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(Revision of
IEEE Std 524-1992)

# 524™

# IEEE Guide to the Installation of Overhead Transmission Line Conductors

## IEEE Power Engineering Society

Sponsored by the
Transmission & Distribution Committee

IEEE

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# IEEE Guide to the Installation of Overhead Transmission Line Conductors

Sponsor

**Transmission & Distribution Committee**
of the
**IEEE Power Engineering Society**

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**Abstract:** General recommendations for the selection of methods, equipment, and tools that have been found to be practical for the stringing of overhead transmission line conductors and overhead groundwires are provided.
**Keywords:** overhead transmission line conductors, overhead groundwires

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# Introduction

(This introduction is not part of IEEE Std 524-2003, IEEE Guide to the Installation of Overhead Transmission Line Conductors.)

This guide provides general recommendations for the selection of methods, equipment, and tools that have been found to be practical for the stringing and grounding of overhead transmission line conductors and overhead groundwires. The following revisions have been made and are intended to improve the usefulness of the document:

a) The IEEE Std 524, Guide to the Installation of Overhead Transmission Line Conductors and the supplemental IEEE Std 524a, Guide to Grounding During the Installation of Overhead Transmission Line Conductors have been combined into one document.

b) The stringing specification for fiber optic cables has been expanded

c) A clause on All Dielectric Self-Supporting (ADSS) cable has been added

d) SSAC conductor type designation has been changed to the current ACSS designation

e) Helicopter installation methods have been expanded

f) All units have been changed to conform with IEEE metric policy

## Participants

At the time this standard was revised, the membership of the Task Group of the Working Group on the Construction of Overhead Lines of the Towers, Poles, and Conductors Subcommittee, was as follows:

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# IEEE Guide to the Installation of Overhead Transmission Line Conductors

## 1. Overview

### 1.1 Scope

This guide provides general recommendations for the selection of methods, equipment, and tools that have been found to be practical for the stringing of overhead transmission line conductors and overhead groundwires. The guide also includes a comprehensive list of definitions for equipment and tools used in stringing and for stringing terms commonly employed. This guide does not address special conductors such as those used for river and canyon crossing. These conductors may be custom designed and often may require special considerations.

### 1.2 Purpose

The purpose of this guide is to present in one document sufficient details of present day methods, materials, and equipment to outline the basic considerations necessary for maintaining safe and adequate control of conductors during stringing operations. References are given in Clause 2 and the bibliography in Annex A for those desiring more detailed information. Because the terminology used for many hardware items and for many stringing terms varies from place to place, a list of definitions is included to provide correlation and clarification of the terms most commonly employed.

### 1.3 Application

This guide is broad enough, yet specific enough, to be applicable to the stringing of conventional overhead transmission conductors and overhead groundwires (OHGW) of the following types: AAAC, AAC, AACSR, ACAR, ACSR, ACSR/TW, CU, aluminum-clad steel OHGW, and galvanized steel OHGW.[1] Since stringing practices for different projects will be strongly influenced by the magnitude and nature of each project and by local circumstances, alternate methods that have been successfully employed are presented. Information contained in this guide may not be sufficient for certain special cases, such as when stringing extremely long spans, severe line angles, high tensions, or special conductors. In these cases, the manufacturer should be consulted. The practices that are described in this guide provide for continuous control of the conductor from the initial setup to the ready-for-service condition. Any legal requirements of national, state, or local regulations must, of course, be observed.

[1]See 3.2 for definitions of all acronyms.

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The approach used within this guide is first to describe, in general terms, the stringing methods most commonly employed, then the specific requirements of the various tools and equipment used. Finally, this guide describes the application of the methods and equipment used in the stringing process.

## 2. References

This guide shall be used in conjunction with the following publications. If the following publications are superseded by an approved revision, the revision shall apply.

ASTM F855-97e1, Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment.

IEC 61230 (1993-09), Live working—Portable equipment for earthing or earthing and short-circuiting.

IEEE Std 80™-2000, IEEE Guide for Safety in AC Substation Grounding.

IEEE Std 935™-1989 (Reaff 2001), IEEE Guide on Terminology for Tools and Equipment to Be Used in Live Line Working.

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## 3. Definitions and cross reference of terminology

Terminology for equipment and procedures associated with the installation of overhead transmission line conductors varies widely throughout the utility industry. Therefore, definitions (see 3.1) have been included to provide a correlation between the terminology used in this guide and industry synonyms. Note that these synonyms are terms that are commonly used in the industry and, because many are not necessarily good usage, they should therefore not be taken as equivalents to the guide terminology.

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B13][2] should be referenced for terms not defined in this clause.

### 3.1 Definitions and terminology for conductor stringing equipment

**3.1.1 Aerex:** *See* **explosives.**

**3.1.2 aerial platform:** A device designed to be attached to the boom tip of a crane or aerial lift and support a worker in an elevated working position. Platforms may be constructed with surrounding railings that are fabricated from aluminum, steel, or fiber reinforced plastic. Occasionally, a platform is suspended from the load line of a large crane. *Syn:* **cage, platform.**

**3.1.3 alive:** *See* **energized.**

**3.1.4 all terrain vehicle:** *See* **off-road vehicle.**

**3.1.5 alligator:** *See* **running board.**

[2]The numbers in brackets correspond to those of the bibliography in Annex A.


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**3.1.6 aluminum alloy conductor, steel reinforced:** A composite conductor made up of a combination of aluminum alloy and coated steel wires. In the usual construction, the aluminum wires surround the steel.

**3.1.7 aluminum conductor, aluminum alloy reinforced:** A composite conductor made up of a combination of aluminum and aluminum alloy wires. In the usual construction, the aluminum wires surround the aluminum alloy.

**3.1.8 aluminum conductor, steel reinforced:** A composite conductor made up of a combination of aluminum and coated steel wires. In the usual construction, the aluminum wires surround the steel.

**3.1.9 aluminum conductor, steel supported:** An ACSR with the aluminum wires annealed.

**3.1.10 American Society for Testing and Materials:** Founded in 1898, the society is a scientific and technical organization formed for the development of standards on characteristics and performance of materials, products, systems, and service; and the promotion of related knowledge.

**3.1.11 American Wire Gage:** Also known as the Brown and Sharp gage, the gage was devised in 1857 by J. R. Brown. This gage has the property such that its sizes represent approximately the successive steps in the process of wire drawing. Also, its numbers are retrogressive; a larger number denotes a smaller wire corresponding to the operations of drawing. These gage numbers are not arbitrarily chosen, but follow the mathematical law upon which the gage is founded.

**3.1.12 anchor:** A device that serves as a reliable support to hold an object firmly in place. The general term "anchor" is normally associated with cone, plate, screw, or concrete anchors. The terms snub, deadman, and anchor log are usually associated with pole stubs or logs set or buried in the ground to serve as temporary anchors. The latter are often used at pull and tension sites. *Syn*: **anchor log, deadman,** and **snub.**

**3.1.13 anchor log:** *See* **anchor.**

**3.1.14 anchor site:** The location along the line where anchors are installed to temporarily hold the conductors in facilitating splicing, pulling, or tensioning.

**3.1.15 Baker board:** *See* **lineperson's platform.**

**3.1.16 basket:** *See* **bucket, woven wire grip.**

**3.1.17 bicycle:** *See* **cable car.**

**3.1.18 binder:** *See* **load, binder.**

**3.1.19 bird:** *See* **running board.**

**3.1.20 birdie:** *See* **running board.**

**3.1.21 block:** A device designed with one or more single sheaves, a wood or metal shell, and an attachment hook or shackle. When rope is reeved through two of these devices, the assembly is commonly referred to as a block and tackle. A set of fours refers to a block and tackle arrangement utilizing two 10 cm double sheave blocks to obtain four load-bearing lines. Similarly, a set of fives or a set of sixes refers to the same number of load-bearing lines obtained using two 12.5 cm or two 15 cm double sheave blocks, respectively. *Syn:* s**et of fours, set of fives, set of sixes.**

**3.1.22 block ground:** *See* **traveler ground.**

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**3.1.23 boatswain's chair:** A seat designed to be suspended on a line reeved through a block and attached to a pulling device to hoist a workman to an elevated position. *Syn:* **bosun's chair.**

**3.1.24 body resistance:** Determined from the ratio of voltage applied to current flowing in a human body, neglecting capacitive and inductive effects.

**3.1.25 bonded:** The mechanical interconnection of conductive parts to maintain a common electrical potential. *Syn:* **connected.**

**3.1.26 bosun's chair:** *See* **boatswain's chair.**

**3.1.27 boxing glove:** *See* **conductor lifting hook.**

**3.1.28 brake:** *See* **bullwheel tensioner.**

**3.1.29 bucket:** A device designed to be attached to the boom tip of a line truck, crane, or aerial lift to support workers in an elevated working position. It is normally constructed of fiberglass to reduce its physical weight, maintain strength, and obtain good dielectric characteristics. *Syn:* **basket.**

**3.1.30 buffalo:** *See* **conductor grip.**

**3.1.31 bull line:** A high-strength line, normally synthetic fiber rope, used for pulling and hoisting large loads. *Syn:* **bull rope, pulling line, threading line.**

**3.1.32 bull rope:** *See* **bull line.**

**3.1.33 bullet:** *See* **connector link.**

**3.1.34 bullwheel:** A wheel incorporated as an integral part of a bullwheel puller or tensioner to generate pulling or braking tension on conductors or pulling lines, or both, through friction. A puller or tensioner normally has one or more pairs of wheels arranged in tandem incorporated in its design. The physical size of the wheels will vary for different designs, but 43 cm face widths and diameters of 150 cm are common. The wheels are power driven or retarded and lined with single or multiple groove neoprene or urethane linings. Friction is accomplished by reeving the pulling line or conductor around the groove of each pair.

**3.1.35 bullwheel puller:** A device designed to pull pulling lines and conductors during stringing operations. It normally incorporates one or more pairs of urethane or neoprene-lined, power-driven, single or multiple groove bullwheels in which each pair is arranged in tandem. Pulling is accomplished by friction generated against the pulling line that is reeved around the grooves of a pair of the bullwheels. The puller is usually equipped with its own engine, which drives the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner. *Syn:* **puller.**

**3.1.36 bullwheel tensioner:** A device designed to hold tension against a pulling line or conductor during the stringing phase. Normally, it consists of one or more pairs of urethane or neoprene-lined, power-braked, single or multiple groove bullwheels in which each pair is arranged in tandem. Tension is accomplished by friction generated against the conductor that is reeved around the grooves of a pair of the bullwheels. Some tensioners are equipped with their own engines, which retard the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner. Other tensioners are only equipped with friction type retardation. *Syn:* **brake, retarder, tensioner.**

**3.1.37 bundle, two-conductor, three-conductor, four-conductor, multi-conductor:** A circuit phase consisting of more than one conductor. Each conductor of the phase is referred to as a subconductor. A two-conductor bundle has two subconductors per phase. These may be arranged in a vertical or horizontal configuration. Similarly, a three-conductor bundle has three subconductors per phase. These usually are


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arranged in a triangular configuration with the vertex of the triangle up or down. A four-conductor bundle has four subconductors per phase. These normally are arranged in a square configuration. Although other configurations are possible, those listed are the most common. *Syn:* **twin-bundle, tri-bundle, quad-bundle.**

**3.1.38 butt ground:** *See* **structure base ground.**

**3.1.39 cable:** *See* **conductor.**

**3.1.40 cable buggy:** *See* **conductor car.**

**3.1.41 cable car:** A seat or basket-shaped device, designed to be suspended by a framework, and two or more sheaves arranged in tandem to enable a workman to ride a single conductor, wire, or cable. *Syn:* **bicycle, cable trolley, conductor car.**

**3.1.42 cable clamp:** A device designed to clamp cables together. It consists of a "U" bolt threaded on both ends, two nuts, and a base, and is commonly used to make temporary bend back eyes on wire rope. *Syn:* **clip, Crosby, Crosby clip.**

**3.1.43 cable trolley:** *See* **cable car.**

**3.1.44 cage:** *See* **aerial platform.**

**3.1.45 carrying:** *See* **energized.**

**3.1.46 carrying current:** *See* **energized.**

**3.1.47 cat:** *See* **crawler tractor.**

**3.1.48 chain binder:** *See* **load, binder.**

**3.1.49 chain hoist:** *See* **hoist.**

**3.1.50 chain tugger:** *See* **hoist.**

**3.1.51 Chinese finger:** *See* **woven wire grip.**

**3.1.52 Chicago grip:** *See* **conductor grip.**

**3.1.53 choker:** *See* **traveler sling.**

**3.1.54 clamping-in:** *See* **clipping-in.**

**3.1.55 clearance: (1)** The condition in which a circuit has been de-energized to enable work to be performed more safely. A clearance is normally obtained on a circuit presenting a source of hazard prior to starting work. *Syn:* **outage, permit, restriction. (2)** The minimum separation between two conductors, between conductors and supports or other objects, or between conductors and ground or the clear space between any objects.

**3.1.56 clip:** *See* **cable clamp.**

**3.1.57 clipping:** *See* **clipping-in.**

**3.1.58 clipping-in:** The transferring of sagged conductors from the travelers to their permanent suspension positions and the installing of the permanent suspension clamps. *Syn:* **clamping-in, clipping.**

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**3.1.59 clipping offset:** A calculated distance, measured along the conductor from the plumb mark to a point on the conductor at which the center of the suspension clamp is to be placed. When stringing in rough terrain, clipping offsets may be required to balance the horizontal forces on each suspension structure.

**3.1.60 clock:** *See* **dynamometer.**

**3.1.61 Coffing:** *See* **hoist.**

**3.1.62 Coffing hoist:** *See* **hoist.**

**3.1.63 come-along:** *See* **conductor grip.**

**3.1.64 compression joint:** A tubular compression fitting designed and fabricated from aluminum, copper, or steel to join conductors or overhead groundwires. It is usually applied through the use of hydraulic or mechanical presses. However, in some cases, automatic, wedge, and explosive-type joints are utilized. *Syn:* **conductor splice, sleeve, splice.**

**3.1.65 conductor:** A wire, or combination of wires not insulated from one another, suitable for carrying an electric current. It may be, however, bare or insulated. *Syn:* **cable, wire.**

**3.1.66 conductor car:** A device designed to carry workmen and ride on sagged bundle conductors, thus enabling them to inspect the conductors for damage and install spacers and dampers where required. These devices may be manual or powered. *Syn:* **cable buggy, cable car, spacer buggy, spacer cart, spacing bicycle.**

**3.1.67 conductor grip:** A device designed to permit the pulling of conductor without splicing on fittings, eyes, etc. It permits the pulling of a continuous conductor where threading is not possible. The designs of these grips vary considerably. Grips such as the Klein (Chicago) and Crescent utilize an open-sided rigid body with opposing jaws and swing latch. In addition to pulling conductors, this type is commonly used to tension guys and, in some cases, pull wire rope. The design of the come-along (pocket-book, suitcase, four bolt, etc.) incorporates a bail attached to the body of a clamp that folds to completely surround and envelope the conductor. Bolts are then used to close the clamp and obtain a grip. *Syn:* **buffalo, come-along, Crescent, four bolt, grip, Chicago grip, Kellem, Klein, pocketbook, seven bolt, six bolt, slip-grip, suitcase.**

**3.1.68 conductor hook:** *See* **conductor lifting hook.**

**3.1.69 conductor lifting hook:** A device resembling an open boxing glove designed to permit the lifting of conductors from a position above them. It is normally used during clipping-in operations. Suspension clamps are sometimes used for this purpose. *Syn:* **boxing glove, conductor hook, lifting shoe, lip.**

**3.1.70 conductor payout station:** *See* **tension site.**

**3.1.71 conductor safety:** A sling arranged in a vertical basket configuration, with both ends attached to the supporting structure and passed under the clipped-in conductor(s). These devices, when used, are normally utilized with bundled conductors to act as a safety device in case of insulator failure while workers in conductor cars are installing spacers between the subconductors, or as an added safety measure when crossing above energized circuits. These devices may be fabricated from synthetic fiber rope or wire rope.

**3.1.72 conductor splice:** *See* **compression joint.**

**3.1.73 connected:** *See* **bonded.**

**3.1.74 connector:** *See* **connector link.**


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**3.1.75 connector link:** A rigid link designed to connect pulling lines and conductors together in series. It will not spin and relieve torsional forces. *Syn:* **bullet, connector, link, slug.**

**3.1.76 control span:** *See* **sag span.**

**3.1.77 counterpoise:** *See* **ground grid.**

**3.1.78 crawler:** *See* **crawler tractor.**

**3.1.79 crawler tractor:** A tracked unit employed to pull pulling lines, sag conductor, level or clear pull and tension sites, and miscellaneous other work. It is also frequently used as a temporary anchor. Sagging winches on this unit are usually arranged in a vertical configuration. *Syn:* **cat, crawler, tractor, dozer.**

**3.1.80 Crescent:** *See* **conductor grip.**

**3.1.81 Crosby:** *See* **cable clamp.**

**3.1.82 Crosby clip:** *See* **cable clamp.**

**3.1.83 crossing structure:** A structure built of poles and, sometimes, rope nets. It is used whenever conductors are being strung over roads, power lines, communications circuits, highways, or railroads, and is normally constructed in such a way as to prevent the conductor from falling onto or into any of these facilities in the event of equipment failure, broken pulling lines, loss of tension, etc. *Syn:* **guard structure, H-frame, rider structure, temporary structure.**

**3.1.84 D-board:** *See* **lineperson's platform.**

**3.1.85 dead:** *See* **de-energized.**

**3.1.86 deadend board:** *See* **lineperson's platform.**

**3.1.87 deadend loop:** *See* **jumper.**

**3.1.88 deadend platform:** *See* **lineperson's platform.**

**3.1.89 deadman:** *See* **anchor.**

**3.1.90 de-energized:** Free from any electric connection to a source of potential difference; not having a potential different from that of the ground. The term is used only with reference to current-carrying parts that are sometimes alive (energized). To state that a circuit has been de-energized means that the circuit has been disconnected from all intended electrical sources. However, it could be electrically charged through induction from energized circuits in proximity to it, particularly if the circuits are parallel. *Syn:* **dead.**

**3.1.91 diving board:** *See* **lineperson's platform.**

**3.1.92 dolly:** *See* **traveler.**

**3.1.93 dolly car:** *See* **traveler rack.**

**3.1.94 double drum hoist:** *See* **puller, two drum, three drum.**

**3.1.95 double drum winch:** *See* **puller, two drum, three drum.**

**3.1.96 Dozer:** *See* **crawler, tractor.**

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**3.1.97 drum puller:** A device designed to pull conductor(s) during stringing operations. It is normally equipped with its own engine which drives the drum(s) mechanically, hydraulically, or through a combination of both. It may be equipped with synthetic fiber rope or wire rope to be used as the pulling line. The pulling line is payed out from the unit, pulled through the travelers in the sag section, and attached to the conductor. The conductor is then pulled in by winding the pulling line back onto the drum. This unit is sometimes used with synthetic fiber rope acting as a pilot line to pull heavier pulling lines across canyons, rivers, etc. *Syn:* **hoist, single drum hoist, single drum winch, tugger.**

**3.1.98 dynamite:** *See* **explosives.**

**3.1.99 dynamometer:** A device designed to measure loads or tension on conductors. Various models of these devices are used to tension guys or sag conductors. *Syn:* **clock, load cell.**

**3.1.100 earth wire:** *See* **overhead groundwire.**

**3.1.101 electric field induction (capacitive coupling):** The process of generating voltages and/or currents in conductive objects or electrical circuits by the induction process that results from time-varying quasi-static electric fields.

NOTES:

1—The term "electric field induction" is preferred over "electric induction" because the latter may be taken to mean electric flux density.

2—Electric field induction was formerly called electrostatic induction. This usage is deprecated because electrostatic fields are time invariant.

**3.1.102 electromagnetic field induction (electromagnetic coupling):** The induction process that results from time-varying electromagnetic fields.

**3.1.103 energized:** Electrically connected to a source of potential difference, or electrically charged so as to have a potential different from that of the ground. *Syn:* **alive, current carrying, hot, live.**

**3.1.104 equipotential:** An identical state of electrical potential for two or more items.

**3.1.105 equipotential work zone (area, site):** A work zone (area, site) where all equipment is interconnected by jumpers, grounds, ground rods, and/or grids that will provide acceptable potential differences between all parts of the zone under worst-case conditions of energization.

**3.1.106 explosives:** Mixtures of solids, liquids, or a combination of the two that, upon detonation, transform almost instantaneously into other products that are mostly gaseous and that occupy much greater volume than the original mixtures. This transformation generates heat, which rapidly expands the gases, causing them to exert enormous pressure. Dynamite and Primacord are explosives as manufactured. Aerex, Triex, and Quadrex are manufactured in two components and are not true explosives until mixed. Explosives are commonly used to build construction roads, blast holes for anchors, structure footings, etc. *Syn:* **Aerex, dynamite, fertilizer, powder, Primacord, Quadrex, Triex.**

**3.1.107 fault (components):** A physical condition that causes a device, a component, or an element to fail to perform in a required manner, for example, a short-circuit, a broken wire, and an intermittent connection.

**3.1.108 fault current (general):** A current that flows from one conductor to ground or to another conductor owing to an abnormal connection (including an arc) between the two. A fault current flowing to ground may be called a ground fault current.

**3.1.109 fertilizer:** *See* **explosives.**


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**3.1.110 finger line:** A lightweight line, normally sisal, manila, or synthetic fiber rope, that is placed over the traveler when it is hung. It usually extends from the ground and passes through the traveler and back to the ground. It is used to thread the end of the pilot line or pulling line over the traveler and eliminates the need for workmen on the structure. These lines are not required if pilot lines are installed when the travelers are hung. *Syn:* **finger rope.**

**3.1.111 finger rope:** *See* **finger line.**

**3.1.112 four bolt:** *See* **conductor grip.**

**3.1.113 grip:** *See* **conductor grip.**

**3.1.114 ground (earth) (ground system):** A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.

NOTE—It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting body current to and from the earth (or the conducting body).

**3.1.115 ground chain:** *See* **structure base ground.**

**3.1.116 ground electrode:** *See* **ground rod.**

**3.1.117 ground gradient mat:** *See* **ground grid.**

**3.1.118 ground grid:** A system of interconnected bare conductors arranged in a pattern over a specified area either on or buried below the surface of the earth. Normally, it is bonded to ground rods driven around and within its perimeter to increase its grounding capabilities and provide convenient connection points for grounding devices. The primary purpose of the grid is to provide safety for workmen by limiting potential differences within its perimeter to safe levels in case of high currents that could flow if the circuit being worked became energized for any reason or if an adjacent energized circuit faulted. Metallic surface mats and gratings are sometimes utilized for this same purpose. When used, these grids are employed at pull, tension, and midspan splice sites. *Syn:* **counterpoise, ground gradient mat, ground mat.**

**3.1.119 ground mat:** *See* **ground grid.**

**3.1.120 ground rod:** A rod that is driven into the ground to serve as a ground terminal, such as a copper-clad rod, solid copper rod, galvanized iron rod, or galvanized iron pipe. Copper-clad steel rods are commonly used during conductor stringing operations to provide a means of obtaining an electrical ground using portable grounding devices. *Syn:* **ground electrode.**

**3.1.121 ground roller:** *See* **running ground.**

**3.1.122 ground source:** *See* **ground (earth).**

**3.1.123 ground stick:** *See* **personal ground.**

**3.1.124 ground system (general):** Consists of all interconnected grounding connections in a specific area. *Syn:* **grounding system.**

**3.1.125 grounded (conductor stringing equipment):** Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.

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**3.1.126 grounding clamp:** A device used in making a connection between the electrical apparatus or conductors and the ground bus or grounding electrode.

**3.1.127 guard structure:** *See* **crossing structure.**

**3.1.128 H-frame:** *See* **crossing structure.**

**3.1.129 hard line:** *See* **pulling line.**

**3.1.130 hoist:** An apparatus for moving a load by the application of a pulling force and not including a car or platform running in guides. These devices are normally designed using roller or link chain and built-in leverage to enable heavy loads to be lifted or pulled. They are often used to deadend a conductor during sagging and clipping-in operations and during the tensioning of guys. *Syn:* **chain hoist, chain tugger, Coffing, Coffing hoist, drum puller.**

**3.1.131 hold-down block:** A device designed with one or more single groove sheaves to be placed on the conductor and used as a means of holding it down. This device functions essentially as a traveler used in an inverted position. It is normally used in midspan to control conductor uplift caused by stringing tensions, or at splicing locations to control the conductor as it is allowed to rise after splicing is completed. *Syn:* **splice release hold-down block roller, hold-down traveler.**

**3.1.132 hold-down roller:** *See* **hold-down block.**

**3.1.133 hold-down traveler:** *See* **hold-down block.**

**3.1.134 hook ladder:** *See* **tower ladder.**

**3.1.135 hose clamp:** *See* **strand restraining clamp.**

**3.1.136 hot:** *See* **energized.**

**3.1.137 hub:** A reference point established through a land survey. A hub or point on tangent (POT) is a reference point for use during construction of a line. The number of such points that are established will vary with the job requirements. Monuments, however, are usually associated with state or federal surveys and are intended to be permanent reference points. Any of these points may be used as a reference point for transit sagging operations, provided that all necessary data pertaining to them is known. It is quite common to establish additional temporary hubs as required for this purpose. *Syn:* **monument, point on tangent.**

**3.1.138 Insulated Cable Engineers Association:** Founded in 1925, the Insulated Cable Engineers Association is a professional society of insulated cable engineers to promote the reliability of covered and insulated conductors for the transmission and distribution of electric energy, control, and instrumentation of equipment and communications.

**3.1.139 insulated ground stick:** An insulated rod, fabricated from fiberglass reinforced plastic, with specialized connection hardware, operating mechanism, and of sufficient length to allow for safe gripping and installation of grounding clamps.

**3.1.140 insulator lifter:** A device designed to permit insulators to be lifted in a string to their intended position on a structure. *Syn:* **insulator saddle, potty seat.**

**3.1.141 insulator saddle:** *See* **insulator lifter.**


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**3.1.142 isolated: (1)** Physically separated, electrically and mechanically, from all sources of electrical energy. Such separation may not eliminate the effects of electrical induction. **(2)** An object that is not readily accessible to persons unless special means for access are used.

**3.1.143 Jacob's ladder:** *See* **rope ladder.**

**3.1.144 jumper: (1)** The conductor that connects the conductors on opposite sides of a deadend structure. *Syn:* **deadend loop. (2)** A conductor placed across the clear space between the ends of two conductors or metal pulling lines that are being spliced together. Its purpose, then, is to act as a shunt to prevent workers from accidentally placing themselves in series between the two conductors.

**3.1.145 Kellem:** *See* **conductor grip, woven wire grip.**

**3.1.146 Klein:** *See* **conductor grip.**

**3.1.147 leader:** *See* **pilot line.**

**3.1.148 leader cone:** A tapered cone made of rubber, neoprene, or polyurethane that is used to lead a conductor splice through the travelers, thus making a smooth transition from the smaller diameter conductor to the larger diameter splice. It is also used at the connection point of the pulling line and running board to assist in a smooth transition of the running board over the travelers, thus significantly reducing the shock loads. *Syn:* **nose cone, tapered hose.**

**3.1.149 lead line:** *See* **pilot line.**

**3.1.150 level:** *See* **transit.**

**3.1.151 life line:** *See* **safety life line.**

**3.1.152 lifting shoe:** *See* **conductor lifting hook.**

**3.1.153 light line:** *See* **pulling line.**

**3.1.154 lineperson's platform:** A device designed to be attached to a wood pole or metal structure, or both, to serve as a supporting surface for workers engaged in deadending operations, clipping-in, insulator work, etc. The designs of these devices vary considerably. Some resemble short cantilever beams, others resemble swimming pool diving boards, and still others as long as 12 m are truss structures resembling bridges. Materials commonly used for fabrication are wood, fiberglass, and metal. *Syn:* **Baker board, D-board, deadend board, deadend platform, diving board.**

**3.1.155 link:** *See* **connector link.**

**3.1.156 lip:** *See* **conductor lifting hook.**

**3.1.157 live:** *See* **energized.**

**3.1.158 load binder:** A toggle device designed to secure loads in a desired position. It is normally used to secure loads on mobile equipment. *Syn:* **binder, chain binder.**

**3.1.159 load cell:** *See* **dynamometer**.

**3.1.160 logger:** *See* **wheel tractor.**

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**3.1.161 magnetic field induction (inductive coupling):** The process of generating voltages and/or currents in conductive objects or electric circuits by the induction process that results from time-varying quasi-static magnetic fields.

NOTES:

1—"Magnetic field induction" was formerly called "electromagnetic induction." This usage is now deprecated because electromagnetic induction refers to the combined electric and magnetic field effects.

2—The term "magnetic field induction" is preferred over "magnetic induction" because the latter may be taken to mean magnetic flux density.

3—The fields in the vicinity of a transmission line can be adequately described as an electric field and a magnetic field. Electromagnetic may imply one or both of these fields. There should be no questions as to what is meant when the electric field or the magnetic field is discussed.

**3.1.162 marker:** *See* **plumb marker pole.**

**3.1.163 master ground:** A portable device designed to short circuit and connect (bond) a de-energized circuit or piece of equipment, or both, to an electrical ground. Normally located remote from, and on both sides of, the immediate work site. The master ground is primarily used to provide safety for personnel during construction, and during reconstruction, it is used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Syn:* **ground set, ground stick.**

**3.1.164 moving ground:** *See* **running ground.**

**3.1.165 monkey tail:** *See* **running board.**

**3.1.166 monument:** *See* **hub.**

**3.1.167 nose cone:** *See* **leader cone.**

**3.1.168 off-road vehicle:** A vehicle specifically designed and equipped to traverse sand, swamps, muddy tundra, or rough mountainous terrain. Vehicles falling into this category are usually all wheel drive or tracked units. In some cases, units equipped with special air bag rollers having a soft footprint are utilized. *Syn:* **all terrain vehicle, swamp buggy.**

**3.1.169 offset marker (pole):** *See* **plumb marker pole.**

**3.1.170 Optical Ground Wire:** Concentric-lay-stranded composite conductor for use as overhead groundwire with telecommunication capability. The conductor is constructed with a central optical fiber core surrounded by helically laid aluminum-clad wires, aluminum alloy wires, galvanized steel wires, or combinations thereof.

**3.1.171 outage:** *See* **clearance.**

**3.1.172 overhead groundwire (lightning protection):** Multiple grounded wire or wires placed above phase conductors for the purpose of intercepting direct strokes in order to protect the phase conductors from the direct strokes. *Syn:* **earth wire, shield wire, skywire, static wire.**

**3.1.173 payout site:** *See* **tension site.**

**3.1.174 peanut:** *See* **rope connector.**

**3.1.175 permit:** *See* **clearance.**


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**3.1.176 personal ground:** A portable device designed to connect (bond) a de-energized conductor or piece of equipment, or both, to an electrical ground. It is distinguished from a master ground in that it is utilized at the immediate site when work is to be performed on a conductor or piece of equipment that could accidentally become energized. *Syn:* **ground stick, working ground, red head.**

**3.1.177 pilot line:** A lightweight line, normally synthetic fiber rope, used to pull heavier pulling lines that, in turn, are used to pull the conductor. Pilot lines may be installed with the aid of finger lines or by helicopter when the insulators and travelers are hung *Syn:* **lead line, leader, P-line, sock line, straw line.**

**3.1.178 pilot-line winder:** A device designed to payout and rewind pilot lines during stringing operations. It is normally equipped with its own engine, which drives a drum or a supporting shaft for a reel mechanically, hydraulically, or through a combination of both. These units are usually equipped with multiple drums or reels, depending upon the number of pilot lines required. The pilot line is payed out from the drum or reel, pulled through the travelers in the sag section, and attached to the pulling line on the reel stand or drum puller. It is then rewound to pull the pulling line through the travelers. A pilot-line winder can be a unit similar to a bullwheel puller and often has the reel winder as an integral part of the machine. *Syn:* **insulator saddle.** *See* **insulator lifter.**

**3.1.179 pilot rope:** *See* **pilot line.**

**3.1.180 platform:** *See* **aerial platform.**

**3.1.181 P-line:** *See* **pilot line.**

**3.1.182 plier clamp:** *See* **strand restraining clamp.**

**3.1.183 plumb mark:** A mark placed on the conductor located vertically below the insulator point of support for steel structures and vertically above the pole center line at ground level for wood pole structures used as a reference to locate the center of the suspension clamp.

**3.1.184 plumb marker pole:** A small diameter, lightweight pole with a marking device attached to one end, having sufficient length to enable a worker to mark the conductor directly below him/her from a position on the bridge or arm of the structure. This device is utilized to mark the conductor immediately after completion of sagging. *Syn:* **marker, offset marker (pole).**

**3.1.185 pocketbook:** *See* **conductor grip.**

**3.1.186 point on tangent:** *See* **hub.**

**3.1.187 potty seat:** *See* **insulator lifter.**

**3.1.188 powder:** *See* **explosives.**

**3.1.189 Primacord:** *See* **explosives.**

**3.1.190 protector joint:** A split sleeve that fits over a conductor compression joint used to protect the joint from bending or damage if the joint must pass through travelers. The joint protector usually has split rubber collars at each end to protect the conductor from damage where it exits at each end of the sleeve.

**3.1.191 pull setting:** *See* **sag section.**

**3.1.192 pull site:** The location on the line where the puller, reel winder, and anchors (snubs) are located. This site may also serve as the pull or tension site for the next sag section. *Syn:* **reel setup, tugger setup.**

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**3.1.193 puller:** *See* **bullwheel puller.**

**3.1.194 puller, two drum, three drum:** The definition and application for this unit is essentially the same as that for the drum puller. It differs in that this unit is equipped with two or three drums and thus can pull one, two, or three conductors individually or simultaneously. *See* **drum puller.** *Syn:* **double drum hoist, triple drum hoist, double drum winch, three drum winch, triple drum winch, two drum winch, tugger.**

**3.1.195 pulley:** *See* **sheave.**

**3.1.196 pulling line:** A high-strength line, normally synthetic fiber rope or wire rope, used to pull the conductor. However, on reconstruction jobs in which a conductor is being replaced, the old conductor often serves as the pulling line for the new conductor. In such cases, the old conductor must be closely examined for any damage prior to the pulling operations. *Syn:* **bull line, hard line, light line, sock line, pulling rope.**

**3.1.197 pulling rope:** *See* **pulling line.**

**3.1.198 pulling vehicle:** Any piece of mobile ground equipment capable of pulling pilot lines, pulling lines, or conductors. However, helicopters may be considered as a pulling vehicle when utilized for the same purpose.

**3.1.199 quad-bundle:** *See* **Bundle, two-conductor, three-conductor, four-conductor, multi-conductor.**

**3.1.200 Quadrex:** *See* **explosives.**

**3.1.201 red head:** *See* **personal ground.**

**3.1.202 reel puller:** A device designed to pull a conductor during stringing operations. It is normally equipped with its own engine, which drives the supporting shaft for the reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, drives the reel. The application of this unit is essentially the same as that for the drum puller. Some of these devices function as either a puller or tensioner. *See* **drum puller.**

**3.1.203 reel setup:** *See* **pull site, tension site.**

**3.1.204 reel stand:** A device designed to support one or more conductor or groundwire reels having the possibility of being skid, trailer, or truck mounted. These devices may accommodate rope or conductor reels of varying sizes and are usually equipped with reel brakes to prevent the reels from turning when pulling is stopped. They are used for either slack or tension stringing. The designation of reel trailer or reel truck implies that the trailer or truck has been equipped with a reel stand (jacks) and may serve as a reel transport or payout unit, or both, for stringing operations. Depending upon the sizes of the reels to be carried, the transporting vehicles may range from single-axle trailers to semi trucks with trailers having multiple axles. *Syn:* **reel trailer, reel transporter, reel truck.**

**3.1.205 reel trailer:** *See* **reel stand.**

**3.1.206 reel transporter:** *See* **reel stand.**

**3.1.207 reel truck:** *See* **reel stand.**

**3.1.208 reel winder:** A device designed to serve as a recovery unit for a pulling line. It is normally equipped with its own engine, which drives a supporting shaft for a reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, drives the reel. It is normally used to rewind a pulling line as it leaves the bullwheel puller during stringing operations. This unit is not intended to serve as a puller, but sometimes serves this function where only low tensions are involved. *Syn:* **takeup reel.**


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**3.1.209 restriction:** *See* **clearance.**

**3.1.210 retarder:** *See* **bullwheel tensioner.**

**3.1.211 rider structure:** *See* **crossing structure.**

**3.1.212 roller:** *See* **sheave.**

**3.1.213 rolling ground:** *See* **running ground, traveler ground.**

**3.1.214 rope connector:** A special high strength steel link used to join two lengths of pulling rope by means of the eye splice at each end. Although designed to pass easily through the grooves of the bullwheels on the puller, it should not be passed under full load. *Syn:* **peanut.**

**3.1.215 rope ladder:** A ladder having vertical synthetic or manila suspension members and wood, fiberglass, or metal rungs. The ladder is suspended from the arm or bridge of a structure to enable workers to work at the conductor level, hang travelers, perform clipping-in operations, etc. *Syn:* **Jacob's ladder.**

**3.1.216 ruling span:** A calculated span length that will have the same changes in conductor tension due to changes of temperature and conductor loading as will be found in a series of spans of varying lengths between deadends.

**3.1.217 running board:** A pulling device designed to permit stringing more than one conductor simultaneously with a single pulling line. For distribution stringing, it is usually made of lightweight tubing with the forward end curved gently upward to provide smooth transition over pole crossarm rollers. For transmission stringing, the device is either made of sections hinged transversely to the direction of pull or of a hard nose rigid design, both having a flexible pendulum tail suspended from the rear. This configuration stops the conductors from twisting together and permits smooth transition over the sheaves of bundle travelers. *Syn:* **alligator, bird, birdie, monkey tail, sled.**

**3.1.218 running ground:** A portable device designed to connect a moving conductor or wire rope, or both, to an electrical ground. These devices are normally placed on the conductor or wire rope adjacent to the pulling and tensioning equipment located at either end of a sag section. They are primarily used to provide safety for personnel during construction or reconstruction operations. *Syn:* **ground roller, moving ground, rolling ground, traveling ground.**

**3.1.219 safety life line:** A safety device normally constructed from synthetic fiber rope and designed to be connected between a fixed object and the body belt of a worker working in an elevated position when his/her regular safety strap cannot be utilized. *Syn:* **life line, safety line, scare rope.**

**3.1.220 safety line:** *See* **safety life line.**

**3.1.221 sag:** The distance measured vertically from a conductor to the straight line joining two points of support. Unless otherwise stated, the sag referred to is at the midpoint of the span.

**3.1.222 sag board:** *See* **target sag.**

**3.1.223 sag section:** The section of line between snub structures. More than one sag section may be required in order to sag properly the actual length of conductor that has been strung. *Syn:* **pull setting, stringing section.**

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**3.1.224 sag span:** A span selected within a sag section and used as a control to determine the proper sag of the conductor, thus establishing the proper conductor level and tension. A minimum of two, but normally three, sag spans are required within a sag section in order to sag properly. In mountainous terrain or where span lengths vary radically, more than three sag spans could be required within a sag section. *Syn:* **control span.**

**3.1.225 sag target:** A device used as a reference point to sag conductors. It is placed on one structure of the sag span. The sagger, on the other structure of the sag span, can use it as a reference to determine the proper conductor sag. *Syn:* **sag board, target.**

**3.1.226 sagger:** *See* **wheel tractor.**

**3.1.227 scare rope:** *See* **safety life line.**

**3.1.228 scope:** *See* **transit.**

**3.1.229 secondary shock:** A shock of a magnitude such that it will not produce direct physiological harm, but may cause involuntary muscle reactions. The results of secondary shock are annoyance, alarm, and aversion (see [B7] and [B27]).

