

\$28.95 U.S.

Practical Guide To Electrical Grounding

An
ERICO
Publication

W. Keith Switzer

Practical Guide to Electrical Grounding



Electrical Protection Products
34600 Solon Road
Solon, Ohio 44139

W. Keith Switzer, Senior Staff Engineer
Phone: (440) 248-0100
Fax: (800) 677-8131
E-mail: kswitzer@erico.com

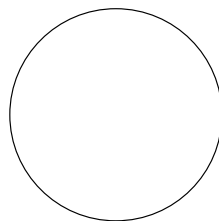
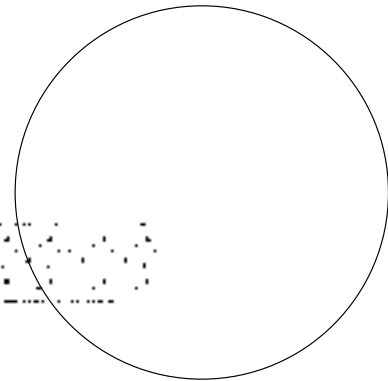
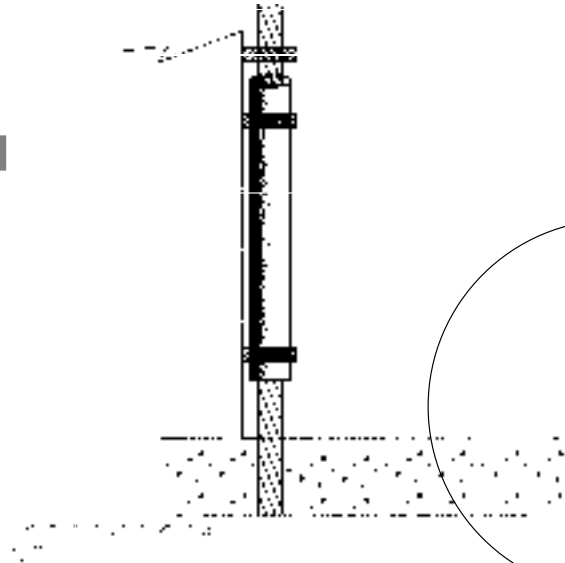
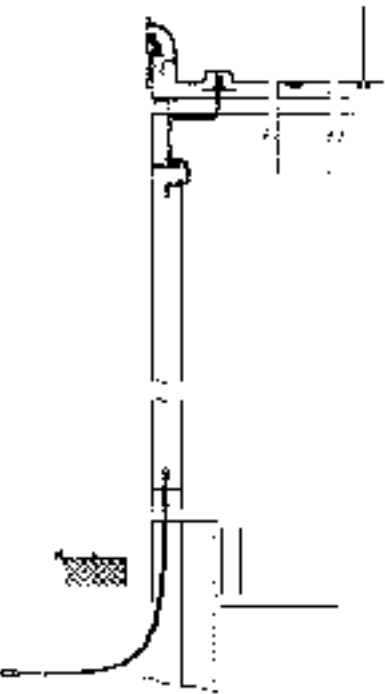
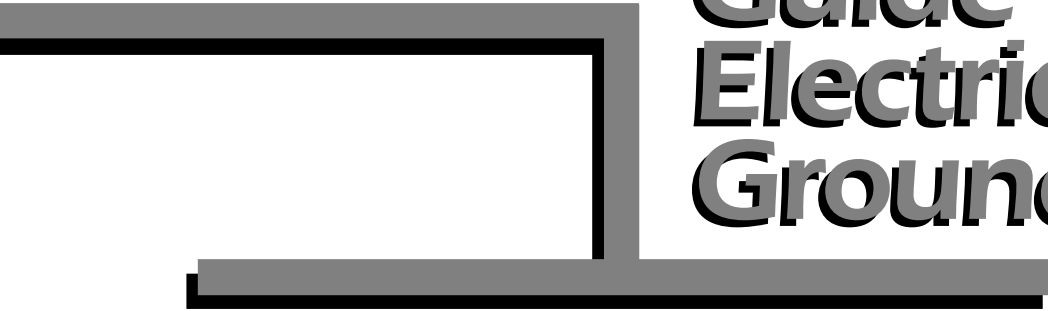
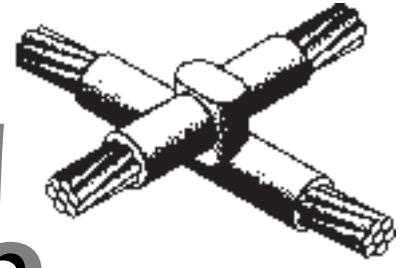
Library Of Congress Catalog
Card Number: 99-72910

Copyright © 1999 ERICO, Inc.

All rights reserved. No part of this work covered by the copyright hereon may be reproduced or used in any form or by any means – graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage and retrieval systems – without written permission of ERICO, Inc.



Practical Guide To Electrical Grounding



An
ERICO

Publication
First Printing, First Edition, August 1999

W. Keith Switzer

Table of Contents

Chapter	Description	Page
①	Building and Service Entrance Grounding - The grounding of buildings and facilities where people work. Building Grounding Ground Resistance Electrical Service Grounding Ufer Grounding	1
②	Building Lightning Protection - A critical extension of grounding.	21
③	Building Interior Bonding and Grounding - The bonding and grounding of building steel, electrical panels and other power systems equipment. Introduction Bonding Grounding Ground Bars & Ground Bus	47
④	Transients & Other High Frequency Bonding and “Grounding” Requirements The bonding and grounding of electronic systems.	65
⑤	Selection of Components Used in Grounding Grounding Conductors Connectors Grounding Electrodes	79
⑥	Special Grounding Situations - Areas not covered elsewhere Airports Corrosion and Cathodic Protection Radio Antenna Grounding Static Grounding Wire Mesh Fences and Gates	89
⑦	Application of Surge Protection Devices	113
	Definitions	119
	References and Bibliography	121

WHY DO WE NEED ANOTHER BOOK ON GROUNDING?

This book is designed for the contractor who finds that installing grounding systems, which are in compliance with all relevant codes and standards, is a complex and somewhat mystifying assignment. While in larger facilities, the design of a proper grounding system is certainly complex and should be left to a qualified engineer, the everyday grounding installations and applications covered in this text are well within the scope of the qualified contractor. In most facilities, a thoughtful contractor can follow the guidelines and techniques in this book and be reasonably ensured that he has done a competent and code compliant job. This book is not written for the casual contractor who was in the painting business last week. It is for the electrical contractor who intends to be in business next week, next year, and in the years to come. Design and installation of electrical grounding systems is one of the most important aspects of any electrical distribution system, yet it is all too often misunderstood and subsequently installed improperly. Some detailed knowledge of the facility is needed, and the contractor who intends to do the job correctly must make the investment in time and tools - or hire someone to do these things for him. Guesswork won't do! The subject is too serious and complex for that kind of approach. We hope you find our recommended approaches helpful and cost-effective.

Article 250 of the National Electrical Code (NEC) contains the general requirements for grounding and bonding of electrical installations in residential, commercial and industrial establishments. Many people often confuse or intermix the terms grounding, earthing and bonding. To use simple terms:

Grounding is connecting to a common point which is connected back to the electrical source. It may or may not be connected to earth. An example where it is not connected to earth is the grounding of the electrical system inside an airplane.

Earthing is a common term used outside the US and is the connection of the equipment and facilities grounds to Mother Earth. This is a must in a lightning protection system since earth is one of the terminals in a lightning stroke.

Bonding is the permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed. A comprehensive review of grounding and bonding requirements contained in the NEC appears in Chapter 3 of this text.

NEC is a copyright of NFPA.

WHY GROUND?

There are several important reasons why a grounding system should be installed. But the most important reason is to protect people! Secondary reasons include protection of structures and equipment from unintentional contact with energized electrical lines. The grounding system must ensure maximum safety from electrical system faults and lightning.

A good grounding system must receive periodic inspection and maintenance, if needed, to retain its effectiveness. Continued or periodic maintenance is aided through adequate design, choice of materials and proper installation techniques to ensure that the grounding system resists deterioration or inadvertent destruction. Therefore, minimal repair is needed to retain effectiveness throughout the life of the structure.

The grounding system serves three primary functions which are listed below.

Personnel Safety. Personnel safety is provided by low impedance grounding and bonding between metallic equipment, chassis, piping, and other conductive objects so that currents, due to faults or lightning, do not result in voltages sufficient to cause a shock hazard. Proper grounding facilitates the operation of the overcurrent protective device protecting the circuit.

Equipment and Building Protection. Equipment and building protection is provided by low impedance grounding and bonding between electrical services, protective devices, equipment and other conductive objects so that faults or lightning currents do not result in hazardous voltages within the building. Also, the proper operation of overcurrent protective devices is frequently dependent upon low impedance fault current paths.

Electrical Noise Reduction. Proper grounding aids in electrical noise reduction and ensures:

1. The impedance between the signal ground points throughout the building is minimized.
2. The voltage potentials between interconnected equipment are minimized.
3. That the effects of electrical and magnetic field coupling are minimized.

Another function of the grounding system is to provide a reference for circuit conductors to stabilize their voltage to ground during normal operation. The earth itself is not

essential to provide a reference function. Another suitable conductive body may be used instead.

The function of a grounding electrode system and a ground terminal is to provide a system of conductors which ensures electrical contact with the earth. Two Fine Print Notes (FPN) that appear in Section 250-1 of the NEC provide a good summary of the reasons for grounding systems and circuit conductors and the conductive materials which enclose electrical conductors and equipment.

TYPES OF GROUNDING

As noted above, grounding and bonding are not the same. In addition, not all grounding is the same. Each chapter or section in this book will describe one or more of the various types of grounding and bonding that are widely used in the electrical industry. Topics of primary interest are:

- Power System Grounding Including The “Service Entrance”
- Bonding
- Grounding Electrical Equipment
- Lightning Protection
- Protection Of Electronic Equipment (Shielding Is Not Discussed)

Grounding is a very complex subject. The proper installation of grounding systems requires knowledge of soil characteristics, grounding conductor materials and compositions and grounding connections and terminations. A complete guide to proper grounding is often part of national and international standards. For example, IEEE Std 80, Guide for Safety in AC Substation Grounding, is a comprehensive and complex standard for only one particular grounding application. This standard is needed for proper substation design in an electric power transmission facility or the power feed to a very large factory. Smaller facilities can use these design guides also, but such an approach may be too costly. This book takes “conservative” shortcuts that allow the design of the grounding system to proceed without undue design effort. We emphasize that the approaches in this book, in order to be conservative and correct, may trade a small increase in grounding components in order to avoid a large engineering expense. Remember that any electrical installation is, and properly should be, subject to a review by the authority having jurisdiction over the electrical installation. Electrical design and installation personnel are encouraged to discuss and review the electrical installation with the authority having jurisdiction PRIOR to beginning any work on the project.

Designers of electrical grounding systems also should find this a handy guide because we have included extensive references to the National Electrical Code (NEC) (NFPA70), ANSI and IEEE Standards as well as other NFPA Standards. It is not the purpose to be a guide to the NEC but we will not make recommendations that disagree with it. Keep in mind that Section 90-1 (c) of the NEC states that the Code is not intended to be used as a design specification. Still, it is difficult to imagine how personnel design and construct electrical systems in the USA without referencing the NEC. Also keep in mind that the NEC contains minimum requirements only. In some cases, minimum standards are not sufficient or efficient for the design project. For example, existing standards do not cover the need to maintain the operational reliability of modern electronic equipment - especially telecommunications and information technology (computer-based) systems. We will cover these situations in this book. Where no standards exist, the ERICO engineering staff can make recommendations based on more than 58 years of successful experience.

While written primarily for readers in the U.S. and Canada, readers from other nations also will find this work useful because it concentrates on cost-effective, proven solutions. This book is written around U.S. standards with references to Canadian Standards. The standards in your country may be different. We welcome your comments. ERICO operates in 23 countries around the globe. We are familiar with most commonly referred standards. If you contact us, we will try to assist you in any way.

A fundamental fact is that electricity ALWAYS flows back to its source. Some designers and installers who accept and use this fact in their designs of power systems, seem to forget it when designing and installing grounding systems. Our job is to ensure that electricity, including faults, lightning and electronic noise, return to their source with a maximum of safety to people while maintaining the reliability of equipment. This means that we must be sure to route the current back to its source with a minimum voltage drop. In many individual situations there are no specific NEC requirements to accomplish this so we will let theory and experience be our guide.

ERICO is publishing this book as a service to our customers and other industry professionals who realize that grounding, bonding, lightning protection and overvoltage protection are an integral part of a modern electrical design. We have referenced many of our products in the midst of a comprehensive technical paper. We acknowledge that there are other good products one could use. ERICO's 70 plus years of experience in designing and manufacturing bonding and grounding products has led us to what we feel

are some of the best, long lasting and cost effective products available. Here we combine these with our knowledge of methods to assist the industry professional in sound choices. It is most often an electrician or electrical worker who is affected by poorly designed ground systems.

All of the drawings (non shaded versions) in this book are available in AutoCAD® .DWG files. These are available through the ERICO CAD-Club™. Please write for information on this no-cost shareware program. We encourage you to join.

This book is designed to be useful immediately. We know, however, that no work is ever really complete. We look forward to your comments (both favorable and not-so-favorable) and suggestions so that future editions may be improved.

ABOUT THE AUTHOR

The primary author of this book is Keith Switzer, who has over 40 years of technical and managerial experience in the electrical industry. He has a BSME degree from Pennsylvania State University. Switzer joined ERICO, Inc. in 1958 and has worked in various engineering departments. He is currently Senior Staff Engineer in the Electrical/Electronic Engineering Section at the ERICO headquarters in Solon, Ohio.

Switzer is a member of IEEE Power Engineering Society, Substations Committee, Working Groups D7 (Std 80, IEEE Guide for Safety in AC Substation Grounding), D9 (Std 837, IEEE Standard for Qualifying Permanent Connectors Used in Substation Grounding), D4 (Std 1246, IEEE Guide for Temporary Protective Grounding Systems Used in Substations), and E5 (Std 998, Direct Lightning Stroke Shielding of Substations.)

He is a member of the Technical Advisory Committee (TAC) of the National Electrical Grounding Research Project (NEGRP), investigating the long-term reliability of various electrodes in various types of soils. He is also a member of the USNG/IEC TAG reviewing proposed IEC standards. Switzer is also a member of American Society of Mechanical Engineers (ASME), Armed Forces Communications and Electronics Association (AFCEA), Insulated Conductors Committee (ICC), International Association of Electrical Inspectors (IAEI), National Association of Corrosion Engineers (NACE), National Electrical Manufacturers Association (NEMA), and Society of American Military Engineers (SAME).

Many thanks to Michael Callanan, Frank Fiederlein, Warren Lewis, Dick Singer and Dr. A.J (Tony) Surtees for their input to this book.

DISCLAIMER

While the staff of ERICO and the outside contributors to this book have taken great pains to make sure our recommendations, pictures and list of references are accurate and complete, we may have missed something. We do not assume responsibility for the consequential effects of these errors or omissions. The designer is still completely responsible for his own work regarding fitness of the design and adherence to applicable laws and codes. In the same manner, the contractor is responsible for following the design and for the installation in a workmanlike manner.

Chapter 1

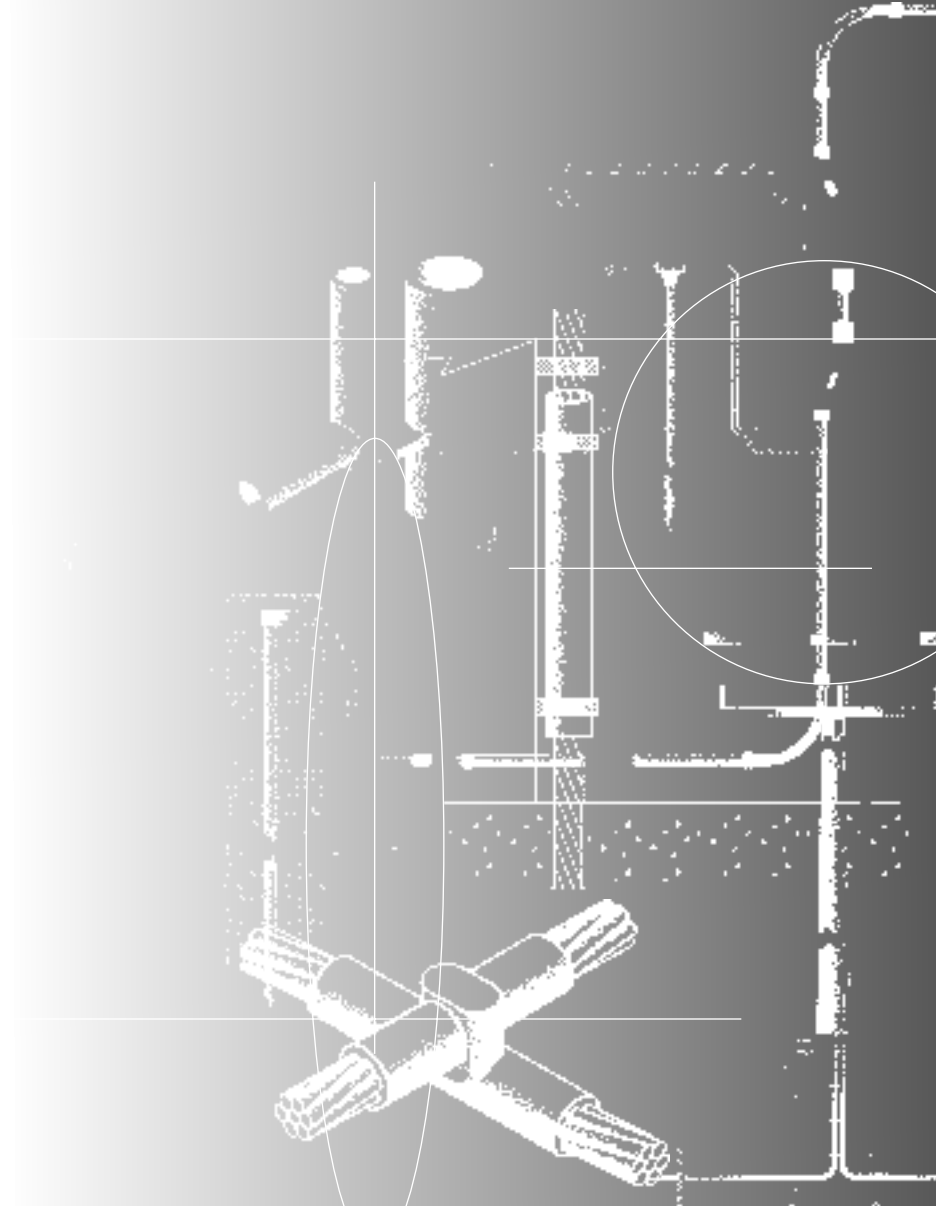
Building and Service Entrance Grounding

Building Grounding

Ground Resistance

Electrical Service Grounding

Ufer Grounding

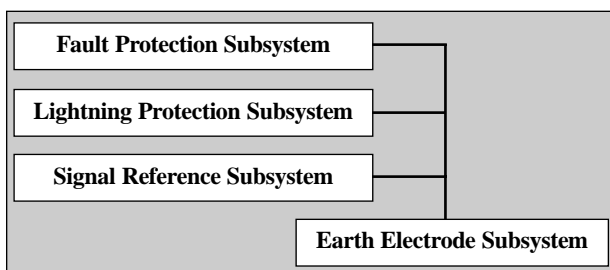


BUILDING GROUNDING — AN OVERVIEW

Despite the electrical designers' best efforts, electrical ground faults, short circuits, lightning and other transients can and often do occur in building electrical distribution systems. ERICO believes that, besides attempting to minimize the occurrence of these faults, designers and installers of electrical grounding systems should design these systems to clear these faults in the quickest possible manner. This requires that the grounding system be constructed to achieve the lowest practical impedance. Many factors determine the overall impedance of the grounding system. Building components, such as structural steel and interior piping systems, can be used to create an effective grounding system. The manner in which these components are installed and interconnected can have a dramatic effect on the overall effectiveness of the grounding system. One of the primary factors that can increase the impedance of the grounding system is the type and manner in which the electrical connections to the grounding system are made. ERICO has a complete line of connectors which can be used to make grounding connections without affecting the integrity of the grounding system. Contractors and others who install these systems cannot underestimate the importance of ensuring that each grounding connection is made in a manner that is efficient and effective.

Interconnected electronic equipment, such as telecommunication systems and computer systems, also require a low-impedance grounding system. Specific bonding and grounding techniques are available and are covered in Chapter 4, which will help to enhance the operation of this sensitive electronic equipment.

Designers and installers of these systems will do well to include all aspects of facilities protection in the initial design. The figure below includes the major subsystems of facilities grounding. Any omission of these subsystems by design personnel is risky at best. Later additions and/or modifications to the system can be very costly.



With these thoughts in mind, let's look at the components of the building grounding system and see how these individual components impact the overall effectiveness of the grounding system.

GROUND RESISTANCE

While many factors come into play in determining the overall effectiveness of the grounding system, the resistance of the earth itself (earth resistivity) can significantly impact the overall impedance of the grounding system. Several factors, such as moisture content, mineral content, soil type, soil contaminants, etc., determine the overall resistivity of the earth. In general, the higher the soil moisture content, the lower the soil's resistivity. Systems designed for areas which typically have very dry soil and arid climates may need to use enhancement materials or other means to achieve lower soil resistivity. ERICO has products available which help to reduce earth resistivity and maintain a low system impedance. See the discussion on GEM™ on page 14.

Ground resistance is usually measured using an instrument often called an earth resistance tester. This instrument includes a voltage source, an ohmmeter to measure resistance directly and switches to change the instrument's resistance range. Installers of grounding systems may be required to measure or otherwise determine the ground resistance of the system they have installed. The National Electric Code (NEC), Section 250-84, requires that a single electrode consisting of rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less shall be augmented by one additional electrode of the type listed in Section 250-81 or 250-83. Multiple electrodes should always be installed so that they are more than six feet (1.8 m) apart. Spacing greater than six feet will increase the rod efficiency. Proper spacing of the electrodes ensures that the maximum amount of fault current can be safely discharged into the earth.

To properly design a grounding system, the earth resistivity must be measured. Several methods can be used to measure earth resistivity: the four-point method, the variation in-depth method (three-point method) and the two-point method. The most accurate method and the one that ERICO recommends is the four-point method. The details of making these measurements and the set-up for the measurements are included with the testing equipment.

BUILDING GROUNDING

Electrical design and installation professionals need to consider several different building grounding systems for any building or structure on which they may work. Building grounding components can be broken down into several subdivisions:

- The building exterior grounds
- The electrical service grounding
- The building interior bonding
- Equipment grounding and bonding
- Lightning protection

This chapter will look at the first two items. Lightning protection will be covered in Chapter 2, interior bonding and grounding will be covered in Chapter 3 and equipment grounding and bonding in Chapter 4.

BUILDING EXTERIOR GROUNDS

It is important to keep in mind that the requirements contained in the NEC constitute minimum electrical installation requirements. For many types of installations, the requirements listed in Article 250 of the NEC do not go far enough. These minimum requirements cannot ensure that the equipment operated in these buildings will perform in a satisfactory manner. For these reasons electrical design personnel often will require additional grounding components. One of the most common of these consists of a copper conductor that is directly buried in the earth and installed around the perimeter of the building. The steel building columns are bonded to this conductor to complete the grounding system.

The columns around the perimeter of the building are excellent grounding electrodes and provide a good path into the earth for any fault currents that may be imposed on the system. The electrical designer, based on the size and usage of the building, will determine whether every column or just some of the columns are bonded. ERICO recommends that at least one column every 50 feet shall be connected to the above described ground ring. (Fig. 1-1)

When grounding large buildings, and all multiple building facilities, perimeter grounding provides an equipotential ground for all the buildings and equipment within the building that are bonded to the perimeter ground. The purpose of this perimeter grounding is to ensure that an equipotential plane is created for all components that are connected to the perimeter ground system. The size of the ground ring will depend upon the size of the electrical service but is seldom less than 1/0 AWG copper. In some

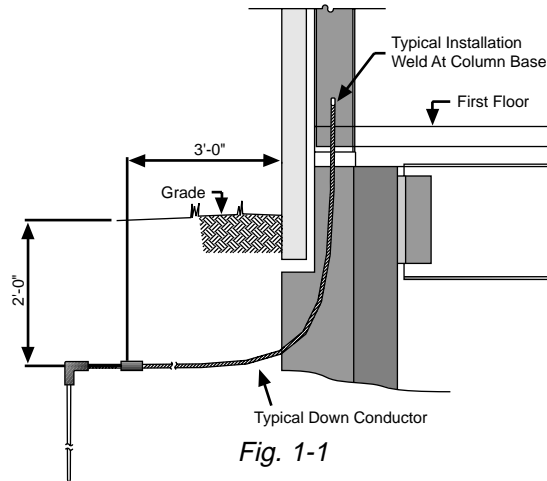


Fig. 1-1

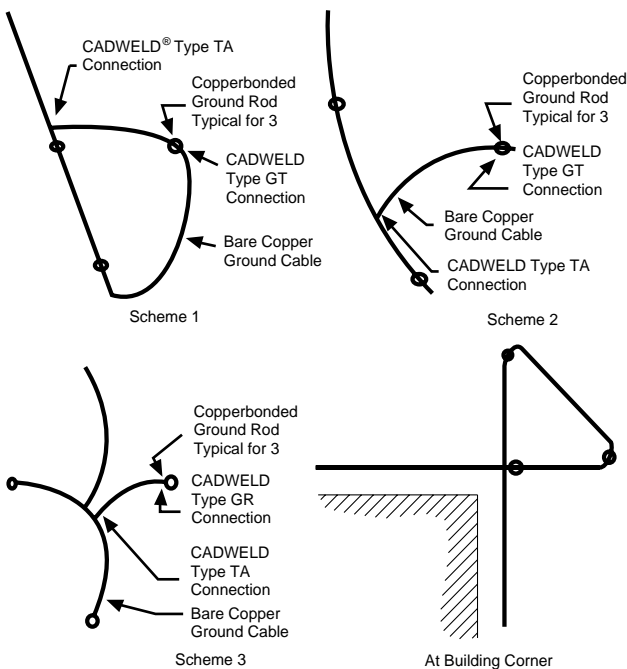
cases, an electrical design requires ground rods to be installed in addition to the perimeter ground ring. The use of ground rods helps to minimize the effects of dry or frozen soil on the overall impedance of the perimeter ground system. This is because the ground rods can reach deeper into the earth where the soil moisture content may be higher or the soil may not have frozen. ERICO offers a complete line of ground rods from 1/2 inch to 1 inch in diameter to meet the needs of the designer and installer. It is recommended that the ground ring and ground rods be copper or copperbonded steel and installed at least 24 inch from the foundation footer and 18 inch outside the roof drip line. This location will allow for the greatest use of the water coming off of the roof to maintain a good soil moisture content.

Although less common than in the past, “triad” ground rod arrangements (rods placed in a triangular configuration) are sometimes specified, usually at the corners of the building or structure. Figure 1-2 shows possible conductor/ground rod configurations. Triad arrangements are not recommended unless the spacing between the ground rods is equal to or greater than the individual ground rod length. Three rods in a straight line spaced at least equal to the length of the individual ground rods are more efficient and result in a lower overall system impedance.

Installers of these perimeter ground systems need to provide a “water stop” for each grounding conductor that passes through a foundation wall. This is especially important when the grounding conductor passes through the foundation wall at a point that is below the water table. The water stop ensures that moisture will not enter the building by following the conductor strands and seeping into the building. A CADWELD Type SS (splice) in the unsplined conductor and imbedded into the concrete wall provides the required water stop (Fig. 1-3).

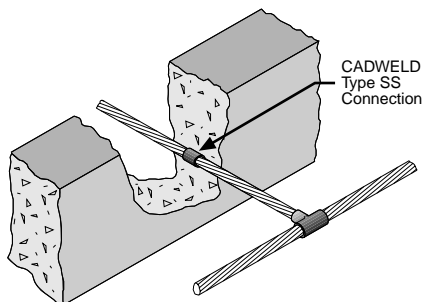
When “inspection wells” are required to expose points from which to measure system resistance, several methods are available. Inspection wells are usually placed over a ground rod. If the grounding conductors do not have to be disconnected from the rod, the conductors can be welded to the rod, and a plastic pipe, Figure 1-4, a clay pipe, Figure 1-5, or a commercial box, ERICO T416B, Figure 1-6, can be placed over the rod.

The plastic pipe also works well when an existing connection must be repeatedly checked, since it can be custom made in the field to be installed over an existing connection. If the conductors must be removed from the rod to enable resistance measurements to be made, either a bolted connector or lug may be used (Fig. 1-7).



“Triad” Ground Rod Details

Fig. 1-2



Where a stranded conductor enters a building through a concrete wall below grade, a waterstop may be made on the cable by installing a CADWELD Type SS on the conductor where it will be buried inside the wall.

Fig. 1-3

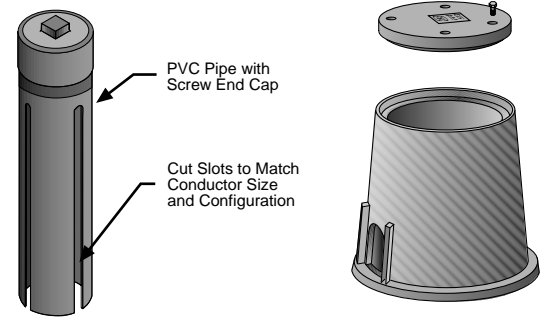


Fig. 1-4

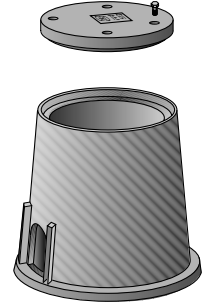


Fig. 1-6

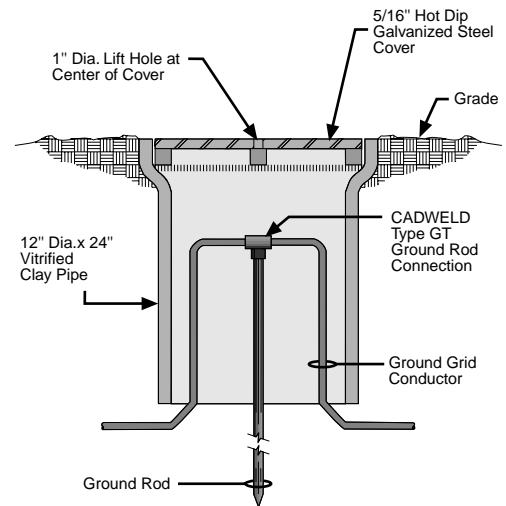


Fig. 1-5

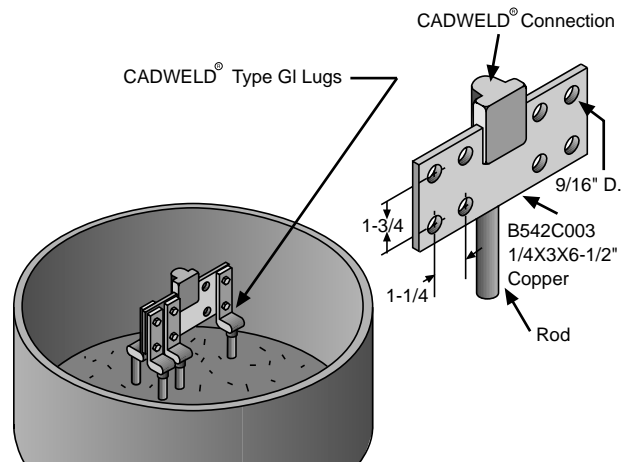


Fig. 1-7

Disconnect for attaching 1 to 8 1" wide lugs.

When the required resistance is not achieved using the usual grounding layouts, ERICO prefabricated wire mesh can be added to lower the overall grounding impedance (Fig. 1-8). ERICO offers a complete line of prefabricated wire mesh products in sizes ranging from No. 6 to No. 12 AWG solid conductors. Another method which can be used to lower the grounding system impedance is ground enhancement materials. These materials can be added around ground rods or other conductors to enhance system performance. See the discussion on GEM™ on page 14 and see Fig. 1-9, Fig. 1-10 and Fig. 1-35.

The National Electrical Safety Code (NESC) recommends that where fences are required to be grounded, such

grounding shall be designed to limit touch, step and transferred voltages in accordance with industry practice. The NESC requires that the grounding connection be made either to the grounding system of the enclosed equipment or to a separate ground. In addition, the NESC in Section 92E, lists six separate requirements for fences:

1. Where gates are installed, the fence shall be grounded at each side of the gate or similar opening (Fig. 1-11).

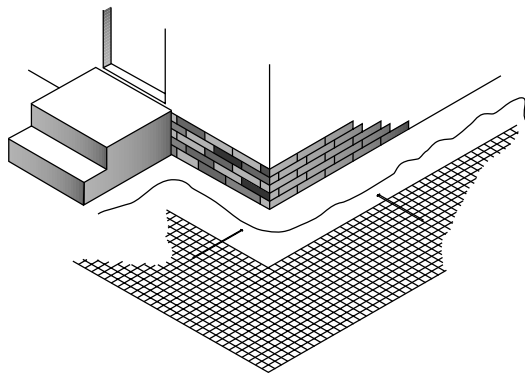


Fig. 1-8

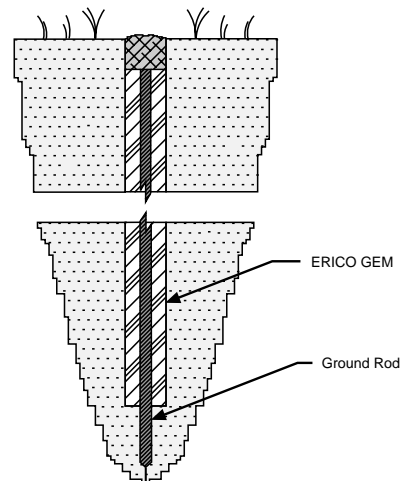


Fig. 1-9

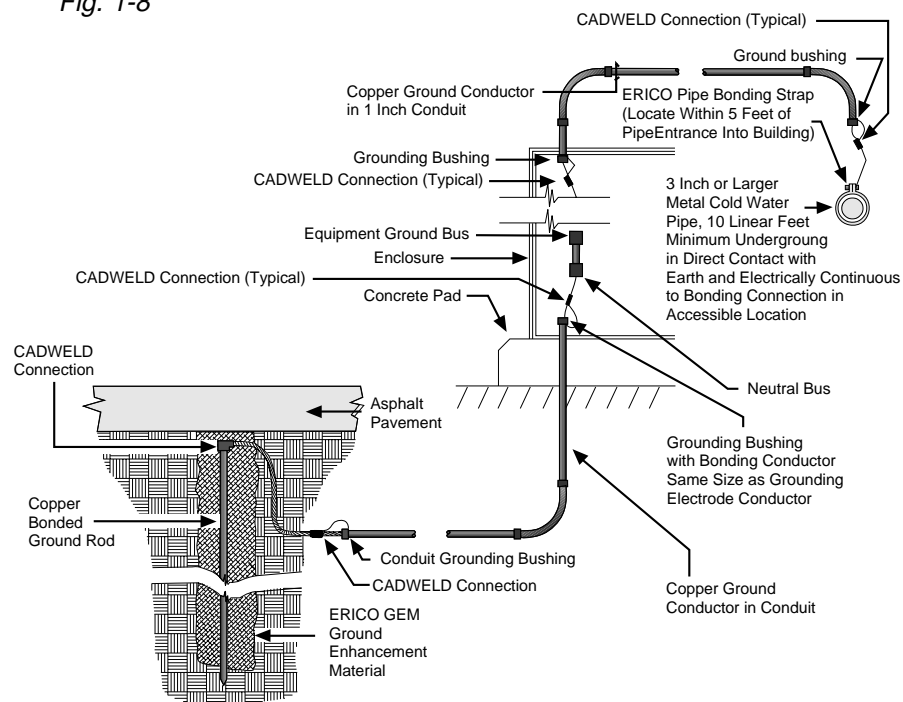


Fig. 1-10

2. If a conducting gate is used, a buried bonding jumper must be installed across the opening (Fig. 1-11).
3. Where gates are installed, they shall be bonded to the fence, grounding conductor or other bonding jumper (Fig. 1-12).
4. If the fence posts consist of a conducting material, the grounding conductor must be connected to the fence posts with a suitable connecting means (Fig. 1-13).
5. If the fence contains sections of barbed wire, the barbed wire must also be bonded to the fence, grounding conductor or other bonding jumper (Fig. 1-14).
6. If the fence posts consist of a nonconducting material, a bonding connection shall be made to the fence mesh strands and barbed wire strands at each grounding conductor point (Fig. 1-14).

ERICO offers a complete line of welded connections suitable for use with various shaped fence posts. (Fig. 1-15). Any fence around a substation on the property should be grounded and tied into the substation ground system. If a facility fence meets the substation fence, it is recommended to isolate the two fences to prevent any fault in the substation from being transferred throughout the facility using the fence as the conductor (Fig. 1-16). For further discussion on fence grounding, see Chapter 6.

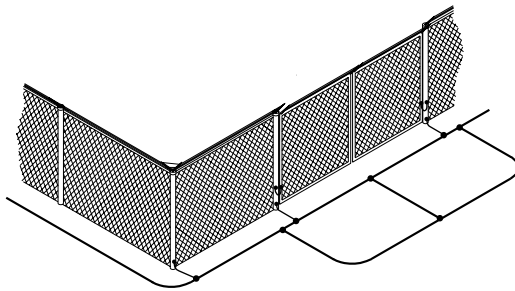
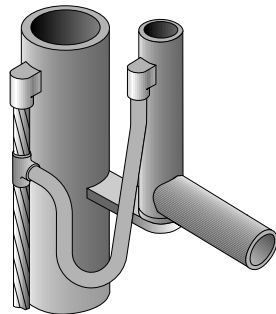
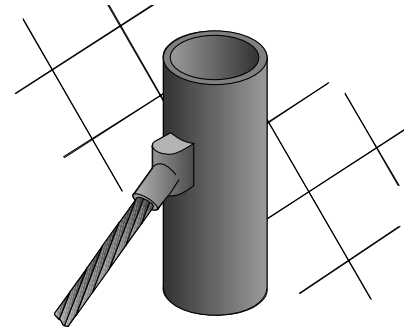


Fig. 1-11



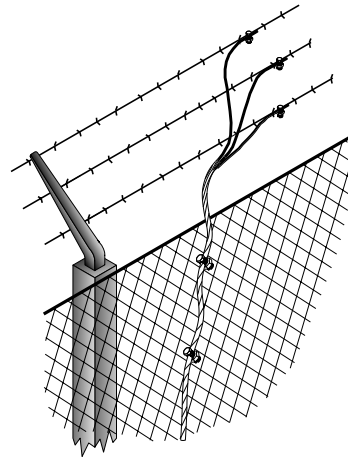
**ERICO Flexible Jumper With
CADWELD Connections.**

Fig. 1-12



CADWELD Type VS Connection

Fig. 1-13



Split Bolt Connectors

Fig. 1-14

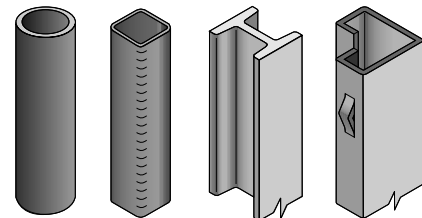
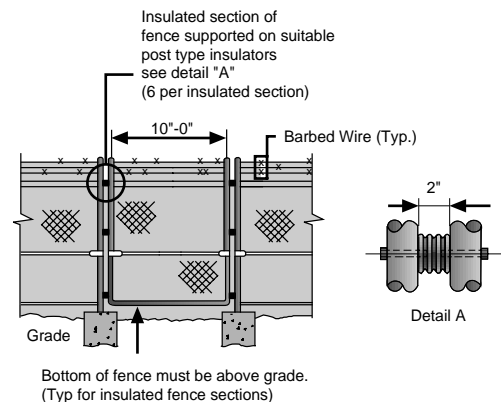


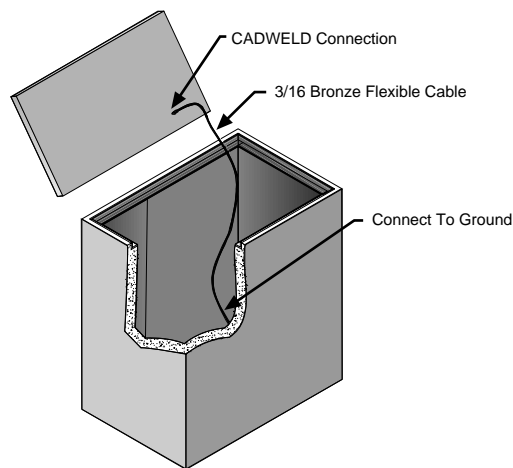
Fig. 1-15



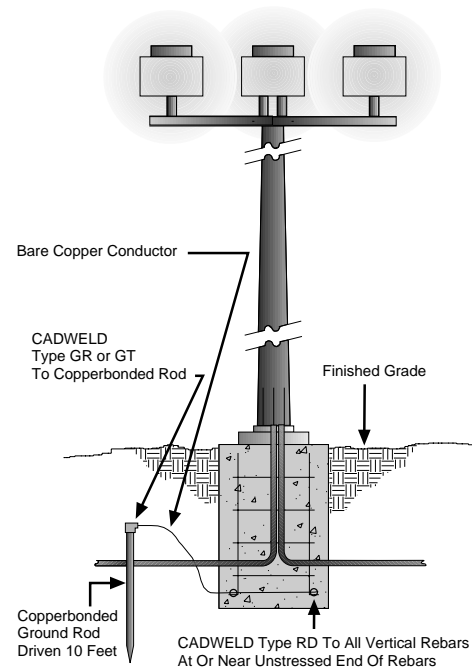
Typical Perimeter Fence Isolation Section

Fig. 1-16

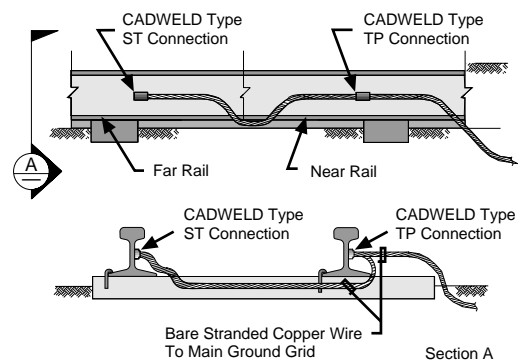
Other items that are located on the outside of the building that should be considered are lighting fixture standards, pull box covers and rails. Handhole, manhole and pull box covers, if conductive, should be bonded to the grounding system using a flexible grounding conductor (Fig. 1-17). The NEC Section 370-40 (d) requires that a means be provided in each metal box for the connection of an equipment grounding conductor. Metal covers for pull boxes, junction boxes or conduit bodies shall also be grounded if they are exposed and likely to become energized. The NEC in Section 410-15 (b) Exception, permits metal poles, less than 20 feet (6.4 m) in height to be installed without handholes if the pole is provided with a hinged base. Both parts of the hinged base are required to be bonded to ensure the required low impedance connection. Lighting standards in parking lots and other areas where the public may contact them should be grounded (Fig. 1-18). Keep in mind that the earth cannot serve as the sole equipment grounding conductor. Light standards which are grounded by the use of a separate ground rod must also be grounded with an equipment grounding conductor to ensure that the overcurrent protective device will operate. Rails or sidings into hazardous locations such as grain storage facilities, ammunition dumps, etc., should also be properly bonded and grounded (Fig. 1-19). Designers and installers must not forget that distant lightning strikes can travel through the rails for many miles. In northern climates suitable bonding jumpers should be applied across slip joints on water pipes to enable thawing currents to be applied without burning the joint gasket (Fig. 1-20).



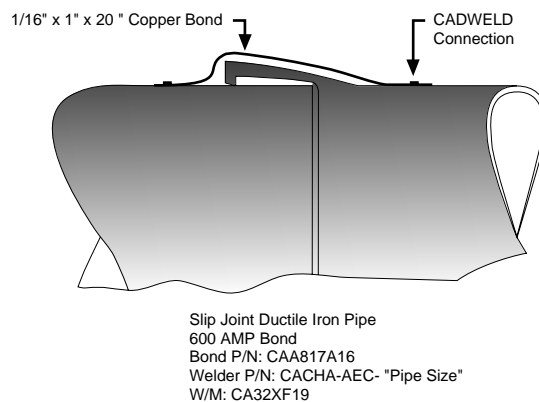
Pull Box Cover Grounding
Fig. 1-17



Light Pole Grounding
Fig. 1-18



Rail Siding Grounding
Fig. 1-19



Water Pipe Bonding
Fig. 1-20

Grounding conductors shall be protected against physical damage wherever they are accessible (Fig. 1-21). Grounding conductors installed as separate conductors in metal raceways always must be bonded at both ends to ensure that current flow is not choked off by the inductive element of the circuit. See page 15 for a discussion of how to accomplish the required bonding.

ELECTRICAL SERVICE GROUNDING

Article 230 of the NEC contains the requirements for installing electrical services for buildings and dwellings. Contractors, however, should keep in mind that local authorities, including local electrical utilities, often have requirements which supersede or augment the NEC. Contractors should contact the local authorities and determine if requirements for electrical services exist which differ from the NEC.

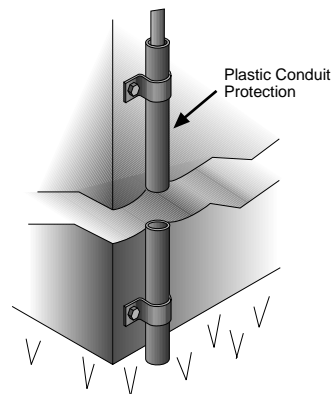
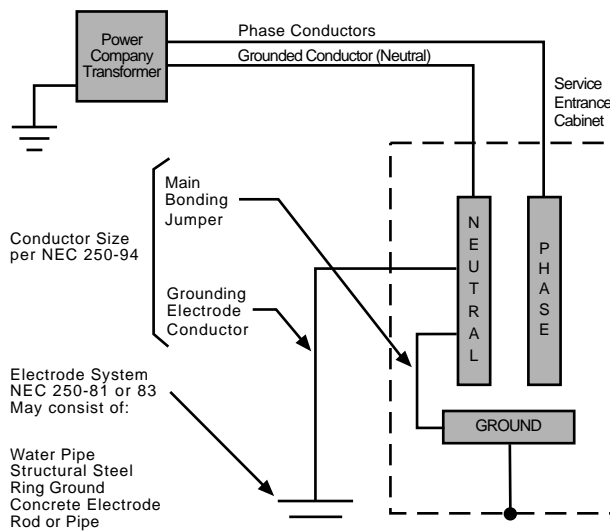


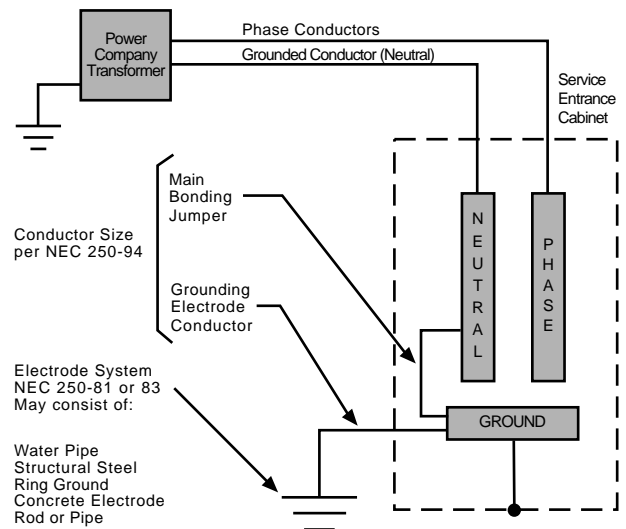
Fig. 1-21



Grounding Of AC Power Per NEC 250-23

Fig. 1-22

The requirements for grounding electrical services are contained in Article 250 of the NEC. Section 250-23(a) requires that a grounded electrical system, which supplies a building or structure, shall have at each service a grounding electrode conductor connected to the grounding electrode system. In addition, the grounding electrode conductor shall also be connected to the grounded service conductor. This connection may occur at any accessible point from the load end of the service drop or service lateral to the grounded conductor (neutral) terminal block in the service disconnecting means. (Fig. 1-22 and Fig. 1-23) Keep in mind that the service disconnecting means is often the heart of the electrical system. This is frequently the point at which the required grounding connections occur (Fig. 1-24).



Grounding Of AC Power Per NEC 250-23 Exception 5

Fig. 1-23

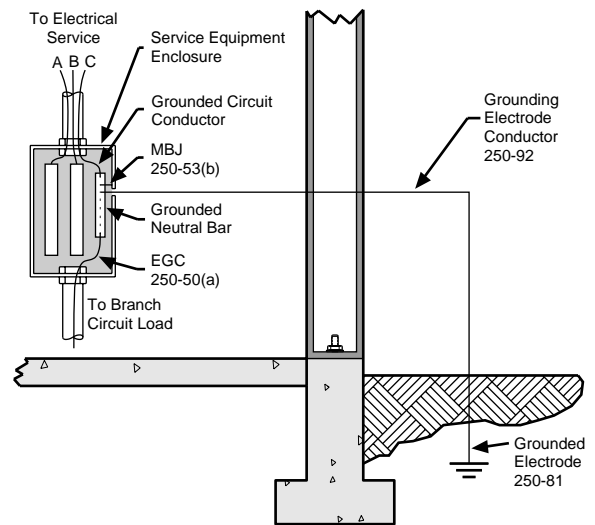
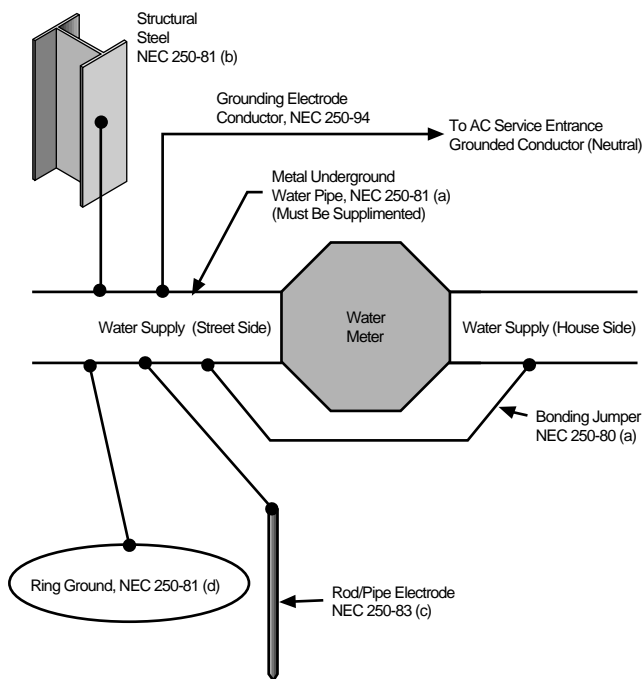


Fig. 1-24

The grounding electrode system is designed to provide multiple electrical paths into the earth. As stated in the Preface, grounding of electrical systems helps to ensure personnel safety, provide equipment and building protection and achieve electrical noise reduction. Section 250-81 requires that four components, if available, be bonded together to form the grounding electrode system. Notice the words “if available.” Contractors are not given the choice of which components they want to bond together. If they are available, all four must be used. (Fig. 1-25)



Typical Electrodes

Fig. 1-25

The first component is the metal underground water pipe. Metal water piping that is in direct contact with the earth for 10 feet or more must be part of the grounding electrode system. Contractors should be aware that, with the increasing presence of plastic in water piping systems, these systems may not be suitable as grounding electrodes. Note, however, that under the bonding requirements of Section 250-80 (a) all interior metal water piping shall be bonded to the service equipment enclosure or other permissible attachment points as listed in the section. When connecting the grounding electrode conductor to the metal water pipe, use a UL listed clamp or other listed means to make the connection. Ground clamps shall be listed for the materials of which the metal water pipe is constructed and not more than one grounding electrode conductor shall be

connected to each clamp unless the clamp is listed for multiple connections (Fig. 1-26). One final consideration when connecting the metal water piping to the grounding electrode system: the point of connection must be located within the first 5 feet of the point of entrance of the metal water pipe into the building. This is to ensure that downstream alterations of the piping system, such as the installation of plastic fittings, doesn't result in isolation of the grounding electrode system. The NEC does not permit metal water piping beyond the first 5 feet into the building to be used as part of the grounding electrode system or as a conductor to interconnect parts of the grounding electrode system. Contractors should be aware that, because of the uncertainty of the metal water pipe construction, the metal water pipe is the only grounding electrode which must be supplemented by an additional electrode. If the other electrodes are not available, a “made” electrode will need to be installed by the contractor to supplement the metal water piping. Made electrodes are discussed on page 14.

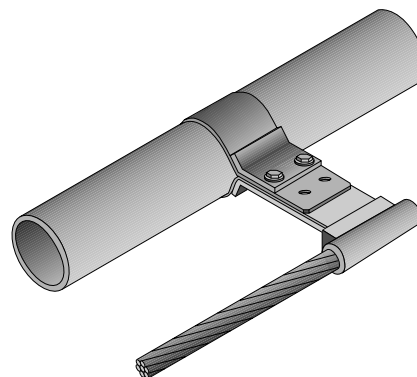


Fig. 1-26

The second component of the grounding electrode system is the metal frame of the building. If the metal frame of the building is effectively grounded, meaning it is intentionally connected to the earth by means of a low-impedance ground connection, it must be bonded to the grounding electrode system. Once again the connection of the grounding electrode conductor to the building steel must be accomplished by the use of exothermic welding (CADWELD), listed lugs, listed pressure connectors, listed clamps or other listed means. See Section 250-115. If the building steel is dirty or contains nonconductive coatings, contractors are required by the NEC to remove coatings, such as paint, lacquer and enamel, from contact surfaces to ensure good electrical continuity. See Section 250-118. ERICO has a full line of horizontal and vertical cable to steel or cast iron connections that can meet any installation requirements (Fig. 1-27).

