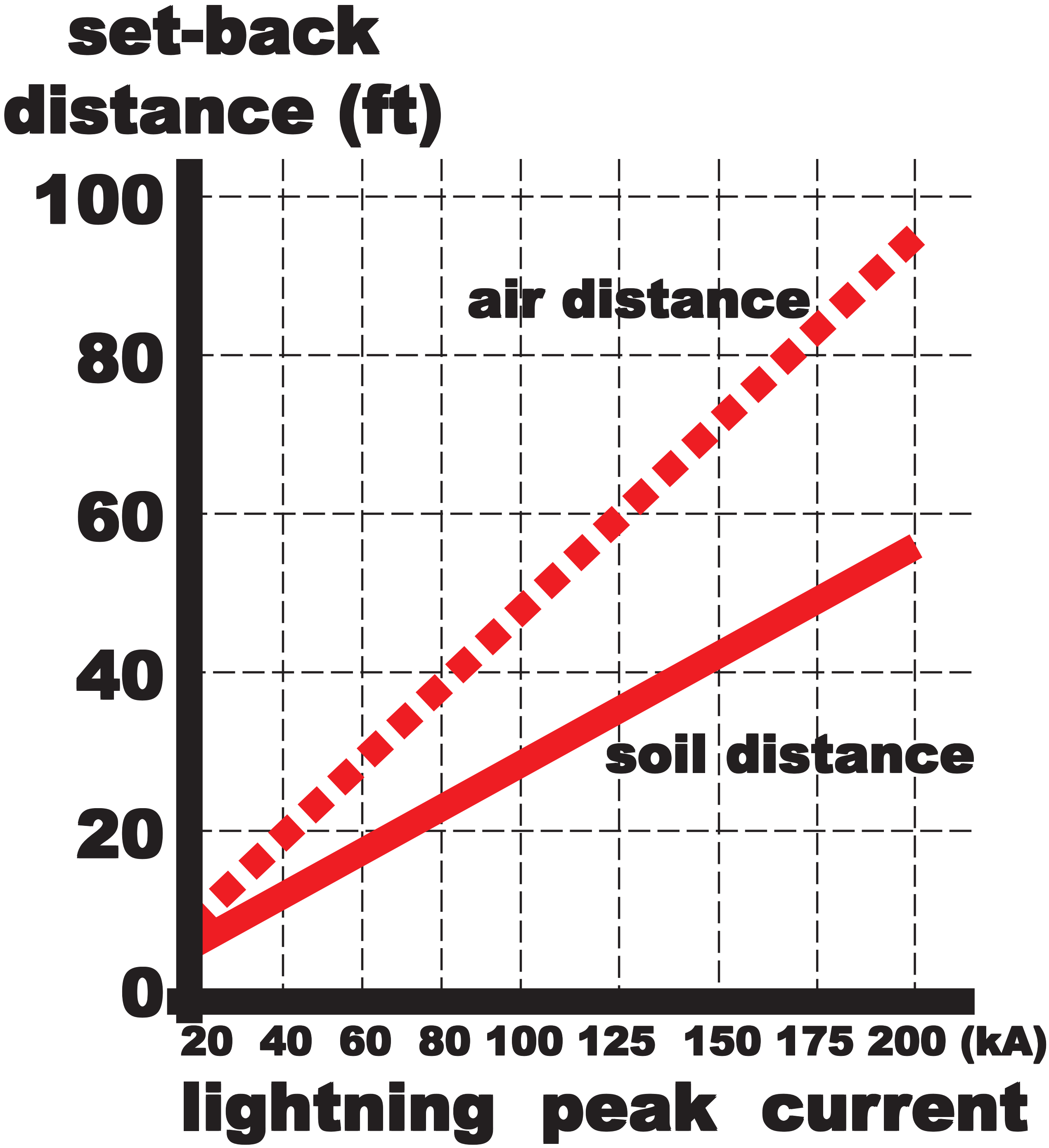

Figure 8: Minimum air and soil distances (in feet) between a lightning conduction system and above ground structures / metal services within a soil for lightning peak current.
(Rakov 2012)