**3.1.230 self-damping conductor:** An aluminum conductor steel reinforced that is designed to control aeolian vibration by integral damping. Trapezoidal aluminum wires and annular gaps are utilized.

**3.1.231 set of fives:** *See* **block.**

**3.1.232 set of fours:** *See* **block.**

**3.1.233 set of sixes:** *See* **block.**

**3.1.234 seven bolt:** *See* **conductor grip.**

**3.1.235 shaped wire compact conductor:** *See* **trapezoidal wire.**

**3.1.236 sheave: (1)** The grooved wheel of a traveler or rigging block. Travelers are frequently referred to as sheaves. *Syn:* **pulley, roller, wheel, traveler. (2)** A shaft-mounted wheel used to transmit power by means of a belt, chain, band, etc.

**3.1.237 sheave ground:** *See* **traveler ground.**

**3.1.238 shield wire:** *See* **overhead groundwire.**

**3.1.239 single drum hoist:** *See* **drum puller.**

**3.1.240 single drum winch:** *See* **drum puller.**

**3.1.241 site marker:** *See* **transit.**

**3.1.242 six bolt:** *See* **conductor grip.**

**3.1.243 skidder:** *See* **wheel tractor.**

**3.1.244 Skookum:** *See* **snatch block.**

**3.1.245 skywire:** *See* **overhead groundwire.**


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**3.1.246 slack stringing:** The method of stringing conductor slack without the use of a tensioner. The conductor is pulled off the reel by a pulling vehicle and is dragged along the ground, or the reel is carried along the line on a vehicle and the conductor is deposited on the ground. As the conductor is dragged to, or past, each supporting structure, the conductor is placed in the travelers, normally with the aid of finger lines.

**3.1.247 sled:** *See* **running board.**

**3.1.248 sleeve:** *See* **compression joint.**

**3.1.249 sleeving trailer:** *See* **splicing cart.**

**3.1.250 slip-grip:** *See* **conductor grip.**

**3.1.251 slug:** *See* **connector link.**

**3.1.252 snatch block:** A device normally designed with a single sheave, wood or metal shell, and hook. One side of the shell usually opens to eliminate the need for threading of the line. It is commonly used for lifting loads on a single line or as a device to control the position or direction, or both, of a fall line or pulling line. *Syn:* **Skookum, Washington, Western.**

**3.1.253 snub:** *See* **anchor.**

**3.1.254 snub structure:** A structure located at one end of a sag section and considered as a zero point for sagging and clipping offset calculations. The section of line between two such structures is the sag section, but more than one sag section may be required in order to sag properly the actual length of conductor that has been strung. *Syn:* **O structure, zero structure.**

**3.1.255 sock:** *See* **woven wire grip.**

**3.1.256 sock line:** *See* **pulling line.**

**3.1.257 spacer buggy:** *See* **conductor car.**

**3.1.258 spacer cart:** *See* **conductor car.**

**3.1.259 spacing bicycle:** *See* **conductor car.**

**3.1.260 splice:** *See* **compression joint.**

**3.1.261 splice release block:** *See* **hold-down block.**

**3.1.262 splice site:** The location along the line where the conductors are temporarily anchored to join the conductors together to form a splice.

**3.1.263 splicing cart:** A unit that is equipped with a hydraulic compressor (press) and all other necessary equipment for performing splicing operations on conductor. *Syn:* **sleeving trailer, splicing trailer, splicing truck.**

**3.1.264 splicing trailer:** *See* **splicing cart.**

**3.1.265 splicing truck:** *See* **splicing cart.**

**3.1.266 static charge:** Any electric charge at rest, e.g., charge on capacitor. Static charge is often loosely used to describe discharge conditions resulting from electric field coupling.

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**3.1.267 static wire:** *See* **overhead groundwire.**

**3.1.268 step potential:** *See* **step voltage.**

**3.1.269 step voltage:** The potential difference between two points on the earth's surface separated by a distance of one pace (assumed to be 1 m) in the direction of maximum potential gradient. This potential difference could be dangerous when current flows through the earth or material upon which a worker is standing, particularly under fault conditions. *Syn:* **step potential.**

**3.1.270 strand restraining clamp:** An adjustable circular clamp commonly used to keep the individual strands of a conductor in place and to prevent them from spreading when the conductor is cut. *Syn:* **block, cable binding, hose clamp, plier clamp, vise grip.**

**3.1.271 straw line:** *See* **pilot line.**

**3.1.272 stringing:** The pulling of pilot lines, pulling lines, and conductors over travelers supported on structures of overhead transmission lines. Quite often, the entire job of stringing conductors is referred to as stringing operations, beginning with the planning phase and terminating after the conductors have been installed in the suspension clamps.

**3.1.273 stringing block:** *See* **traveler.**

**3.1.274 stringing section:** *See* **sag section.**

**3.1.275 stringing sheave:** *See* **traveler.**

**3.1.276 stringing traveler:** *See* **traveler.**

**3.1.277 structure:** *See* **snub structure.**

**3.1.278 structure base ground:** A portable device designed to connect (bond) a metal structure to an electrical ground. It is primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations. *Syn:* **butt ground, ground chain, structure ground, tower ground.**

**3.1.279 structure ground:** *See* **ground structure base.**

**3.1.280 suitcase:** *See* **conductor grip.**

**3.1.281 swamp buggy:** *See* **off-road vehicle.**

**3.1.282 switching surge:** A transient wave of overvoltage in an electrical circuit caused by a switching operation. When this occurs, a momentary voltage surge could be induced in a circuit adjacent and parallel to the switched circuit in excess of the voltage induced normally during steady state conditions. If the adjacent circuit is under construction, switching operations should be minimized to reduce the possibility of hazards to the workmen.

**3.1.283 swivel:** *See* **swivel link.**

**3.1.284 swivel link:** A swivel device designed to connect pulling lines and conductors together in series or to connect one pulling line to the drawbar of a pulling vehicle. The device will spin and help relieve the torsional forces that build up in the line or conductor under tension. *Syn:* **swivel.**


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**3.1.285 T-2™ :** A two-conductor twisted construction designed to control wind-induced motion.
NOTE—T-2 Conductor is a registered trademark of CPI, Consumer Products, Inc. a wholly owned subsidiary of Reynolds Metals Company.

**3.1.286 tag line:** A control line, normally manila or synthetic fiber rope, attached to a suspended load to enable a worker to control its movement. *Syn:* **tag rope.**

**3.1.287 tag rope:** *See* **tag line.**

**3.1.288 takeup reel:** *See* **reel winder.**

**3.1.289 tapered hose:** *See* **leader cone.**

**3.1.290 target:** *See* **target sag.**

**3.1.291 temporary structure:** *See* **crossing structure.**

**3.1.292 tension site:** The location on the line where the tensioner, reel stands, and anchors (snubs) are located. This site may also serve as the pull or tension site for the next sag section. *Syn:* **conductor payout station, payout site, reel setup.**

**3.1.293 tension stringing:** The use of pullers and tensioners to keep the conductor under tension and positive control during the stringing phase, thus keeping it clear of the earth and other obstacles that could cause damage.

**3.1.294 tensioner:** *See* **bullwheel tensioner.**

**3.1.295 threading line:** A lightweight flexible line, normally manila or synthetic fiber rope, used to lead a conductor through the bullwheels of a tensioner or pulling line through a bull wheel puller. *Syn:* **bull line, threading rope.**

**3.1.296 threading rope:** *See* **threading line.**

**3.1.297 three drum winch:** *See* **puller, two drum, three drum.**

**3.1.298 touch potential:** *See* **touch voltage.**

**3.1.299 touch voltage:** The potential difference between a grounded metallic structure and a point on the earth's surface separated by a distance equal to the normal maximum horizontal reach, approximately 1 m. This potential difference could be dangerous and could result from induction or fault conditions, or both. *Syn:* **touch potential.**

**3.1.300 tower ground:** *See* **structure base ground.**

**3.1.301 tower ladder:** A ladder complete with hooks and safety chains attached to one end of the side rails. These units are normally fabricated from fiberglass, wood, or metal. The ladder is suspended from the arm or bridge of a structure to enable workers to work at the conductor level, to hang travelers, perform clipping-in operations, etc. In some cases, these ladders are also used as lineperson's platforms. *Syn:* **hook ladder.**

**3.1.302 tractor:** *See* **crawler tractor, wheel tractor.**

**3.1.303 transit:** An instrument primarily used during construction of a line to survey the route, to set hubs and point on tangent (POT) locations, to plumb structures, to determine downstrain angles for locations of anchors at the pull and tension sites, and to sag conductors. *Syn:* **level, scope, site marker.**

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**3.1.304 trapezoidal wire:** Conductors that are designed to increase the aluminum area for a given diameter of conductor by the use of trapezoidal shaped aluminum wires.

**3.1.305 traveler:** A sheave complete with suspension arm or frame used separately or in groups and suspended from structures to permit the stringing of conductors. These devices are sometimes bundled with a center drum or sheave and another traveler, and are used to string more than one conductor simultaneously. For protection of conductors that should not be nicked or scratched, the sheaves are often lined with nonconductive or semi conductive neoprene or nonconductive urethane. Any one of these materials acts as a padding or cushion for the conductor as it passes over the sheave. Traveler grounds must be used with lined travelers in order to establish an electrical ground. *Syn:* **block, dolly, sheave, stringing block, stringing sheave, stringing traveler.**

**3.1.306 traveler ground:** A portable device designed to connect a moving conductor or wire rope, or both, to an electrical ground. It is primarily used to provide safety for personnel during construction or reconstruction operations. This device is placed on the traveler (sheave, block, etc.) at a strategic location where an electrical ground is required. *Syn:* **block ground, rolling ground, sheave ground.**

**3.1.307 traveler rack:** A device designed to protect, store, and transport travelers. It is normally designed to permit efficient use of transporting vehicles, spotting by helicopters on the line, and stacking during storage to utilize space. The exact design of each rack is dependent upon the specific travelers to be stored. *Syn:* **dolly car.**

**3.1.308 traveler sling:** A sling of wire rope, sometimes utilized in place of insulators, to support the traveler during stringing operations. Normally, it is used when insulators are not readily available or when adverse stringing conditions might impose severe downstrains and cause damage or complete failure of the insulators. *Syn:* **choker.**

**3.1.309 traveling ground:** *See* **running ground.**

**3.1.310 tri-bundle:** *See* **Bundle, two-conductor, three-conductor, four-conductor, multi-conductor.**

**3.1.311 Triex:** *See* **explosives.**

**3.1.312 triple drum hoist:** *See* **puller, two drum, three drum.**

**3.1.313 triple drum winch:** *See* **puller, two drum, three drum.**

**3.1.314 tugger:** *See* **drum puller; puller, two drum, three drum.**

**3.1.315 tugger setup:** *See* **pull site.**

**3.1.316 twin-bundle:** *See* **Bundle, two-conductor, three-conductor, four-conductor, multi-conductor.**

**3.1.317 two drum winch:** *See* **puller, two drum, three drum.**

**3.1.318 uplift roller:** A small single-grooved wheel designed to fit in or immediately above the throat of the traveler and keep the pulling line in the traveler groove when uplift occurs due to stringing tensions.

**3.1.319 vise grip:** *See* **strand restraining clamp.**

**3.1.320 Washington:** *See* **snatch block.**

**3.1.321 Western:** *See* **snatch block.**


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**3.1.322 wheel:** *See* **sheave.**

**3.1.323 wheel tractor:** A wheeled unit employed to pull pulling lines, sag conductor, and miscellaneous other work. Sagging winches on this unit are usually arranged in a horizontal configuration. It has some advantages over crawler tractors in that it has a softer footprint, travels faster, and is more maneuverable. *Syn:* **logger, sagger, skidder, tractor.**

**3.1.324 wire:** *See* **conductor.**

**3.1.325 wire mesh grip:** *See* **woven wire grip.**

**3.1.326 wire rope splice:** The point at which two wire ropes are joined together. The various methods of joining (splicing) wire ropes together include hand tucked woven splices, compression splices that utilize compression fittings but do not incorporate loops (eyes) in the ends of the ropes, and mechanical splices that are made through the use of loops (eyes) in the ends of the ropes held in place by either compression fittings or wire rope clips. The latter are joined together with connector links or steel bobs and, in some cases, are rigged eye to eye. Woven splices are often classified as short or long. A short splice varies in length from 2 to 5 m for 6 to 38 mm diameter ropes, respectively, while a long splice varies from 4 to 14 m for the same size ropes.

**3.1.327 working ground:** *See* **personal ground.**

**3.1.328 woven wire grip:** A device designed to permit the temporary joining or pulling of conductors without the need of special eyes, links, or grips. *Syn:* **basket, Chinese finger, wire mesh grip, Kellem, sock.**

**3.1.329 zero structure:** *See* **snub structure.**

## 3.2 Acronyms

AAAC all aluminum alloy conductor, concentric-lay-stranded

AAC all aluminum conductor, concentric-lay-stranded.

AACSR aluminum alloy conductor, steel reinforced

ACAR aluminum conductor, aluminum alloy reinforced

ACSR aluminum conductor, steel reinforced

ACSS aluminum conductor, steel supported

ADSS all-dielectric self supporting optical cable

ASTM American Society for Testing and Materials

ATV all terrain vehicle

AWG American Wire Gage

CU Copper conductor

FAA Federal Aviation Administration

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ICEA Insulated Cable Engineers Association

OHGW overhead groundwire

OPGW optical ground wire

SDC self-damping conductor

TW trapezoidal wire

## 4. Conductor stringing methods

Unless specifically stated otherwise, all references to the term "conductor" in this document include overhead groundwires (OHGWs). Conductor stringing systems currently employed in the power industry are almost as numerous as the organizations that string conductors. Outlined in 4.1 and 4.2 are the basic methods currently in use, but they are invariably modified to accommodate equipment readily available and the ideas and philosophies of the responsible supervisors. In addition to a description of the various methods being used are comments relative to application and a listing of equipment applicable to each method. This list is not all inclusive since, for example, a reel winder would not be necessary as a separate piece of equipment if this function is designed into the puller or tensioner being used, nor would a loader be required if the reel stand were self-loading.

### 4.1 Slack or layout method

Using this method, the conductor is dragged along the ground by means of a pulling vehicle, or the reel is carried along the line on a vehicle and the conductor is deposited on the ground. The conductor reels are positioned on reel stands or jacks, either placed on the ground or mounted on a transporting vehicle. These stands are designed to support the reel on an arbor, thus permitting it to turn as the conductor is pulled out. Usually, a braking device is provided to prevent overrunning and backlash. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor is placed in travelers attached to the structure before proceeding to the next structure.

This method is chiefly applicable to the construction of new lines in cases in which maintenance of conductor surface condition is not critical and where terrain is easily accessible to a pulling vehicle. The method is not usually economically applicable in urban locations where hazards exist from traffic or where there is danger of contact with energized circuits, nor is it practical in mountainous regions inaccessible to pulling vehicles.

Major equipment required to perform slack stringing includes reel stands, pulling vehicle(s), and a splicing cart.

### 4.2 Tension method

Using this method, the conductor is kept under tension during the stringing process. Normally, this method is used to keep the conductor clear of the ground and obstacles, which might cause conductor surface damage, and clear of energized circuits. It requires the pulling of a light pilot line into the travelers, which in turn is used to pull in a heavier pulling line. The pulling line is then used to pull in the conductors from the reel stands using specially designed tensioners and pullers. For lighter conductors, a lightweight pulling line may be used in place of the pilot line to directly pull in the conductor. A helicopter or ground vehicle can be used to pull or lay out a pilot line or pulling line. The tension method of stringing is applicable where it is desired to keep the conductor off the ground to minimize surface damage or in areas where frequent crossings are


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encountered. The amount of right-of-way travel by heavy equipment is also reduced. Usually, this method provides the most economical means of stringing conductor. The helicopter use is particularly advantageous in rugged or poorly accessible terrain.

Major equipment required for tension stringing includes reel stands, tensioner, puller, reel winder, pilot line winder, splicing cart, and helicopter or pulling vehicle.

# 5. Grounding equipment and methods

## 5.1 Protective grounding principles

A grounding system shall be established at transmission line construction sites that will provide a safe environment for the transmission line construction workers. The grounding system and equipment to be used for each situation should be established by the user knowing the degree of exposure to electrical hazards and the soil conditions for that site. Generally, the most significant hazard results from work in proximity to energized lines.

The approach used within this guide is first to present methods of protecting personnel, develop electrical concepts, and describe hazards during transmission line construction. Then, in conjunction with ASTM F855-97e1[3], specific criteria and testing requirements of the grounding equipment to be met are discussed. Next, the application of methods and equipment to the process of grounding during the installation of overhead transmission lines is described. And finally, a floppy disk, documentation, and instructions on using the computer programs are presented to aid in determining appropriate grounding equipment and grounding systems for the various situations encountered during installation of overhead transmission line conductors.

All equipment, conductors, anchors, and structures within a defined work area must be bonded together and connected to the ground electrode. The recommended procedures of personnel protection are as follows:

a) Establishment of equipotential work zones
b) Selection of grounding equipment for the worst-case fault
c) Discontinuation of all work when the possibility of lightning exists, which may affect the work site

In addition to the grounding system, the best safety precaution is to treat all equipment as if it could become energized.

## 5.2 Protection of personnel

The main concern of this guide is the protection of personnel from injury. The personnel at the work site must be protected against electric field coupling and magnetically induced voltages and currents caused by energized adjacent lines. Personnel must be protected from the hazards that result from accidental line energization or faults. Personnel protection can be achieved by placing adequate protective ground systems at the work area.

All appropriate line components and equipment within the work area should be bonded together to create an equipotential work zone. A non-conductive barrier (see Figure 6) placed around the work area (includes the ground electrode) will reduce the exposure to touch and step voltages. Grounding equipment should be selected and installed in a manner that will minimize the likelihood of cables striking personnel during fault conditions.

[3]Information on references can be found in Clause 2.

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## 5.3 Hazards and electrical concepts

### 5.3.1 Source of hazards

Electrical charges may appear on a de-energized transmission line due to one or a combination of the following factors:

a) Charges induced by electric or magnetic field coupling, or both, with energized adjacent lines especially under fault conditions and lightning strokes

b) De-energized lines accidentally energized

c) Static charge induced on de-energized lines due to atmospheric conditions

In addition to electrical hazards, there is the hazard posed by violent mechanical movements of cables during fault current exposure.

### 5.3.2 Ground protection

The purpose of grounds and grounding procedures is to reduce electrical shock hazards to an absolute minimum. Unfortunately, people who work on and around high-voltage equipment can falsely assume that only energized high-voltage circuits are really dangerous. Shocks from voltages well below 50 V can

a) Cause surprise to the extent that balance may be lost and falls may occur, with the risk of bodily injury

b) Cause an involuntary recoil so that physical contact with moving machinery may occur, with the risk of bodily injury

c) Cause a muscular paralysis so that release of grip on the source of shock cannot occur

Adequate grounding shall be established at construction work areas. The methods required and equipment used should be based on exposure to maximum system electrical hazards and soil conditions at the site.

All equipment, conductors, anchors, and structures within the work area shall be bonded together and grounded. The recommended method of personnel protection is the establishment of equipotential work zones to limit touch and step voltage to a safe level. An acceptable equipotential zone may be accomplished by the proper use of low-resistance shunts, jumpering, and grounding equipment. Grounding equipment includes personal grounds, master grounds, structure base grounds, running grounds, traveler grounds, ground grids, and ground rods. Definitions and discussions of these terms can be found in Clause 3 of this guide.

## 5.4 Grounding equipment, methods, and testing

### 5.4.1 Equipment

All grounding equipment must be sized to carry the maximum steady-state induced currents as well as the largest fault current and clearing time likely to be encountered for a time period long enough to allow the line protection system to operate. After the grounding equipment has carried fault current, all components of the grounding system should be immediately replaced, and later inspected and reconditioned, if necessary, before reuse. Ground cables that have carried fault current should be replaced and not reused.

Personal grounds, master grounds, structure base grounds, running grounds, traveler grounds, ground grids, and ground rods are devices used in a grounding system.

High-quality clamps with a steady-state and fault-current capability equal to the grounding cables should be used. They should clamp positively on the object being grounded. Clamps with serrated clamping jaw inserts are preferred to ensure proper contact.


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Resistance readings for all grounding systems should be established and all grounding electrodes used should be checked to ensure that their resistance is below an acceptable maximum value. Resistance from the main contact to the attached cable contact should be less than that for an equal length of maximum size cable(s) for which the clamp is rated.

#### 5.4.1.1 Grounding cable

Grounding cables should be flexible and be of Type I or Type II per clause 32.3 of ASTM F855-97e1. Cable size should be capable of sustaining maximum fault current, with full asymmetry, when part of a portable grounding assembly, as demonstrated by tests per clause 12.3 of ASTM F855-97e1 or per clause 6.6 of IEC 61230 (1993-09).

#### 5.4.1.2 Master ground

A master ground (see Figure 1) is a portable device designed to short circuit and connect (bond) a de-energized circuit or piece of equipment, or both, to a ground electrode. It is normally located remote from, and on both sides of, the immediate work site, and primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations.



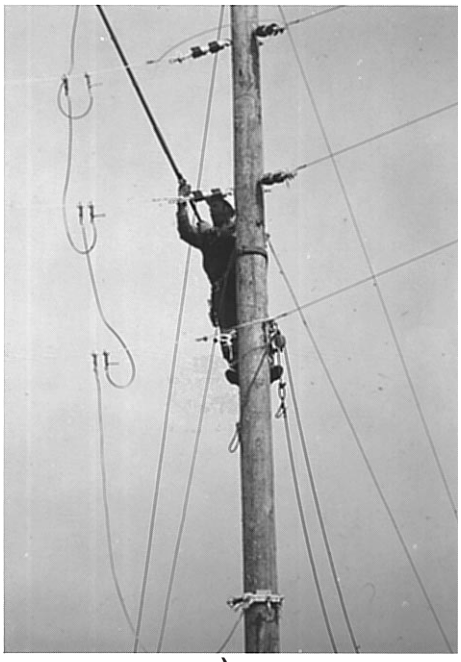
**Figure 1—Master ground**

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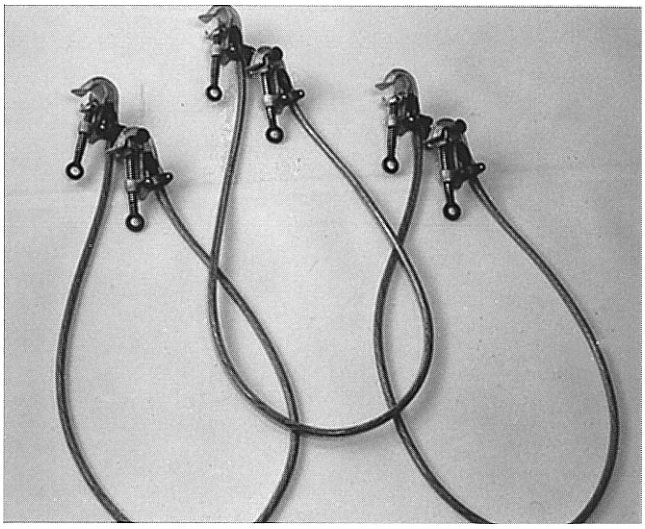

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#### 5.4.1.3 Personal ground

A personal ground (see Figure 2a and Figure 2b) is a portable device designed to connect (bond) a de-energized conductor or piece of equipment, or both, to a ground electrode. It is distinguished from a master ground in that it is utilized at the immediate site when work is to be performed on a conductor or piece of equipment that could accidentally become energized.



a)



b)

**Figure 2—Personal ground**

#### 5.4.1.4 Structure base ground

A structure base ground (see Figure 3) is a portable device designed and used to connect (bond) equipment to a metal structure. It is primarily used to provide safety for personnel during construction, reconstruction, or maintenance operations.

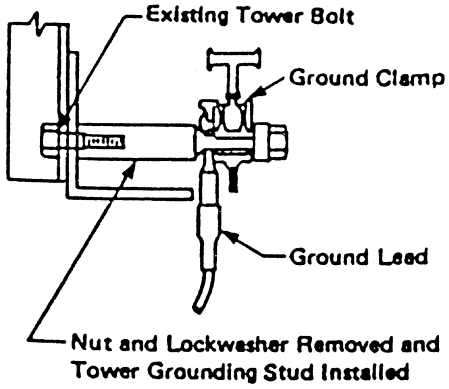



**Figure 3—Structure base ground**


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#### 5.4.1.5 Running ground

A running ground (see Figure 4) is a portable device designed to connect a moving conductor or wire rope, or both, to a ground electrode. This device is normally placed on the conductor or wire rope adjacent to the pulling and tensioning equipment located at either end of a sag section. It is primarily used to provide safety for personnel during construction or reconstruction operations.

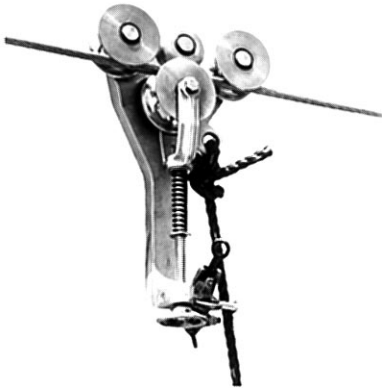
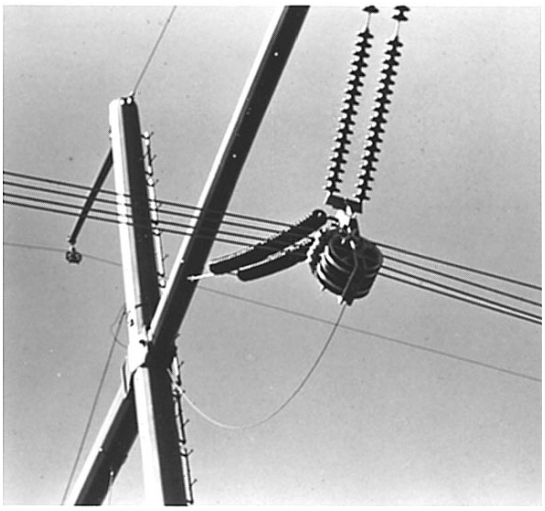


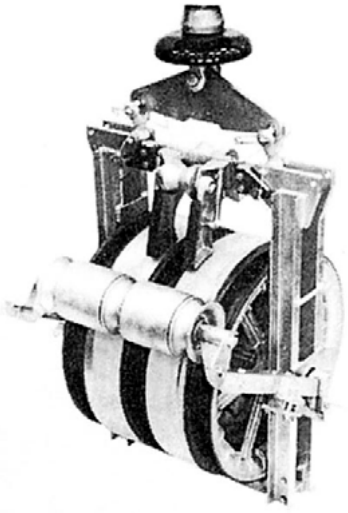
**Figure 4—Running ground**

#### 5.4.1.6 Traveler ground

A traveler ground (see Figure 5) is a portable device designed to connect a moving conductor or wire rope, or both, to a ground electrode. It is primarily used to provide safety for personnel during construction or reconstruction operations. This device is placed on the traveler (sheave, block, etc.) at strategic locations where electrical grounds are required.



**a) Application of traveler ground**



**b) Individual traveler ground**

**Figure 5—Traveler ground**

A traveler with a ground is usually sensitive to direction pull. Care shall be exercised in hanging the traveler. Usually the ground is to the pulling end. It shall be connected with temporary grounding, or to some conductive medium that is at ground potential. Care shall be taken in regard to the length of the grounding cable and

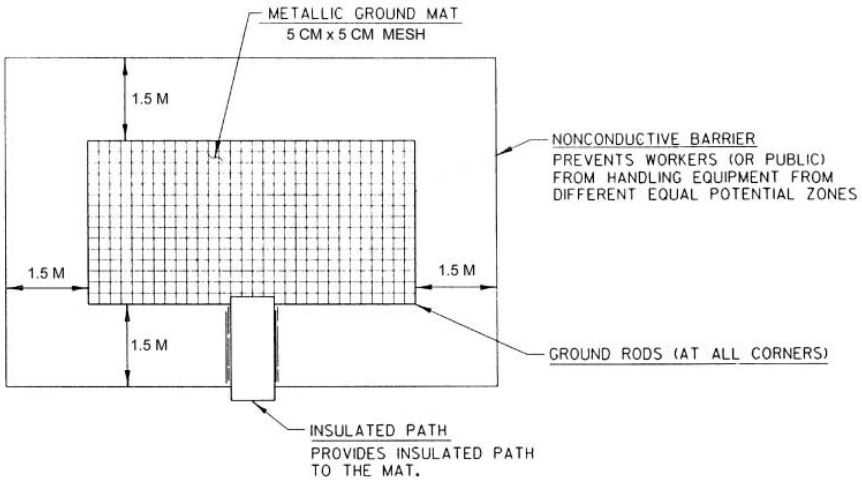
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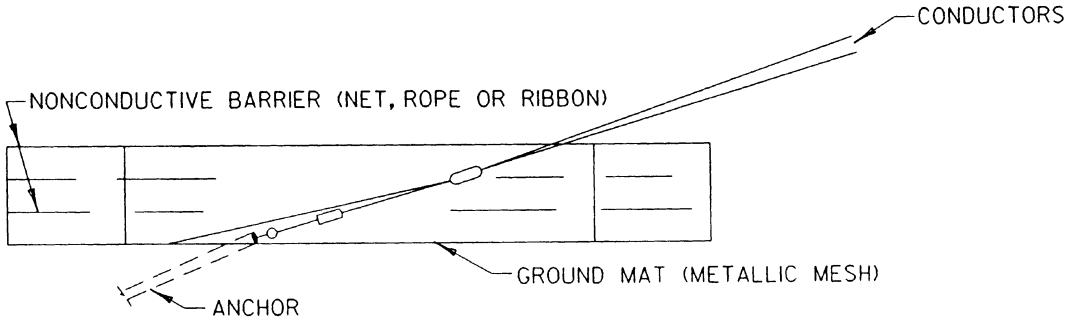
the anchor point. Too short of a cable may pull with block movement, and too long of a cable may become entangled with the sheaves and rollers, thus destroying the cable and conductor. The traveler ground should have a suitable grounding stud located in an accessible position to enable placing and removing the ground clamps, with a ground stick when necessary. The traveler ground will also help protect the sheave linings.

### 5.4.1.7 Ground grids

A ground grid (see Figure 6a and Figure 6b) is a system of interconnected bare conductors, metallic surface mats, and/or grating, arranged in a pattern over a specified area. Normally, it is bonded to ground rods driven around and within its perimeter to increase its grounding capabilities and provide convenient connection points for grounding devices. The primary purpose of the grid is to provide safety for workers by limiting potential differences within its perimeter to safe levels in case of high currents that could flow if the circuit being worked became energized for any reason or if an adjacent energized circuit faulted. When used, these grids are employed at pull, tension, and splice sites.




**a) Plan view**




**b) Elevation**

**Figure 6—Ground grid**


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### 5.4.1.8 Ground rod

A ground rod (see Figure 7) is a rod that is driven into the ground to serve as a ground terminal, such as a copper-clad rod, solid copper rod, galvanized iron rod, or galvanized iron pipe. The ground rod is commonly used during conductor stringing operations to provide a means of obtaining a ground electrode using portable grounding devices.

If a ground rod is free of paint, grease, and oil, the contact resistance between the rod and the earth is negligible. Therefore, the main resistance is contained in the body of earth immediately surrounding the ground rod.

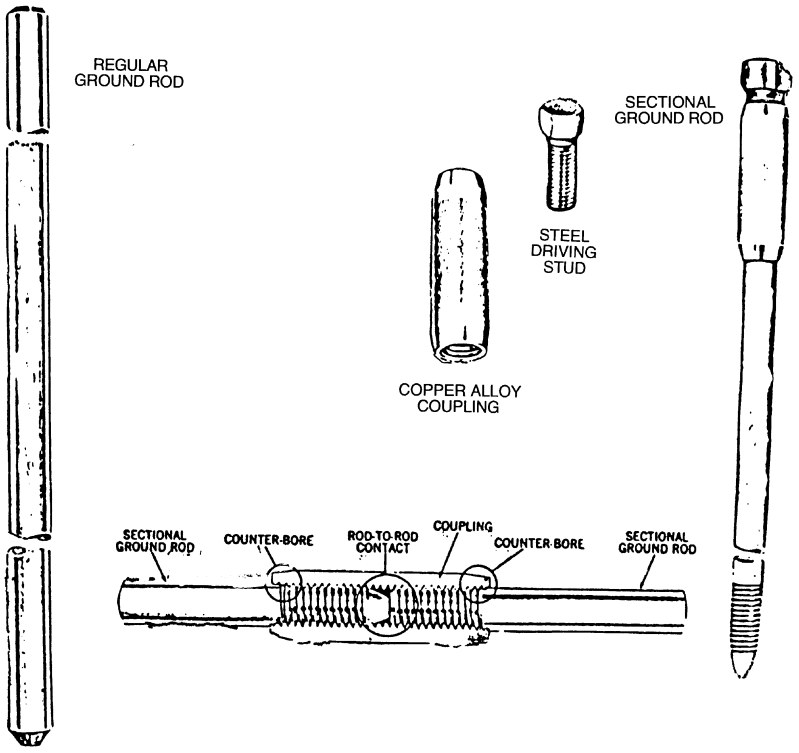



**Figure 7—Ground rods**

When a current flows from a ground rod into the earth, it flows outward in all directions. It can be assumed that the current flows through a series of concentric spherical-like shells, surrounding the ground rod (see Figure 8).

The shell immediately surrounding the electrode has the smallest cross sectional area (highest resistance); as the distance from the electrode is increased, each shell is correspondingly larger in cross section (lower resistance). Therefore, when a current flows, the voltage drop next to the ground rod is very high and decreases as it moves out from the rod.

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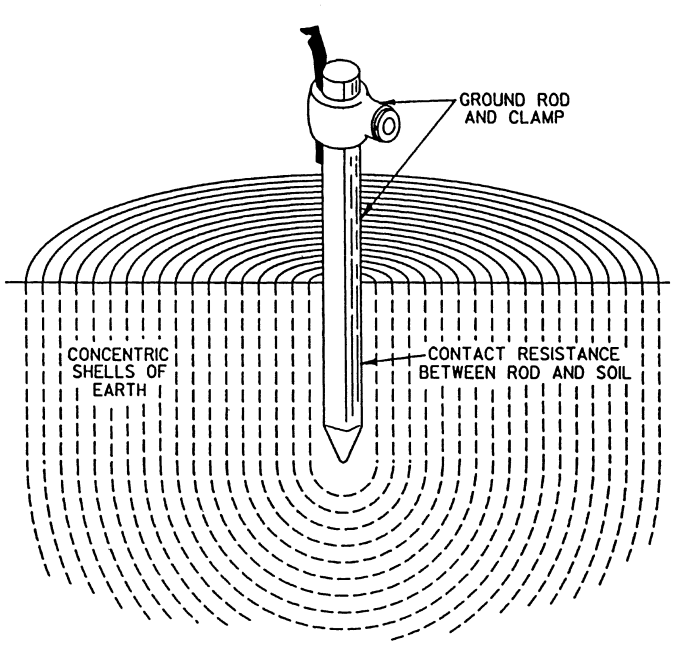



**Figure 8—Resistive components of a ground rod**

### 5.4.2 Methods

#### 5.4.2.1 Soil resistance and use of ground rods

The resistivity of the earth plays a significant role in how effectively a fault current or induced current is drained off. The resistivity of the ground varies with the type, moisture content, and temperature of the soil. These variables affect the ground resistance in a direct, proportionate relationship. Therefore, seasonal changes cause major fluctuations in the ground resistance.

A grounding system with a low resistance when the soil moisture content is high could easily exhibit an excessively high resistance and hence, an unsafe condition during the drier part of the year when the soil moisture content is very low.

The resistance of the grounding system is very important as it determines the voltage rise between the ground rods, grids, and the earth, as well as the voltage gradients that will be created when the current flows into the ground.

The following three components contribute to the resistance of the grounding system:

a) The resistance of the connections between the grounding leads, phase conductor, and the ground rod(s), and the resistance of the grounding lead itself.

b) The contact resistance between the ground rod and the soil.

c) The resistance of the body of earth immediately surrounding the rod. Of the three components involved in “resistance,” the resistance of the earth is the most critical and the most difficult to calculate and minimize.


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To achieve the best results, ground rods should be driven into undisturbed earth. The practice of placing rods adjacent to poles or footing is the least effective. Methods of installation vary from sledge hammer to sophisticated hydraulic equipment. Some types of power installation enable driving multiple sectional rods easily and effectively in undisturbed earth (see Figure 9).



a)



b)



c)



d)

**Figure 9—Power driven ground rod**

### 5.4.2.2 Effect of rod depths and multiple rods

The distance a ground rod extends into the earth has a great effect on its measured ground resistance. A shallow driven rod will usually have a high year-round resistance because of its small effective resistance area, and will always be subject to excessive seasonal variations due to varying moisture contents in the soil. Multiple sectional deep rods will have a larger effective resistance area and may approach a permanent moisture level; therefore, its resistance will be much lower.

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In effect, a series of multiple-driven rods become a set of resistances in parallel; however, the parallel resistance law is not precisely applicable (because of the concentric shells of earth are overlapping). For the best results from a practical point of view, the spacing between the rods should not be less than the depth of the individual rods.

#### 5.4.2.3 Recommended methods

The following are recommended methods on the use of ground rods in grounding:

a) Use deep driven multiple sectional ground rods where soil conditions permit or are required.

b) Use additional multiple sectional ground rods to increase the current capacity of ground electrode.

c) Add additional grounds where possible along the line under construction to decrease the current flow through the individual ground connection source.

### 5.4.3 Testing

It is essential that equipment used in grounding during stringing provide adequate performance for a given application. Therefore, determination of the equipment performance characteristics should be made either by the user or provided by the manufacturer or both. This subclause includes recommended test procedures for equipment used in overhead stringing that are not covered in other standards.

This guide makes no attempt to establish ratings, safety factors, categories, or classes of grounding equipment.

#### 5.4.3.1 Testing of grounding equipment

Grounding electrode installations for electrical equipment and systems are necessary to protect personnel and equipment. In order to accomplish this purpose the grounding installation should provide an adequately low ground resistance and be capable of conducting the available current without causing damage to itself or creating a hazard to equipment or personnel.

The currents that a grounding electrode may be required to carry can be considered to be the following:

a) Low ac of long duration—such as unbalance, low fault current, or induced current that occurs when the current is not large enough to interrupt the supply.

b) High ac of short duration—such as fault current that occurs when protective equipment operates normally.

c) Impulse current—such as surge current that occurs during a lightning stroke.

All components of the grounding system should be of a design that has been tested and proven to have adequate current-carrying capabilities as well as very low resistance.

#### 5.4.3.2 Information to be obtained from tests

In order to evaluate the operational characteristics of grounding equipment, the relationship between current levels, duration of applied current voltage drop across the device, and mechanical durability must be obtained. This information is best obtained from manufacturer's design test information.

### 5.4.4 Examples of test setups

Figure 10, Figure 11, and Figure 12 are recommended test setups for traveler grounds, running grounds, clamps, and ground rods.