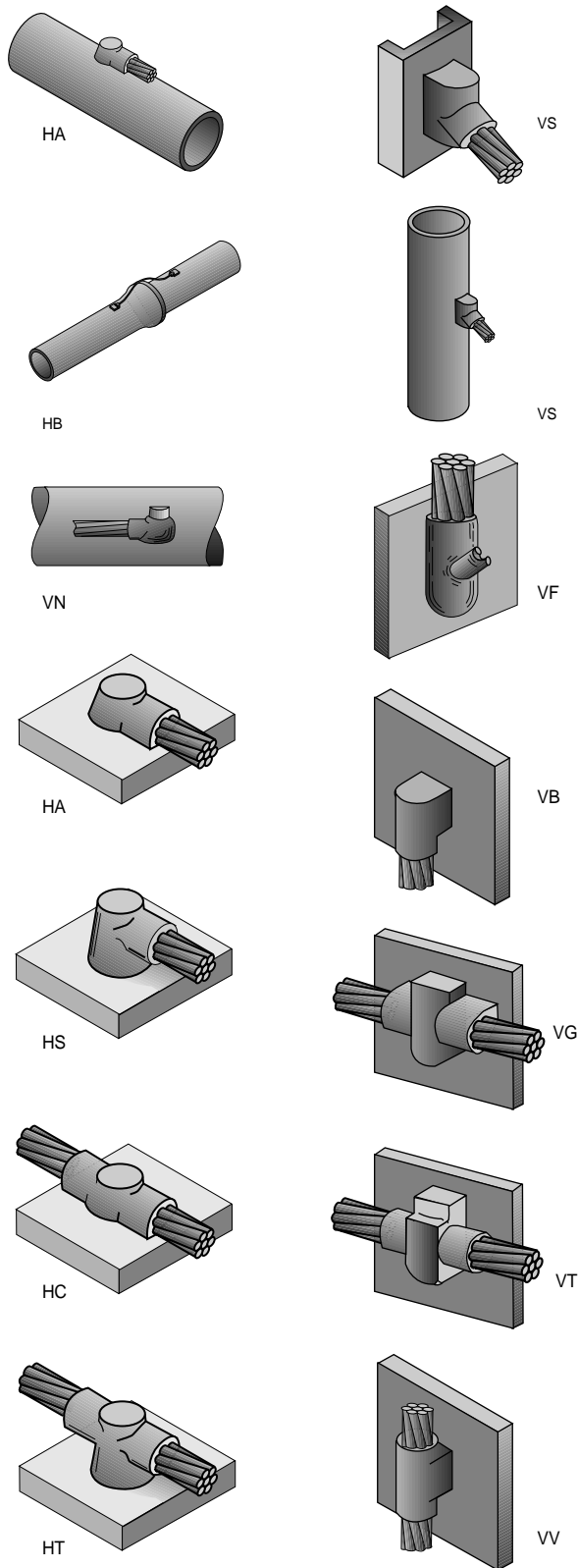
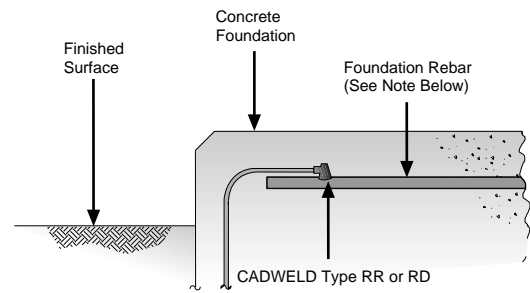


Fig. 1-27

The third component of the grounding electrode system is concrete-encased electrodes. These are usually referred to as “rebar,” which is short for reinforcing bar (Fig. 1-28 and 1-29). Rebar is used to add strength to poured concrete installations and by its nature tends to be an excellent grounding electrode. This is because the rebar is surrounded by concrete which has a lower resistivity than the earth. This, coupled with the fact that concrete absorbs moisture from the surrounding earth, makes the concrete-encased electrode an excellent grounding electrode. See the discussion on page 17 on “Ufer” grounding. The NEC requires that the concrete-encased electrode be covered by at least 2 inch (50 mm) of concrete and consist of at least 20 feet (6.4 m) of reinforcing bars of not less than 1/2 inch in diameter (No. 4 rebar) located near the bottom of a concrete footing or foundation. Contractors should look closely at the material used for the reinforcing bars. The rebar is often covered with a nonconductive coating, such as epoxy, which do not make them suitable for grounding electrodes. The NEC also permits at least 20 feet (6.4 m) of bare copper, not smaller than No. 4 AWG, to be used as a substitute for the rebar for a grounding electrode. (Fig. 1-30) Connections of the grounding electrode are critical to maintaining the integrity of the grounding system. Section 250-115 requires that where the grounding



Foundation Rebar Ground Connection

Fig. 1-28

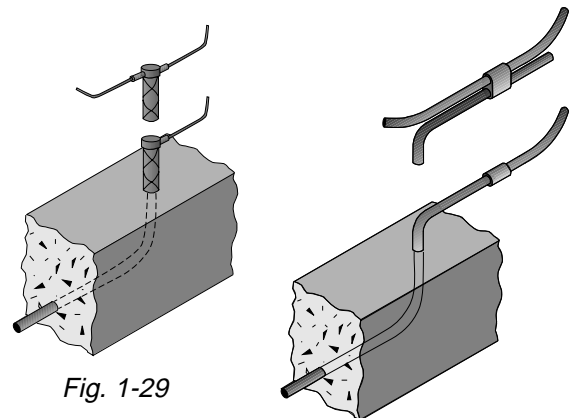


Fig. 1-29

Copper Wire As Concrete Encased Electrode

Fig. 1-30

electrode conductor is connected to buried electrodes the clamp or fitting must be listed for direct soil burial. CADWELD offers the best solution for contractors trying to meet the NEC requirements for connecting to rebar. CADWELD offers a full line of connections in various configurations for welding of grounding conductors to reinforcing bars (Figure 1-31). Contractors should select the point of attachment for such connections by locating the weld away from areas of maximum tensile stress, such as near the free end of the bar in a lap splice, to avoid harmful stresses in the rebar. Note, where rebar mat is required to be bonded, bar to bar bonds should be made with a copper conductor jumper (Fig. 1-32). CADWELD connections cannot be used to make direct rebar to rebar electrical connections.

If a foundation with rebar is used as part of the grounding electrode system, it is recommended that the anchor bolts be bonded to the main rebars and a conductor extended from the rebar to an outside electrode to minimize possible damage to the foundation. See (Figure 1-33) and the discussion on "Ufer" grounding on page 17.

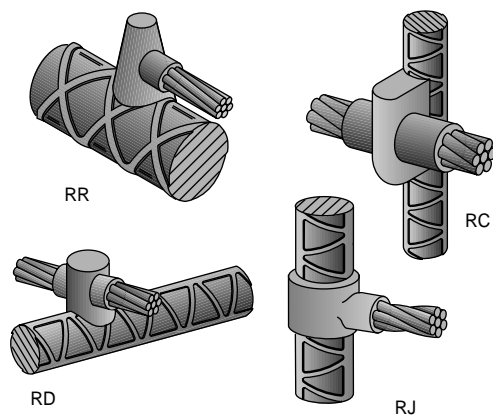


Fig. 1-31

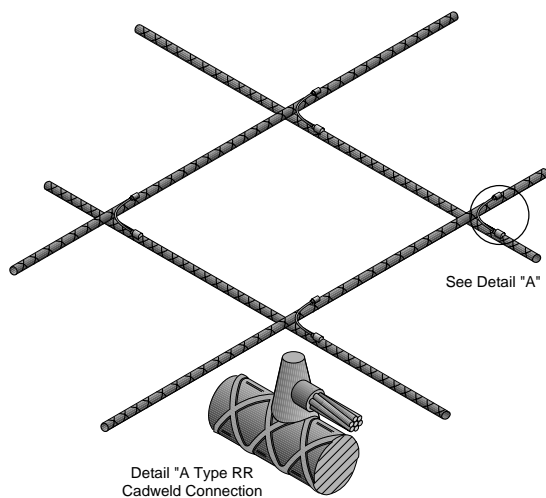


Fig. 1-32

The last component of the grounding electrode system is a ground ring. The NEC requires that if a ground ring is available it shall be bonded to the grounding electrode system. A ground ring should consist of at least 20 feet (6.4 m) of No. 2 AWG bare copper or larger which encircles the building. The ground ring should be in direct contact with the earth at a depth below the earth surface of at least 2 1/2 feet (0.75 m). Contractors should note that while the ground ring is frequently not "available," it is becoming more and more prevalent as a supplemental grounding system component, especially when highly sensitive electronic equipment is installed within the building. As noted above, the connection to the ground ring will more than likely be a direct burial connection so the ground clamps or fittings must be listed for direct soil burial. ERICO has a full line of cable-to-cable connections that can meet any installation or application requirement (Fig. 1-34).

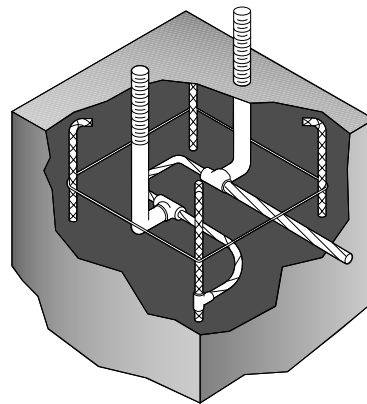


Fig. 1-33

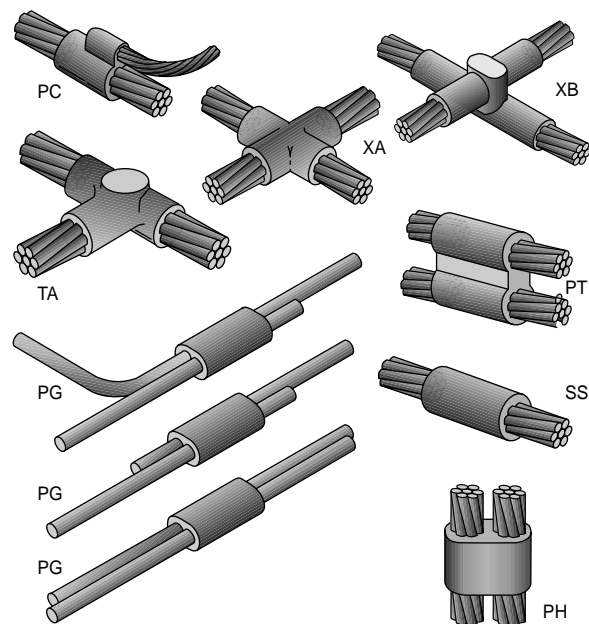


Fig. 1-34

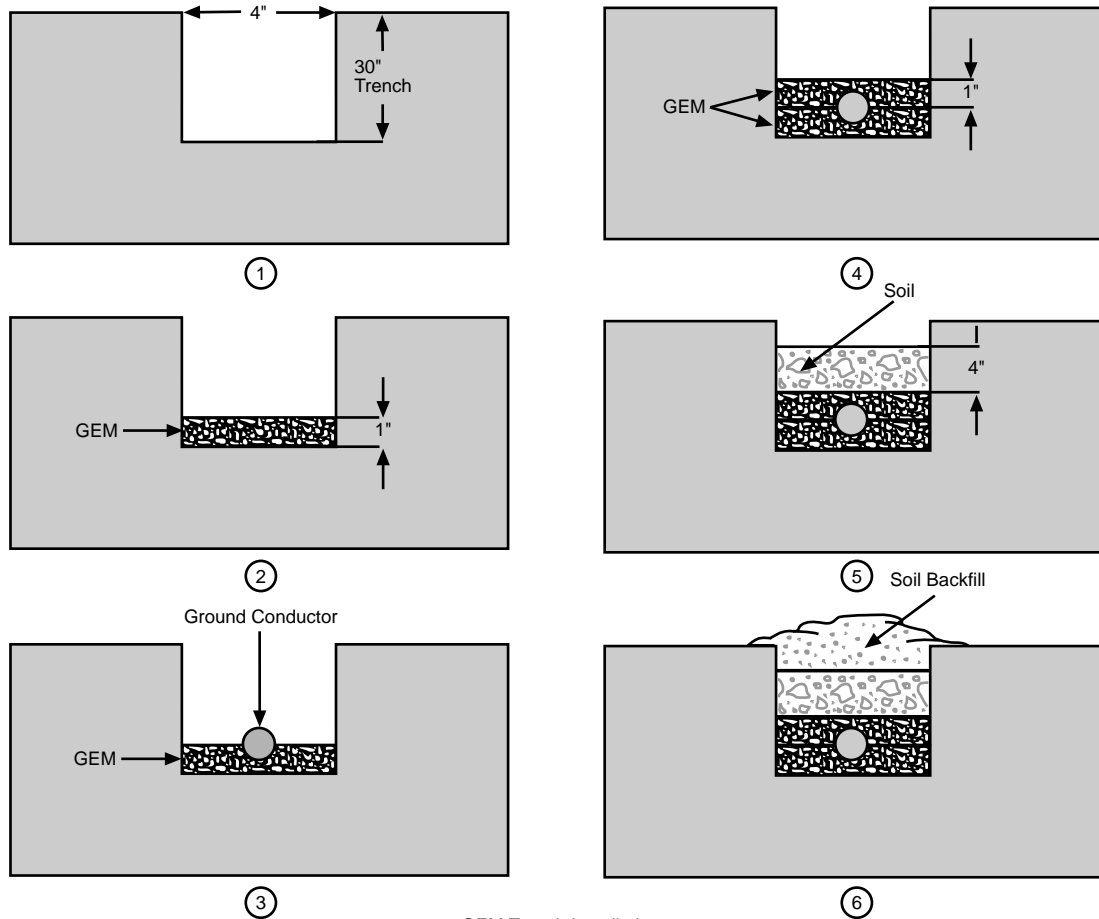
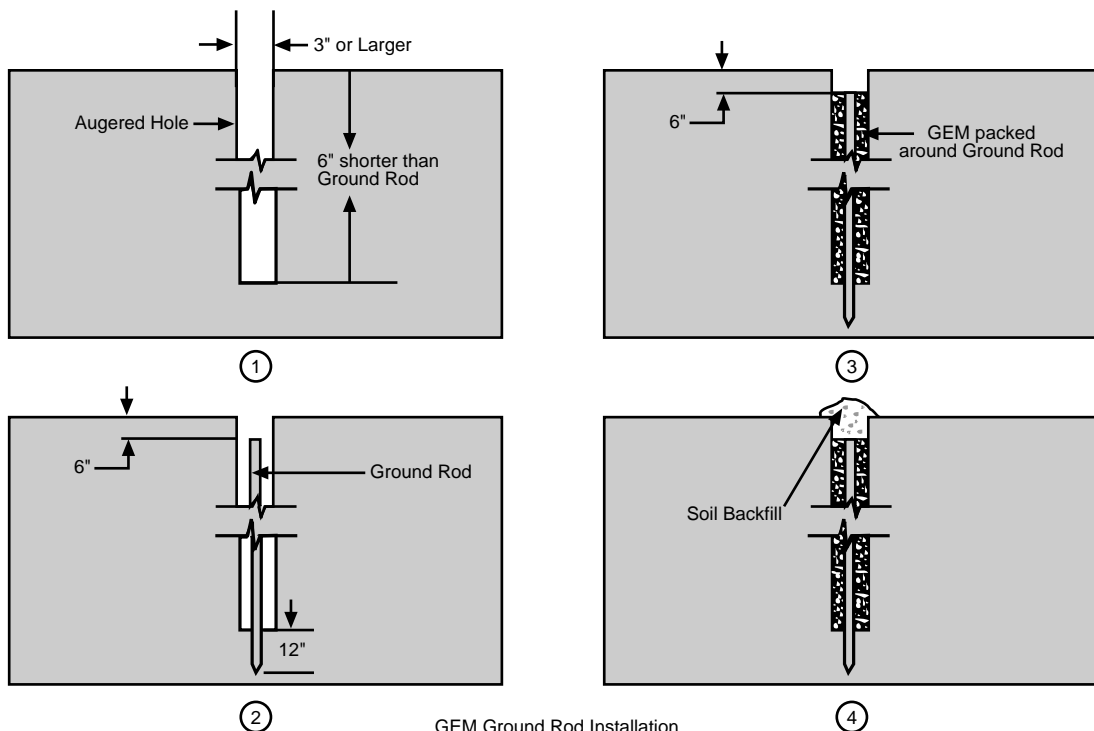
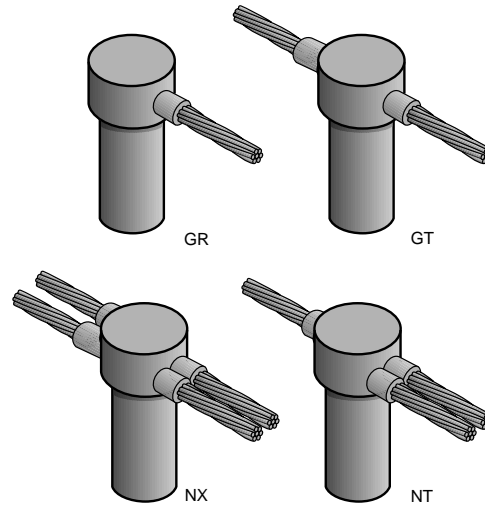
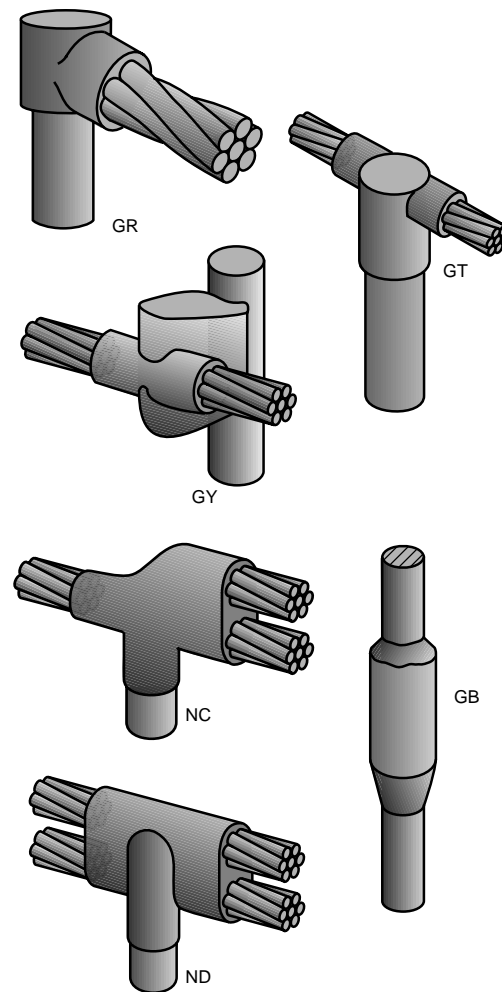
GEM Trench InstallationGEM Ground Rod Installation

Fig. 1-35

Section 250-83 contains requirements for other (frequently referred to as “made”) electrodes. These electrodes can be used to supplement the grounding electrode system or are to be used when none of the grounding electrodes covered previously are available. Local metal piping systems, such as water wells, can be used but metal underground gas piping systems shall not be used as the grounding electrode. The most common made electrodes consist of rod, pipe or plates. Ground rods can be constructed of iron or steel, of at least 5/8 inch in diameter. Nonferrous ground rods, such as copperbonded steel or stainless steel can also be used, provided they are not less than 1/2 inch in diameter and are listed. Design life of the facility being protected should be considered when choosing ground rod material. Galvanized steel ground rods are often used for grounding structures such as a telephone booth with an anticipated service of 10 years or less. A UL Listed copperbonded steel ground rod with a copper thickness of 10 mils (0.25 mm) will last 30 years or more in most soils. A 13 mil (0.33 mm) copper thickness copperbonded steel rod will last 40 years or more in most soils. Unusual soil conditions demand additional considerations. Contractors should be aware of the many factors that influence the impedance of grounding systems that utilize ground rods. The dimension of the ground rod does have some affect on its resistance. Typically, the larger the diameter of the ground rod, the lower its resistance, but to a very minor extent. A far more important factor in determining the resistance of the ground rod is the depth to which it is driven. Usually, the deeper the ground rod is driven, the lower its resistance. Another very important and frequently unknown factor is the resistivity of the soil where the ground rod is driven. As stated above, the higher the moisture content of the soil, the lower its resistivity. ERICO GEM™, Ground Enhancement Material, is the answer in situations where reducing earthing resistance and maintaining low resistance permanently is required. GEM reduces the resistance of the electrode to the earth and performs in all soil conditions. GEM can be used around ground rods in an augured hole or installed in a trench as permitted by Section 250-83 (c) (3), of the NEC. See Figure 1-35 (Page 13). As with all of the grounding electrodes, the connection is critical to maintaining the integrity of the grounding system. While listed clamps or fittings are permitted, exothermic welding provides the best solution to the contractor needs. ERICO offers a complete line of cable to ground rod connections, including the CADWELD ONE-SHOT® connection, which can be used for both plain or threaded copperbonded and galvanized steel or stainless steel rods. See (Figures 1-36 and 1-37).



CADWELD One-Shot® Connections
Fig. 1-36



CADWELD Ground Rod Connections
Fig. 1-37

Also fitting into this category are chemical type ground electrodes consisting of a copper tube filled with salts. Moisture entering the tube slowly dissolves the salts, which then leach into the surrounding earth thru holes in the tube. (Fig. 1-38) This lowers the earth resistivity in the area around the electrode, which reduces the electrode resistance.

For maximum efficiency, we recommend back-filling the electrode with bentonite for the lower 1 to 2 feet and then ERICO GEM to the level marked on the electrode. Alternatively, the electrode can be back-filled only with bentonite for a less efficient installation or only with earth for an even lower efficient installation. Long term (over five years) tests comparing 10-foot chemical type electrodes back-filled with bentonite to 8-foot copper bonded rods back-filled with ERICO GEM indicated that the two are nearly equal with the GEM back-filled rod slightly better.

The chemical ground electrode system is available from ERICO. Chemical electrodes are available in both vertical and horizontal configurations. All ERICO chemical electrodes are provided with a pigtail welded to the electrode using the CADWELD process. Standard pigtail sizes include 4/0 AWG and #2 AWG tinned solid copper conductors.

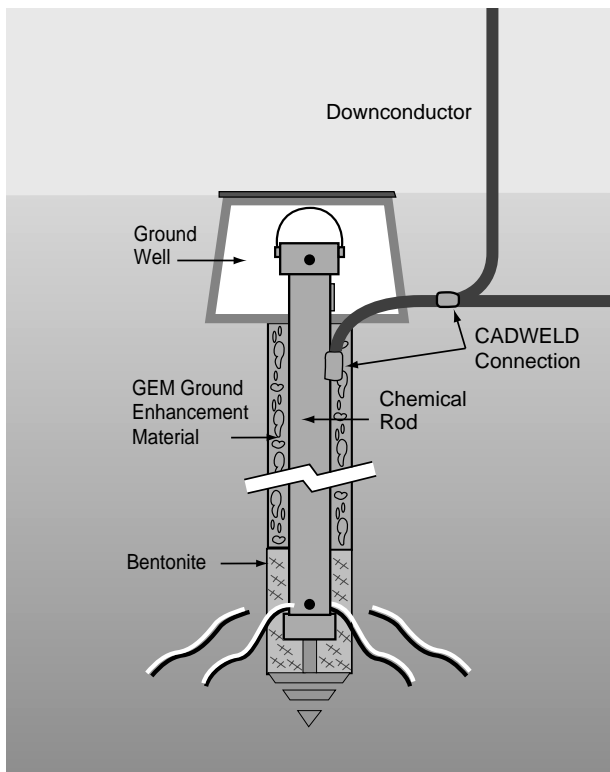


Fig. 1-38

The NEC requires that the ground rods be installed such that at least 8 feet (2.5 m) of length is in contact with the earth. If rock is encountered, the ground rod can be driven at an angle, not to exceed 45° from vertical, or buried in a trench which is at least 2 1/2 feet (0.75 m) below the earth. The point of connection of the grounding electrode conductor shall be below or flush with grade unless it is suitably protected against physical damage.

The remaining type of “made” electrode permitted by the NEC is the plate electrode. Section 250-83 (d) permits plate electrodes that offer at least 2 square feet (0.19 sq. m) of surface area which is in contact with the earth to be used. The plates may be constructed of iron or steel of at least 1/4 inch (6.4 mm) in thickness or other nonferrous materials of at least 0.06 inch (1.5 mm) in thickness. ERICO provides copper plate electrodes with CADWELD pigtails that meet the requirements of the NEC. CADWELD horizontal and vertical steel surface connections can be used to connect the grounding electrode conductor to the plate electrodes. Wherever possible, the plates should be installed below the permanent moisture or frost line. As with all electrode connections, any nonconductive coatings shall be removed before making the connection. Recent testing indicates that plate electrodes are the least-efficient type of grounding electrode for power system grounding. Plate electrodes do, however, provide large surface area for capacitive coupling (high frequency) required in lightning protection.

No matter which grounding electrode or electrodes are used the NEC requires that the grounding electrode conductor, which connects to these electrodes, be suitably protected. Section 250-92 (a) of the Code permits the grounding electrode conductor (GEC) to be securely fastened directly to the surface of a building or structure. A No. 4 AWG or smaller copper or aluminum GEC, which is exposed to severe physical damage must be protected. While there is no definition provided for “severe”, it is safe to assume that locations subject to vehicular traffic, forklifts or lawn mowers would be such locations. A No. 6 AWG GEC that is free from exposure to physical damage can be installed on the surface of a building or structure without any mechanical protection. Smaller conductors shall be installed in rigid metal conduit, intermediate metal conduit, rigid nonmetallic conduit, electrical metallic tubing or cable armor.

Installers of electrical systems should be aware that Section 250-92 (b) of the NEC requires that any metal enclosures or raceways for the grounding electrode conductor shall be electrically continuous from the electrical equipment to the grounding electrode. If the metal enclosures are not electrically continuous they shall be made so by bonding

each end of the enclosure or raceway to the grounding conductor. IEEE paper No. 54 and other studies have shown that, in cases where such bonding is omitted, the impedance of the conductor is approximately doubled. Bonding in these cases is essentially to ensure proper operation of the grounding electrode system. Bonding can be accomplished by connecting each end of the GEC enclosure or raceway to the electrical equipment enclosure and the actual electrode. Section 250-79 (d) requires that the size of the bonding jumper for GEC raceways or enclosures be the same size or larger than the enclosed grounding electrode conductor (Fig. 1-39). Another possible solution to protecting the grounding electrode conductor from physical damage is to use a nonmetallic raceway. Such raceways are permitted and, because they are constructed of nonmetallic materials, they do not require bonding (Fig. 1-40).

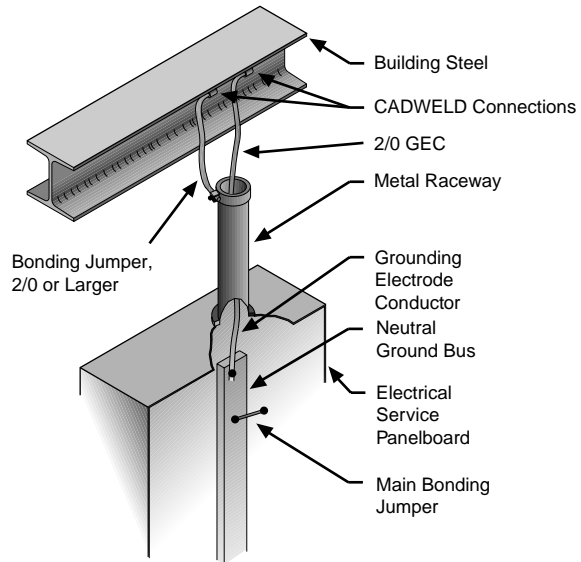


Fig. 1-39

Occasionally during construction, a grounding conductor may be damaged where it is stubbed through the concrete. Installers should note that ERICO features a full line of CADWELD connections that can be used to repair the conductor without any loss of capacity in the conductor. Repair splices are available for both horizontal and vertical conductors. A minimum amount of concrete may need to be chipped away in order to make the splice (Fig. 1-41). Installers may also encounter applications where the GEC needs to be extended to a new service location or for a modification to the electrical distribution system. Section 250-81 Exception No. 1 permits the GEC to be spliced by means of irreversible compression-type connectors listed for this use or by the exothermic welding process. CADWELD offers a complete line of connections suitable for splicing the full range of grounding electrode conductors.

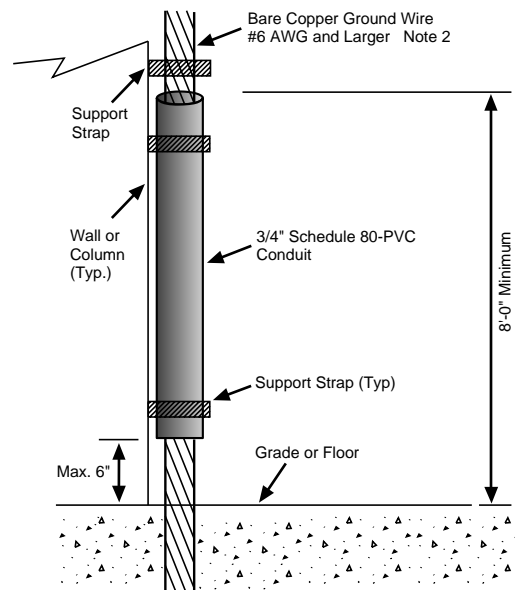
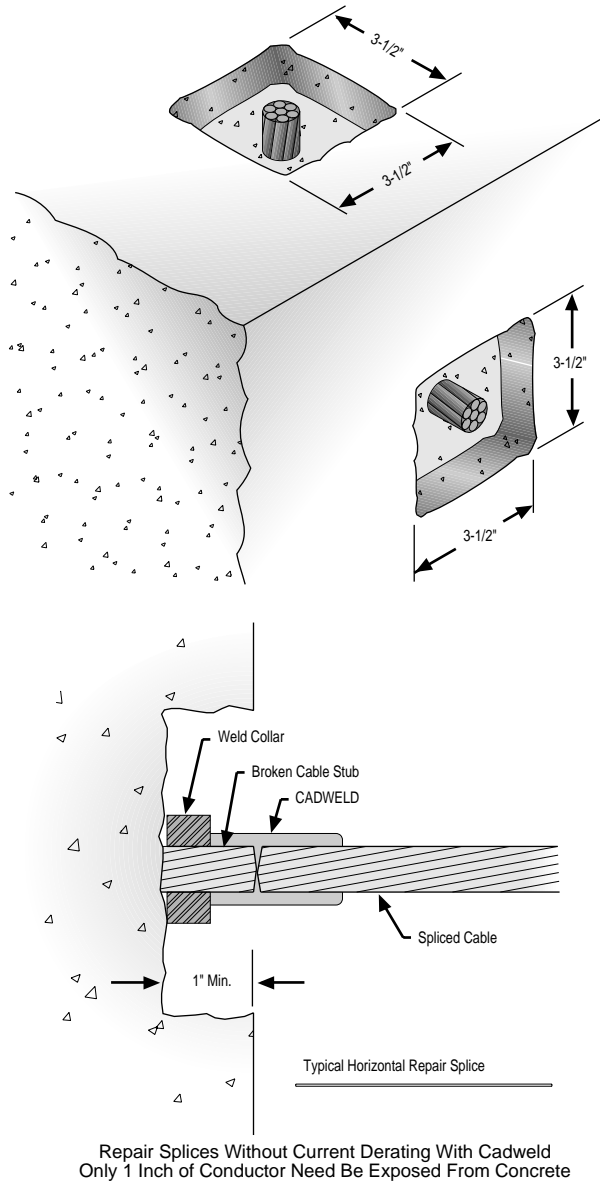


Fig. 1-40

All of these components, when installed, comprise the grounding electrode system for the building or structure served. All of these must be bonded together and when they are installed where multiple grounding systems are present, such as lightning protection systems, they shall be installed at a point which is not less than 6 ft (1.8 m) from any other electrode of another grounding system. Section 250-54 requires that when an AC system is connected to a grounding electrode system, as described above, the same electrode shall be used to ground conductor enclosures and equipment in or on that building. Separate grounding electrode systems are not permitted within the same building. In the event that a building is supplied by two or more services as permitted by Section 230-2 Exceptions, the same grounding electrode system shall be used. Two or more electrodes which are bonded together are considered

a single grounding electrode system.

Contractors must understand that these grounding connections are critical to the overall electrical power distribution system and they must take great care when they make these connections.



Conductor Size	Horizontal Splice		Vertical Splice		Weld Collar*
	Mold P/N	Weld Metal	Mold P/N	Weld Metal	
1/0	SSR2C001	#45	SVR2C001	#90	B3452C
2/0	SSR2G001	65	SVR2G001	90	B3452G
4/0	SSR2Q005	90	SVR2Q001	115	B3452Q
250	SSR2V002	115	SVR2V001	150	B3452V
350	SSR3D002	150	SVR3D001	200	B3453D
500	SSR3Q003	200	SVR3Q001	250	B3453Q

*One required per weld, horizontal or vertical splice.
L160 handle clamp required for above molds.
Contact factory for other sizes.

Fig. 1-41

CONCRETE ENCASED ELECTRODES, "UFER GROUNDING"

Herb Ufer reported on probably the first use of concrete-encased electrodes at a bomb storage facility at Davis-Monthan AFB in Tucson, Arizona which he inspected early in World War II. The grounding system was to protect against both static electricity and lightning. He later reinspected the installation and made further tests, proving that concrete-encased electrodes provide a lower and more consistent resistance than driven ground rods, especially in arid regions. Due to this early usage, the use of a wire or rod in the concrete foundation of a structure is often referred to as a "Ufer ground."

The concrete electrode, however, was never tested under high fault conditions until 1977 when Dick and Holliday of the Blackburn Corp. published an IEEE paper discussing high-current tests on concrete-encased electrodes. They concurred with the previous tests that concrete-encased electrodes do provide a low resistance ground, both before and after high current faults. But they also found that a high current fault (500 to 2600 amperes) usually caused damage to the concrete - from minor damage to complete destruction.

In a 1975 survey of 1414 transmission towers, a large electrical utility found 90 fractured foundations that were grounded using the Ufer method. They believed the fractures were the result of lightning strikes on the static wires. Verbal reports have discussed leakage currents causing disintegration of the concrete (which turns to powder) if a break in the metallic path occurs within the current path in the concrete. This could also be the case if the anchor bolts were not connected to the rebar cage in the foundation.

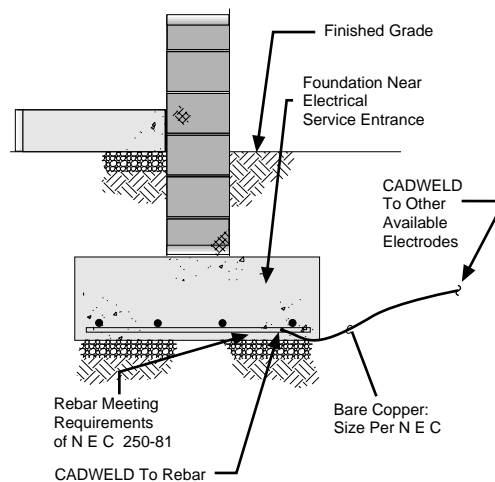
Based on the above and other reports, the latest edition (1986) of IEEE Std 80 (substation grounding guide) discusses both the merits and problems of the Ufer ground. The document also points out that it is practically impossible to isolate the rebar from the grounding system.

The lower resistance of the Ufer grounding system can be explained by both the large diameter or cross section of the concrete as compared to a ground rod and the lower resistivity of the concrete as compared to the earth. Concrete is hygroscopic (absorbs moisture from the surrounding earth). This aids in lowering the resistance, even in arid regions.

The damage to the concrete can be explained due to its non-homogeneous character and moisture content. During a fault, one path from the rebar to the outside soil through the concrete will have a lower resistance than any other. The fault current following this path will cause heating and vaporization of the water (moisture). The expansion, as the water turns to steam, can cause the concrete to crack or spill.

The Ufer grounding system is an excellent method for low fault currents (housing, light commercial, etc.), especially in arid regions where driven rods are less effective. But when high current faults are possible, including lightning, care must be exercised in designing the system, especially since it is impossible to isolate the foundations from the rest of the grounding system.

We recommend that the current path into the foundation must be connected (wire ties between rebars as a minimum) and a metallic path should be provided from the rebar to the earth. This metallic path should be connected to an external ground electrode. See Figure 1-42, "Ufer" ground detail.

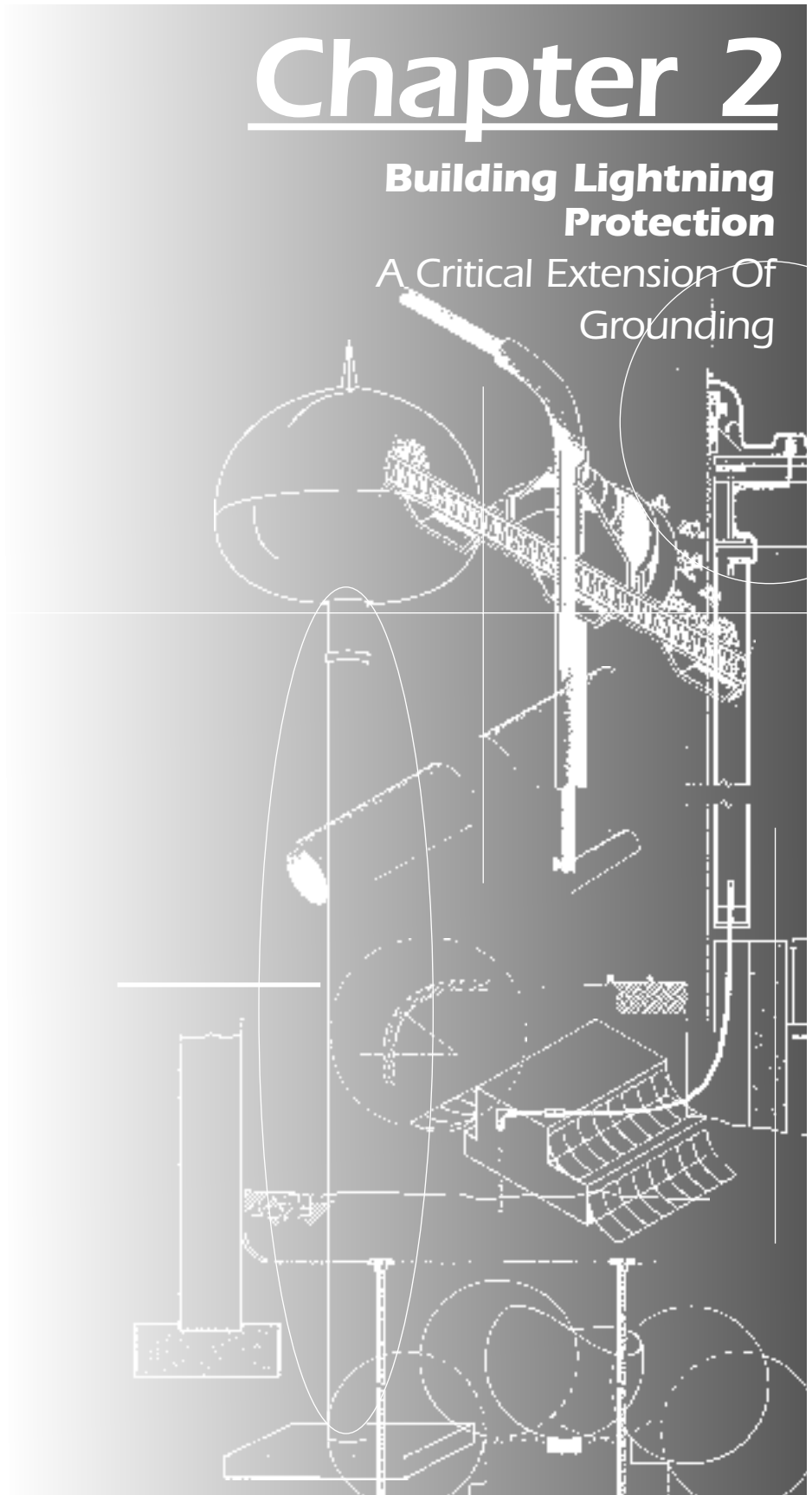


"UFER " Ground Detail
Fig. 1-42

Chapter 2

Building Lightning Protection

A Critical Extension Of
Grounding



LIGHTNING - AN OVERVIEW

Lightning is an electrical discharge within clouds, from cloud to cloud, or from cloud to the earth. Lightning protection systems are required to safeguard against damage or injury caused by lightning or by currents induced in the earth from lightning.

Clouds can be charged with ten to hundreds of millions of volts in relation to earth. The charge can be either negative or positive, although negative charged clouds account for 98% of lightning strikes to earth. The earth beneath a charged cloud becomes charged to the opposite polarity. As a negatively charged cloud passes, the excess of electrons in the cloud repels the negative electrons in the earth, causing the earth's surface below the cloud to become positively charged. Conversely, a positively charged cloud causes the earth below to be negatively charged. While only about 2% of the lightning strikes to earth originate from positively charged clouds, these strikes usually have higher currents than those from negatively charged clouds. Lightning protection systems must be designed to handle maximum currents.

The air between cloud and earth is the dielectric, or insulating medium, that prevents flash over. When the voltage withstand capability of the air is exceeded, the air becomes ionized. Conduction of the discharge takes place in a series of discrete steps. First, a low current leader of

about 100 amperes extends down from the cloud, jumping in a series of zigzag steps, about 100 to 150 feet (30 to 45 m) each, toward the earth. As the leader or leaders (there may be more than one) near the earth, a streamer of opposite polarity rises from the earth or from some object on the earth. When the two meet, a return stroke of very high current follows the ionized path to the cloud, resulting in the bright flash called lightning. One or more return strokes make up the flash. Lightning current, ranging from thousands to hundreds of thousands of amperes, heats the air which expands with explosive force, and creates pressures that can exceed 10 atmospheres. This expansion causes thunder, and can be powerful enough to damage buildings.

The National Weather Services of the National Atmospheric Administration (NAA) keeps records of thunderstorm activity. This data is plotted on maps showing lines of equal numbers of thunderstorm days (days in which there was at least one occurrence of thunder is heard). Such isokeraunic charts show a wide geographic variation of thunderstorm activity, from more than 90 days per year in central Florida to less than 5 on the West Coast. (Fig. 2-1) Such charts cannot predict the lightning activity at any location, but make it possible to judge the extent of exposure and the potential benefits of a lightning protection system. However, the overriding concerns in protection must be the protection of people and the reliability of equipment.

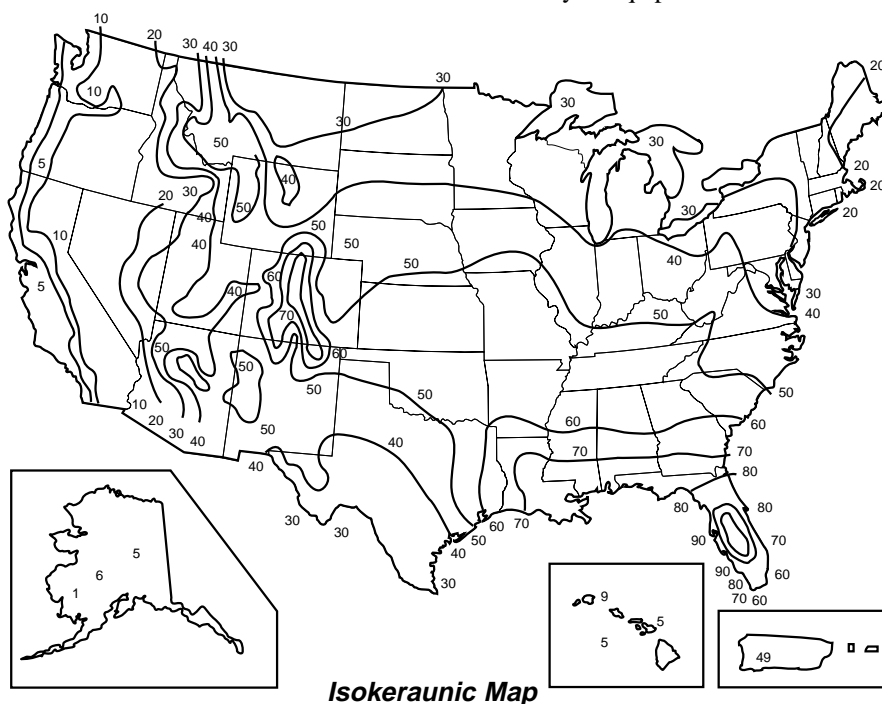


Fig. 2-1

This isokeraunic map shows mean annual number of days with thunderstorms in the United States. The highest frequency is encountered in south central Florida.

New detection devices have been installed around the U.S. which count the total number of lightning strokes reaching the earth. This data results in precise occurrence of the total strokes for a particular period of time for any particular area rather than thunderstorm days per year.

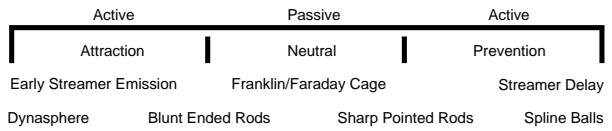
Lightning is the nemesis of communication stations, signal circuits, tall structures and other buildings housing electronic equipment. In addition to direct strike problems, modern electronics and circuitry are also highly susceptible to damage from lightning surges and transients. These may arrive via power, telecommunications and signal lines, even though the lightning strike may be some distance from the building or installation.

LIGHTNING PROTECTION

Lightning protection systems offer protection against both direct and indirect effects of lightning. The direct effects are burning, blasting, fires and electrocution. The indirect effects are the mis-operation of control or other electronic equipment due to electrical transients.

The major purpose of lightning protection systems is to conduct the high current lightning discharges safely into the earth. A well-designed system will minimize voltage differences between areas of a building or facility and afford maximum protection to people. Direct or electro-magnetically induced voltages can affect power, signal and data cables and cause significant voltage changes in the grounding system. A well-designed grounding, bonding and surge voltage protection system can control and minimize these effects.

Since Ben Franklin and other early studiers of lightning, there have been two camps of thought regarding the performance of direct strike lightning protection systems. Some believe that a pointed lightning rod or air terminal will help prevent lightning from striking in the immediate vicinity because it will help reduce the difference in potential between earth and cloud by "bleeding off" charge and therefore reducing the chance of a direct strike. Others believe that air terminals can be attractors of lightning by offering a more electrically attractive path for a developing direct strike than those other points on the surface of the earth that would be competing for it. These two thought "camps" form the two ends of a continuum upon which you can place just about any of the direct strike lightning protection theories. The continuum could be represented as shown below.



ACTIVE ATTRACTION SYSTEMS

On the left we have systems that are designed to attract the lightning strike. The theory behind this practice is to attract the lightning to a known and preferred point therefore protecting nearby non-preferred points. The most common way this is done is to have an air terminal that initiates a streamer that will intercept the lightning down stroke leader with a pre-ionized path that will be the most attractive for the main lightning energy to follow.

PASSIVE NEUTRAL SYSTEMS

The middle of the continuum represents the conventional or traditional theory of direct strike protection. Conductors are positioned on a structure in the places where lightning is most likely to strike should a strike occur. We have labeled these systems as neutral since the air terminal or strike termination devices themselves aren't considered to be any more attractive or unattractive to the lightning stroke then the surrounding structure. They are positioned where they should be the first conductor in any path that the lightning strike takes to the structure.

ACTIVE PREVENTION SYSTEMS

The right third of the continuum is where we find the systems that are designed to prevent the propagation of a direct stroke of lightning in the area where they are positioned. There are two theories as to how preventative power occurs. The first is the "bleed off" theory mentioned previously. The second is that the sharp points on the prevention devices form a corona cloud above them that makes the device an unattractive path to the lightning stroke.

There are some commonalities in these three approaches. Each system's design requires the following:

- 1. The air terminal or strike termination device must be positioned so that it is the highest point on the structure.
- 2. The lightning protection system must be solidly and permanently grounded. Poor or high resistance connections to ground is the leading cause of lightning system failure for each one of these systems.

To go further in our comparison, we must separate the prevention systems from the other two. Obviously, if you are counting on preventing a lightning stroke from arriving near you, you don't have to worry about how to deal with the lightning current once you have it on your lightning protection system. None of these systems claims to protect against 100% of the possibility of a lightning stroke arriving near you. A compromise must be made between protection and economics.

There is general agreement that the best theoretical lightning system is a solid faraday cage around whatever it is that is being protected. An airplane is an example of this. But even in the case of the airplane, there are incidents reported of damage from direct lightning strokes. On the ground, a complete faraday cage solidly tied to ground is an attractive protection scheme, but is expensive to accomplish. If it is a general area, and not a structure that you are trying to protect, the faraday cage approach is very impractical.

This book will dwell basically on the passive “Franklin Rod” theory for lightning protection. While lightning cannot be prevented, it is possible to design a lightning protection system that will prevent injury to people and damage to installations in the majority of lightning strikes. Standards and codes for passive lightning protection materials and installations that ensure safety and minimize damage and fire hazards in the great majority of lightning strikes are published by Underwriters Laboratory (UL96 & 96A), the National Fire Protection Association (NFPA 780) and the Lightning Protection Institute (LPI-175). Protection for 100% of the lightning strikes is usually cost prohibitive.

Meeting the codes and standards does not necessarily provide protection to sensitive electronic equipment and data interconnections. These can be damaged or affected by voltage levels below those that will harm people or start fires. A well-designed lightning system exceeds the minimum code requirements, providing not only safety to people and protection against fire, but also providing protection for equipment and the integrity of data and operations. Manmade structures of steel, concrete or wood are relatively good conductors compared to the path of lightning through the ionized air. The impedance of a structure is so low compared to that of the lightning path that the structure has virtually no effect on the magnitude of the stroke. As a result, lightning can be considered a constant current source. The current may divide among several paths to earth, along the outside walls, sides and interior of a structure, reducing the voltage drop to ground. Better protection is provided by multiple paths to ground, including the many paths through the steel building structure. All structural metal items must be bonded. Bolted joints in steel columns are usually adequately bonded as are properly lapped and tied or mechanical rebar splices.

Effective lightning protection involves the integration of several concepts and components. In general, lightning protection can be indexed as follows:

1. Capture the lightning strike on purpose designed lightning terminals at preferred points.

2. Conduct the strike to ground safely through purpose designed down conductors.
3. Dissipate the lightning energy into the ground with minimum rise in ground potential.
4. Eliminate ground loops and differentials by creating a low impedance, equipotential ground system.
5. Protect equipment from surges and transients on incoming power lines to prevent equipment damage and costly operational downtime (See Chapter 7).
6. Protect equipment from surges and transients on incoming telecommunications and signal lines to prevent equipment damage and costly operational downtime (See Chapters 4 and 7).

My thanks to Dr. A. J. (Tony) Surtees, Manager - Facility Electrical Protection, North / South America, ERICO, Inc. who greatly assisted in the following section.

A NEW APPROACH TO LIGHTNING PROTECTION

The overall purpose of a lightning protection system is to protect a facility and its inhabitants from the damage of a direct or nearby lightning strike. Since ERICO believes that trying to prevent a lightning strike is unreliable, the best way to protect is to shunt the lightning energy “around” the vital components/inhabitants of the facility and dissipate that energy into the earth where it wants to go anyway. The first step in that process is to make sure that lightning, when approaching the facility, is attracted to the strike termination devices that have been installed on the structure for that purpose. The role of a lightning strike termination system is to effectively launch an upward leader at the appropriate time so that it, more so than any other competing feature on the structure, becomes the preferred attachment point for the approaching down leader (lightning strike).

As the down leader approaches the ground, the ambient electric field rapidly escalates to the point where any point on the structures projecting into this field begin to cause air breakdown and launch upward streamer currents. If the ambient field into which such streamers are emitted is high enough, the partially ionized streamer will convert to a fully ionized up-leader. The ability of the air termination to launch a sustainable up-leader that will be preferred over any other point on the structure, determines its effectiveness as an imminent lightning attachment point.

The Franklin Rod or conventional approach to lightning protection has served the industry well, but since its

inception over 200 years ago, the nature and scope of lighting protection has changed considerably. Lightning protection then was principally a defense against fire. Wooden buildings, when struck by lightning, would often burn. Barns and churches were the main facilities seeking this protection due to their height. Today, fire is still a concern, but not always the main concern. A modern facility of almost any kind contains electronic equipment and microprocessors. Facility owners are concerned about avoiding downtime, data loss, personnel injury & equipment damage as well as fire.

The materials used to construct facilities have changed dramatically also. Steel columns and the steel in reinforced concrete compete as low impedance conductors for lightning energy. The myriad of electrical/electronic equipment and conductors that crisscross every level of the facility are at risk just by being near conductors energized from nearby lightning strikes. The lightning codes of the past don't adequately address these issues. Bonding of downconductors to electrical apparatus within 3 to 6 feet is required and can add substantial wiring to a facility if there are a lot of downconductors. Further, the need for lightning protection for these electrically sophisticated facilities is growing.

The amount of knowledge about lightning has increased dramatically also. Information about the behavior of leaders, the changing of electrical fields leading up to a strike, the effects of impedance of various competing downconductors, and diagnostic equipment has all increased dramatically. This gives today's designers of lightning protection systems a large advantage over those of just 20 years ago.

These technological advances and market demands for more cost effective lightning protection systems have prompted many new and novel approaches to lightning protection. One such system is the ERICO System 3000™. This system's components are Dynasphere™ Controlled Leader Triggering (CLT) air terminals typically used with Ericore™ low impedance, insulated downconductor. This system enables the facility owner to use fewer air terminals with fewer downconductors. The result is:

- fewer conductors to bond to nearby electrical apparatus.
- the ability to run downconductors down through the middle of a building.
- less congestion on the roof of a building (this is especially important when reroofing).
- a safer building roof for workers.
- the ability to protect open spaces as well as buildings.
- an overall more cost effective lightning protection system.

The Dynasphere CLT is a passive terminal, which requires no external power source, relying solely on the energy contained in the approaching leader for its dynamic operation. This remarkable terminal has the ability to concentrate only that electric field which occurs in the millisecond time slots as the leader charge approaches the ground. The principle of operation of this terminal relies on the capacitive coupling of the outer sphere of the terminal to the approaching leader charge. This in turn raises the voltage of the spherical surface to produce a field concentration across the insulated air gap between the outer sphere and grounded central finial. As the leader continues to approach, the voltage on the sphere rises until a point is reached where the air gap between the central finial and outer surface breaks down. This breakdown creates local photo-ionization and the release of excess free ions. These then accelerate under the intensified field to initiate an avalanche condition and the formation of an up streamer begins.

The DYNASPHERE CLT is designed to ensure that it only launches an up-streamer when it has sensed that the electric field ahead of it is high enough to ensure propagation. This is unlike the way in which many other so called Early Streamer Emission terminals operate. It was developed through research and test equipment that wasn't available to earlier designers, but also developed by building on the wealth of knowledge created by those that came before us.

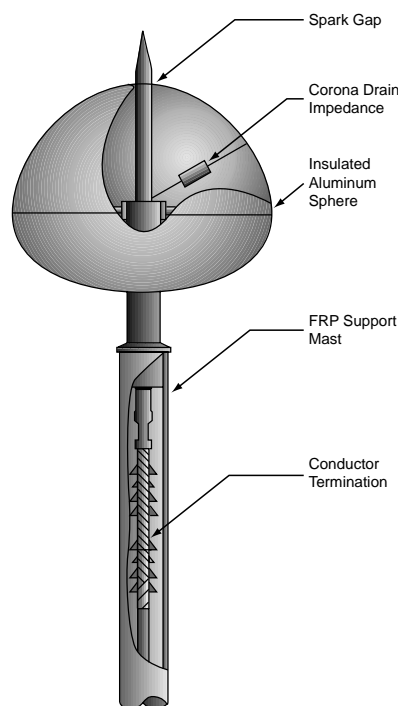


Fig. 2-2 Dynasphere™ Controlled Leader Emission (CLT) Air Terminal

Calculation of the Protective Coverage offered by an air terminal

Collection Volume Design Method

A more efficient air terminal demands a new design philosophy and discipline. ERICO has developed an alternative design method matched to the performance of the System 3000™ lightning protection system. This method is based on the work of Dr. A. J. Eriksson, the noted lightning researcher. A detailed description can be found in the Australian Lightning Protection Standards NZS/AS1768-1991, section A8.

The Collection Volume method provides an empirical and quantitative method based on design parameters such as, the structure height, field intensification of structural projections, leader charge, site height and relative propagation velocities of the intercepting leaders. The model can be developed for three dimension structures and offers a more rigorous approach to lightning protection design.

Item	Lightning Characteristic	Percentage of events having value of characteristic							Unit
		99	90	75	50	25	10	1	
1	Number of component strokes	1	1	2	3	5	7	12	
2	Time Interval between strokes	10	25	35	55	90	150	400	ms
3	First stroke current I_{max}	5	12	20	30	50	80	130	kA
4	Subsequent stroke peak current I_{max}	3	6	10	15	20	30	40	kA
5	First stroke between strokes $(di/dt)_{max}$	6	10	15	25	30	40	70	GA/s
6	Subsequent stroke $(di/dt)_{max}$	6	15	25	45	80	100	200	GA/s
7	Total charge delivered	1	3	6	15	40	70	200	C
8	Continuing current charge	6	10	20	30	40	70	100	C
9	Continuing current I_{max}	30	50	80	100	150	200	400	A
10	Overall duration of flash	50	100	250	400	600	900	1500	ms
11	Action integral	10^2	3×10^2	10^3	5×10^3	3×10^4	10^5	5×10^5	A ² .s

Table 1 (Table A1 NZS/AS1768-1991)
Distribution of the Main Characteristics of the Lightning Flash to Ground

Table 1 (taken from NZS/AS1768-1991) illustrates the statistical distribution of lightning parameters. Item 3 in the table can be used in determining the statistical levels of protection. Using the equation below, protection levels directly relating to peak current discharge, I , and the corresponding leader charge, Q , are derived:

$$I = 10.6 Q^{0.7}$$

where I is measured in kA and Q in coulombs. From Table 2 a discharge having a peak current of 5kA would correspond to a leader charge of approximately 0.5 coulombs. Further calculation and extrapolation from Table 1 are shown in Table 2.