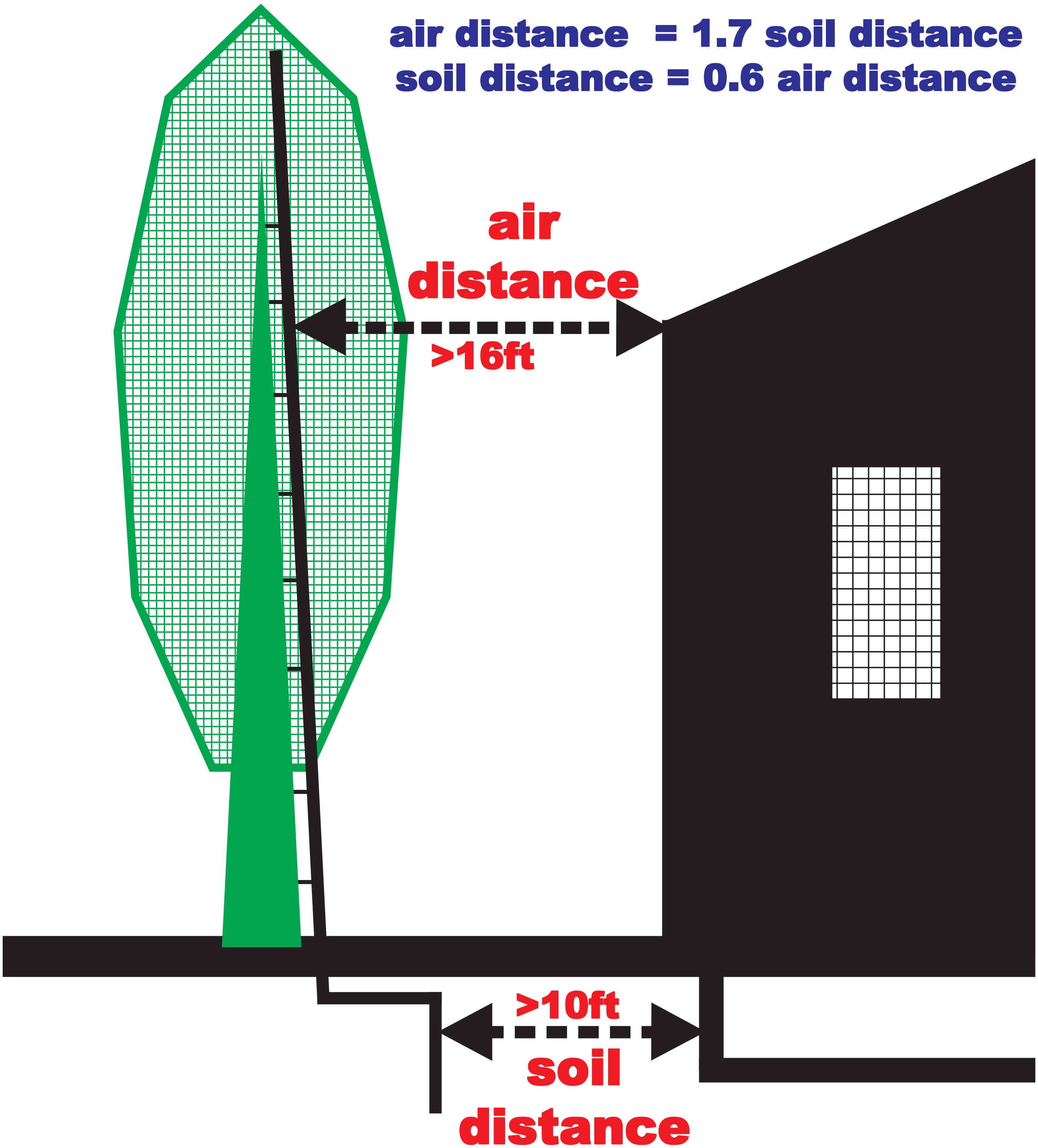

Figure 9: Minimum distances, and ratio of air and soil distances, between lightning conduction system in tree and surrounding structures / metal services above ground and below ground. (Rakov 2012)