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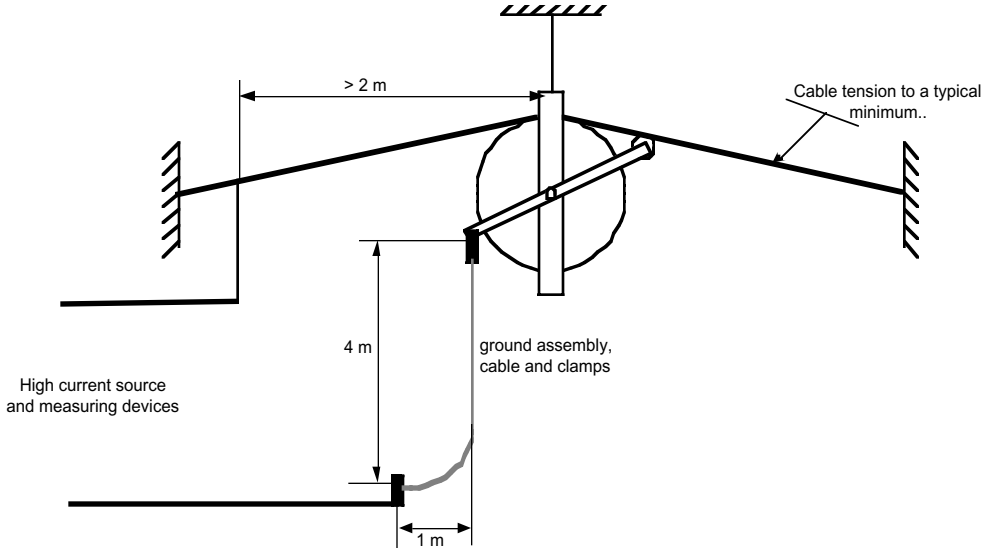



**Figure 10—Typical electrical and mechanical arrangement for testing traveler grounds**

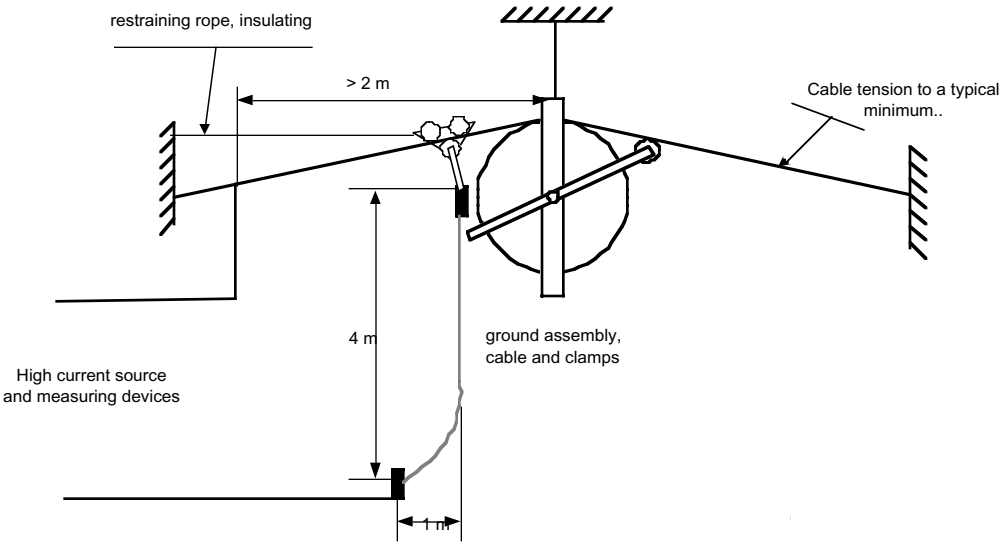



**Figure 11—Typical electrical and mechanical arrangement for testing running grounds**

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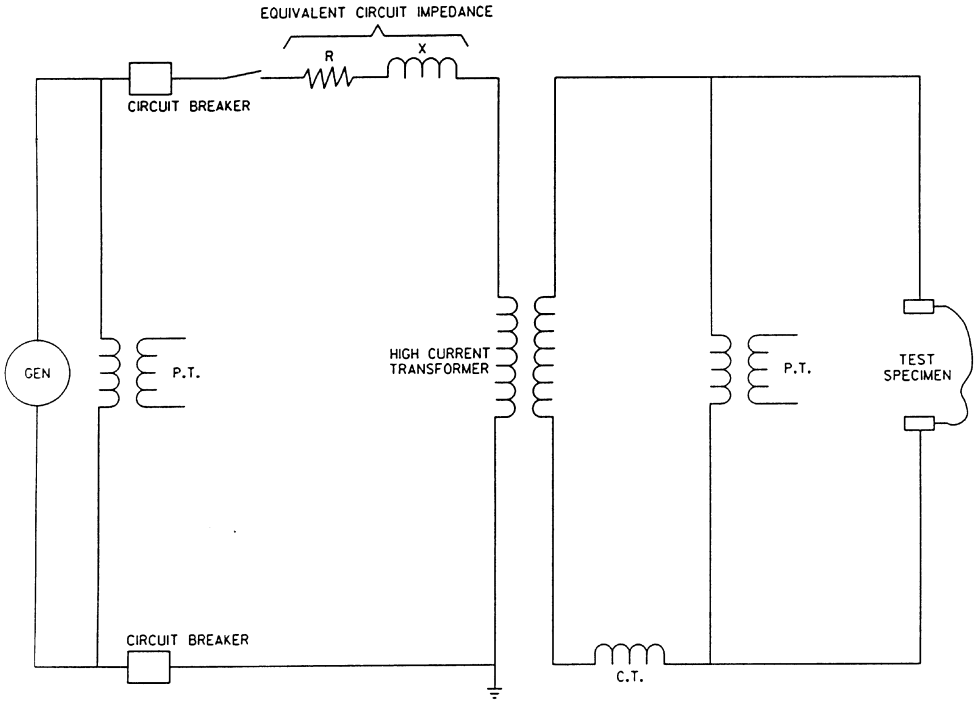



**Figure 12—Typical electrical arrangement for testing clamps**

## 5.5 Transmission line construction grounding systems

### 5.5.1 General

In order to have a totally effective grounding system, the grounding system shall

a) Protect personnel from step and touch voltages by providing an equipotential zone(s) or a low-impedance path to ground, thereby reducing step and touch voltages to an acceptable level to protect personnel and equipment.

b) Withstand and dissipate fault and surge currents.

c) Provide rugged mechanical properties.

The value of a grounding system depends on a low-resistance path. All equipment shall be kept in excellent condition. All surfaces to which grounding clamps are to be connected shall be cleaned to ensure proper contact. Frequent inspection of all components is essential.

#### 5.5.1.1 Metering

Resistance readings for designing all grounding systems should be established and all grounding electrodes used should be checked to ensure that their resistance is below an acceptable maximum value.

#### 5.5.1.2 Ground equipment

The installation and removal of grounding devices should be performed with an insulated ground stick.


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**CAUTION**
Grounding cables must be connected to the ground electrode first, then to the object being grounded. Personnel should never be in series with a ground lead. When removing grounds, the ground must be removed from the grounded object first and then from the ground electrode.

The object being grounded with an insulated ground stick should not be teased or buzzed with the grounding clamp. The clamp should be poised by the object, snapped on quickly and firmly, and tightened. If an arc is drawn, the clamp should not be withdrawn, but kept on the conductor, thus grounding the line.

When induced currents are of such magnitude that they will cause a hazardous arc during ground removal, a load interrupter device may be used in conjunction with the grounding equipment.

Ferrules pressed onto the cable should be used to join the cable to the connector. Grounding cables should not be coiled in order to reduce their length or wrapped around any metallic objects.

#### 5.5.1.3 Mechanical restraint

It is very important to give attention to restraint of grounding jumpers to minimize possible severe mechanical movement should a fault occur.

#### 5.5.1.4 Ground wires

Grounding methods and procedures when stringing ground wires are the same as those for conductors.

### 5.5.2 Grounding of stringing equipment

For any given situation, the bonding together of all stringing and related equipment and electrical grounds in a common array is of major importance. The degree of grounding protection required for a given stringing operation is dependent upon the exposure to electrical hazards that exist within the project area. For a project in a congested area with exposure to numerous parallel lines and crossing situations, or with probability of adverse weather conditions or both, extensive grounding requirements are called for i.e., use of ground grids. At locations where ground grids are deemed necessary, adequate measures must be utilized to ensure effective contact with the ground electrode. Burying the grid conductor or placing metallic grid mats on the ground surface and using ground rods may accomplish these measures. All grid conductors and ground rods shall be interconnected, and all equipment, structures, anchors, metallic pulling lines, conductor, and overhead ground wire within the area shall be bonded to the grid.

The area of the grid shall be sufficient to enable all equipment to be placed and all work performed within its perimeter. It is desirable to install temporary barriers to control access to the grid area. In addition, an insulated walkway should be provided for isolation of personnel from step voltage while walking to and from the work area.

#### 5.5.2.1 Pull site

Puller equipment should be effectively grounded to a driven rod, rods, or other suitable grounding sources, in the following order of preference:

1) Substation ground grids
2) Ground grid mats, where deemed necessary
3) Tower or steel pole grounds
4) Pole ground

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The first tower away from the puller should use traveler grounds, and the puller should incorporate the use of a running ground bonded to the grounding subconductors, which should be bonded together. Clearly marked warning barriers should be used at the puller site to identify the hazardous areas. Rubber gloves and protectors (overgloves) should be worn by personnel working on the ground in the designated area during stringing operations.

#### 5.5.2.2 Tension site

Tensioning equipment should be effectively grounded to the best source in order of preference during stringing operations. Tensioners, reel carts, and reel trailers should be connected to a ground electrode and bonded together. The first tower away from the tensioner should incorporate the use of a traveling ground bonded to the grounding source used at the tension site. When pulling bundled conductors, the subconductors should be bonded together. Clearly marked barriers should be used at the tensioner site to identify the hazardous areas. Rubber gloves and protectors (overgloves) should be worn by personnel working on the ground in the designated area during stringing operations.

#### 5.5.2.3 Anchor site

In addition to the grounding system at the anchor site, the first tower in either direction should have grounds in use until clipping-in has been accomplished. All subconductors and all phases should be jumpered together at the anchor site and connected to the ground electrode. Bypass jumpers should be installed to tie each end of each phase together.

#### 5.5.2.4 Splicing site

Splicing vehicles should be effectively grounded prior to making splices in the conductors. The ground system should remain in place until the spliced conductors are raised to clear the splicing site. When the splice is completed, the jumper connecting the phases and subconductors together may be removed prior to raising the conductor with the winch line above the splicing site and out of reach of all ground personnel. These procedures should be repeated until all splices are complete and all phases are raised to clear the splice site.

### 5.5.3 Grounding during stringing operation

#### 5.5.3.1 Installation of pilot and pulling line

During installation of conductive pulling lines, running grounds should be installed on the pulling line at the tension and puller sites. In addition, traveler grounds should be used on the first tower away from the tensioner or puller or both, on either side of energized line crossings, and at intervals of not more than 3 kilometers[4] along the line being strung. The tensioner and puller machines should be effectively grounded and bonded to the wire rope and reel stands.

When installing semiconducting lines, care should be taken to prevent deterioration of lines due to excessive leakage currents that may occur at traveler or running ground locations.

#### 5.5.3.2 Installation of conductors and ground wire

During stringing operations, conductors and ground wire should be grounded at the first tower away from the tensioner and puller and on either side of energized line crossings and at intervals of not more than 3 kilometers[5] apart along the line while pulling. When pulling a bundled conductor, all subconductors shall be

[4] 2 miles
[5] 2 miles


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grounded and bonded together. Reel stands should be bonded to tension machines and connected to a ground electrode during stringing operations.

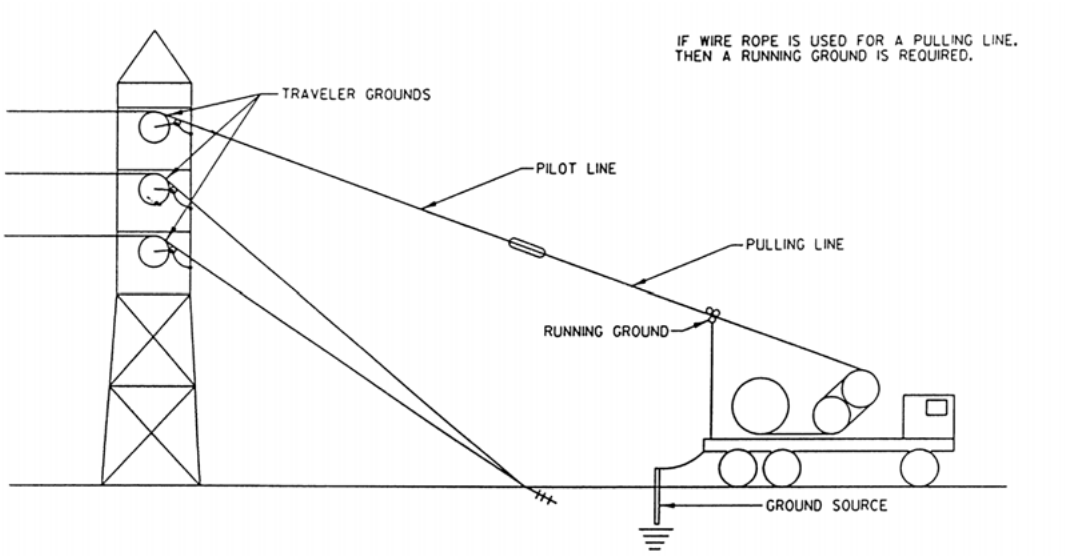



**Figure 13—Puller equipped with pulling line connected to pilot line**

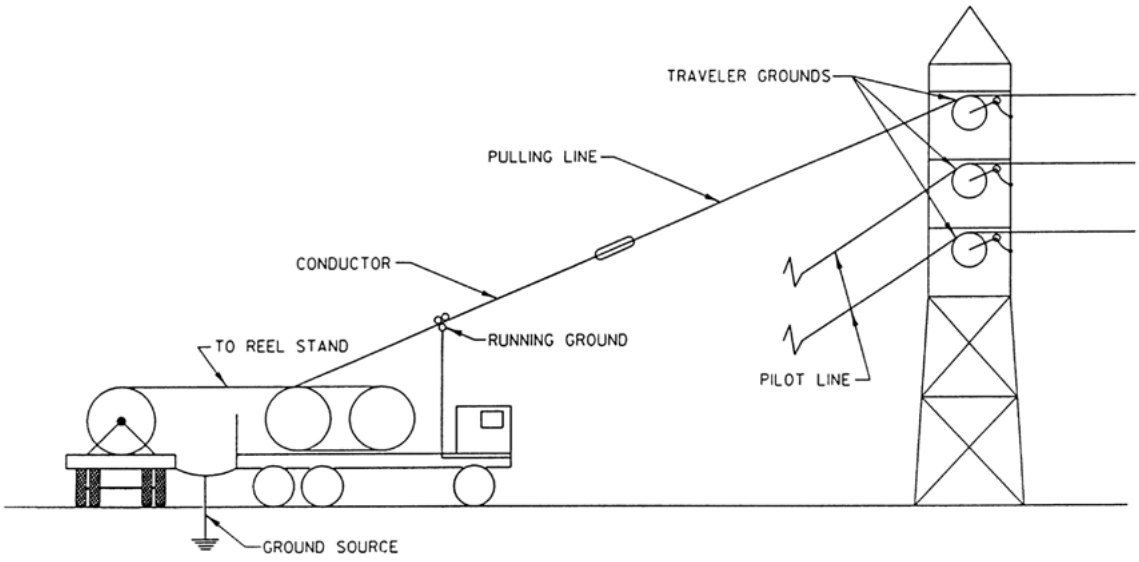



**Figure 14—Tensioner with conductor connected to pulling line and ground connection between conductor tensioner and reel trailer**

### 5.5.3.3 Conductor in field snubs

At the field snub site, a driven rod or rods are used as a grounding source in addition to the first tower in either direction having traveler grounds in use until clipping-in has been accomplished. All subconductors and all phases should be jumpered together at the field snub site and connected to the ground electrode. Bypass jumpers should be installed to tie each end of each phase together.

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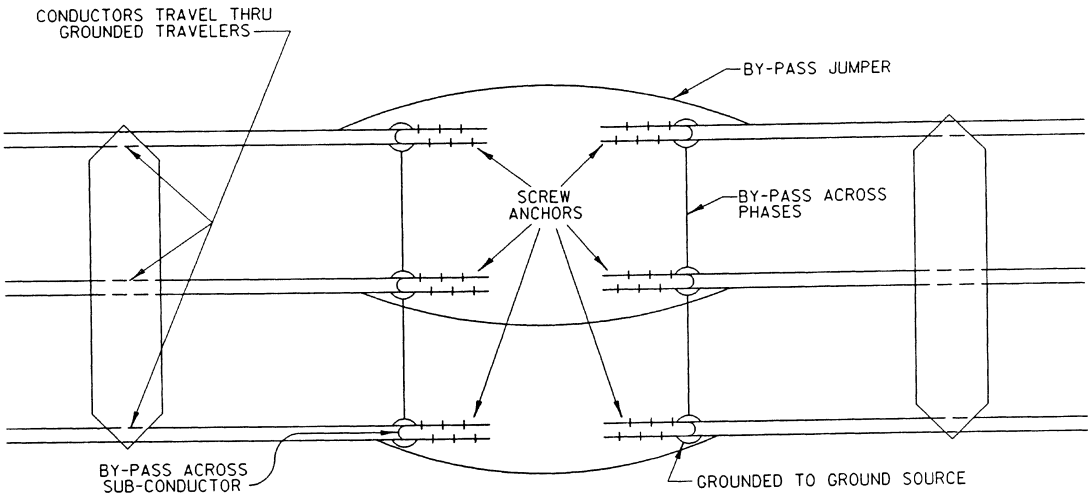



**Figure 15—Conductors in field snubs**

### 5.5.3.4 Installation of splices

A ground shall be located at each side and within 3 meters[6] of working areas where conductors, subconductors, or overhead ground wires are being spliced at ground level. The two ends to be spliced shall be connected to a ground electrode and using an insulated ground stick, bonded to each other prior to handling the conductor. It is recommended that splicing be carried out on either an insulated platform or on a conductive metallic grounding mat bonded to both grounds. When a grounding mat is used, it is recommended that the grounding mat be roped off and an insulated walkway provide for access to the mat.

Splicing vehicles should be grounded prior to making splices in the conductors. The ground system should remain in place until the spliced conductors are raised to clear the splicing site. When the splice is complete, the jumper connecting the phases and subconductors together may be removed prior to raising the conductor with the winch line above the splicing site and out of reach of all ground personnel. These procedures should be repeated until all splices are complete and all phases are raised to clear the splice site (see Figure 16).

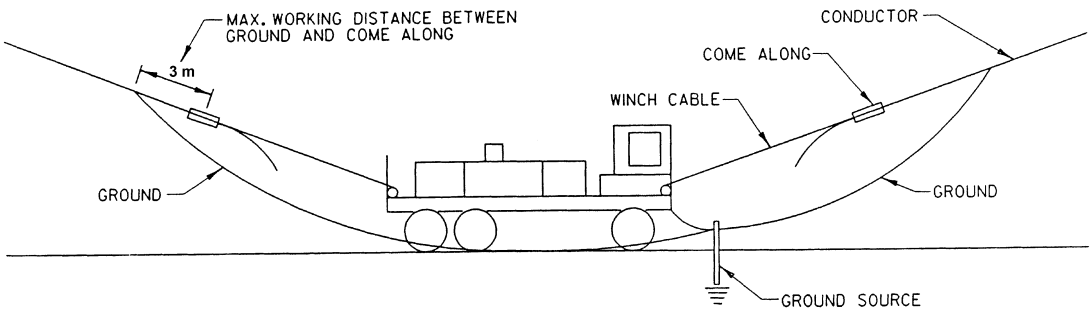



**Figure 16—Splicing truck arrangement grounded conductors prior to splicing conductor**

[6] 10 feet


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#### 5.5.3.5 Grounding during sagging operation

Equipment used to sag conductor should be grounded (see Figure 17).

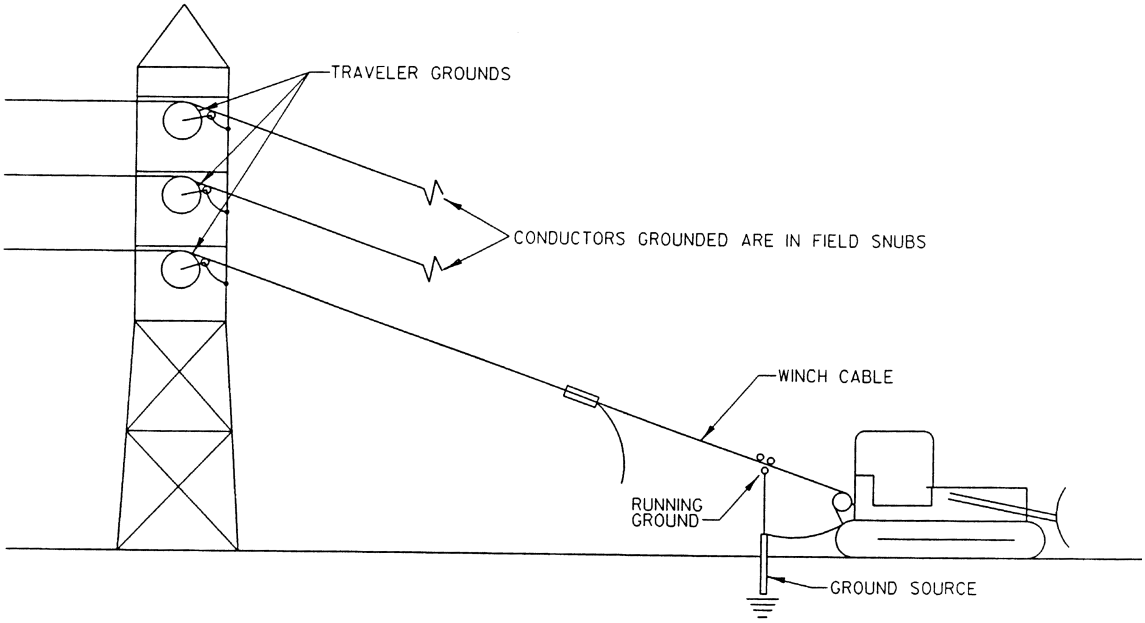



**Figure 17—Sagging conductors utilizing tractor**

### 5.5.4 Grounding during dead-ending operation

Bypass jumpers should be installed on each subconductor on both sides of the structure prior to installing dead-ends.

### 5.5.5 Grounding during clipping-in operation

Personal grounds should be used at each clip-in point in addition to other grounds that may be required.

### 5.5.6 Grounding during removal of conductor and ground wire

Equipment used to pull, or wind up, both conductor or ground wire as it is being removed, should be grounded. Running grounds should be used on the pulling side of the pulling machine. Traveler grounds should be used on either side of energized line crossings and should not be more than 3 kilometers[7] apart.

### 5.5.7 Additional grounding consideration when paralleling energized lines

Additional traveler grounds maybe required when paralleling energized lines to reduce the induced potential created by the close proximity to the energized line.

### 5.5.8 Removal of grounds

Grounds shall be left in place until all operations of conductor installations are complete. See **CAUTION** note in 5.5.1.2.

[7] 2 miles

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# 6. Communications

Slack stringing requires a minimum of communications. It is, however, desirable to have communication between the pulling vehicle and the personnel at the reel location.

Tension stringing requires good communications between the personnel at the tensioner end and those at the puller end and at intermediate check points at all times during the stringing operation. During the stringing of bundled conductors with a running board, it is desirable to observe the running board as it passes through each traveler. The running board observer(s) should have reliable communications with both pulling and tensioning ends. When following the board from the ground is not practical, this can be accomplished with the aid of helicopters.

During helicopter stringing of the pilot line or conductor, reliable radio contact with all ground work sites is extremely important. Radio failure contingency plans should be discussed in a team meeting prior to the pull. Contingency plans should be developed for potential radio failure due to signal or equipment problems.

# 7. Conductor reels

## 7.1 Reel types

Reels are supplied by the conductor manufacturer and can either be of the non-returnable wooden (NR) or the returnable metal (RM, RMT) type. Table K.1 shows the standard reel sizes and nominal dimensions as published by the Aluminum Association, including supplementary footnotes. (See Annex K.) Gross weight and type of reel can be obtained from the conductor manufacturer.

## 7.2 Reel handling

The type and construction of the reel stand and the type of reel determine the method and tools for handling. Reels are constructed so that they must be supported either on an axle through the arbor hole or by the reel flange. Returnable metal reels may be supported by a single-tree arrangement that clamps to the flange and is lifted from above. When the reels are lifted by an axle supported from above, a spreader bar must be employed to prevent damage to the conductor or reel, or both, by inward pressure on the reel flange. Proper equipment must be available to lift the reels.

# 8. Special requirements for mobile equipment

## 8.1 Reel stand

Reel stands are designed to be used with tensioners to supply the necessary back tension to the conductor. The stand(s) are selected to accommodate the conductor (or groundwire) reel dimensions and gross weight.

Some reels are not designed to withstand the forces developed by braking during tension stringing operations. Direct tension stringing from the reel at transmission line stringing tensions should not be attempted. The conductor may be pulled directly from the reel stand when employing slack stringing methods.

If the reel stand is not self-loading, a crane, forklift, or other suitable equipment is used to load the reel into the stand.


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## 8.2 Helicopter

When pulling lines with a helicopter (see Figure 18), advantage in control and pulling capacity has been achieved with the use of special attachment devices that permit pulling from the side of the aircraft at a point near the center of gravity. These devices allow pulling of loads while maintaining full operational control of the aircraft, thus increasing pulling capacity. The devices are equipped with quick release mechanisms and are subject to FAA approval. Break-a-way devices, approved by the FAA, are also often used between the sidehook on the helicopter and the sock line. These devices are designed so that, if something hangs up during the pull, everything will fly away from the helicopter instead of towards it.



**Figure 18—Helicopter installing pilot line**

## 8.3 Tensioner bullwheel characteristics

The depth, $D_g$, and flare of grooves in the bullwheels are not critical. Semicircular grooves with depths in the order of 0.5 or more times the conductor diameter and with flare angles in the order of 5° to 15° from the vertical generally have been found to be satisfactory.

The number of grooves in the bullwheel must be sufficient to prevent the outer layer of wires of multilayer conductors from slipping over underlying layers. The minimum diameter of the bottom of the grooves, $D_b$, should be in accordance with Figure 19.

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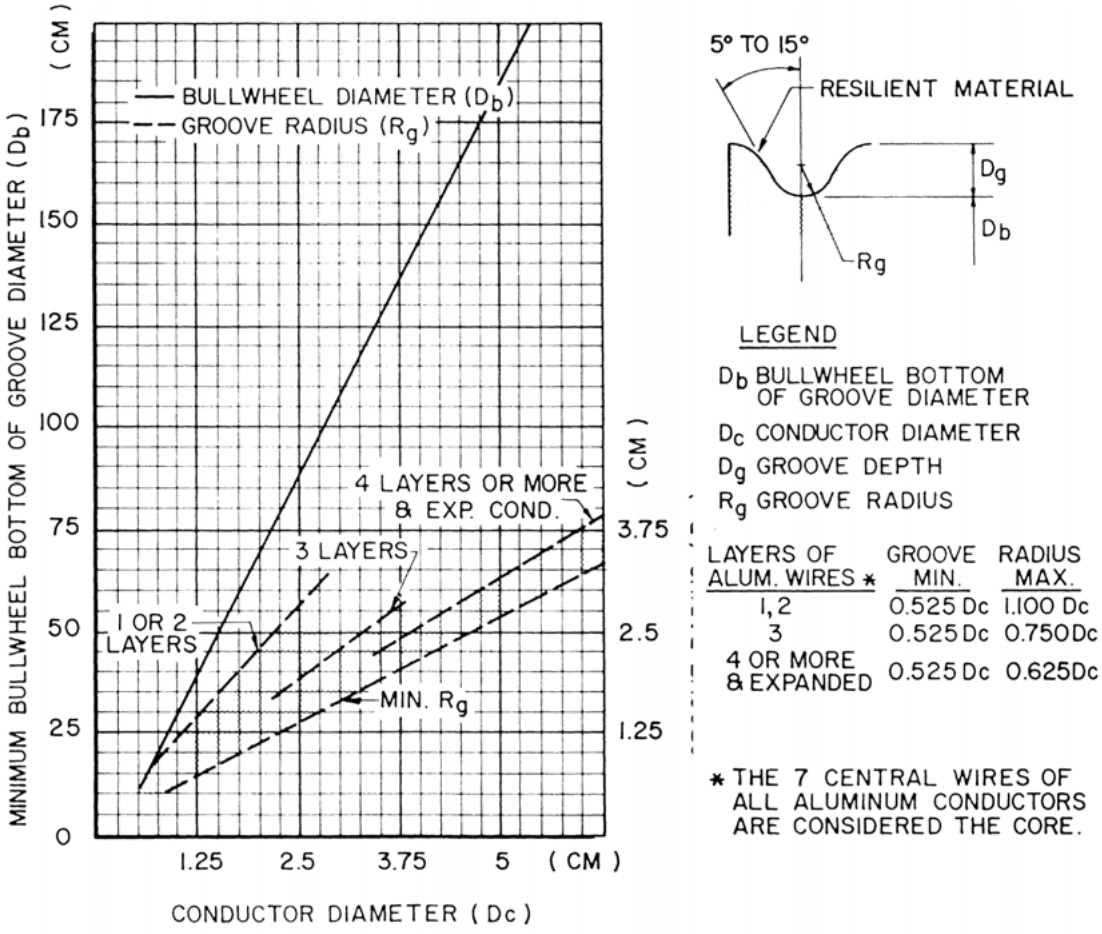



**Figure 19—Recommended bullwheel dimensions**

Tandem bullwheels should be so aligned that the offset will be approximately one-half the groove spacing. For normal conductors having a right-hand direction of lay for the outer wires, bullwheels should be arranged so that, when facing in the direction of pull, the conductor will enter the bullwheel on the left and pull off from the right side. For any conductors having a left-hand direction of lay for the outer wires, the conductor should enter on the right and pull off from the left. This arrangement is necessary to avoid any tendency to loosen the outer layer of strands as the conductor passes over the bullwheels. See 10.4.2, Figure 27.

The material and finish of the grooves must be such as not to mar the surface of the conductor. Elastomer-lined grooves are recommended for all conductors, but are particularly important for nonspecular conductors. When a semiconducting elastomer is used for lining the grooves, it should not be relied upon for grounding.

Difficulties have been experienced with single V-groove type bullwheels on some multilayer and special construction conductors. These types of bullwheels should only be used with the concurrence of the conductor manufacturer.


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## 8.4 Puller and tensioner operating characteristics

The pulling and braking systems should operate smoothly and should not cause any sudden jerking or bouncing of the conductor. Each system should be readily controllable and capable of maintaining a constant tension.

Pullers and tensioners may be mounted separately or in groups for bundled conductor installation. The controls should allow the independent adjustment of tension in each conductor. It is recommended that the tensioner have an independently operated set of bullwheels for each subconductor when stringing bundled conductor, particularly when more than two subconductors per phase are being installed. Pullers should be equipped with load-indicating and load-limiting devices. The load-limiting device should automatically stop the puller from acting further if a preset maximum load has been exceeded. Tensioners should be equipped with tension indicating devices.

Capacity selection of the puller and tensioner is dependent upon conductor weight, the length to be strung, and the stringing tensions. The capacities of the puller and tensioner should be based on the conductor, span length, terrain, and clearances required above obstructions. In general, stringing tensions will be about 50% of sag tensions. Sag tensions should never be exceeded during stringing. Required capacity for both puller and tensioner can be calculated by referring to Annexes D, F, H, and I of this guide.

Tensioner bullwheels must be retarded so that conductor tension may be maintained at various pulling speeds. Positive braking systems are required for pullers and tensioners to maintain conductor tension when pulling is stopped. Failsafe-type braking systems are recommended.

There are basically two types of pulling machines used in the construction of transmission lines being strung under tension. These are defined as bullwheel and drum-type or reel-type pullers. (See Figure 20, which shows a drum-type puller.) Some drum-type or reel-type pullers are available with level wind features to provide uniform winding of the line. Some drum-type and all reel-type pullers provide easy removal of the drum (or reel) and line to facilitate highway mobility. This feature also provides the advantage of interchangeability of drums. The control of payout tension of the pulling line is a desirable feature of many pullers. Mobility of the pullers and tensioners is important to minimize downtime between pulls. Also critical are the setup and leveling features of the units.

The overhead groundwire tensioner is normally a separate unit from the conductor tensioner as the requirements are independent of each other.

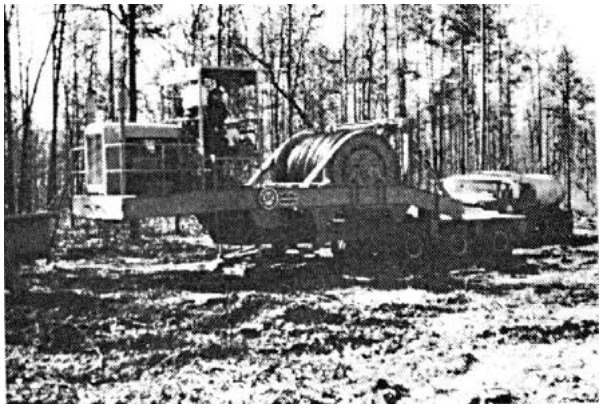


**Figure 20—Drum-type puller**

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### 8.5 Pilot-line winder operating characteristics

Drum-type pilot-line winders have operating characteristics similar to drum-type pullers. They usually have multiple drums to provide pilot lines for several phase or groundwire positions, or both. See Figure 21. Bullwheel-type pilot line machines have similar operating characteristics to bullwheel-type pullers, except that they normally have the reelwinder attached to the rear of the machine. This reelwinder is usually a self-loading type to facilitate the changing of reels of pilot line quickly. These units normally have the capability for high-speed operation. Retardation of the drum(s) is desirable in order to provide controlled payout of the pilot lines. These units are frequently employed to directly pull in overhead groundwire.



**Figure 21—Pilot-line winder**

## 9. Travelers

### 9.1 Sheave diameter

It is generally recognized that as sheave diameters are made larger, the following advantages are gained:

a) The radius of bending of the conductor is increased, so the amount of strain and the amount of relative movement between individual wires in the conductor are reduced. This, in turn, reduces the amount of energy required to bend and straighten the conductor as it passes through the travelers. The force and energy required for such bending and straightening retards the passage of the conductor in much the same way as friction in the bearings of the travelers.

b) The bearing pressures between conductor strand layers are reduced, thus reducing potential conductor internal strand damage. This is commonly known as strand notching.

c) The force required to overcome friction in the bearings is reduced because of the greater moment arm for turning.

d) The number of rotations and speed of rotation are reduced, so wear on the bearings and grooves is alleviated.

The obvious disadvantages of larger sheaves are cost and added weight.

The minimum sheave diameter, $D_s$, at the bottom of the groove, as shown in Figure 22, should be satisfactory for typical conductor stringing operations. However, for stringing conductors in excess of approximately 3 kilometers[8] or over substantially uneven terrain, the recommended minimum bottom groove diameter of sheaves is $[20D_c - 10]$ cm or larger, where $D_c$ stands for conductor diameter. In exceptionally arduous circumstances, accurate sagging may sometimes be very difficult with sheaves having diameters of less than $19D_c$ or $20D_c$.

[8] 2 miles


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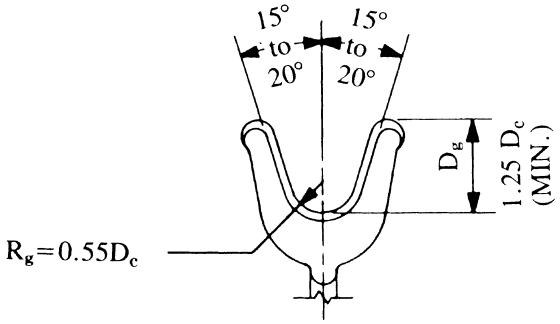
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## 9.2 Configuration of groove

The minimum radius at the base of the groove, $R_g$, is recommended to be 1.10 times the radius of the conductor as shown in Figure 22.

Sheaves having a groove radius as discussed above may, with limitations, be used with smaller conductors. The limitations relate to the number of layers of aluminum wires in the conductor. The more layers of aluminum wires, the more important it is to support the conductor with a well-fitting groove.

The depth of groove, $D_g$, should be a minimum of 25% greater than the diameter of the conductor. The sides of the groove should flare between 12° and 20° from the vertical to facilitate the passage of swivels, grips, etc., and to contain the conductor within the groove, particularly at line angles.




where

$D_s$(min) = 20 $D_c$ – 20 cm except that $D_s$ shall not be less than 12 $D_c$,

$D_s$ = sheave diameter at base of groove,

$D_c$ = conductor diameter,

$R_g$ = sheave groove radius,

$D_g$ = groove depth.

| Number of layers of aluminum wires* | $R_g$ | | $D_g$ |
|---|---|---|---|
| | Minimum | Maximum | Minimum |
| 1 or 2 | 0.55 $D_c$ | 1.1 $D_c$ | 1.25 $D_c$ |
| 3 | 0.55 $D_c$ | 0.75 $D_c$ | 1.25 $D_c$ |
| 4 or more and Expanded Conductors | 0.55 $D_c$ | 0.625 $D_c$ | 1.25 $D_c$ |

A sheave designed for a conductor of a given diameter, in accordance with this figure, may be used for stringing conductors of smaller diameters using above table or as follows:

| Number of layers of aluminum wires* | Minimum diameter conductor that may be used in a sheave designed for a conductor of a larger diameter in percent of the diameter of the larger conductor |
|---|---|
| 1 or 2 | 50% |
| 3 | 75% |
| 4 or more and Expanded Conductors | 87.5% |

The seven central wires of all-aluminum conductors shall be considered as a core.

**Figure 22a—Recommended sheave configuration**

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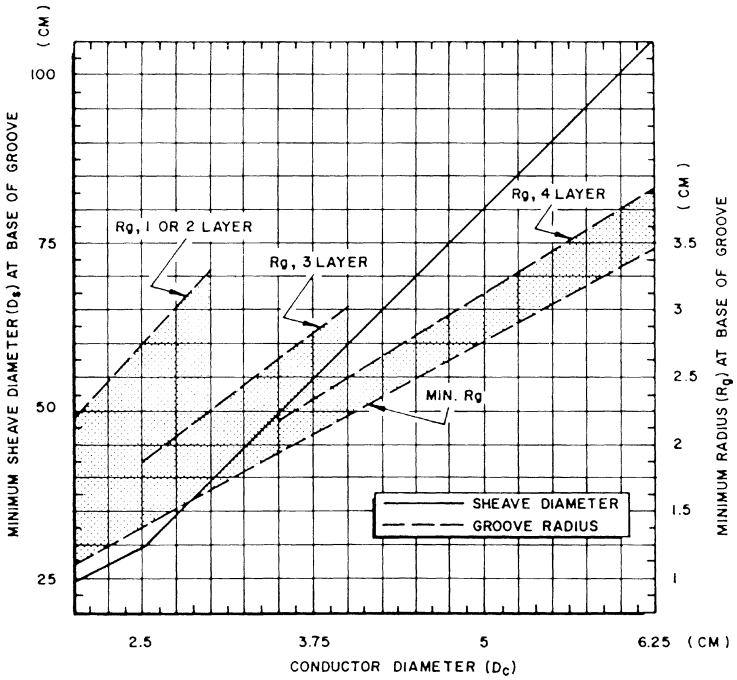



**Figure 22b—Recommended sheave configuration**

## 9.3 Bearings

The bearings should preferably be ball or roller type with adequate provisions for lubrication and shielding against contamination. The lubricant must be suitable for the temperature range involved; and, where sealed bearings are not used, care should be taken to ensure subsequent lubrication with the same type of grease. Mixing of greases of different types (that is, lithium base and calcium base) may cause degradation of the lubricant and subsequent bearing failure, see Boner, [B1]. Bearings should have sufficient capacity to withstand running or static loads without damage. Proper maintenance is essential.