Leader Charge (Q)	Peak Current (I)	Percent Exceeding Value	Protection Level
0.5C	6.5kA	98%	High
0.9C	10kA	93%	Medium
1.5C	16kA	85%	Standard

Table 2 - Statistical probability of a down-leader exceeding the peak current indicated

Figure 3 shows a downward leader approaching an isolated ground point. A striking distance hemisphere is set up about this point. The radius is dependent on the charge on the leader head and corresponds to the distance where the electric field strength will exceed critical value. That is, the field strength becomes adequate to launch an intercepting upward leader.

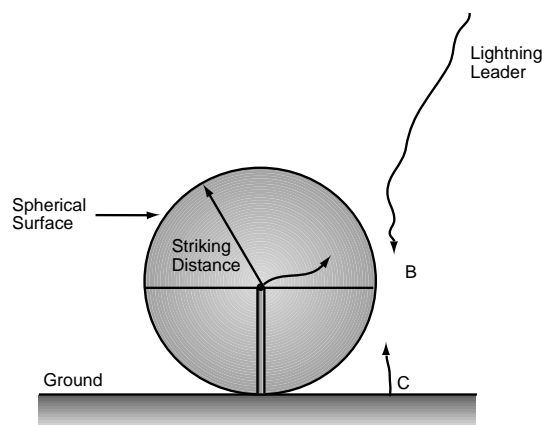


Fig. 2-3 Spherical Surface with Striking Distance radius about point A

The striking distance hemisphere reveals that lightning leaders with weak electric charge approach much closer to the ground point before achieving the critical conditions for initiation of the upward leader. The higher the magnitude of charge, the greater the distance between leader and ground point when critical conditions are achieved. For design purposes a hemisphere radius can be selected which relates to a desired level of protection. The Collection Volume method takes into account the relative velocities of the upward and downward leaders. Not all leaders that enter a striking distance hemisphere will proceed to interception. Leaders entering the outer periphery of the hemispheres are likely to continue their downward movement and to intercept a different upward leader (issuing from an

alternative structure or feature on the ground). This leads to the development of a limiting parabola. The enclosed volume is known as the Collection Volume. A downward progressing leader entering this volume is assured of interception. Figure 4 shows how the velocity parabola limits the size of the Collection Volume.

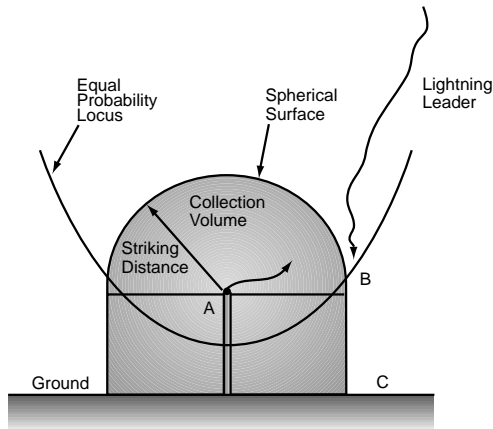


Fig. 2-4 Collection Volume formed by equal-probability locus and spherical surface

Designing with Collection Volumes using statistically derived lightning parameters as in Table 2 will provide designers with better risk analysis. Magnitudes of Collection Volumes are determined according to peak current. That is, if the designer desires a high level of protection (peak current 6.5kA), 98% of all lightning exceeds this value. Discharges of greater magnitude will have larger Collection Volumes that create greater overlap in the capture area of air terminals. A design based on lightning with small peak current can be considered conservative. The design performed to 98% High level does not mean that all lightning less than that level will miss an air termination. There is simply a statistical chance some lightning may not intercept with an upward leader emanating from within the Collection Volume.

The Collection Volume model assumes all points on the structure are potential strike points, and as such exhibit natural Collection Volumes.

ERICO, Inc. has developed a computer program that evaluates the corresponding electric field intensity at each stage and compares the electric field intensification of competing points (building corners and edges, antennae, equipment, masts etc). The program then evaluates which point will first generate the upward moving leader which meets the downward leader. The main discharge return stroke follows the upward/downward leader path. An attractive radius for each relevant point can then be calculated.

The larger collection volumes of enhanced air terminals means that fewer such terminals are required on a structure. They should be positioned such that their collection volumes overlap the natural small Collection Volumes of the structure projections.

This method is visually more attractive and convenient to apply by consultants in lightning protection design. Figure 5 shows the Collection Volume Concept when applied to a structure.

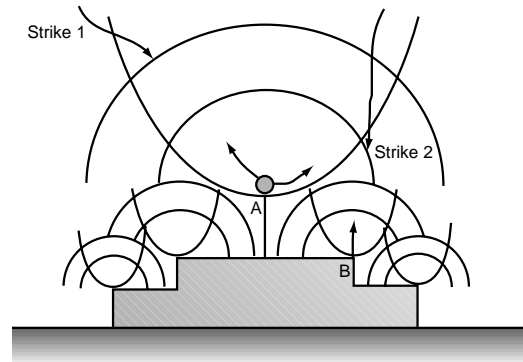


Fig. 2-5 The Collection Volume Design Concept

The design discipline employed in lightning protection design is critical to reliable systems. ERICO's system has been tested and has been used in the accomplishment of over 7000 successful installations around the globe over the past 15 years. Many of these installations are on high risk structures in some of the most active lightning environments on the planet.

LIGHTNING PROTECTION COMPONENTS

A lightning protection system is comprised of a chain of components properly specified and properly installed to provide a safe path to ground for the lightning current. The lightning protection system provides an uninterrupted conductive (low impedance) path to earth. Lightning does not always strike the highest point. The rolling ball theory of determining what is protected from lightning strikes, described below, is widely accepted as a sound approach to sizing and positioning air terminals on the top of structures, and for tall structures, on the sides of the structure.

Properly designed lightning protection systems based on existing standards ensure adequate conducting and surge diverting paths which have been proven safe for people, structures and equipment in the great majority of cases. Other systems exist which are not covered in standards. These systems, which claim to prevent lightning strikes, must be considered carefully before installation.

The following are basic components for a lightning protection system. Sketches at the end of this section depict the many requirements discussed.

Air terminals, often called lightning rods, lightning points or strike termination devices are blunt or pointed, solid or tubular rods of copper, bronze, stainless steel or aluminum. On large (over 500 sq. inch [0.323 sq. m] flue cross section), tall (over 75 feet or 23 m) smoke stacks, the air terminals must be stainless steel, monel metal or lead jacketed solid copper. (Fig. 2-6) Air terminals are normally between 10 and 24 inch (254 to 610 mm) long but may be longer. Although they are normally pointed, a blunt rod has been tested and found to be more effective. Since they are usually thin pointed rods, protection should be provided to minimize the danger of injury in areas where personnel may be present. The protection can be in several forms but the most common is the use of tall air terminals or blunt rods. Terminals that are more than 24 inches (610 mm) high require extra support other than the base mount.

Conductors connect the air terminals to each other, to the metal structure of the building, to miscellaneous metal parts of the building and down to the counterpoise and/or earth electrodes. Building connections are made to the steel columns or to the rebars (steel reinforcing bars) used in concrete construction. In most large buildings, the heavy steel structure provides a much lower impedance path to earth than separate down conductors installed as part of the lightning protection system. These steel columns can be used as the down conductors. Since the lightning current is not effected by the structure, multiple down conductor paths in parallel will result in lower voltage differences between the top of the building and the foundation. This voltage differential can be important in buildings with electronic equipment interconnected between floors, in antenna towers and similar instances.

The size of the conductors is not too important although they must meet the minimum requirements of the lightning code. For example, a 4/0 conductor is only slightly better (lower impedance) than a No. 6 AWG conductor for the short duration (high frequency) of the lightning stroke. Although the ampacity (DC resistance) of these two conductors are different (by a factor of approximately 8), short time impulses have voltage drops that are usually within about 20% of each other.

The lightning down conductors must be bonded to the building steel. Also included are any conductive items which may cause side flashes resulting from instantaneous voltages that exceed the voltage withstand capability of the air or other insulating material between the conductor and

the conductive item. Side flashes can occur between lightning conductors and building steel, permanently mounted ladders, equipment, etc. even though all are connected to a common ground or earthing point. The instantaneous voltage difference can become dangerously high because of the high impedance of the various paths to the steep wave front lightning current, resulting in large voltage drops. Even when no side flash occurs, the large voltage differences can cause electronic noise and component failure. Often, latent component failure, created by repeated voltage stress, will cause equipment failure at a time when no lightning or other outside influence is present. This problem is likely to be made much worse where there are separate equipment grounds, not bonded together (which is a violation of the National Electrical Code [NEC]).

A few general rules are that the conductors must be horizontal or course downward from the air terminal to the ground electrode; they cannot have a bend over 90° (Fig. 2-7); they cannot have a bend radius tighter than 8 inch (200 mm) radius (Fig. 2-7); they cannot be coursed through the

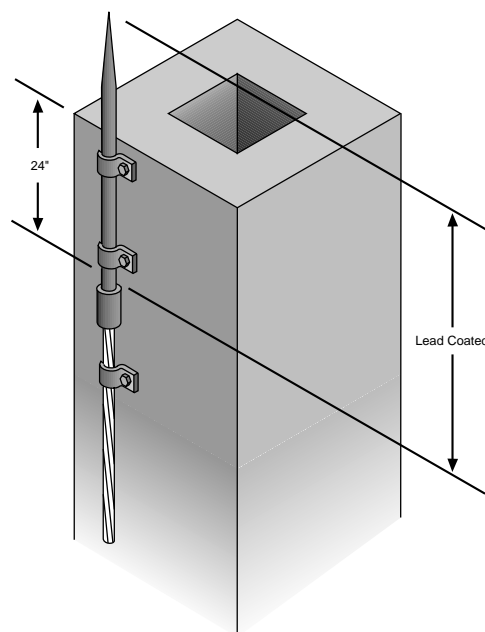


Fig. 2-6

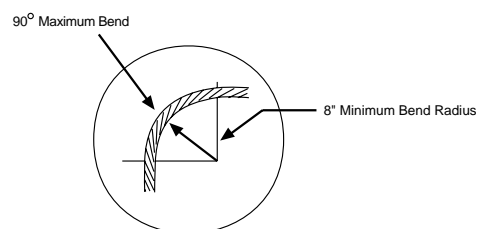


Fig. 2-7

air without support for more than 3 feet (0.9 m) (Fig. 2-8) and they must be fastened at a maximum of every 3 feet (0.9 m) using non-ferrous fasteners. (Fig. 2-9)

Conductor material must comply with the lightning codes and be compatible with the surfaces which it contacts. Aluminum conductors cannot be used within 18 inches (460 mm) of finished grade.

Conductors must be at least the minimum size specified by the National Fire Protection code (NFPA-780), UL96 and/or LPI-175, and for heavy fault conditions should be calculated in accordance with IEEE Std 80.

NEC (250-46) requires electrical raceways, equipment, etc. that are within 6 feet (1.8 m) of a lightning conductor to be

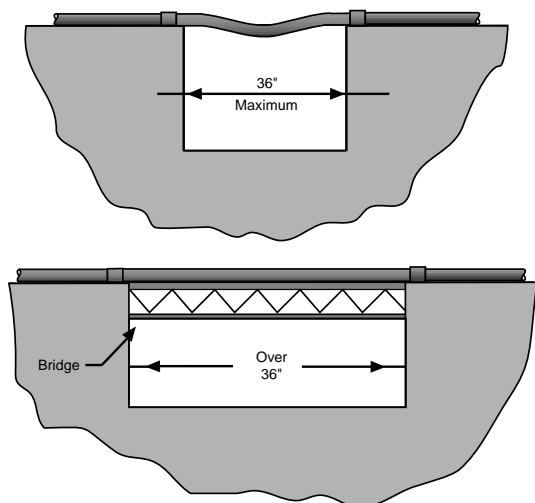


Fig. 2-8

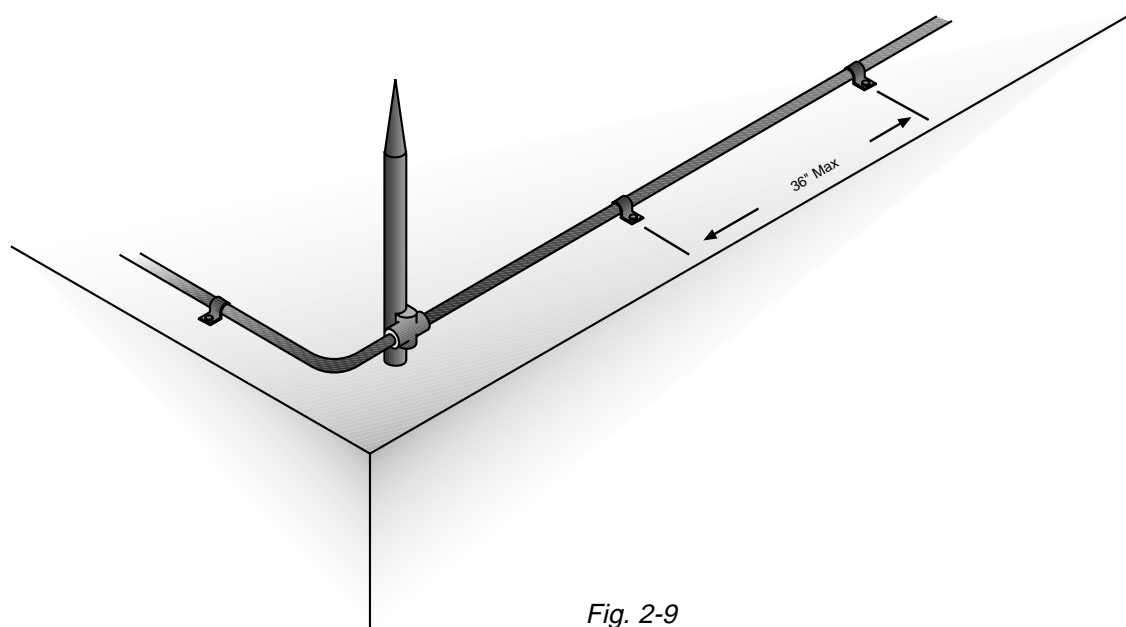
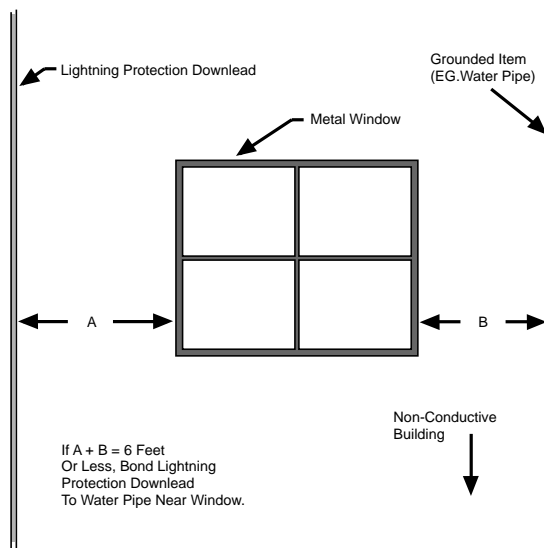


Fig. 2-9

bonded to the conductor at the location where that separation distance is less than 6 feet (1.8 m). NFPA 780 further clarifies this in cases where a metallic object is between the downlead and the grounded item. (Fig 2-10) In addition, Section 250-86 requires that lightning conductors and driven rods or pipes, or any other made electrode that is used for lightning system protection shall not be used in lieu of the grounding electrode system discussed in Chapter 1. This is not to say that the two systems shall not be bonded together, only that there must be two systems with two distinct purposes that are interconnected. The intercon-



Side Flash Bounding Requirements

Fig. 2-10

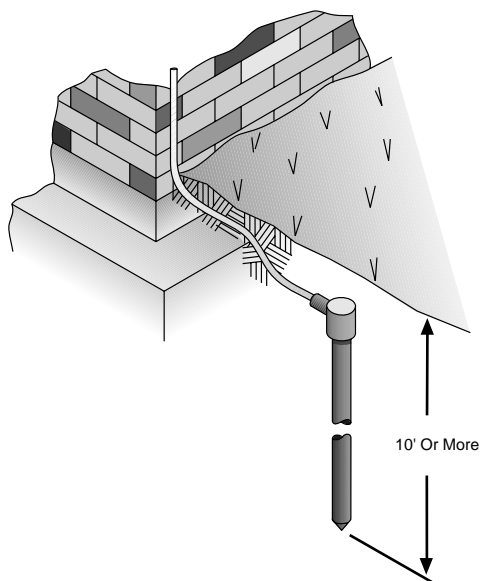
**Moist Clay Soil**

Fig. 2-11

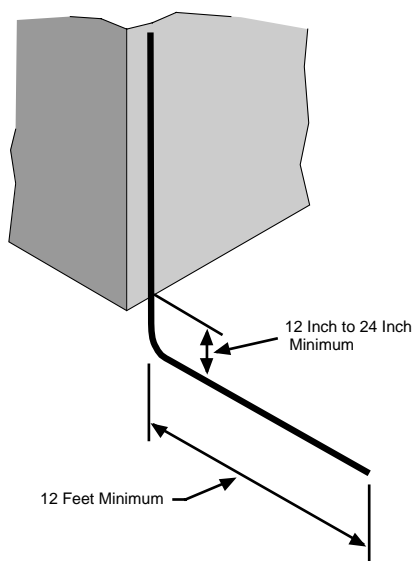
**Shallow Topsoil**

Fig. 2-12

necting or bonding of the two systems helps to ensure that there is little possibility of a difference of potential between the two systems or the two systems' components.

Because this bonding requirement is difficult to implement in many facility installations, some low impedance screened down conductors are being used successfully by ERICO in Australia and Asia. These conductors are specially constructed and therefore relatively expensive, but the reduced chance of side flashes and the ease of installation are very attractive.

Connectors bond the conductors to the air terminals,

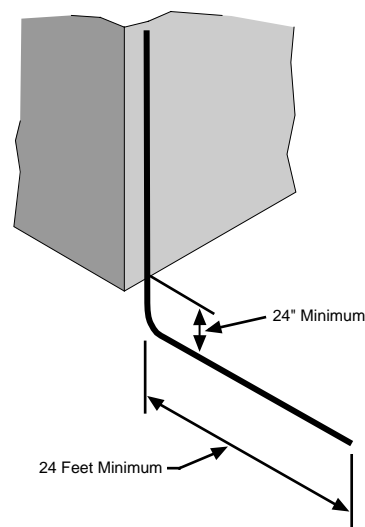
**Shallow Sandy Soil**

Fig. 2-13

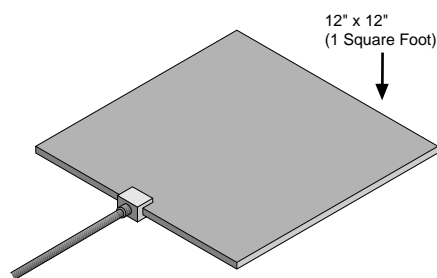
**Plate Electrode**

Fig. 2-14

structures, equipment and ground electrodes. They can be mechanical devices or exothermic welded connections. Connections to thin metal or to aluminum items must be mechanical. A properly made connection must last as long as the planned life of the facility and have:

1. Adequate mechanical strength to withstand the forces of nature and any outside force it may encounter.
2. High thermal capacity for high current surges.
3. Low and constant impedance.
4. Corrosion resistance.
5. No electrochemical deterioration when joining different materials.

Grounding electrodes make the connection between the lightning protection system and the earth. The lightning electrodes must be bonded to all other grounding system

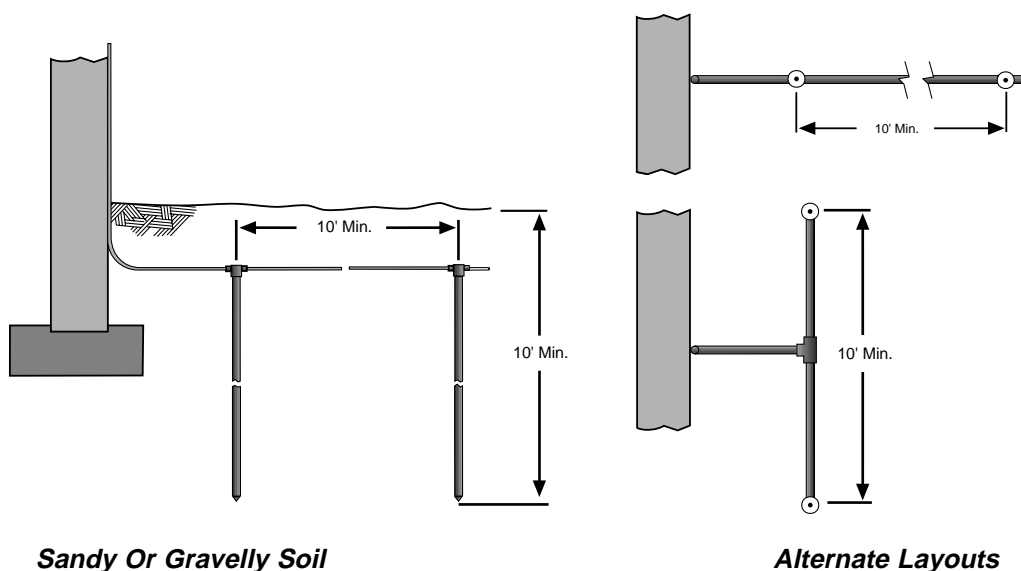


Fig. 2-15

electrodes as required by the NEC (250-81 and 250-86) and the several lightning codes such as NFPA 780. No exceptions! Failure to bond all grounding electrodes together can result in dangerous voltage differences between exposed metal connected to ground points, especially during lightning strikes or ground faults. Such voltage differences injure people and destroy equipment.

Transient earth clamps are available that act as an open switch during normal operation but turn on during an overvoltage event to bond the systems together. These are approved for use in some countries for bonding between the separate ground electrode systems.

The purpose of establishing a low resistance connection to earth is to conduct lightning current away from people, equipment and structures. A low resistance grounding system is desirable in a lightning protection system but not essential. In an area where the soil resistivity is high, an extensive network of conductors still may not provide a low grounding resistance. But, the potential distribution about the building is substantially the same as though it were setting on conductive soil with a low resistance grounding scheme. The resulting lightning protection is also substantially the same. The minimum electrode requirements vary with the soil type.

Moist clay. The electrode shall extend vertically at least 10 feet into the earth. The rod size shall be at least $\frac{1}{2}$ inch by 8 feet (5/8 x 8 for buildings over 75 feet high). (Fig. 2-11)

Shallow top soil. If bedrock is near the surface, the

conductors are laid in trenches extending away from the building. The trenches shall be 1 to 2 feet (0.31 to 0.62 m) deep and 12 feet (3.7 m) long in clay soil (Fig. 2-12) and 2 feet (0.62 m) deep and 24 feet (7.4 m) long in sandy or gravelly soil. (Fig. 2-13) In rare cases where this is impracticable, the lightning cable shall be buried in 2 feet (.62 m) deep trenches. Where this is impossible, the cable may be laid directly on top of the bedrock at least 2 feet (0.62 m) from the foundation or exterior footing. This cable must be terminated on a buried copper plate at least 0.032 in (0.813 mm) thick and 1 square foot (0.093 square m) area. (Fig. 2-14)

Sandy or gravelly soil. In sandy or gravelly soil, the lightning conductor shall extend away from the building in a trench at least 12 inch deep. The ground rod shall be 20 feet long or greater or there shall be 2 or more rods separated at least 10 feet driven vertically to a minimum 10 feet below grade. (Fig. 2-15)

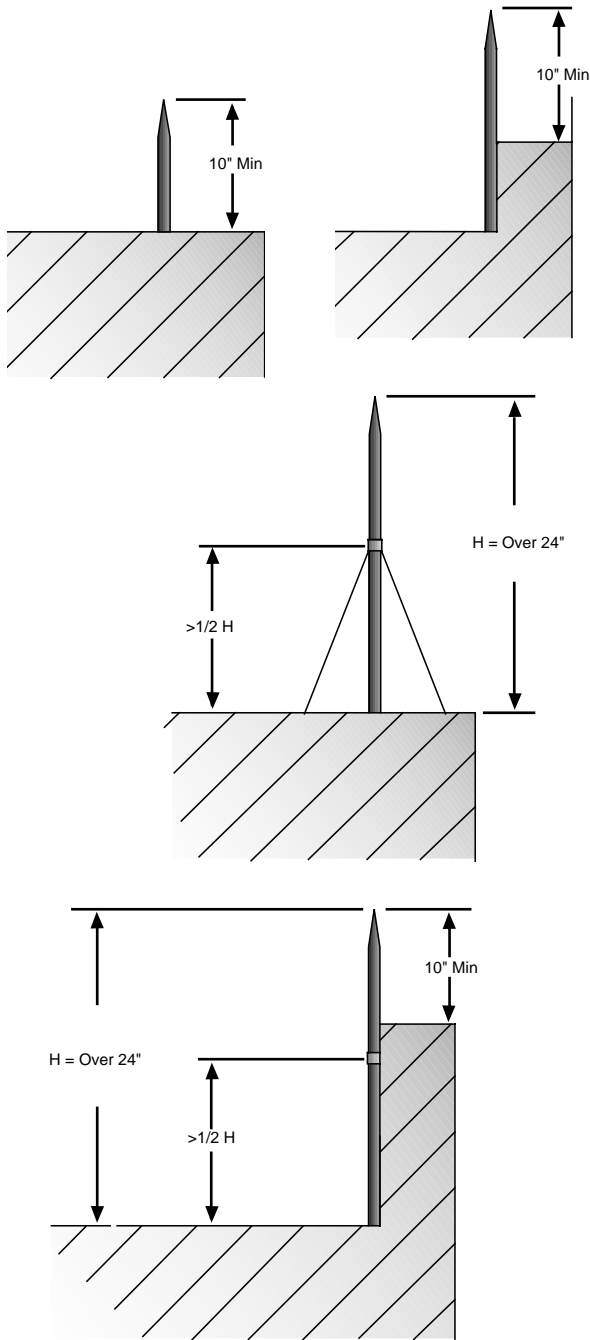
If the soil is less than 12 inch thick, a counterpoise (or network of conductors) in a trench or rock crevices shall surround the structure. The counterpoise conductor must be copper, sized to meet Class I main cable size. If the structure is over 75 feet in height, the cable must be sized to meet Class II main size copper. These cable sizes are listed in the various lightning codes. In extreme cases, copper plates may also be required.

NFPA 780, STANDARD FOR THE PROTECTION OF LIGHTNING SYSTEMS - AN OVERVIEW

In addition to the general requirements covered above, the following requirements apply to those lightning installations which must be installed in conformance with NFPA 780. Keep in mind that these requirements represent a small portion of NFPA 780. Designers and installers who must meet these requirements are encouraged to obtain a copy of the standard to review all of the lightning system provisions.

1. Section 1-3: Unless approved by the authority having jurisdiction, all lightning system components shall be listed or labeled. In other words, a testing laboratory, such as Underwriters Laboratories (UL), must have evaluated the product to determine that it meets appropriate designated standards and is suitable for use in a specified manner. Exothermic connections, properly installed, while not listed, are routinely approved by UL inspectors.
2. Section 1-4: As with any electrical work performed under the NEC, the installation of lightning protection systems installed under NFPA 780, must be in a neat and workmanlike fashion. While the terms “neat and workmanlike” are undefined, this general requirement should clearly prohibit shoddy work on lightning protection systems.
3. Section 3-1: NFPA 780 contains two classes of materials that must be used to install lightning protection systems, Class I and Class II materials. Class I materials are used on ordinary structures which do not exceed 75 feet in height. Class II materials must be used for ordinary structures which exceed 75 feet in height. An ordinary structure can be a residential, industrial, commercial, farm or institutional type of structure. NFPA 780 contains charts which list the different materials for both classes. For example, solid type air terminals for Class I structures must be a minimum diameter of 3/8 inch copper or 1/2 inch aluminum. For Class II structures, solid type air terminals must be a minimum of 1/2 inch copper or 5/8 inch aluminum.
4. Section 3-7: Any lightning system protection components which are subject to physical damage or displacement are required to be adequately protected by protective molding or coverings. Metal raceways are permitted to be used, but as with the grounding electrode conductor, metal raceways must be bonded at both ends to ensure electrical continuity.
5. Section 3-9.1: In general, where air terminals are used, they shall be mounted such that the tip of the terminal is at least 10 inches above the object or area it is to protect. (Fig. 2-16) However, Section 3-11 allows air terminals to be placed at 25 foot intervals (rather than 20 foot intervals) provided they are at least 24 inches above the object or area they are intended to protect. (Fig. 2-17)
6. Section 3-10.3.1: The rolling ball theory of protection is a frequently used concept to determine the area of protection around a building or structure from lightning strikes. Basically, the zone of protection is thought to include the space not intruded by rolling a ball, which has a radius of 150 feet. In other words, if the rolling ball were to touch two air terminals, there must be a gap between the bottom of the rolling ball and the structure to be in the zone of protection. (Fig. 2-18)
7. Section 3-16.1: Ground rods which are used to terminate a down conductor must be at least 1/2 inch in diameter and a minimum of 8 ft in length. Ground rods are permitted to be constructed of copperbonded steel, copper, hot-dipped galvanized steel or stainless steel. The connection of the down conductor to the ground rod must be made by bolting, brazing, welding or other listed high-compression connectors. ERICO offers a full line of high-strength, corrosion-resistant ground rods and accessories such as CADWELD connections, grounding clamps, couplers and driving tools to meet the needs of contractors installing ground rods.
8. Section 3-17: To ensure that a common grounding potential exists for all metal objects in and around the building, all metal objects shall be interconnected, including; electrical service, telephone, CATV, underground metallic piping systems and gas piping systems, provided the connections are made on the customer's side of the meter.
9. Section 3-19.1: If the building contains a structural steel framework, such framework may be permitted to be used as the main conductor of the lightning protection system provided the structural steel is electrically continuous. (The LPI standard LPI-175 also requires the steel to be at least 3/16” (4.8mm) thick.) Where such steel is not electrically continuous it can be made so by the use of appropriate bonding jumpers. (Fig. 2-19)

10. Section 3-19.4: Where the building structural steel is used as the main conductor of the lightning protection system, a ground rod or other ground terminal shall be connected to approximately every other perimeter steel column. Such connection shall be made at the base of the column and at intervals not to exceed an average of about 60 feet.



Air Terminals Height And Supports
Fig. 2-16

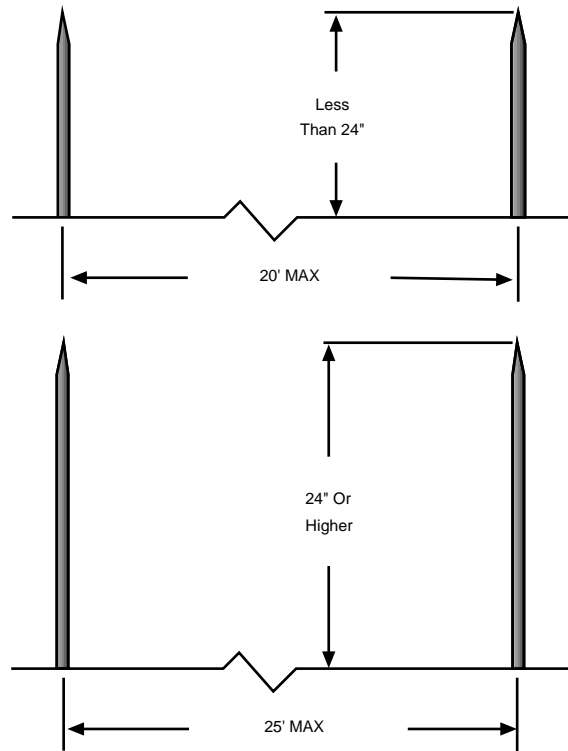


Fig. 2-17
Air terminals less than 24" in height are located at 20 feet maximum intervals. If 24 inches or higher, they can be spaced at 25 feet intervals. Air terminals located in areas where personnel may be present, 60 inch terminals are recommended at mid-roof locations.

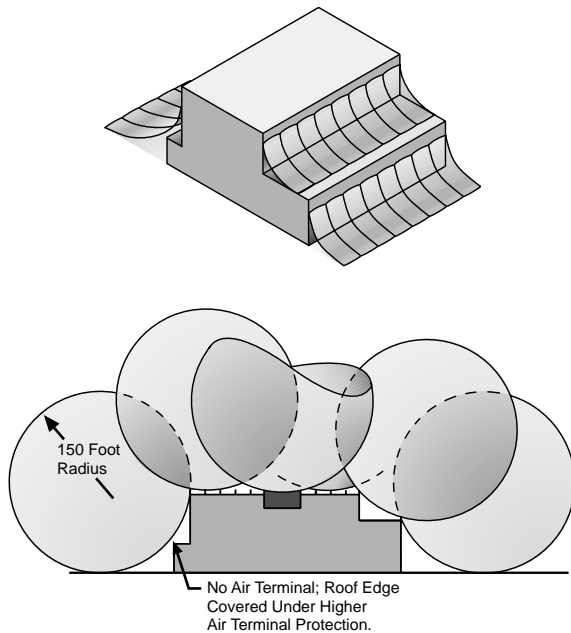


Fig. 2-18

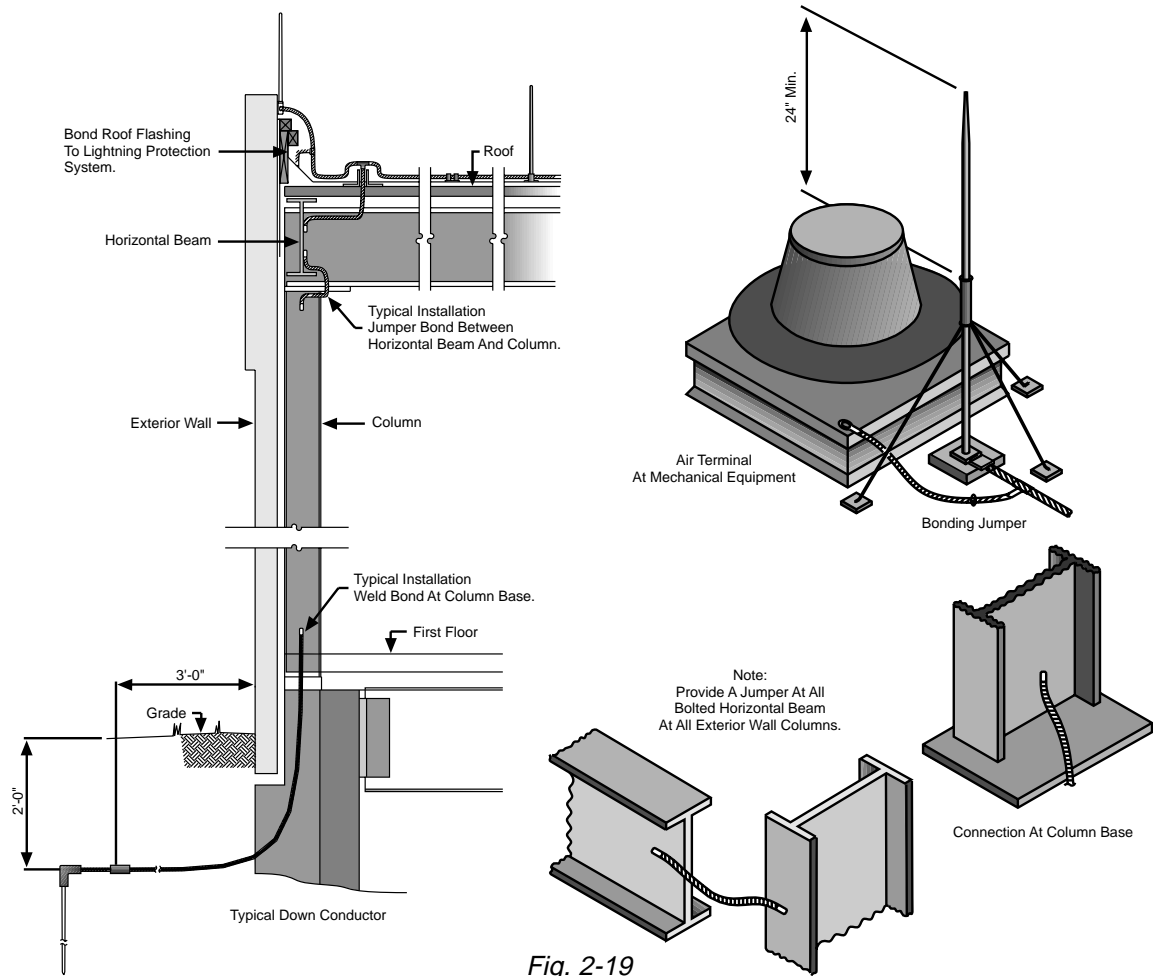


Fig. 2-19

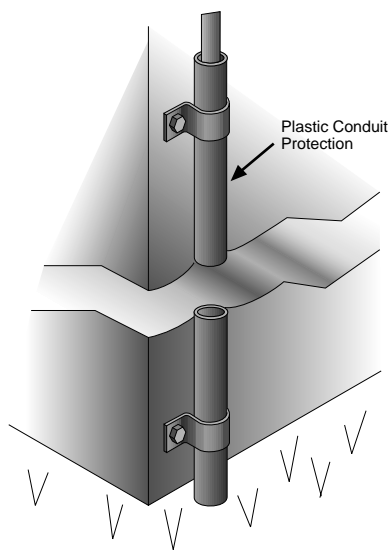


Fig. 2-20

Protection must be provided to the conductor in areas where physical damage or displacement may occur. PVC conduit is the preferred protector.

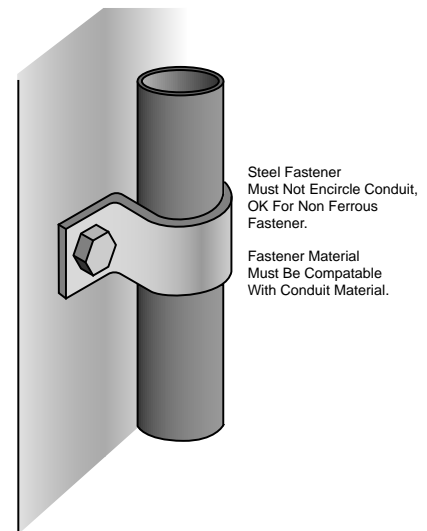


Fig. 2-21

Fasteners for either the conductor or the conduit must not encircle the conduit or conductor if made of a ferrous material. The fastener must be of a material compatible with the item fastened.

LIGHTNING SAFETY ANALYSIS

It is recommended that a lightning safety analysis be made of facilities and areas subject to lightning. Following are parameters to consider and recommendations:

1. Make a physical inspection. Identify hazards and threats which will contribute to lightning danger at the site.
2. Make a study of lightning strike probability. Review the five-year actual strike data from archives. Estimate the probable future annual strike density within 1 square km.
3. Do a grounding analysis. Measure existing grounds (ohms). Do a soil analysis (ohms-m). Determine type and amount of additional grounding needed to meet desired resistance. Establish an inspection / maintenance protocol.
4. Evaluate the existing air terminal / down conductor / bonding / shielding. Evaluate all appropriated designs and options. Establish an inspection / maintenance protocol.
5. Consider surge suppression devices. Make a study of the electrical signature of the facility. Identify vulnerabilities. Identify signal / energy protection options. Recommend detailed Fortress Concept protection.
6. Perimeter review. Identify "safe / not safe" zones or areas for personnel. Identify potential DC, Capacitive and inductive coupling to critical and non-critical areas. Recommend "best available" shelter options.
7. Lightning detection and personnel notification. Develop criteria for cessation of activities. Recommend appropriate lightning detection and signaling devices. Integrate decisions into overall Facility Safety Plan.
8. Implement recommendations. Certify correct installation of all safety devices. Create appropriate safety signage, brochures, literature, posters and text relating to the lightning plan at the facility. Prepare affidavit indicating that the facility uses "best available technology" for lightning safety.

(From National Lightning Safety Institute.)

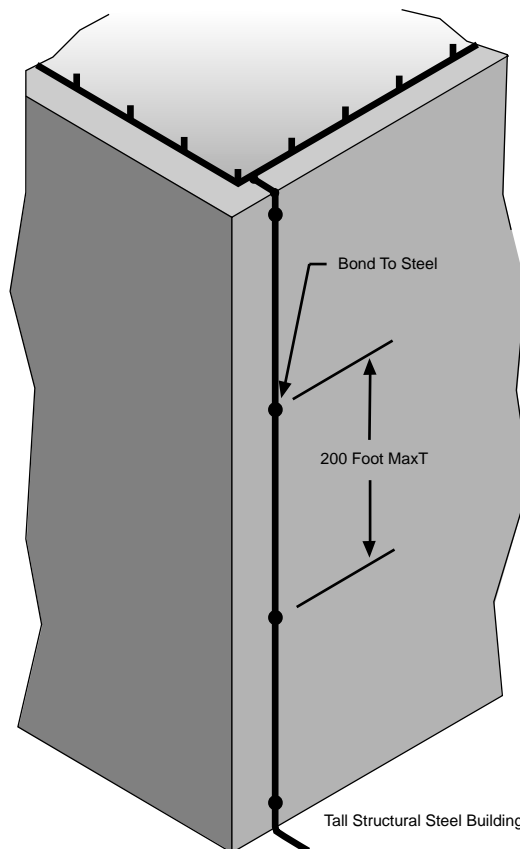


Fig. 2-22

Downleads following steel members must be bonded to the steel at the upper and lower extremities and at 200 foot maximum intervals.

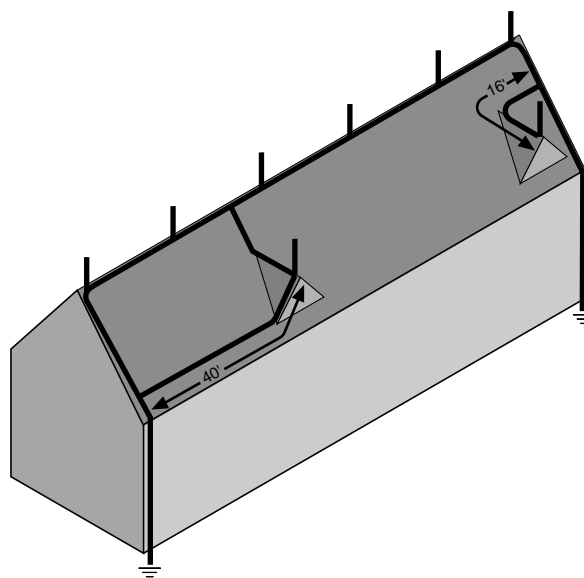


Fig. 2-23

A dead end conductor must be no longer than 16 feet. If over 16 feet, a second conductor path must be added.

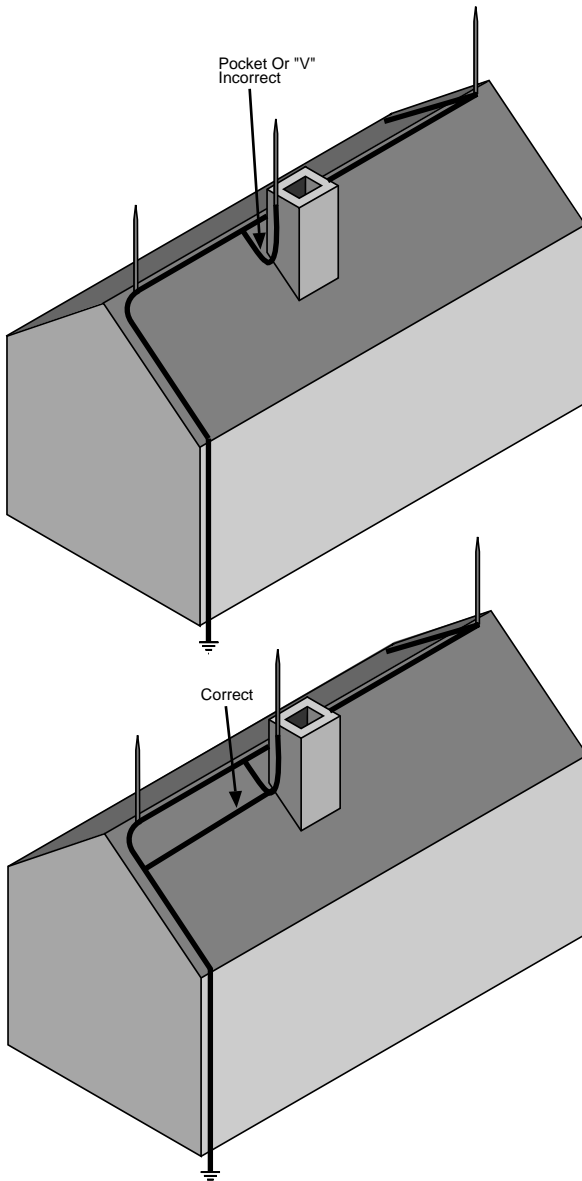


Fig. 2-24
Conductors must never be coursed upward.

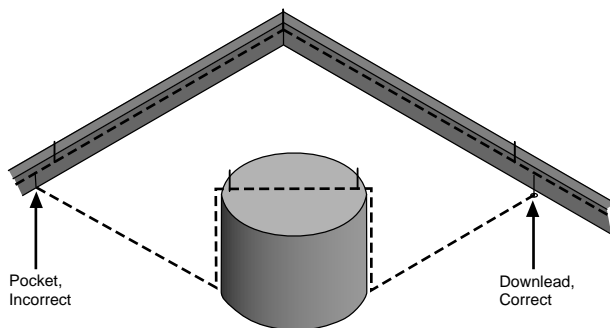


Fig. 2-25
The conductor must never be coursed upward.

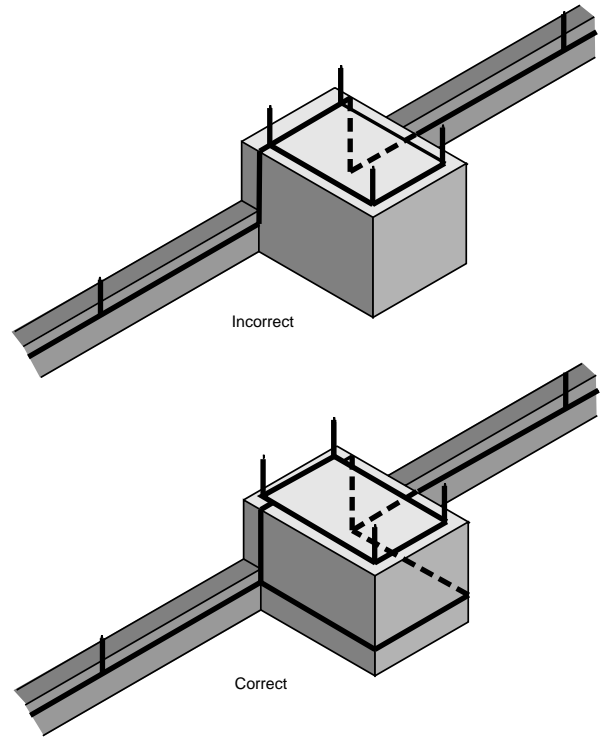


Fig. 2-26
The main conductor must never be coursed upward.

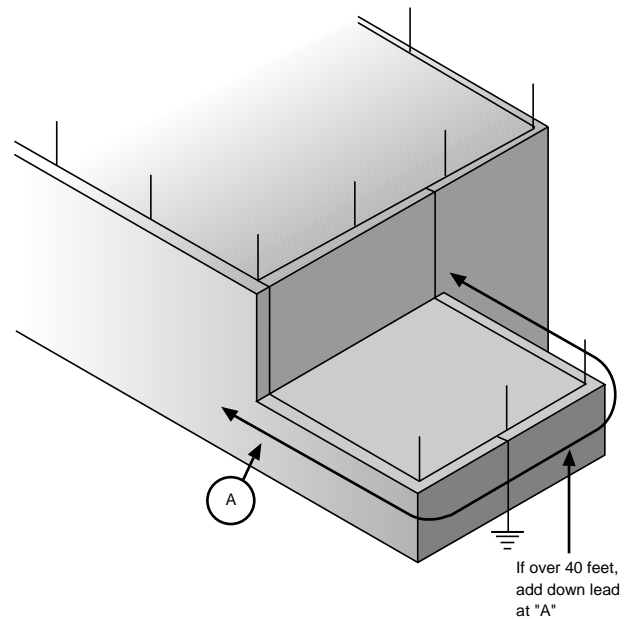


Fig. 2-27
If a projection is over 40 feet on the three sides, a downlead must be provided at (A) on both sides of the projection.

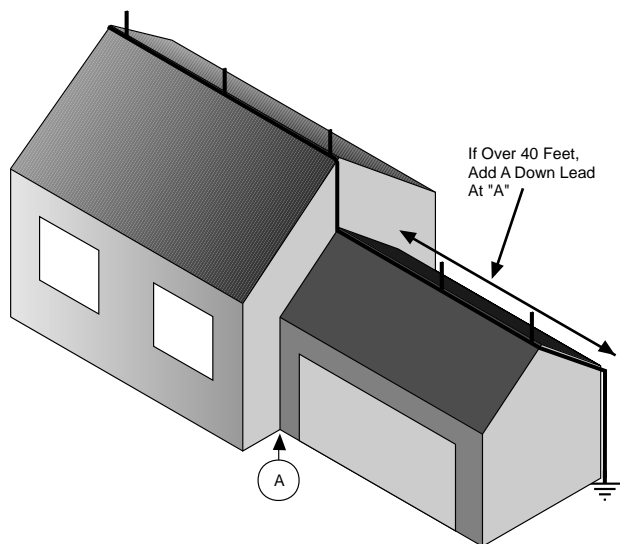


Fig. 2-28

If a projection extends over 40 feet, a downlead at (A) must be provided on the projection.

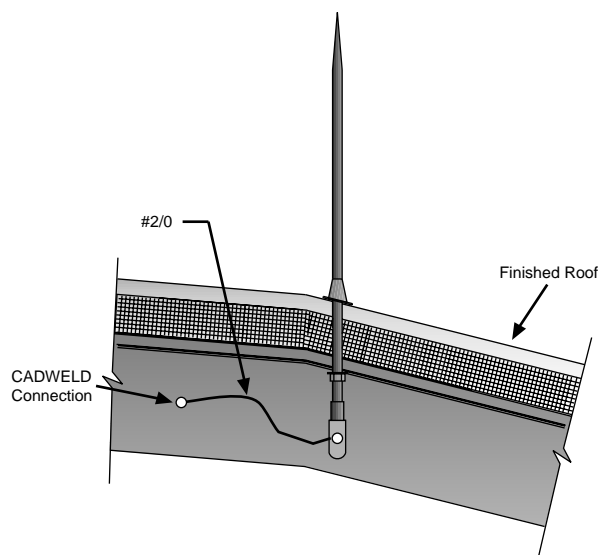


Fig. 2-31

Using the structural steel as the down conductor.

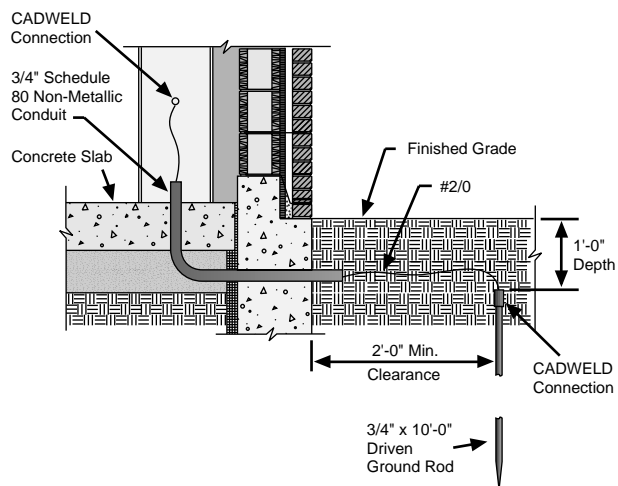


Fig. 2-29

Using the structural steel as the down conductor.

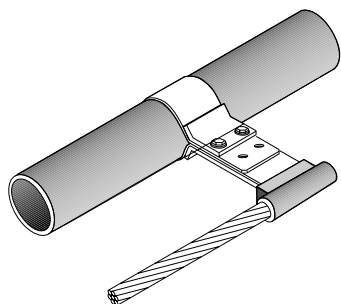


Fig. 2-30

Clamp to cast iron or copper water pipe.

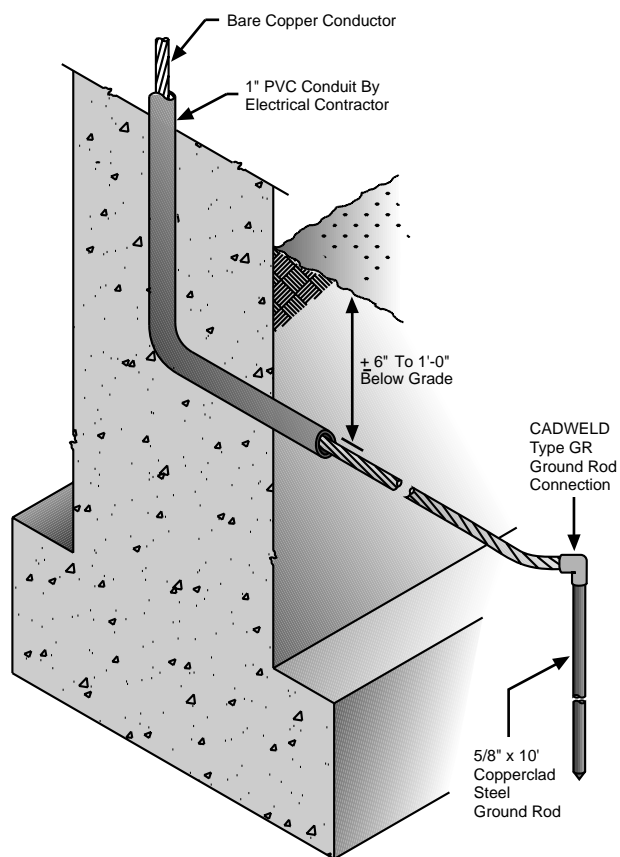


Fig. 2-32

Detail of conductor through the foundation.

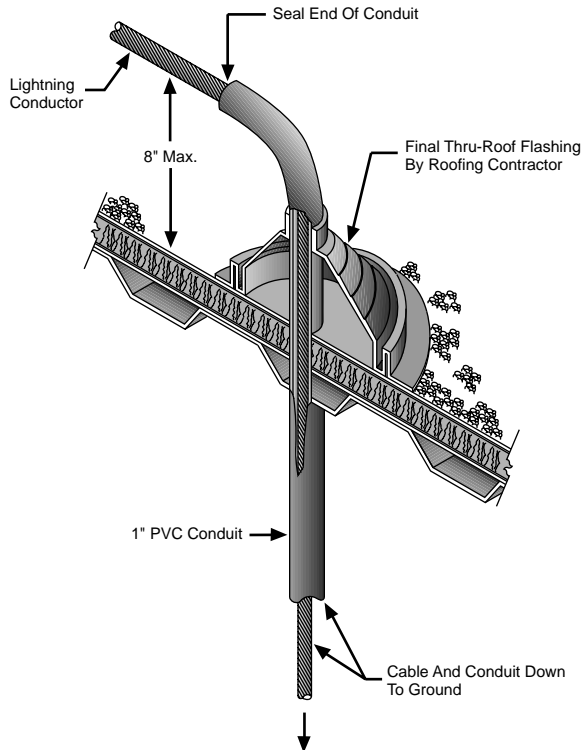


Fig. 2-33
Detail of conductor through the roof.