## 9.4 Material and construction

Travelers may be of any suitable material, with due consideration given to weight. Unlined sheaves for stringing aluminum conductors should be made of aluminum or magnesium alloy, and the grooves should have a smooth, polished finish. It is recommended that the manufacturer's safe working load, or other identification to enable determination of such load, be permanently displayed on the traveler. Always ensure that the manufacturer's safe working load for the traveler is not exceeded. This is particularly important for situations in which travelers are used on heavy line angles or on the first or last towers at which the conductor comes to ground level. Maximum loads usually will result when the conductor is being pulled up to sag tensions.

It is recommended that clearances between the sheave(s) and frame, particularly in the traveler throat area, be kept as small as possible. This will prevent the pilot line from jamming should the pilot line come out of the pulling line sheave. It is recommended that the vertical throat opening of the stringing block be kept as small as possible while still allowing the safe passage of the pulling line, swivels, and the running board. This practice will minimize the distance the conductors need to be lifted during the clipping-in operation.


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For bundle conductor configurations, the traveler frame and shaft should be sufficiently sized so that deflection due to load, particularly during the sagging operation, does not cause adjacent sheaves to contact. Excessive deflection can cause difficulty in sagging individual conductors.

## 9.5 Lining

While grooves may be unlined or lined, lining with elastomer provides cushioning to increase bearing area and precludes damage to the conductor from scratched or marred groove surfaces. Steel pulling lines are likely to scratch or mar the surface of unlined grooves; therefore, where such lines are to be used in the same groove as conductor, grooves definitely should be lined. It is generally recommended that all sheaves be lined. It is recommended that the total surface of the groove, including the top lip, be lined to give maximum protection to the conductor.

The elastomer used for sheave linings should be capable of withstanding all anticipated temperatures without becoming brittle or developing semi-permanent flat areas. It should be sufficiently hard to prevent the conductor from climbing up the side of the groove. Bearing pressure limits for sheave linings are further discussed in Annex G.

## 9.6 Electrical characteristics

Neither lined nor unlined travelers should be relied on for grounding the conductor being installed. Greased bearings do not provide necessary conductivity and may be damaged by relatively small currents passing from the sheave to the body of the traveler. Semiconductive linings, commonly referred to as conductive linings, tested to date are reported burned with currents as low as 20 mA.

The induced electrical charges on conductor and pulling lines, particularly when stringing in the proximity of energized lines, must be drained off with traveler grounds that bypass the linings or greased bearings, or both. Traveler grounds provide a means to bypass electrically the sheaves and ground the conductor directly to a ground electrode.

After any grounding device has experienced fault current, it should be inspected for damage and replaced if needed.

## 9.7 Bundled configurations

Bundled conductor type travelers for stringing two or more subconductors simultaneously require special considerations. When even numbers of conductors are strung, a symmetrical arrangement may be used with an equal number of conductors on each side of the pulling line. An independent center sheave is provided only for the pulling line and should be of suitable material to withstand the abrasion of the pulling line.

When odd numbers of subconductors are strung, the center one could follow the pulling line in the center sheave. However, this is usually not desirable because of the material of the groove or because of contaminants deposited in this groove by the pulling line, or because of both. Offset-type bundle conductor travelers are used that balance the load by properly spacing the even and odd number(s) of conductors on each side of the pulling force. These travelers are directional and should be color-coded. Care should be taken to ensure their proper orientation.

When multiple conductors are strung in bundled conductor type travelers, reduced horizontal spacing between grooves can result in conductor oscillation, even in a very light crosswind, too severe to permit satisfactory sagging. (For example, groove spacing of 5.4 conductor diameters permitted sagging of conductors in a crosswind condition that repeatedly prevented sagging with a groove spacing of 2.7 conductor diameters because of very active conductor oscillation.)

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When stringing multiple conductors around line angles in excess of 5°, bundle conductor travelers are required until the running board passes through the traveler, but should be replaced prior to sagging with single-type travelers to provide proper wire length in the clipped-in position. It is desirable during sagging for the horizontal spacing of the sheaves to match the final subconductor spacing to aid in preventing subconductor sag mismatch.

Some bundle conductor travelers may be converted to single conductor type travelers.

Multi-sheave bundle conductor type travelers and running boards must be designed to complement each other and work in unison. Running boards should only be used to pull in conductors. They should not be used to line up the conductors with an anchor (that is, running boards should not be pulled sideways). Running boards should have their safe working load displayed. It is recommended that all running boards and swivel links be proof tested to 50% over the safe working load. During stringing, normal pulling speeds should be maintained when the running board approaches a traveler.

## 9.8 Helicopter travelers

Helicopter travelers utilize outrigger arms that guide the pilot line into the throat area of the traveler. These outriggers are usually brightly painted to be easily seen from the air. Spring-loaded gates are employed to contain the line. For bundle conductor travelers, additional guides may be utilized to funnel the lines into the proper groove. The design of helicopter travelers should be such that personnel are not required on the structure during placement of the pilot line. After initial placement of the line by helicopter, normal stringing practices are employed.

Some helicopter travelers are directional, and care must be exercised to orient them properly on the structures. Due to the rotor wash of the helicopter, if the attachment method of travelers does not prevent twisting, yaw bars or a piece of light rope should be utilized to stabilize the traveler.

Some standard travelers may be converted to helicopter type by the addition of accessory parts.

## 9.9 Uplift rollers and hold-down blocks

Uplift rollers that attach to the traveler (see Figure 23) or hold-down blocks that are separate devices must be used at positions where uplift might occur. Uplift can occur with the pulling line during the stringing operation, due to its higher tension to weight ratio and, thus, much flatter sag. This condition is most likely to occur in hilly terrain at the towers in the low points of the pull. Hold-down blocks or uplift rollers should be used in these cases. Since the uplift condition will normally stop when the conductor(s) arrive, hold-down blocks that can be removed prior to the arrival of the conductor(s) without stopping the pulling should be used. Uplift devices that attach to bundle travelers are usually directional, and are usually positioned toward the pulling end. These devices should have a breakaway feature in the event of fouling of the pulling line or incorrect installation.


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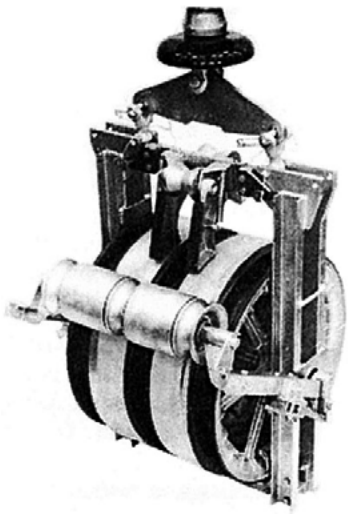


**Figure 23—Bundle conductor traveler with uplift roller and grounds**

### 9.10 Traveler suspension

The vertical location of sheaves should be considered for sagging purposes. For simplicity in marking and clipping procedures, it is desirable for the vertical position of the conductor in the sheave to be at the same elevation as when clamped in the final position in the suspension clamp.

Clearance required for running boards over the sheaves of the bundle conductor-type traveler frequently prevents proper vertical positioning of conductors. The few centimeters of the drop of the conductor below its final position may be unimportant on tangent towers.

## 10. Typical procedures for stringing operations

### 10.1 Pull, tension, anchor, and splicing sites

#### 10.1.1 Site selection

The selection of pull, tension, snub structure, and splicing sites should consider accessibility, terrain, angles in the pull section, location of usable deadends, length of conductor to be strung, available conductor and line lengths, puller capacity, snub structure loads, the physical area needed for placement of the equipment, and the ability to provide an adequate grounding system.

#### 10.1.2 Equipment location

The location of the puller, tensioners, and intermediate anchor sites must be selected so that the snub structures are not overloaded. Where possible, a pulling line slope of three horizontal to one vertical from the traveler to the site is considered good practice. Refer to Annex D for calculation of snub structure loads. It is also necessary that the puller be positioned so that the pulling line enters the machine at a minimum horizontal angle to minimize any possibility of damaging the line. When a bullwheel-type puller is employed, the

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reel winder to recover the pulling line is located at the pulling site. The pilot-line winder is located at the tension site. See Figure 24 and Figure 26.



**Figure 24—Tension site**

The arrangement of the tensioner and reel stands should be such that the lateral angle between the conductor as it approaches the bullwheel and the plane of rotation of the wheel is not great enough to cause the conductor to rub on the sides of the groove. As an example, birdcaging problems were eliminated with large conductors by using a maximum fleet angle of 1.5° from the plane normal to the conductor-reel axis and a back tension of approximately 4.5 kN.[9] For additional information on back tension considerations, see 10.4.2. The problems of birdcaging are normally more acute with large conductors of three or more aluminum layers.

The conductor reel should be aligned with the tail fairlead on the tensioner such that, during the payout of the conductor, it will not scrub on either of the flanges of the reel as it is being unwound. See Figure 24.

### 10.1.3 Anchors

Anchors are normally required for holding equipment in place and snubbing conductors against tensions imposed. The type of anchor is dependent upon the soil conditions and sagging and stringing tensions. Portable equipment is often used for this purpose, as well as ground type anchors. Slack should be removed from all anchor lines prior to loading to minimize the possibility of equipment movement or impact loads to the anchors.

### 10.1.4 Equipment grounding

Grounding and bonding is particularly important for protection of machinery and personnel where the new transmission line is being installed adjacent to, and parallel with, an existing energized transmission line. Hazardous voltages and currents can be encountered in such cases.

Adequate grounding must be established at all sites. The methods required and equipment used will be determined by the degree of exposure to electrical hazards around the equipment as well as the pull section and the soil conditions at the site. All equipment, conductors, anchors, and structures within the work area must be bonded together and to the ground electrode.

[9] 1000 lbs


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## 10.2 Section between snub structures

### 10.2.1 Crossing structures

When crossing roads, highways, railroads, energized lines, etc., some type of supplemental crossing structure should be considered. This can be guard poles erected in a football goalpost fashion of suitable height. In some cases, rope nets are strung between the poles to give more positive protection. A system of blocks can also be used to cradle the pulling lines and conductors. This is accomplished with support lines, space lines, and load lines to properly locate the special cradle blocks to afford protection should tension be lost during the stringing operation. See Figure 25.

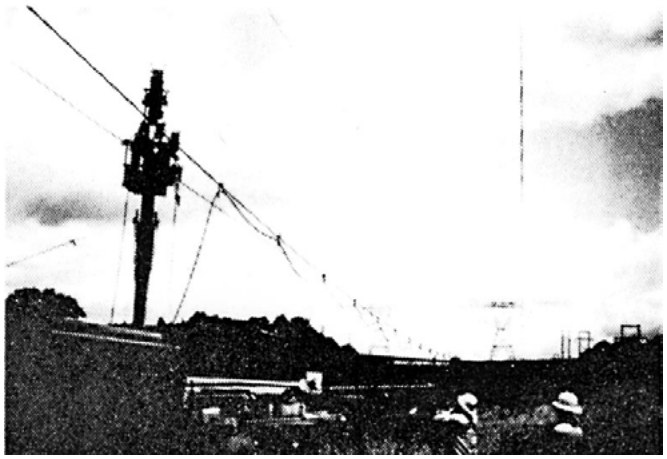


**Figure 25—Cradle block system**

### 10.2.2 Terrain problems

The terrain must be analyzed to determine if there are areas of impaired ground clearance under stringing tensions. If such areas exist, precautions must be taken to protect the conductor. Locations of conductor or pulling line uplift must also be identified in order that hold-down blocks and uplift rollers can be provided. Other unusual terrain features may dictate special consideration.

### 10.2.3 Traveler installation

Installation of travelers, including finger lines where used, requires consideration of traveler attachment methods and the need for and location of traveler grounds and uplift rollers. For single-conductor vertical insulator assemblies, the travelers are normally connected directly to the insulators and, with V-string insulator assemblies, to the yoke plate. For most bundled conductor lines, the travelers are connected to the yoke plate. With post-type insulators, the travelers are connected to the end of the insulators. Where travelers are installed to string through deadend towers, the travelers are normally connected directly to the tower. If substantial line angles are involved, two travelers in tandem may be required to reduce the bending radius of the conductor or the load on each traveler, or both.

Where bundled conductor travelers are used at line angle locations of over 5°, it is advisable to change to individual single conductor travelers after the passage of the running board to facilitate accurate sagging.

When adequate quantities of travelers are available, it is common practice to install them at the same time that the insulators are installed. Under some situations, travelers may be attached to slings or rods in place of the normal insulator assembly.

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The need for traveler grounds and required locations should be based on the degree of exposure to electrical hazards. When such hazards exist, traveler grounds should be installed, as a minimum, at the first and last tower between the tensioner and puller. When stringing in proximity to energized lines, additional grounds must be installed as required, but at a maximum distance not exceeding 3 kilometers.[10] Additionally, grounds must be installed within a reasonable distance on each side of an energized crossing, preferably on the adjacent structures.

Travelers with grounds are usually sensitive to direction, and care should be exercised in hanging them. Usually, the grounds are oriented to the pulling end. Each traveler with grounds must be connected with temporary grounding sets to provide an electrical connection between the traveler and earth, or to some conductive medium that is at earth potential. Personnel should never be in series with a ground lead. Traveler grounds should have a suitable grounding stud located in an accessible position to enable placing and removing the ground clamps with hot sticks, when necessary. Traveler grounds will also help protect the sheave linings.

At the time the travelers are hung, finger lines, when used, should be installed and tied off at the base of the structures. If the helicopter method of pilot-line installation is not to be used, the pilot line could be installed at this time in lieu of finger lines.

## 10.3 Conductor splicing

### 10.3.1 Conductor reel lengths

Standard conductor reel lengths and dimensions are shown in Annex H and Annex I. Normally, more than one conductor reel length will be required to obtain the total length of conductor to be strung at one time. Therefore, the conductor lengths must be spliced together at the tension site or midspan sites, or both. Regardless of the site; however, the required equipment and basic procedures are essentially the same and are applicable to conductors, overhead groundwires, and metal pulling lines.

### 10.3.2 Equipment

The major equipment required for splicing operations consists of a splicing cart equipped with a hydraulic pump and compressor, compression joints, strand restraining clamps, hold-down blocks, rope, conductor grips, hoists, ground rods, personal grounds, bonding cables, and bare conductor and clamps for a ground grid (when it is to be installed). All equipment must have adequate mechanical or electrical capabilities, or both, for the work involved.

### 10.3.3 Bonding and grounding of conductor ends

It is extremely important that precautions be taken to prevent personnel from accidentally placing themselves in series between two conductors that are to be connected together, or in series to ground with either conductor. Accidents of this type can be prevented by providing an equipotential work area, by grounding and placing a jumper across the opening between the ends of the two conductors to serve as a shunt, or by a combination of both.

The following method is recommended when the line being strung might accidentally become energized; when it is adjacent, parallel, or both, to an existing energized transmission line; or when the possibility of high fault currents exists and the work is to be performed at ground level by personnel in direct contact with the earth.

a) Install a ground grid if the splice is to be made in midspan. Ground grids installed at the pull and tension sites will suffice for splices made at those locations.

[10] 2 miles


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b) Bond the splicing cart and all other mobile equipment, such as tractors, which may be holding the conductor ends, to the grid.

c) Bond the two conductors to be spliced to a common ground using personal grounds connected within 3 meters[11] of each conductor end, then bond the conductor ends directly together using a jumper.

d) Perform all splicing work within the grid perimeter.

In lieu of the ground grid, a metallic grounding mat may be used. The conductor ends and the mat must be bonded to a common ground. As before, a jumper should be installed directly between the conductor ends. If multiple ground rods are used, they should be bonded together. All splicing work should be performed on the mat.

If neither the grid nor the mat are used, all splicing work may be performed on an insulated platform. The conductor ends should be bonded to a common ground and directly together with a jumper as before. If multiple ground rods are used, they should be bonded together.

As a minimum, regardless of the level of exposure, a system of interconnected ground rods should be used, but the magnitude of potential electrical hazards must be thoroughly considered.

### 10.3.4 Compression joint application

The die or dies used to compress the compression joint must be of the correct size, and all presses must be made in the proper sequence specified by the manufacturer of the joint. Compounds that aid electrical contact, prevent corrosion, and ensure mechanical holding power should be used as specified by the compression joint manufacturer. Proper centering of joints on the conductor is very important. Failure to adhere to these requirements will result in defective splices, which, in turn, may become potential hazards.

### 10.3.5 Passing compression joints over travelers

The number of sites required for splicing conductors is dependent upon the terrain, limitations of the equipment, and the maximum conductor reel lengths available.

The most common stringing practice avoids pulling compression joints over the travelers. It consists of using woven wire grips to join the conductor lengths at the tension site until the total required length of conductor has been strung. The conductor is then lowered to the ground at each location, stripped of the woven wire grips, spliced, and later pulled up to sag.

Another stringing practice consists of splicing the conductor lengths together at the tension site with compression joints specifically designed to be pulled over travelers. This approach has the advantage of splicing being done at one location, thus reducing the total number of required operations when compared with the previous practice, particularly when ground grids are required. If this practice is to be employed, a preliminary study of the line to be strung should be made to determine the maximum stringing tensions and roll-over angles that would be encountered. Compression joint manufacturers should be consulted. If the splices are to be passed through the travelers, the groove of the conductor sheave should be designed to allow this. A groove that is too narrow to pass the splice could result in spreading of the sheave groove and breakage.

[11] 10 feet

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## 10.4 Stringing procedures

### 10.4.1 Installation of pulling lines

When finger lines are installed, they are used to pull the pilot line or pulling line through the travelers as it is pulled out. The pilot line, when used, is then pulled back by use of the pilot-line winder behind it, pulling the pulling line from a reel or drum puller, which can in turn be used to pull in the conductor. The initial pulling out of the pilot line or pulling line is usually done with any vehicle such as a pickup truck or tractor, as appropriate.

In difficult or mountainous terrain, the pilot line is sometimes carried into position on the right of way by hand in short lengths and, after being stretched out, each length is joined to the other with special rope connectors. This technique is used particularly when the pilot line puller is a bullwheel-type machine.

When helicopter methods are used, the pilot line is first pulled out by the helicopter (or from the helicopter) and placed by the helicopter pilot into travelers specially designed for this method. This initial line is usually small diameter synthetic rope, but could also be small steel line. This pilot line is then used to pull in the pulling line in the same manner as previously described. In cases in which it is necessary to string a line through the window of a structure, special devices are available to accomplish this stringing. These devices include the harpoon and the flytrap and/or needle methods.

Some general rules for helicopter pulls are as follows:

a) When possible, plan to pull from the bottom of the hill to the top. This will help protect against the sock line form floating up into the rotor blades if it comes loose from the traveler.

b) If it is not possible, such as when pulling in mountains where it is necessary to pull up and down hill several times during one pull, the pilot should always keep the rotor blades above the sockline.

c) When using a side pull, the socklines should be installed “bottom to top” and “front to rear” because the helicopter is generally perpendicular to the powerline being built. Therefore, if the bottom sockline is pulled first, the pilot does not have to worry about getting the main rotor or tail rotor into a sockline. Likewise, if the sockline in front is pulled first, the pilot will not have to worry about getting the tail rotor or main rotor into a sockline behind the ship. When using this rule on a single circuit tower with the center phase higher than the two outside phases, the pilot would fly the bottom front (outside) phase, as seen from the pilot, then the bottom rear outside phase, then the center phase, then the front top static wire, and then the rear top static wire.

d) Do not pull a conductor up to tension until all sock lines are pulled in.

### 10.4.2 Installation of conductor

See Figure 26. Once the rope pulling lines have been installed, and prior to pulling in any conductor or conductive-type pulling lines, two running grounds should be installed—one between the reel stand or conductor tensioner for conductor and the first tower, and one between the puller for the pulling line and the last structure. These grounds must be bonded to the ground previously established at each site.

It is recommended that, in places where synthetic ropes are used as either a pilot line or a pulling line, they should be installed under tension such that they do not contact the ground between towers. The outer surface of the synthetic rope can be easily abraded and damaged if it is pulled over the earth surface for any distance.

Pulling lines are usually pulled in under tension. The pulling line is then connected to a single conductor through a swivel link, or to bundle conductors through swivel links and a running board. Swivels must not be used to connect lengths of pulling line. A rope connector should be used for this purpose.

Pulling lines may be made from synthetic fiber or wire rope. When synthetic pulling lines are used, a torque-balanced rope is recommended to minimize problems caused by kinking or twisting. Swivel links should not


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be used on three-strand synthetic pulling lines. When a wire rope is used, it is recommended that a swaged-type swivel be used because of its tendency to rotate less under load, minimizing most rope spinning problems. Swaged rope also has a much smoother outer surface and this smoother surface, plus low rotation, minimizes wear on traveler sheaves and bullwheel grooves on pullers.

When replacing an existing conductor or OPGW cable on a line, it is often common to use the existing cable as a pulling line to pull in the new cable conductor.

A specially designed steel reel should be used for winding up the pulling line or pilot line. This is particularly true if the line is a synthetic rope that can generate large or very large crushing stresses on a reel when it is wound in multiple layers.

A ball-bearing swivel link is usually used for the connections between pulling lines, running boards, and conductors. Swivel links should be of sufficient rated working load to withstand loads placed on them during tension stringing. They should also be compatible with the travelers being used so that they can pass through without spreading or damaging the sheaves. These special line-stringing swivel links are clevis type and are compatible with woven wire grips and swaged steel pulling lines. It is recommended that swivel links not be passed over bullwheels under significant tension because they may be weakened or damaged due to bending.

When reeving the bullwheels of a tensioner with the conductor entering and leaving the wheel from the top facing in the direction of pull, the conductor should enter from the left and leave from the right for right-hand lay (standard for aluminum conductor) and enter from the right and leave from the left for left-hand lay (standard for groundwire, including OPGW). This procedure will avoid the tendency to loosen the outer layer of strands as the conductor passes around the bullwheels. (See Figure 27.)

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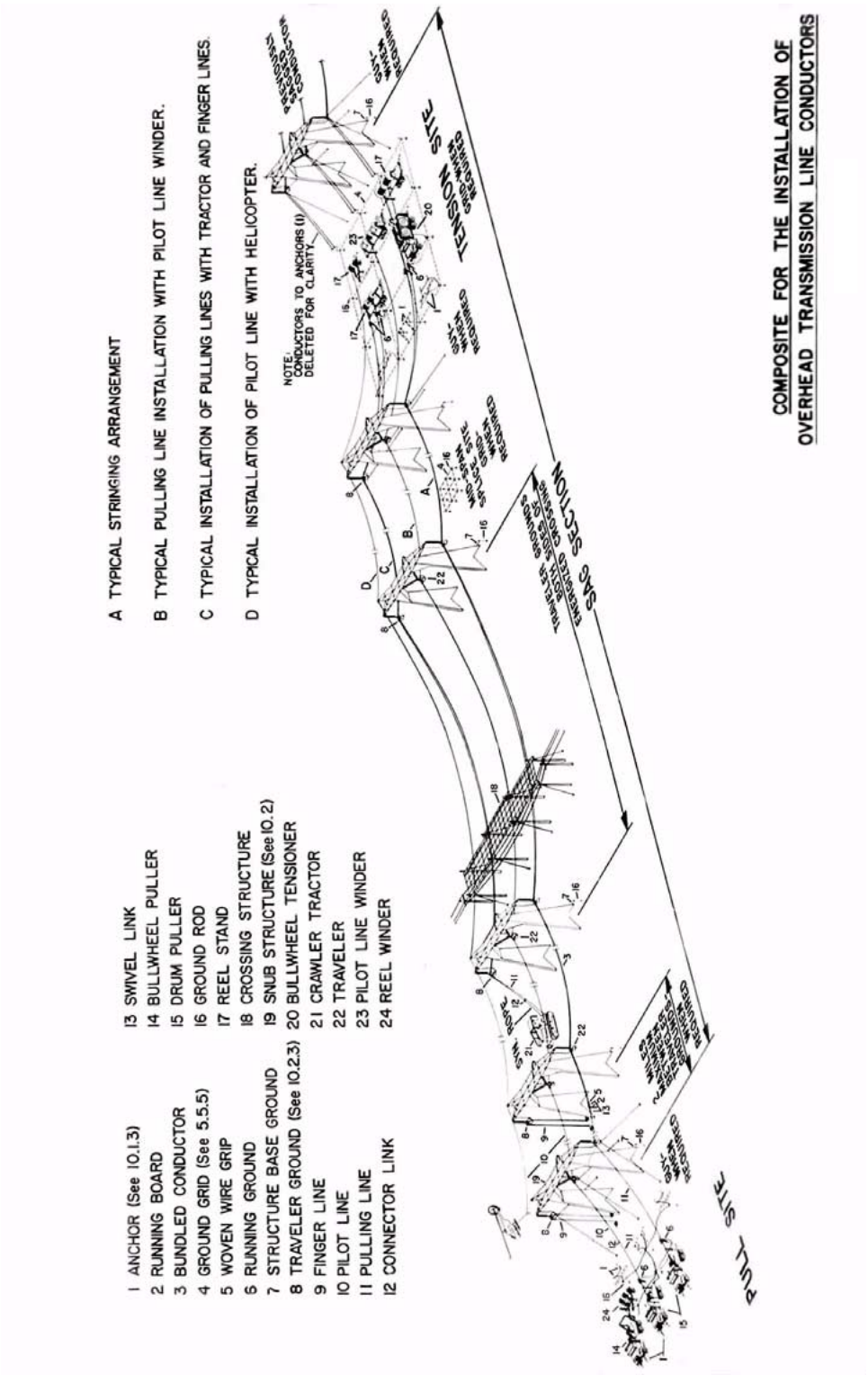



**Figure 26—Composite for the installation of overhead transmission line conductors**



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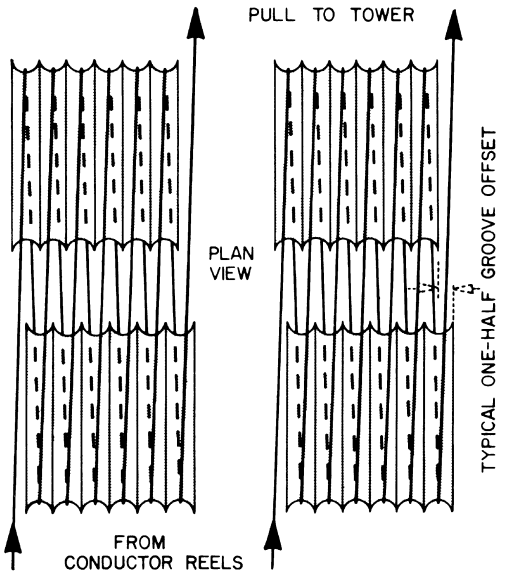



**Figure 27—Bullwheel reeving for right-hand lay conductor**

It is recommended that conductor of only one manufacturer and one drawing stock (rod-type cast or rolled) be used in a given pull, and preferably in any given sagging section. This precaution will help avoid significantly different conductor sag characteristics. Sets of reels with matched lengths are often specified to complement set-up locations and minimize scrap. A review of the conductor lengths available and selective grouping is a good practice.

Attachment of the conductor to the pulling line, to the running board, or to another reel of conductor to be pulled successively is accomplished by the use of woven wire grips. These grips should be of compatible strength and sized to the conductor or pulling line on which they are used. The overall diameter of the grip, when placed over the conductor or rope, should be small enough to pass over the sheaves without causing damage to the sheave or its lining. The grip should also be capable of connecting with a proper size swivel link.

Metal bands should be installed over the grip to prevent it from accidentally coming off and dropping the conductor. The open end of the grip should be secured with two bands. This should then be wrapped with tape to prevent accidentally stripping the grip off the conductor if the end were to snag or catch. This is particularly important when these grips are used between lengths of conductor when more than one reel is strung because the grips are passed through the travelers backwards. If the ends are not banded and taped, they could be stripped off.

Experience has shown that pulling speed is an important factor in achieving a smooth stringing operation. Speeds of 5–8 km/h[12] usually provide a smooth passage of the running board or connecting hardware, or both, over the travelers; whereas slower speeds may cause significant swinging of the traveler and insulator-hardware assemblies. Higher speeds create a potential hazard of greater damage in case of a malfunction.

The maximum tension imposed on a conductor during stringing operations should not exceed that necessary to clear obstructions on the ground. It may be necessary, under certain circumstances, to string the conductor near sag tension to clear crossing structures such as poles over highways, roads, or existing distribution lines. This clearance should be confirmed by observation. If stringing tensions are greater than 10% of the conductor's breaking strength, consideration must be given to any possible pre-stressing of conductors that may result, based on the tension and time involved. Consideration must also be given to the fact that when

[12] 3–5 m.p.h.

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long lengths of conductor are strung, the tension at the pulling end may exceed the tension at the tensioner by a significant amount. Differences in tension are caused by the length of conductor strung, number and performance of travelers, differences in elevation of supporting structures, etc. (See Annex F.)

Light and steady back tension, sufficient to prevent over-run in case of a sudden stop, should be maintained on the conductor reels at all times. The tension must also be sufficient to cause the conductor to lie snugly in the first groove of the bullwheel and to prevent slack in the conductor between bullwheels. It may be necessary periodically to loosen the brake on the reel stand as the conductor is payed off. As the reel empties, the moment arm available to overcome the brake drag is reduced, and therefore the tension rises. This may cause the conductor to wedge into the underlying layers on the reel. The reel should be positioned so that it will rotate in the same direction as the bullwheels. Loosening of the stranding that often occurs between the reel and the bullwheels of the tensioner is caused to a great extent by coil memory in the conductor. As the conductor is unwound from the reel and straightens out, the outer strands become loose, a condition that is particularly noticeable in a large diameter conductor and can be best observed at the point at which it leaves the reel. As the conductor enters the bullwheel groove, the pressure of contact tends to push the loose outer strands back toward the reel where the looseness accumulates, leading to the condition commonly known as birdcaging, see Figure 28. If this condition is not controlled, the strands can become damaged to the extent that the damaged length of conductor must be removed. This problem can be remedied by allowing enough distance between the reel and tensioner to permit the strand looseness to distribute along the intervening length of conductor and simultaneously maintaining enough back tension on the reel to stretch the core and inner strands to sufficiently tighten the outer strands. It is recommended that the back tension or braking tension of the conductor reel not exceed 4.5 kN,[13] since drawing down of the conductor into the lower layers on the reel may cause surface damage. For smaller diameters and wooden reels, the back tension should be considerably less. Excessive back tension on the reel can

a) Deform the reel flanges leading to tangles in the conductor,

b) Scratch or damage to the adjacent conductor layers, and/or

c) Crush the reel drum.

The amount of permissible tension depends on the reel construction. When the conductor has been drawn down to the last few wraps on the reel, the installation procedure should be stopped and any required back tension transferred off the conductor on the reel to some other anchor point. The end conductor attachment in the reel should never be used as a brake or end stop and exposed to a conductor “run-out” condition.

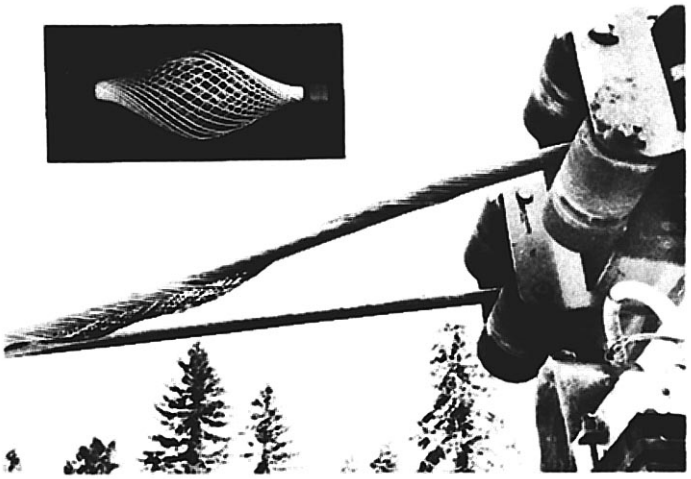


**Figure 28—Birdcaging**

[13] 1000 lbf


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The maximum time conductors may safely remain in the travelers depends upon wind-induced vibration or other motion of the conductors. Windblown sand can severely damage conductors in a few hours if clearance is less than about 3 meters[14] over loose sand with little vegetation. Damage from vibration at sagging tensions is quite possible and, when required, dampers should be installed promptly. However, at lower tensions generally used for initial stringing, damage to conductors or sheave bearings, or both, is not likely to occur from vibration. Even for travelers having lined sheaves with root diameters 20 times the conductor diameter, it is important to complete conductor stringing, sagging, plumb marking, clipping, spacing, and damping operations as soon as possible to prevent conductor damage from weather, particularly wind. Conductor should not be strung if adverse weather is predicted before the entire sequence can be completed.

Subconductor oscillation may occur in bundled conductor lines. Tie-down methods, temporary spacers, or other means may be required to prevent conductor surface damage prior to the installation of spacers. Temporarily positioning one subconductor above another to prevent conductor clashing is undesirable because different tension history will later produce subconductor sag mismatch, unless the tensions are low and the duration is short enough so that creep is not a factor. Conductor clashing can mar the strands and produce slivers that can result in radio noise generation.

If a bullwheel-type puller is utilized, the pulling line should be recovered during the pulling operation on a separate piece of equipment. This function is usually performed by a reel winder that is placed behind the puller in an arrangement similar to the reel stand at the tension site. Some bullwheel pullers, particularly those used on smaller transmission lines, may have the reelwinder mounted on the rear frame of the puller itself. These reelwinders are usually self-loading for ease of removing full reels and installing empty ones. For these types of machines, typically two or three separate lengths of pulling line are used in a pull section.

Once the conductor has been pulled into place, one end is normally attached to the structure through a dead-end insulator-hardware assembly or to a previously sagged section of conductor, and the other end is transferred from the puller or tensioner to the sagging unit. Attachment of the conductor to the sagging unit is accomplished by means of a properly designed conductor grip that should be capable of holding, without slipping, full sagging tension with appropriate safety factors. This must take into account possible impact loads that may be encountered as the sagging winch line wraps on the sagging winch drum, as well as overtension if the conductor is accidentally pulled above desired sag. In some cases, multiple grips will be required.

Extreme caution must be exercised when transferring a conductor from one holding device to another, or when connecting two conductors to ensure that the conductors are at all times adequately bonded together and to all equipment being used. This is essential to ensure that personnel cannot get in series with two items at different potentials or with a conductor that could conduct induced potential to a grounded object.

Methods and procedures for the installation of overhead groundwires and fiber optic cables are the same as those indicated for conductors except that the loads and tensions involved are lighter. Groundwires are commonly pulled with lightweight pulling lines that are installed directly without the use of a pilot line. The groundwire(s) are normally installed after pulling the conductors due to their higher location on the structures and in order to avoid the risk of the rotor blades making contact with the ground wire when pulling in the sock line.

When using a helicopter, overhead ground wires are generally pulled in directly. In this case, the end of the groundwire cable is hooked directly to the helicopter. As the cable is fed out, the helicopter may have to hover while a second and a third reel are spliced, socked, or pressed to the end of the previous pull. Overhead ground wires may be pulled in first without a helicopter to get the groundwires out of the way of other helicopter pulling operations. However, when using a helicopter, the groundwires should be pulled in after the conductor socklines are installed in order to avoid the risk of the rotor blades making contact with the overhead ground wire while pulling in the phase socklines.

[14] 10 feet

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## 10.5 Sagging procedures

### 10.5.1 Sagging and clipping offset theories

Theoretically, conductor sagging is based upon hyperbolic functions describing a true catenary curve, see Lummis and Fischer [B20] and Winkelman [B29]. In practice, however, parabolic approximations of the catenary are often utilized.

In a series of suspension spans located in hilly terrain, wire in the sheaves will tend to run downhill. Gravity acting on the wire in the sheaves will cause excessive sag in the lower spans of the sagging section and too little sag in the upper spans. The unbalanced horizontal tensions will result in the insulators being pulled off from plumb in an uphill direction. To equalize the horizontal tensions, it is necessary to redistribute the wire between the spans. This process of pulling the wire uphill is known as "clipping offsets." The theory of clipping offsets is based upon the fact that, between snub structures, the total length of conductor at sag in the travelers is equal to the total length of conductor at sag in the suspension clamps. The distance that the clamp should be offset from the plumb position is calculated in order to pull slack from the lower spans and move it to the overly tight uphill spans.

There are several conditions that should be understood regarding the application of clipping offsets.

a) Offsets must be calculated for the exact section being sagged. Insertion of a temporary snubbing position will change the offsets; therefore, offsets cannot be calculated until the sagging operation is determined.

b) All offsets must be marked prior to any clipping-in of the wire.

c) Offsets can be minimized by the judicious use of snubbing positions to separate line sections at different elevations.

Sags and clipping offsets are interrelated because sag corrections required for computing sags are dependent upon clipping offset computations. The application of sags and clipping offsets computed in this manner will produce balanced horizontal forces that will be the same for each structure within the sag section, see Paper TP64-146 [B18].

Figure E.1 through Figure E.7 depict a basic analysis for clipping offsets and typical parabolic methods and computations required for sagging conductors. Where greater accuracy or more detailed information is required, see Paper TP64-146 [B18], Lummis and Fischer [B20], and Wagner and Lloyd [B28].

### 10.5.2 Records and forms

To assist in an accurate compilation of sag section data, a set of prepared forms should be devised to record accurately all field data, computations, drawing numbers, etc., as soon as they are obtained. Should questions arise while the work is in progress or at a later date, the availability of such records might greatly assist in providing the answers.

### 10.5.3 Design criteria

A complete set of design criteria for the sag section should be available in the field. Included should be structure design data, stringing data, line profiles, conductor and pulling line sag templates, etc.

### 10.5.4 Equipment

Major equipment used for sagging could include transits (or similar viewing devices), portable radios, conductor thermometers, sagging watches, sagging platforms and targets, hand levels, stadia rods, dynamometers, measuring tapes, and miscellaneous marking devices.


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### 10.5.5 Pull site and snub structure relationship

A pull site should be adjacent to the snub structure whenever possible. However, if a deadend structure is used as a snub structure, it could be located several spans away. When this occurs, the conductor between the pull site and the snub structure must be slacked down as much as possible at sag completion to minimize pre-stressing of the conductor. It is not a desirable situation since the next sag section will include the pre-stressed conductor together with unstressed conductor. Such situations should be avoided.

### 10.5.6 Conductor uplift

Under certain conditions, conductor uplift within a sag section could occur at sag tension. Hold-down blocks or uplift rollers, or both, will be required to hold the conductor in the travelers to compensate for this condition.

### 10.5.7 Sag section length

A sag section should not exceed 7 kilometers,[15] or approximately 20 spans, in length. Exceptions do occur but should be avoided, particularly in hilly or mountainous terrain. Excessive sag section length will usually result in sagging difficulties.

### 10.5.8 Sag span locations

Before sag spans are selected, a scale profile of the entire sag section should be reviewed to provide a complete, clear picture of the relationship between the terrain and the conductor. Such a profile is a valuable tool to be used in the selection of the sag spans and may emphasize locations of potential problems.

Sag spans should be at or near each end of the sag section. For sag sections over 3 kilometers long[16], additional sag span(s) near the center of the sag section should be utilized. Sag spans should be the longer, more level spans. If the sag span is not a level span, it is best if the transit is located at the lower structure since conductor control is increased. Sag spans should also be located on each side of line angles greater than 10 degrees.

### 10.5.9 Tension changes

Tension changes may occur at any point within a stringing section at which a strain structure is located. The most complicated situation occurs, however, when tension changes divide the stringing section into three or more separate parts, each of which must be sagged independently of the other. Under these conditions, two or more ruling spans, and hence two or more required tensions, exist within the stringing section. Although the conductor is continuous throughout the entire stringing section, the tension changes may be accomplished by deadending or the correct use of grips and hoists. Strain structures will always exist at any point where conductor tension changes, but the mere existence of a strain structure does not always imply a tension change.