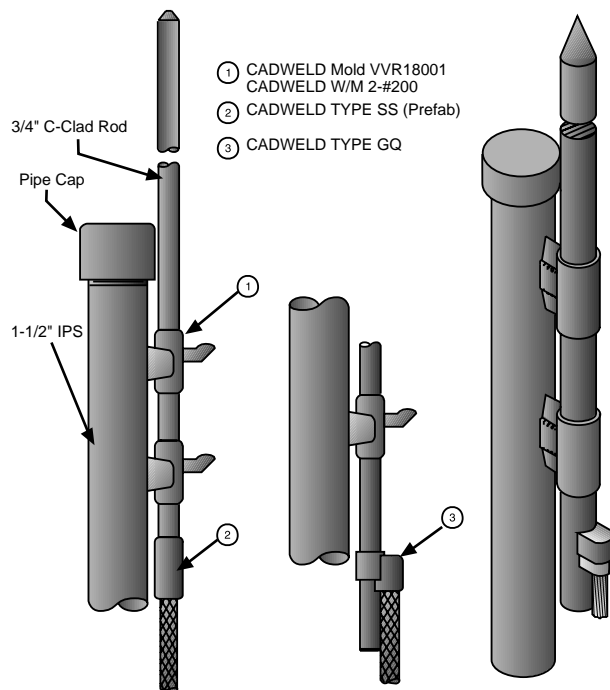


Fig. 2-34
Using a copper-clad rod welded to a pipe as an air terminal.

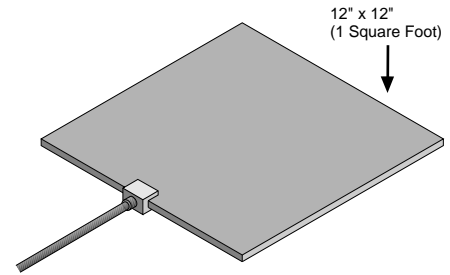


Fig. 2-35
Electrodes made from copper or steel plates are often used in soil less than 12" thick.

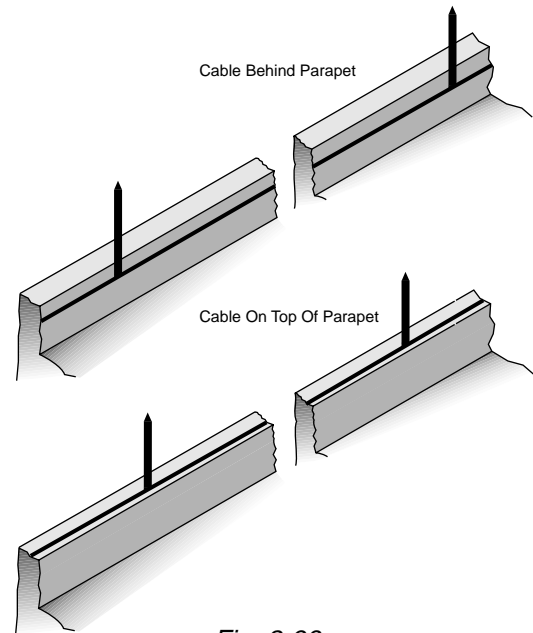


Fig. 2-36
Lightning conductors and points may be mounted on top of or behind the parapet of flat roofs.

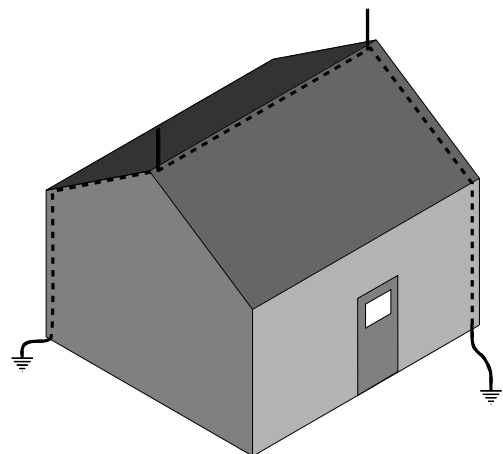


Fig. 2-37
Two paths from the air terminals to the ground electrode system are required.

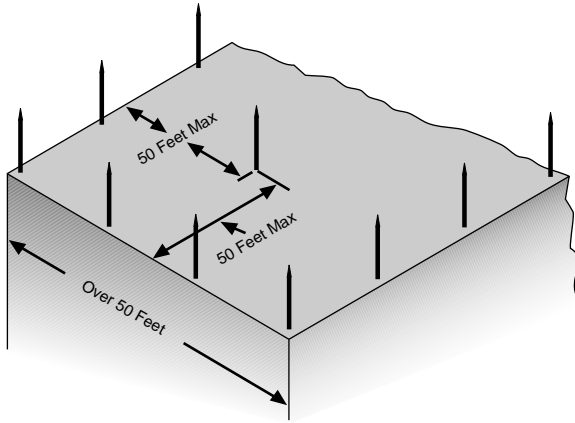


Fig. 2-38

On large flat roofs or gently sloping roofs, air terminals are placed in the center area at intervals not exceeding 50 feet.

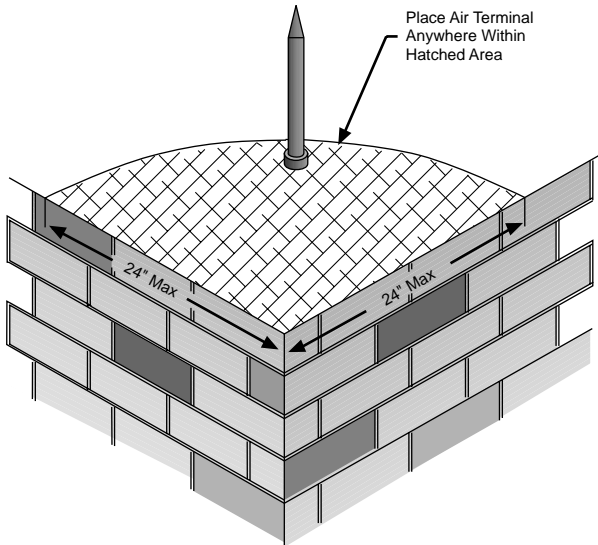


Fig. 2-39

Air terminals must be placed within 2 feet of the corners and edges of flat or gently sloping roofs and the ends of roof ridges.

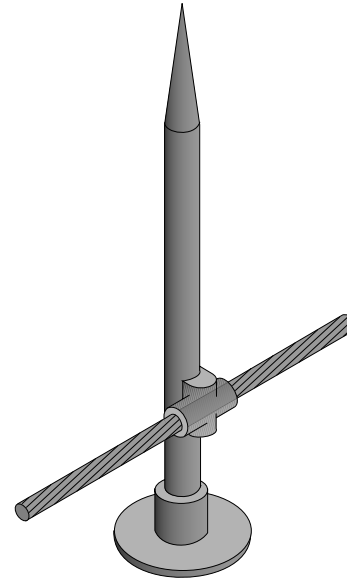


Fig. 2-40

Conductor may be welded to air terminal or attached with an approved clamp.

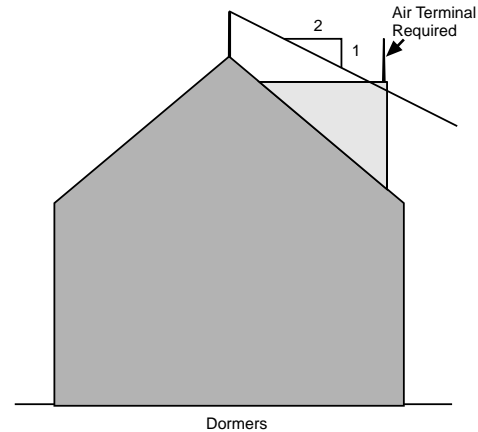
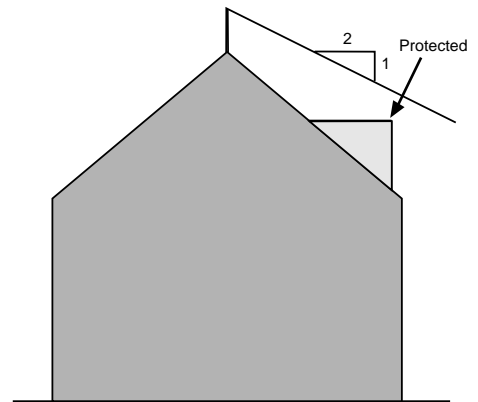


Fig. 2-41

Dormers on buildings 25' or less in height require air terminals on the dormer projecting beyond the 2:1 pitch line require air terminals.

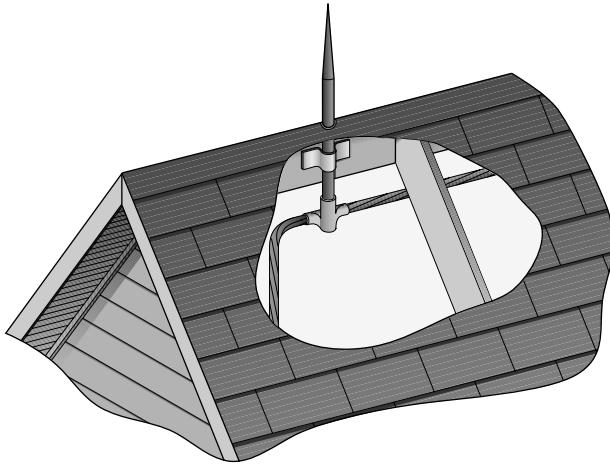


Fig. 2-42
Concealed systems are common on residential installations.

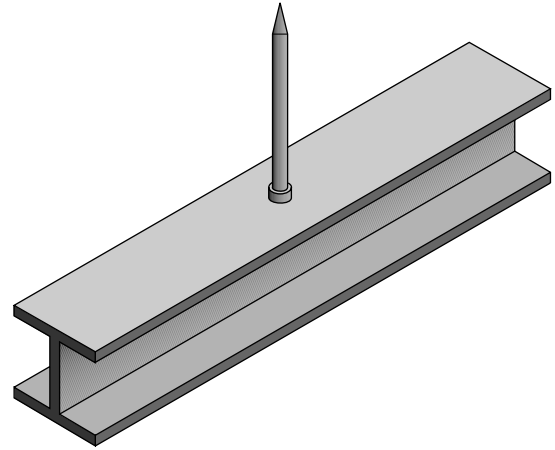


Fig. 2-45
Structural steel may be used as the conductor if properly bonded.

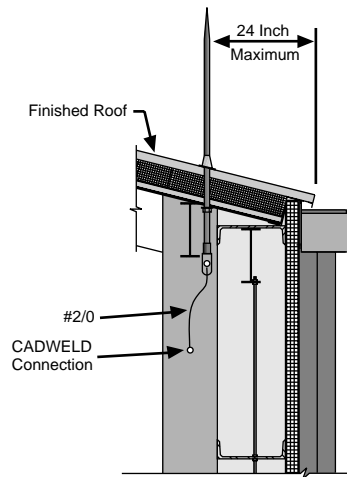


Fig. 2-43
Detail of air terminal with the steel structure used as the down conductor.

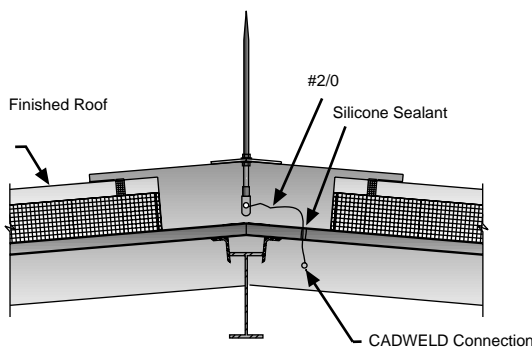


Fig. 2-44
Detail of air terminal with the steel structure used as the down conductor.

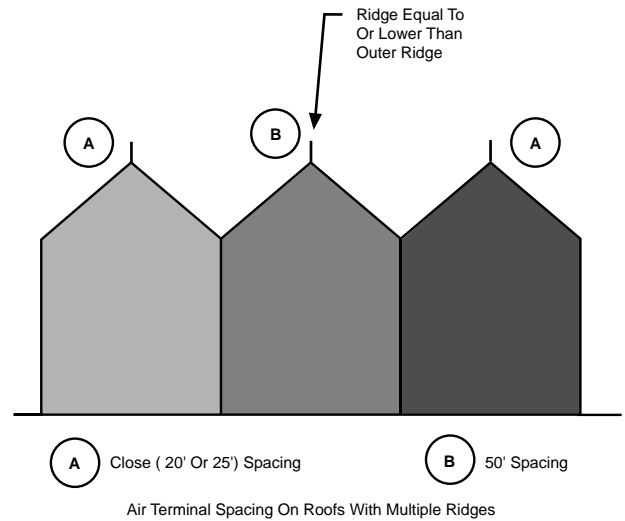
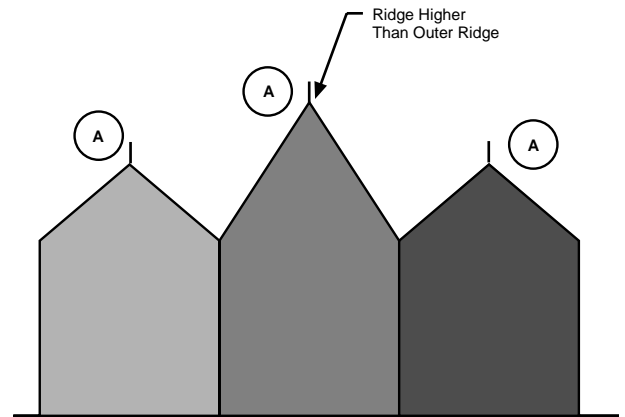


Fig. 2-46
Air terminal placement on ridged roofs vary with ridge height in relation to the other ridges.

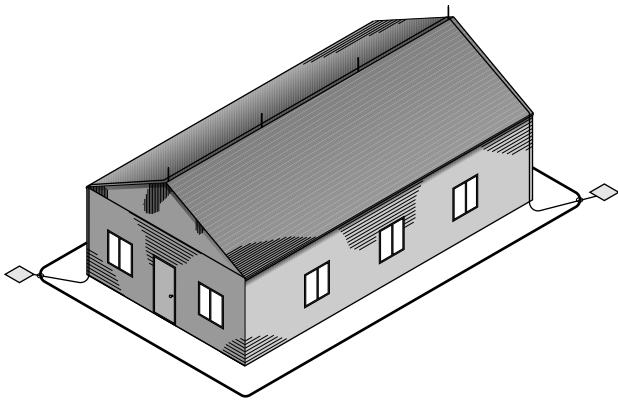


Fig. 2-47

More extensive systems are required on larger buildings and with different soil conditions.

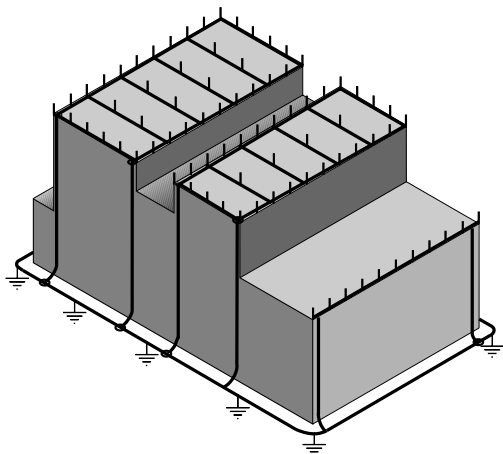


Fig. 2-48

Very large buildings require more air terminals, down leads and ground terminals.

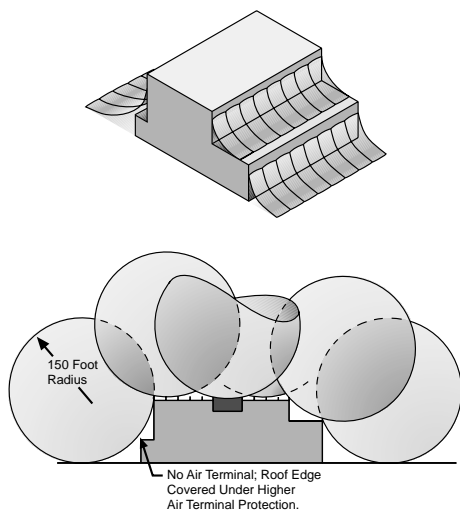


Fig. 2-49

Protected areas can also be determined using the rolling ball theory.

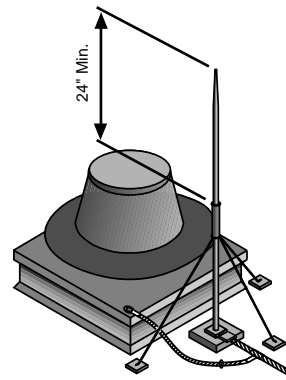


Fig. 2-50

All rooftop equipment must have air terminals unless they have skins more than 3/16 inch thick. If they have skins more than 3/16 inch, they must be properly bonded and will be considered as air terminals.

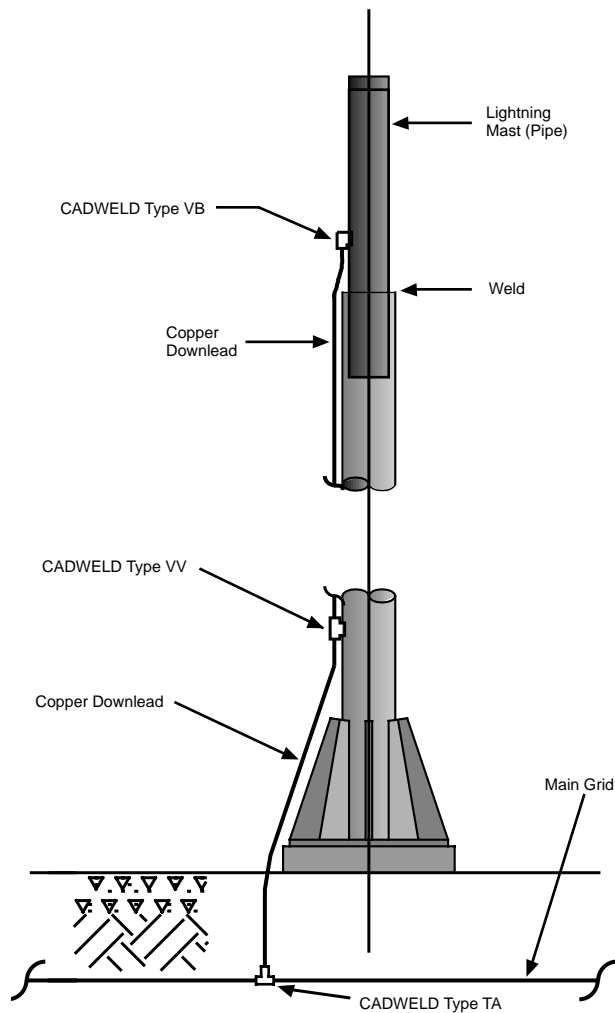


Fig. 2-51

Steel tower lightning masts may be used in locations such as electrical substations.

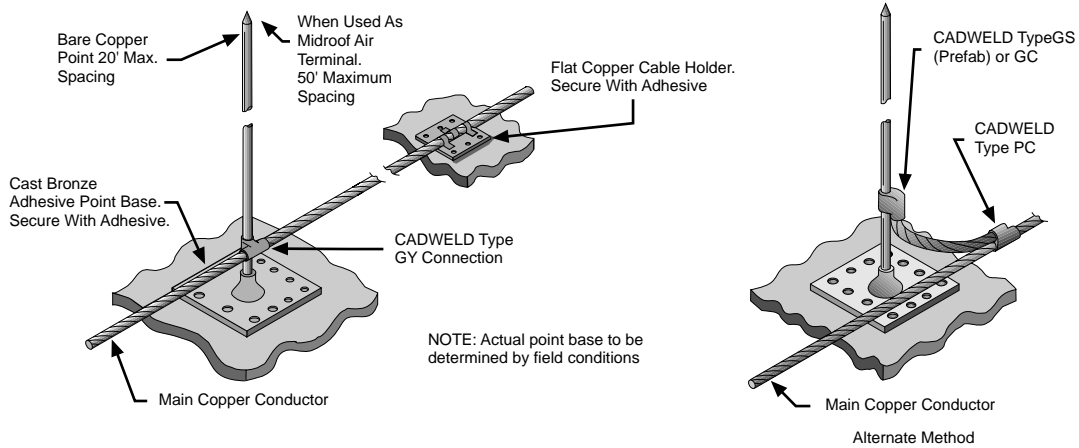


Fig. 2-52

Connections to air terminals may be CADWELD welded connections.

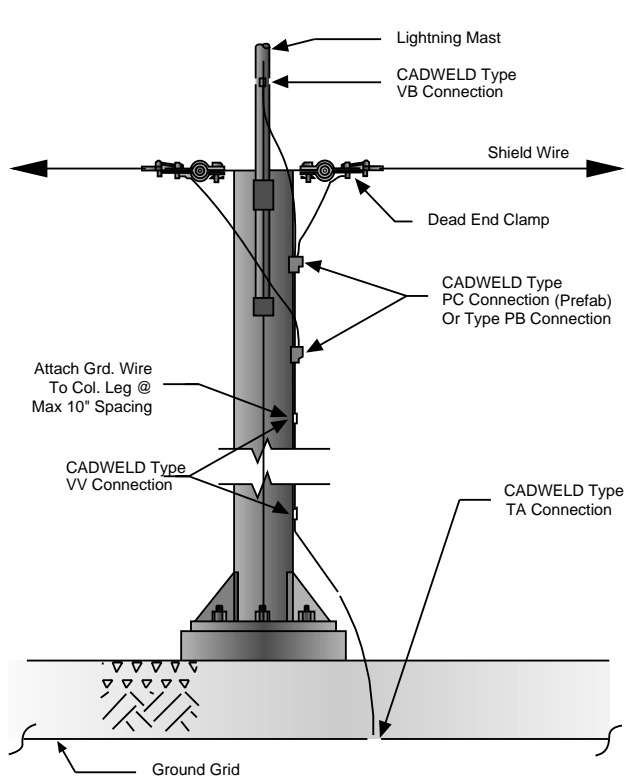


Fig. 2-53

Steel tower lightning masts and shield wires may be used in locations such as electrical substations.

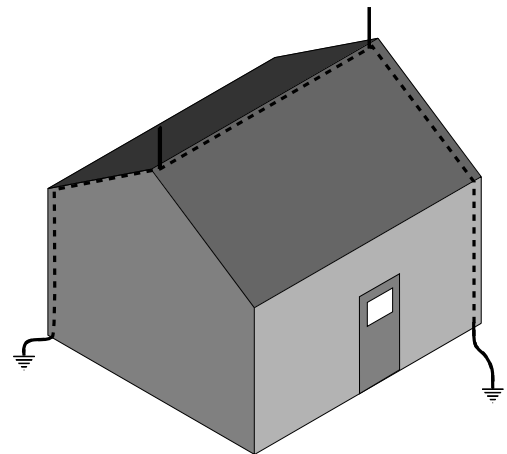


Fig. 2-54

Basic lightning protection on a small building consisting of air terminals, down leads and ground electrodes.

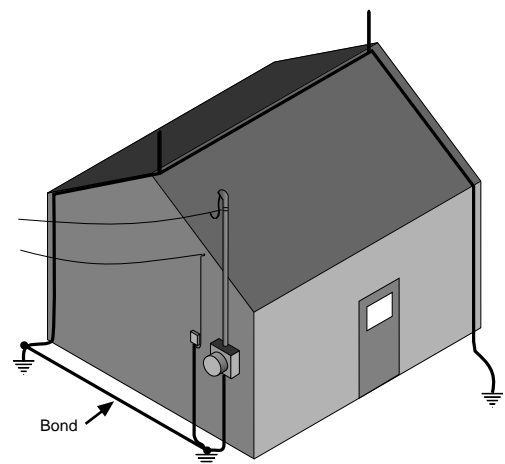


Fig. 2-55

The lightning protection system must be bonded to the electrical grounding system.

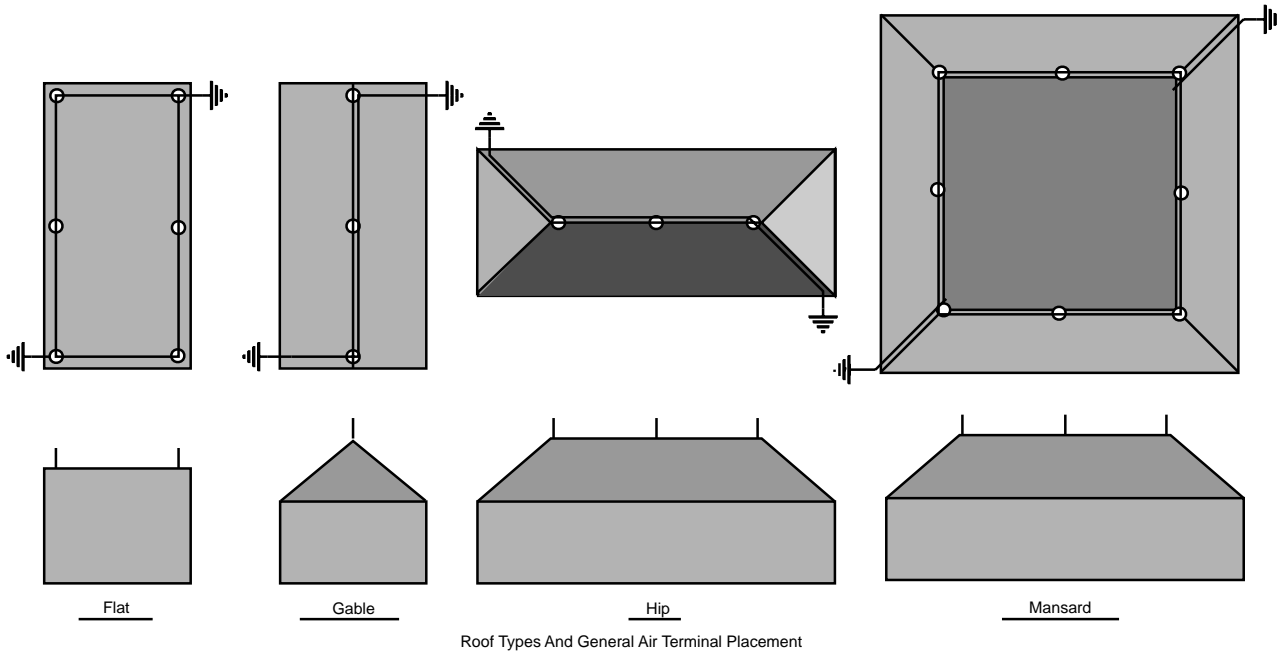


Fig. 2-56
Air terminal placement shown on various types of roofs.

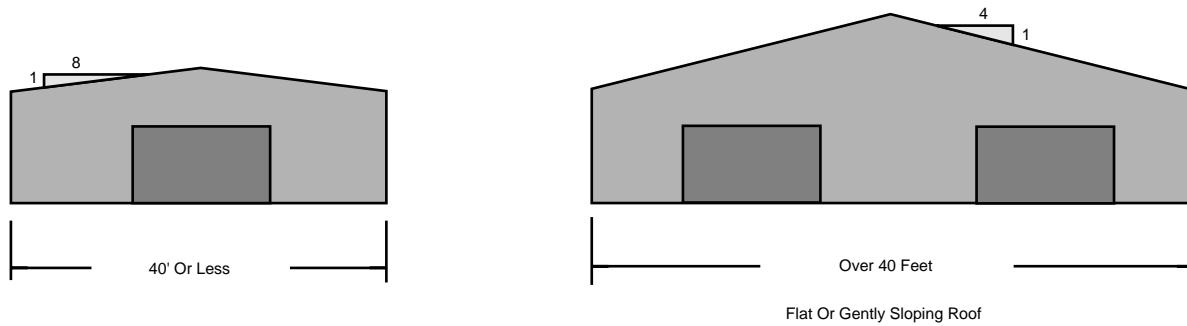


Fig. 2-57
Flat or gently sloping roofs are defined as shown.

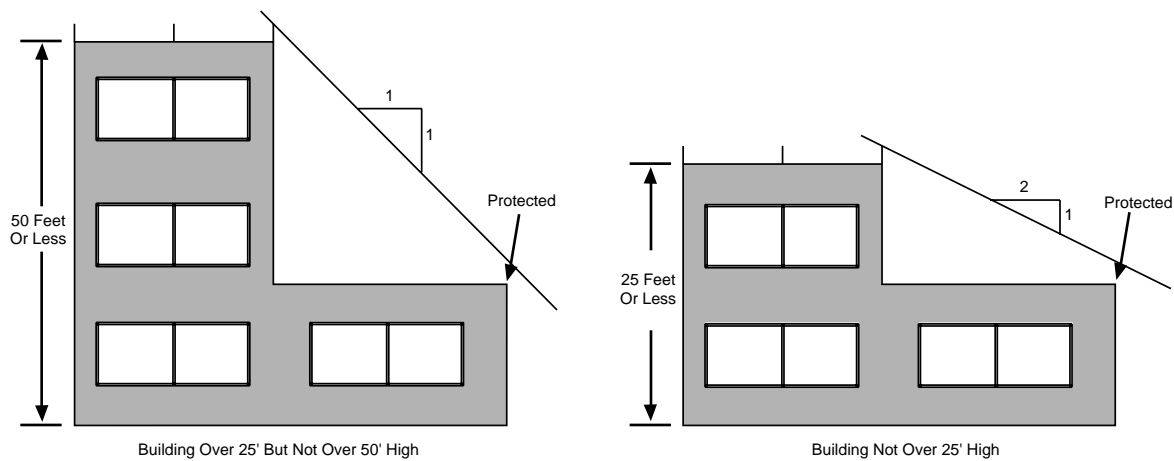


Fig. 2-58
Protected areas can be determined using a sloping line, with the angle dependent on the height of the structure.

Chapter 3

Building Interior Bonding And Grounding

The Bonding And Grounding Of Building Steel, Electrical Panels And Other Power Systems Equipment.

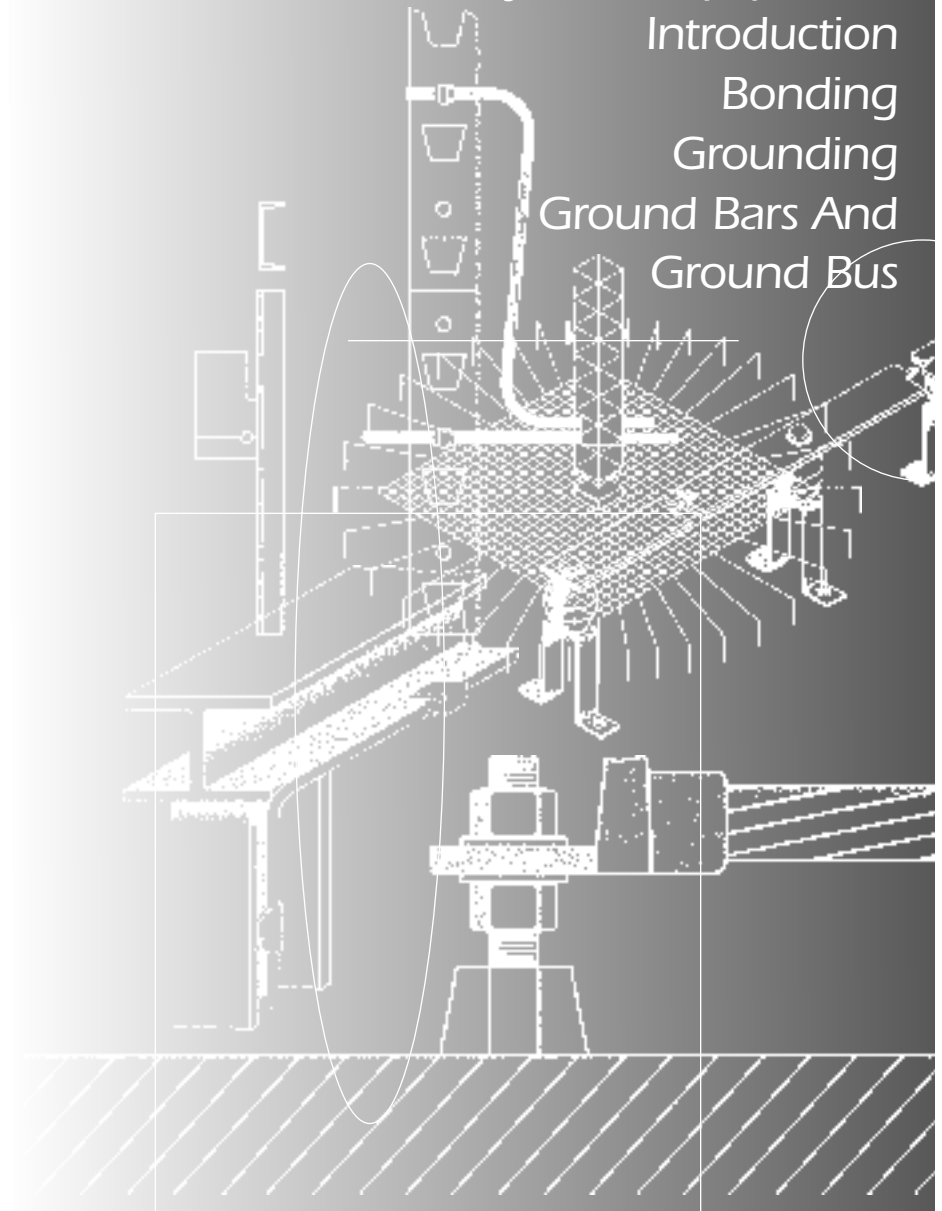
Introduction

Bonding

Grounding

Ground Bars And

Ground Bus



INTRODUCTION

In addition to electrical service grounding and supplemental building grounding, designers and installers of electrical systems face critical grounding and bonding decisions throughout the entire building. The purpose of this chapter is to focus on the equipment grounding and bonding requirements set forth in the National Electrical Code (NEC). Keep in mind that the purpose of bonding is different from that of grounding. Metallic components of electrical systems are bonded to ensure electrical continuity of the components. The purpose of bonding is to create an equipotential plane that ensures that all metallic components are at the same potential to ground. Grounding, on the other hand, is an intentional connection to the earth or some other conducting body that serves in place of the earth. The purpose of grounding conductive materials, such as metal raceways and equipment enclosures, is to limit and stabilize the voltage to ground on such enclosures. Unintentional contact with higher voltage lines or lightning strikes results in increased voltages on the electrical equipment. The most important reason however, for grounding such enclosures is to provide a low impedance path for ground-fault current. The low impedance path ensures that the overcurrent device which is protecting the conductors will operate. Several specific bonding requirements are included in the NEC, covering topics such as: service bonding, enclosure bonding, bonding over 250 volts, bonding of piping systems and exposed structural steel, and swimming pools and fountain bonding. Grounding requirements include: general equipment grounding provisions, specific equipment grounding provisions, grounding cord-and-plug connected equipment, and receptacle grounding.

BONDING

Service Equipment Bonding. Section 250-71 of the NEC contains the general provisions for bonding of service equipment. Service equipment is any equipment necessary for the main control and means of cutoff of the supply of electricity to a building or structure. Specifically, the following service equipment must be effectively bonded together: service raceways, cable trays, service cable armor/sheath, cablebus framework, service equipment enclosures and any metallic raceways which contain a grounding electrode conductor. Keep in mind that it is critical that these components be effectively bonded together to ensure the fastest possible clearing of faults. This is because for most service entrance conductors the only overcurrent protection provided is on the line side of the utility transformer. In most cases the rating or setting of these primary devices will not be adequate to protect the service equipment if large magnitude fault currents are not cleared promptly.

Installers should also be aware that Section 250-71 (b) contains a frequently overlooked provision regarding the interconnection of other systems which may be present in the building or structure. This section requires that an accessible means be left at the service equipment, in an external location, which can be used for connecting bonding and grounding conductors of other systems. Recall that Section 250-54 requires a common grounding electrode system to be installed and prohibits separate grounding system installations. Installers of the service equipment must provide a means for interconnecting the grounding systems of communication circuits, radio and television equipment and CATV circuits. Section 250-71 (b) lists three permissible methods to facilitate the interconnection of these systems. The first option is to use the exposed metallic service raceways. The second option is to connect to the exposed GEC. The last option is to bond a copper or other corrosion-resistant conductor of at least a No. 6 AWG copper, to the service raceway or equipment. ERICO has a complete line of CADWELD connections and mechanical connectors that can be used to meet the requirements of Sections 250-71, 800-40, 810-21 and 820-40.

Section 250-72 lists the permissible methods which can be used to bond together the service equipment listed above. Five basic methods are listed, any one of which can be used to bond the service equipment together. The first method is to use the grounded service conductor. On the line side of the service equipment there is no separate equipment grounding conductor. The grounded conductor assumes this role on the line side of the service. Section 250-113 lists the permissible means for any connection made to the grounded conductor. These include CADWELD exothermic welded connections, listed pressure connectors (wirenuts), listed clamps, and other listed means. The second method is to use threaded connections. This includes threaded couplings or bosses. It is important that these connections be made wrenchtight to ensure a low impedance connection. The third method is to use threadless couplings or connectors. These fittings are available for rigid metal conduit, intermediate metal conduit and EMT. Once again it is important that the connections be made up wrenchtight to ensure the low impedance ground path. Installers should note that the NEC specifically prohibits the use of standard locknuts or bushings, even if a double arrangement is used, (one on the inside and one on the outside) to achieve the bonding required by this section. The fourth method is to use bonding jumpers. Bonding jumpers ensure electrical continuity by providing a low impedance path across concentric or eccentric knockouts that may be part of the service equipment. The last method is to use other approved

devices. This would include fittings such as bonding-type locknuts and grounding bushings. These fittings are designed to make good contact with the metal enclosure and help to ensure good electrical continuity.

Bonding Other Enclosures. In addition to the service equipment enclosures, other noncurrent-carrying enclosures are also required to be bonded by the NEC. Section 250-75 requires that metal raceways, cable trays, cable armor, cable sheaths, enclosures, frames, fittings and any other metal noncurrent-carrying parts be bonded if they are to serve as grounding conductors. This requirement applies regardless of whether a supplementary equipment grounding conductor is present. The purpose of this rule is to ensure that these metallic components cannot become energized because they are isolated from a low impedance ground path. If these components were not properly bonded and they were to become energized due to some fault condition, the overcurrent device may not operate. This would result in personnel being put at risk to serious electrical shock hazards. This section also contains an important requirement when making any electrical connection. Prior to making any bonding or grounding connection, installers must ensure that they have removed any nonconductive coatings, such as paint, enamel or other similar coatings, from the metal surface to which they are making a connection. Failure to do so could drastically increase the impedance of the ground path.

Bonding Over 250 Volts. Installers of electrical systems frequently overlook the bonding requirements for electrical circuits which operate at over 250 volts to ground. Section 250-76 requires that such circuits be bonded to ensure electrical continuity of metal raceways or cable armors or sheaths. The permissible methods which can be used to achieve the required bonding are: threaded connections, threadless couplings and connectors, bonding jumpers or other approved devices. These methods are the same as those used for service equipment with the exception of the grounded conductor which is not permitted for over 250-volt applications. Another installation requirement which installers of electrical systems need to be especially aware of is the use of 250 volt circuits where oversized concentric or eccentric knockouts are present. If these types of knockouts are encountered, one of the methods listed above must be utilized to achieve the required bonding. An exception to Section 250-76, however, does permit alternate bonding methods where such knockouts are not encountered or where they are encountered in a box or enclosure which has been tested and the enclosure or box is listed for the use. In such cases, any of the following methods may be used in lieu of those listed above for bonding circuits of over 250 volts to ground: threadless

couplings and connectors for metal sheath cables, double locknut installations for RMC, IMC, fittings with shoulders which seat firmly against the enclosure for EMT, flexible metal conduit (FMC), and cable connectors, and other listed fittings. Keep in mind that if the box or enclosure has been listed for use with these concentric or eccentric locknuts it will be identified or labeled as such. If a box or enclosure is encountered and such identification is not provided, one of the methods listed above must be used and the exception is not applicable.

Bonding of Piping Systems and Exposed Structural Steel. Section 250-80 of the NEC contains requirements for bonding interior metal water piping systems, other piping systems and structural steel. Section 250-81(a) requires that metal underground water pipe which is in direct contact with the earth for at least 10 ft be included as part of the grounding electrode system. Installers of electrical systems should note that even if for some reason the metal water piping is not used as part of the grounding electrode system it is still required to be bonded per Section 250-80. The purpose of such bonding is to ensure that the metal water piping throughout the building or structure is at the same potential to ground as the service ground. Keeping the water piping at the same potential helps to ensure that an electrical shock hazard could not exist if the metal piping were to become inadvertently energized. Section 250-80 (a) permits the bonding to occur to the service equipment enclosure, the service grounded conductor, the grounding electrode conductor or to the one or more grounding electrodes that comprise the grounding electrode system.

Installers and designers of electrical systems should also note that a 1996 NEC change now requires that the metal water piping in areas served by a separately derived system also be bonded to the grounded conductor of the separately derived system. The most frequently encountered source of separately derived systems is an isolation transformer. Keep in mind that due to the magnetic coupling of the transformer windings, grounds cannot be transferred across such systems. A new grounding electrode system must be established for each separately derived system. See Section 250-26 for a complete list of the requirements for grounding separately derived systems.

Part (b) of Section 250-80 covers other interior piping systems that are required to be bonded. Any interior piping systems, such as, domestic well water, or any piping which contains a liquid or a gas, and "may become energized," shall be bonded. Once again the permissible bonding locations are to the service equipment enclosure, the grounding electrode conductor, the service grounded conductor or the one or more grounding electrodes that

comprise the grounding electrode system. While these guidelines may appear to be somewhat vague, a good rule of thumb to follow is: If the interior metal piping system contains any electrical devices, such as, solenoids or mechanized valves, the piping “may become energized” and it should be bonded.

The last part of Section 250-80 contains a new requirement in the 1996 NEC. This section requires that any exposed structural steel which is interconnected to form a building frame and is not intentionally grounded shall be bonded. Once again this steel must be bonded only if it “may become energized.” Installers and designers of electrical systems should recognize that there are many ways the steel “may” become energized by equipment which may be mounted to or in contact with the steel. For this reason the recommended course is to make the bond. As both cases above, the permissible bonding locations are to the service equipment enclosure, the grounding electrode conductor, the service grounded conductor or to the one or more grounding electrodes that comprise the grounding electrode system. This requirement does not apply to isolated steel girders or beams which may be installed in a building or structure. Such beams or girders are not “interconnected to form a steel building frame” and need not be bonded.

Article 680 Bonding. One last area that should be of great concern for designers and installers of bonding and grounding systems is Article 680 of the NEC. Because of the constant presence of moisture, installations in and around swimming pools, fountains, spas and similar locations present an increased risk of electrical shock. Section 680-22 covers the bonding requirements for permanently installed swimming pools. For all permanently installed pools the following components must be bonded together:

1. All metal parts of the pool, including the pool structure, shell, coping stones and deck.
2. No-niche fixture forming shells and mounting brackets.
3. All metal fittings associated with the pool structure.
4. All metal parts of any electric equipment associated with the pool filtering or circulating system.
5. All metal parts of any equipment associated with pool covers.
6. Metal-sheathed cables, raceways, metal piping and all other metal components that are located in a zone which extends from the edge of the pool to a distance which is 5 ft (1.5 m) horizontally and 12 ft

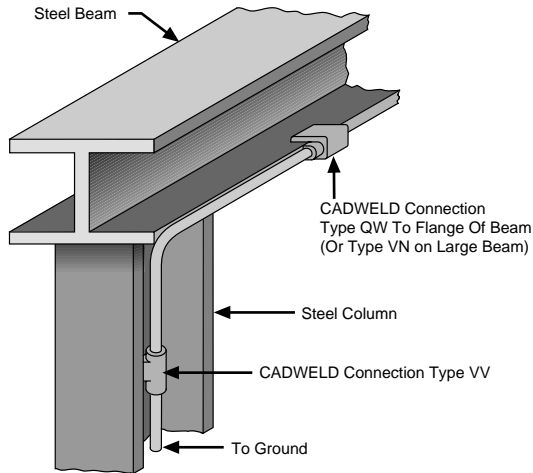
(3.7 m) above the maximum water level of the pool. Included also would be any diving structures, observation decks, towers, etc., which are not separated from the pool by a permanent barrier.

It is interesting to note that a FPN which precedes these requirements states that it is not the intent that the copper conductor which is used to interconnect these components be extended or otherwise attached to any remote panelboard service equipment or grounding electrode. This note clearly distinguishes the difference between bonding and grounding. The purpose of these requirements is to bond all of the metal components listed above together, to establish a common bonding grid. The common bonding grid establishes an equipotential plane which minimizes any difference of potential between any of the common components. Without a difference of potential there can be no risk of electrical shock. Part (b) of Section 680-22 requires that the common bonding grid be connected with at least a No. 8 copper conductor. Installers should note that the means of connection must be by pressure connectors or clamps or CADWELD exothermic connections. Care should be taken to ensure that the connectors selected are suitable for direct burial applications and with the type of material used (copper, aluminum etc.). Section 680-41 (d) contains similar requirements for bonding for spas and hot tubs. In either case, bonding is critical to protecting personnel who might be exposed to an electrical shock hazard if the low impedance bonding grid is not maintained. ERICO offers a complete line of connectors which can be used to ensure the common bonding grid is installed in a manner which ensures the safety of anyone using the pools, hot tubs or spas.

BUILDING INTERIOR BONDS

The interior columns and beams with riveted or bolted construction joints may require positive bonding of beams to columns to provide long term low resistance joints for electrical continuity throughout the building (Fig. 3-1). The low resistivity also may be achieved if all columns through their footers are bonded together. Welding a ground bar to the column provides future attachment points for other grounding conductors (Fig. 3-2). At expansion joints, a flexible conductor bonds the columns or beams on each side of the joint (Fig. 3-3). The bottom chord of a bar joist easily can be bonded (Fig. 3-4). Steel columns within the building should be bonded to the footer with the conductor extending to the main ground grid (Fig. 3-5 and Fig. 3-6). The column anchor bolts must be electrically connected to the footer reinforcing bars.

On multi-floor buildings, the grounding conductor should



Building Steel Ground
Fig. 3-1

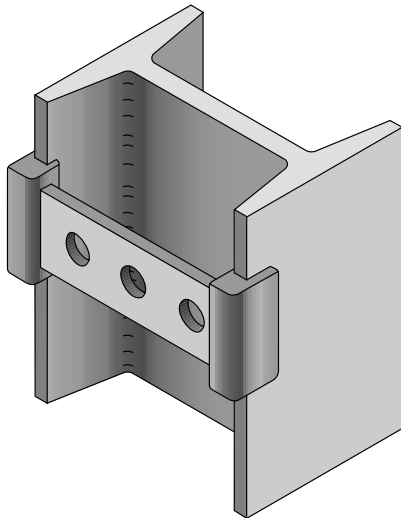
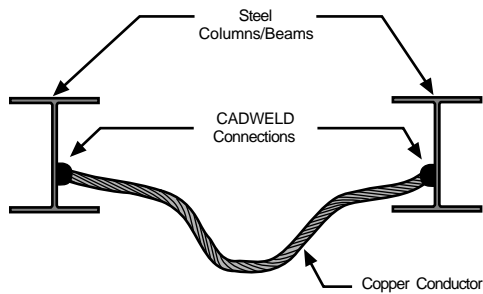


Fig. 3-2



Expansion Joint Bonding Detail
Fig. 3-3

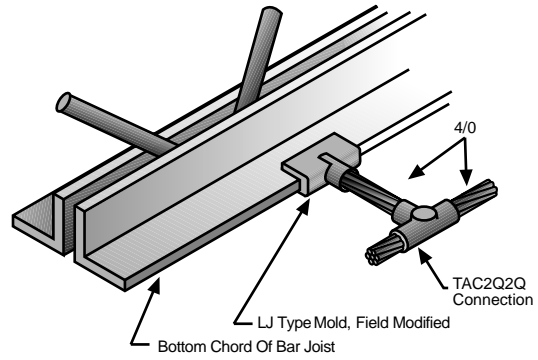
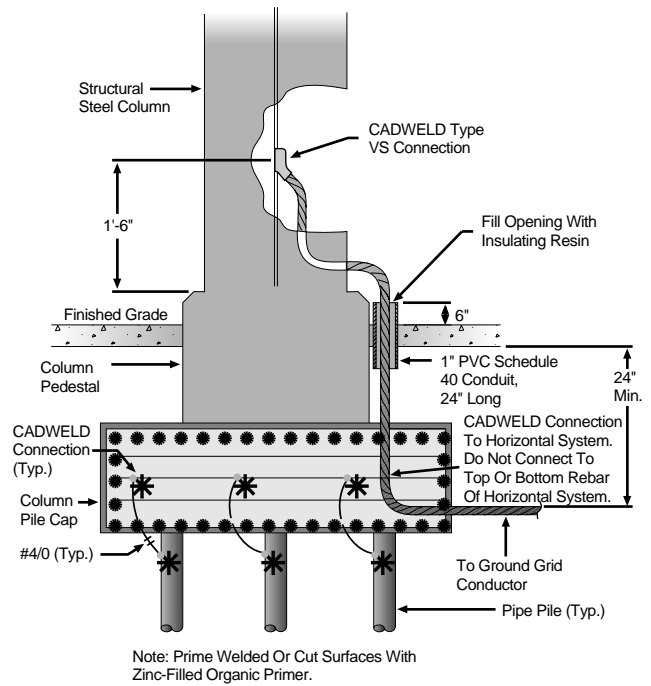


Fig. 3-4



Structural Footer
Fig. 3-5

extend to each floor (Fig. 3-7). For accessible ground points at each floor, ground bars provide the ideal solution. They can be bolted to either the wall or the floor or a long bus attached to the wall with insulators and mounting brackets. (Fig. 3-8). On exposed steel buildings, the ground bars can be welded directly to the steel column (Fig. 3-9 and Fig. 3-10). Cast copper alloy ground plates can be embedded in concrete structures for attachment of future grounding conductors (Fig. 3-11 and Fig. 3-12). The plates are provided with drilled and tapped holes for lug attachment. When large quantities are required on a job, they are available with a pigtail already attached from the factory to reduce field labor (Fig. 3-13). The ground plate also can be exothermically welded directly to a steel column where the column is to be fireproofed (Fig. 3-14). Light duty ground points can be made in office columns (Fig. 3-15).

In areas where a conductive floor is required, it is bonded to the ground system as shown in Figure 3-16. In areas where static electricity must be controlled, metal doors and frames must be bonded as shown in Figure 3-17. More details on the control of static electricity are discussed in Chapter 6. At large facilities having multiple buildings with underground utilities, the cable racks in the manholes can be grounded as detailed in Figure 3-18 and Figure 3-19. Metal handrails should be grounded if there is an accessible ground conductor available, a good reason to use cast copper alloy ground plates embedded in the concrete at frequent intervals. (Fig. 3-20).

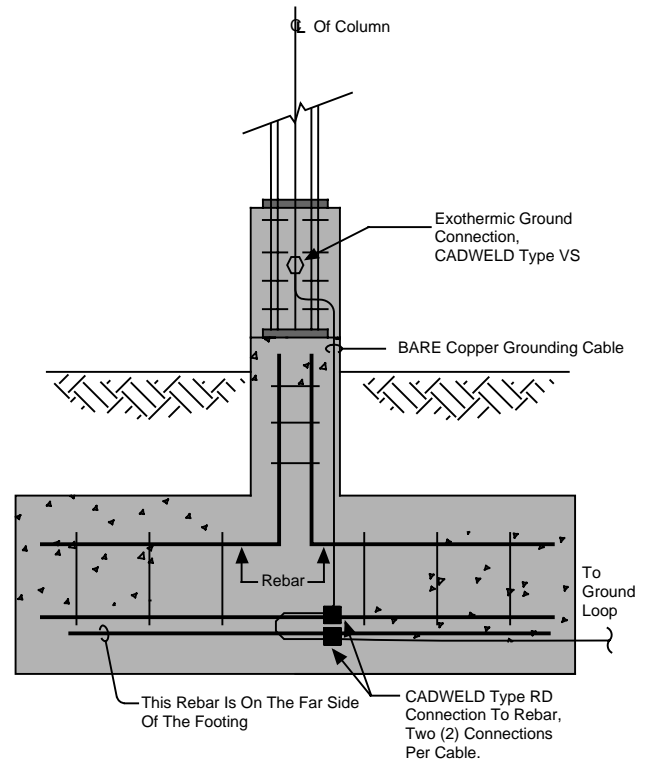
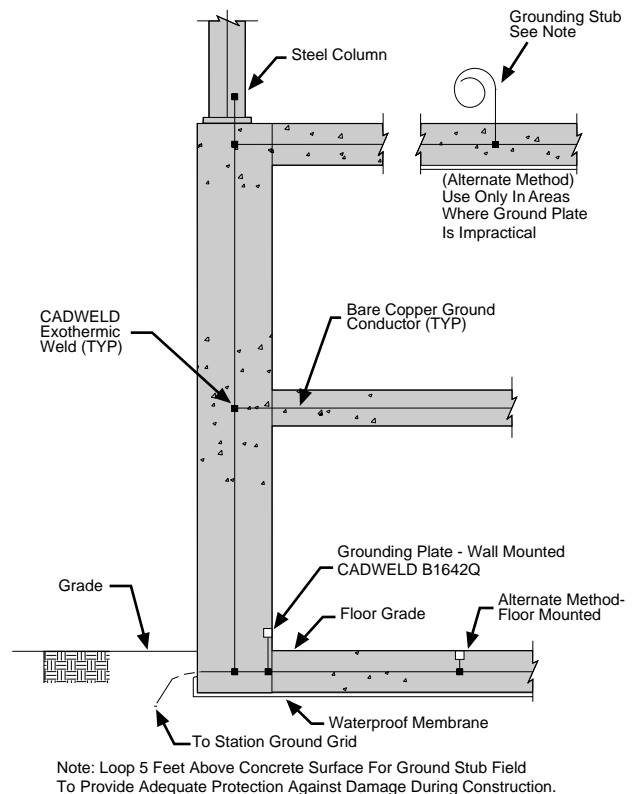


Fig. 3-6



Grounding System Routing

Fig. 3-7

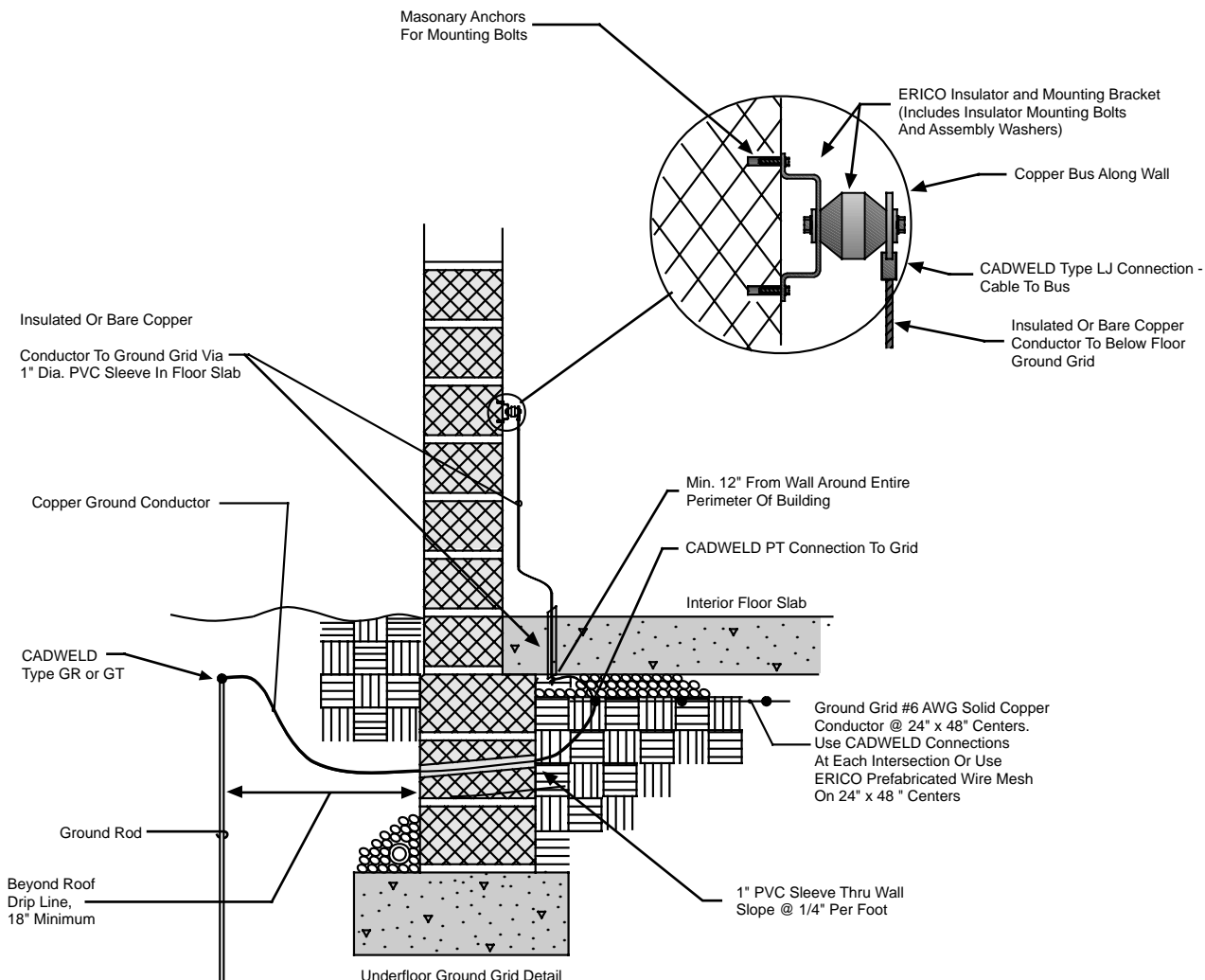


Fig. 3-8

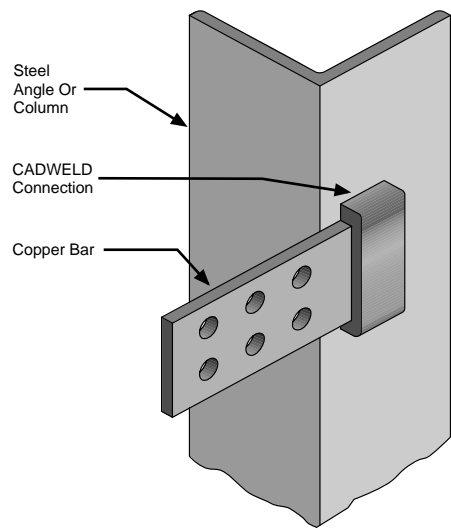
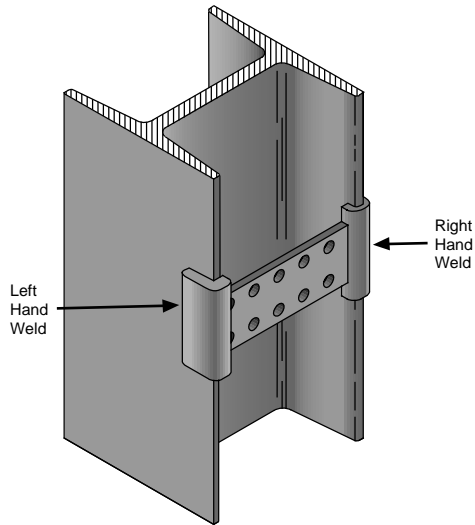


Fig. 3-9

Copper Bar Size	Mold Part No.	Weld Metal	Minimum Width Of Steel
1/8 x 1	DFCCE*	#115	3"
1/4 x 1	DFCEE*	150	3"
1/4 x 2	DFFE*	2-200	4"
1/4 x 3	DFFE*	500	4"
1/4 x 4	DFFE*	3-250	4"

*Add RH or LH for right or left hand right hand shown.



Copper Bar Size	Left Hand Mold Part No.	Right Hand Mold Part No.	Weld Metal
1/4 x 2"	DFRHEHLH	DFRHEHRH	#250
1/4 x 3	DFFHEKLH	DFFHEKRH	2-#200
1/4 x 4	DFFHEMLH	DFFHEMRH	3-#250

NOTE: The Following Inserts Are Required. They fit behind the bar and become part of the mold.

Column Type	Insert P/N
Standard Flange	DFSTD
Wide Flange, Parallel Flange	DFWFP
Wide Flange, Tapered Flange	DFWFT

Fig. 3-10

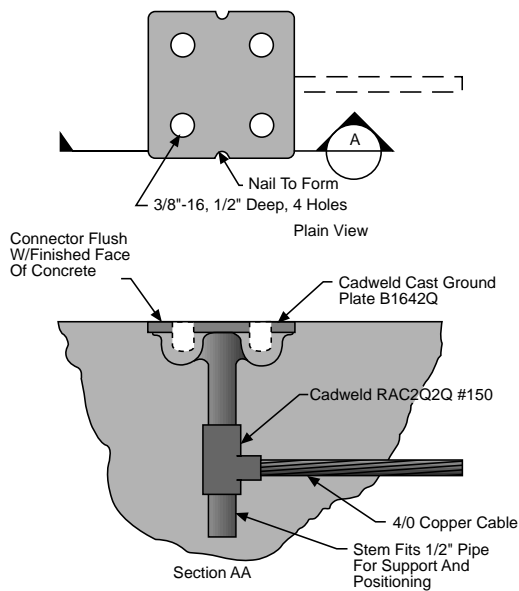
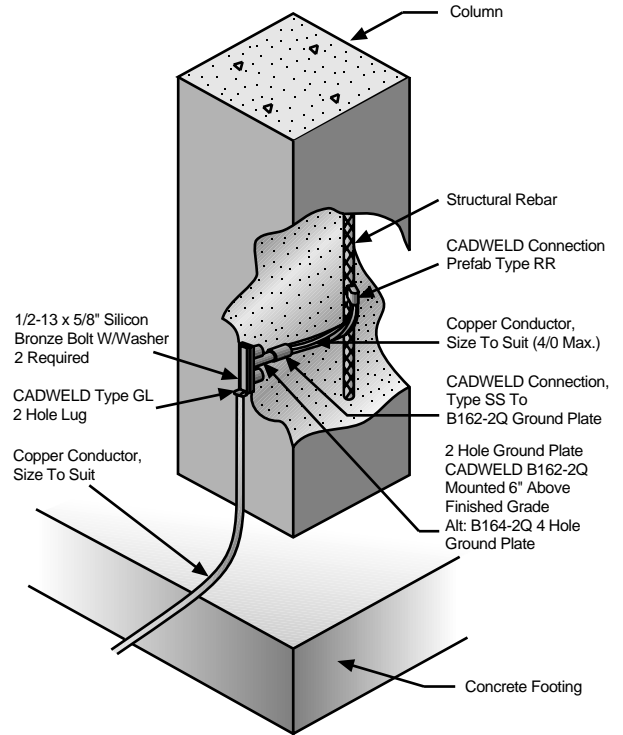


Fig. 3-11



NOTES:

1. Bond Column Rebars To Footer Rebars.
2. Ground Footer Rebars To An External Ground Grid or Rod.
3. Bond Anchor Bolts To Rebars.

Equipment Grounding Pad At Concrete Column
Fig. 3-12

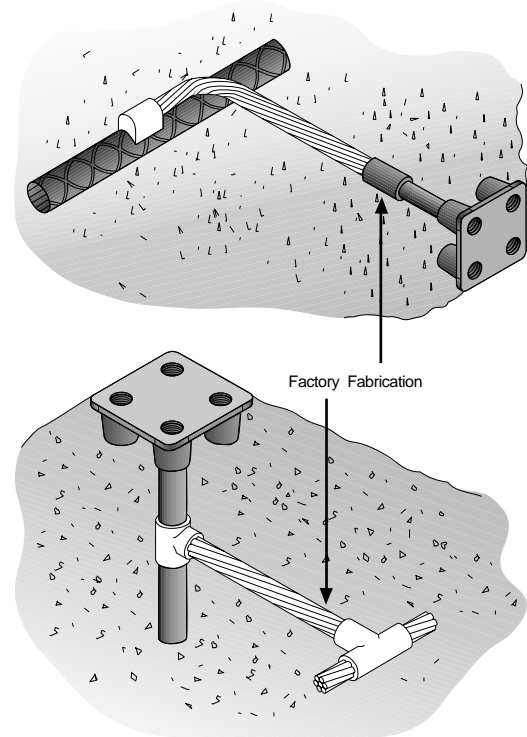


Fig. 3-13

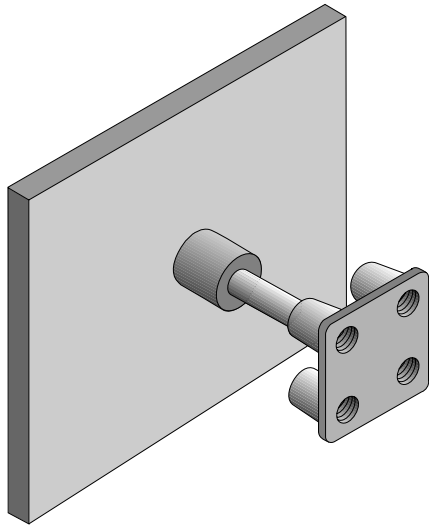
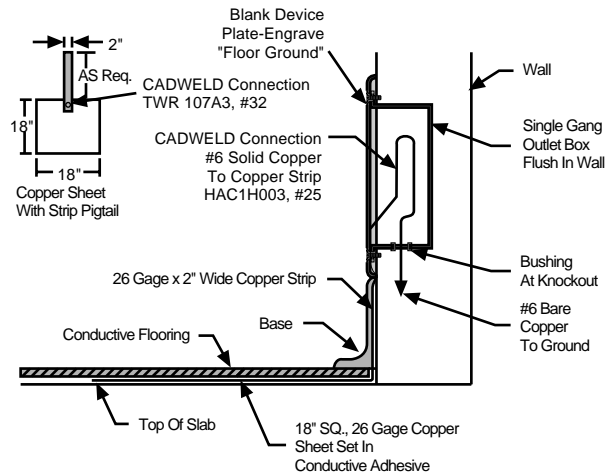


Fig. 3-14



Detail - Conductive Floor Ground
Fig. 3-16

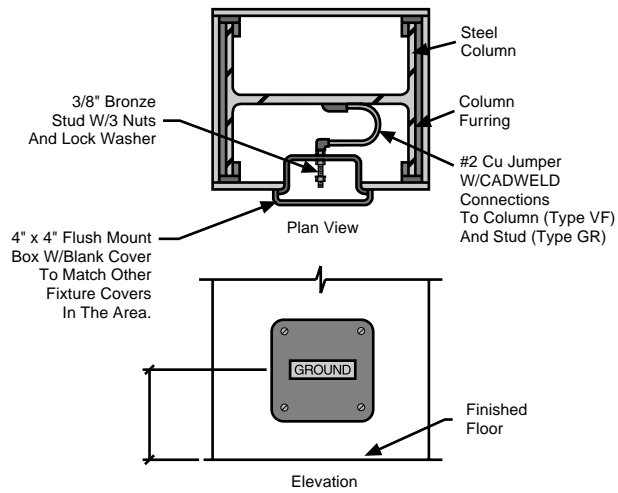


Fig. 3-15

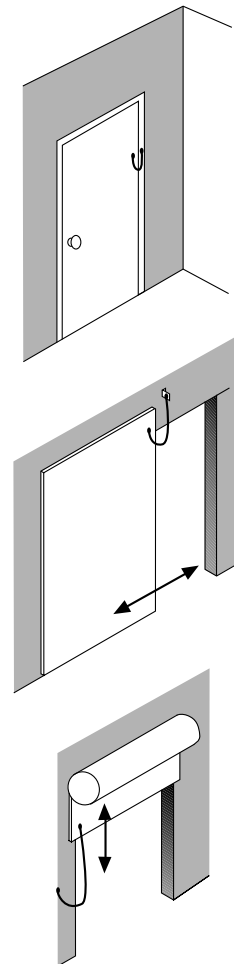
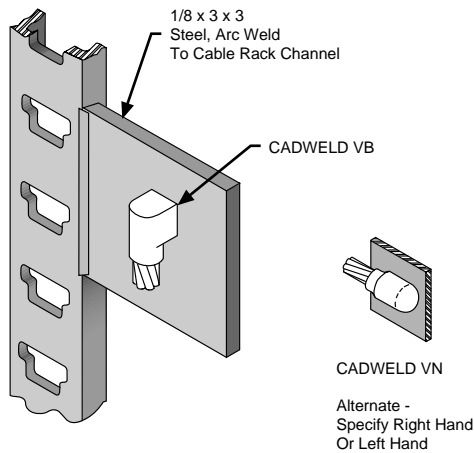
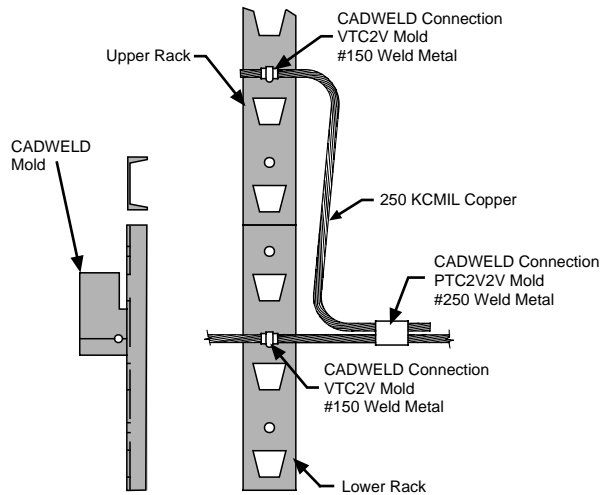
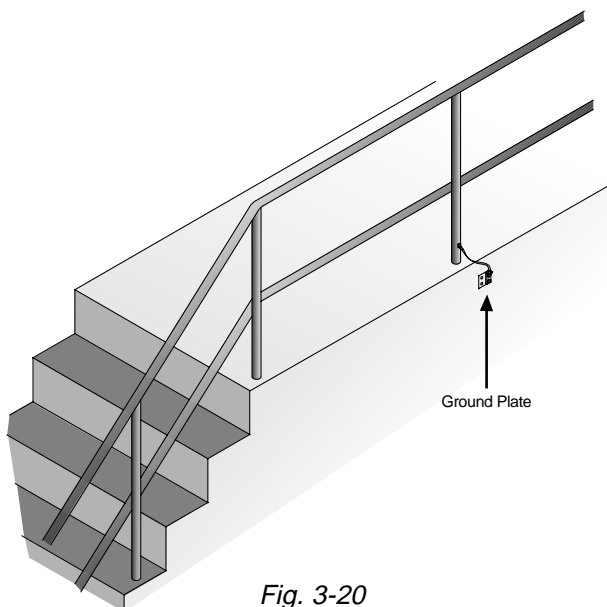
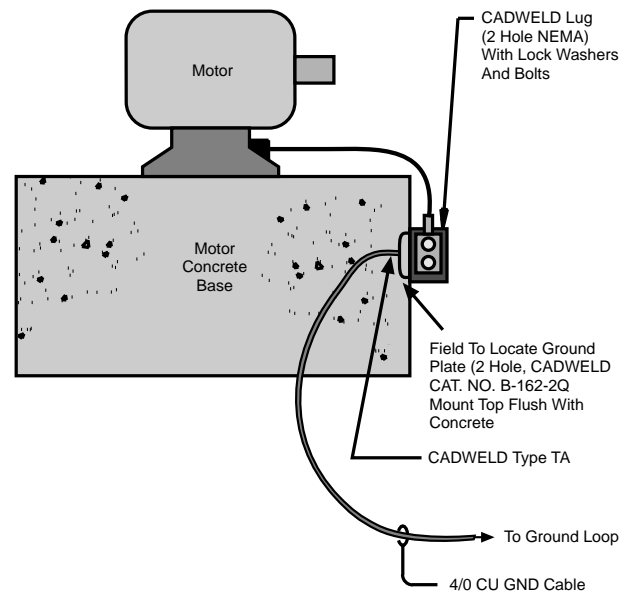


Fig. 3-17

**Cable Rack Grounding****Fig. 3-18****Fig. 3-19****Fig. 3-20****EQUIPMENT BONDING**

Equipment within the facility must be carefully considered as to its need to be bonded to the facility ground system. Of course, all electrical equipment must have a grounding conductor as dictated by the NEC. Additional grounding is sometimes needed as shown in Figure 3-21. As pointed out previously, the frequent use of ground plates (Fig. 3-22) provides accessible grounding points throughout the building. When removable grounds are required near a grounded column or beam, a stud can be welded to the steel and the bonding jumper can be attached using a lug (Fig. 3-23). Providing mechanical protection to the stud is recommended.

In cable installations, the tray's bolted joints do not always provide the required low resistance. A separate ground conductor must then be run the length of the tray, bonded to each tray section and to adjacent steel columns. Or, jumpers can be used across each joint. The cable can be welded to the tray if it is steel (Fig. 3-24) or bolted to the tray if it is aluminum (Fig. 3-25).

**Large Motor Grounding Detail****Fig. 3-21**

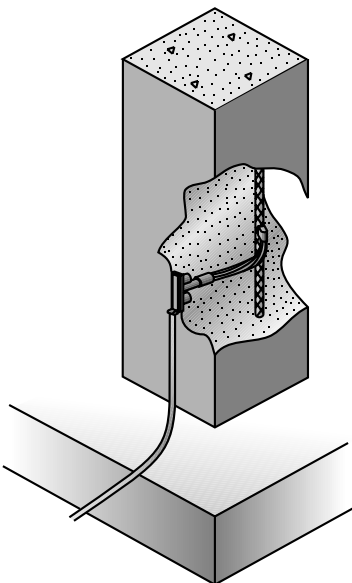


Fig. 3-22

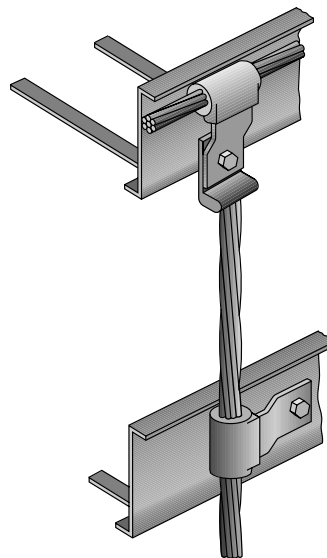


Fig. 3-25

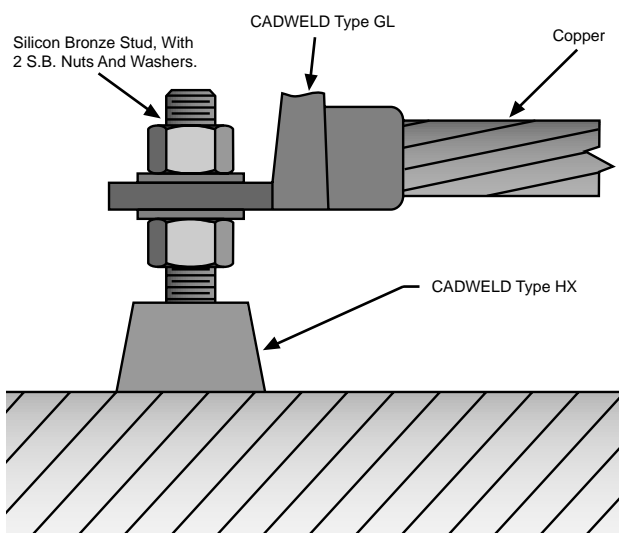


Fig. 3-23

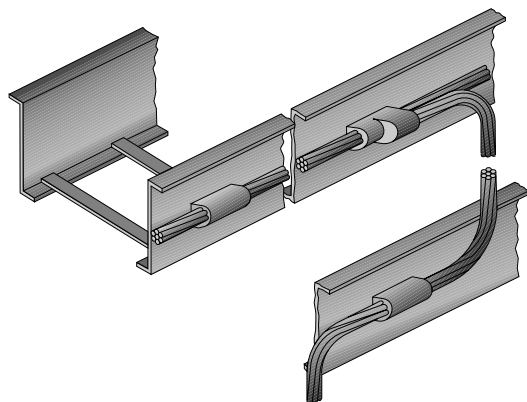


Fig. 3-24

GROUNDING

General Provisions - Equipment Fastened in Place. As noted above, the primary reason equipment and enclosures are grounded is to provide a low impedance path for ground-fault current. Such a path helps to ensure that the overcurrent protective device operates in an effective manner to protect people and property exposed to ground-fault currents. Section 250-42 establishes six general conditions under which exposed noncurrent-carrying metal parts of fixed equipment likely to be energized must be grounded:

The first condition requires grounding whenever such metal parts are located within a zone that extends within 8 feet (2.4 m) vertically and 5 feet (1.5 m) horizontally of ground or any grounded objects which may be contacted by persons. This establishes a reach or touch zone that ensures protection if persons could come in contact with such objects.

The second condition requires that any exposed metal parts, if not isolated, be grounded if installed in wet or damp locations. The NEC defines a wet location as one which is subject to saturation with any liquid and other locations underground or in concrete slabs. Damp locations are those locations subject to moderate degrees of moisture such as partially protected outdoor locations and some basements.

The third condition requires grounding of metal parts when in electrical contact with metal.

The fourth condition covers grounding in hazardous locations. These high-risk locations are covered in Articles

500 - 517 of the NEC and installers and designers of electrical systems should review these articles prior to designing or installing electrical systems in these types of locations.

The fifth condition requires exposed noncurrent-carrying metal parts of fixed equipment to be grounded anytime such equipment is supplied by metal-clad, metal-sheathed, metal raceways or any other wiring method which has provisions for an equipment grounding conductor.

The last condition requires that where fixed equipment operates with any terminal at over 150 volts to ground, any exposed noncurrent-carrying parts of such equipment must be grounded.

These six conditions provide the general guidelines for grounding exposed metal parts. There are several exceptions to these guidelines but in general, these provisions ensure that noncurrent-carrying metal parts are grounded to protect personnel from the risk of electrical shock.

General Provisions - Specific Equipment Fastened in Place. In addition to the general provisions contained in Section 250-42, the NEC contains provisions under which exposed noncurrent-carrying metal parts of specific fixed equipment shall be grounded. Sections 250-43 requires that these metal parts in the following equipment must be grounded: switchboard frames and structure, pipe organs, motor frames, enclosures for motor controllers, elevators and cranes, garages, theaters and motion picture studios, electric signs, motion picture projection equipment, power-limited remote-control, signaling and fire alarm circuits, lighting fixtures, motor-operated water pumps and metal well casings. In general, any exposed noncurrent-carrying metal parts associated with any of the above mentioned specific equipment shall be grounded. Of course, there are some exceptions to these general provisions. Designers and installers of electrical systems who plan to work on these specific types of equipment should reference the NEC for specific application guidelines.

General Provisions - Equipment Connected by Cord-and-Plug. Section 250-45 contains the provisions for grounding cord-and-plug connected equipment. In general, four conditions exist under which exposed noncurrent-carrying metal parts of cord-and-plug connected equipment, which is likely to become energized, shall be grounded:

The first condition requires grounding in hazardous locations. These high-risk locations are covered in Articles

500 - 517 of the NEC and installers and designers of electrical systems should review these articles prior to designing or installing electrical systems in these types of locations.

The second condition covers equipment which operates at over 150 volts to ground. As with fixed equipment, there are several exceptions for this provision, such as for motors, metal frames of electrically heated appliances and listed equipment which incorporates double insulation systems.

The third requirement applies to cord-and-plug connected equipment installed in residential occupancies. All of the following equipment, when installed in residential occupancies, must be grounded: refrigerators, freezers, air conditioners, washing machines, dryers, dish-washing machines, kitchen waste disposers, sump pumps, electrical aquarium equipment, hand-held motor-operated tools, stationary and fixed motor-operated tools, light industrial motor-operated tools, hedge clippers, lawn mowers, snow blowers, wet scrubbers and portable handlamps. An exception to Section 250-45 (c) does permit listed tools and appliances that use a system of double insulation to be operated ungrounded.

The last requirement applies to cord-and-plug connected equipment in other than residential occupancies. All of the following equipment, when installed in other than residential occupancies, must be grounded: refrigerators, freezers, air conditioners, clothes-washing, clothes-drying, dish-washing machines, electronic computer/data processing equipment, sump pumps, electrical aquarium equipment, hand-held motor-operated tools, stationary and fixed motor-operated tools, light industrial motor-operated tools, hedge clippers, lawn mowers, snow blowers, wet scrubbers, cord-and-plug connected appliances used in damp or wet locations by persons standing on the ground or in or on metal surfaces such as metal tanks or boilers, tools used in wet or conductive locations and portable handlamps.

There are two exceptions from grounding in other than residential occupancies:

The first permits tools and portable lamps used in wet or conductive locations to be ungrounded provided the tool or lamp is supplied through an isolating transformer with an ungrounded secondary of not over 50-volts.

The second exception permits hand-held, motor-operated tools, stationary and fixed motor-operated tools, light industrial motor-operated tools and appliances to be operated ungrounded provided they are listed and they

employ a system of double insulation which is distinctively marked on the tool or appliance.

Receptacle Grounding. Since the early 1970s Section 210-7 of the NEC has required that all receptacles installed on 15- and 20- ampere branch circuit be of the grounding type. Grounding-type receptacles include provisions for connecting an equipment grounding conductor and are easily identifiable by the ground pin slot included in the face of the receptacle. When installing grounding-type receptacles the question often arises as to which way to install the grounding pin, up or down? The NEC does not address this but the most frequent practice is to install them with the grounding pin down. A little thought, however, gives a different perspective. For example, in cases where the attachment plug is not fully inserted into the receptacle, a greater degree of protection can be achieved by mounting the receptacle with the grounding pin facing up. This is because if a metal faceplate were to loosen and drop down across the attachment plug blades or other metal objects were to fall into the receptacle, they would most likely make contact with the grounding pin, and not the energized conductors. ERICO therefore believes that mounting receptacles with the grounding pin up should result in the safest possible installation. In installations where the receptacle is mounted in the horizontal position, the receptacle should be mounted with the neutral conductor (long slot) up (Fig. 3-26). (Note: Several European standards also require the grounding pin up.)

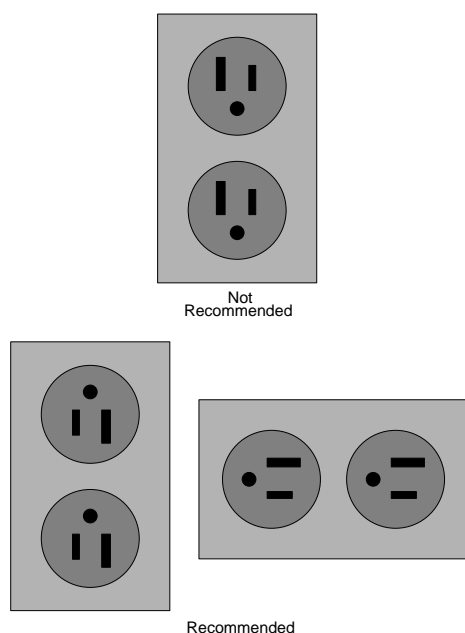


Fig. 3-26

Other important requirements should be considered when installing receptacles. Section 250-114 requires that the equipment grounding conductors shall be terminated on the receptacle in a manner that the disconnection of the receptacle will not interrupt the continuity of the equipment grounding conductor. This requirement results in the need to splice all the equipment grounding conductors together and take a "pigtail" off to the receptacle. A similar requirement exists for the grounded conductor in multi-wire branch-circuits. See the NEC Section 300-13 (b). Another important installation practice for receptacles is found in Section 410-56 (d). This section requires that metal faceplates be grounded. All faceplates, when installed, must completely cover the wall opening and seat firmly against the mounting surface.

Section 410-56 (c) also contains provisions for installing

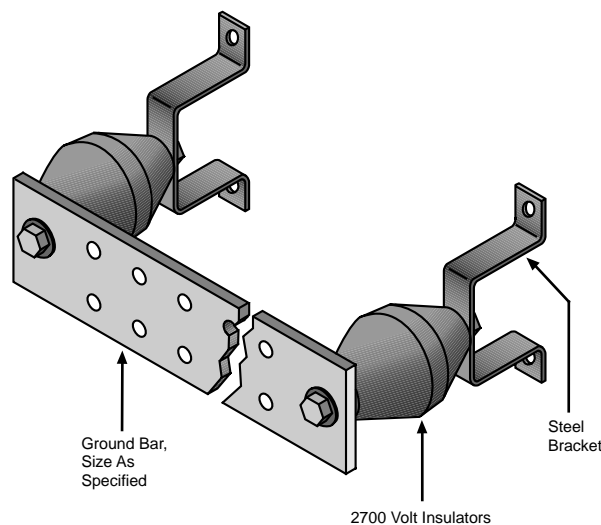


Fig. 3-27

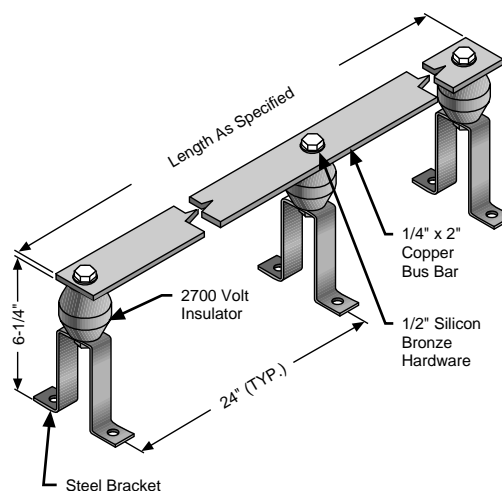


Fig. 3-28

Ground bus may be floor mounted.

isolated ground (IG) receptacles. These IG receptacles are frequently used for electronic/data processing equipment applications. The use of a separate, “isolated” grounding

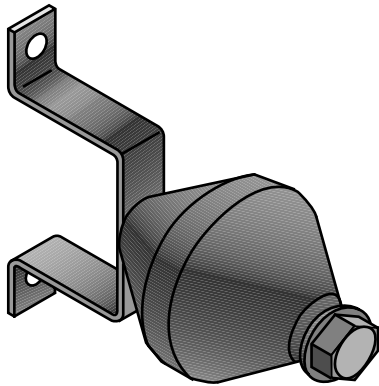


Fig. 3-29

Insulators and mounting brackets are available for mounting your own bar.

conductor ensures that the cord-and-plug connected equipment receives a “clean” source of power, free from EMF or RF interference. Installers of IG receptacle should note that the IG receptacles must be identified by an orange triangle located on the face of the receptacle. The grounding requirements for these receptacles are found in Section 250-74, Ex. No. 4. This section requires that the receptacle grounding terminal be grounded by an insulated equipment grounding conductor run with the circuit conductors. The isolated equipment grounding conductor is permitted to run through one or more panelboards provided it terminates within the same building to an equipment grounding conductor terminal for the applicable derived system or service. Note that the isolated equipment grounding conductor must be in addition to the regular equipment grounding conductor for the branch circuit. Because the IG terminal of the receptacle is isolated from the yoke of the receptacle, a separate equipment grounding conductor for the raceway system and outlet box still must be run.

LIGHTNING AND SURGE PROTECTION

This is discussed in Chapter 2, Lightning Protection and Chapter 7, Surge Protection Devices.

GROUND BARS AND GROUND BUS

Ground bus and ground bars have several applications:

1. Ground bus may be installed around the walls of a room where accessible ground points are needed, frequently for the control of static electricity (Fig. 3-30 and 3-32). The bus is generally mounted using standoff brackets usually with insulators. (Fig. 3-27, 3-28 and 3-29) In installations with raised floors, the bus may be mounted on the sub-floor (below the raised floor) (Fig. 3-31). This is used only for permanently attached equipment grounding conductors.
2. Ground bus may be used as a single point to which all equipment in a given area or of a specific type is connected. This equipment is usually associated with computers, telecommunications or radio/TV.
3. Special ground plates are available to meet your specific needs. Figures 3-33 and 3-34 are two styles specified on FAA installations which are protected by plexiglass and include special markings.

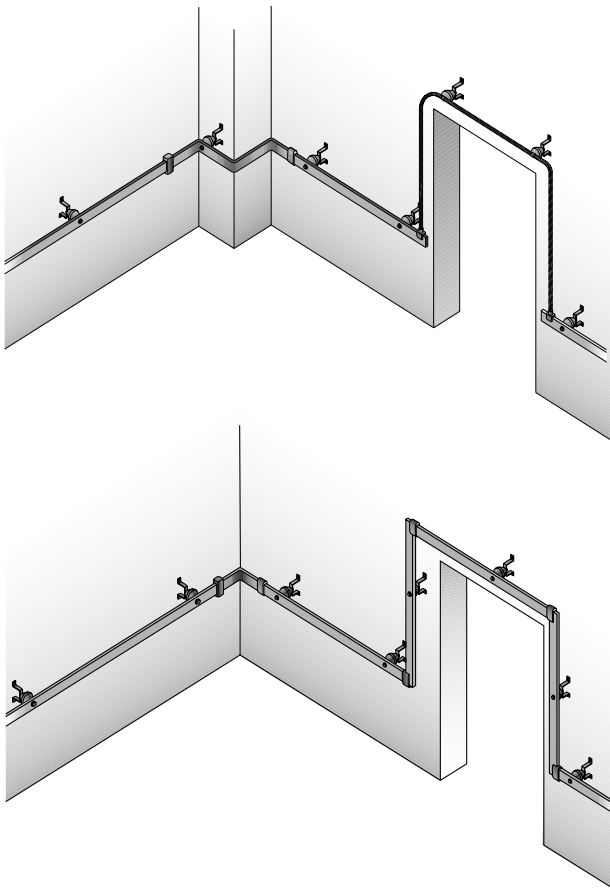
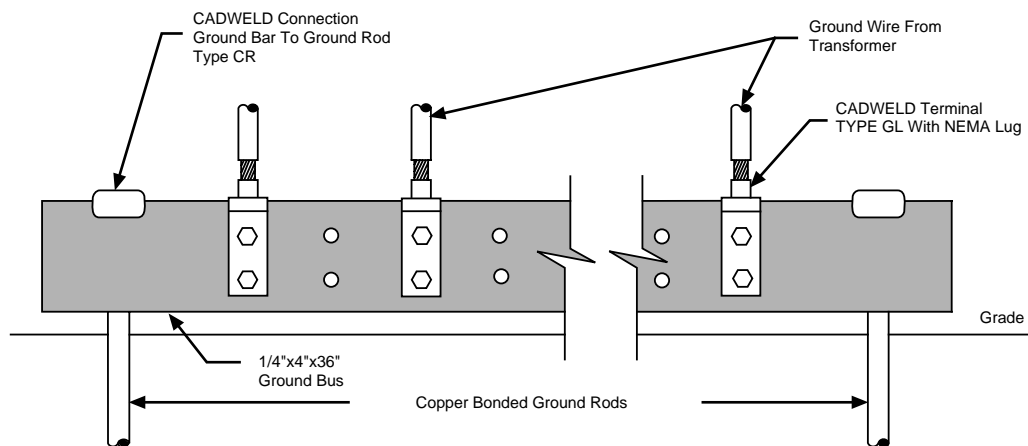
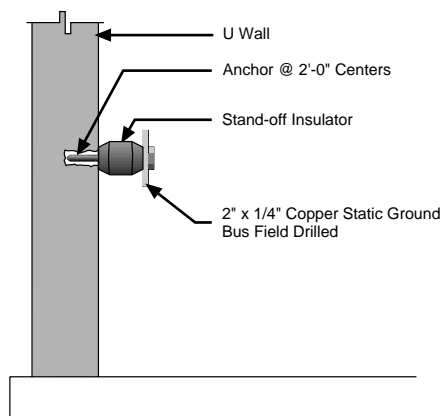


Fig. 3-30

When mounting ground bus on the wall, either bus or cable may be used to bond over the door way.



Transformer Ground Bus Detail
Fig. 3-31



Static Ground Bus Detail
Fig. 3-32

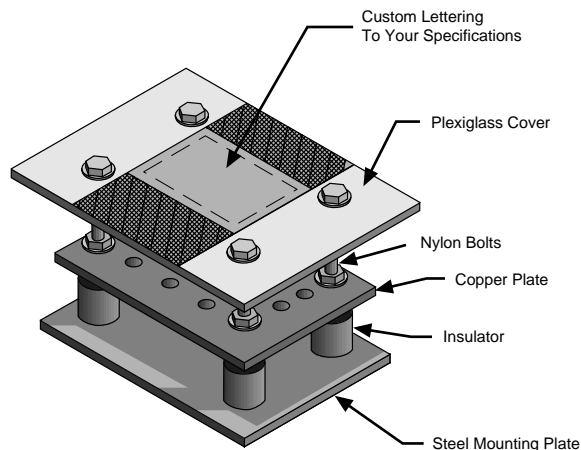


Fig. 3-34

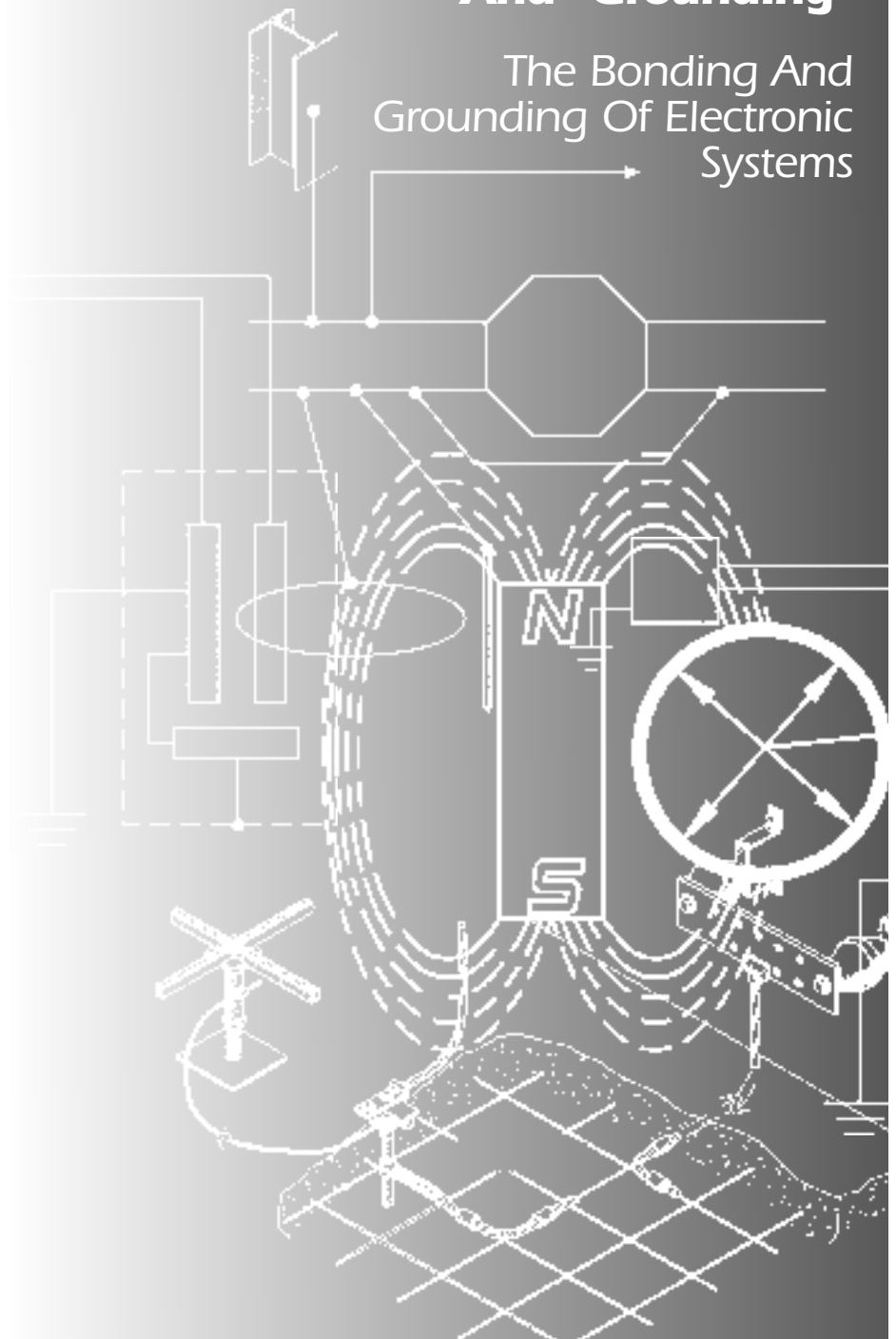


Fig. 3-33

Chapter 4

Transients And Other High Frequency Bonding And “Grounding”

The Bonding And
Grounding Of Electronic
Systems



INTRODUCTION TO ELECTRONIC SYSTEM “GROUNDING”

Grounding electronic equipment for personal safety and clearing of faults is no different than that of any other equipment. Safe grounding requires fast opening of circuit breakers or fuses and minimization of voltage differences between exposed metal surfaces on all of the involved electrical system and equipment, to levels that are safe for people.

What makes electronic systems different is the sensitivity of their circuit components to relatively small transient currents and voltages. It is also inherent in the nature of solid state devices to be very fast, so they are affected by equally “fast” electrical disturbances. Even lightning is a slow transient compared to the response of almost any electronic device. Typical threats to proper operation of electronic devices and systems include:

1. Lightning - Direct strikes, but the effects also include overhead cloud-to-cloud, and nearby strikes causing induced voltages
2. Switching transients from power network operations and power factor capacitor switching, lightning arrestor operation, and fault clearing activities- especially on nearby power circuits.
3. Static electricity - Directly applied arcs to the equipment, but sometimes arcs near the equipment will also affect the equipment.
4. Electrical fast transients - Typically as caused by arcing contacts or collapsing magnetic fields in the coils of contactors in equipment - usually very near the affected equipment

BASICS OF TRANSIENT PROBLEM SOLVING

Solving transient problems is never easy. They may be random or repetitive. In general, they have waveshapes which are not easily analyzed. Transients though are capable of being tamed by:

1. Limiting overvoltages (surge voltages) on the ac power conductors with surge protective devices (SPDs)
2. Reducing the chances of electrical noise getting on power circuits connected to electronic equipment and the data signal circuit cables that interconnect the units of equipment. This can often be accomplished by observing the requirements for

proper routing and grounding of branch circuits including their conduits, and ensuring adequate separation of power and data signal wiring.

3. Proper grounding involving the correct installation of equipment grounding conductors of all types, and neutral terminal grounding and bonding at the service entrance and for separately derived ac systems.

While the above are all within the scope of the contractors’ job, we want to emphasize that the equipment supplier can and must provide equipment that can “live within” practical levels of transients as are known to exist on the typical commercial and industrial site. Otherwise, extensive effort and great expenditures may be needed in order to get this kind of too-sensitive equipment to work in an acceptable way.

The kinds of power and data Surge Protective Devices, (SPDs) that are needed for the control of transients are discussed in Chapter 7 and will not be discussed in detail in this chapter. It is assumed that properly selected devices are used where we suggest one be applied.

INTERCONNECTED ELECTRONIC EQUIPMENT SYSTEMS

This section deals with grounding of electronic systems that are interconnected by signal, data, or telecommunications cables. It is helpful to think in terms of two kinds of grounding with this kind of equipment:

1. Safety grounding for fire and personnel protection. This kind of grounding also helps to provide for the protection of equipment to minimize damage from electrical system faults and transients such as lightning.
2. Performance grounding for the protection of data circuits and solid-state components within various items of interconnected equipment making up an electronic system. Sometimes this is called “computer” or “electronic” grounding but these are not very accurate terms. Note that the protection of data circuits does not have to involve earth grounding electrode connections, although good grounding to the building service equipment’s grounding electrode system makes this protection a lot easier.

For example and as mentioned above, airplanes flying through lightning storms have no earth grounds connected to them but, while experiencing lightning hits, are probably safer than many land-based systems. And after a lightning strike all of the electronic equipment within the aircraft is expected to continue to work in flawless fashion.

SOME IMPORTANT POINTS ABOUT GROUNDING

- (1) Typically the safety grounding of equipment is exactly the same for electronic equipment as it is for any other kind of apparatus, whether it is a refrigerator or a printing press. The “green wire” and conduit/raceway system’s grounding which is well documented in the NEC and other codes, defines these requirements completely. This chapter is not primarily concerned with this form of grounding.

Safe equipment grounding requires fast clearing of circuit breakers or fuses and minimization of voltage differences on exposed metal surfaces of equipment to levels that are safe for people. This is called the control of “touch potential.” There is absolutely no conflict between NEC defined grounding and the more specialized grounding and bonding practices described in (2) below. An unnecessary conflict can be created however, such as when someone attempts to create a “separate”, “dedicated” or “clean” grounding connection that is not permitted by the NEC!

- (2) Protection of data circuits generally requires additional considerations beyond the intent of the NEC, but not in violation of it. Protection of data circuits from disruption or even damage does not always involve grounding, although good grounding makes this protection a lot easier. Aircraft have no earth grounds while they are flying. The airplane carries its own “grounding” system for its ac and dc systems, and signal grounding purposes. This grounding system is entirely metallic in nature and it is often called a self contained power and signal reference system, which is a more accurate description. Even direct lightning “hits” are not likely to cause equipment damage or even disruption to signals.
- (3) The circuits of most electronic systems are almost always sensitive to voltages of a few tens of volts or even to as little as one or two volts. As a result, these systems are designed with great care to keep transients out of the actual circuitry and off of the signal paths between interconnected units of a system. To accomplish this, some equipment uses electrostatically shielded isolation transformer techniques and ac-dc power supplies designed to reject transients. However, for these techniques to be fully effective, good grounding and bonding practices exceeding those required in the NEC, must often be employed.

- (4) Data signals inside most electronic systems consists of bits of information processed as square waves or impulses at about 5 volts in amplitude and clock speeds which can exceed 200 MHz. Data transferred between equipment often has a magnitude of 12-18 volts, and the speed of transfer is lower than that of the signal processing speed available inside of the equipment. In any case, the signal rise-times of the clock and most other signal pulses such as those used to transfer bits, are far faster than the typical lightning strike. Yet, even at these speeds the systems can be made to have high reliability and to be relatively immune to interference if good grounding and bonding practices are followed.
- (5) Lightning related waveforms are usually the “worst case” situation for transients on most ac power system wiring and related grounding systems. This makes lightning the principal threat. More information about lightning and its typical waveforms may be obtained by consulting ANSI/IEEE Std C62.41-1992
- (6) Fast electrical transients are created in some equipment with electromechanical contactors. The interference problem from these items could be serious, but it is easy to solve by installing RC snubbers (consisting of resistors and capacitors) across the contacts, coils, or both items of the offending device. This kind of interference with electronic circuits can sometimes be controlled by more stringent shielding, or grounding and bonding practices. However, the root cause of this kind of problem is really not a shielding, or grounding and bonding related problem. Instead it is an equipment circuit modification problem and this is the kind of thing which typical electrical contractors should normally not be expected to identify or to solve.

HARMONICS

Note that by itself, harmonic current and voltage generation is not a grounding problem unless due to a miswired circuit or a component’s failure in which some of the harmonic current gets impressed onto the equipment grounding system. In this case, the effort is not to stamp-out the harmonics, but to find the miswire or failed component and to effect the repair.

Harmonics are often an important safety concern on the neutral conductor of a three-phase, wye-connected ac system where it is supporting line-to-neutral connected nonlinear loads- such as computers, etc. In this case the entire neutral path must be increased in ampacity to as

much as 200% of the ampacity used for the related line conductors. This is regularly done in order that a fire be avoided due to current overload from third harmonic and other odd multiple harmonics called “triplens”.

Other steps may be required to prevent harmonics from interfering with proper system operation. However, the exact method and point chosen for grounding of the neutral conductor at the ac supply source, will not improve any problems associated with harmonics. Ungrounding of the neutral is likely to be an NEC violation in almost all designs, and would decrease personnel safety. Solving problems related to harmonics is beyond the scope of this book, however something can be said in this regard.

HARMONIC CURRENT FILTERS (TRAPS)

Harmonic filters commonly called “traps” are not grounding problems unless they are miswired to direct the current through them into the equipment grounding system. This is an unusual situation and involves an NEC violation which would need correction. Typically, the trap is connected line-to-line, line-to-neutral, or both, but never to equipment or any other ground.

SURGE PROTECTIVE DEVICES (SPDs) AND GROUNDING CONNECTIONS

In addition to line-to-line and line-to-neutral connections, surge protective devices (SPDs) are also connected to the circuit’s equipment grounding conductor. Any transient voltage which then operates the SPD and causes current flow through it and to the equipment grounding conductor, raises the ground potential as measured at the installation point of the SPD and to the remote “ground” used as a zero voltage reference. Because SPDs may be subject to very high voltages with steep (e.g., fast rise time) wavefronts, the concurrent effects on the grounding system may be very severe.

SOME PRACTICAL RECOMMENDATIONS

These are some of the practical electrical installation considerations we recommend:

- (1) Field installed electrical grounding/bonding conductors routed between the metal frame or enclosures of separate units of electronic equipment should be connected to the NEC “green wire” grounding system at both ends, not isolated or insulated from it.
- (2) Isolation transformers with electrostatic shielding between the windings are readily available and should be employed to interface the electrical system to the panelboard used to supply branch circuit power to the electronic equipment. The installation of both the transformer and panelboard(s) should occur as physically close to the served electronic equipment as is possible. Note that the electrostatic shielding can provide useful attenuation of most types of common mode transients up to about 1000:1 (e.g., -60 dB). Attenuation figures above this value are generally unrealistic and are not likely to be provided by a transformer that is installed into a real-world installation and in conformance with the NEC. In any case, follow the transformer manufacturer’s recommendations closely to achieve the maximum benefit, but only if the instructions conform to the NEC.
- (3) Interconnecting cables between electronic system enclosures in equipment rooms should be routed in close proximity to the structural subfloor. This is especially the case if it contains substantial metal structures that are well grounded such as steel decking, etc. The best results however, are obtained when these cables are laid in close proximity to a specially installed signal reference grid, such as is recommended to be installed under a raised floor normally used in a computer room. If interconnecting cables are routed between locations in a cable tray or wireway, then the use of random lay is preferred rather than “neat” bundling in these forms of raceway. (This is recommended as random lay decreases the coupling of noise from one adjacent conductor into the other when they are laid parallel to one another for any significant length.)
- (4) If wireways are used to route cables, they should be made from metal, be well and continuously grounded and bonded, and be equipped with a tight cover such as one fastened by screws. Ladder tray is less desirable than solid-bottom tray.
- (5) Field installed data cables should normally be separated from power cables and conduits to the greatest practical distance. This reduces unwanted coupling between the two circuits. To avoid noise coupling problems where one circuit crosses over or under the other, try to make the crossover at right-angles.
- (6) Where metal raceways or conduits are used to contain interconnecting data cables, it is recommended that additional bonding connections be made at several points along their entire length

to ensure good longitudinal coupling. In addition to being well grounded/bonded to the equipment at the ends of the run, the conduit or raceway should also be bonded to any nearby structural steel along the run.

- (7) All metallic piping, ducting, conduit/raceway, wireway and cable tray located within 6 feet (horizontal or vertical) of any installed Signal Reference Grid (SRG) must be bonded to the SRG. This is especially important where these conductors enter or leave the area defined by the SRG. If this is not done, then lightning side flash may occur from the above or any nearby grounded metal items to the SRG. A side flash can cause a fire, electronic circuit damage, or both. More about the subject of side flash may be obtained by reference to ANSI/NFPA-780-1995, the National Lightning Protection Code.
- (8) In addition to any NEC requirements, the neutral terminal, such as the Xo terminal on a wye-secondary connected transformer of a separately derived system, should be connected to the SRG and if available, also to the closest building steel.
- (9) Be sure to bond the SRG to any nearby accessible building steel so as to create many points of grounding/bonding. This is important to do along the SRG's perimeter and for any steel that penetrates the SRG's surface.
- (10) Grounding for ac systems and equipment must conform completely to NEC requirements. Also, if the electrical or electronic equipment has been tested and listed by an NRTL (Nationally Recognized Testing Laboratory, such as UL), then there may be additional or special grounding/bonding requirements which must also be met if proper operation is to be obtained. Again, any use of a "dedicated", "clean" or other non-NEC allowed connection, such as one which is separated from the building's service grounding electrode and the associated equipment grounding conductor system, is totally against the intent of this book. Only grounding systems and connections which meet National Electrical Code requirements are suitable.
- (11) Special care must be used to assure proper grounding if NEC permitted isolated grounding is specified. "Isolated/Insulated grounding" (IG) must be per NEC Section 250-74; Connecting Receptacle Terminal to Box; exception No. 4; and Section 250-75, Bonding Other Enclosures for field wired (e.g., direct) branch circuit connections to electronic equipment.
- (12) In particular, no attempt must be made during or after installation to separate the electronic system's equipment grounding conductors from the ac power system's equipment grounding conductors and its associated earth electrode grounding connections. Such separations would violate the NEC and produce potential electrical fire and shock hazards. They would also be likely to damage circuits inside the related electronic equipment, or to at least degrade the operation of it.
- (13) Note that the use of the IG method even if it follows NEC requirements, does not always improve the performance of equipment. In fact, the use of the IG wiring method is just as likely to make things worse or to result in no observable change to the operation of the equipment. There is usually no way to predict the benefits if any, of isolated ground circuits except by direct observation and comparison between solid grounding (SG) and IG methods in each case.
- (14) It is relatively easy to convert existing IG circuits to SG circuits on an as-needed basis. On the other hand, it is generally both impractical and not cost effective to convert an existing SG circuit to an IG style that conforms to NEC requirements. Accordingly, circuits used to supply power to electronic equipment can be designed and first installed as IG types, so that they may later be converted back and forth between IG and SG as needed.
- (15) The equipment grounding conductors in a feeder or branch circuit must always be routed within the same conduit or raceway containing that circuit's associated power circuit conductors. This also applies to flexible cord and cable assemblies.
- (16) Where transfer switches (including those found in UPS systems) are used, the possibility of common mode noise is not removed. Proper grounding between alternate sources of power is required, usually by solid interconnection of the two system's neutrals, but with only one of the two ac systems being the one with the neutral grounded. Unless the two involved ac systems are installed physically adjacent to one another, a ground potential shift disturbance may occur during transfer operations on the switch. This shift in ground potential can then unwantedly introduce common-mode noise into the load being served by the switch.
- (17) Ground potential-shift problems and common-mode noise problems in general are avoided when

an isolation transformer is installed adjacent to the served loads and is positioned between the output of a transfer switch and the input of the served electronic loads. In these cases the neutral terminal on the secondary of the isolation transformer is solidly grounded and both the transformer and electronic load equipment are made common to one another for broadband grounding purposes, if they are also connected to an SRG that has been installed in the equipment room and just beneath the equipment.

- (18) More than one isolation transformer may be used in the above manner if the site is large. For example, multiple isolation transformers installed and grounded to an SRG in an equipment room are a recommended practice for larger sites. Also, multiple, separated, but SRG equipped rooms may each be provided with its own isolation transformer and grounded as above.
- (19) Specially designed, “original” forms of grounding which are not in literal compliance with NEC requirements are not recommended. This includes approaches to grounding called “clean”, “dedicated”, “single point” and other forms of “isolated” grounding not permitted by the NEC. The authors are aware of instances where all grounds are initially properly connected together with a jumper which the owner or operator can later remove at his discretion. Since removal of this connection creates both an NEC violation and fire/shock safety hazard, the authors do not recommend this approach!
- (20) Surge Protective Devices (SPDs) are described in Chapter 7. SPDs provide overvoltage protection at various points for power and data circuits wherever they are properly applied. Proper use of SPDs is highly recommended.
- (21) After the electrical installation is complete, a careful inspection of the wiring is needed to ensure safety and performance criteria have all been met. Regarding grounding, the following should be part of the inspection process:
 - (a) Misidentification of conductors such as the neutral and “green wire” safety grounding conductors, often occurs. The problem shows up at the point where they terminate. A mistake of this kind is a serious violation of NEC Section 250-21, and others. Cross-connection between neutral and ground conductors results in unwanted current flow in the equipment grounding system, but will

normally not cause an overcurrent protection device to operate. Hence, there is often no immediate indication of a problem such as when the power is first applied. Therefore, these conductors and connections need to be verified before power is applied.