### 10.5.10 Sagging on flexible structures

Flexible angle structures (such as unguyed, self-supporting tubular steel poles) further complicate the sagging operation. If both sides of the structure are not sagged simultaneously, the deflection of the structure under differential conductor loads may alter the sag. It is therefore recommended, where practical, to sag through these type of structures in order to achieve the desired deflection and sag.

[15] 4.5 miles
[16] 2 miles

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Where it is not possible to simultaneously sag both sides of the structure, the sags should be re-checked and adjusted as necessary after both spans have been brought up to sag.

### 10.5.11 Control factors

The three basic sagging methods often used for sagging conductors are: transit method, dynamometer method, and stopwatch method.

#### 10.5.11.1 Transit method

The transit method is usually the most desirable method of checking sag because it can provide the most accurate control of conductor sag. There are three types of transit sagging methods used—calculated angle of sight method (see Figure E.4), calculated target method (see Figure E.5), and horizontal line of sight (see Figure E.6). When choosing one of these three methods, it should be kept in mind that the point of tangency of the line of sight from the transit to the conductor should fall in the middle third of the span. Reference to the profiles will usually give an indication of the best transit sagging method to use. For example, tall structures on flat terrain and short spans indicate that the target or line of sight methods would probably provide the best control. Steep slopes, long spans, and large conductor sag indicate that the angle of sight method might be best. After the sag spans have been selected, they should be field checked for potential difficulties that might occur during sagging. At the same time, if required, sagging hubs should be established and sagging computation measurements obtained.

#### 10.5.11.2 Dynamometer method

The dynamometer or direct tension measurement method inserts a dynamometer in-line with the sagging equipment and displays the actual tension of the line. The dynamometer must be accurately calibrated and sized so that the anticipated readings will be approximately midscale. The location of the tension-measuring device on the conductor can be critical to the accuracy of this method due to efficiency loss from the sheaves. It is therefore best to locate the device as close as possible to the actual span with a minimum number of sheaves between the span and the dynamometer. A dynamometer can also be used as a sag check using a shunt dynamometer installed after the conductor has been secured. The dynamometer method works best on small conductors and shorter spans. It also is a good method of checking loads during the stringing operation.

#### 10.5.11.3 Stopwatch method

The stopwatch or sagwatch method is a quick and accurate means of checking sag. This method involves jerking or striking the conductor and measuring the time it takes the shock wave to be reflected back to the initial point. Usually, three or five return waves provide an accurate measurement of the tension in the span. This method is most effective on small conductors and shorter spans. This method is also sometimes difficult on lines with long unbraced horizontal post insulators because the insulators may absorb too much wave energy and make it difficult to detect multiple return waves.

### 10.5.12 Preparation prior to sagging

Preparations for performing the mechanics of conductor sagging should be completed well in advance of the actual sagging operation. Otherwise, excessive costs and delay can be incurred.

When required, sag span transit hubs should be located and staked, transit height reference marks placed on the structures, and sagging platforms and transit mount brackets installed.

Sagging thermometers should be installed at or near the conductor prior to the actual sagging operation to allow temperature stabilization, and far enough above the ground to avoid the effect of ground heat


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radiation. Thermometers should be inserted in a container (sometimes a conductor section) to represent the internal conductor temperature. See Figure 29.

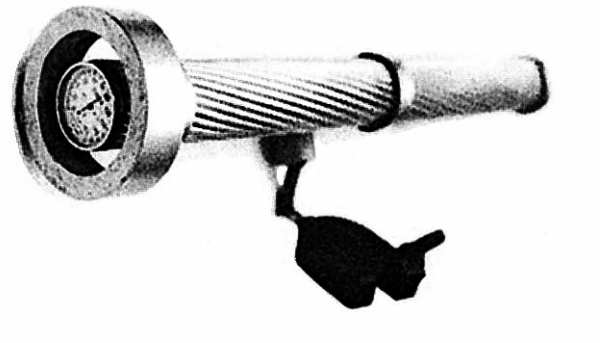


**Figure 29—Sagging thermometer and container**

The availability of sufficient portable radios should be ensured, and, if necessary, transportation should be arranged.

All sagging personnel should ensure that they have the proper equipment and sagging data in their possession. The person who controls the sagging should have in his/her possession a complete set of records pertaining to the entire sagging operation.

Due to adverse terrain conditions, sagging personnel will not always be able to observe all spans of the sag section. A study of the sag section profile will normally reveal such a situation. If the condition exists, additional help will be required to ensure that the conductors are sagging evenly in the blind spans.

### 10.5.13 Performance of sagging operation

After all preparations have been made and all personnel associated with the sagging operation are in position, the person who controls the sag should relay all last minute details to the puller operator.

Sagging personnel should obtain last minute thermometer readings and use the average of the two readings adjusted for an estimated increase or decrease in temperature at sag completion as the temperature for sagging the conductor. This information should be relayed to all persons involved in the sagging.

A conductor should never be sagged to the level of a previously sagged conductor. All conductors should be sagged based on temperature design criteria only. At the time of sagging conductors, the sag of any given phase should be within a tolerance of plus or minus 13 millimeters[17] sag of the theoretical value for each 30 meters[18] of span length, but not more than 152 millimeters[19] of sag in any one span. The sag of all phases of a circuit should have similar tolerances and direction from theoretical sag. Subconductors within a phase should have tolerances between each other of not over two conductor diameters with a maximum of 5 centimeters.[20] Due to the effects of solar radiation, vertical bundle conductors should not be sagged during midday if one subconductor is in the shadow of another subconductor. When checking sags at a time after original sagging, it should be remembered that creep will increase the sag and greater tolerance limits should be allowed for this and other unavoidable variations. Although it is desirable to check sags as soon as possible, it should be remembered that errors may be introduced during the clipping and deadending processes.

[17] 0.5 inch
[18] 100 feet
[19] 6 inches
[20] 2 inches

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Communications and cooperation between the personnel who are sagging and the puller operator, and among the personnel themselves, are essential. The personnel should keep the puller operator constantly informed of the conductor movement, and, if bundled conductors are being sagged, they should also keep him/her advised of the state of evenness existing between the subconductors.

Conductor is sagged in progressive order from the tensioner end of the sag section to the puller end. Therefore, as the puller operator initiates conductor movement at the puller end, each person in a sag span, progressing from the puller end to the tensioner end, should inform the person who is actually sagging of the conductor movement as it moves through the sag section. Two benefits are derived by this method of communication. First, the person who is actually sagging knows when to expect conductor movement in the sag span, and, second, the puller operator knows when to slow down or stop pulling.

Actual conductor sagging is initiated by the person who controls the sag and is first performed by that person in the sag span farthest from the puller working with persons who have spliced the conductor in the span containing the anchors for the previous sag. As the conductor is slowly released from the anchors, the person who is sagging should have the puller operator take the slack out of the conductor until it is slightly below sag. This condition should be maintained until the conductor is completely released from the hold-down blocks. Once the conductor is completely released, it can be pulled to sag.

If bundled conductors are being sagged, they should be brought to sag as evenly as possible. Should one of the subconductors be inadvertently pulled above sag in the sag span, severe difficulties can develop. In this situation, an attempt to slack one subconductor of the bundle down to sag usually results in unevenness in all of the other spans. Should this situation occur after an attempt to slack one subconductor down to sag, the sag should be stopped and the entire bundle should be slacked down below sag and evened. Another attempt to sag the conductors can then be made. Once the first sag span has been brought to sag, the subconductors of the bundle should be checked for evenness, and then the next sag span should be sagged. Unevenness in the sag spans in the middle or puller end of a sag section can usually be corrected by some manipulations of the conductors and, under normal conditions, will not result in starting the sag over again.

Attempts to sag conductor on excessively windy days should be avoided since serious errors can result due to conductor uplift caused by wind pressure on the conductor. Should severe wind conditions occur after a sag is in progress, allowances must be made for conductor uplift or the sag must be stopped.

### 10.5.14 Techniques for checking satisfactory sag progression

There are various techniques that are employed to determine if a conductor is sagging correctly. As stated before, conductor is sagged progressively toward the puller end of a sag section. As the first sag span comes to sag, the second person to sag should find that the conductor in his/her sag span is too high. This is to be expected and is normal, unless the conductor is excessively high. As the second person slacks his/her conductor down to sag, the third person should find the conductor too low in his/her sag span, and so on until the sag is completed. If any of the personnel who are sagging do not have the required conditions when the conductor is brought to sag in the preceding sag span, the entire sagging operation should be halted until the trouble is located.

If the conditions above are met, satisfactory sag progression is indicated. However, if an attempt to sag any sag span results in serious movement of a previously sagged span, trouble is again indicated, and the sagging operation should be halted until the trouble is located.

When the sag is completed, a tension reading should be recorded if a dynamometer has been used. The reading should be very close to the nominal tensions expected. Should the reading deviate excessively from the nominal tensions expected, the trouble should be located and any corrections should be made before the completed sag is accepted.


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### 10.5.15 Conductor reaction to sagging tensions

The reaction of conductor to tensions applied during sagging operations is similar to the wave created by dropping a stone in water. Once the wave is initiated, it continues for some period of time. Similarly, when tensions are applied to the conductor at the puller end of a sag section, the movement of the conductor is initiated at that point, and, although the tension may be held constant (puller stops), the movement of the conductor continues toward the other end at a decreasing rate. This movement must be dealt with when sagging conductor.

The travelers that are used to string conductor are not frictionless and, therefore, can cause problems during a sagging operation. If one or more of the travelers becomes jammed, sagging can become very difficult. A traveler that swings in the direction of the pull may be an indication of a defective traveler. Should unexplainable sagging difficulties occur, the travelers should be checked. Tensions applied to the conductor to overcome sticky or jammed travelers can cause sudden, abrupt movement of the conductor in the sag spans and quickly cause loss of sag, particularly if the conductor is already very close to sag.

## 10.6 Deadending precautions

### 10.6.1 Electrical hazards

The electrical hazards that exist when deadending work is being performed are analogous to those that exist during splicing operations. Therefore, precautions must be taken to prevent personnel from accidentally placing themselves in series with a potential electrical circuit.

### 10.6.2 Tension and pull sites

Continuity of grounding and bonding must be maintained when conductors or conductive pulling lines are transferred between pieces of equipment or between pieces of equipment and anchors. In the majority of cases, it will be necessary to move an existing ground on a conductor or pulling line before it can be transferred. Before removing the existing ground, the person must install his own personal ground to ensure that he/she will not place his or herself in series to ground with the conductor or line being transferred.

When two conductors or pulling lines, or any combination of them, are to be spliced or connected together in any way, the recommendations of 10.3.3 should be followed.

### 10.6.3 Deadend structures

Prior to installing or removing a deadend jumper on a metal structure, a personal ground must be installed on the conductors on both sides of the intended work area and connected to the structure. If the structure is wood, they should be connected to a common ground electrode. In some cases, after one end of the jumper has been permanently attached to one conductor, electrical induction may be so severe that a third personal ground will be required to bond the loose end of the jumper to the other conductor in order that the jumper may be permanently attached.

## 10.7 Clipping-in

The clipping portion of the conductor stringing operations involves the work following sagging and plumb marking of the conductors. This entails removing the conductors from the travelers and placing them in their permanent suspension clamps attached to the insulator assemblies.

Clipping begins once the conductor has been brought to sag and is initiated by placing plumb marks on the conductor directly below the insulator attachment points on the structures with a plumb marker pole. This marking is done as soon as possible after reaching sag to minimize the effect of creep and possible

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movement of the conductor between spans. In rugged terrain, clipping offsets may be used whereby the suspension clamp, rather than being placed at the plumb marks, is offset a calculated distance from the mark to compensate for the unevenness of the terrain and to allow the insulator assemblies to hang vertically when all structures have been clipped in. When clipping is being done, care must be exercised to be certain that the conductors are grounded prior to clipping, despite the fact that the lines being clipped are not attached to any electrical source. This involves placing a personal ground upon the conductor at the location being worked.

After the conductors have been marked, personnel lift the weight of the conductors, allowing the travelers to be removed and the suspension clamps and armor rod, if used, to be placed on the conductors. Lifting is normally done by use of a hoist suspended from the structure and a conductor lifting hook that is designed so as not to notch or severely bend the conductors. This conductor lifting hook should have an elastomer cover so as not to damage the surface of the conductors. After placing the suspension clamps on the conductor, the hooks are lowered, thereby placing the weight of the conductor on the suspension clamp and completing the assembly. Where bundled conductors are used, the multiple conductors may be lifted simultaneously by the use of a yoke arrangement supporting the hooks and a single hoist or other lifting means. Unbraced horizontal post insulators, with conductor attached to them, should not be used to hoist conductors below during the clipping-in operation.

It is recommended that conductors not be allowed to hang in the stringing blocks more than 24 h before being pulled to the specified sag. If this time is exceeded, the cable manufacturer should be consulted to determine if short time creep correction factors are required. The total time that the conductors are allowed to remain in the stringing blocks before being clipped should not be more than 72 h. If this time is exceeded, damage may occur to the conductors and/or sheaves.

### 10.8 Damper installation

Dampers, if required, are normally placed on the conductors immediately following clipping to prevent any possible wind vibration damage. Damage can occur in a matter of a few hours at initial tensions.

### 10.9 Spacer and spacer damper installation

When spacers are required for bundled lines with horizontal pairs of conductors, they should be installed immediately following the conductor clipping operations. Spacers can be installed using a bucket truck or by placing personnel on the conductors through the use of a conductor car. A conductor car is placed on the conductors and used to ride the conductors from structure to structure. Care should be exercised to ensure that the concentrated load of the person, car, and equipment does not increase the sag sufficiently to cause a hazard from obstructions over which the conductor car will pass. The installation and location of the spacers on the conductor varies with the type and manufacture of the spacer and is normally done is accordance with the manufacturer's recommendations. When unequal spacing is used, accuracy in spacer location is critical to protect the line against damage. Ground targets or car distance counters are necessary for accurately locating the spacers. Car footage counter accuracy should be verified to span length.

The load of the person, car, and equipment should be equally distributed to all subconductors of the phase. This is particularly important at the time each spacer is attached.

## 11. Special conductors

Special conductors, for the purpose of this guide, consist of: ACSS, T-2, SDC, and OPGW. These conductors are considered special due to the fact that they require specialized installation and handling procedures. Each of the following subclauses on these conductors generally cover those procedures required by the


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existing manufacturers of these conductors. It is recommended that the manufacturer be consulted prior to installation and handling to be sure that further precaution is not required.

## 11.1 ACSS—steel supported aluminum conductor

ACSS is an aluminum-steel composite conductor that looks like conventional ACSR. The difference is that while the aluminum wires in conventional ACSR are hard drawn, those used in ACSS are softer and fully annealed. The annealed aluminum wires in ACSS, being softer, have much more ductility than hard drawn wires in ACSR. They are also more susceptible to damage through improper handling.

Although ACSS can be pulled in and sagged generally in the same manner as ACSR, particular attention should be given to the following paragraphs.

Additional emphasis should be placed on normal precautions to avoid scuffing of the surface. ACSS should not be dragged across any surface. Only tension stringing methods should be used. Pay-off should be straight from the reel in order to avoid scuffing of the conductor against adjacent turns of the reel. Woven wire grips should be properly sized and double banded on the ends. Bolts on pocketbook type come-alongs and on bolted dead-end clamps should be clean and well lubricated. The bolts should be snugged-up and then tightened with at least five passes over them with full torque recommended by the manufacturer. Open-sided parallel jaw grips should be closely sized to the conductor diameter to minimize strand distortion. Tandem grips or core gripping methods may be required for certain high-tension applications. All stringing sheaves and bullwheels should be lined and sized according to this guide. Only multi-groove tensioners should be used with ACSS because single V-groove tensioners may damage the conductor or cause it to birdcage excessively.

Conductor distortion and minor birdcaging with ACSS can often be repaired satisfactorily by hand reshaping with a small block of wood. Severed strands require armor rods or repair sleeves.

If the ACSS is to be pre-stretched prior to sagging, refer to the manufacturer for recommendations on the magnitude and the duration of the pre-stressing.

## 11.2 T-2 Conductor—twisted bare conductors

T-2 Conductor consists of two standard concentric stranded conductors twisted around each other. T-2 Conductor may be installed using techniques and equipment similar to those used to install single concentric round wire conductors, with a few special procedures used to maintain equal tension between the two component conductors.

### 11.2.1 Handling

It is important to maintain the relationship of the conductor lengths established during manufacturing. Therefore, T-2 Conductor should not be rewound in the field from the shipping reel to another reel. Reels containing T-2 Conductor should be stored upright resting on the rims; never lay the reel on its side.

### 11.2.2 Tensioners and sheaves

Most methods of installation used for standard round conductor can be used to install T-2 Conductor. However, tension methods of stringing are preferred.

Figure 30 illustrates two multi-groove bullwheel tensioners that can be used to install T-2 Conductor.

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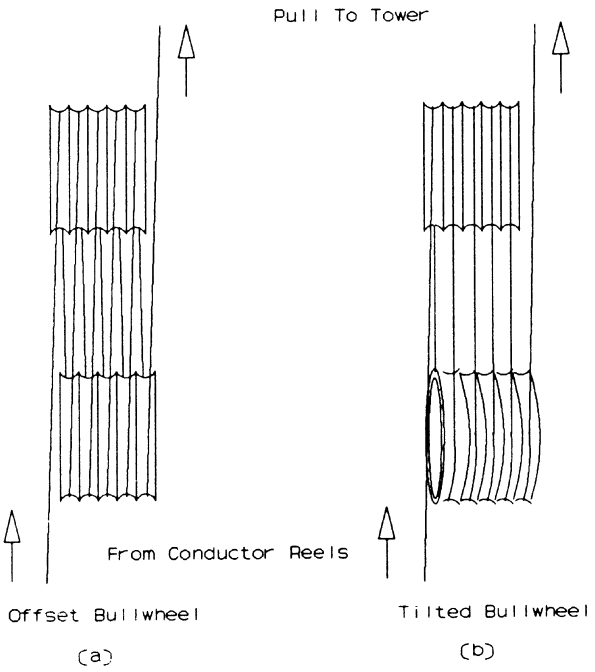



**Figure 30—T-2 bullwheel tensioners**

**CAUTION**
Smaller than recommended diameter sheaves and/or high stringing tensions may cause a build-up of torsional stress into the conductor.

Figure 30(a) represents a unit in which the alignment of the front and back bullwheels is offset by one half of the groove spacing. This design is satisfactory for installing smaller sizes of T-2 Conductor where the conductor will lay flat in the bottom of the groove. If improper equipment is used, the ridge between the grooves may separate the T-2 Conductor individual members.

Figure 30(b) illustrates another preferred type tensioner. In this design, one bullwheel is tilted slightly in relation to the other bullwheel. This allows the conductor to ride in the bottom of the grooves. This type of tensioner, properly sized, is preferred.

V-groove tensioners cannot be used.

Recommended bottom groove diameters for sheaves and bullwheels should be sized in accordance with this guide, except the bottom groove diameter for sheaves should not be less than 14 times the maximum diameter of the T-2 Conductor. See Figure 22. References to the conductor diameter, D, should be the maximum diameter for the T-2 Conductor (twice the diameter of one component conductor).

The groove radius of the sheave and bullwheel must be wide enough for the T-2 Conductor to pass through with the two component conductors laying side by side. The minimum groove radius must be 0.55 times the maximum diameter of the T-2 Conductor. (See Figure 22.)

### 11.2.3 Tensioning

T-2 Conductor is tensioned by placing a separate grip on each component conductor. The two grips are connected through a snatch block with a short pulling rope. Tension is applied to the snatch block. This arrangement will apply even tension between the component conductors.


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### 11.2.4 Splicing

T-2 Conductors are joined by separately splicing each component conductor. Where possible, the individual conductor splices should be staggered about 1.5 meters.[21] An additional twist may be needed before the second splice is made to remove any looseness between the component conductors. This will ensure that each component conductor carries an even share of line tension. Both splices should be made before tension is applied.

### 11.2.5 Repairs

Repairs to damaged component conductors can be made using the following procedure:

a) Attach two wire grips facing each other approximately 4.6 meters[22] apart on the undamaged component conductor.

b) Attach a chain hoist to the grips and take up tension. (As the tension increases, slack will appear in the damaged component conductor.)

c) Increase tension until there is enough slack to make repairs.

**CAUTION**
If it is necessary to cut the damaged conductor to install a splice, a second set of grips and hoist should be installed on the damaged conductor before it is cut. The above procedure should be used to install the grips.

Helically applied rods may be used for repair in accordance with utility policy, given the nature and severity of damage. Follow the above procedures to install the repair rods on the damaged conductor.

## 11.3 Self-damping conductor (SDC)

The general recommendations for the installation of SDC are basically the same as for ACSR and are as given in this guide. There are, however, two major differences from normal practice that should be followed to prevent the steel core from being drawn inside the aluminum layers. They are

a) *The installation of pulling sleeves on the pulling end of the conductor*. If two reels are pulled in tandem, pulling sleeves should also be installed on the drum end of the lead conductor. This is done just after the tail end is pulled off the reel with the conductor still held in the tensioner. As a precautionary measure, it is recommended that at least a two-bolt grip be placed on the conductor approximately 0.6 meters[23] from the end.

b) *The use of bolted grips or come-alongs with elliptical grooves for holding the conductor during sagging or snubbing*. The elliptical groove is necessary in order for the aluminum layers to be deformed sufficiently into an oval shape to grip the steel core.

### 11.3.1 Preparation for sagging

In preparation for transfer to the sagging unit or for temporarily snubbing-off prior to sagging, come-along(s) need only be attached to the conductor directly in front of the tensioner. The conductor can then be let out from the tensioner and handled like a conventional conductor. It is not necessary to install another come-along or two-bolt grip at the tail end of the conductor. The steel core may draw in approximately 2.5 centimeters[24] as the conductor is let out of the tensioner. This is not detrimental and is no more than what, at times, happens with conventional ACSR.

[21] 5 feet
[22] 15 feet
[23] 2 feet
[24] 1 inch

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When installing come-alongs on SDC, it may be necessary to re-torque the nuts one or two more times than for conventional ACSR before uniform recommended torque readings are obtained. The nuts should be re-torqued periodically when a come-along is used for snubbing over an extended period of time to be certain that relaxation has not occurred.

Upon removal of a come-along, SDC will retain an oval shape in the area under the come-along. Its original shape can be restored by hitting the major axis of the oval with a wood or rubber mallet or with a heavy piece of wood.

A precautionary note—to insure that the required clamping force is always obtained, come-alongs should be properly maintained. The eyebolts should be kept cleaned and lubricated. The conductor groove should be clean and dry. This applies to all come-alongs, regardless of the type of conductor.

### 11.3.2 Sagging

The sagging procedure for SDC is the same as for any other type of conductor; however, SDC has a tendency to be slightly less free running than a conventional conductor. This is because that portion of SDC that rests in the sheaves between the time that it is strung and then pulled up to sag becomes slightly oval.

### 11.3.3 Clipping

Although not absolutely essential, it is advisable to let any conductor, after being pulled up to sag, sit in the stringing sheaves a minimum of two hours before being clipped in. This gives an opportunity for the conductor tension to equalize between spans.

### 11.3.4 Bullwheel dimensions

The recommended bullwheel dimensions for stringing SDC are the same as those shown in Figure 19.
NOTE—Universal V-groove bullwheels should not be used with SDC.

### 11.3.5 Sheave diameters

If too small a stringing sheave is used with SDC, the conductor becomes sufficiently oval while resting stationary in the sheaves to raise or pop a strand. Once a strand raises, it is extremely difficult, if not impossible, to get it back in place without taking the tension off the conductor in that area. Therefore, larger diameter sheaves are recommended with SDC than with conventional conductor.

A minimum sheave diameter at the bottom of the groove of 20 times the conductor diameter should be satisfactory for typical SDC stringing operations.

Extremely long vertical (weight) spans and large approach and snub angles may result in the conductor being sufficiently deformed in the sheaves to pop strands. At these locations, sheaves with diameters at the bottom of the grooves of greater than 20 times the conductor diameter, or larger, may be necessary.

## 11.4 Composite overhead groundwire with optical fibers (OPGW)

OPGW was developed in order to provide large capacity telecommunication capabilities to utilities by allowing the utilization of their overhead power transmission lines. The product is one in which the central core of the overhead groundwire contains many fibers and various manufacturers have different ways of enclosing the fibers. The balance of the OPGW is generally made of aluminum clad steel wires of varying conductivities but may utilize other wire types and combinations to satisfy the strength/fault current requirements.


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### 11.4.1 Stringing

Lined blocks are recommended for use with OPGW and the minimum sheave diameter is dependent upon the cable design. When installing OPGW, the cable manufacturer should be consulted for a recommendation on the minimum sheave and bullwheel diameters, the specific maximum pulling speeds and the maximum pulling tension.

Using the correct size sheave is very important to ensure that the optical fibers in an OPGW are not crushed during the stringing process. If specific sheave recommendations are not available from the manufacturer, a conservative sheave diameter is 40*D* (i.e., 40 × *D*; *D* = diameter of the OPGW). On-line angles or pullover angles greater than 30°, larger sheave diameters may be needed. If specific bullwheel diameter recommendations are not available, a conservative bullwheel diameter for tensioners is 70*D*. For OPGW with left-hand lay, the bullwheel must be reeved from right to left. The opposite reeving direction is appropriate for OPGW with right-hand lay. The use of a swivel on the pulling line followed by an anti-rotation device should be used to minimize the tendency of the OPGW to twist during stringing. Some cable design and installation tension combinations of OPWG may not require an anti-rotation device.

The setup location for the cable reel, the tensioner and the puller should take into consideration the slope of the cable between the tensioner and the sheave at the first structure. This slope should never be steeper than three to one (3 horizontal and 1 vertical). If the tensioner cannot be placed at the proper distance from the first structure, the tensioner should be repositioned or the first sheave temporarily lowered during the pulling operation, then later raised for final hardware installation.

Experience has shown that pulling speed, maximum tension imposed on the line during stringing, and the number of times the line passes through stringing blocks in one section are important factors in achieving a smooth operation. Typical stringing tensions are in the range of 15% or less of the OPGW's rated breaking strength. The maximum stringing tension should generally be limited to 20% of the rated breaking strength and pulling speeds of 2–5 km/h[25] are recommended.

### 11.4.2 Sagging

The method used to sag OPGW is similar to that used for conductors and overhead ground wires. Certain grips used for conductor and overhead ground wire are normally not acceptable for OPGW because they could crush the fiber tube(s). Pocket book type comealongs are available, but are typically designed for the specific OPWG cable. These special tools are machined to closely match the diameter of the OPGW so that they will not crush the cable. Formed wire grips may sometimes be used, if they are approved by the manufacturer. Sag/tension data is normally supplied by the OPGW manufacturer.

### 11.4.3 Splicing

There is one primary difference between OPGW and conventional overhead groundwires. Conventional overhead groundwires are often spliced midspan with a compression type connector. OPGW, on the other hand, is typically spliced at a tower. A 9–20 meters[26] tail is therefore required to make up the connection, depending on the particular splice box arrangement being used.

## 11.5 All-dielectric self supporting fiber cable (ADSS)

ADSS cable was developed for telecommunications applications on high-voltage power lines. The cable contains no metallic or electrical conducting elements, and yet contains sufficient strength from dielectric strength members such as aramid or fiberglass yarns to be suspended between supports without the need to

[25] 1.5–3 m.p.h.
[26] 30–65 feet

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be lashed to or integrated with a steel messenger cable. Extremely long spans and small sags are possible depending on the ADSS design.

### 11.5.1 Stringing

Although ADSS cable is non-conductive, when it is installed in close proximity to energized or potentially energized high-voltage lines, general safety precautions should be followed similar to those precautions employed when installing a conductive wire in similar situations.

When installing ADSS, the cable manufacturer should be consulted for a recommendation on the minimum sheave and bullwheel diameters, the specific maximum pulling speeds and the maximum pulling tension. The ideal method for installing ADSS is the *Stationary Reel* method. This method requires the reel of the cable to be stationed at one end of the pull and a take up reel on the other end. A pull line is threaded through the sheaves using a pull line of matched weight and minimum induced torque. Once the pulling line is threaded and all the sheaves are balanced or tied up, then the take-up mechanism is started and the ADSS cable is pulled through the sheaves under tension.

The *Moving Reel* method is generally not recommended for ADSS installation on long spans or areas of difficult access to the tower because the pulling tensions and loading on the structure are often uneven. However, the moving reel method is often used successfully for short span, distribution type, applications.

It is critical not to exceed the minimum bending radius and crush resistance specified by the cable manufacturer. If the cable is bent too tightly, the cable may kink resulting in excessive stresses on the fibers or the lateral sidewall pressure may be too great causing the internal tubes containing the fiber to be crushed.

There are several rules to follow in order not to exceed the minimum bending diameter. The appropriate sheave diameter is critical when installing ADSS cable. If the required large sheaves do not fit on the structure, the cable manufacturer should review the concerns and give recommendations. The appropriate sheave diameter should not be less than $30D$ (i.e., $30 \times D$; $D$ = diameter of the ADSS), or the cable manufacturer's recommendation, whichever is larger. The groove depth should be at least 1.25 times the cable diameter. Bare metal sheaves or lined sheaves may both be used for ADSS. If bare metal sheaves are used, they must be totally free of burrs or ruts, with a smooth polished surface.

It is often recommended that the sheaves on angle structures be tied up at an angle to keep the ADSS cable in the bottom of the groove to avoid excessive twisting of the cable. Excessive twisting may damage the buffer tubes and fibers in an ADSS cable. Heavy angle structures may need two or three large sheaves to direct the cable through wide lattice steel type structures, with the entrance and exit sheaves tied up close to horizontal. Hold-down (feed-in) sheaves may be required to direct and keep the ADSS in the sheave groove.

Typical tension stringing equipment consists of a double bull-wheel type tensioner with a minimum groove diameter of at least $35D$ and with a minimum of three (3) cable turns over the bullwheels. A load-limiting device on the puller should be used to monitor the pulling tension. When the measured tension approaches the maximum allowable tension, the pull should be stopped and the cause of the increased tension resolved (e.g., cable climbing the sheave, binding in the yoke, out of alignment with the sheaves), then the pull continued. At no time is it recommended to use a breakaway swivel as the means to monitor tension unless a bypass loop is installed to prevent a total release of the cable. Typical ADSS stringing tensions range from 180 to 550 kilograms.[27]

The setup location for the cable reel, the tensioner and the puller should take into consideration the slope of the cable between the tensioner and the sheave at the first structure. This slope should never be steeper than three to one (3 horizontal and 1 vertical). If the tensioner cannot be placed at the proper distance from the

[27] 400–1200 lbs


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first structure, the tensioner should be repositioned or the first sheave temporarily lowered during the pulling operation, then later raised for final hardware installation.

ADSS cable should be attached to the pulling rope using a double swivel eye and wire mesh grip. Wire mesh grips are intended only for pulling the cable through the system and, at the end of the installation process, the wire mesh grip and approximately 5 meters[28] of cable should be cut off. The wire mesh grip can be inspected and evaluated for reuse. Split wire mesh grips or clamping devices should not to be used to tension or to hold ADSS cable under tension. Only deadends designed for ADSS applications or aramid yarn pulling grips should be used for mid-span tensioning. The swivel and the pulling grip for connecting the cable to the pulling rope should be a balanced design to transmit the pulling force to the ADSS cable evenly and to maintain alignment during stringing without inducing torque. Cable twist may be monitored by using a cloth flag or "tail" taped on the cable jacket and allowed to dangle approximately 10 cm.[29] An additional flag may be taped to the pulling rope to monitor the rope torque. If the swivel is working, the pulling rope flag will spin and the ADSS flag will not. If the ADSS flag flips coming out of the sheave, it indicates the sheave is not properly aligned and is allowing the ADSS to climb the sheave wall, therefore inducing torque on the ADSS. Different manufacturers may have different recommendations for the acceptable amount of twisting during installation. As a rule of thumb, if the ADSS flag flips less than ten times in a span, the torque is acceptable.

### 11.5.2 Sagging

The manufacturer should be consulted for the maximum sagging tension.

Line-of-sight sagging or transit sagging is generally recommended for ADSS cable sagging. Dynamometer tension sagging does not give accurate sag characteristics if multiple sheaves are used at each structure or if the segment has excessive angles. General experience has shown that pulling through multiple sheaves on lattice structures can result in significantly higher sagging tensions than measured with a dynamometer. The transit method, used in one span, is recommended for each five to eight spans between deadends. A minimum of three spans should be checked in a pulling section.

ADSS cable should be sagged from deadend segment to deadend segment and not sagged through heavy angles. ADSS should not be tensioned directly from the puller, tensioner or from the reel in order to avoid crushing of the buffer tubes. The first structure should have an appropriate length for splicing and a deadend installed. At the next deadend structure, a temporary deadend assembly and chain hoist should be used to sag the first segment via the transit method and the tension held while the permanent deadend assemblies are installed. A cable drip loop between the deadends should generally be at least 30–50 centimeters[30] and formed downward.

If the system requires aeolian vibration dampers and/or corona rings, they should be installed shortly after clipping into the suspension hardware on each structure. The cable and hardware manufacturers should be consulted for vibration damper requirements.

### 11.5.3 Splicing

Splicing should be performed on the ground. The splice can then be stored aerially, at ground level in a pedestal or cabinet, or underground in a hand hole or manhole. Sufficient length of cable ends should allow the cable to descend the structure and enter a splicing vehicle. Each splice should have a storage loop of cable allowing the splice to be removed from the base of the structure and extended into a splicing vehicle. Extra length may be needed if the vehicle cannot be located close to the structure. Cable down guides should be used to attach the ADSS cable to the structure along its entire height.

[28] 15 feet
[29] 4 inches
[30] 12–20 inches

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# Annex A

(informative)

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# Annex B

(informative)

# Electrical theory

Assume a de-energized transmission line that is paralleled by an energized transmission line. The following two cases should be considered.

a) *Electric field induction*. The energized line is not carrying any load. As such, the de-energized line will be exposed only to a time-varying electric field. This electric field will induce a voltage on the de-energized transmission line. If the de-energized transmission line is grounded at any point, a charging current or displacement current will flow in the ground. The magnitudes of these voltages and currents are a function of the capacitive relationships that are established between the two transmission lines.

b) *Magnetic field induction*. The energized line is carrying load current. In this case, the de-energized transmission line lies within a time-varying magnetic field. This magnetic field will induce open circuit voltages on the de-energized transmission lines. If the line is grounded at two points, a circulating current will flow in the grounded section.

Each type of induction will be addressed separately in the following subclauses.

## B.1 Electric field induction

Consider a long and straight conductor that has a charge of q coulombs per unit length. The potential difference between two distant points A and B due to the charge on the conductor (see Figure B.1) can be expressed as

$$V_{AB} = \int_{L1}^{L2} E dx = \int_{L1}^{L2} (q/2\pi\varepsilon_0 x) dx = (q/2\pi\varepsilon_0 x dx)\ln(L2/L1)V \quad \text{(B.1)}$$

where

$E$ is electric field strength,
$q$ is instantaneous charge per unit length of conductor,
$\varepsilon_0$ is permittivity in free space,
$L$ is the distance from point on conductor to point in space.

Assume two energized parallel conductors $M$ and $N$ with radii $r_M$ and $r_N$, respectively. The conductors are assumed to have linear charge densities $q_M$ and $q_N$ coulombs per unit length, respectively. The conductors do not carry any load (see Figure B.2).

To calculate the potential difference between two distant points A and B, the effect of the positive charges $q_m$ and $q_n$ on the overhead conductors plus the effect of the negative charges $q_M$ and $q_N$ on the image conductors must be considered. Expanding on the form of Equation (B.1), it can be stated that the potential difference between points A and B is

$$V_{AB} = 1/2p\varepsilon_0(q_M\ln(D_{MB}/D_{MA})) + q_N\ln(D_{NE}/D_{NA}) - q_M\ln(D_{M*B}/D_{M*A}) - q_N\ln(D_{M*A}/D_{N*A}) \quad \text{(B.2)}$$

where


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$D_{MB}$ is the distance from conductor $M$ to point $B$,
$D_{M*B}$ is the distance from the image of conductor $M$ to point $B$.

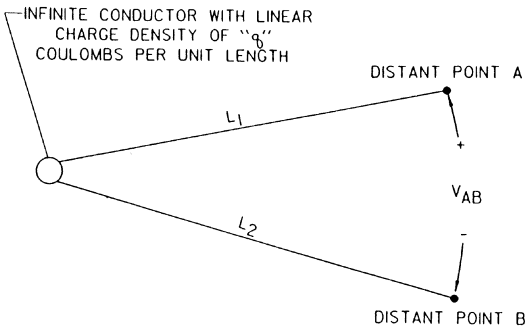



**Figure B.1—Potential difference between two points**

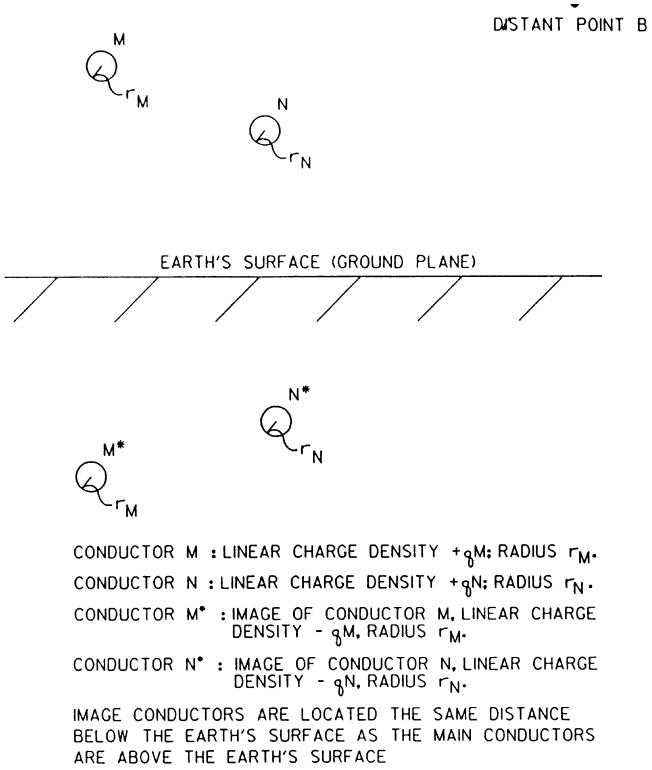



**Figure B.2—Two conductors and their images**

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The points *A* and *B* can be assumed to be at the center of conductors *M* and *N,* respectively. Letting *M* equal *A* and *N* equal *B*, the theory can be expanded to show the relationship between the two conductors as

$$V_A = 1(2\pi\varepsilon_0)(q_A \ln(D_{AA*}/r_A) + q_a \ln(D_{BA*}/D_{BA})) \quad \text{(B.3)}$$

$$V_B = 1(2\pi\varepsilon_0)(q_B \ln(D_{AB*}/D_{AB}) + q_B \ln(D_{BB*}/r_B))$$

which can be written in the form

$$\begin{bmatrix} V_A \\ V_B \end{bmatrix} = [P] \times \begin{bmatrix} q_A \\ q_B \end{bmatrix} \quad \text{(B.4)}$$

where

$$P = \begin{bmatrix} P_{AA} & P_{AB} \\ P_{BA} & P_{BB} \end{bmatrix}$$

The elements of the P matrix are often referred to as potential coefficients as they relate the charges on the conductors to the potentials that they induce on other conductors.

This relationship can be stated as

$$V = PQ \quad \text{(B.5)}$$

where

*V* is the voltage matrix,
*P* is the potential coefficient matrix,
*Q* is the charge matrix.