- (b) All metallic conduit, wireway, raceway and other metallic enclosures, must be well-bonded along their length to ensure end to end continuity. They should also be well grounded at multiple points along their length to building steel and SRGs within 6 feet to provide effective high frequency grounding. Effectively grounded, end terminations to and from served equipment are most important.
- (c) Ensure that the shortest possible lead length has been used to connect SPDs to the conductors they are protecting. Ideally, the SPD would be mounted directly on or inside the equipment it protects. External mounting in a separate enclosure and a conduit connection to the protected equipment creates longer distances between the SPD and the load it protects. This decreases the effectiveness of the protection.
- (d) Any connection that is not a good electrical connection over the life of the installation is potential trouble. Such a poor connection can be a cause of noise or of a total interruption of the signal process or power continuity. Either a connection is made properly, or it must be reworked to bring it within specifications.

GROUND CURRENT INTERFERENCE WITH CATHODE RAY TUBE (CRT) BASED EQUIPMENT

Low frequency magnetic fields such as those associated with the power system's fundamental of 60 Hz and harmonics from it, will sometimes be seen to interfere with the normal deflection of the electron beam being used to paint the image on the CRT's screen. This magnetic field interference is seen by the equipment's operator as a wavy or rippling display that is often very disconcerting to the operator. (See Fig. 4-1)

One way magnetic fields of the type involved in this kind of interference are created in grounding conductors is by any continuous or nearly so, flow of current in externally attached supplementary equipment grounding conductors, grounding electrode conductors, structural steel members, piping, ducting, cable trays, wireways, etc. Stray ground currents in any of these items can produce the same effects on the CRT's screen.

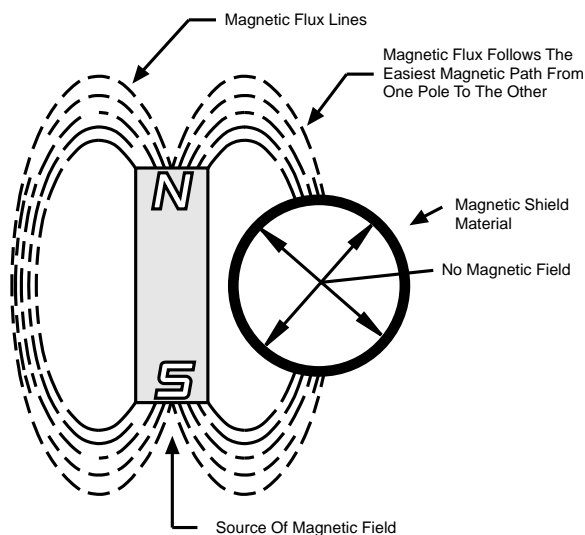
Fortunately, the effects of these interfering magnetic fields falls off exponentially with distance between the source of the field and the equipment that is being affected. Also, the orientation of the CRT to the lines of force of the magnetic field affects the severity of the problem. Therefore, increased spacing and reorientation of equipment is often the first and a successful step, in the resolution of the problem.

Another practical approach to reducing the effects of magnetic fields on a CRT is to increase the number and location of any grounding/bonding connections between grounded items, including the one involved in the interference. For instance, more bonding between cold water piping, building steel, and grounding electrode conductors often solves the problem. (See Fig. 4-2)

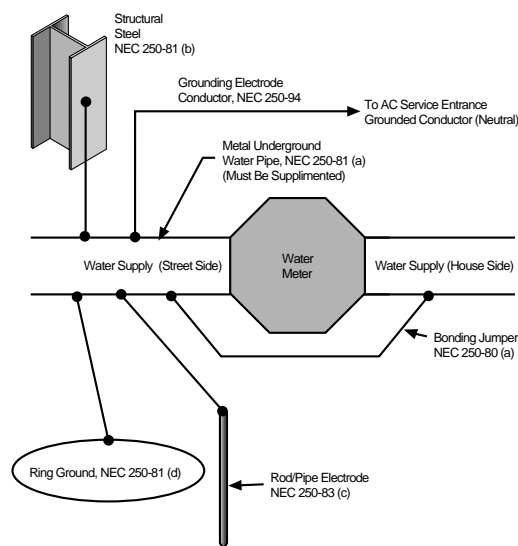
The foregoing procedure generally works since it breaks up the currents from one conductor into several smaller ones. In example, since the magnetic field surrounding a conductor is proportional to the current's amplitude, the process of providing multiple paths for a current reduces the current in any one conductor and therefore the stray magnetic field being emitted from it. The best approach of all however, is to find out how the unwanted current is getting into the conductor and to fix the problem in accordance with NEC requirements such as per Section 250-21, Objectionable Current On Grounding Conductors.

GROUND LOOPS

A formal definition of a ground loop that is very general is provided in IEEE Std. 100-1991, IEEE Dictionary as follows: . . . a ground loop is "formed when two or more points in an electrical system that are nominally at ground potential are connected by a conducting path such that either or both points are not at the same potential." While this is a good general purpose definition, it is not sufficiently specific for use when dealing with signal level circuits and grounding connections. Therefore, a more specific and useful definition as provided in this document is as follows:



Magnetic Field Shielding
Fig. 4-1



Typical Electrodes
Fig. 4-2

Ground Loop (unwanted)— Any conductive path involving “ground” via a grounding or grounded conductor or the earth itself, through which any part or all of the desired signal process current is passed, so that it may be algebraically added to any unwanted current such as “noise” that may also be flowing in the shared ground path.

Ground Loop (desired)— Any number of paralleled conductors and connections involving grounded or grounding conductors of any description, or the earth, and through which it is intended to conduct ac system ground fault or lightning currents, for the purpose of reducing arcing, touch potential hazards, and as an aid to fault clearing.

Ground Loop (benign)— Either of the above two ground loops or a combination of them, where despite the existence of the ground loop, no electrical hazards are created and no signal processes are disrupted, by its existence.

Since we are concerned with the unwanted effects of ground loops on signals, we will mainly use the first of the above definitions in this document.

Signals which are transmitted on isolated balanced pairs are not referenced to ground, and differentially coupled signals that are referenced to ground are relatively immune to problems involving the ground reference to which they are connected. With these circuits we are only concerned with voltages to ground that are high enough to cause voltage breakdown of insulation systems or electronic components, or to saturate the magnetics that may be used to isolate and couple the signal between the signal cable and the electronics used to drive or receive the signal on the path.

Unbalanced signals referenced to ground fall into two general categories:

- (1) There are those that typically employ coaxial cable with only one center conductor for the signal transport process and where the outer braid is grounded at both ends. This includes many kinds of circuits used with computers, process control systems, and similar installations.
- (2) There are those that use a common conductor which is grounded, as a part of the signal return path for one or more signals on a multi-conductor cable. Standard signal protocol, RS-232 usually falls into this category.

In both of the above examples, if unwanted current flow is caused in the grounded conductor that also carries signal, and if there is an overlap between the bandwidth of the

interfering signal and the desired one, then the signal process is almost certain to be disrupted once the interference reaches a minimum level of amplitude.

Two principle means of dealing with the above ground loop problem generally exist as follows:

- (1) Change the signal’s protocol using a converter, to one that does not use the “ground” path for any of the signal current, or;
- (2) Shunt the ends of the cable involved in the ground loop by effectively bonding the equipment at each end of the cable to the same SRG. This greatly reduces the effects of the noise current in the signal conductor path by providing a myriad of parallel paths for it to flow in via the low impedance SRG. However, the desired signal will still stay relatively evenly divided between the two signal conductors on the cable and not flow into the SRG. This occurs because the mutually coupled fields from the closely coupled supply and return conductors in the cable and for the signal, act to make this path a much lower impedance for the signal currents to travel in than the SRG.

Our recommendation is to properly design and implement the facility’s grounding system to avoid its unwanted involvement with the operation of the equipment. This kind of approach can also eliminate the need to consider equipment modifications and to engage in costly diagnostic efforts since most trouble involving common-mode noise is avoided in the signal circuits. A properly installed SRG along with good bonding practices is a recommended method of minimizing common-mode noise problems, so it becomes a first-line of defense in such cases.

While it may be true that an SRG based design of this kind is both conservative and somewhat more costly (initially) than other wiring techniques that are commonly used, our experience clearly shows that using the SRG approach produces superior and ultimately, more cost-effective results due to the lack of later operational problems. In other words, a conservative design involving an SRG costs a little more, but avoids lots of very difficult and potentially expensive problems after the job is done.

RECOMMENDATIONS:

It is generally not possible in complex systems with interconnected data and signal conductors to avoid all ground loops. Some approaches that may be used to avoid the detrimental effects of such ground loops include:

- (1). Where possible, cluster the interconnected electronic equipment into an area that is served by a single signal reference grid (SRG). If the interconnected equipment is located in separate, but adjacent rooms, then a common signal reference grid should serve all the rooms.
- (2) Effectively bond each frame/enclosure of the interconnected equipment to the SRG. In this way, the SRG acts like a uniformly shared ground reference that maintains a usefully low impedance over a very broad range of frequency. Typically, from dc to several tens of MHz, for example.
- (3) Where a work area exists and its PC is connected to a network, keep all of the work area's equipment (e.g., CPU, monitor, printer, external modem, etc.) closely clustered and powered by a work area dedicated branch circuit. If it is required to use more than one branch circuit for the work area's power, be sure that both are powered from the same panelboard. Avoid connecting any other equipment to the branch circuit(s) used by the work area's equipment.
- (4) Use fiber optical paths for data circuits. The best, but also the most expensive solution is to use fiber optical cables for all data circuits since there can be no ground loops with these kinds of circuits (or surge current problems). However, due to increased initial cost and added complexity, the use of fiber optic cable circuits is usually (and unfortunately) viewed as a last resort. Instead, it should be viewed as an important first strategy that avoids problems that may ultimately cost more to resolve.
- (5) Use opto-isolators which can provide several kV of isolation for the data path that they are used on. These are available as add-on data transmission protocol converters for most popular forms of data circuits. This is a very useful retrofit option for data circuits being affected by surges and ground loops. Surge protection devices (SPD) are also recommended to be applied to these circuits if protection from the higher voltages associated with larger currents is needed.
- (6) Other forms of protocol converters can be applied to standard forms of signal circuits to make them less susceptible to common-mode noise on grounding conductors associated with the signal path. For example, a conversion from RS-232 to RS-422 or RS-485, etc. should be considered in especially noisy environments.

- (7) Improve the shielding provided for the data signal cables. Place the cables into well and frequently grounded metal conduits or similar raceways.
- (8) Follow the recommendations for installing signal cables in IEEE Std. 1100, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (e.g., the Emerald Book).

Equipment interconnected by data signal cables and located on different floors or that is widely separated in a building, may not be able to effectively use some or all of the above solutions, except those involving optical isolation and certain of the protocol conversion techniques. This occurs since the terminating equipment for the signal cables is likely to be powered from different branch circuits, panelboards, and even separately derived ac systems. Therefore, the associated equipment ground references are likely to be at different potential at least some of the time.

While the best solution to the above situation involves either fiber optic or opto-isolation techniques, it is often possible to achieve good performance by providing each of the separate locations with an SRG, and then interconnecting the SRGs with widely spaced apart and multiple grounding/bonding conductors, solid-bottom metal cable trays, wireways, or conduits containing the data signal cables.

An example of using widely spaced grounding/bonding conductors to interconnect two SRG areas is when there is structural building steel available and when it can be used in this role. Since structural steel columns are installed on standard spacings in a given building, these columns can typically be used for the purpose. Wide spacing is necessary since the conductors involved are inductors and the mutual inductance between such conductors that are not widely spaced, is quite high. This makes several closely spaced conductors appear as a single inductor and not as paralleled inductances, which exhibit lower overall reactance between the items they are being used to interconnect.

Also, each of the above separated equipment areas containing SRGs should be ac powered from a locally installed and SRG referenced isolation transformer as opposed to them being powered from panelboards and feeders from some remotely located power source.

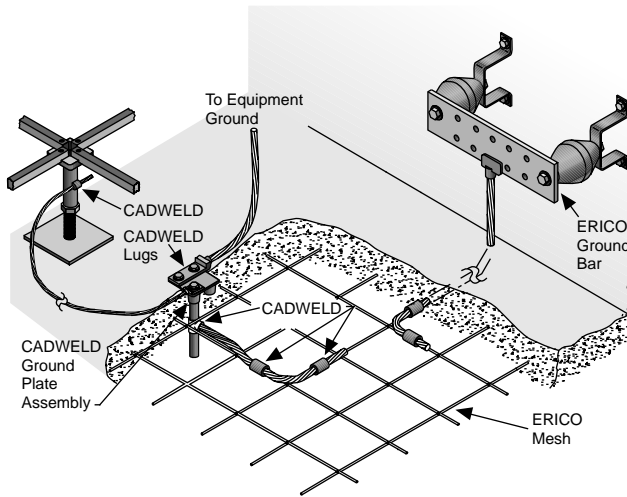
Finally, since separated areas in a building are subject to large potential differences due to lightning discharge currents and some forms of ac system ground faults, the ends of the signal cables should always be equipped with surge protection devices (SPDs).

otherwise the reinforcing steel is simply periodically welded to the SRG at those points where the two structures have nearby or intersecting elements.

SOME FURTHER THOUGHTS ON NETWORKED WORKSTATION EQUIPMENT

Workstations that are part of a network and use Local Area Network (LAN) interface plug-in cards or modems, or are connected to servers, printers, or similar peripheral devices that are not located at the workstation, typically need special attention to be paid to how they are grounded so that common-mode noise will not be a significant problem with their operation. Accordingly, here are some suggestions:

- (1) Provide an externally applied supplementary equipment grounding conductor network that is connected to each item of the workstation and to the “greenwire” of the branch circuit(s) serving the workstation.
- (2) If there is any excess length in the ac power line cords or data signal cables used to connect the workstation’s equipment to the branch circuit or network’s signal circuits, loop the excess into a small coil whose loops are secured by tie-wraps or plastic electrical tape. This creates a “choke” effect that can reduce the higher frequency common-mode noise currents in the path to which the technique is applied, and without affecting the power or signal transport process. Observe bending radius limits of conductors to avoid overstressing the insulation or causing excessive heat rise.
- (3) Electromagnetic Interference (EMI) in the form of coupled radio waves into signal cables, is not a common problem in most installations. However, it is not an unknown problem either, especially if the source of the EMI is located close to the affected cable and its served circuits. Where interference with low-level signal processes is encountered and if traced to EMI at radio frequencies such as from a radio transmitter or some other industrial process occurring at radio frequencies, additional signal cable shielding and in extreme cases signal filtering at the cable’s ends, may need to be provided on the affected circuits. The application of such filters may need to be carried out inside of the related equipment, so close involvement of the equipment’s original manufacturer (OEM) is very important.



For applications of mesh used as signal reference grid (SRG) embedded in the concrete floor, a CADWELD Cast Ground Plate is mounted flush with the finished floor and connected to the mesh. Future equipment is then connected to the ground plate.

Fig. 4-3

ELECTRONIC GROUNDING DETAIL

When a metallic mesh is embedded in the structural concrete subfloor, it may be used for an electronic signal reference grid (SRG). When this is done the problem becomes how to make connections to the SRG. The typical approach is to embed a ground plate at each intersection of the SRG’s conductors, but on a spacing of around 2x2 or 4x4 feet square. This conforms to the standard practices for SRGs such as those used in conjunction with a computer room’s cellular raised floor. In other cases where connection points on 2-foot centers are not needed, a ground connection plate per Figure 4-3 may be installed wherever necessary. The exposed surface of the embedded stud or tie-plate is then used to make connections to and from the SRG that is below the surface of the concrete.

Note that for electrical equipment and mechanical equipment rooms, spacings of 2x2 feet are often closer than is needed—especially if the floorplan is known in advance. In these cases the concrete embedded SRG studs or ground plates are installed to place them close to the equipment that is planned to be permanently installed in the room. Spacings of around 4 to 6 feet square are common in these kinds of cases.

The concrete floor embedded SRG is often combined with the steel reinforcing bar system that is installed in the poured concrete. In some cases where the reinforcing steel system is welded together, it can serve as the actual SRG,

**TELECOMMUNICATIONS SYSTEMS
GROUNDING**

Grounding of telecommunications systems, such as voice and data grade telephone circuits, has become a well defined area of grounding. The rules are explicit. If not followed, the systems will be more sensitive to noise disturbances. As with other forms of electronic systems grounding, there is no conflict between a safe system and a reliable one. In all cases, the NEC's requirements fully apply to all aspects of the telecommunications wiring. The proper installation of telecommunications circuits is generally beyond the scope of this document, but some helpful references are provided as follows:

- (1) ANSI/EIA/TIA Standard 569A-1997 Commercial Building Telecommunications Cabling Standard
- (2) ANSI/EIA/TIA Standard 569-1990, Commercial Building Standard for Telecommunications Pathways and Spaces
- (3) ANSI/EIA/TIA Standard 570-1991, Residential and Light Commercial Telecommunications Wiring Standard

The publisher of the above standards is:

Telecommunications Industry Association
Standards and Technology Department
2500 Wilson Boulevard
Arlington, VA 22201

We emphasize that while these standards are well written and complete, they may not be fully compatible with the recommendations made in this document nor with all current or future requirements of the NEC. Therefore, some care is required in interpreting them and applying them in the field.

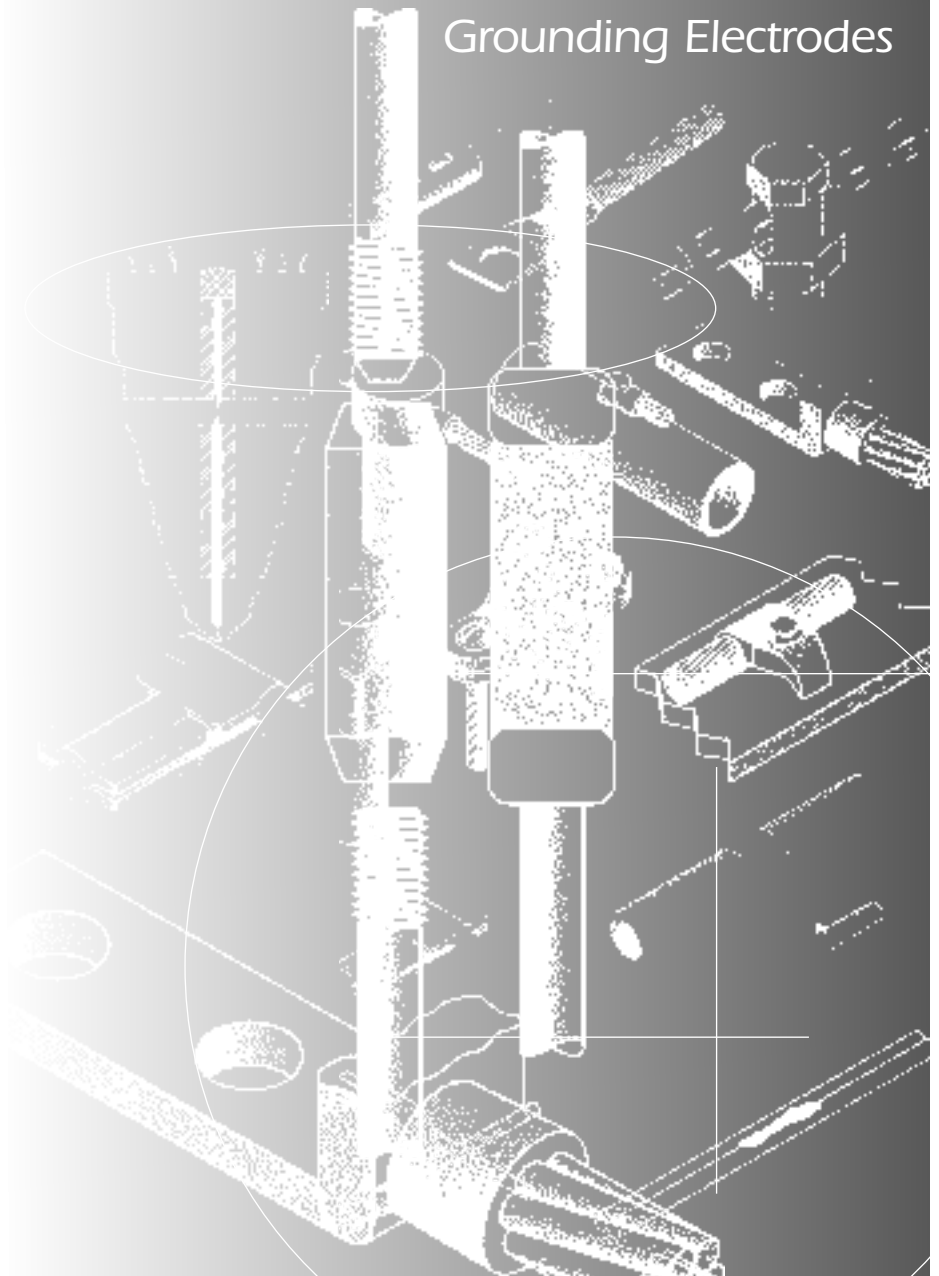
Chapter 5

Selection Of Components Used In Grounding

Grounding Conductors

Connectors

Grounding Electrodes



SELECTION OF GROUNDING SYSTEM COMPONENTS

The overall effectiveness of any grounding system will be determined by the individual components that are used to construct the system and the manner in which the components are connected. The purpose of this chapter will be to review the selection of these components and the methods by which they should be interconnected. Great care must be exercised in selecting all of the following grounding components:

- The Grounding Conductors
- The Grounding Electrodes
- The Connectors

THE GROUNDING CONDUCTORS

The NEC contains requirements for both the equipment grounding conductors (EGC) and the grounding electrode conductor (GEC). Recall that the EGC is used to connect the noncurrent-carrying metal parts of equipment, enclosures, raceways, etc., to the system grounded conductor and/or the grounding electrode conductor at the service or source of a separately derived system. The GEC, on the other hand, is used to connect the grounding electrode to the EGC and/or grounded conductor at the service or source of a separately derived system.

EQUIPMENT GROUNDING CONDUCTORS

Materials:

Section 250-91 (b) lists 11 components which are permitted to serve as the equipment grounding conductor for both branch-circuits and feeders. The permissible items are a copper or other corrosion-resistant conductor. EGC's are permitted to be either solid or stranded; insulated, covered, or bare; and in the form of a wire or a busbar of any shape, rigid metal conduit, intermediate metal conduit, electrical metallic tubing, flexible metal conduit where both the conduit and fittings are listed for grounding, armor of Type AC cable, the copper sheath of mineral-insulated, metal-sheathed cable, the metallic sheath or the combined metallic sheath and grounding conductors of Type MC cable, cable trays as permitted in Sections 318-3(c) and 318-7 of the NEC, cablebus framework as permitted in Section 365-2(a) of the NEC, other electrically continuous metal raceways listed for grounding.

Installation:

No matter what type of EGC is selected, the NEC requires in Section 300-3 (b) that in general, all conductors of the circuit, including the EGC must be contained within the same raceway, cable tray, trench, cable or cord. The purpose of this requirement is to ensure the impedance of the EGC remains at the lowest possible value. When the circuit conductors are run in parallel, as permitted by Section 310-4 of the NEC, the equipment grounding conductors are also required to be run in parallel. In these parallel installations the EGC must be a full sized conductor based on the ampere rating of the overcurrent protective device protecting the circuit conductors. The NEC further requires in Section 250-92 (c) that the EGC shall be installed with all of the applicable provisions in the Code for the type of EGC which is selected. In other words, if rigid metal conduit (RMC) is used as the EGC, as permitted in Section 250-91 (b) (2), the RMC must be installed in a manner that meets all of the requirements for RMC contained in Article 346 of the NEC. Installers of electrical systems should understand that when they install a raceway system, such as RMC, and it is used as an EGC, each length of conduit is part of the overall equipment grounding system. For this reason, any terminations at boxes or couplings must be made up wrenchtight to ensure a low impedance ground path.

Size:

When the equipment grounding conductor is a separate conductor, as permitted by 250-91 (b) (1), the size of the EGC is determined by the rating or the setting of the overcurrent protective device (fuse or circuit breaker) which is ahead of the equipment, conduit, etc. Table 250-95 of the NEC contains the minimum size for aluminum, copper-clad aluminum and copper equipment grounding conductors. The table includes sizes for circuits from 15-amperes up to 6000-amperes. The values listed in the table are based on a maximum circuit conductor length of 100 feet. For conductor lengths longer than 100 ft, an adjustment in the EGC size may be necessary. Section 250-95 requires that where the circuit ungrounded conductors are increased in size to allow for voltage drop, the circuit equipment grounding conductors must be adjusted proportionately as well.

GROUNDING ELECTRODE CONDUCTORS

Materials:

The grounding electrode conductor is permitted to be constructed of copper, aluminum, or copper-clad

aluminum. Copper-clad aluminum is constructed of a minimum of 10% copper which is metallurgically bonded to the aluminum core. The GEC is permitted to be a solid or stranded conductor and it can be an insulated, covered or bare conductor. Solid conductors provide less surface area to corrode and subsequently are used when installed in corrosive locations. However, stranded conductors in general are easier to work with so they are used more frequently. With stranded conductors of a given size, the greater the number of strands, the smaller each strand is and the conductor is more flexible. Copper is by far the most common choice for grounding electrode conductors but copper-clad aluminum may be used to reduce the likelihood of repeated theft of the copper GEC. The major disadvantage to using aluminum is the installation restriction in damp or wet locations. See installation provisions below.

Installation:

In general, grounding electrode conductors are required to be installed in one continuous length, without splices or joints. As noted above however, the GEC can be spliced by means of irreversible compression-type connectors listed for the use or by means of the exothermic welding process (CADWELD). Also as noted above, the GEC can be installed directly on a building structure, if a No. 6 AWG or larger, and not subject to physical damage. If the GEC is going to be subject to physical damage it should be installed in a raceway or cable armor for protection. Section 250-92 (a) prohibits the use of aluminum or copper-clad aluminum grounding electrode conductors when they are installed in direct contact with masonry, the earth, or where they are subject to corrosive conditions. Another important restriction for aluminum or copper-clad aluminum GEC's is the prohibition against their use outdoors within 18 inches of the earth. This requirement effectively precludes the use of aluminum or copper-clad aluminum for connection to "made" electrodes installed outdoors.

Size:

The size of the grounding electrode conductor is based on the size of the largest service-entrance conductor that supplies the building or structure. When the service conductors are installed in parallel, the size of the GEC is based on the size of the equivalent area of a single conductor. For example, if a 3-phase, 4-wire service consists of two, 500 kcmil conductors per phase, in parallel, the size of the GEC would be based on the equivalent area of a single phase, 1,000 kcmil, (500 kcmil x 2 conductors). Table 250-94 of the NEC contains the minimum size for aluminum, copper-clad aluminum and copper grounding

electrode conductors. The table includes sizes for circuits from No. 2 AWG copper and No. 1/0 AWG aluminum up to 1100 kcmil copper and 1750 kcmil aluminum or copper-clad aluminum. Designers and installers of electrical systems should note that no matter what the size of the service, the GEC is never required to be larger than a 3/0 AWG copper or a 250 kcmil aluminum or copper-clad aluminum conductor. The reason for this limitation is that the grounding electrode is unable to dissipate any more current into the earth than can be carried by these conductors. So even if the conductor size were increased, the effectiveness of the grounding electrode system would not be improved. As noted in Chapter 3, there may be particular applications where design personnel oversize the grounding electrode conductor because of the size of the facility or the nature of the equipment which may be used in the facility. For large facilities where outdoor equipment and exposed conductors are used, available fault current and maximum clearing times must be considered. IEEE Std 80 gives guidance for choosing conductor size and material.

THE GROUNDING ELECTRODE

Many different types of grounding electrodes are available, some "natural" and some "made". The natural types include metal underground water pipe, the metal frame of the building (if effectively grounded), copper wire or reinforcing bar in concrete foundations or underground structures. "Made" electrodes are specifically installed to improve the system grounding or earthing. Made electrodes include rods or pipe driven into the earth, metallic plates buried in the earth or a copper wire ring encircling the structure. Note that underground gas piping is not permitted to be used as a grounding electrode. Likewise, aluminum electrodes are prohibited by the NEC.

Other rules for the above electrodes also may apply. Those in effect at the time of this writing include:

1. All water pipe electrodes must be in contact with the earth for at least 10 feet and must be supplemented by an additional electrode as listed above. (If the water pipe happens to be disconnected or if a section of plastic pipe is installed at a later date, the supplemental electrode would still be effective.)
2. The copper conductor in the concrete foundation or footer must be #4 AWG or larger and must be at least 20 feet if it is to be used as a grounding electrode. If rebars are used, they must be 1/2 inch (#4) or larger, bare or coated with an electrically conductive material and at least 20 feet long. The foundation must be in direct contact with the earth.

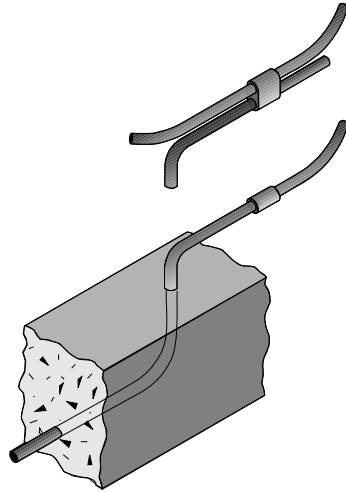


Fig. 5-1

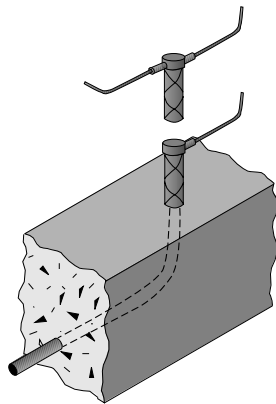


Fig. 5-2

This type of electrode is commonly called a “Ufer Ground”. (A plastic sheet must not be used to separate the concrete from the earth.) Figure 5-1 shows a #4 AWG or larger copper wire imbedded in the concrete foundation. Figure 5-2 shows a #4 (1/2”) or larger rebar imbedded in the concrete foundation. CADWELD Connections are used to make permanent connections to either the copper wire or the rebar.

3. The copper wire ground ring encircling a building or structure must be #2 AWG or larger, at least 20 feet (6 m) long and buried at least 2 1/2 feet (.76m) in the earth.
4. Rod or pipe electrodes shall be at least 8 ft long with a minimum of 8 feet in contact with the earth, installed vertically except where rock is encountered, in which case they may be driven at a 45° angle or buried in a trench 2 1/2 feet deep. The

upper end of the rod or pipe must be flush or below grade unless the top end and the connector are protected from damage. Pipe electrodes shall be 3/4 inch trade size or larger and shall have their outer surface galvanized or another metal coating for corrosion protection. Rod electrodes shall be 5/8 inch diameter if of iron or steel. Stainless steel rods less than 5/8 inch and nonferrous rods, including copper clad steel rods, shall be listed and not less than 1/2 inch diameter.

5. Plate electrodes must be at least 1 square foot (0.093 square meter) and 1/4 inch (6.3 mm) thick if steel or 0.06 inch (1.5 mm) thick if nonferrous. Note the plate thickness required by the NEC is different than that required for lightning protection. Burial depth is not specified by code. If used, we suggest that to get the best performance, it be installed on edge and with the top at least 18 inch (460 mm) below grade. Plate electrodes, however, are not as efficient as most other types of electrodes and are usually used only in special conditions where other types of electrodes cannot be used.

Recommended practice is to install the electrodes and interconnecting conductors 18 inches (460 mm) beyond the roof drip line. This provides additional moisture to reduce resistance.

The electrodes used to ground lightning protection systems shall not be the same ones used for the electrical system ground electrodes but the electrodes from both systems must be bonded together. Not only required by the NEC but also required for safety of all who may come in contact with the electrical system, all grounding electrodes must be interconnected. Separate and isolated ground systems are dangerous and are not permitted! While separate and isolated ground systems were once specified for many electronic systems, this practice has been shown to corrupt the data, damage the equipment and in addition can be extremely dangerous.

GROUND RODS

Ground rods are commonly available as copperbonded steel and galvanized steel. Solid stainless steel, solid copper and occasionally plain steel are also utilized. Rods are also available with a factory welded pigtail (Fig. 5-3). While copper bonded steel rods have a slightly lower electrical resistance than galvanized or plain steel rods, they are not chosen for their lower electrical resistance but rather for their resistance to corrosion. Copper is a more noble metal than steel and will therefore resist corrosion much better than steel, or even galvanized steel in most soils. (Fig. 5-3)

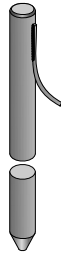


Fig. 5-3

Rods are also available with factory attached copper wire pigtails.

However, when copper is interconnected electrically to steel in the presence of an electrolyte, the steel will corrode to protect the copper. Since the ratio of steel to copper in the grounding system is usually large, the amount of steel corrosion is usually so small it can be neglected. However, in cases where the steel to copper ratio is small, the corrosion aspect must be considered, for example as in a pole having both a ground rod and a guy anchor. These may be electrically connected. If the guy anchor is steel and the electrode is a copperbonded rod, an insulator in the guy wire should be used to break the electrical interconnection. Otherwise, galvanic corrosion on the guy anchor may occur. Ground rods are discussed further on page 14.

If the soil resistivity is very high, a backfill material is used around the ground rod to lower the system resistance. Care must be considered in choosing the material used. It should be of a material compatible with the ground rod, conductor and connection material.

See the discussion on ERICO GEM™ below. (Fig. 5-4)

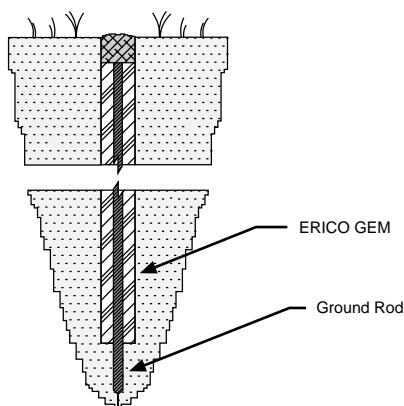


Fig. 5-4

GEM is easily installed. Auger a 3 to 6 inch hole to a depth equal to 6 inches less than the rod length.

Drop the rod down the hole with the lower end centered and driven in 6 inches. Fill the hole using either dry GEM or premixed (slurry) GEM material.

Often, one ground rod will not provide the ground resistance required for the particular installation. The NEC requires the ground resistance with one rod, pipe or plate electrode to be 25 ohms or less. If it is over 25 ohms, a second electrode is required, connected to the first electrode and separated by 6 feet or more. The resistance of the two electrodes does not have to meet the 25 ohm maximum resistance requirement.

More often, a maximum resistance is called out in the job specifications. This may be 5 ohms or sometimes as low as 1 ohm. Depending on the earth resistivity at the site, a low resistance may be difficult to acquire. There are several ways to lower system ground resistance:

Use multiple rods. Unless the surface layer of soil (top 8 to 10 feet) is of a relatively low resistance, the use of multiple rods may not be effective. Multiple rods should be separated 8 to 10 feet for maximum efficiency and economy requiring a larger area which may not be available.

Use deep driven rods. Many high resistance sites have a high resistivity soil in the upper levels (for example a rocky surface) but a lower resistivity at lower levels. Deep driven rods will reach this low resistivity layer. Sometimes it is necessary to drive 100 to 150 feet to reach this low resistivity layer. Since a continuous rod cannot be installed, the method of splicing the rod sections must be carefully examined. The methods available are threaded couplers, compression (threadless) type and welded type. ERICO has a full line of ground rods and ground rod accessories. (Fig 5-5)

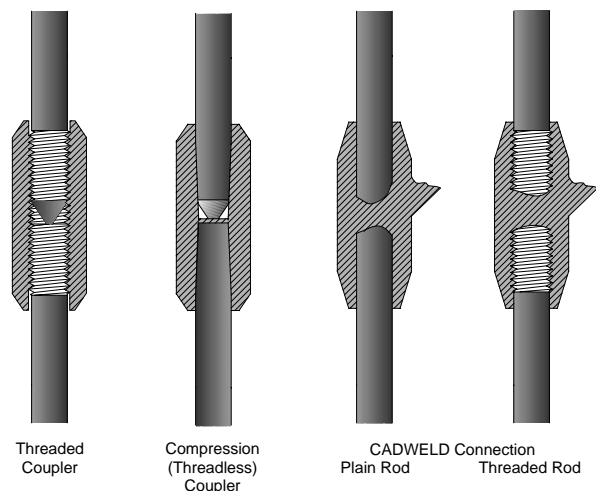


Fig. 5-5

Although the welded type are more expensive, they assure that the couplings will not become a high resistance member in the current path over the life of the system. One loose coupling will render all of the lower rod sections useless.

Also available is a connection which is a combination of a screw coupling and a welded coupling. After the screw coupling is installed, two CADWELD connections are made to weld the coupling to both the top and bottom rods. (Fig. 5-6)

When using deep driven rods to reach soils of low resistance, tests have shown that the rods do not have to be separated more than 10 feet for maximum efficiency. This is probably due to the fact that only the lower 10 feet of rod is in the lower resistance soil.

USE A GROUND ENHANCEMENT MATERIAL

Several materials are available to lower the resistance of the installed rod electrode. They are placed around the rod which has been installed in an augured hole. Although they have a resistivity higher than the metal rod, their resistivity is lower than the surrounding soil. This, in effect, increases the diameter of the rod. Following are some of the materials commonly used as ground enhancement materials along with their resistivities;

concrete : 3000 to 9000 ohm-cm (30 -90 ohm-m)

bentonite (clay) : 250 ohm-cm. (2.5 ohm-m) (Shrinks and looses contact with both rod and earth when it dries)

GEM™ : 12 ohm-cm (0.12 ohm-m) or less.
(Permanent, sets up like concrete and does not shrink or leach into soil)

USE A CHEMICAL TYPE OF GROUNDING ELECTRODE

Several makes of chemical types of ground electrodes are available. They are essentially a copper pipe with holes in it. The pipe is filled with a salt, such as magnesium sulfate. The salt slowly leaches from the holes in the pipe infiltrating the soil. The salts must be periodically replaced for the electrode to remain effective. Also, the Environmental Protection Agency (EPA) may object to adding salts to the soil. Chemical type electrodes are discussed in more detail on page 15.

USE A SALT AROUND THE ROD

Adding salt to a trench around the ground rod is an inexpensive method to add salts to the soil. The salts must be periodically renewed. The EPA may also object to this method. Some salts may corrode the grounding conductors. This approach to lowering the ground resistance is not recommended.

CONNECTIONS

The connections to the ground rod can be as important as the rod itself. (Connectors are discussed further in the following section.) Often, a large conductor is connected to one or two ground rods. In many cases, this is a mismatch since the rod cannot carry as much current as the conductor. Table 5-1 lists the equivalent copper conductor size for various rod sizes based on fusing formulas.

Rod Size	Type	Closest Equivalent Copper Size
1/2" (0.447 D)	Sectional (1/2" Thread)	#1 AWG
1/2" (0.475 D)	Copper-Bonded	1/0 AWG
1/2" (0.505 D)	Plain Copper-Bonded	1/0 AWG
	Sectional (9/16" Thread)	
	Copper-Bonded	
1/2" (0.5 D)	Galvanized Steel	#2 AWG
5/8" (0.563 D)	Copper-Bonded	3/0 AWG
5/8" (0.625 D)	Galvanized Steel	#1 AWG
3/4" (0.682 D)	Copper-Bonded	4/0 - 250 KCMIL
3/4" (0.75 D)	Galvanized Steel	2/0 AWG
1" (0.914 D)	Copper-Bonded	400 KCMIL
1" (1.0 D)	Galvanized Steel	250 KCMIL

Ground Rods
Table 5-1

One must also consider the current flow into the rods. If the current heats the surrounding soil to 100° C or higher, the moisture evaporates and the soil resistivity increases. The maximum one second fault current for a 5/8" x10' ground rod in 100 ohm-meter soil is 27 amperes to limit the temperature to 60° C. (Ref IEEE Std 80-1986)

In areas where the amount of available land is limited and the soil resistivity is high, the use of multiple rods with interconnecting conductors will lower the system resistance. When this is not sufficient, using GEM around either the rods or the conductors, or both, should be considered. (Fig. 5-4)

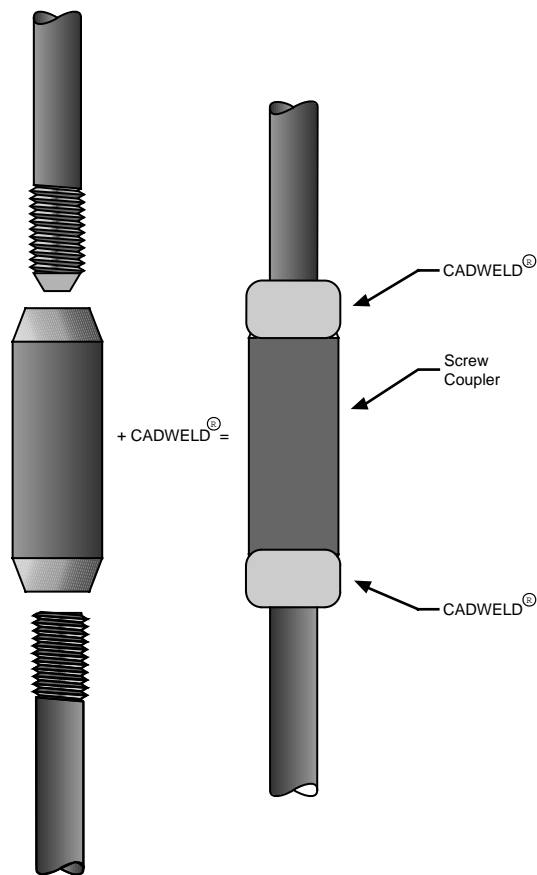


Fig. 5-6

CONNECTORS

For most connector applications there is a choice of good - better - best. This choice depends on required life, expected corrosion, expected level of current (lightning and faults) and total installed cost. Grounding connections carry little or no current until a fault occurs. Then, the currents can be very high and the likelihood of detecting a damaged connector is low since many of them are concealed. The result is system degradation or failure. For connectors hidden behind walls or in the ground, there is no way to determine if something has degraded. Failure of even one connection point in a grounding network may be dangerous, yet go undetected for years.

Connectors are listed in Table 5-2 showing relative cost, installation time, applicable tests and codes, and recommendations where they should not, in the author's opinion, be used. The final decision is up to the designer!

Description	Relative Cost	Installation Time	Codes Tests	Not to use
Split Bolt	LOW	MEDIUM	UL	Hidden
Service Posts	LOW	MEDIUM	UL	Hidden
Pipe Clamp		MEDIUM	UL	Hidden
Compression Devices	MEDIUM TO HIGH	MEDIUM TO HIGH	UL	
Ground Rod Clamps	VERY LOW	MEDIUM	UL	
Brazed Connection	LOW	HIGH		
CADWELD Connection	MEDIUM TO HIGH	MEDIUM TO HIGH	IEEE Std 80, IEEE Std 837 and UL	

Connectors
Table 5-2

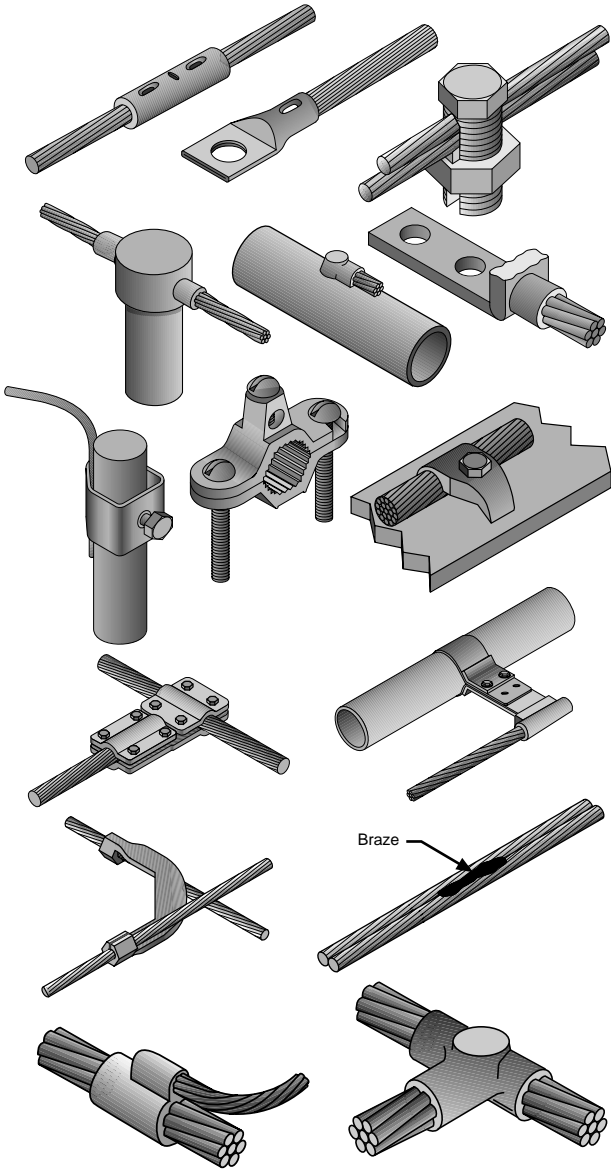


Fig. 5-7

Chapter 6

Special Grounding Situations

Areas Not Covered
Elsewhere

Airports

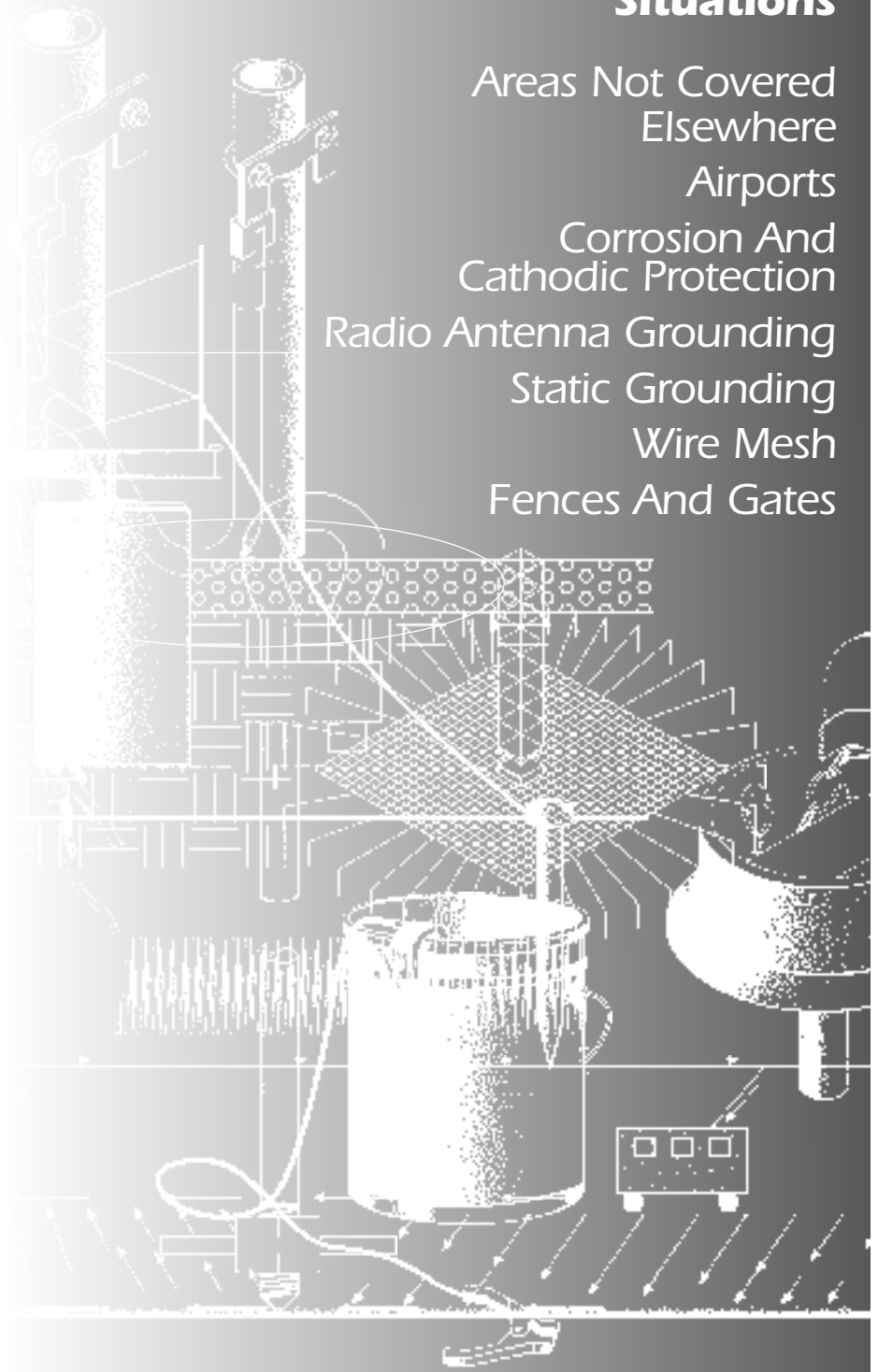
Corrosion And
Cathodic Protection

Radio Antenna Grounding

Static Grounding

Wire Mesh

Fences And Gates



AIRPORTS

Airports require special attention to grounding. They not only handle fuel in close proximity to masses of people, but the airport is usually on high ground and therefore subject to lightning strikes. Static grounding is required whenever an airplane is refueled. This is normally accomplished by positioning a properly installed static grounding receptacle in the tarmac near the location where the refueling takes place. A static ground lead is attached to this receptacle from both the refueling vehicle and from the aircraft before the fuel hoses are attached to the aircraft. This equalizes any potential difference between the two vehicles preventing a static spark.

Static grounding receptacles are installed flush with the finished tarmac (Fig. 6-1). The receptacle is welded to either a ground rod or ground grid or both. Receptacles that screw onto a threaded (sectional) rod are also available but the threaded connection may increase in resistance with time.

Static grounding receptacles have an internally cast ball (also available with a removable ball) for attaching the grounding clamp and are supplied with an attached cover. Static grounding receptacles can be welded directly to a ground rod. A ground conductor can be welded to the static grounding receptacle at the same time the receptacle is welded to a ground rod.

Lightning protection also should be installed on the airport structures. Lightning protection is discussed in detail in Chapter 2.

Anchor rods are also available for static grounding and tie downs. Installation requires augering a hole, inserting the assembly and backfilling. A large washer or steel plate with nuts are also required to secure the rod (Fig. 6-2).

A combination static grounding receptacle / tie down is also available. It may be welded to a rod and/or a conductor (Fig. 6-3).

CORROSION AND CATHODIC PROTECTION

Cathodic Protection. There are two general methods of cathodic protection, the galvanic system and the impressed current system. The galvanic system uses a sacrificial anode of a material having a higher potential on the electromotive series than the material to be protected (Fig. 6-4).

Magnesium, zinc or aluminum are typical sacrificial anode materials. These anodes are designed to corrode and “sacrifice” themselves to protect the pipe, tank, etc. The anodes must be large enough to provide protection for a reasonable length of time before they are dissipated. Then they must be replaced for protection to continue.

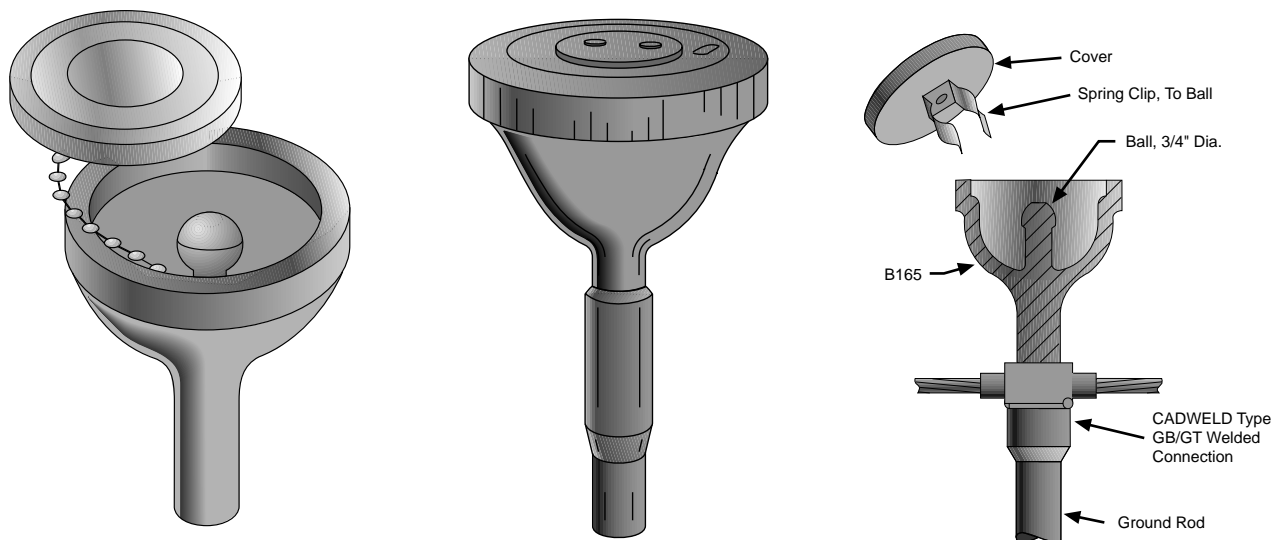


Fig. 6-1

Static grounding receptacles have an internally cast ball (also available with a removable ball) for attaching the grounding clamp and are supplied with an attached cover.

Static grounding receptacles can be welded directly to a ground rod.

A ground conductor can be welded to the static grounding receptacle at the same time the receptacle is welded to a ground rod.

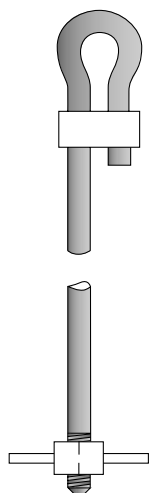


Fig. 6-2
Anchor rods are also used for static grounding and tie downs.

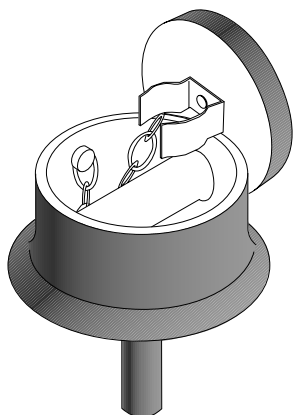
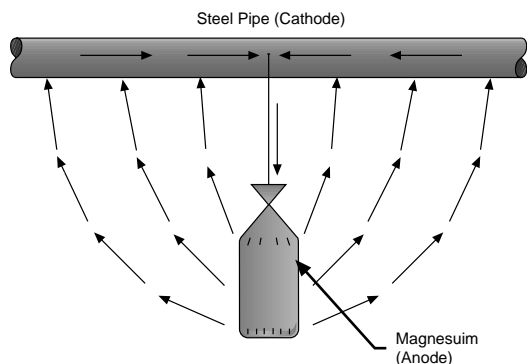
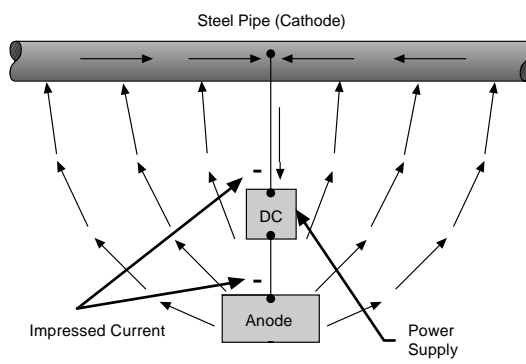


Fig. 6-3
A combination static grounding receptacle/tie down.



Sacrificial Anode Galvanic System
Fig. 6-4



Impressed Current Galvanic System
Fig. 6-5

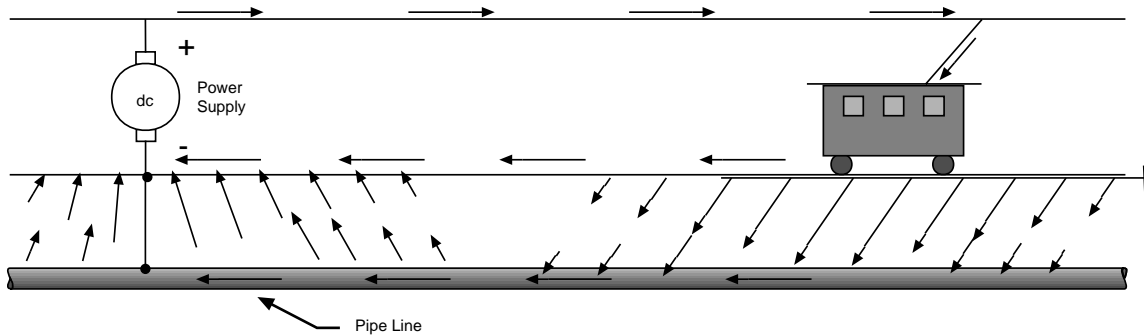
Electromotive Series		
Material	Voltage	
Magnesium	-2.34	Most Anodic ↑ + ↓ Most Cathodic
Aluminum	-1.67	
Zinc	-0.76	
Cast Iron/Steel	-0.44	
Brasses	-0.28	
Tin	-0.14	
Lead	-0.13	
Hydrogen	0.00	
Copper	+0.34	
Silver	+0.86	
Graphite (Carbon)	+0.86	
Platinum	+0.90	
Gold	+1.36	

Electromotive Series (In Seawater)
Table 6-1

The electromotive series (Table 6-1) lists several materials from the most anodic, or most active, at the top of the list to the most cathodic, or least active, at the bottom of the list. Also listed is the voltage or potential of the materials in seawater in relation to hydrogen. Any material on the list will protect any material listed below it.

The impressed current system uses an outside source of electricity from a DC power supply, powered by solar, wind or the power company. This system uses a DC current of a magnitude greater than, and flowing in the opposite direction to, the natural galvanic cell current. An anode is also required with the impressed current system but it can be of an inexpensive material such as scrap steel or graphite (Fig. 6-5). There is practically no limit on the current output in an impressed current system.

To conserve the current requirements for cathodic protection on a pipeline, normal installation practice calls for pipes to be coated to insulate the pipe from the corrosive environment. However, these coatings are never perfect



Stray DC Current

Fig. 6-6

and/or are damaged when the pipe is installed. The breaks in the coating (called holidays) are protected by the cathodic protection system. Since the amount of steel exposed at the holidays is very small compared to a bare pipeline, the amount of current required to protect the pipeline is reduced in a direct ratio.

To protect the pipeline in the case of stray current, the pipe must be bonded to the negative side of the DC power supply station with a low resistance conductor. This provides a direct metallic path for the return current to follow as it leaves the pipe (Fig. 6-6).

A few basic rules in designing a cathodic protection system include:

1. Bonding together of all structures (tanks, pipes, both across joints and between different pipes, etc.) is of absolute necessity for proper protection. This will provide a metallic return current path for any cathodic current.
2. A study is needed to determine any effect of the cathodic protection system on any "foreign" (owned by others) nearby structures. Any cathodic protection current picked up by a foreign structure must also leave that structure - which may cause corrosion.

CADWELD Connections. Let us look at the electrical connections required in a cathodic protection system and why they are different than those required for a grounding system.

Cathodic connections are low current connections rather than grounding connections. Grounding connections are required to withstand damage while conducting huge surges of ground fault current. Cathodic protection connections are required to carry only a small but

continuous current. Therefore cathodic protection connections do not have to be as massive as grounding connections.

A very low resistance system is required for a cathodic protection system, and it must remain low in resistance over the life of the system. The higher the resistance, the less efficient is the cathodic protection system. CADWELD Cathodic Protection Connections meet this low resistance requirement, both when installed and over the life of the system.

The pipe used in transmission pipeline systems is usually a highly stressed thin wall steel pipe. Any connection to this pipe by the cathodic protection wires or the test leads must not damage the pipe. CADWELD Cathodic Protection Connections use a special alloy weld metal (designated as F-33) developed to minimize the effect the weld has on the pipe. These connections have been proven by independent tests not to be detrimental to the pipe, and more than 45 years of usage without any detrimental effects have provided field proof to the tests.

CADWELD Weld Metal for cathodic protection has a green cap on the weld metal tube to properly identify it as F-33 alloy. The CADWELD Weld Metal used for grounding connections should not be used to make cathodic connections to high stressed pipe. (CADWELD cathodic connections should never be used to make high current grounding connections.)

Making Connections. Cadweld cathodic protection connections can be made to live pipelines and to fuel tanks with certain restrictions. ANSI/ASME Codes (B31.4 and B31.8) allow cathodic connections to be made to liquid petroleum transmission lines and to gas transmission and distribution lines with a limit of a 15 gram (CADWELD CA15) weld metal. The lines must be full of product with no air pockets and when welding to tanks, the weld must be

made below the liquid level. Pure fuel will not burn or explode. It will burn or explode only when mixed with oxygen (air) within certain ratios.

Codes & Standards. Section 80 of the 1994 Canadian Electrical Code contains installation requirements for impressed current cathodic protection systems. The section includes requirements for the selection of wiring methods for direct current conductors, splices, taps and connections, branch circuit requirements and warning signs and drawing requirements.

Interestingly, the NEC does not contain specific requirements for the installation of cathodic protection systems. The American Society of Mechanical Engineers (ASME) publishes codes relating to the design and installation of pressure piping systems:

1. ANSI/ASME B31.8, Gas Transmission and Distribution Piping Systems.
2. ANSI/ASME B31.4, Liquid Transportation Systems for Hydrocarbons.

In both, under corrosion control, the code allows the attachment of electrical leads using exothermic welding but limits the weld metal size to:

1. CADWELD CA15 for steel pipe.
2. CADWELD CA32XF19 for cast, wrought or ductile iron pipe.

These restrictions allow welding of a No. 4 AWG and smaller conductor to steel pipe using CADWELD cathodic Type CAHA connections and No. 6 AWG and smaller conductor to cast, wrought or ductile iron pipe using Type CAHB connections. When larger sized conductors must be welded to pipes falling under these codes, several alternatives are available:

1. Using a formed terminal bond, a No.2 AWG can be welded to a cast, wrought or ductile iron pipe with a CA32XF19.
2. Use a copper Bonding strap.
3. Use a CADWELD "Punched Strap" Bond.
4. Unstrand the larger conductor and make multiple welds of one (or more) strands at a time.

RADIO ANTENNA GROUNDING

Antennas require grounding for both lightning protection and electrical fault protection. However, depending upon the frequency of the radio transmission, such as AM, a ground plane also may be required for proper and efficient transmission of energy. The ground plane may be made up of radials, all bonded to the antenna base plate, and ending at a set distance from the base. The radials are usually spaced at 1 or 2 degree intervals. Ground rods and/or a circumferential wire are commonly used at the ends of the radials. (Fig. 6-7)

The ground plane also may be made using prefabricated mesh around the antenna base with radials from the edge of the mesh. (Fig. 6-8)

Some installations use copper tubing because of its excellent high frequency characteristics and low cost compared to other conductors having equal high frequency characteristics. Although connections can be made on the round tube, they are both costly and difficult to make. Fig. 6-9 shows the preferred method. Since the tube comes in different sizes and types (with different wall thickness), the exact specification of the tube must be given.

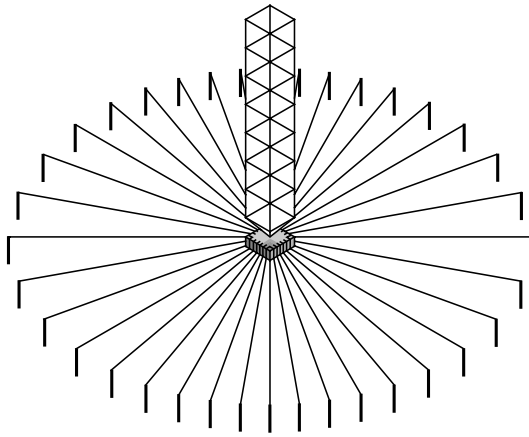
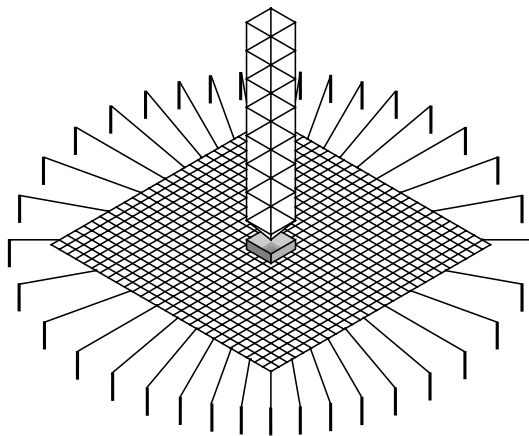
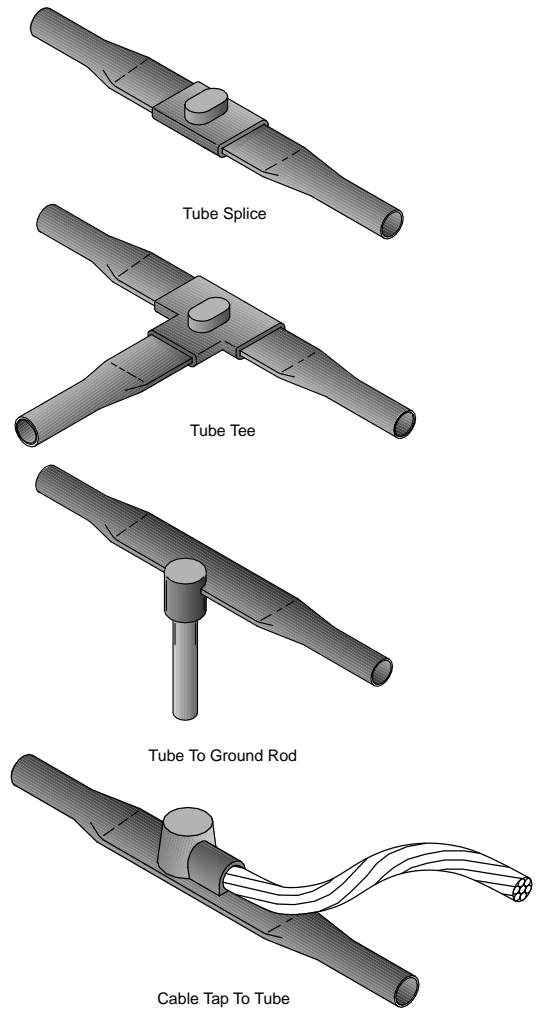
In addition to copper tubing, wide solid copper strip is often used as a low impedance conductor at high frequencies. CADWELD connections of strip to strip and strip to ground rods can be utilized as shown in Fig. 6-10 and 6-11. Thin strip is usually recommended over tubing.

The transmission conductor must also be properly grounded and equipped with surge protection. This, however, is beyond the scope of this book.

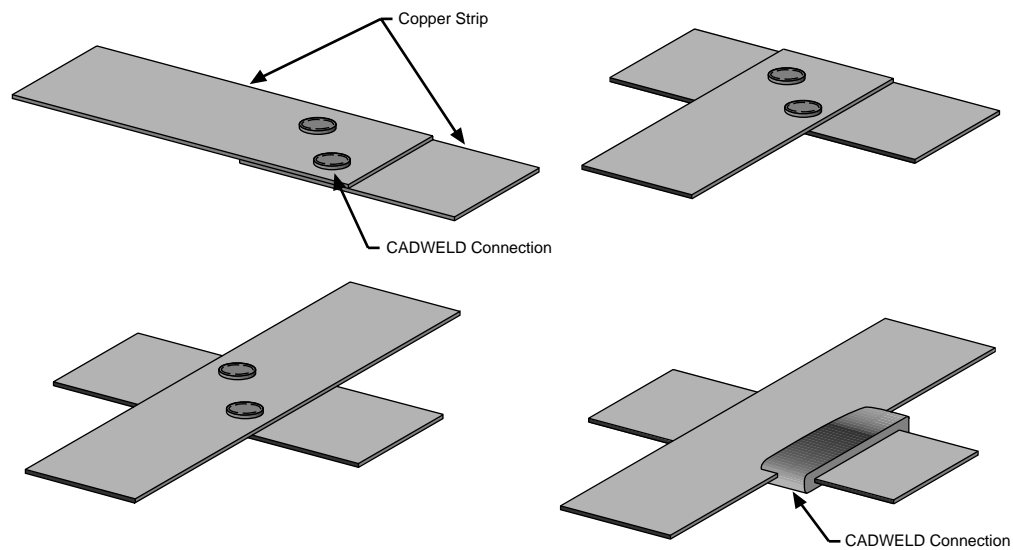
The towers themselves are grounded using standard connections to the tower legs and to the ground rod. (Fig. 6-12 and 6-13)

Guyed towers also must have the guys and guy anchors grounded. This can usually be accomplished by grounding the anchor plate (Fig. 6-14) or the guy after it is terminated. Do not weld or braze to any guy conductor that is (or will be) under tension.

Since most communication towers, including broadcast types, are located on the highest available site, the earth resistivity is often very high. Extensive ground fields may be required. The use of a ground enhancement material such as ERICO GEM25™ may be a cost-effective method of reducing system resistance. See the discussion on GEM in Chapter 5.

*Fig. 6-7**Fig. 6-8**Fig. 6-9*

CADWELD Connections on copper tubing used for high frequency grounding, with copper tube flattened.

*Fig. 6-10*

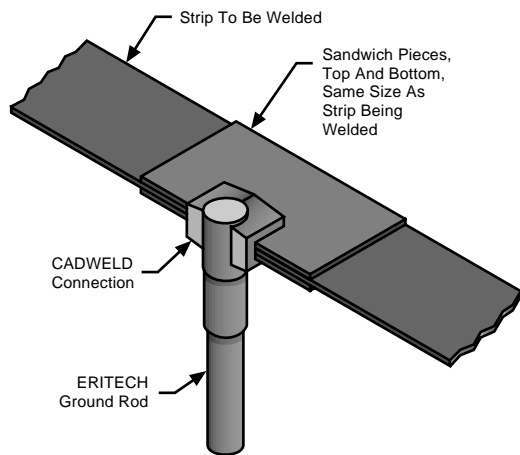
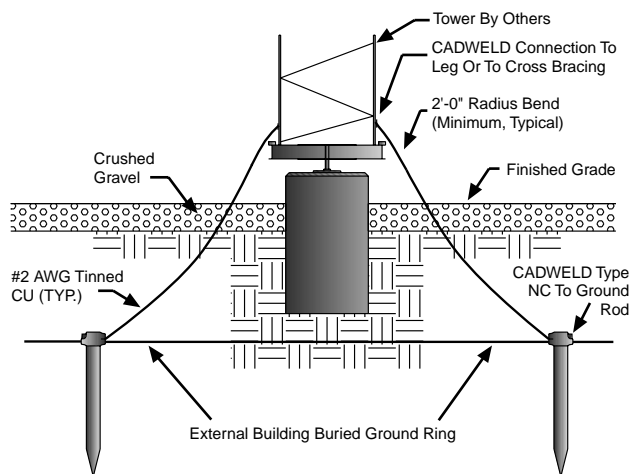


Fig. 6-11



Guyed Tower Ground Detail

Fig. 6-12

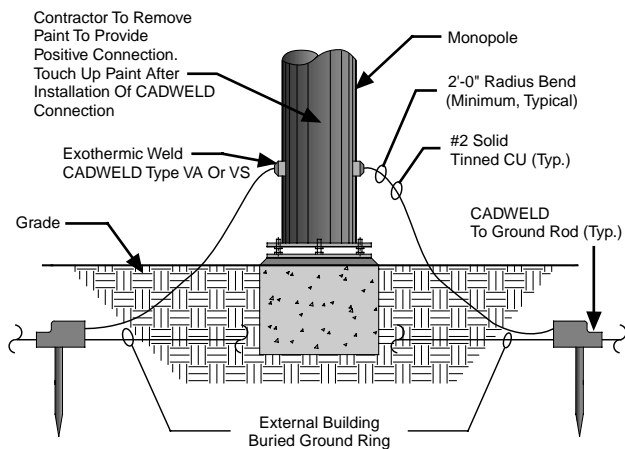


Fig. 6-13

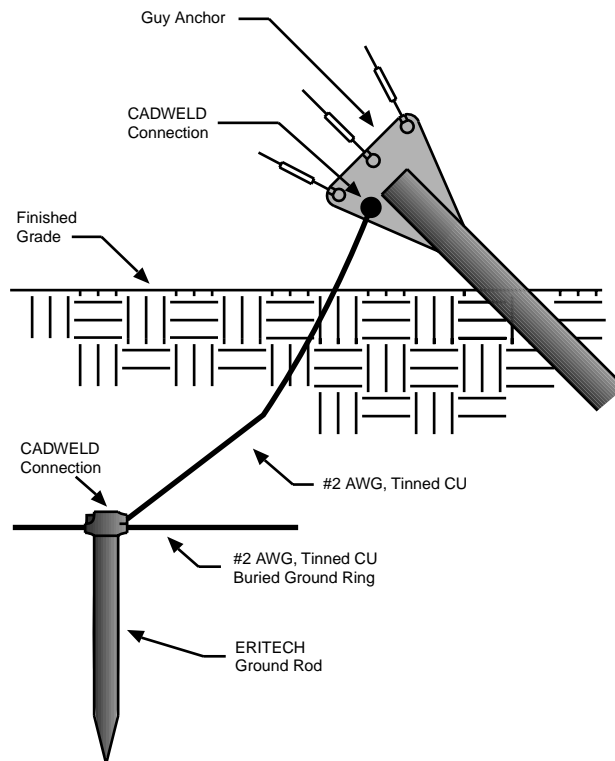


Fig. 6-14

STATIC GROUNDING

Static electricity is a major cause of fires and explosions where flammable powders and liquids are stored and handled. The hazard of electrostatic spark ignition of a flammable vapor can be minimized by taking actions to limit the accumulation of electrostatic charges to safe values. Of primary importance is the proper bonding and grounding of equipment and containers. In addition, charge accumulation must be limited, in many instances, by controlling the rate of charge generation and/or the rate of charge dissipation. Occasionally, such methods cannot be applied and the use of an inert gas in vapor spaces must be used.

Sources of Static Generation

The most common generators of static electricity are processes using flammable powders and liquids. Static electricity is generated by materials flowing through pipes and in mixing, pouring, pumping, filtering or agitating. The rate of generation is influenced by conductivity, turbulence, the interface area between the materials and other surfaces, velocity and the presence of impurities.

NOTE: The statements contained in this section are based on the experience of user. Each situation requiring static charge control is different and is the total responsibility of the designer.

Some specific areas where static electricity is generated include:

Piping Systems - In piping systems, the generation rate and the subsequent accumulation of static charges are a function of the materials, the flow rate, flow velocity, pipe diameter and pipe length.

Filling Operations - The turbulence experienced in filling operations caused by high flow rates, splashing or the free-falling of liquids or powder fines and the need to connect and disconnect hoses, valves and the like increases the charge accumulation and the chances of a hazardous charge.

Filtration - Filters, because of their large surface area, can generate as much as 200 times the electrostatic charge generated in the same piping system without filters.

Dispersing Operations - Dispersing operations can be particularly hazardous in view of the extremely high rate of charge generation when particulates are present. With poorly conductive materials, the charge accumulation can cause hazardous sparking in the mixer, such as to an exposed agitator bar or to a conductive fill pipe in a ball or pebble mill. High charge generation rates can also occur when materials are mixed, thinned, combined or agitated.

Methods of Static Control

In addition to being dependent on the charge generation rate, charge accumulation is a function of the resistance of the path by which charges dissipate. Within the material, the dissipation of static electricity is dependent on the material's "conductivity." Some flammable liquids have a very low conductivity and tend to accumulate static charges. Toluene, an example of such a liquid, has a long history of causing industry fires. Lange's Handbook lists conductivity data of some pure liquids. Although the generation of static electricity cannot be eliminated, its rate of generation and accumulation can be reduced by the following procedures:

Piping Systems - The most effective method of reducing the accumulation of static charges in piping systems is through the proper pipe sizing to keep flow velocities low and to keep the flow as laminar as possible. The typical maximum velocity in piping systems is 15 feet per second. Table 6-2 lists the flow rates for various pipe sizes for a velocity of 15 feet per second. Each user must determine the maximum velocity that can be safely allowed.

Filling Operations - Splash filling and free fall of

Schedule 40 Pipe Size (Diameter in Inches)	Flow Rates	
	Flow Rate (GPM at 15 Ft/Sec)	Flow Rate (GPM at 3 Ft/Sec)
1	40	8
1 1/2	95	19
2	157	31
2 1/2	224	45
3	346	69
3 1/2	462	92
4	595	119

Flow Rates
Table 6-2

flammable liquids should be eliminated to the maximum extent practical by lowering the fill velocities, by providing diverters to direct the discharge of material down the side of the grounded vessel being filled or by submerging fill pipes below the level in the vessel. Submerging of fill pipes may not always be practical. In bulk filling operations, the velocity of the incoming liquid typically should not exceed 3 feet per second until the pipe outlet is covered. The velocity may then be increased to the 15 feet per second mentioned previously. Table 6-2 also lists the flow rates for various pipe sizes for the velocity of 3 feet per second.

Filtration - Experience has shown that the static electricity hazard may be controlled by installing filters far enough upstream of the discharge point to provide a 30 second relaxation time period prior to discharge. The relaxation time depends upon the conductivity, the liquid velocity and the type of filter. For example, the 30 second relaxation time may not be necessary with a highly conductive liquid.

Dispersing Operations - For dispersing operations of solids into liquids, the conductivity of the liquid should be raised, if necessary, to above 2000 conductivity units (C.U.), which is 2×10^{-5} micromho/cm, before particulates are added. If possible, polar solvents should be added before non-polar solvents or particulates are added. Polar solvents are more conductive than non-polar solvents. In some instances, proprietary anti-static agents, developed for use with fuels, can be used as additives to reduce the charge accumulation. Typically, only a few parts per million of the additive are required. Tests should be conducted to ensure that the conductivity additive does not cause formulation problems. The additive may not be suitable for use in coatings for food containers. If the liquid conductivity cannot be raised to the recommended value, the vessel should be inerted (filled with an inert material). For dispersing solids into solids, contact with the mixing vessel or agitator is the usual path to ground. Raising the humidity

level in the mixer and/or providing a liquid conductive medium to dissipate the charge will help. If this is not possible, the vessel should be inerted. It should be noted that the static accumulation in liquids should be controlled by raising the ambient humidity.

Pebble mills present an additional hazard because the porcelain lining is an insulator that will prevent the flow of static charges from the liquid to ground, even if the mill is grounded. This hazard is best controlled by inerting the mill.

Nonconductive Plastic Containers and Stretch Film.

The use of nonconductive plastic containers in potentially flammable locations may be an ignition hazard. Static charge accumulations on such containers, caused by the transfer of poorly conductive materials or by contact charging, cannot be dissipated by bonding and grounding.

Contact (“triboelectric”) charging of a nonconducting container in a low humidity environment creates a spark ignition hazard by inducing charges in materials in a container. These induced charges may cause sparking, for example, when the material is poured into a grounded safety can. Surprisingly, this hazard of charge induction is greatest when the material is conductive.

For example, experience in the coating industry suggests the following precautions:

Fiberboard Drums - No hazard of static accumulation except for metal rims which should be grounded during product transfer.

Kraft Paper Bags and Plastic-Lined Paper Bags - No hazard with paper bags. Plastic-lined paper bags are usually not hazardous, but the static electrification for each bag/contents combination should be measured. All plastic bags and bags with removable plastic liners should be avoided unless measurements of electric field intensity at the bag surface during product transfer is less than 5 kV/cm (12.5 kV/inch).

Plastic Bottles and Nonconductive Drum Liners - Both of these items are subject to the hazard of charge induction as a result of electrification. Precautions must be taken to minimize contact charging or to neutralize contact charges before use. Removal of plastic bottles from plastic bags may cause contact charging. Electric field intensities greater than 5 kV/cm (12.5 kV/inch) at the surface of the bottle or liner should be neutralized before a conductive flammable liquid is put into the bottle. It is also important to avoid charging a plastic bottle that even contains a small

quantity of a conductive, flammable liquid.

Stretch Wrap - Stretch wrap must be removed from pallets in a nonflammable location. This material is usually highly charged and represents a serious hazard in flammable locations.

Semi-Bulk “Supersacks” - Electrostatic field intensity at the bag surface should be less than 5 kV/cm (12.5 kV/inch). Bags that contain metallic filaments must be grounded during product transfer.

Conductive Plastic Liners and Containers - Although most plastic materials are nonconductive, some conductive plastic liners and containers are commercially available. Conductive plastic materials must be grounded during product transfer in flammable locations.

Bonding and Grounding Principles

Bonding and grounding are very effective techniques for minimizing the likelihood of ignition from static electricity. A bonding system connects various pieces of conductive equipment and structures together to keep them at the same potential. Static sparking cannot take place between objects which are at the same potential. Grounding is a special form of bonding in which the conductive equipment is connected to the facility grounding system in order to prevent sparking between conductive equipment and ground.

In potentially flammable locations, all conductive objects that are electrically isolated from ground by nonconductors such as nonconductive piping or hoses, flexible hoses, flexible connections, equipment supports or gaskets should be bonded. An isolated conductive object can become charged sufficiently to cause a static spark. Objects that can become isolated include screens, rims of nonconductive drums, probes, thermometers, spray nozzles and high pressure cleaning equipment.

In order to successfully achieve the objective of the same ground potential for all materials and their containers when there are additional and/or redundant grounding systems, and particularly when there are supplementary grounding electrodes, all such grounding electrodes and systems must be interconnected as required by the NEC and NFPA Lightning Protection Code.

Bonding and grounding conductors must be durable and of a low resistance. Connections of bonding conductors to equipment must be direct and positive for portable equipment. Clamps must make contact with metal surfaces

through most paint, rust and surface contaminates. Single point clamps are superior to battery type and “alligator” type clamps for making direct contact.

Caution must be exercised in the installation of static grounding systems so that no part of the electrical current-carrying system is used as a ground. Fires have occurred in plants where static-control grounds were tied into the electrical system neutrals. These neutrals must never be part of the ground system except at the service entrance or other approved common bonding point.

Testing and Inspection of Bonding and Grounding Systems

The proper installation of bonding and grounding devices is important in the protection of personnel and equipment. At the time of installation, a resistance test is needed to confirm electrical continuity to ground. In addition, an effective inspection and periodic maintenance program is needed to ensure that continuity exists throughout the system.

In evaluating maintenance requirements, the bonding and grounding requirements can be divided into three categories:

1. The point type clamps equipped with flexible leads used for temporary bonding of portable containers to the facility grounding system.
2. The fixed grounding conductors and busbars used to connect the flexible leads and fixed equipment to ground.
3. The facility grounding system.

The flexible leads are subject to mechanical damage and wear, as well as corrosion and general deterioration. For this reason, they usually should be uninsulated and should be inspected frequently. This inspection should evaluate cleanliness and sharpness of clamp points, stiffness of the clamp springs, evidence of broken strands in the conductor and quality of the conductor connections.

A more thorough inspection should be made regularly using an approved ohmmeter to test electrical resistance and continuity. One lead of the ohmmeter is attached to a clean spot on the container, the other lead is connected to the facility grounding system. The measured resistance should be less than 25 ohms and will usually be about 1 ohm. Shake the leads to make sure that the contact point and the leads are sound. Do not rely on contact through dirt or rust.

The fixed leads and the busbar are not usually subject to damage or wear but should be annually checked with an ohmmeter. They are checked between the leads or bus and the facility ground. The measured resistance should be less than 1 ohm.

Conductive hoses should be checked regularly and after any repairs are made. The conductive segments may break or may not be properly repaired. Nonconductive hoses with an internal spiral conductor should be installed so that the spiral conductor makes contact with the adjacent metallic fittings. Shake the hose whenever possible when making the measurements.

Facility Ground System.

The final component of the static bonding and grounding system is the facility ground system. The facility ground must conform to the rules of the NEC as described elsewhere in this book.

Underground piping equipped with cathodic protection should not be used as the grounding system.

Inerting Methods and Procedures

The introduction of an inert gas such as nitrogen into a ball or pebble mill or mixer may prevent a flash fire if an electrostatic spark occurs within the vessel. Care must be exercised that sufficient inert gas is introduced to adequately displace the oxygen (air) throughout the entire vessel. The most common inert gases are nitrogen and carbon dioxide (CO₂).

Two important considerations when inerting are gas pressure and gas velocity. High gas pressure could damage a closed vessel. To avoid overpressurization, a relief valve is recommended on the gas line to the mill. Inerting with carbon dioxide is potentially hazardous, and such systems must be carefully designed and installed. A CO₂ fire extinguisher should never be used to inert a vessel. Continuous automatic inerting systems are available which can monitor the oxygen content in a vessel and can adjust the flow of inert gas to maintain a nonflammable environment within the vessel.

NFPA 69 “Explosion Prevention Systems” published by the National Fire Protection Association further discusses inert gas systems.

Conductor Sizing

Proper sizing of conductors is determined by many factors such as industry standards, insurance requirements, local codes, etc. These standards supersede any recommendations in this book. The following is based on many years of experience and NFPA 77 "Static Electricity," 1994.

There is no single answer to conductor sizing, although the following guidelines can be provided:

1. Conductors which are connected and disconnected frequently should be light enough to provide an adequate life. A 1/8 inch stainless steel, No. 6 AWG extra flexible copper, 3/16 inch flexible bronze or galvanized steel will carry the current required for static grounding and will fit the majority of applications.
2. Permanently mounted conductors are generally recommended to be at least No. 6 AWG copper, although conductors of #2 to 2/0 are generally used because they are more sturdy. Copper busbar is often used where mounted on a wall or floor. The minimum size recommended is 1/8 inch by 1 inch.
3. Outdoor grounding conductors are generally sized for the particular facility and are larger than the minimum required for static grounding requirements alone. A minimum size of #2 AWG is recommended. If fault currents must be considered, a larger size may be necessary.

The question of insulation is important if the static conductor or clamp comes in contact with an object that may be electrically energized. Another consideration is the operator being in parallel with the static discharge path. If neither of these is a concern, then most users would probably prefer bare conductors that are easier to inspect. Metal doors must be bonded to the grounding system in critical areas. (Fig. 6-15, 6-16, 6-17, and 6-18) A personnel static ground bar is necessary to dissipate any static charge before entering a room. (Fig. 6-19) Ground bars are available for attachment of static ground clamps. (Fig. 6-20)

Various bonding jumpers are available from plain or coiled conductors to reels. (Fig. 6-21) Copper ground busbars should be located at room periphery for easy access for ground clamps. (Fig. 6-22)

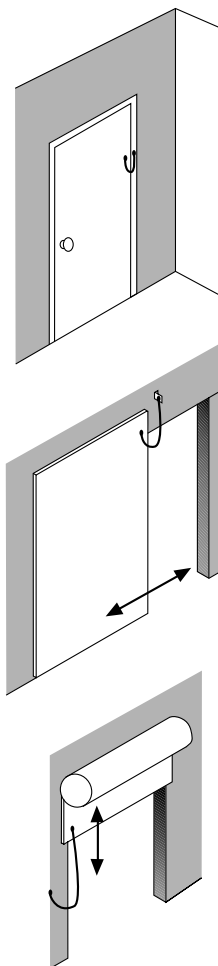
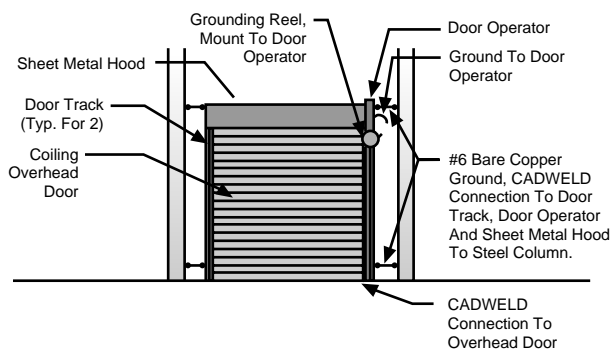
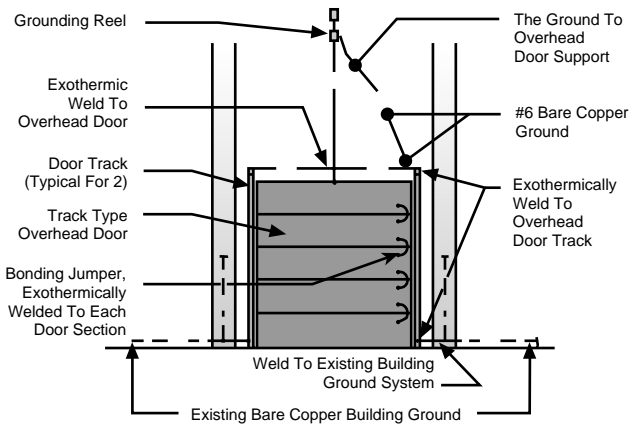


Fig. 6-15



Coiling Overhead Door Grounding
Fig. 6-16



Overhead Track Type Door Grounding
Fig. 6-17

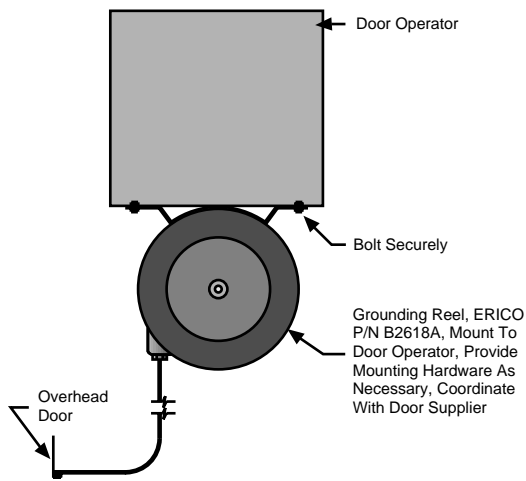


Fig. 6-18

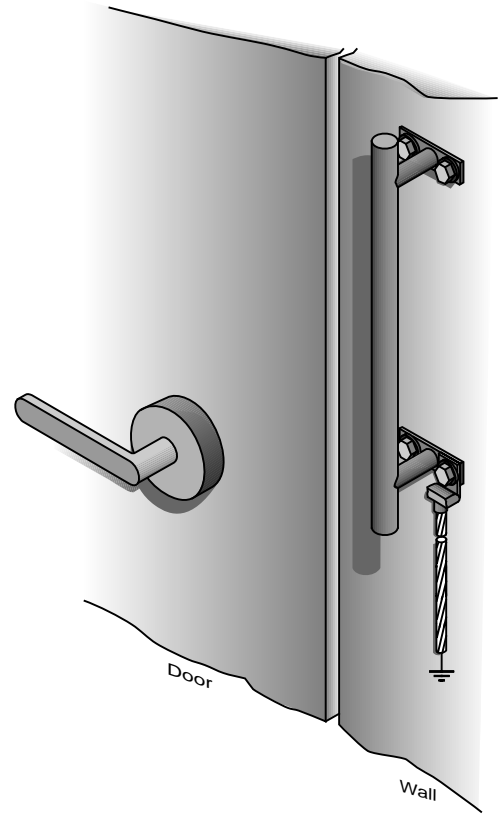
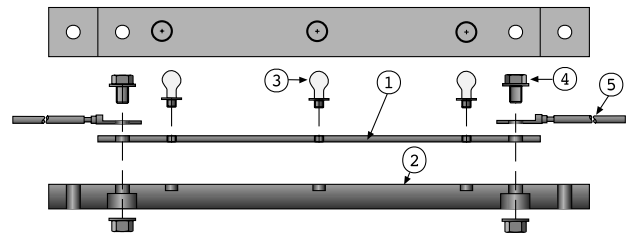


Fig. 6-19



Item	Quantity	Description
1	1	14 x 2 x 18 Copper Bar
2	1	1 x 2 x 22 Phenolic Bar
3	3	Grounding Stud, Brass
4	2	Silicon Bronze Hardware
5	2	Insulated Ground Conductors

Fig. 6-20

Static ground bar with ball studs. The Aircraft Grounding Clamp easily attaches to the stud for temporary static grounding.

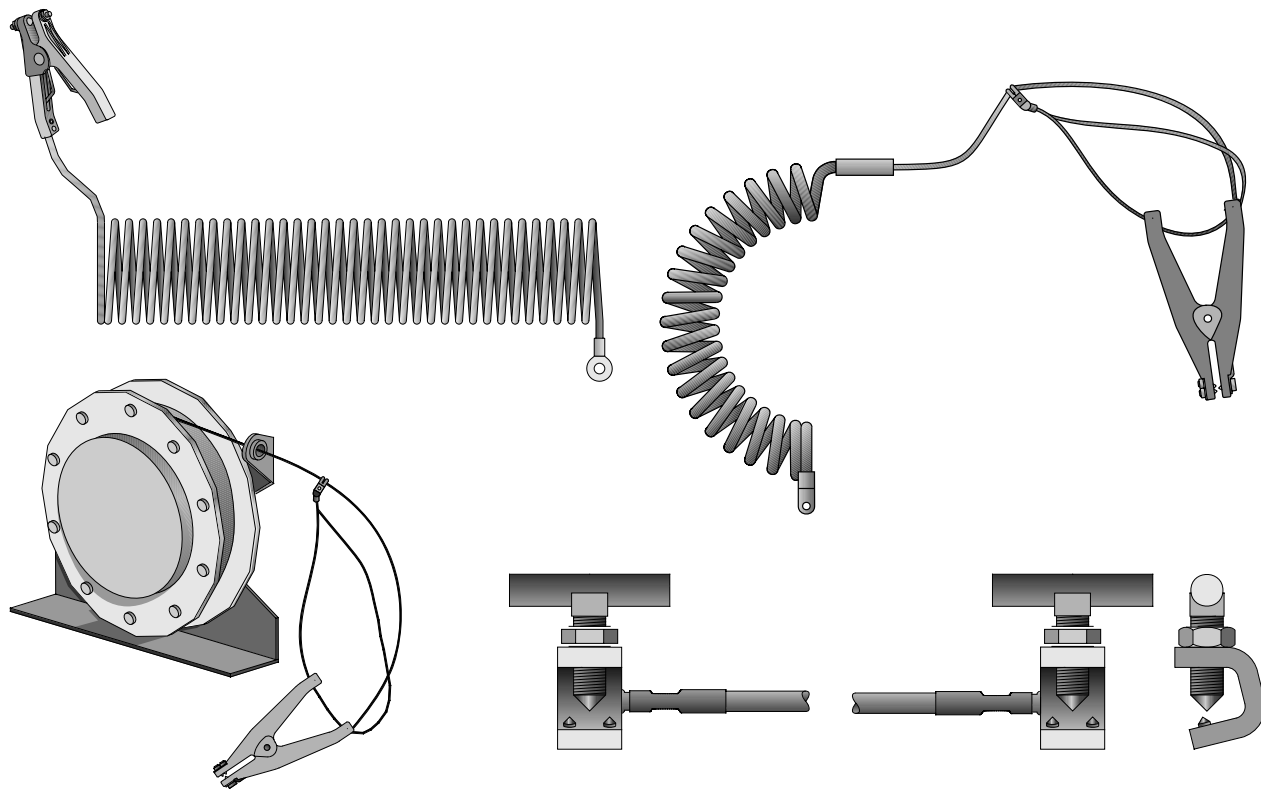


Fig. 6-21

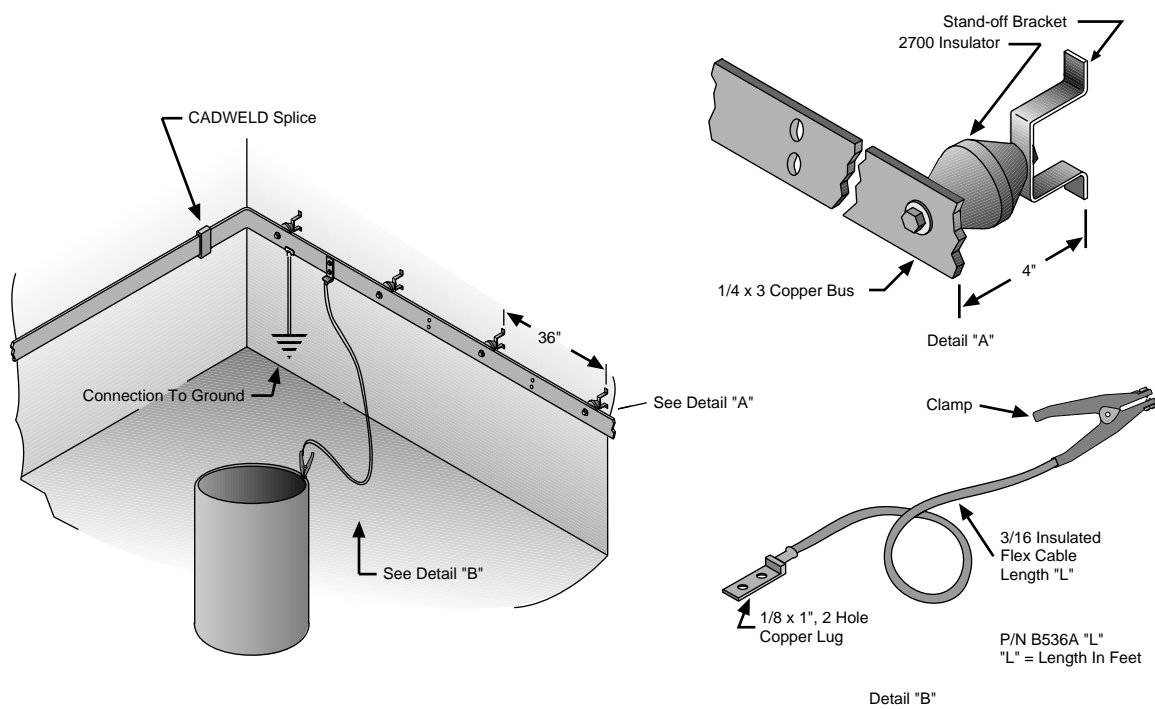
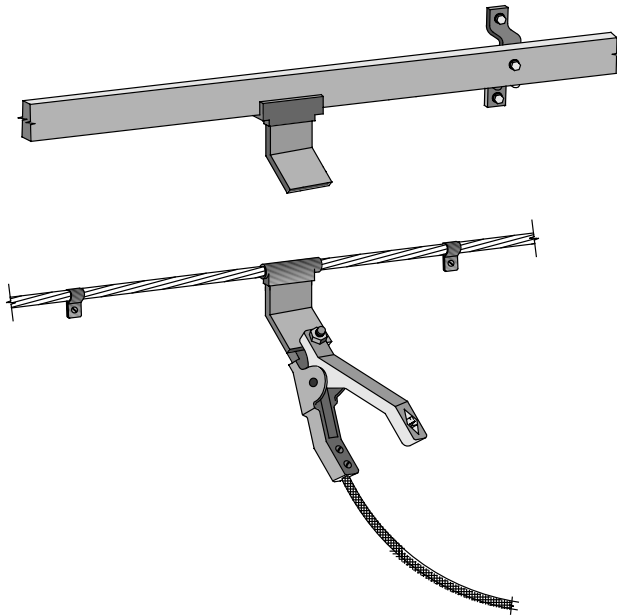
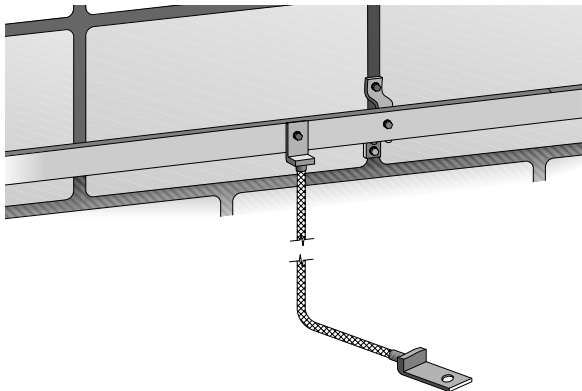


Fig. 6-22

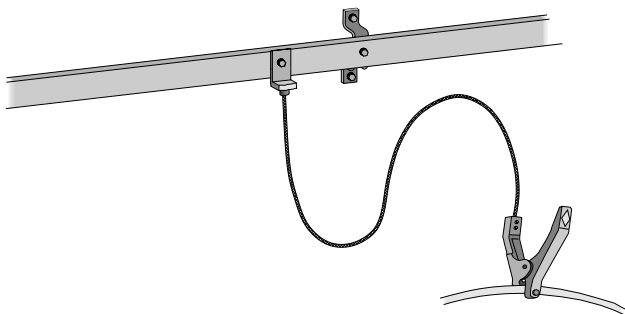
Following are application sketches showing a few of the static grounding schemes. Figures 6-23 through 6-37



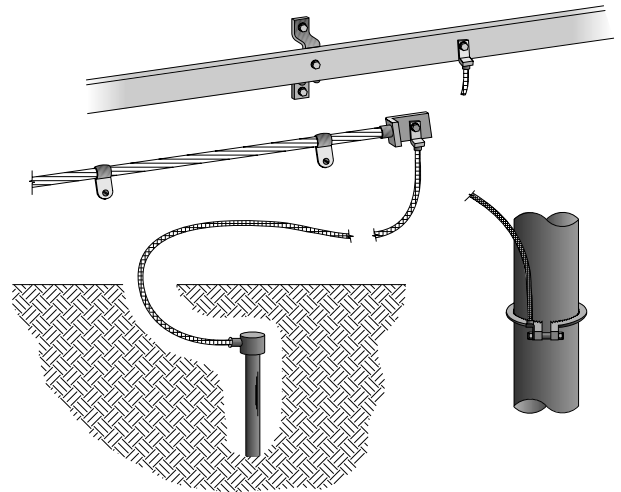
Attachments to ground bus.
Fig. 6-23



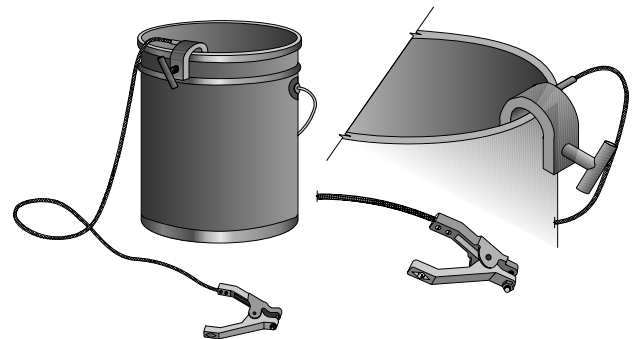
Jumper to ground bus.
Fig. 6-24



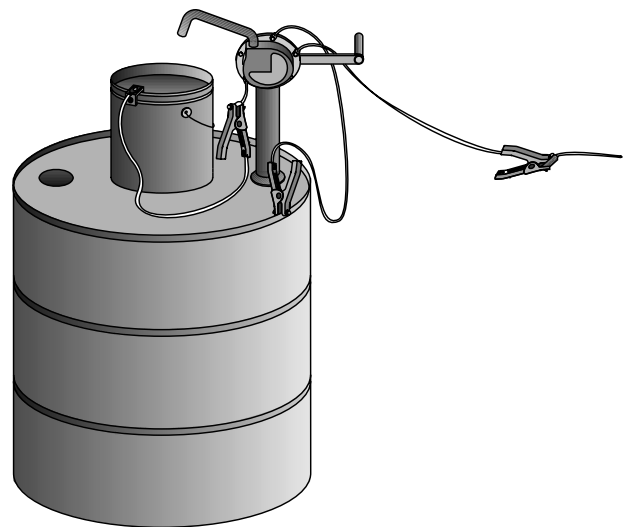
Drum or pail bonding to ground bus.
Fig. 6-25



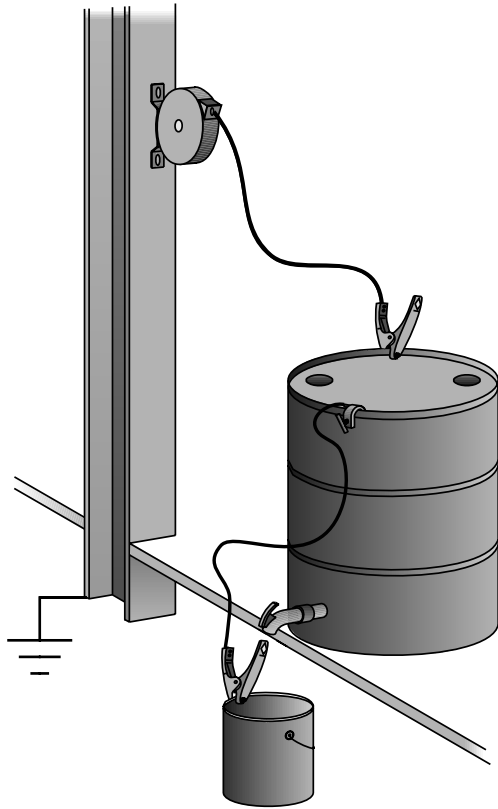
Bus to facility ground and pipe grounding.
Fig. 6-26



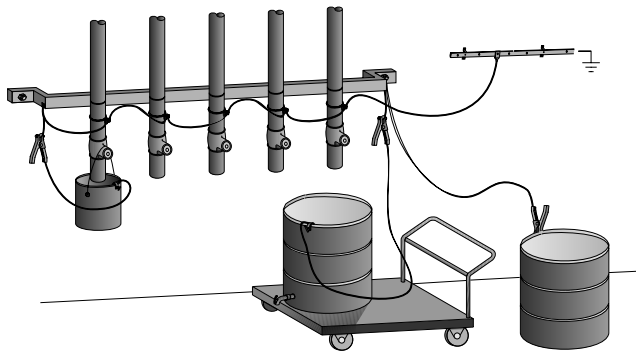
Temporary bonding jumper to pail.
Fig. 6-27



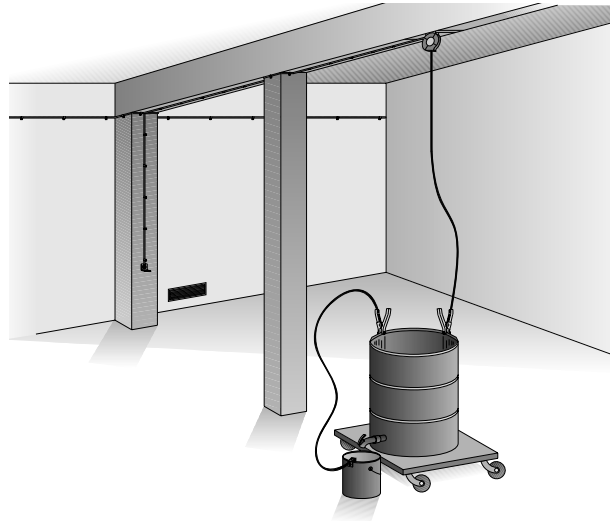
Drum pump bond.
Fig. 6-28



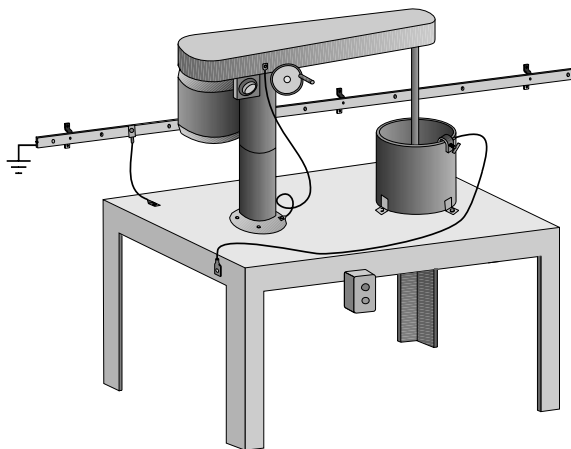
Drum and pail bonding.
Fig. 6-29



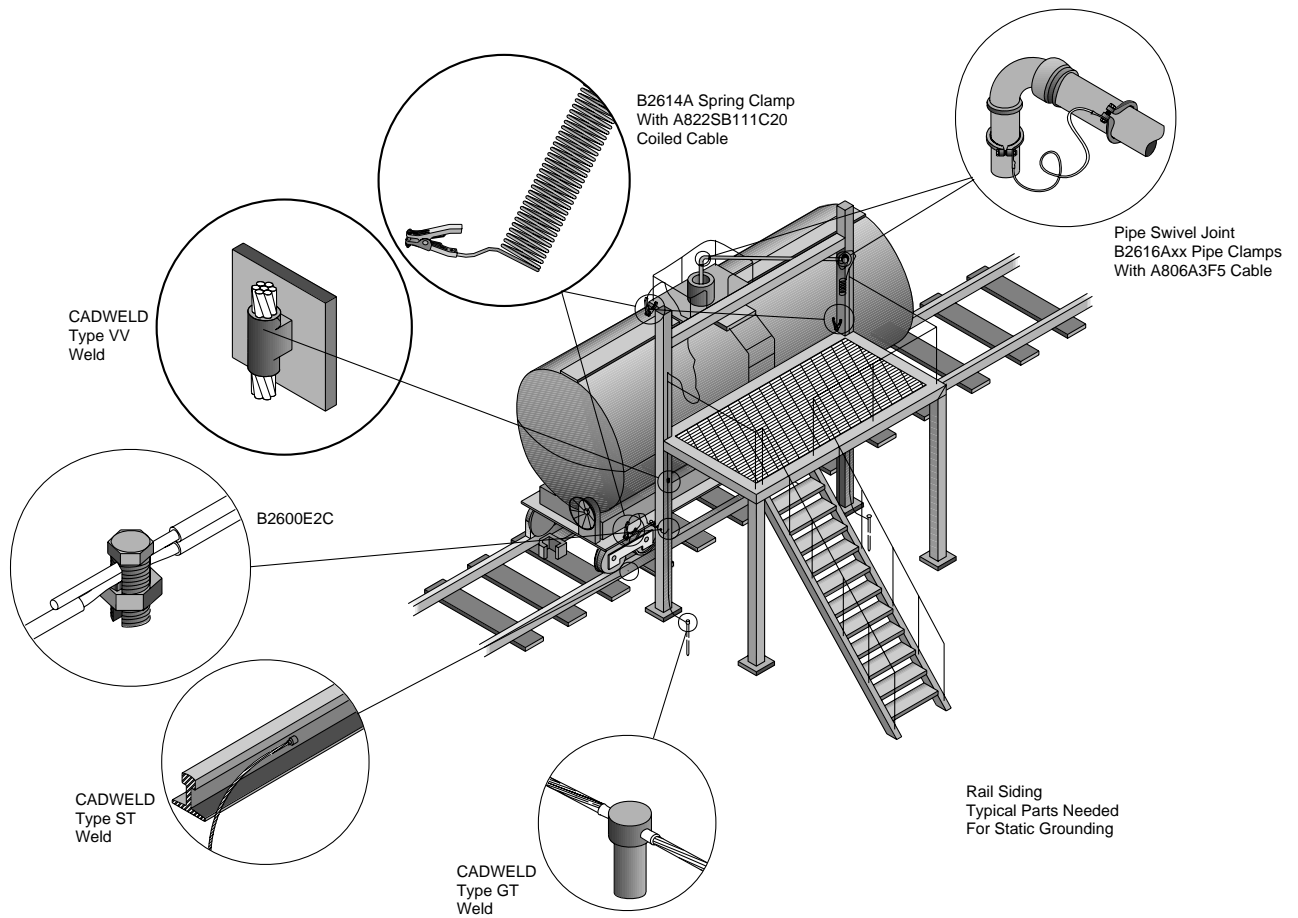
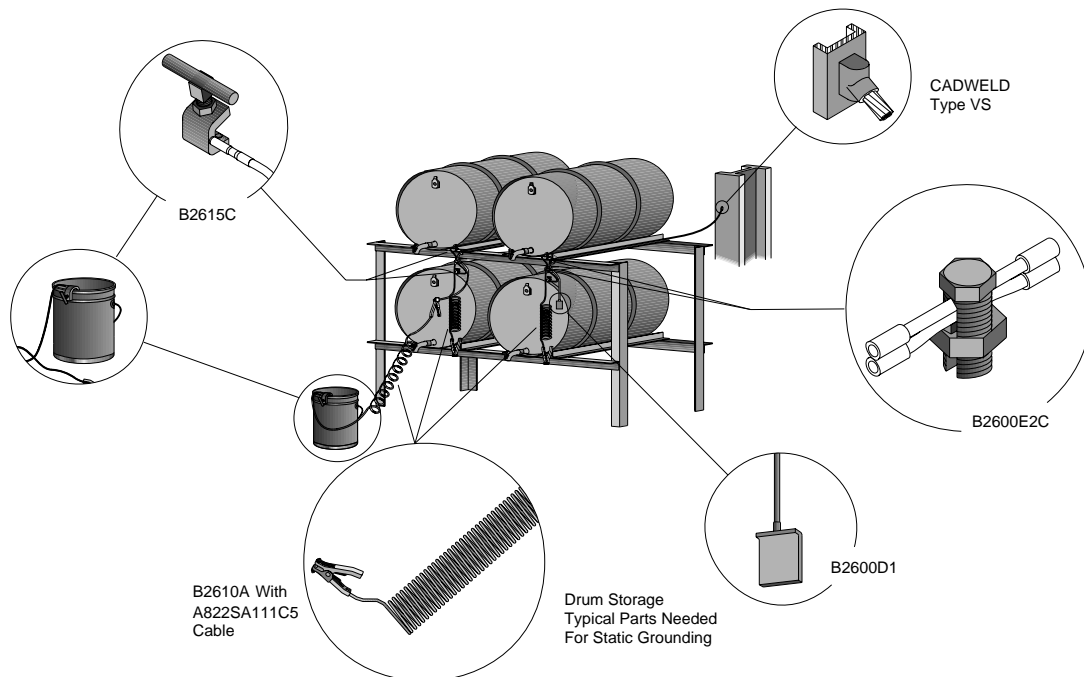
Pipe and drum.
Fig. 6-30

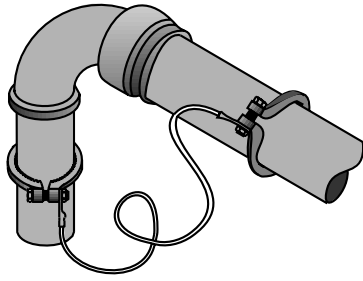


Drum and pail bonding.
Fig. 6-31

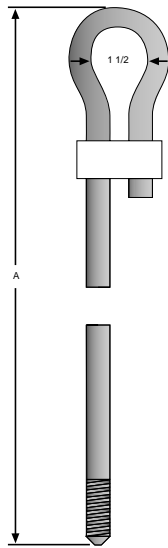


Mixer bonding.
Fig. 6-32

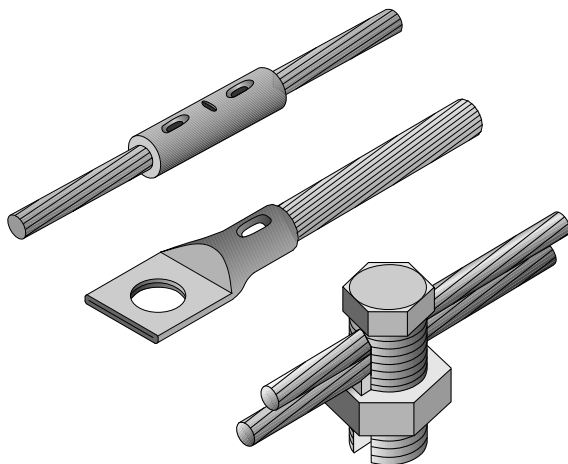
**Tank car bonding at siding.***Fig. 6-33***Drum storage rack bonding.***Fig. 6-34*



Pipe Swivel Joint Bonding
Fig. 6-35



Static Tie Down Rod
Fig. 6-36



Typical mechanical connectors used in static grounding.
Fig. 6-37

WIRE MESH

ERICO prefabricated wire mesh is a convenient, efficient and economical means of improving grounding systems at large facilities of high voltage installations and wherever large area communications grounds are required. It reduces step and touch potentials at substations and effectively minimizes ground plane fluctuations at communications antenna sites. This mesh is also an excellent antenna ground plane, reflector and electronic shield for large facilities. (Fig. 6-38)

Personnel Safety Mats of prefabricated wire mesh are ideal safety mats to protect operators against lethal touch potentials at manually operated disconnect switches.