The elements of *P* are

$$P_{AA*} = 1/(2\pi\varepsilon_0)\ln(D_{AA*}/r_A) \quad \text{(B.6)}$$

$$P_A = 1/(2\pi\varepsilon_0)\ln(D_{BA*}/D_{BA})$$

Potential coefficients by themselves are of little use; however, simple matrix manipulation will result in the formation of the capacitance matrix, which is useful.

Capacitance is defined by $C = Q/V$. By rearrangement, we find that

$$CV = Q$$

Since V = PQ, $P^{-1}$ V = Q because CV = Q

Then $P^{-1}$ V = CV = Q

We see that $P^{-1}$ = C


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Thus, the inverse of the potential matrix is the capacitance matrix.

To obtain an expression in matrix form that allows calculation of the voltage induced on the de-energized conductors by the energized conductors, take the time derivative of the charge $Q$ on the line (in phasor form).

$$dQ/dT = I = jwQ = jwCV \tag{B.7}$$

The matrix relationship is now

$$\begin{bmatrix} I_{\text{energized conductors}} \\ I_{\text{de-energized conductors}} \end{bmatrix} = jw\left[C\right]\begin{bmatrix} V_{\text{energized conductors}} \\ V_{\text{de-energized conductors}} \end{bmatrix} \tag{B.8}$$

If the de-energized circuit is not grounded, then

$I$ (de-energized conductors) = 0

The voltage induced in the de-energized conductors can be solved for using matrix algebra.

If the de-energized circuit is grounded, the voltage at this point is zero. By setting

$V$ (de-energized conductors) = 0,

the current induced in the de-energized conductors can be determined.

## B.2 Magnetic field induction

Magnetic field induction is the process of generating voltages or currents, or both, in an electric circuit by means of a time-varying magnetic field.

A transmission line carrying load current will have a time-varying magnetic field surrounding it. A nearby de-energized transmission line that parallels the load carrying line will lie within this time-varying magnetic field. If the de-energized line is not grounded or is grounded at only one point, voltages will be induced on the line. To calculate the magnitude of these induced voltages, it is necessary to calculate the self and mutual impedance of the transmission lines. This may be done by using phase quantities.

In developing the impedance values for the transmission lines, each conductor's self and mutual impedance must be calculated. The self impedance of each conductor is independent of its position with respect to all other conductors. The mutual impedances of each conductor to the other conductors are dependent upon its relative position with respect to all other conductors. The matrix is symmetrical, but $Z_{AB}$ is not necessarily equal to $Z_{AC}$ or to $Z_{BC}$.

Equations for the self impedance of a conductor with earth return and the mutual impedance between two conductors with common earth return were developed by Dr. John R. Carson [B2]. These equations, as modified by Edith Clark [B3], use phase quantities and assume the earth's conductivity to be constant. The equations are presented here in a matrix format.

*Self impedance of conductors*

$$Z(A,A) = R + jX = RES + FF \times 4 \times w \times P(A,A) + j\{FF \times 2 \times w \times LN(2Y(A)/GMR) + 4 \times w \times Q(A,A)\} \tag{B.9}$$

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*Mutual impedance of conductors*

$$Z(A,B) = R + jX = FF \times 4 \times w \times P(A,B) + j\{FF \times (2 \times w \times LN(DIND/DD)) + 4 \times w \times Q(A,B)\} \quad \text{(B.10)}$$

*Definitions of variables*

*FF* is $0.1609347 \times 10^{-3}$ Ω/mi,
*w* is $2 \times \pi \times$ frequency,
*RES* is the resistance of the conductor in ohms/mile,
*Y(A)* is the vertical height of conductor above ground in feet,
*DI* is the diameter of conductor in inches,
*DIND* is the distance between a conductor and the image of a conductor in feet,
*DD* is the distance between two conductors in feet,
*GMR* is the Geometric Mean Radius.

The *P* and *Q* terms are functions of an infinite series. This infinite series converges rapidly for transmission line impedance parameters. The following expansions of *P* and *Q* approach the infinite series value within 1% and are sufficiently accurate for this development.

$$P(A,B) = (\pi/8) - (1/3\sqrt{2})K\cos\theta + (K^2/16)\cos 2\theta(0.6728 + \ln 2/K)$$
$$+ (K^3/16)\theta\sin 2\theta + K^2\cos 3\theta/45\sqrt{2} - \pi K^4\cos 4\theta/1536$$

$$Q(A,B) = -0.0386 + \frac{1}{2}\ln(2/K) + (1/3\sqrt{2})K\cos\theta - \pi K^2/64\cos 2\theta + K^3\cos 3\theta/45\sqrt{2}$$
$$-K^4\theta/384\sin 4\theta - K^4\cos 4\theta/384 \cdot \ln 2/K + 1.0895$$

NOTE—q is in radians.

If $A = B$, then

$$K = 0.856467 \times 10^{-3} \times 2Y(A) \times \sqrt{f/\rho}$$
$$\theta = 0$$

If $A \neq B$, then

$$K = 0.856467 \times 10^{-3} \times D \times \sqrt{f/\rho}$$
$$\theta = \mathrm{ATN}(F/\sqrt{1 - F^2})$$

where

*F* is H/D,
*f* is frequency,
ρ is resistivity of earth in ohm-meters,
*D* is the distance between conductor *A* and the image of conductor *B,*
*H* is the horizontal distance between conductor *A* and *B*.

Assume a double circuit system. Circuit 1 is energized and carrying load current. Circuit 2 is grounded at only one location. To calculate the voltage induced on circuit 2, realize that the currents on the de-energized conductors are equal to zero. Then


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$$\begin{bmatrix} V_{\text{energized conductors}} \\ V_{\text{de-energized conductors}} \end{bmatrix} = [Z] \begin{bmatrix} I_{\text{energized conductors}} \\ I_{\text{de-energized conductors}} \end{bmatrix}$$

where

$Z$ is the impedance matrix

The voltages induced on the de-energized can be solved for using matrix algebra.

A complete development of these theories can be found in Schnell [B26].

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# Annex C

(informative)

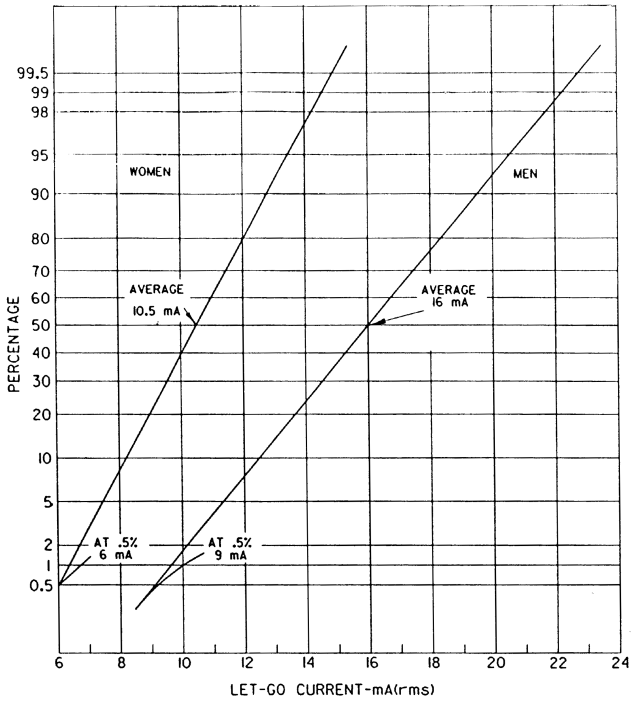
# Grounding electrical concepts

## C.1 Physiological reactions

Shock currents can be classified according to the degree of severity of the shock they produce. Primary shock currents can produce direct physiological harm. Secondary shock currents do not produce direct physiological harm but are annoying and may cause involuntary muscle reaction. Both primary and secondary shock currents can be either steady-state or transient in nature. While large charges produced by lightning strokes can cause primary shocks, the transient current effects are a product of time and current magnitude and may or may not produce direct physiological harm.

The effect of ac and dc currents is given in Table C.1. With increasing shock currents, the control of the muscles in which the current flows becomes increasingly difficult. *Let-go current* is the value of current at which a human holding an energized conductor cannot control his/her muscles enough to release the conductor. The let-go current depends on the type of current, dc or ac. Figures C.1 and C.2 show the distribution curve of let- go current for ac current at 60 Hz frequency and dc current (Dalziel [B5]). Figure C.1 shows a let-go current of 9 mA for men and 6 mA for women. The let-go currents are chosen as those corresponding to 99.5% probability of not losing muscular control.

Currents above the let-go current shall be avoided since prolonged muscle contraction in the chest area can lead to suffocation (respiratory tetanus).

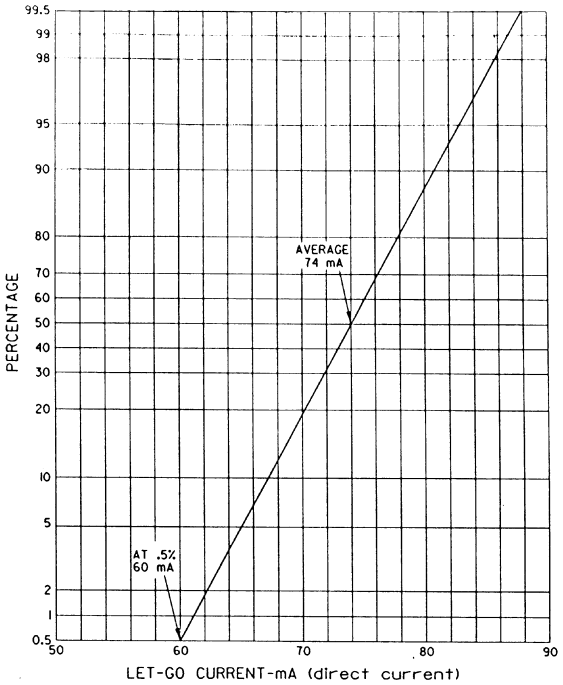



NOTE—Data from test results of 28 women and 134 men

**Figure C.1—Distribution curve of let-go values of alternating currents**


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NOTE—Data from test results of 28 men.

**Figure C.2—Distribution curve of let-go values of direct currents**

**Table C.1—Effects of ac and dc current**

| Effects | Current (mA) | | | |
|---|---|---|---|---|
| | Direct current | | 60 Hz rms | |
| | Men | Women | Men | Women |
| No sensation on hand | 1.0 | 0.6 | 0.4 | 0.3 |
| Slight tingling—"threshold of perception" level | 5.2 | 3.5 | 1.1 | 0.7 |
| Shock; uncomfortable, but not painful; muscular control not lost | 9.0 | 6.0 | 1.8 | 1.2 |
| Painful shock; muscular control not lost—"safe let-go" level for 99.5% of persons tested | 62.0 | 41.0 | 9.0 | 6.0 |

The goal of protective grounding is to avoid adverse physiological effects. Charles Dalziel (see Dalziel [B5]) carried out extensive research on the magnitude of current flow and the related effects on human participants. He investigated a time-current relationship of this primary shock, given by the following equation:

$$I = (K/\sqrt{T})A \quad \text{(C.1)}$$

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where

*I* is the ventricular fibrillation current in amperes,
*T* is the time duration of current flow in seconds,
*K* is an empirical constant.

for a probability of 0.5% of ventricular fibrillation, $K = 0.116$.

Using Dalziel's empirical equation, the curve relating current and time is shown in Figure C.3.

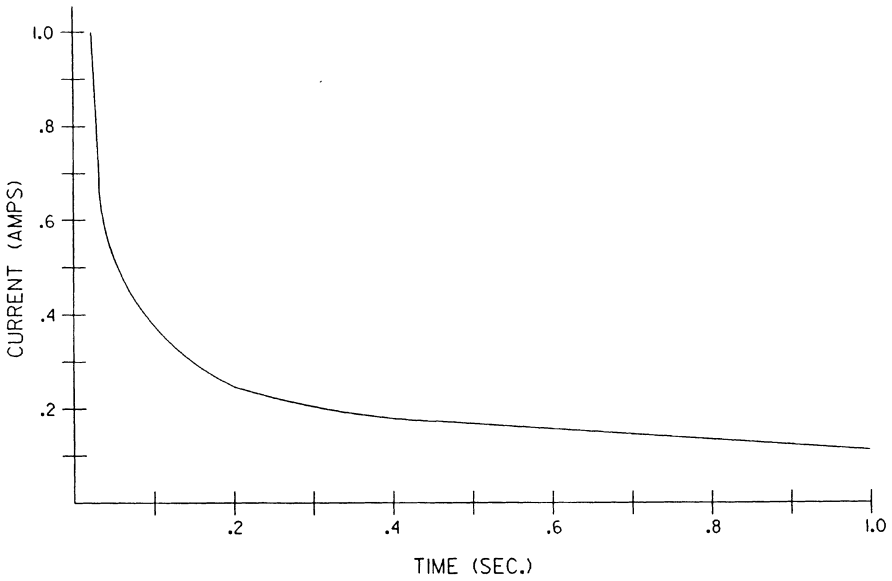



**Figure C.3—Plot of Dalziel's empirical equation**

*Example*

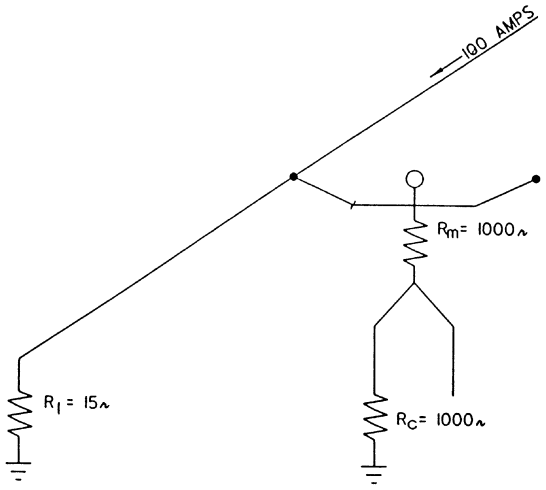
Assume the following situation depicted in the figure that follows:

a) During stringing of a transmission line, the brakes fail on the tensioner, the guard structure collapses and the line under construction is accidentally energized by a distribution line.
b) The resistance of the ground at the tensioner end is 15 Ω.
c) The fault current is 100 A.
d) Voltage across man is approximately $V_m = I \times R_1 = 100 \times 15 = 1500$ V.
e) The contact resistance plus the body resistance of the man is 1000 Ω plus 1000 Ω = 2000 Ω. Man is standing on the ground and is not protected by a ground.


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f) Current through man, $I_m = V_m/R_m = 1500/2000 = 0.75$ A



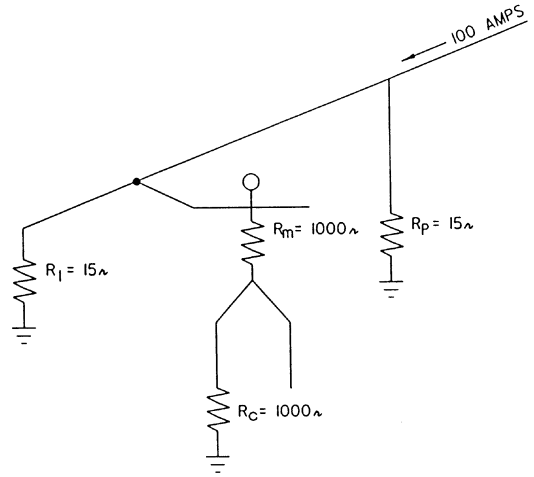

g) Using Dalziel's electrocution formula

$$I = 0.116\sqrt{T} \tag{C.2}$$

$T = (0.116/I)^2 = (0.116/0.75)^2 = 0.024s$

Therefore, for a possible fatal shock it would take only 1/40 s.

Assume the same conditions above with the addition of a personal ground.




h) $V \cong (100)(15/2) = 750$ V

i) $V_m/R_m = (750)/(2000) = 0.375$ A

j) $T = (0.116/I_m)^2 = (0.116/0.375)^2 = 0.096$ s

From the above information and examples of accidental contact with an energized circuit, it is obvious that the results can be hazardous even from a momentary contact, when the worker is not adequately protected from electrical shock. It also shows that for a ground-level work site, application of personal grounds does not necessarily establish a hazard-free equipotential zone for the worker. Precautions such as the following must be exercised to avoid problems from such hazardous conditions:

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a) Use of insulated mats
b) Use of conductive mats (grids)
c) Use of properly rated gloves
d) Use of properly rated insulated hot sticks
e) Use of barricades
f) Staying on properly grounded and bonded equipment

It can also be shown that some situations can develop secondary shock current values. This secondary shock hazard provides justification for requirements such as use of safety belts when working on towers.

## C.2 Body resistance

For determination of the potential differences, which should not be exceeded in safe work sites, an effectively correct value of body resistance shall be utilized. Values for applicable body resistance vary from 100 Ω through values of several thousand ohms when thick calluses are present on skin surfaces. By use of Ohm's law we can see that the most critical body currents for a given voltage will occur when low body resistance is used. However, a body resistance of 1000 Ω is recommended by and is adopted for calculations in this guide.

## C.3 Step voltage

With an overhead transmission line, ground-fault current ($I_e$), initiated by breakdown or flashover of an insulator string enters the earth through the footing of steel towers or through any other object connected to ground. Assuming the ground is homogenous, the current spreads uniformly in all radial directions. The current produces substantial voltage gradients, as shown in Figure C.3. If a man is walking as in Figure C.5 in the neighborhood of a faulted transmission tower, voltage is impressed across his feet. This voltage is called step voltage and is given by the line integral of the voltage gradient over the step width *S* between his feet at a distance *X* from the faulted tower footing (see "Grounding and Jumpering" [B9] and Heppe [B11]). *S* is usually assumed to be 1 m.

$$V_s = \int_{x}^{x+5} E_{dx} \qquad \text{(C.3)}$$

where

E = ρ ($I_e$ /2 Π x $^2$) and
ρ = resistivity of earth


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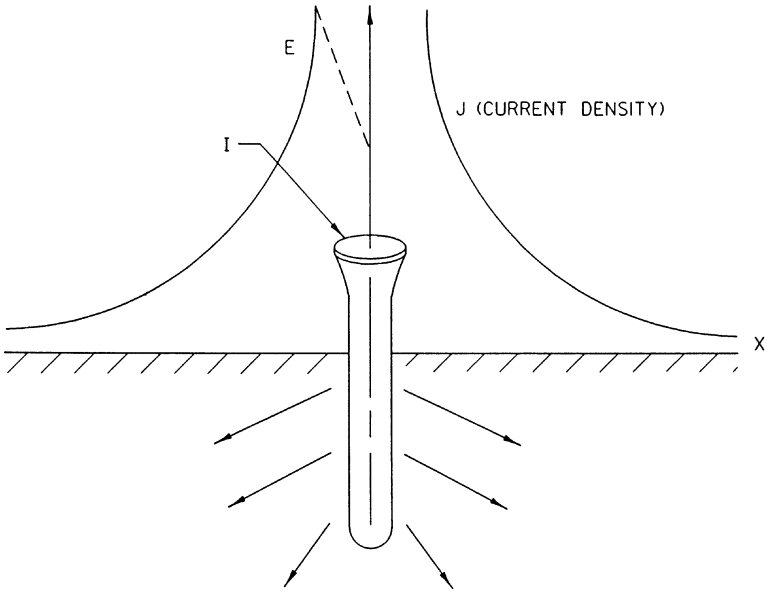



**Figure C.4—Physical representation of voltage gradients near a ground rod**

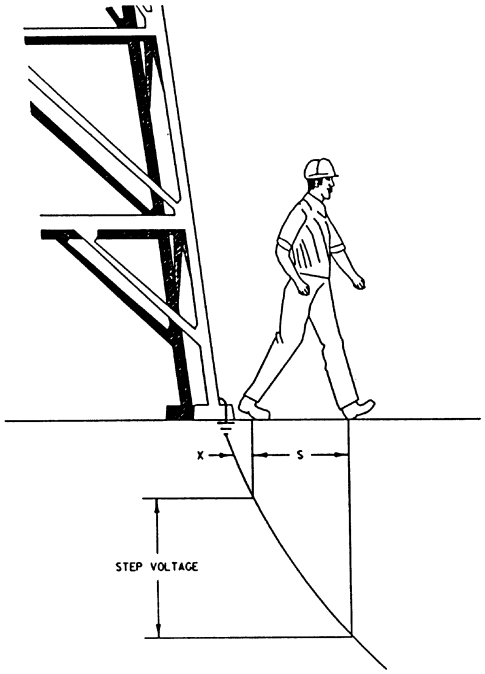



**Figure C.5—Physical representation of step voltage**

This simple model assumes uniform soil resistivity and that the current in the grounding electrodes is equally divided and discharges into earth uniformly along the length of each electrode. It is cautioned that simplified formulas can fail to accurately predict the results, sometimes within an order of magnitude, in most cases where the soil structure and grounding configuration is complex (see [B17]).

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The step voltage $V_s$ is equaled to the gradient of $V(s,x)$ multiplied by the distance $S$ between a person's feet in the direction of the gradient.

The body current $i_B$ passing through a person's legs is given by

$$i_B = V_s/(R_b + R_c) \quad \text{(C.4)}$$

where

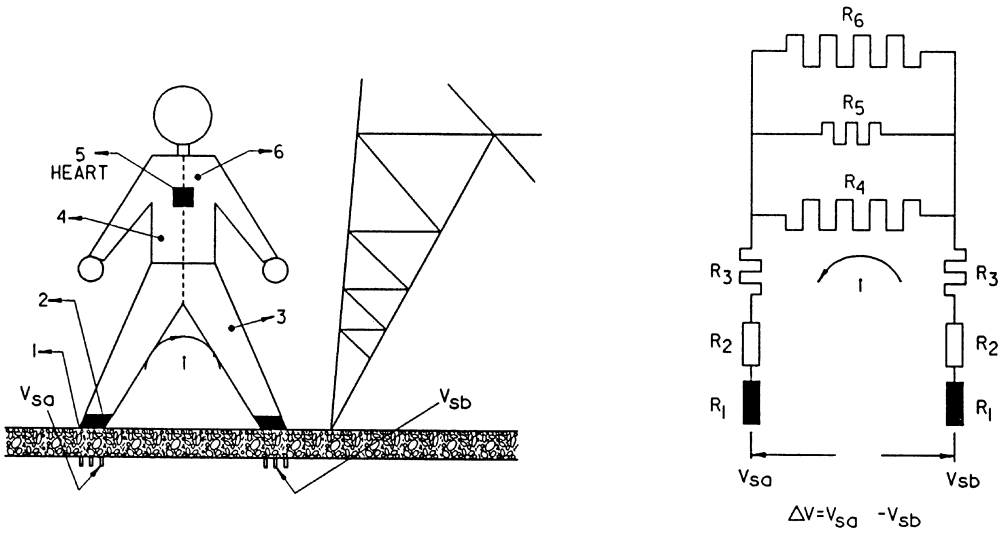
$V_s$ is the voltage of the step or source,

$R_b$ is the body resistance, including the resistance of the shoes, and the skin on the feet and body itself,

$R_c$ is the contact resistance between a person's feet and the ground, for a homogenous soil, Heppe [B11].

IEEE Std 80-2000 gives an expression of the contact resistance $R_c$ if the soil has two layers and the top layer is thin.

The step voltage depends not only on the ground current and the distance from the ground electrode, but also on the step width and the resistivity of the grounds, and increases with both these values.




**a) Actual circuit** **b) Equivalent circuit**

**Figure C.6—Schematic representation of step voltage [B17]**

## C.4 Touch voltage

The potential differences described in C.3 make it such that a person could be standing with both feet on a single equipotential line. Under such conditions that person would not have a resultant current flow from foot-to-foot. However, as illustrated in Figure C.7, it can be seen that a person may touch a piece of construction equipment that is not at the same potential as the person's feet.

The body current $i_B$ passing through a person's arm to leg is given by Equation (C.5):

$$i_B = V_s/(R_b + R_c) \quad \text{(C.5)}$$

where

$R_b$ is the body resistance, including the resistance of the shoes, and the skin on the feet and body itself,

$R_c$ is the contact resistance of a person's hand and feet.


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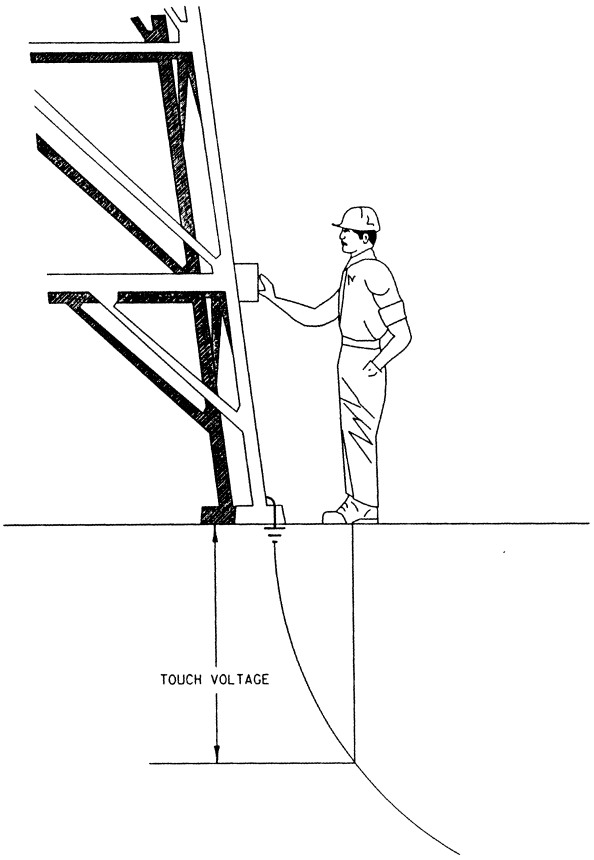
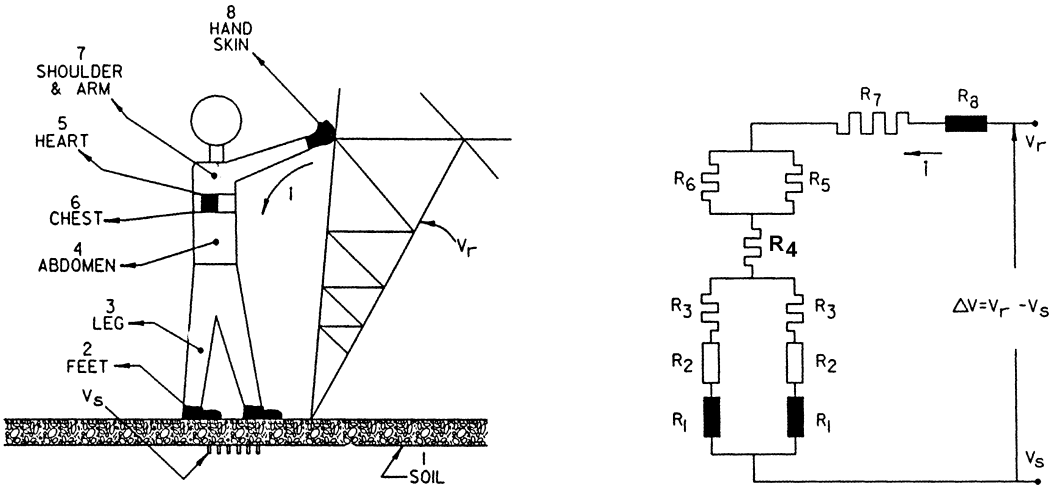



**Figure C.7—Physical representation of touch voltage**




**a) Actual circuit** **b) Equivalent circuit**

**Figure C.8—Schematic representation of step voltage**

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## C.5 General theory summary

Potential differences can result in hand-to-foot or foot-to-foot current flows of dangerous levels.

**CAUTION**

When establishing equipotential zones, one must include "touch" areas as well as "step" areas.

## C.6 Induced voltages and currents

### C.6.1 Electric field induction

A de-energized line in close proximity to an energized line will have a voltage induced on it through electric field (capacitive coupling) induction. This voltage will have a magnitude somewhere between zero voltage (ground) and the voltage of the energized line. In practical circumstances, induced voltage can be as high as 30% of the energized line voltage (see [B23], [B27]).

If the de-energized line is solidly grounded, the electrically induced voltage will be zero at the ground locations, and will be of a small magnitude at locations between grounds. The ground connections of the de-energized line will carry continuous 60 Hz induced current which may be as high as 60 mA per kilometer of the parallel lines (see [B6], [B23]). Currents and associated voltages of this magnitude make it imperative that adequate grounding procedures be used at all times to avoid serious danger to workers.

The relationship between the voltages and charges on an energized line and the induced voltages and induced charges on a de-energized line can be given in a matrix form as follows (see [B14], [B15], [B16]):

$$[V] = [P]\,[Q] \tag{C.6}$$

where
$V$ is the conductor potential in volts with respect to ground,
$Q$ is the conductor charge in coulombs per unit length,
$P$ is the potential coefficient.

Details of the development of Equation (C.7) are summarized in B.1 of Annex B.

An example illustrating expansion of Equation (C.6) and its application to the case of an energized 345 kV circuit paralleling a grounded and an ungrounded circuit is discussed in Annex L. Annex L also includes a discussion of the development of the computer program which is part of this guide.

*Electric field conclusions*

Estimation of voltages and currents induced in a de-energized circuit requires a rigorous calculation of several different effects as outlined in this guide. A de-energized line adjacent to an energized line will have a voltage induced on it through electric field (capacitive) coupling. This is a voltage phenomenon in which the de-energized line "floats" capacitively at a voltage somewhere between zero voltage (ground) and the voltage of the energized line. This effect is distinct from the magnetic coupling discussed in C.6.2, and is unrelated to the load current that may be flowing in the energized line. This voltage is highest when the de-energized conductor parallels in close proximity over the entire length of the energized line. In practical condition, it can be as high as 30% of the energized line voltage. By solidly grounding the line, the electric field induced voltage will be zero at ground locations and nearly zero at intermediate points. This is accomplished by allowing 60 Hz capacitive charging current to flow to the de-energized line through the ground connections. Charging currents can be as high as 100 mA per mile of parallel line. To avoid serious hazard to workers, the line under construction must be effectively grounded at all times and removed with care to avoid exposing the workers to the induced voltages and currents.


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To summarize,

a) Electric field induction (capacitive coupling) from energized conductors can induce high voltages on de-energized lines.

b) A single ground will reduce this voltage to a safe level; however, additional grounds may be required to satisfy other safety aspects as discussed in other clauses of this guide.

c) Ground connections will carry a continuous 60 Hz current as high as 60 mA per kilometer of parallel line. Removal of the final remaining ground can be expected to produce heavy arcing, and will allow the reappearance of a high induced voltage.

## C.6.2 Magnetic field induction

Magnetic fields can induce hazardous open circuit voltages in partially grounded loops of de-energized lines adjacent to energized lines. This voltage can be as high as 190 V/m under normal load conditions or as high as 3100 V/km under short circuit conditions on a parallel energized line. In addition, hazardous current levels can be induced in grounded loops to levels that create hazardous step or touch voltages at or near ground electrodes (see [B15], [B27]).

A person working on or near a line can be subjected to the following magnetic field induced situations:

a) Potentials between an open ended line and ground

b) Potentials between a grounded line and a remote ground

c) Step or touch voltages at or near ground electrodes

To calculate the magnetically induced voltage, the approach given by the IEEE Working Group on E/S and E/M Effects is used (see [B14], [B16]) and summarized in B.2 of Annex B. Figure C.9 shows a de-energized conductor f grounded at one point and in parallel with an energized conductor *a*. The open circuit voltage at *P* is given by

$$V_P = I_a \ Z_{af} \tag{C.7}$$

where

$Z_{af}$ is the mutual impedance/unit length between conductors multiplied by their total parallel length between conductors multiplied by their total parallel length.

Expressions of the mutual impedance can be found in [B14], [B15], and [B16]. In the case of a three-phase line, the induced open circuit voltage at *P* is given by

$$V_P = I_a Z_{af} + I_b Z_{bf} + I_c Z_{cf} \tag{C.8}$$

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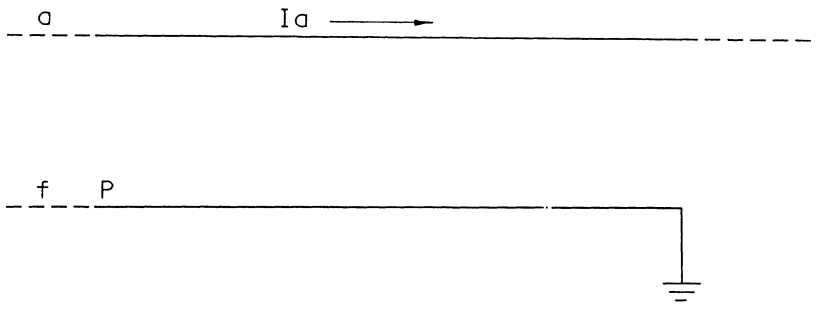



**Figure C.9—Magnetic field induction**

The shock current seen by someone touching the open end of the line f is shown schematically in Figure C.10. This current is limited by the total impedance of the line $Z_{ff}$ plus that of the ground return path $R_g$ and the contact resistance $R_c$. The expression of the shock current is given by

$$I = \frac{V_p}{(R_g + Z_{ff}) + R_p}$$

where

$R_p$ $= R_c + R_b + R_{g'}$
$R_b$ is the worker's body resistance,
$R_{g'}$ is ground contact resistance.

In most practical circumstances, problems of magnetic field induction have no electric field component and vice versa. Theoretically, it is quite possible to have both components present, in which case they can be added.

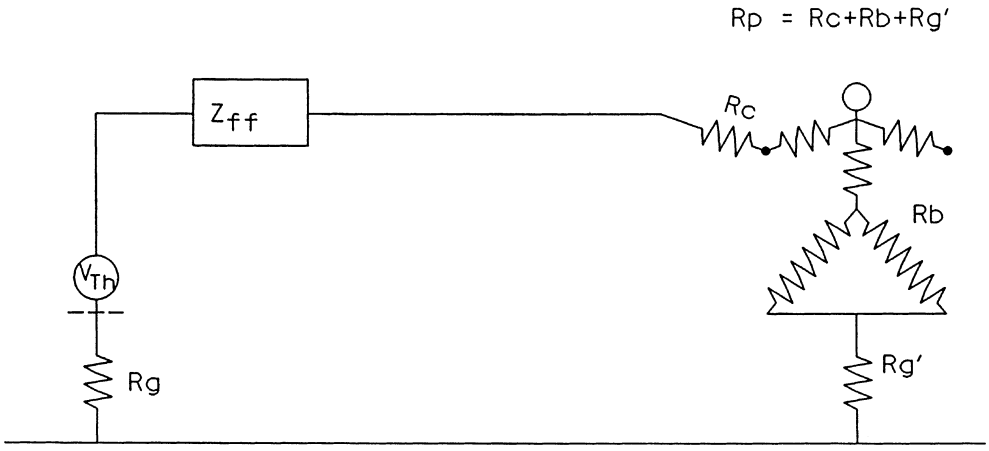



**Figure C.10—Equivalent touch voltage circuit from magnetic induction**

See Annex L for an example of computing the magnetic field induction of the de-energized circuit from an energized circuit.


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*Magnetic field induction conclusions*

The determination of voltages and currents induced in a de-energized circuit adjacent to an energized circuit requires a rigorous calculation as outlined in the annexes of this guide.

The currents flowing in the energized circuit will induce voltages or currents or both in the adjacent circuits. This includes phase conductors and overhead ground wires. If a de-energized conductor is ungrounded or grounded at only one point, no current can flow; however, dangerous voltages can exist. With parallel lines and a single ground point, the voltage induced on a de-energized line will be zero at the ground point only and will increase in direct proportion to the distance from the ground point.

With no intentional grounds on the de-energized line, there will be no voltage to ground induced by magnetic coupling. However, this should not be construed as a safe condition since contact by a grounded worker will present a path for the flow of electric field induced current, as explained in C.6.1. With two or more grounds, circulating currents will flow in each loop. Maximum currents will flow at the outermost grounds. The current that will flow in the intermediate ground connections is dependent upon the uniformity of the line conditions.

The currents flowing in the ground connections, especially at the outermost locations, can be very large. Care shall be taken to ensure that the steady-state capability of the ground equipment and conductor is adequate. Also, contact resistance must be low enough to avoid hazardous step and touch voltages in the vicinity of the ground connections. Attachment or removal of the ground connection creates transient hazards that must be taken into account (see 5.5.1.2).

There are several major points to consider with respect to magnetic field induction including the following:

a) Magnetic field induction will induce circulatory currents in the loops that are created when multiple temporary grounds are attached.

b) It may be desirable to use more than two grounds in order to prevent excessive voltage between grounds to satisfy other aspects as discussed in other sections of this guide.

c) Removal of grounds may create a hazard that is dependent on the current magnitude to be interrupted and the voltages induced following removal (see 5.5.1.2).

## C.7 Fault conditions

One potentially hazardous situation with transmission lines is the occurrence of large transient currents and voltages during a fault on the energized line(s). This situation can induce voltages and currents on partially grounded de-energized lines adjacent to energized transmission lines. The induced voltages and currents can be calculated by substituting the maximum expected transient voltages and currents in place of the steady-state voltages and currents used in procedures presented in C.6.

If an accidental contact between the energized circuit and the line under construction creates the fault, then the temporary ground connection can become the primary fault-to-ground path(s). Step-and-touch voltages under these circumstances can be especially hazardous. Also, this may present the worst-case condition that determines the necessary ground system duty rating.

Even if the line under construction is not directly involved in the fault, its proximity to the faulted line can allow it to carry a portion of the ground fault current. Step-and-touch potentials must be considered.

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## C.8 Lightning

Lightning causes the most dangerous disturbances in open-line networks and is considered to be one of the main sources of hazards to workers. Charges induced on a de-energized line by a lightning stroke can cause bodily primary shock.

**CAUTION**

It is recommended that work in the vicinity of overhead lines cease during periods when lightning hazards are possible.

## C.9 Accidental energized line

If the line under construction comes in contact with an energized line, the de-energized line will be energized by the same voltage as the energized line. The de-energized line should be adequately grounded to protect the workers in the event of this condition. Appropriate guarding should be provided to mechanically prevent this occurrence.

## C.10 Static charge (atmospheric)

A natural electric field always exists above the earth's surface. This field results from atmospheric conditions, in other words, from the static charges existing in the air. In the undisturbed state, the lines of force of this field extend vertically upward and end in space charges far above the transmission line. The result is a statically induced voltage on ungrounded transmission lines and therefore, can be a hazard to workers.

## C.11 Summary

Clause 5 has shown that electrical charges can appear on de-energized transmission lines. Table C.2 summarizes the conditions under which this can occur and the effects that are produced.

Based on the hazards in Table C.2, adequate grounding systems should be employed for the type of condition that may occur. When there is a possibility of lightning, work should cease. The possibility of accidental contact between energized lines should be avoided. In addition to electrical hazards, there is the hazard posed by violent mechanical movements of cables during fault current exposure.


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**Table C.2—Summary of hazardous effects from various energy sources**

| Energy source | Condition main | Main hazardous effects | Secondary hazardous effects |
|---|---|---|---|
| Line voltage of energized line | Electric field induction | Voltage on ungrounded line | Current through ground connections |
| Line current of energized line | Magnetic field induction | a) Induced voltage on line grounded at one end<br>b) Currents at ground points for lines grounded at two or more points | Step and touch voltages near grounds |
| Faulted line | Fault on adjacent line | a) Induced voltage on line grounded at one end<br>b) Higher than steady-state induced currents at ground points for lines grounded at two or more points | Higher than steady- state induced currents in ground connections<br>Higher step and touch voltages at points between grounds |
| Faulted line | Accidental contact between energized and de-energized lines | Step and touch voltages at all points on de-energized line | Movement of the cables |
| Wind | Atmospheric static charge | Voltage when system is ungrounded | — |
| Lightning discharge | Lightning | Overvoltage on line | Overcurrent in ground connections |
| Energized line | Accidental energization of line | Voltage on line; voltage & current at or near ground connections | Movement of the cables |

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# Annex D

(informative)

## Travelers or snub structure load calculation

The following is a method for calculating the actual load on travelers and snub structures when tension stringing. If structures are at the same elevation and there are no angles in the line, only the first and last travelers need to be considered. However, in rough terrain and situations in which angles are encountered, the load at these points should also be calculated. For snub structure loading, the weight of insulator assemblies and travelers must also be considered.