Prefabricated wire mesh is made from solid wire, either copper or copperbonded steel wire. The copperbonded wire has the strength of steel and the conductivity and corrosion resistance of copper. It is available in either 30% or 40% conductivity of copper, although 30% is the most popular.

All joints of the prefabricated wire mesh are silver brazed at the wire crossing points. This method provides joints strong enough to resist separation during installation and to bear the traffic of construction vehicles. Like the wire itself, the silver brazed joints are highly resistant to corrosion. A non-corrosive flux is used in the brazing process that will not promote corrosion after the mesh is installed. The electrical conductivity of a silver brazed joint is excellent because of the low resistivity of the silver brazing material.

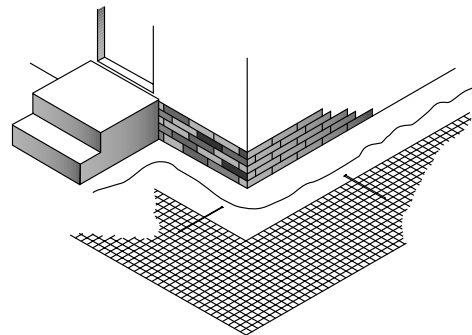


Fig. 6-38



Fig. 6-39

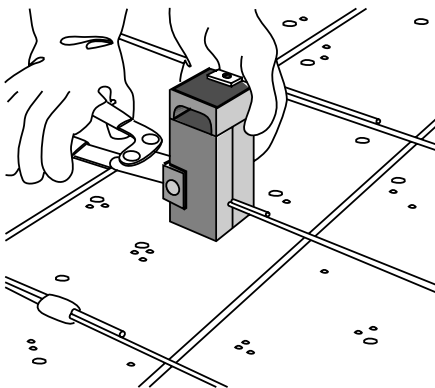


Fig. 6-40

Prefabricated wire mesh is custom made to meet the needs of the installation. Wire size can range from No.6 AWG to No.12 AWG (0.162 inch to 0.081 inch diameter). Widths up to 20 feet (6.0 m) are available. The length will depend on the roll weight which has a limit of 500 pounds (227 kg).

Prefabricated mesh is easily installed with no digging or trenching. It is simply unrolled like a roll of carpeting. (Fig. 6-39) Adjacent rolls are easily and economically joined using CADWELD type PG connections. (Fig. 6-40) On large jobs, at least 30 connections per hour can be made. Communications and shielding applications require connections to the grounding electrode system. When used as shielding inside a building, it is attached to the floor, walls and/or ceiling, depending upon the installation. It can be stapled to the wall studs or ceiling joists before the finished surface is installed. (Fig. 6-41)

Mesh can also be installed in the concrete slab to be used as a signal reference grid (SRG). Embedded ground plates connected to the mesh and flush with the floor are used to connect to the equipment. While thin flat strip SRGs are usually used and laid on top of the finished concrete, embedded mesh installations are also popular. (Fig. 6-42)

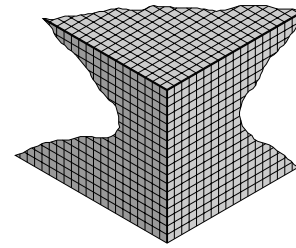
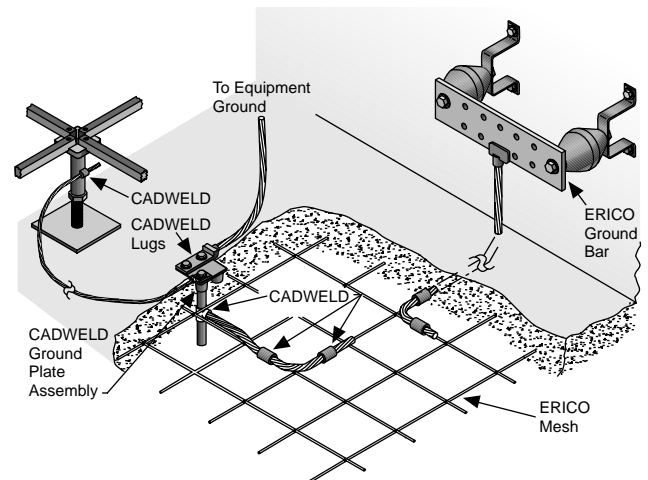


Fig. 6-41



For applications of mesh used as signal reference grid (SRG) embedded in the concrete floor, a CADWELD Cast Ground Plate is mounted flush with the finished floor and connected to the mesh. Future equipment is then connected to the ground plate.

Fig. 6-42

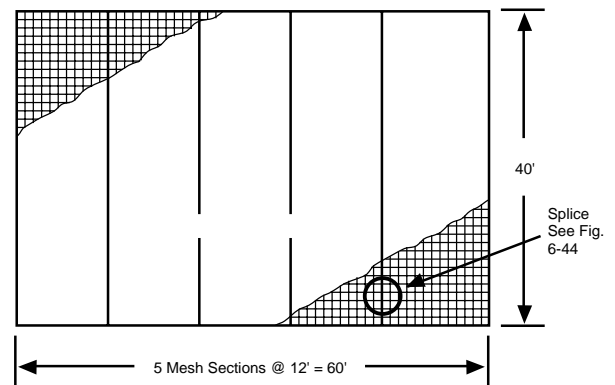


Fig. 6-43

Prefabricated wire mesh, when installed in large areas requiring interconnections between rolls, is furnished with the cross wires overhanging the outside long wire equal to an amount of $\frac{1}{2}$ the mesh size plus 2 inches. (Fig. 6-43 and 6-44) As shown, this allows the mesh to be spliced side-to-side or end-to-end while still maintaining the mesh opening at the splice area.

When prefabricated wire mesh is used for personnel protection from faults at switch handles, it is usually made in 4 by 4 feet or 4 by 6 feet rectangular sheets although larger sizes can be made. Some users also purchase the mesh in rolls and cut off pieces as needed. The wire size

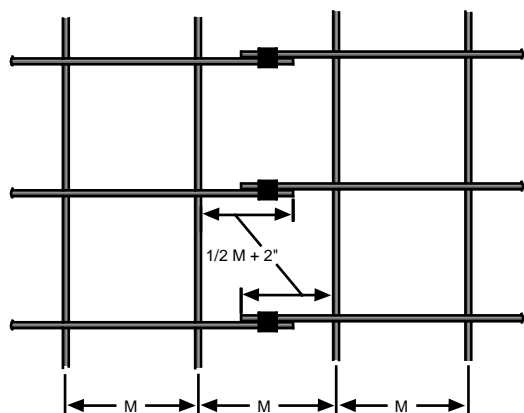


Fig. 6-44

most commonly used is No.6 copperbonded steel, 30% conductivity. CADWELD connections are used to connect the conductor between the switch handle and the mat. (Fig. 6-45).

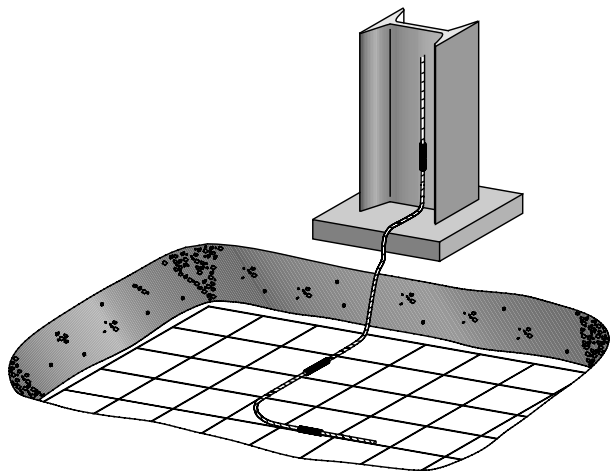


Fig. 6-45

FENCES AND GATES

Where fences surround electrical facilities or areas where a fence could be energized from a fault, either from within the facility or one transferred in from attached fences or other metallic connections, they must be grounded to protect both the worker in the facility and the general public who may touch it from the outside. The normal scheme for grounding the fence is to ground all corner posts and one line post every 50 feet (15 m). There are two methods used in designing the fence grounding system, especially at an electrical facility:

1. Electrically connect the fence grounding system to the facility ground system (Fig. 6-46). This method must be used when the fence is within or close to the facility ground grid.
2. Use a separate grounding system for the fence, isolated from the facility ground system (Fig. 6-47).

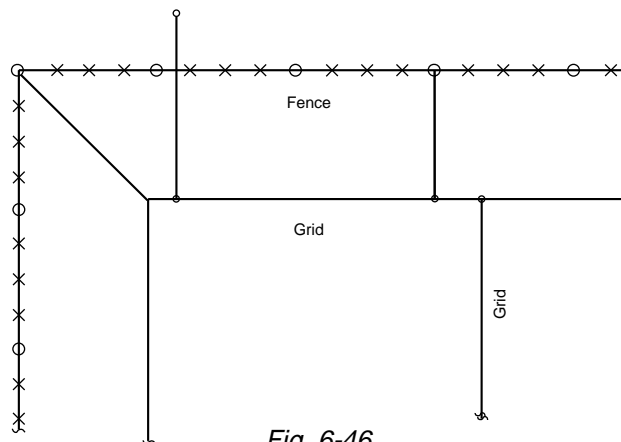


Fig. 6-46

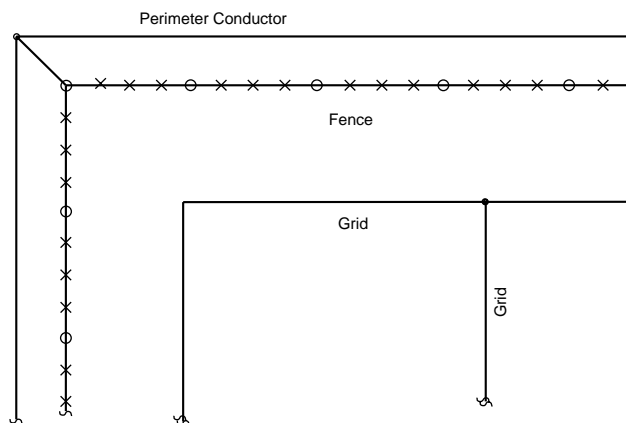


Fig. 6-47

When the fence is tied to the grid, this increases the grid size which reduces both the grid resistance and the ground grid voltage rise. However, the internal and perimeter gradients must be kept within safe limits because the fence is also at the full potential rise. This can often be accomplished by burying a perimeter conductor 3 to 4 feet outside the fence and bonding the fence and the perimeter conductor together at frequent intervals (Fig 6-48). The conductor could be buried under the fence line if one is unable to place it outside. But the touch potential for a person standing one meter outside the fence would be about 60% greater than if the perimeter conductor were buried one meter outside (see Note 1).

Note 1. Based on IEEE Std 80-1986 (16.2 and Appendix 1, example 1) with a grid spacing of 8 m and conductor burial of 0.5 m.

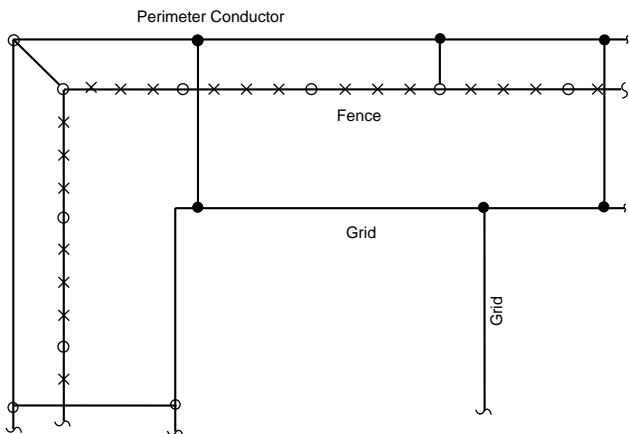


Fig. 6-48

With the perimeter conductor one meter outside the fence, a worker standing inside the fence will have an increase in touch potential, but only by about 10%. If the fence is not connected to the main grid (Fig. 6-47), the following must be considered:

1. Could an energized line fall on the fence?
2. Could other hazardous potentials exist during other types of faults?
3. Can the fence be completely isolated from the main grid at all times, including future expansions?

Fence grounding specifications. Some ground only the fence fabric, others only the fence post. Some continue the conductor up and ground the top rail while others ground the top barbed wire.

The National Electrical Safety Code (NESC), ANSI C2-1997, states (Rule 92E) that where substation fences are required to be grounded they shall be designed to limit touch, step and transferred voltages in accordance with industry practices. When the fence posts are constructed of conducting materials the grounding conductor shall be connected to the fence posts with suitable connectors.

When the posts are made of a non-conductive material, the fence barbed wire or mesh strands shall be bonded at each grounding conductor point. (Fig. 6-49) The NESC also requires that fences be grounded on each side of a gate or similar opening and the gate shall be bonded to the grounding conductor, jumper or fence. ERICO offers a complete line of factory-made flexible bonding jumpers and clamps for use with just about any fence. In addition, all conductive gates shall be bonded across the opening by a buried conductor. (Fig 6-50)

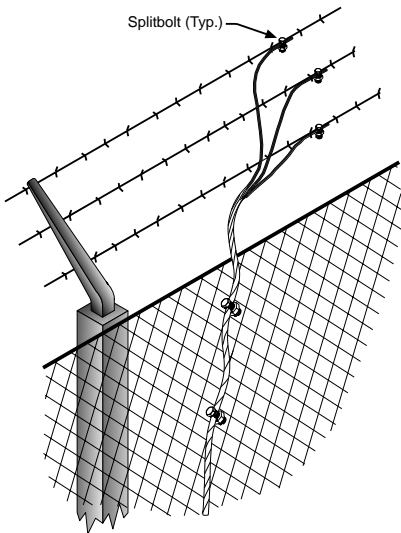


Fig. 6-49

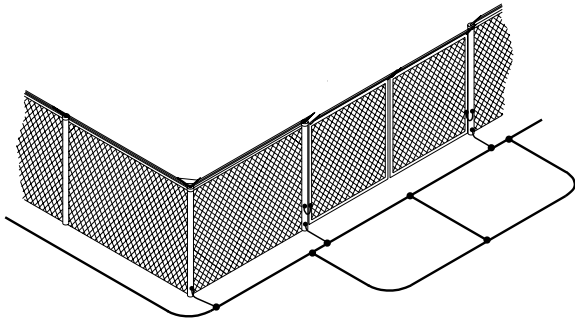
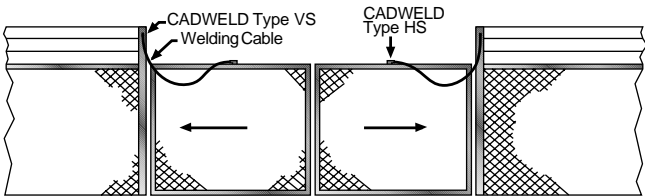


Fig. 6-50



Cable	Post Connection			Gate Connection		
	Mold*	W/M	Sleeve	Mold*	W/M	Sleeve
1/0 W.C.	VSC2E-PS	#90	S4292E16	HSC2E-PS	#90	S429E16
2/0 W.C.	VSC2J-PS	#90	S4292J16	HSC2J-PS	#90	S4292J16
4/0 W.C.	VSC2S-PS	#115	S4292S16	HSC2S-PS	#115	S4292S16

*Add Pipe Size (P.S.)

Rolling Gate Bonding
Fig. 6-51

A second conductor, although not required by NESC, offers personnel protection if installed under the swing area of the gates as shown in (Fig. 6-50). It is also common practice to connect the ground conductor to each corner post and to line posts every 50 feet. Rolling gates can be bonded to the gate post as shown in Figure 6-51.

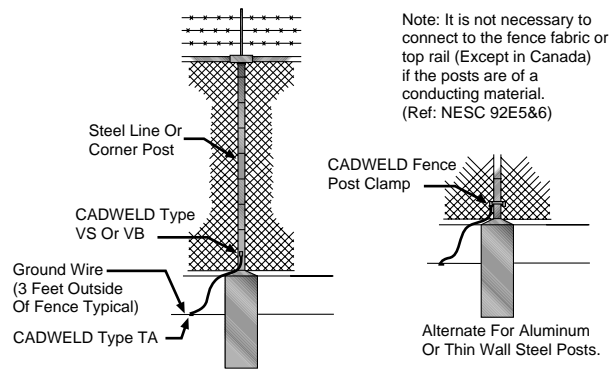


Fig. 6-52

Typical construction drawing detail showing fence line and corner post grounding.

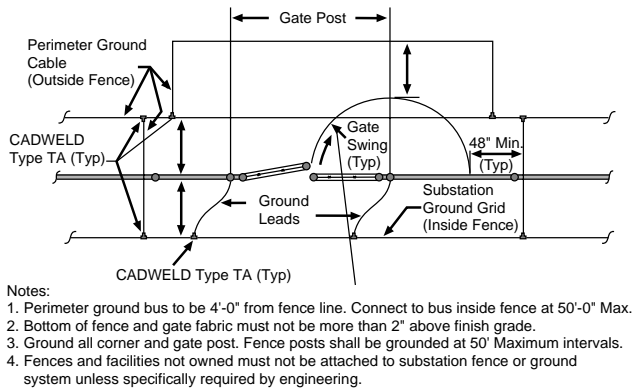


Fig. 6-53

Typical construction drawing detail showing gate and gate post grounding.

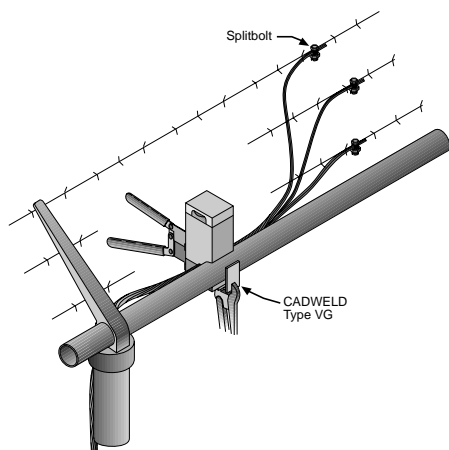


Fig. 6-54

Following are fence and gate grounding details which may be helpful. (Fig. 6-52, 6-53 and 6-54)

Various styles of clamps are available for fence post grounding and for gate and gate post bonding and grounding. (Fig. 6-55) Various styles of welded connections are available for gate bonding and gate post grounding, including a combination of welds and a clamp where the gate must occasionally be removed. (Fig. 6-56)

Both the Canadian Electrical Code (36-312 [4]) and the NESC (92 E [4]) require that the barbed wire above the fence mesh at a substation to be grounded. ERICO recommends that the connections to the barbed wire use split bolt connectors. (Fig. 6-54)

Fence posts come in a variety of sizes and shapes. (Fig. 6-57)

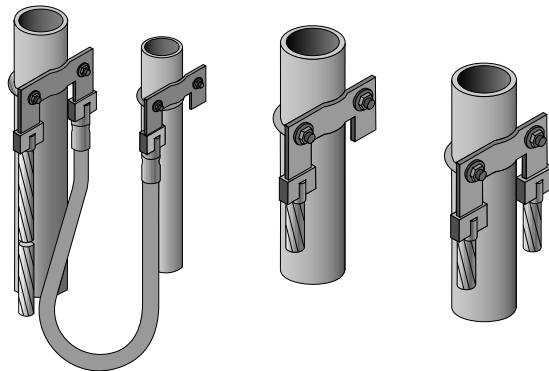


Fig. 6-55

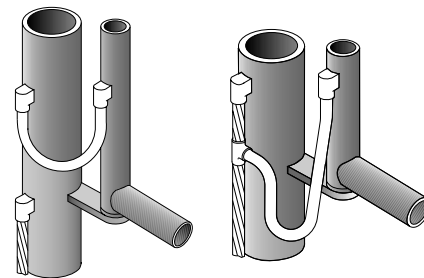


Fig. 6-56

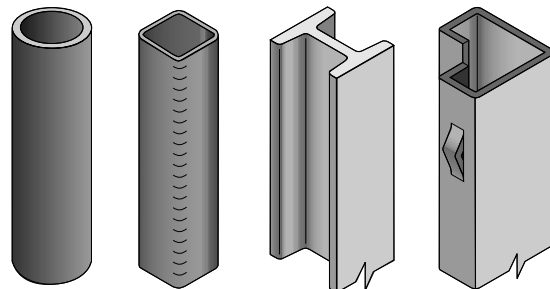
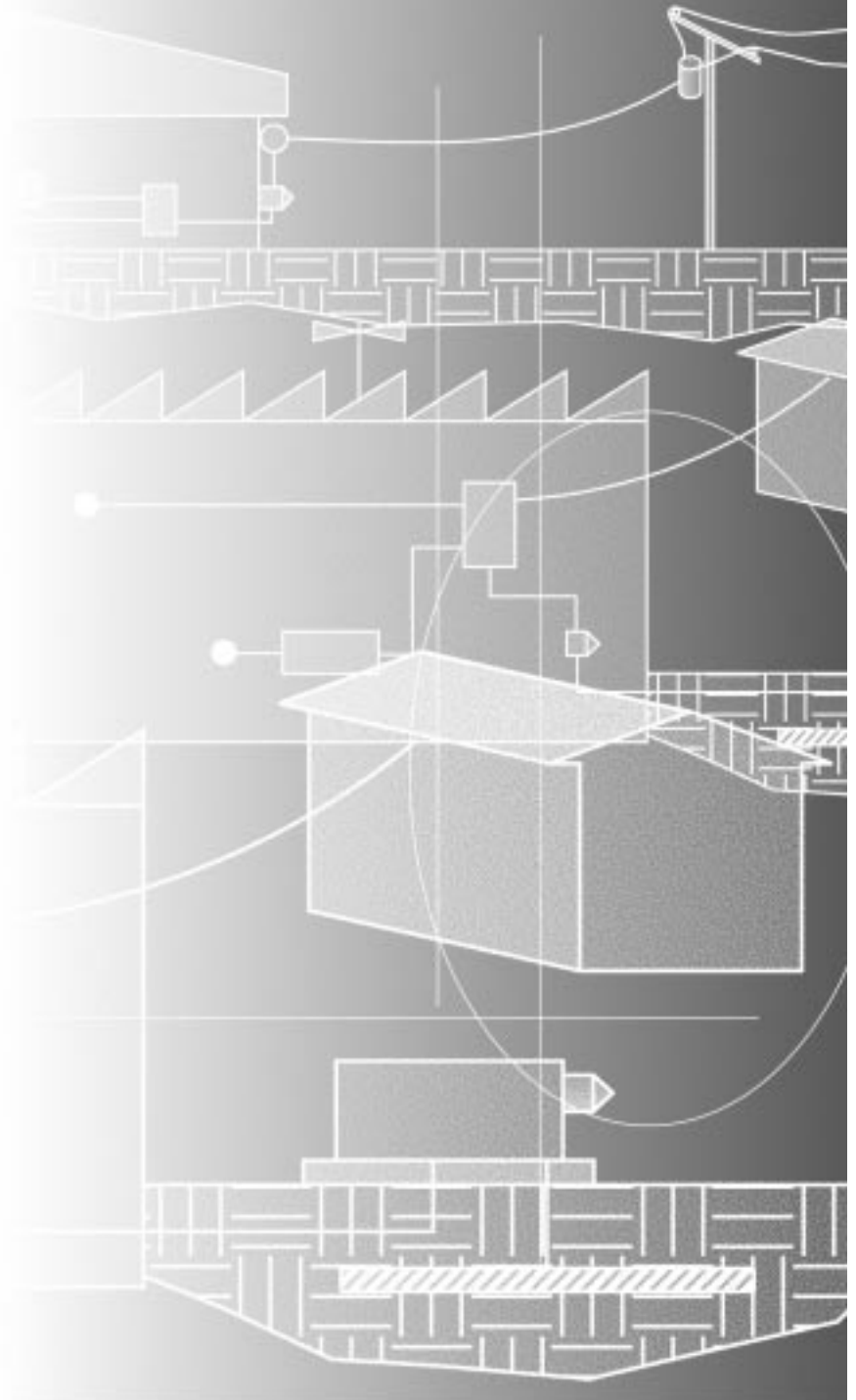


Fig. 6-57

Chapter 7

Application Of Surge Protection Devices



SURGE PROTECTION

Good grounding without good surge protection may not be totally effective in protecting equipment and data. Surge protection devices (SPDs) are usually needed. These devices are proven and inexpensive - the best life insurance your money can buy. But SPDs must be selected and installed properly, otherwise they are not very effective. Another term for SPDs is Transient Voltage Surge Protectors (TVSS) but we will use the term SPD here.

The electric power company uses surge protection devices called lightning arresters to protect its own facilities and equipment. The building owner or tenant must also supply surge protection devices to protect his electronically controlled apparatus including computers, variable frequency drives, PLCs, etc. Residences often have computers, electronically controlled heating and cooling systems and appliances which should be protected. Sources of transients include induced or conducted manmade transients which arise on incoming power lines and inside the facility, as well as from lightning. In commercial and industrial facilities most transients arise from within the facility. The equipment itself may generate transients.

SPDs are manufactured using a variety of technologies. These choices all provide advantages and disadvantages. By far the most widely used technology is the Metal Oxide Varistor (MOV) which consists of a pellet or block of specially prepared zinc oxide with “impurities” added to provide the desired voltage limiting characteristics. MOVs are fast and give excellent protection at low cost in most situations.

MOVs “clip” the voltage transient at a known level which should be above the maximum possible steady state value of the peak line voltage. A protective level of 300 volts or even 400 volts is not unreasonable for most 120 volt applications. Many specifiers try to “improve” the protection level by overspecifying MOVs. Not only is this unnecessary, it reduces the reliability of the overall system. The SPD will have a rating called the MCOV (Maximum Continuous Operating Voltage). This is the maximum value of continuous rms voltage which the SPD can reliably withstand.

Because MOVs have limited capability to absorb energy, a standard has been proposed based on extensive studies by the National Institute of Science and Technology (NIST) and others, to assist the specifier. Many of these findings are incorporated in ANSI/IEEE Std. C62.41, UL1449 and corresponding CSA Standards.

Some suppliers of MOVs promise speed of operation of a few nanoseconds. In industrial systems, most transients of any significance are much slower. Indeed, rarely is the response time of the SPD component itself of significance because the inductance of the interconnecting conductor tends to slow the transient risetime. The arrangement and length of the SPD wiring is important. Devices tested to UL 1449 will be assigned a Suppressed Voltage Rating (SVR) which indicates the clamping voltage of the device when tested with a specific impulse. The SVR is an important figure for the SPD.

Branch circuits feeding valuable equipment including process control devices, computers and PLCs need their own SPDs. These must be carefully sized for the voltage and energy levels to which they may be subjected. The energy rating of the branch circuit protection SPD can be lower than that of the service entrance protector. Its voltage rating is selected to be somewhat closer to the actual branch circuit voltage to provide better protection. SPDs are also needed at the point of utilization, or, better yet, inside each piece of equipment. The SPDs need to be coordinated so the larger (and more costly) service entrance SPDs absorb most of the transient energy. This would allow the SPD at the equipment utilization location point to minimize voltage rise to a more acceptable value.

Connection of each SPD is also critical to their proper performance. Short leads are needed on either side of the SPD to minimize voltage drop from high frequency transients. It is very possible that one additional foot of conductor connected to the SPD may add over 1000 volts to the voltage imposed on equipment. Of course, all connections must be clean and tight. One element of these connections is the fact that when they conduct surge current, they raise the voltage along the ground conductor to which they are connected. This voltage rise may be large enough to upset the same or other equipment on the same line. The solution to this unavoidable situation is to assure low impedance in the grounds, especially those associated with interconnected equipment. Signal Reference Grids are one form of desirable solution as described in IEEE Std 1100-1992 “IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment”.

The supplier of SPDs should be able to supply proof of conformance to ANSI/IEEE Std. C62.41- 1991 or latest revision, as well as UL1449 or appropriate CSA standards. IEEE Std C62.41-1991 defines three location categories with SPDs designed separately for each location category.

Location Category C is the incoming service to the building and is the location where the highest energy is

present. (Fig. 7-1) Power line faults, power line equipment problems and lightning are the greatest threat at this location. In many cases the local electric power company provides surge protection on the high voltage side of the supply transformer. The transformer itself is usually provided by the local electric company. SPDs at these locations are designed to limit overvoltages to a value sufficiently less than the transformer's basic insulation rating (BIL) and to protect switchgear and main breakers from internal flashover. These SPDs must be large enough to absorb the high energy available from transients at the service entrance.

Location Category B is the level of protection at the branch circuit level. Phase to neutral protection plus neutral to ground protection is recommended. These SPDs can be somewhat smaller than those at location category C because the peak voltage and energy will be less.

Location Category A is the level of protection at the point of equipment utilization level. Location category A protection can be built into:

1. The load equipment itself - such as an uninterruptible power supply.
2. A separate enclosure containing SPDs of proper design for protecting loads whose needs are known to the installer.
3. Panels serving the above loads
4. Circuit breakers

Line to neutral, line to ground and neutral to ground protection must be applied on single phase and three phase systems. Neutral to ground voltage rises of more than a few volts can cause misoperation of electronic equipment.

The coordination of the SPDs for location categories A, B and C is important, otherwise the benefits needed for proper protection may not be realized. If a location category A device "sees" a surge large enough to have operated the larger location category C device then the location category A device and its associated load may be damaged or destroyed. Proper coordination depends on knowledge of surge magnitudes, as well as number and location of the various branches of the power system circuits. While computer simulations are possible, they are time consuming and expensive. Easier "cook book" methods can also be employed. Design and installation assistance is often supplied by the manufacturers of SPDs. Table 7-1 and 7-2 should be of help in selecting SPDs for the different location categories.

If a Power Center is used, then it should also have its own separate SPD protection. Its Wye secondary neutral should be connected to building steel if possible, to form a separately derived ground. Then, its SPDs should be bonded to the output of the Power Center through the shortest possible lead lengths.

Each piece of equipment also should be protected at or very close to the point of entry for all data and power conductors.

Data line surge protection also should be considered, especially where data lines are long or separated by one or more floors up or down in a multistory building. These specialized devices are not discussed in detail in this book. Typical data lines that should be protected include RS232 or RS485 computer serial data interfaces, PLC signaling connections, LAN cabling and RF coaxial cables. In particular, telephone lines are often exposed over long distances and adequate SPD protection is essential. Having installed both power and data/telephone protection, it is essential that the ground connections on the protective devices be connected to the same ground point to avoid potential differences.

The Tables which follow are derived from ANSI/IEEE Std C62.41-1991. They may be used by the contractor or engineer to define location of SPDs and the severity of expected transients. From this information, it is possible to select an appropriate SPD for the majority of applications.

Location Zone (1)Exposure	System Volts - kV peak (2)	<<Peak Current - kA peak, 1.2/50 μ s	Values (3)>> and 8/20 μ s Amps 0.5 μ s-100kHz Ring Wave	1.2/50 μ s Volts -kA pk (4)
A1	Low	2	70	
A2	Medium	4	130	
A3	High	6	200	
B1	Low	2	170	1
B2	Medium	4	330	2
B3	High	6	500	3
C1	Low	6		3
C2	Medium	10		5
C3	High	20		10

**Location Category And Exposure Levels As Defined By IEEE STD C62.41-1991
For Line-Line & Line-Neutral**

Table 7-1

Note 1. See figure 7-1.

Note 2. See Section 7.3.3 of above standard.

Note 3. Waveshapes are defined in above standard.

Note 4. Combination Wave defined in above standard.

Neutral Grounding Practice (1)	Distance From Surge (2)	System Exposure (3)	0.5 μ s/100 kHz Ring Wave Peak Voltage - kVp	1.2/50 x 8/20 μ s Peak Volt. kVp
Neutral earthed	Close	All	None	None
at service	Nearby	All	1	None
entrance	Far away	All	3	None
Ungrounded	All	Low	2	2
neutral at service	All	Medium	4	4
entrance	All	High	6	6

**Location Category And Exposure Levels As Defined By IEEE STD C62.41-1991
For Neutral-Ground**

Table 7-2

Note 1. Bonding the Neutral to Ground at the service entrance prevents further propagation of Neutral to Ground voltage and current from sources beyond the service entrance (or any separately derived source). When the Neutral is not bonded to the earth or the building ground, then Neutral to Ground voltages may be similar to Line to Neutral voltages and Table 7-1 should be consulted.

Note 2. This has not been defined and is a matter of experience and judgment.

Note 3. See section 7.3.3 of above standard.

RECOMMENDATIONS

1. Specify SPDs for the voltage and energy levels as defined in ANSI/IEEE Std C62.41.

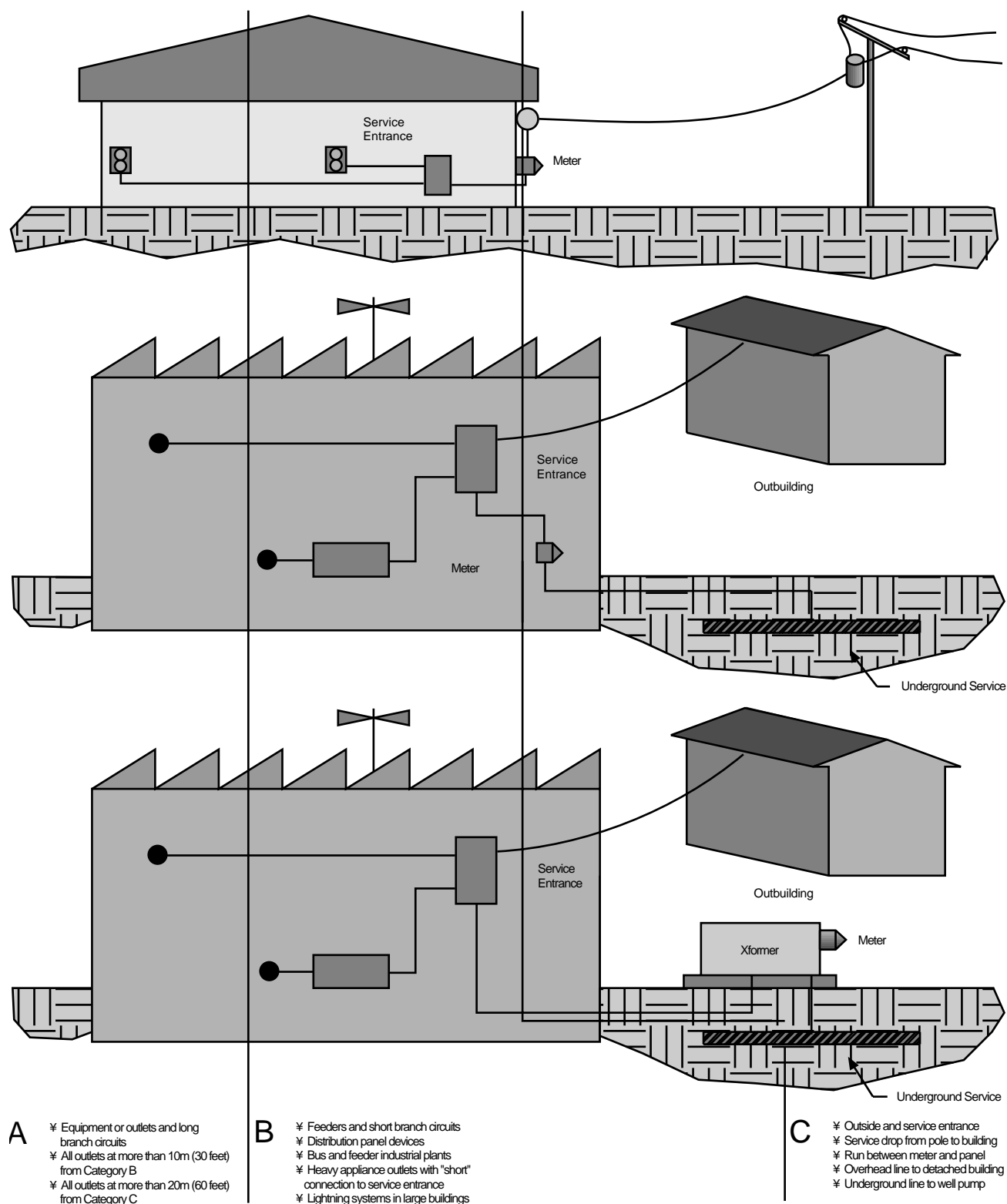
2. Specify SPDs which are UL Listed.

3. SPDs can fail. They usually fail in the short circuit mode. If this feature is important, decide what to do about it. For example, fusing the SPD prevents its shorting from taking out other equipment, but the SPD no longer provides protection.

4. Is the overall grounding system, to which the SPDs are connected, the lowest practical impedance?

5. Are connecting leads short, clean and tight?

6. Is the SPD enclosure, if any, suitable for the operating environment?



Demarcation between Location Categories B and C is arbitrarily taken to be at the meter or at the main disconnect (ANSI/NFPA 70-1990, Article 230-70) for low voltage service, or at the secondary of the service transformer if the service is provided to the user at a higher voltage.

Location Categories For SPD's
Fig. 7-1

DEFINITIONS

Air Terminal: That component of a lightning protection system that is intended to intercept lightning flashes, (commonly known as lightning rod). NFPA 780 [3]

Bonding: The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed. NEC100 [1]

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. NFPA 780 [3]

Bonding Conductor: A conductor intended to be used for potential equalization between grounded metal boxes and the lightning protection system. NFPA 780 [3]

Bonding Jumper: A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected. NEC 100 [1]

Bonding Jumper, Main: The connection between the grounded circuit conductor (neutral) and the equipment grounding conductor at the service. NEC 100 [1]

Current-Carrying Part: A conducting part intended to be connected in an electrical circuit to a source of voltage. Noncurrent-carrying parts are those not intended to be so connected. ANSI C2 [5]

Earth: The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero. (In some countries the term “ground” is used instead of “earth”. ITU K27 [2]. (Also see ground.)

Earth Electrode: A conductive part or a group of conductive parts in intimate contact with and providing an electrical connection with earth. ITU K27 [2]

Earthing Conductor: A protective conductor connecting the main earthing terminal or bar to the earth electrode. ITU K27 [2] (Also see grounding electrode conductor.)

Earthing Network: The part of an earthing installation that is restricted to the earth electrodes and their interconnections. ITU K27 [2]

Ground: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. NEC 100 [1] (Also see Earth.)

Ground Grid: A system of grounding electrodes consisting of interconnected bare cables buried in the earth to provide a common ground. UL96A [4]

Ground terminal: The portion of the 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. NFPA 780 [3]

Grounded: Connected to earth or to some conducting body that serves in place of the earth. NEC 100 [1]

Connected to earth or some conducting body that is connected to earth. NFPA 780 [3]

Grounded Conductor: A system or circuit conductor that is intentionally grounded. NEC 100 [1] (Also see Neutral Conductor.)

Grounded, Effectively: Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazards to connected equipment or to persons. NEC 100 [1]

Grounding Conductor: A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes. NEC 100 [1]

Grounding Conductor, Equipment: The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system. NEC 100 [1] (Green wire)

Grounding Electrode Conductor: The conductor used to connect the grounding electrode to the equipment grounding conductor, to the grounded conductor, or to both, of the circuit at the service equipment or at the source of a separately derived system. NEC 100 [1] (Also see Earthing Conductor.)

Lightning Protection System: A complete system of air terminals, conductors, ground terminals, interconnecting conductors, surge protection devices, and other connectors or fittings required to complete the system. NFPA 780 [3]

Main Earthing Terminal: A terminal or bar provided for the connection of protective conductors including equipotential bonding conductors and conductors for functional earthing, if any, to the means of earthing. ITU K27 [2]

Minimum Approach Distance: The closest distance a qualified employee is permitted to approach either an energized or a grounded object, as applicable for the work method being used. ANSI C2 [5]

Neutral Conductor (N): A conductor connected to the neutral point of a system and capable of contributing to the transmission of electrical energy. ITU K27 [2] (Also see grounded conductor.)

Raceway: Any channel designed expressly and used solely for holding conductors. ANSI C2 [5]

An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this Code. Raceways include, but are not limited to, rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquid tight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways. NEC 100 [1]

REFERENCES

- [1] ANSI/NFPA 70-1996, National Electrical Code (NEC).
- [2] ITU K27-1991, Bonding Configurations and Earthing Inside a Telecommunication Building. (Formerly CCITT.)
- [3] ANSI/NFPA 780-1995, Standard for the installation of Lightning Protection Systems.
- [4] UL 96A, Standard for Installation Requirements for Lightning Protection Systems.
- [5] ANSI C2-1997, National Electrical Safety Code (NESC)
- [6] CSA Standard C22.1-94 Canadian Electrical Code Part I (CEC)

BIBLIOGRAPHY

- ANSI/IEEE Std 80, IEEE Guide for Safety in AC Substation Grounding.
- ANSI/IEEE Std 81, IEEE Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Grounding System.
- ANSI/IEEE Std 142, IEEE Recommended Practice for Grounding of Industrial and commercial Power Systems.
- ANSI/IEEE Std 487, IEEE Guide for the Protection of Wire-line Communication Facilities Serving Electrical Power Stations.
- ANSI/IEEE Std 837, IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.
- ANSI/IEEE Std 1100, IEEE Recommended Practice for Powering And Grounding Sensitive Electronic Equipment.
- ANSI/T1.313 Standard, Electrical Protection for Telecommunications Central Offices and Similar Facilities.
- ANSI/TIA/EIA-607, Commercial Building Grounding and Bonding Requirements for Telecommunications.
- ANSI/UL 467 Standard for Grounding and Bonding Equipment.
- MIL HDBK 419A Grounding, Bonding and Shielding for Electronic Equipment and Facilities, Vol. 1 & 2.
- MIL-STD-188-124B Military Standard Grounding, Bonding and Shielding.
- NEMA CC-1, Electrical Power Connections for Substations.

	Page		Page
A		F (cont.)	
AC System, electrode system grounding	16	Filtration, static control	97
Active Attraction Systems, lightning	24	static grounding	97
Active Prevention Systems, lightning	24	Four-Point Method, ground resistance testing	3
Air Terminal, lightning protection	24, 29	Franklin Rod, lightning	25
protective coverage calculation	27		
Airports, grounding situations	91	G	
Ambient Electric Field, lightning	25	Galvanic System, cathodic protection	91
Anchor Rods, airport grounding	91	Gates, grounding GEM (ERICO Ground Enhancement Material)	6, 13-15, 84, 109
B		Ground Bar, building interior grounding	61
Bibliography	123	building interior bonds	51
Bonded, lightning protection	29	Ground Bus	61
Bonding, electrical systems	15 - 16	Ground Current Interference	72
service equipment	49 - 50	Ground Fault Currents, grounding	58
static electricity	98	Ground Loop	72 - 74
Bonding Conductors, static electricity	98	Benign	73
Bonding Jumper	49 - 50, 57	Desired	73
Bonding Systems, maintenance requirements	99	Unwanted	73
testing and inspection	99	Ground Plane, radio antenna grounding	94
C		Ground Plates, building interior bonds	53
Cable Installations, equipment bonding	57	equipment bonding	57
Cathode Ray Tube (CRT), ground current interference	72	Ground Resistance	3 - 4
Cathodic Protection Systems	91 - 94	Ground Ring	12
Chemical Ground Electrode, grounding	15, 85	Ground Rods	83 - 85
Collection Volume, lightning	27 - 28	building exterior	4
Common Bonding Grid	51	lightning systems	33
Common Grounding Electrode System, bonding	49	Grounded Service Conductor, bonding	49
Concrete Encased Electrode, grounding	11, 17 - 18	Grounding, overview	3 - 4
Concrete Floor Embedded SRG, electronic grounding	75	Electrical service	
Conductive Floor, building interior bonds	53	electronic equipment systems	68
Conductive Plastic Containers	98	electrode system	10
Conductors, lightning protection sizing	29 - 31	equipment fastened in place	58 - 59
Connectors, grounding	86	static electricity	98 - 99
lightning protection	31	Grounding Analysis, lightning safety	36
Cord and Plug Connected Equipment, grounding	59	Grounding Conductor	81
Corrosion	91	equipment bonding	57
Counterpoise (Network of Conductors), lightning protection	32	static electricity	98
D		Grounding Electrode	82 - 83
Data Circuit Protection, electronic equipment systems	68	Grounding Electrode Conductors (GEC)	81 - 82
Definitions	121	Grounding Inspection Process, electrical installation	71
Dielectric, lightning	23	Grounding Pin	60
Direct Strike Lightning Protection System	24	Grounding System Components	81
Dispersing Operations, static control	97	Grounding Systems, maintenance requirements	99
static grounding	97	testing and inspection	99
Downconductor, lightning	26	Grounding Type Receptacle	60
Down Leader, lightning	25	Guy Anchors, radio antenna grounding	94
E		H	
Earth Resistance Tester, ground resistance	3	Harmonic Current Filter (Traps)	69
Earth Resistivity	3	Harmonics	68 - 69
Effective Lightning Protection Components	25	Hazardous Locations, grounding	58 - 59
Electrode System, grounding	9, 10, 16	Hot Tub/Spa, bonding	51
Electrical Installation, recommendations	68 - 71	I	
Electrical Noise, electronic system grounding	67	Impressed Current System, cathodic protection	91 - 92
Electrical Service Grounding	4, 9 - 16	Inerting, methods and procedures	99
Electrode Conductor, grounding	9, 15 - 16	Inspection Wells	5
Electromagnetic Interference (EMI), electronic grounding	75	Insulated Equipment Grounding Conductor	61
Electromagnetically Induced Voltages, lightning	24	Interconnected Electronic Equipment Systems	67
Electronic Grounding Detail	75	Interconnecting Cables, electrical installation	69
Electronic System Grounding	67	Interior Bonding, building grounding	4
Electrostatically Shielded Isolation Transformer	68	Interior Bonds, building	51 - 53, 57
Equipment Bonding, building grounding	4, 57	Interior Piping Systems, bonding	50
Equipment Grounding Conductors (EGC)	81	Internally Cast Ball, airport grounding	91
Equipment Grounding, building grounding	4	Isokeraunic Chart, lightning	23
Eriksson, Dr. A.J., lightning	27	Isolated Ground Receptacle	61
Exothermic Connections	33, 49, 51, 85, 86, 93, 94, 107	Isolated/Insulated	
Exposed Metal parts, grounding	58 - 59	Grounding, electrical installation	70, 71
Exterior Grounds, building grounding	4	Isolation Transformer, bonding	50
F		Isolation Transformer, electrical installation	69, 71
Facility Ground System	99	L	
Faraday Cage, lightning	25	Latent Component Failure, lightning protection	29
Fence Grounding, specifications	7, 109 - 110	Lighting Fixture Standards, building exterior	8
Fence Grounding System	108 - 109	Lightning Protection Systems	4, 23-29
Fiber Optical Path, ground loop	74	Lightning Rod	29
Field Installed Data Cables, electrical installation	69	Lightning Safety Analysis	36
Filling Operations, static control	97	Lightning Strike Probability	36
static grounding	97	Lightning Systems, overview	33
		Lightning, electronic equipment systems grounding	68
		Lightning, electronic system grounding	67
		Lightning, overview	23
		Location Categories A, B, C, surge protection	115 - 116

	Page		
L (Cont.)		Structural Steel, bonding	50
Low Impedance Conductor, lightning	26	Suppressed Voltage Rating (SVR), surge protection	115
Low Resistance Grounding System, lightning protection	32	Surge Protection	115, 116
		Surge Protection Devices (SPDs)	115, 116
M		recommendations	117
Made Electrodes, grounding	14, 82	electronic system grounding	67
Magnetic fields, cathode ray tube	72	grounding connections	69 - 71
MCOV (Maximum Continuous Operating Voltage) Rating	115	Swimming Pools, bonding	51
Metal Frame Building, grounding	10	Switching, electronic system grounding	67
Metal Oxide Varistor (MOV), surge protection	115		
Metal Raceways, lightning systems	33	T	
Metal Underground Water Pipe, bonding	50	Telecommunication Systems Grounding	76
grounding	10	Testing Ground Resistance	3
		Three-Point Method, ground resistance testing	3
N		Transient Earth Clamp, lightning protection	32
National Atmospheric Administration, lightning	23	Transient Voltage Surge Protectors (TVSS)	115
Natural Grounding Electrode	82	Transients	67
NESC (National Electric Safety Code)	6, 109, 110	electronic systems grounding	67 - 68
Network Workstation, grounding	75	Transmission Conductor, radio antenna grounding	94
NFPA 780, lightning protection	33 - 34	Triad Ground Rod Arrangement, building exterior	4
Noncurrent-carrying metal parts, grounding	58	Two-Point Method, ground resistance testing	3
Non-residential Occupancies, grounding	59		
Nonconductive Coatings, bonding	50	U	
Nonconductive Plastic Containers	98	Ufer Grounding	17, 83
Noncurrent-carrying enclosures, bonding	50	Up Leader, lightning	25
Nonmetallic Raceway, grounding	16	Upward Streamer Current, lightning	25
O		V	
Optical Isolation Technique, ground loop	74	Velocity Parabola, lightning	28
P		W	
Passive Neutral Systems, lightning	24	Water Pipe Bonding, building exterior	8
Performance Grounding, electronic equipment systems	67	Water Stop, building exterior	4
Perimeter Ground Ring, building exterior	4	Wire Mesh	6, 106 - 108
Pipe Electrodes, grounding electrode	83	Wireways, electrical installation	69
Piping Systems, bonding	50		
static control	97		
static grounding	97		
Plate Electrode, grounding	15, 83		
Pointed Lightning Rod	24		
Positive Bonding, building interior bonds	51		
Proper Grounding, electronic system grounding	67		
Protocol Conversion Technique, ground loop	74		
Pull Box Cover Grounding, building exterior	8		
R			
Radio Antenna Grounding	94		
Rail Siding Grounding, building exterior	8		
Rebar, grounding	11 - 12		
lightning protection	29		
Receptacle Grounding	60 - 61		
References	123		
Removable Ground, equipment bonding	57		
Residential Occupancies, grounding	59		
Resistivity	3, 32, 84		
Rod Electrodes, grounding electrode	83		
Rolling Ball Theory, lightning protection	28		
lightning systems	33		
S			
Sacrificial Anode, galvanic system	91 - 92		
Safety Grounding, electronic equipment systems	67 - 68		
Salt, lowering ground resistance with	85		
Separately Derived Systems, bonding	50		
Service Conductor, grounding	9		
Service Equipment, bonding	49		
Side Flashes, lightning protection	29		
Signal Reference Grid (SRG), electrical installation	70, 71		
Soil Type, as conductor	32		
Soil, lightning safety analysis	36		
Solid Grounding (SG), electrical installation	70		
Static Control	97		
Static Electricity, electronic system grounding	67		
grounding	96 - 97		
sources	96		
Static Facility Ground System	99		
Static Grounding, airports	91		
Steel, bonding	51		
Strike Termination Device, lightning	24		
Striking Distance Hemisphere, lightning	27		