$A$ = distance of tensioner or puller from structure
$B$ = height of structure arm from elevation of tensioner or puller
$D$ = sag during stringing operation
$E$ = difference in elevation between points of attachment
$F°$ = angle of conductor from tensioner or puller to horizontal
$G°$ = angle tangent to conductor and horizontal
$K°$ = azimuth angle of departure in line
$L$ = length of span
$R_H$ = horizontal load on traveler
$R_V$ = vertical load on traveler
$R_{max}$ = total load on traveler
$T$ = line tension

Example: Stringing tension is 5000 lb (T) and the tensioner is located 300 ft (A) from the first structure. Height from the point of attachment of the traveler to the elevation of the tensioner is 100 ft (B). The first span is 1000 ft (L), and sag during stringing is to be 50 ft (D). The angle of departure from the lead-in from the tensioner is 16° (K). The difference in elevation from the first to the second structure is 98 ft (E). The resultant load on the traveler is calculated as follows:

$A$ = 300 ft
$B$ = 100 ft
$D$ = 50 ft
$E$ = 98 ft
$L$ = 1000 ft

$$\tan F = \frac{B}{A} = \frac{100}{300} = 18.4°$$

$$\tan G = \frac{E + 4D}{L} = \frac{98 + 4 \cdot 50}{1000} = \frac{298}{1000} = 16.6°$$

The lead-in angle is 18.4° from horizontal, and the lead-out angle is 16.6°. The traveler will bisect the total angle of 35°, actually giving a 17.5° angle on either side.

$T$ = 5000 lb
$K$ = 16°


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To solve for $R_V$,

$$R_V = 2T\sin\frac{F^\circ + G^\circ}{2}$$

$$R_V = 2 \cdot 5000 \cdot \sin 17.5^\circ$$

$$R_V = 3000 \text{ lb}$$

To solve for $R_H$,

$$R_H = 2T\sin\frac{K^\circ}{2}$$

$$R_H = 2 \cdot 5000 \cdot \sin 8^\circ$$

$$R_H = 1390 \text{ lb}$$

To solve for $R_{\max}$,

$$R_{\max} = \sqrt{3000^2 + 1390^2}$$

$$R_{\max} = 3307 \text{ lb}$$

Therefore, the total load on the traveler is 3307 lb. This value is approximate because the above formulas are based on parabolic rather than catenary equations, and sag is disregarded between the tensioner and first traveler. However, this method gives slightly less than actual load.

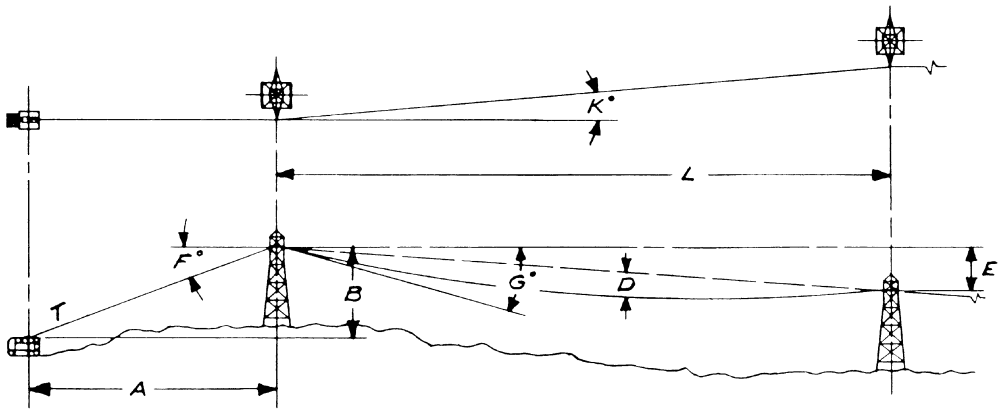



**Figure D.1—Travelers or snub structure diagram**

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# Annex E

(informative)

## Basic analysis for clipping offsets and sagging

The following figures are basic analysis examples for clipping offsets and typical parabolic methods and computations required for sagging operations.

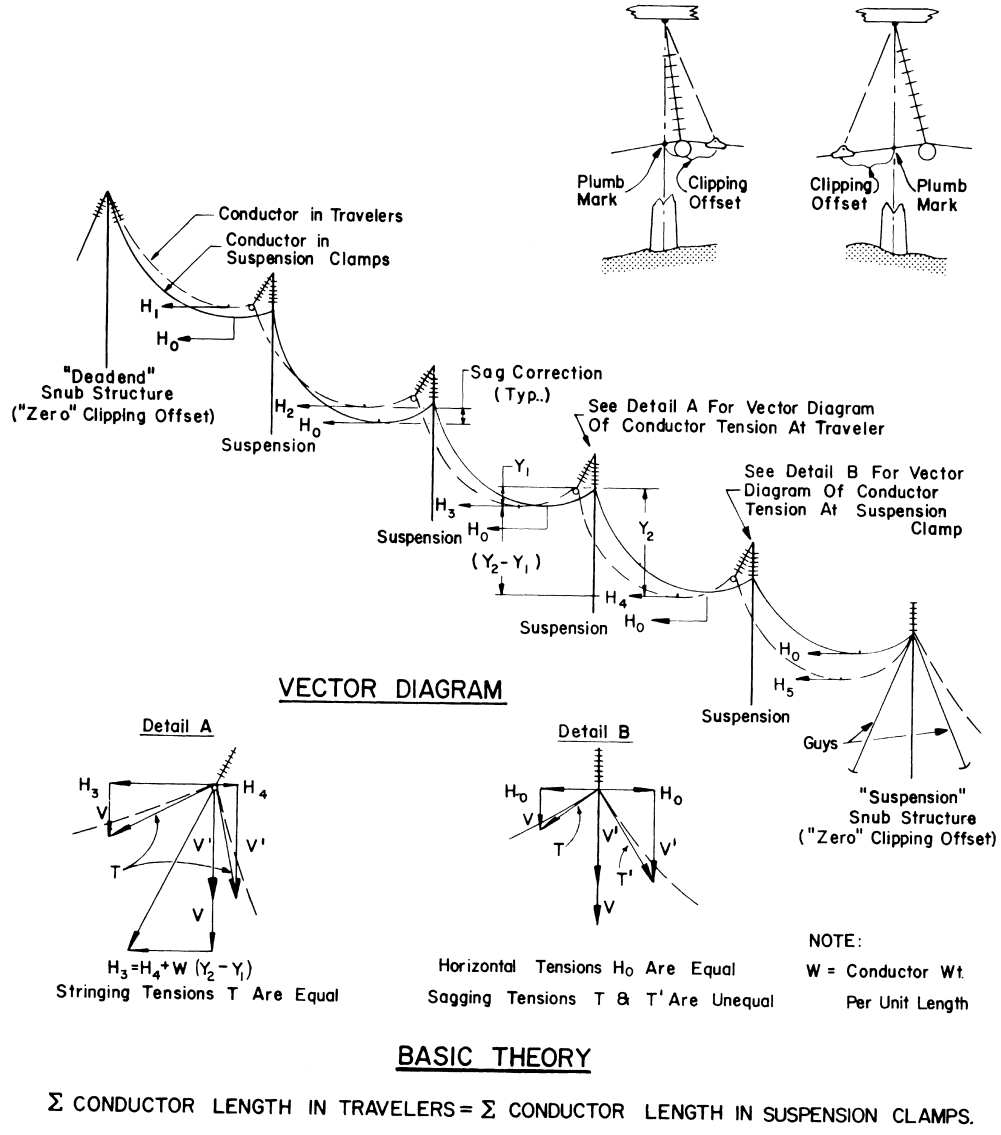



**Figure E.1—Example of application of clipping offsets**



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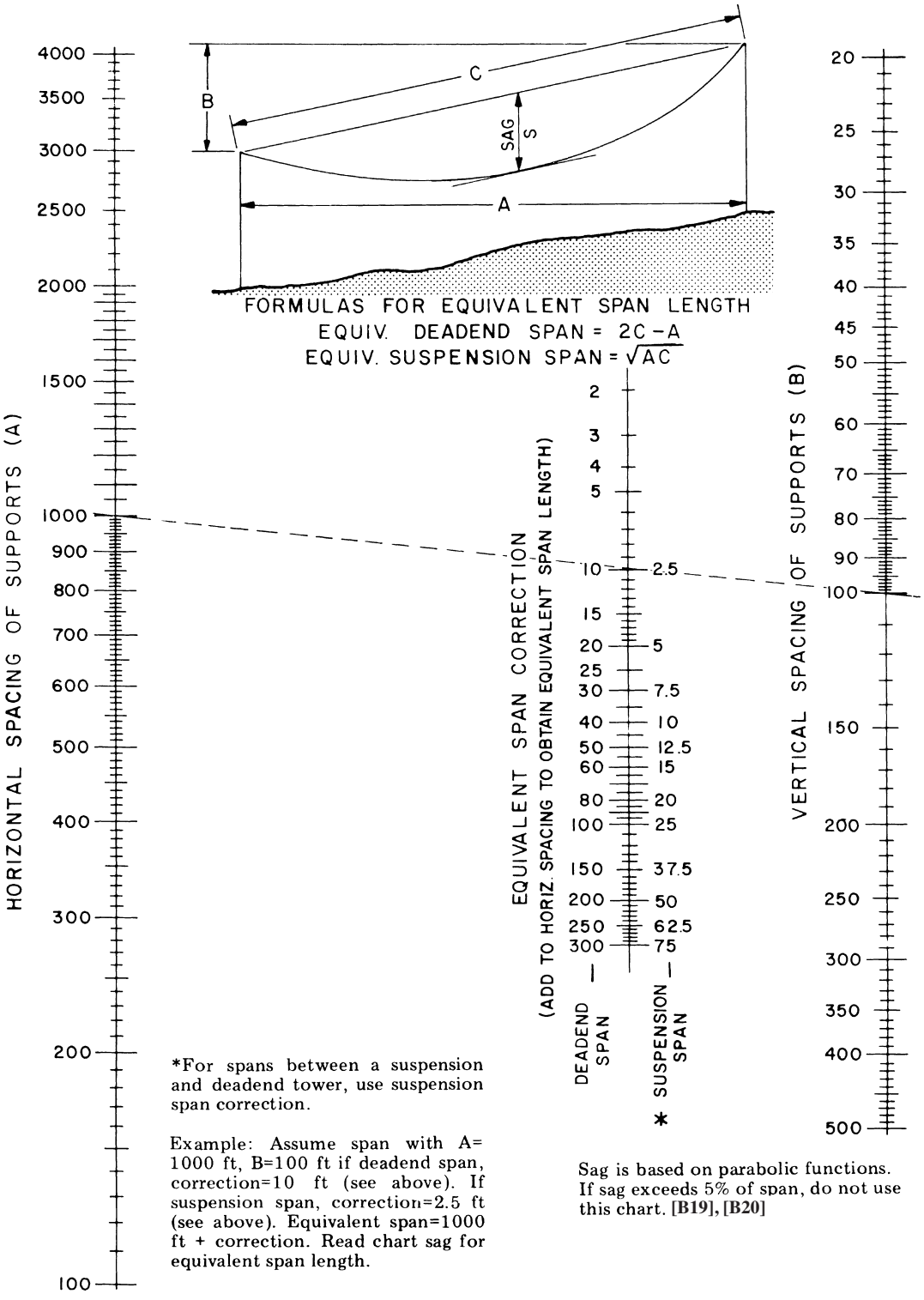



**Figure E.2—Nomograph for determining level span equivalents of non-level spans**

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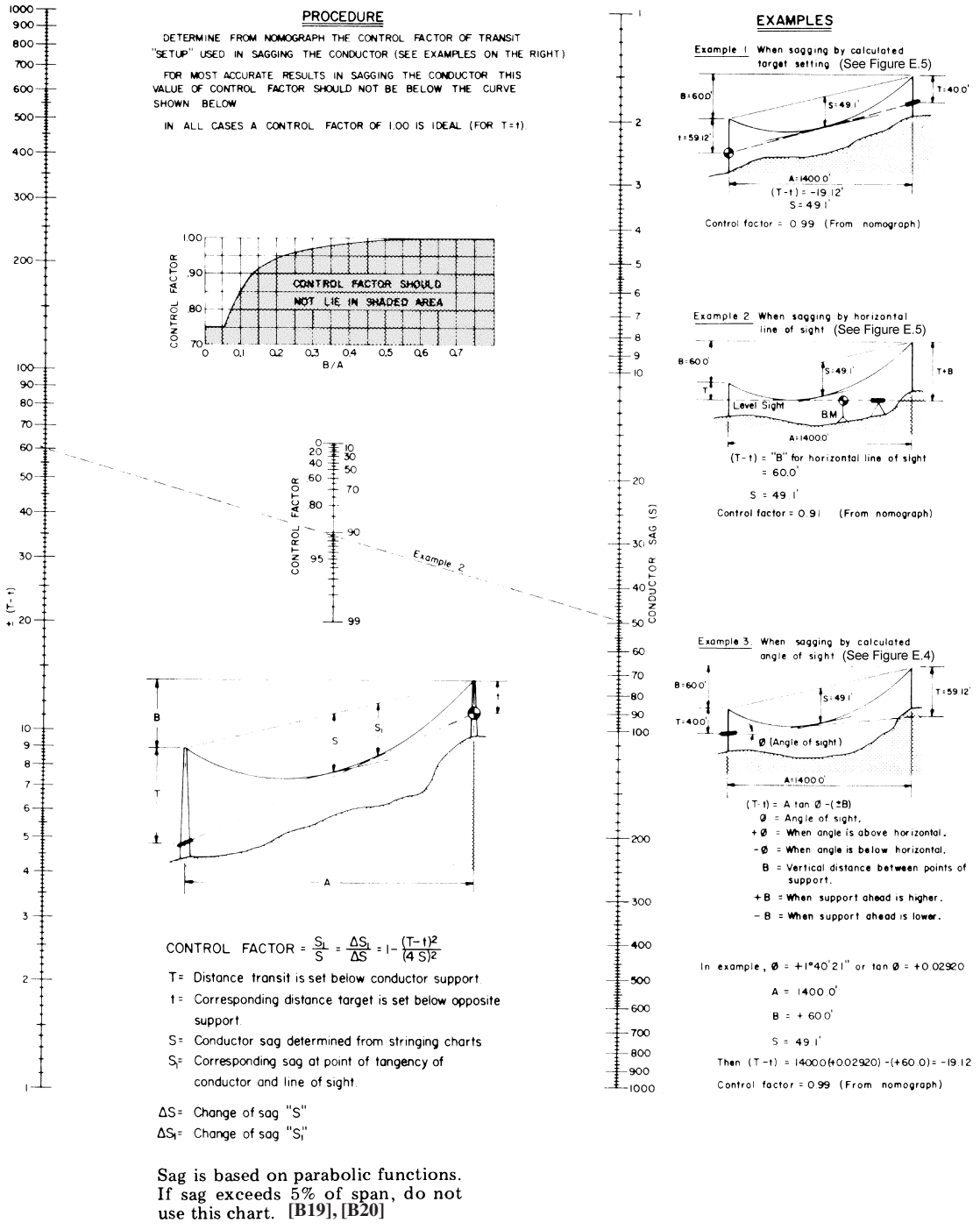



**Figure E.3—Nomograph for determining control factor for conductor sagging**


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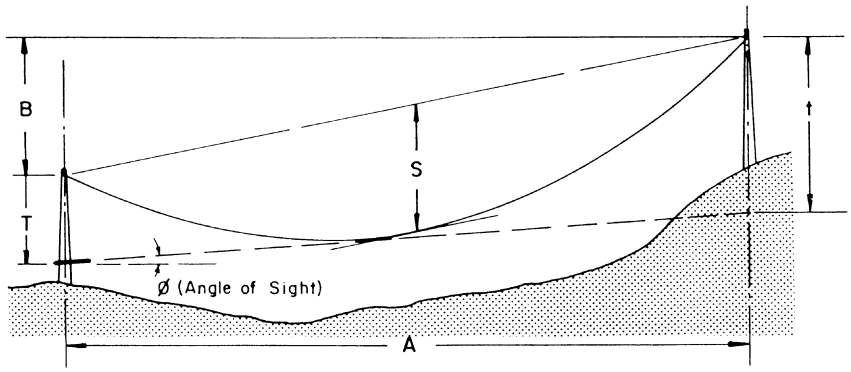
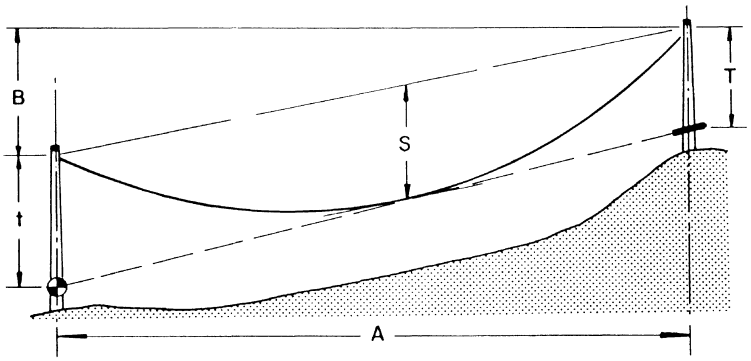



**Figure E.4—Conductor sagging by calculated angle of sight**




METHOD 1: $t = (2\sqrt{S} - \sqrt{T})^2$ (E.1)

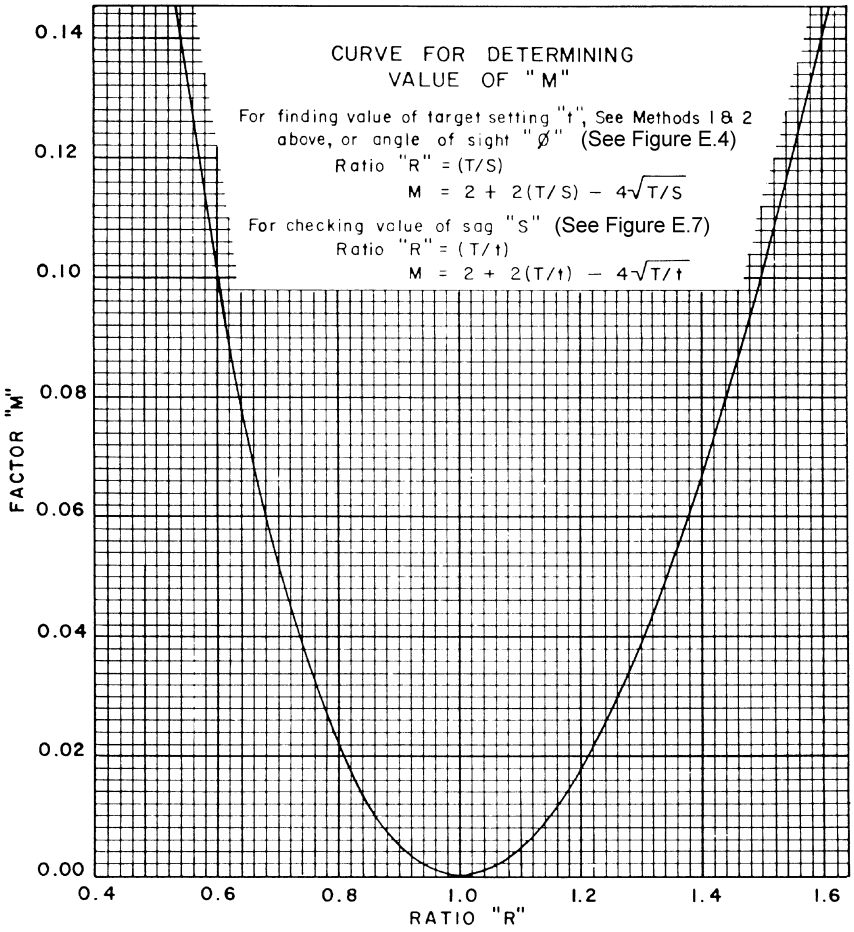
METHOD 2: $t = 2S - T + SM$ (E.2)

$t$ = Vertical distance below support for target
$T$ = Vertical distance below support for transit
$S$ = Sag
$A$ = Horizontal distance between structures—obtained from structure list or plan and profile
$B$ = Vertical distance between points of support—obtained from plan and profile, tower site data sheets or field measurement
$M$ = Determined from curve in Figure E.5b

**Figure E.5a—Conductor sagging by calculated target method**

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NOTE—Sag is based on parabolic functions. If sag exceeds 5% of span, do not use this chart. [B19], [B20].

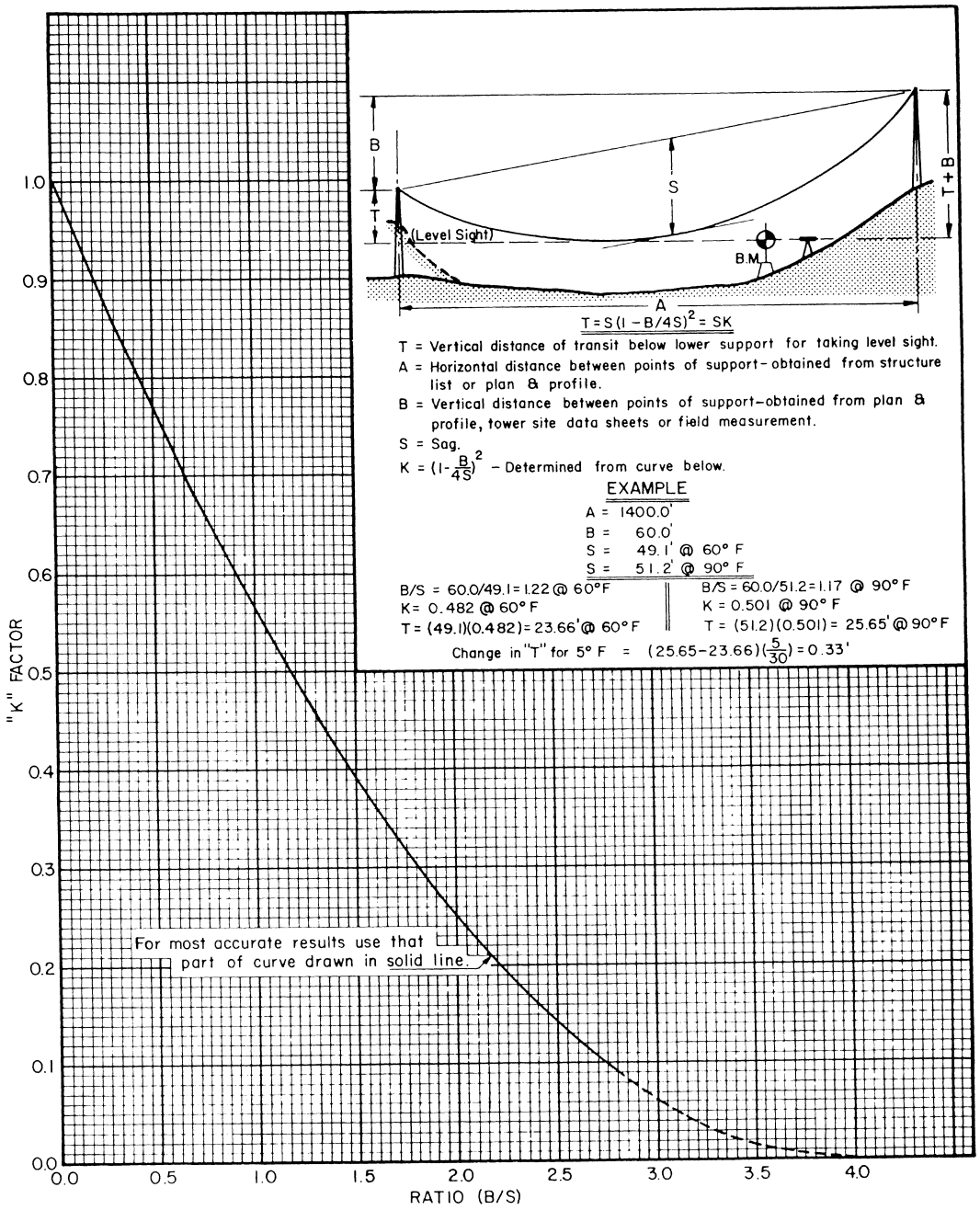
EXAMPLES

| Given | Method 1 | Method 2 |
|---|---|---|
| A =1400.0′ | $t = (2\sqrt{S} - \sqrt{T})^2$ | $t = 2S - T + SM$ |
| B = 60.0′ | $\sqrt{T} = 6325$ | $T/S_{60°F} = 0.815$ |
| T′= 40.0′ | $\sqrt{S_{60°F}} = 7.007$ | $M_{60°F} = 0.019$ |
| S = 49.1′ @ 60ºF | $2\sqrt{S_{60°F}} = 14.014$ | $2S_{60°F} = 98.2'$ |
| S = 51.2′ @ 90ºF | $t_{60°F} = 59.12'$ | $t_{60°F} = 59.13'$ |
| | $\sqrt{S_{90°F}} = 7.155$ | $T/S_{90°F} = 0.781$ |
| | $2\sqrt{S_{90°F}} = 14.310$ | $M_{90°F} = 0.027$ |
| | $t_{90°F} = 63.76$ | $2S_{90°F} = 102.4'$ |
| | Change in *"t"* for 5ºF | $t_{90°F} = 63.78'$ |
| | $= (63.76 - 5912)(5/30) = 0.77'$ | Change in *"t"* for 5ºF |
| | | $= (63.78 - 5913)(5/30) = 0.78'$ |

**Figure E.5b—Conductor sagging by calculated target method**


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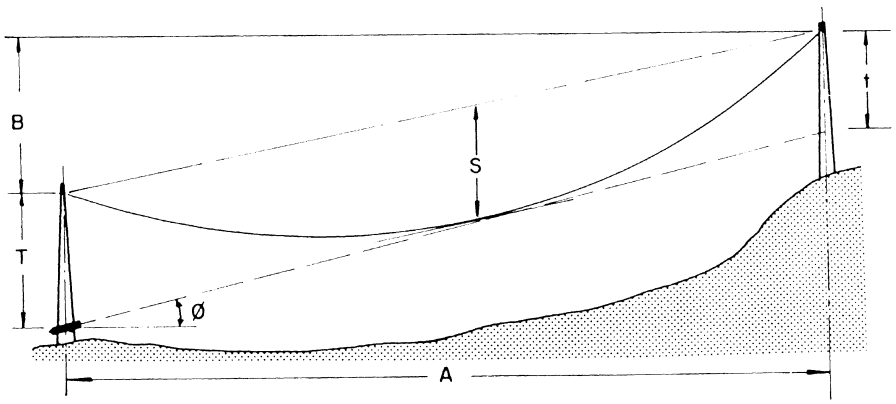



Sag is based on parabolic functions. If sag exceeds 5% of span, do not use this chart. **[B19], [B20]**

**Figure E.6—Conductor sagging by horizontal line of sight**

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METHOD 1: $S = \left(\frac{\sqrt{T} + \sqrt{t}}{2}\right)^2$

METHOD 2: $S = \frac{T}{2} + \frac{t}{2} - \frac{tM}{8}$

$S$ = Sag
$t$ = Vertical distance below support for line of sight
= T ± B – A tan Ø when angle Ø is above horizontal
= T ± B + A tan Ø when angle Ø is below horizontal
$T$ = Vertical distance below support for transit.
$B$ = Vertical distance between points of support—obtained from plan and profile, tower site data sheet or field measurements
+ B when support ahead is higher
– B when support ahead is lower
$A$ = Horizontal distance between points of support—obtained from structure list or plan and profile
Ø = Angle of sight
$M$ = Determined from curve Figure E.5

EXAMPLES:

GIVEN

| | |
|---|---|
| A = 1400.0´ | T = 40.0´ |
| B = 60.0’ | Ø = + 1° 40´ 21" @ 60°F (Field Measured) |

**Figure E.7a—Conductor sagging by checking sag S**


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| Method 1 | Method 2 |
|---|---|
| $S = \left(\frac{\sqrt{T} + \sqrt{t}}{2}\right)^2$ | $S = \frac{T}{2} + \frac{t}{2} - \frac{tM}{8}$ |
| $t = 40.0 + 60.0 - 1400.0 \tan(1° 40' 21") = 59.12'$ | $t = 59.12'$ |
| $\sqrt{t} = 7.689$ | $\frac{t}{2} = 29.56'$ |
| $\sqrt{T} = 6.325$ | M = 0.061 |
| $S_{60°F} = 49.1'$ | $S_{60°F} = 20.0 + 29.56 - \frac{(59.12)(0.061)}{8}$ |
| Sag is based on parabolic functions. If sag exceeds 5% of span, do not use this chart. [B19], [B20]. | $S_{60°F} = 49.1'$ |

NOTE—When using Method 2, value of "T" should lie between 3/4 "S" and 4/3 "S".

**Figure E.7b—Conductor sagging by checking sag S**

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# Annex F

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## Efficiency of travelers during tension stringing

The question of the efficiency of travelers often arises when planning overhead line construction jobs. Before this can be determined, the amount of force, holding power, or tension needed to support the wire in the span must be calculated. For a level span, this can easily be done with the following formula.

$$T_1 = \frac{WL^2}{8D} \tag{F.1}$$

where

$W$ = weight per unit length of conductor,
$D$ = sag (sag during stringing, not final sag),
$L$ = span length,
$T_1$ = tension to support wire in span (static condition).

Once the tension required to support the wire in a static condition is known, the next consideration is the amount of tension needed to pull the wire across the supports, which, in this case, are the travelers. The additional tension required here is primarily the work needed to bend the wire, not to overcome the friction on the bearings of the travelers.

If a solid round metal bar is bent around a radius, the metal on the inside of the bend must compress and the metal on the outside of the bend must stretch. It takes a considerable amount of force acting through an appreciable distance to bend such a rigid bar. Force acting through a distance is called work.

Wire rope or cable strand or conductor is made much more flexible than a solid bar by taking round wires and forming them into a helix. The greater flexibility of such a structure is due to the fact that the wire, at any point on the inside of the bend, does not have to compress, nor does it have to stretch on the outside of the bend. Instead, the wire simply slips around the helix so as to adjust for the shortening on the inside and the lengthening on the outside of the bend.

However, these wires are pressed together with considerable pressure. The pressure is due to and is proportional to the tension in the cable (the pull on the cable). Thus, the slipping of the wire around the helix when the cable is bent is accompanied by considerable friction. Therefore, while it takes a great deal less work to bend a cable than it does to bend a solid bar, it still involves an appreciable amount of work. Friction is proportional to the tension in the cable. Thus, the higher the tension, the more work is required to bend the cable around a radius.

At each point of support, as the cable or conductor is being pulled, the cable or conductor must bend to the sheave radius of the traveler at the entering side and then must be straightened out again at the leaving side. Thus, an appreciable amount of work (or resistance to pull) is developed at each sheave. The amount of work (resistance to pull) is proportional to the tension and is inversely proportional to the diameter of the sheave because it obviously takes more to bend around a smaller arc than around a larger arc.

From this, it is apparent that the tension becomes greater because each traveler is passed since this tension builds up progressively at each support.

If we assume a 2% loss at each block, then the efficiency is 98% at each support. To solve for the total loss or the total efficiency, the number of travelers must be an exponent of the efficiency. The efficiency will


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vary depending on the size of the wire, the size of the block, and the other factors discussed above. Efficiency at 98% is used as representative under normal conditions encountered.

From this, if the initial tension before entering the first sheave = $T_1$, and the final tension after passing over $N$ number of supports = $T_{max}$, then,

$$T_{max} = \frac{T_1}{0.98^N} \tag{F.2}$$

where

$T_1$ = tension to support first span,
0.98 = the efficiency at each traveler,
$N$ = number of supports.

Example:

$D$ = 50 ft (sag in ft during stringing)
$W$ = 2 lb (weight of conductor per ft)
$L$ = 1000 ft (span length in ft)
$T_1$ = tension to support first span
$N$ = 8 (number of supports)
0.98 = assumed efficiency at each traveler
$T_{max}$ = tension to pull conductor

$$T_1 = \frac{WL^2}{8D} = \frac{2 \cdot 1000^2}{8 \cdot 0}$$

$T_1$ = 5000 lb

then

$$T_{max} = \frac{T_1}{98^N} = \frac{5000}{98^N} = \frac{5000}{0.8508} = 5877 \text{ lb}$$

This formula, explanation, and example are published in this form as a guide. Many factors affect the value being sought; however, this is an acceptable figure in most instances. In the case of actual varying field conditions encountered, an allowance should be considered.

Many variables will affect the assumed 98% efficiency of the travelers. Should very small sheaves be used, the efficiency of the travelers will be much less. On the other hand, cases of large sheaves, over 20 times conductor diameter at bottom of groove, have resulted in efficiency of over 99%. This is important as it must be considered in the selection of pulling and tensioning equipment and pulling lines.

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# Annex G

(informative)

## Recommended bearing pressure on sheave linings

Considering bearing pressure between conductors and stringing sheaves, it should be noted that the pressure per unit of length between the conductor and sheave groove is a function of the tension ($T$) in the conductor, the diameter of the sheave to the bottom of the groove ($D_s$), and the diameter of the conductor ($D_C$). The pressure is independent of the angle of radial contact around the sheave and the resulting load on the traveler. The bearing pressure is therefore expressed by the following equation:

$$P = \frac{3T}{D_S D_C} \tag{G.1}$$

where

$P$ = bearing pressure,
$T$ = conductor tension,
$D_S$ = diameter of sheave to bottom of groove,
$D_C$ = diameter of conductor or pulling line.

Limits or guidelines for conductors have been 500–700 psi for lined sheaves, less for unlined ones. To obtain reasonable wear on sheave linings, maximum allowable unit bearing pressure for steel pulling lines is 2000 psi for neoprene, 3500 psi for urethane.

Examples:

$T$ = 12 000 lb for pulling line
$T$ = 6000 lb for each conductor
$D_s$ = 24 in (diameter of sheave to bottom of groove)
$D_c$ = 0.625 in (diameter of pulling line)
$D_c$ = 1.502 in (diameter of conductor)

$$P = \frac{3 \cdot 12000}{24 \cdot 0.625}$$

$P$ = 2400 psi representing unit bearing pressure for the 5/8 in OD pulling line

$$P = \frac{3 \cdot 6000}{24 \cdot 1.502}$$

$P$ = 500 psi representing unit bearing pressure for the 1.502 in OD conductor

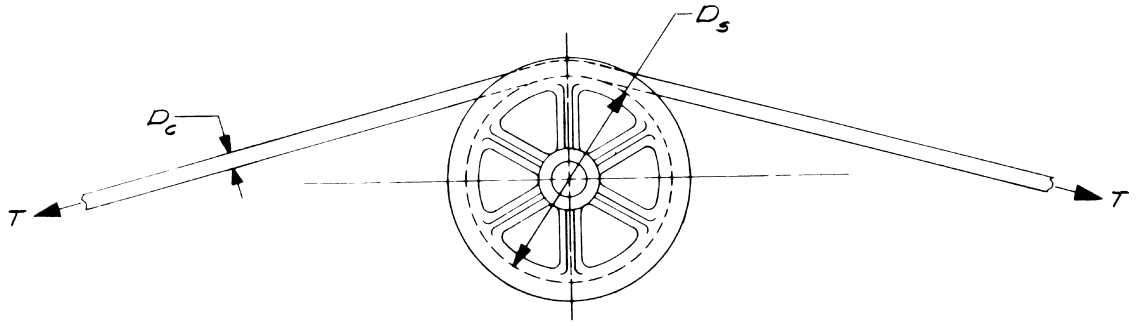



**Figure G.1—Recommended bearing pressure diagram**


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# Annex H

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## All aluminum 1350 alloy conductor standard packages

NOTE—Alloy 1350 was formerly designated as EC.

| Code word | Size | | Strand | No. of layers[a] | Conductor diameter | | Rated strength | Wt. per 1000' | Wt. per km | Reel design | | Standard packaging | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Weight | | Length | |
| | kcmil | ($mm^2$) | | | inch | (mm) | lb | lb | (kg) | | | lb | (kg) | ft | (m) |
| Orchid | 636 | 322 | 37 | 2 | .918 | 23.32 | 1140 | 598.9 | 888.4 | RMT | 84.45 | 7400 | 3355 | 12400 | 3780 |
| | | | | | | | | | | NR | 66.28 | 3700 | 1680 | 6200 | 1890 |
| | | | | | | | | | | RM | 68.32 | 3700 | 1680 | 6200 | 1890 |
| | | | | | | | | | | RM | 68.38 | 3700 | 1680 | 6200 | 1890 |
| | | | | | | | | | | NR | 48.28 | 1850 | 840 | 3100 | 945 |
| Violet | 715.5 | 363 | 37 | 2 | .974 | 24.74 | 12800 | 672.0 | 1000 | RMT | 84.45 | 7400 | 3355 | 11020 | 3360 |
| | | | | | | | | | | NR | 66.28 | 3700 | 1680 | 5510 | 1680 |
| | | | | | | | | | | RM | 68.32 | 3700 | 1680 | 5510 | 1680 |
| | | | | | | | | | | RM | 68.38 | 3700 | 1680 | 5510 | 1680 |
| | | | | | | | | | | NR | 48.28 | 1850 | 840 | 2755 | 840 |
| Arbutus | 795 | 403 | 37 | 2 | 1.026 | 26.06 | 13900 | 746.4 | 1111 | RMT | 84.45 | 7400 | 3355 | 9920 | 3025 |
| | | | | | | | | | | NR | 66.28 | 3700 | 1680 | 4960 | 1510 |
| | | | | | | | | | | RM | 66.32 | 3700 | 1680 | 4960 | 1510 |
| | | | | | | | | | | RM | 68.38 | 3700 | 1680 | 4960 | 1510 |
| | | | | | | | | | | NR | 48.28 | 1850 | 840 | 2480 | 755 |
| Lilac | 795 | 403 | 61 | 3 | 1.028 | 26.11 | 14300 | 746.8 | 1111 | RMT | 90.45 | 9760 | 4425 | 13080 | 3985 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 6540 | 1995 |
| Magnolia | 954 | 483 | 37 | 2 | 1.124 | 28.55 | 16400 | 895.8 | 1333 | RMT | 84.45 | 7400 | 3355 | 8260 | 2520 |
| | | | | | | | | | | NR | 66.28 | 3700 | 1680 | 4130 | 1260 |
| | | | | | | | | | | RM | 66.32 | 3700 | 1680 | 4130 | 1260 |
| | | | | | | | | | | RM | 68.38 | 3700 | 1680 | 4130 | 1260 |
| | | | | | | | | | | NR | 48.28 | 1850 | 840 | 2065 | 630 |
| Goldenrod | 954 | 483 | 61 | 3 | 1.126 | 28.60 | 16900 | 896.1 | 1333 | RMT | 9045 | 9760 | 4425 | 10900 | 3320 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 5450 | 1660 |
| Bluebell | 1033.5 | 524 | 37 | 2 | 1.170 | 29.72 | 17700 | 971.0 | 1444 | RMT | 84.45 | 7400 | 3355 | 7630 | 2325 |
| | | | | | | | | | | NR | 66.28 | 3700 | 1680 | 3815 | 1165 |
| | | | | | | | | | | RM | 66.32 | 3700 | 1680 | 3815 | 1165 |
| | | | | | | | | | | RM | 68.38 | 3700 | 1680 | 3815 | 1165 |
| | | | | | | | | | | NR | 48.28 | 1850 | 840 | 1910 | 580 |
| Larkspur | 1033.5 | 524 | 61 | 3 | 1.172 | 29.77 | 18300 | 970.7 | 1444 | RMT | 90.45 | 9760 | 4425 | 10060 | 3065 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 5030 | 1535 |
| Marigold | 1113 | 564 | 61 | 3 | 1.216 | 30.89 | 19700 | 1045 | 1555 | RMT | 90.45 | 9760 | 4425 | 9340 | 2845 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 4670 | 1425 |
| Hawthorn | 1192.5 | 604 | 61 | 3 | 1.259 | 31.95 | 21100 | 1119 | 1665 | RMT | 90.45 | 9760 | 4425 | 8720 | 2660 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 4360 | 1330 |
| Narcissus | 1272 | 645 | 61 | 3 | 1.300 | 33.02 | 22000 | 1194 | 1777 | RMT | 90.45 | 9760 | 4425 | 8170 | 2490 |

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| Code word | Size | | Strand | No. of layers[a] | Conductor diameter | | Rated strength | Wt. per 1000' | Wt. per km | Reel design | | Standard packaging | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Weight | | Length | |
| | kcmil | ($mm^2$) | | | inch | (mm) | lb | lb | (kg) | | | lb | (kg) | ft | (m) |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 4085 | 1245 |
| Columbine | 1351.5 | 685 | 61 | 3 | 1.340 | 34.04 | 23400 | 1269 | 1888 | RMT | 90.45 | 9760 | 4425 | 7690 | 2345 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 3845 | 1170 |
| Camation | 1431 | 725 | 61 | 3 | 1.379 | 35.03 | 24300 | 1344 | 1999 | RMT | 90.45 | 9760 | 4425 | 7270 | 2215 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 3635 | 1110 |
| Gladiolus | 1510.5 | 765 | 61 | 3 | 1.417 | 35.99 | 25600 | 1419 | 2110 | RMT | 90.45 | 9760 | 4425 | 6880 | 2095 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 3440 | 1050 |
| Coreopsis | 1590 | 806 | 61 | 3 | 1.454 | 36.93 | 27000 | 1493 | 2222 | RMT | 90.45 | 9760 | 4425 | 6540 | 1995 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 3270 | 995 |
| Jessamine | 1750 | 887 | 61 | 3 | 1.525 | 38.74 | 29700 | 1643 | 2445 | RMT | 90.45 | 9760 | 4425 | 5940 | 1810 |
| | | | | | | | | | | RM | 68.38 | 4880 | 2215 | 2870 | 905 |
| Cowslip | 2000 | 1013 | 91 | 4 | 1.630 | 41.40 | 34200 | 1876 | 2793 | RMT | 90.45 | 9100 | 4130 | 4950 | 1480 |
| Sagebmsh | 2250 | 1140 | 91 | 4 | 1.729 | 43.92 | 37700 | 2132 | 3174 | RMT | 90.45 | 9100 | 4130 | 4270 | 1300 |
| Lupine | 2300 | 1267 | 91 | 4 | 1.823 | 46.30 | 41900 | 2368 | 3527 | RMT | 90.45 | 9100 | 4130 | 3840 | 1700 |

[a]The number of aluminum layers does not include the seven central wires which are considered as a core.
( ) Denote approximate value


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# Annex I

(informative)

## ACSR conductor standard packages

| Code Word | Size | | Strand | No. of layers[a] | Conductor diameter | | Rated strength | Wt. Per 1000' | Wt. Per km | Reel design | | Standard packaging | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Weight | | Length | |
| | kcmil | ($mm^2$) | | | inch | (mm) | lb | lb | (kg) | | | lb | (kg) | ft | (m) |
| Kingbird | 636 | 322 | 18/1 | 2 | 940 | 23.88 | 15700 | 691 | 1027 | RM | 66.32 | 4160 | 1885 | 6020 | 1835 |
| | | | | | | | | | | NR | 66.28 | 4160 | 1885 | 6020 | 1835 |
| | | | | | | | | | | RM | 68.38 | 4160 | 1885 | 6020 | 1835 |
| | | | | | | | | | | NR | 48.28 | 2080 | 945 | 3010 | 915 |
| | | | | | | | | | | NR | 42.28 | 1385 | 630 | 2005 | 610 |
| Rook | 636 | 322 | 24/7 | 2 | .977 | 24.82 | 22000 | 819 | 1219 | RMT | 84.36 | 6550 | 2970 | 8000 | 2440 |
| | | | | | | | | | | RMT | 84A5 | 6550 | 2970 | 8000 | 2440 |
| | | | | | | | | | | NR | 60.28 | 3275 | 1485 | 4000 | 1220 |
| Grosbeak | 636 | 322 | 26/7 | 2 | .990 | 25.15 | 25200 | 875 | 1302 | RMT | 84.36 | 7590 | 3445 | 8670 | 2645 |
| | | | | | | | | | | RMT | 84.45 | 7590 | 3445 | 8670 | 2645 |
| | | | | | | | | | | NR | 60.28 | 3795 | 1720 | 4335 | 1320 |
| Egret | 636 | 322 | 30/19 | 2 | 1.019 | 28.88 | 31500 | 988 | 1470 | RMT | 84.45 | 9860 | 4470 | 9980 | 3040 |
| | | | | | | | | | | RM | 66.32 | 4930 | 2235 | 4990 | 1520 |
| | | | | | | | | | | NR | 66.28 | 4930 | 2235 | 4990 | 1520 |
| | | | | | | | | | | RM | 68.38 | 4930 | 2235 | 4990 | 1520 |
| Flamingo | 666.6 | 338 | 24/7 | 2 | 1.000 | 2S.40 | 23700 | 859 | 1277 | RMT | 84.36 | 65SO | 2970 | 7630 | 2325 |
| | | | | | | | | | | RMT | 84.45 | 6550 | 2970 | 7630 | 2325 |
| | | | | | | | | | | NR | 60.28 | 3275 | 1485 | 3815 | 1165 |
| Starling | 715.5 | 361 | 26/7 | 2 | 1.051 | 26.70 | 28400 | 981 | 1466 | RMT | 84.36 | 7590 | 3445 | 7710 | 2350 |
| | | | | | | | | | | RMT | 84.45 | 7590 | 3445 | 7710 | 2350 |
| | | | | | | | | | | NR | 60.28 | 3795 | 1720 | 3855 | 1175 |
| Redwing | 715.5 | 363 | 10.119 | 2 | 1.081 | 27.46 | 34600 | 1111 | 1653 | RMT | 84.45 | 9860 | 4470 | 8880 | 2705 |
| | | | | | | | | | | RM | 66.32 | 4930 | 2235 | 4440 | 1355 |
| | | | | | | | | | | NR | 66.28 | 4930 | 2135 | 4440 | 1355 |
| | | | | | | | | | | RM | 68.38 | 4930 | 2235 | 4440 | 1355 |
| Cuckoo | 795 | 403 | 24/7 | 1 | 1.092 | 27.74 | 27900 | 1024 | 1522 | RMT | 84.16 | 6550 | 2970 | 6400 | 1950 |
| | | | | | | | | | | RMT | 84.45 | 6550 | 2970 | 6400 | 1950 |
| | | | | | | | | | | NR | 60.28 | 3275 | 1485 | 3200 | 975 |
| Drake | 795 | 403 | 26/7 | 2 | 1.108 | 28.14 | 31500 | 1094 | 1628 | RMT | 90.45 | 11380 | 5160 | 10400 | 3170 |
| | | | | | | | | | | RMT | 84.36 | 7590 | 3445 | 6940 | 2115 |
| | | | | | | | | | | RMT | 84.45 | 7590 | 3445 | 6940 | 2115 |
| | | | | | | | | | | NR | 60.28 | 3795 | 1720 | 3470 | 1060 |
| Tern | 795 | 403 | 45/7 | 3 | 1.063 | 27.00 | 22100 | 896 | 1333 | RMT | 90.45 | 10750 | 4875 | 12000 | 3660 |
| | | | | | | | | | | RM | 6838 | 5375 | 2440 | 6000 | 1830 |
| | | | | | | | | | | NR | 6028 | 3585 | 1625 | 4000 | 1220 |
| Condor | 795 | 403 | 54/7 | 3 | 1.093 | 27.76 | 28200 | 1024 | 1524 | RMT | 90.45 | 11800 | 5150 | 11520 | 3510 |
| | | | | | | | | | | RM | 69.38 | 5900 | 2675 | 5760 | 1755 |
| Mallard | 795 | 403 | 30/19 | 2 | 1.140 | 29.96 | 38400 | 1235 | 1838 | RMT | 84.45 | 9860 | 4470 | 7980 | 2430 |

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| Code Word | Size | | Strand | No. of layers[a] | Conductor diameter | | Rated strength | Wt. Per 1000' | Wt. Per km | Reel design | | Standard packaging | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Weight | | Length | |
| | kcmil | ($mm^2$) | | | inch | (mm) | lb | lb | (kg) | | | lb | (kg) | ft | (m) |
| | | | | | | | | | | RM | 66.32 | 4930 | 2235 | 3990 | 1215 |
| | | | | | | | | | | NR | 66.28 | 4930 | 2235 | 3990 | 1215 |
| | | | | | | | | | | RM | 66.28 | 4930 | 1215 | 3990 | 1215 |
| Canary | 900 | 456 | 54/7 | 3 | 1.162 | 29.51 | 31900 | 1159 | 1725 | RMT | 90.45 | 11800 | 1350 | 10180 | 3105 |
| | | | | | | | | | | RM | 68.38 | 5900 | 2675 | 5090 | 1550 |
| Rail | 954 | 483 | 45/7 | 1 | 1.165 | 29.59 | 25900 | 1075 | 1600 | RMT | 90.45 | 10750 | 4875 | 10000 | 3050 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 5000 | 1525 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 3335 | 1015 |
| Cardinal | 954 | 483 | 54/7 | 3 | 1.196 | 30.38 | 33800 | 1229 | 1829 | RMT | 90.45 | 11900 | 5350 | 9600 | 2925 |
| | | | | | | | | | | RM | 68.38 | 5900 | 2675 | 4800 | 1465 |
| Ortolan | 1033.5 | 524 | 45/7 | 3 | 1.212 | 30.78 | 27700 | 1164 | 1734 | RMT | 90.45 | 10750 | 4875 | 9230 | 2815 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 4615 | 1405 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 3075 | 935 |
| Curlm | 1033.5 | 524 | 54/7 | 3 | 1.244 | 31.60 | 36600 | 1330 | 1981 | RMT | 90.45 | 11800 | 5350 | 8870 | 2705 |
| | | | | | | | | | | RM | 68.38 | 5900 | 2675 | 4435 | 1350 |
| Bluejay | 1113 | 564 | 45/7 | 3 | 1.259 | 31.99 | 29800 | 1255 | 1868 | RMT | 90.45 | 10750 | 487S | 8570 | 2610 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 4285 | 1305 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 2855 | 870 |
| Finch | 1113 | 564 | 54/19 | 3 | 1.293 | 32.84 | 39100 | 1431 | 2130 | RMT | 90.45 | 11720 | 5315 | 8200 | 2500 |
| | | | | | | | | | | RM | 68.38 | 5860 | 2660 | 4100 | 1250 |
| Bunting | 1192.5 | 604 | 45/7 | 3 | 1.302 | 33.07 | 32000 | 1344 | 2000 | RMT | 90.45 | 10750 | 4875 | 8000 | 2440 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 4000 | 1220 |
| | | | | | | | | | | NR | 60.28 | 1585 | 1625 | 2665 | 810 |
| Grackle | 1192.5 | 604 | 54/19 | 3 | 1.333 | 33.86 | 41900 | 1533 | 2281 | RMT | 90A5 | 11720 | 5315 | 7650 | 2330 |
| | | | | | | | | | | RM | 68.38 | 5860 | 2660 | 3825 | 1165 |
| Bittern | 1272 | 645 | 45/7 | 3 | 1.345 | 34.16 | 34100 | 1434 | 2134 | RMT | 90.45 | 10750 | 4875 | 7500 | 2285 |
| | | | | | | | | | | RM | 68.38 | 5175 | 2440 | 3750 | 1145 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 2500 | 760 |
| Pheasant | 1272 | 645 | 54/19 | 3 | 1.382 | 35.10 | 3600 | 1635 | 2433 | RMT | 90.45 | 11720 | 5315 | 7175 | 2185 |
| | | | | | | | | | | RM | 68.38 | 5860 | 26160 | 3585 | 1095 |
| Dipper | 1351.5 | 685 | 45/7 | 3 | 1.385 | 35.18 | 36200 | 1523 | 2266 | RMT | 90.45 | 10750 | 4875 | 7060 | 2150 |
| | | | | | | | | | | RM | 68.38 | 375 | 2440 | 3530 | 1075 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 23S5 | 720 |
| Martin | 1351.5 | 685 | 54/19 | 3 | 1.424 | 36.17 | 46300 | 1737 | 2585 | RMT | 90.45 | 11720 | 5315 | 6755 | 2060 |
| | | | | | | | | | | RM | 68.39 | 5860 | 2600 | 3375 | 1030 |
| Bobolink | 1431 | 725 | 45/7 | 1 | 1.427 | 36.25 | 38300 | 1613 | 2400 | RMT | 90.45 | 10750 | 4875 | 6665 | 2030 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 3335 | 1015 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 2220 | 675 |
| Plover | 1431 | 725 | 54/19 | 3 | 1.465 | 37.11 | 49100 | 1840 | 2738 | RMT | 90.45 | 11720 | 5315 | 6375 | 1945 |
| | | | | | | | | | | RM | 68.38 | 5860 | 2660 | 3190 | 970 |
| Nuthatch | 1510.5 | 765 | 45/7 | 3 | 1.466 | 37.24 | 40100 | 1702 | 2533 | RMT | 90.45 | 10750 | 4875 | 6320 | 1925 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 3160 | 965 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 2110 | 645 |
| Parrot | 1510.5 | 765 | 54/19 | 3 | 1.505 | 38.23 | 51700 | 1940 | 3890 | RMT | 90.45 | 11720 | 5315 | 6040 | 1840 |
| | | | | | | | | | | RM | 68.38 | 5960 | 2660 | 3.020 | 920 |



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| Code Word | Size | | Strand | No. of layers[a] | Conductor diameter | | Rated strength | Wt. Per 1000' | Wt. Per km | Reel design | | Standard packaging | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Weight | | Length | |
| | kcmil | ($mm^2$) | | | inch | (mm) | lb | lb | (kg) | | | lb | (kg) | ft | (m) |
| Lapwing | 1590 | 806 | 45/7 | 3 | 1.504 | 38.15 | 42260 | 1792 | 2667 | RMT | 90.45 | 10750 | 4875 | 6000 | 830 |
| | | | | | | | | | | RM | 68.38 | 5375 | 2440 | 3000 | 915 |
| | | | | | | | | | | NR | 60.28 | 3585 | 1625 | 2000 | 610 |
| Falcon | 1590 | 806 | 54/19 | 3 | 1.545 | 39.24 | 54500 | 2044 | 3042 | RMT | 90.45 | 11720 | 5315 | 5740 | 1750 |
| | | | | | | | | | | RM | 68.38 | 5860 | 2660 | 2870 | 875 |
| Chukar | 1780 | 902 | 84/19 | 4 | 1.602 | 40.69 | 51000 | 2075 | 3086 | RMT | 96.60 | 19080 | 8655 | 9200 | 2805 |
| Bluebird | 2156 | 1092 | 84/19 | 4 | 1.762 | 44.75 | 60300 | 2511 | 3737 | RM | 96.60 | 18830 | 8540 | 7500 | 2285 |
| Kiwi | 2167 | 1098 | 72/7 | 4 | 1.737 | 44.12 | 49800 | 2303 | 3427 | RMT | 96.60 | 16120 | 7310 | 7000 | 2135 |
| Thrasher | 2312 | 1172 | 76/19 | 4 | 1.802 | 45.77 | 56700 | 2526 | 3761 | RMT | 96.60 | 17690 | 8025 | 7000 | 2135 |
| Joree | 2515 | 1274 | 76/19 | 4 | 1.880 | 47.75 | 61700 | 2749 | 4091 | RMT | 96.60 | 17325 | 7860 | 6300 | 1920 |

[a]The number of aluminum layers does not include the seven central wires which are considered as a core.
( ) Denote approximate value.

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# Annex J

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## Drum or reel winding

Stranded members should be wound on a drum or reel according to the lay and the direction of travel.

Note the convenient thumb rule. Clench the hand into a fist, with the thumb and index finger protruding. Use the *right hand* for *right lay* and the *left hand* for *left lay*. The clenched fingers represent the barrel and the index finger the direction of pull-off. The thumb points to the proper attachment site.

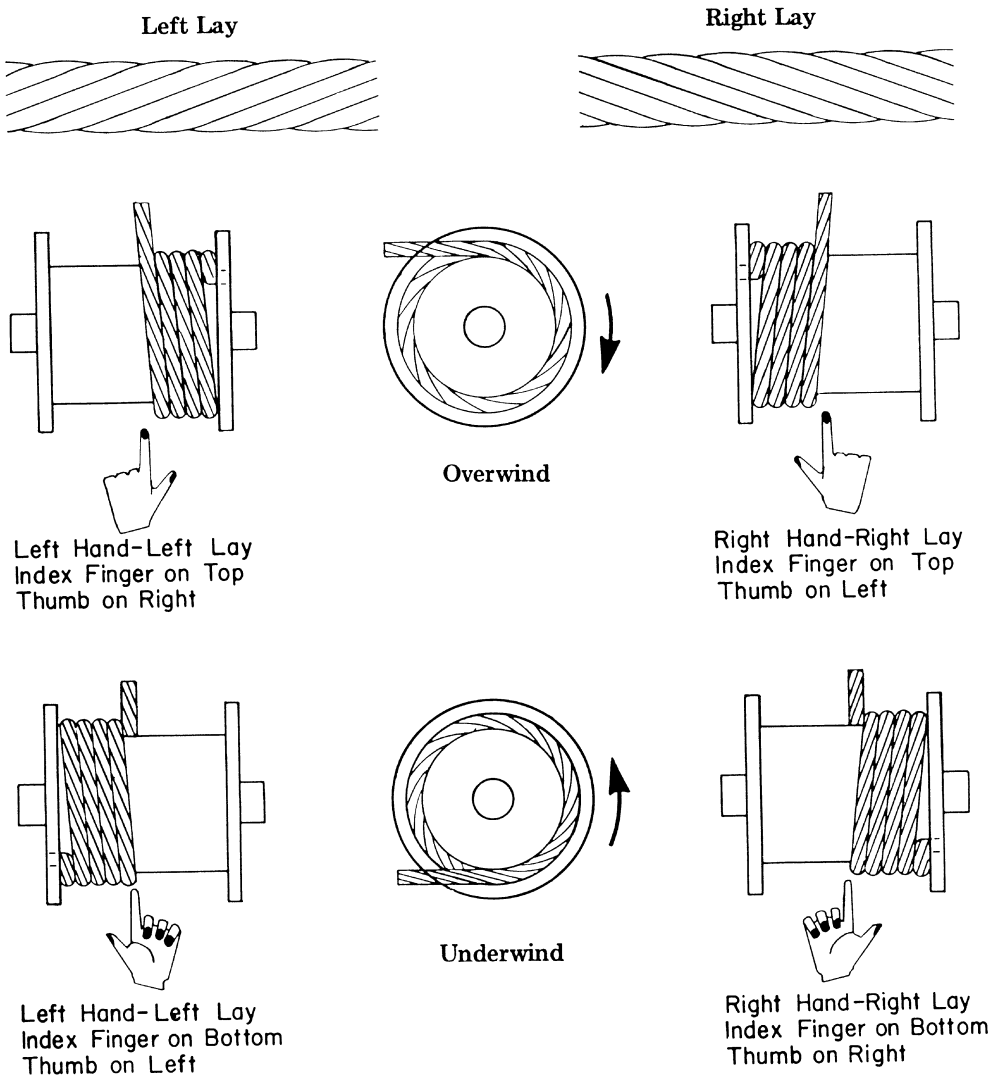



**Figure K.1—Drum or reel winding**


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# Annex K

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# Drum or reel capacities

## K.1 Standard reel sizes and dimensions from Aluminum Association

**Table K.1—Dimensions of standard reels**

| Aluminum Association reel designation | | Total reel volume | | Nominal reel dimensions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Flange diameter | | Drum diameter | | Width | | | | Arbor hole | |
| | | | | | | | | Inside | | Outside | | Diameter | |
| | | $mm^3$ | $in^3$ | m | in | m | in | m | in | m | in | mm | in |
| NR | 30.22 | .182 | 11,100 | .76 | 30 | .41 | 16 | .56 | 22 | .64 | 25 | 76–83 | 3-3 1/4 |
| NR | 36.22 | .275 | 16,800 | .91 | 36 | .46 | 18 | .56 | 22 | .64 | 25 | 76–83 | 3-3 1/4 |
| NR | 38.22 | .295 | 18,000 | .97 | 38 | .51 | 20 | .56 | 22 | .64 | 25 | 76–83 | 3-3 1/4 |
| NR | 42.28 | .477 | 29,100 | 1.07 | 42 | .53 | 21 | .71 | 28 | .83 | 32.5 | 76–83 | 3-3 1/4 |
| NR | 48.28 | .623 | 38,000 | 1.22 | 48 | .61 | 24 | .71 | 28 | .83 | 32.5 | 76–83 | 3-3 1/4 |
| NR | 60.28 | 1.014 | 61,900 | 1.52 | 60 | .71 | 28 | .71 | 28 | .83 | 32.5 | 76–83 | 3-3 1/4 |
| NR | 66.28 | 1.245 | 76,000 | 1.68 | 66 | .76 | 30 | .71 | 28 | .83 | 32.5 | 76–83 | 3-3 1/4 |
| RM | 66.32 | 1.260 | 76,900 | 1.68 | 66 | .91 | 36 | .81 | 32 | .97 | 38 | 76–83 | 3-3 1/4 |
| RM | 68.38 | 1.627 | 99,300 | 1.73 | 68 | .91 | 36 | .97 | 38 | 1.12 | 44 | 76–83 | 3-3 1/4 |
| RMT | 84.36 | 2.001 | 122,100 | 1.98–2.13 | 78–84 | 1.07 | 42 | .91 | 36 | 1.09 | 43 | 127–133 | 5-5 1/4 |
| RMT | 84.45 | 2.502 | 152,700 | 1.98–2.13 | 78–84 | 1.07 | 42 | 1.14 | 45 | 1.32 | 52 | 127–133 | 5-5 1/4 |
| RMT | 90.45 | 3.064 | 187,000 | 2.13–2.29 | 84–90 | 1.07 | 42 | 1.14 | 45 | 1.32 | 52 | 127–133 | 5-5 1/4 |
| RMT | 96.60 | 4.893 | 298,600 | 2.29–2.44 | 90–96 | 1.07 | 42 | 1.52 | 60 | 1.70 | 67 | 127–133 | 5-5 1/4 |
| RMT | 108.74 | 6.922 | 422,400 | 2.59–2.74 | 102–108 | 1.42 | 56 | 1.88 | 74 | 2.12 | 83.5 | 127–133 | 5-5 1/4 |

TABLE NOTES:

1—Prefix NR denotes wooden non-returnable reel, RM denotes metal returnable reel, and RMT denotes metal returnable reel with I-beam tires.

2—Reels RM 66.32 and RM 68.38 have flat rims

3—Reels RMT 84.36, RMT 84.45, RMT 90.45, RMT 96.60, and RMT 108.74 have 3" I-beam tires. Reels with similar dimensions except without I-beam tires are sometimes used.

4—Pay off equipment for reels NR 48.28 and smaller should be a minimum of 2" wider than the normal outside reel width to provide for extension of bolts and for possible flange distortion. For reels NR 60.28 and larger, either wood or metal, pay off equipment should be not less than 4" wider than the reel width.

5—Hub reinforcements will be provided for reels NR 60.28 and NR 66.28.

6—Reels are not designed to withstand the forces required for braking during tension stringing operations.

7—Where NR and RM reels are shown as alternatives, RM reels are preferred for more reliable conductor protection.

8—The RMT 108.74 reel is not employed for any packages included in these standards. It is listed in this table, however, because it may be used for large sizes of conductors that may be added in the future.

9—Total reel volume is the volume to the edge of the flange for NR and RM reels and to inside edge of I-beam for RMT reels.

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## K.2 Length of rope calculation

***Wire rope:***

$$L = (A + D) \times A \times B \times K \quad \text{(K.1)}$$

where

K = constant as tabulated below and as obtained by dividing 0.2618 ft/in$^3$ by the oversize wire diameter squared (see footnote a of Table K.2).

***Fiber rope:***

$$L = \frac{B(H^2 - D^2)}{15.2d^2} \text{ (ft)} \quad \text{(K.2)}$$

where:

$L$ = length of rope (ft),
$d$ = rope diameter (inches),
$A, B, D, H$ are dimensions shown in Figure K.1 (inches).

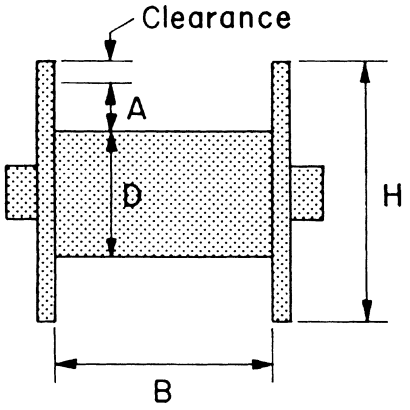



**Figure K.1—Drum dimensions**


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## K.3 Drum and reel capacities table

**Table K.2—Drum or reel capacities**

| Nominal wire diam, in | K, ft/in$^3$ [a] | Nominal wire diam, in | K, ft/in$^3$ [a] | Nominal wire diam, in | K, ft/in$^3$ [a] |
|---|---|---|---|---|---|
| 1/16 | 49.8 | 1/2 | .925 | 1 3/8 | .127 |
| 3/32 | 23.4 | 9/16 | .741 | 1 1/2 | .107 |
| 1/8 | 13.6 | 5/8 | .607 | 1 5/8 | .0886 |
| 5/32 | 8.72 | 11/16 | .506 | 1 3/4 | .0770 |
| 3/16 | 6.14 | 3/4 | .428 | 1 7/8 | .0675 |
| 7/32 | 4.59 | 13/16 | .354 | 2 | .0597 |
| 1/4 | 3.29 | 7/8 | .308 | 2 1/8 | .0532 |
| 5/16 | 2.21 | 1 | .239 | 2 1/4 | .0476 |
| 3/8 | 1.58 | 1 1/8 | .191 | 2 3/9 | .0419 |
| 7/16 | 1.19 | 1 1/4 | .152 | 2 1/2 | .0380 |

[a]Values of *K* allow for normal oversize. Clearance shown on Figure K.2 should be 2 inches unless fittings require greater clearance.

The formula is based on uniform winding and will not give correct results if wound nonuniformly. It is based on the same number of wraps in each layer, which is not strictly correct but which does not result in appreciable error unless the traverse of the reel is quite small compared with the flange diameter (H).

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# Annex L

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# Electric and magnetic field induction computer program presentation with sample problems

## L.1 Description of programs

Two separate programs have been written for use in calculating the magnitude of voltages and currents induced on de-energized transmission lines by parallel three phase energized transmission lines. The programs consider three energized bundled conductors, three de-energized bundle conductors, and up to four shield wires.

### L.1.1 Program objectives

The objectives of these programs are that they are to be interactive and user friendly, and can solve actual problems. This is to be accomplished at the cost of minimal accuracy. The loss in accuracy is considered acceptable as the programs do provide quick answers to complex problems without the need of resorting to more rigorous techniques.

### L.1.2 Program language

The programs are written in "C" for use on personal computers running DOS. They have been written as interactive programs supplying all necessary prompts. A diskette can be found in the attached envelope.

## L.2 Assumptions

Some assumptions have been made in these programs. The transmission lines are considered to be perfectly transposed, infinite in length, and parallel to the ground plane. Although phase quantities are used, positive sequence currents are assumed to indicate that balanced conditions exist. The effects of the supporting structures on the electric field of the transmission lines is neglected, the dielectric constant of the air is constant, and the linear charge density imposed on the energized lines is constant.

Some error is introduced in the bundling of the conductors. This error could be reduced if each subconductor's position was entered into the program rather than bundling the conductor. However, bundling the conductor is quicker to enter and the accuracy obtained is adequate in most applications.

The error caused by these assumptions is not important. The ultimate purpose of the ensuing calculations is to determine an order of magnitude of the induced voltages and currents that will be induced on a de-energized transmission line. An algorithm that would account for all known variables would be extremely lengthy and unwieldy to use.

Exact calculations are difficult and time consuming. Although much more accurate programs are in existence, the programs described in this Annex are of sufficient practical engineering accuracy.


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## L.3 User instructions

The following instructions only apply to the PC DOS program. Disconnection from a local area network may be necessary before using the program.

a) Turn the system on.

b) Wait for the system to "boot."

c) If a message appears on the monitor asking for the current date, press the enter key twice to bypass this entry.

d) Insert the program diskette into drive A.

e) Type "A:" to default to drive A.

f) An "A" will appear on the screen.

g) Type the word "EFINDUC.EXE." or "MFINDUC.EXE." after the "A" prompt (do not include the quotation marks) to run the electric field induction program or the magnetic field induction program, respectively. Then press the enter key.

h) Input data per the program prompts.

NOTE—Programs EFINDUC.EXE and MFINDUC.EXE do not output to a printer, but they output to the screen and to a file called EFINDUC.DAT and MFINDUC.DAT, respectively. The user might list those files to the screen by entering the command "TYPE EFINDUC.DAT|MORE" or "TYPE MFINDUC.DAT|MORE" or list them to a printer by entering the command "PRINT EFINDUC.DAT" or "PRINT MFINDUC.DAT."

A printout of the program source codes for the electric field induction program and the magnetic field induction program may be obtained by entering the commands "PRINT EFINDUC.C" and "PRINT MFINDUC.C," respectively. A copy of the source codes for each program is included in Annexes M and N.

*Input data requirements:*

The following data is required to run the programs:

*Energized conductors:*

a) Radius of energized phase conductors in inches

b) Number of subconductors per bundle

c) Bundling spacing in inches

d) AC resistance in ohms per mile

*De-energized conductors:*

a) a) Radius of de-energized phase conductors in inches

b) b) Number of subconductors per bundle

c) c) Bundle spacing in inches

d) d) AC resistance in ohms per mile

*Shield wires:*

a) Number of shield wires

b) Radius of shield wires in inches

c) AC resistance in ohms per mile

d) GMR in feet

*Conductor and shield wire coordinates:*

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All conductors and shield wires are assumed to lie in the first quadrant. The X and Y coordinates of the bundled phase conductors and shield wires at the tower, plus the Y coordinates of the bundled phase conductors and shield wires at midspan should be known. All coordinates should be in feet.

*Other:*

a) Phase-to-phase magnitude (in volts) of the energized lines

b) Reference angle of the energized lines with respect to each other in degrees

c) The distance between grounds on the de-energized line (if it is grounded at two points)

d) Resistivity of earth in ohm-meters

## L.4 Electric field induction

Figure L.1 is a drawing of a double circuit transmission line with shield wires. Circuit 1 is energized at 345 kV line to line and circuit 2 is de-energized.

a) Calculate the magnitude of potential induced on each phase of circuit 2.

b) Two part calculation as follows:

   5) Calculate the current per mile induced in each phase of circuit 2 assuming that the phase is grounded at both ends.

   6) Calculate the magnitude of current in each phase assuming that the 100 mi of circuit 2 are between grounds.

*Solution:*

The energized bundled phase conductors have been numbered 1-2-3, the de-energized bundled phase conductors 4-5-6, and the shield wires 7-8. All necessary input data can be obtained directly from the figure or by means of a few simple calculations.

*Energized conductors:*

a) Radius of energized conductors in inches: 0.752

b) Number of subconductors per bundle: 2

c) Bundle spacing in inches: 18

*De-energized conductors:*

a) Radius of de-energized conductors in inches: 0.752

b) Number of subconductors per bundle: 2

c) Bundle spacing in inches: 18

*Shield wires:*

a) Number of shield wires: 2

b) Radius of shield wires in inches: 0.216

c) GMR of shield wires in feet: 0.002 34


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*Conductor and shield wire coordinates:*

*X(N)* is the horizontal coordinate of the conductor. *Y(N)* is the vertical coordinate of the conductor at the attachment point of the tower. The midspan height of the conductor is denoted *M(N)*.

| | | | |
|---|---|---|---|
| X(1) = 19.5 | X(3) = 20 | X(5) = 53 | X(7) = 14 |
| Y(1) = 100 | Y(3) = 75 | Y(5) =75 | Y(7) = 116 |
| M(1) = 67 | M(3) =42 | M(5) = 42 | M((7) = 91 |
| X(2) = 0 | X(4) = 53.5 | X(6) =73 | X(8) = 59 |
| Y(2) = 75 | Y(4) = 100 | Y(6) = 75 | Y(8) = 116 |
| M(2) = 42 | M(4) = 67 | M(6) = 42 | M(8) = 91 |

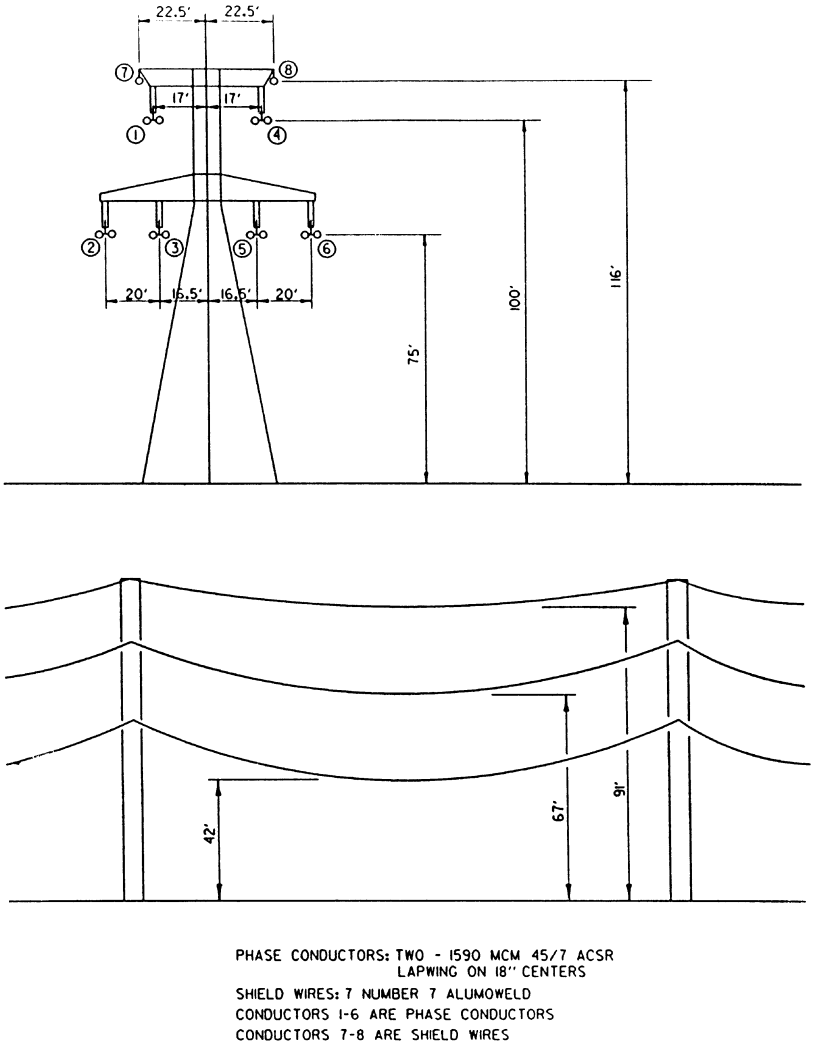



**Figure L.1—Double circuit transmission line**

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*Other:*

The following are phase-to-phase magnitude of energized lines and reference angles:

a) Conductor 1-to-2 345 kV, 0 degrees
b) Conductor 2-to-3 345 kV, 120 degrees
c) Conductor 3-to-1 345 kV, 240 degrees

Note that the magnitude of currents calculated on the de-energized phases is for the case when the phases are grounded. If these grounds were to be lifted, their removal would require circuit interruptions of currents of this magnitude against steady-state, open-circuit voltages as calculated per phase.

## L.5 Magnetic field induction

Assume that the energized circuit in Figure L.1 is carrying 1000 A of positive sequence current and all phases of the de-energized circuit are grounded.
NOTE—These calculations are made using phase quantities. Reference is made to positive sequence current to indicate that balanced conditions exist.

Calculate the open loop voltages per mile of line induced on the de-energized circuit.

*Solution:*

In addition to the input data as presented for the electric field induction problem, the following data must be inputted.

*Energized conductors:*

AC resistance of (sub)conductors in ohms/mile (50 °C): 0.067 8

*De-energized conductors:*

AC resistance of (sub)conductors in ohms/mile (50 °C): 0.067 8

*Shield wires:*

AC resistance in ohms/mile (small currents): 1.937
GMR (ft): 0.002 34

*Other:*

Resistivity of earth in ohm-meters: 100

## L.6 Computer output

### L.6.1 Electric field induction

```
VOLTAGES INDUCED ON (UNGROUNDED) DE-ENERGIZED CONDUCTORS

FOR MAINTENANCE OPERATIONS ON THE DE-ENERGIZED CONDUCTORS, THE CONDUCTORS WOULD BE
GROUNDED AT BOTH ENDS. CALCULATE THE AMOUNT OF ELECTROSTATIC DISPLACEMENT CURRENT
BETWEEN GROUNDS.
```


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| CONDUCTOR | INDUCED VOLTAGE 4 | VOLTAGE MAGNITUDE |
|---|---|---|
| 4 | +1.446E+04+J-9.681E+03 | 1.740E+04 |
| 5 | +2.068E+03+J-1.526E+04 | 1.540E+04 |
| 6 | +3.588E+03+J-8.393E+03 | 9.127E+03 |

| CONDUCTOR | INDUCED CURRENT (A/MI) | CURRENT MAGNITUDE (A/MI) |
|---|---|---|
| 4 | 9.037E-02+J+4.042E-02 | +9.899E-02 |
| 5 | +6.631E-03+J+8.173E-02 | +8.199E-02 |
| 6 | -8.110E-03+J+2.464E-02 | +2.594E-02 |

THIS SECTION CALCULATES THE AMOUNT OF CURRENT INDUCED BETWEEN GROUNDS ON THE DE-ENERGIZED CONDUCTOR.

THE CURRENT IN CONDUCTOR 4 IS 9.899 A FOR 100 MILES OF LINE

THE CURRENT IN CONDUCTOR 5 IS 8.199 A FOR 100 MILES OF LINE

THE CURRENT IN CONDUCTOR 6 IS 2.594 A FOR 100 MILES OF LINE

### L.6.2 Magnetic field induction

MAGNITUDE OF LOAD CURRENT ON ENERGIZED LINES: 1000 A

REFERENCE ANGLE OF LINE 1 IN DEGREES: 0

REFERENCE ANGEL OF LINE 2 IN DEGREES: 120

REFERENCE ANGLE OF LINE 3 IN DEGREES: 240

| CONDUCTOR | INDUCED VOLTAGE (V/MI) | VOLTAGE MAGNITUDE (V/MI) |
|---|---|---|
| 4 | +4.581E+01+J+2.280E+01 | +5.118E+01 |
| 5 | +5.808E+01+J-2.070E+01 | +6.166E+01 |
| 6 | +4.131E+01+J-1.383E+01 | +4.357E+01 |

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# Annex M

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## Source code for the electric field induction program (EFINCUC.C)

```
#include <stdio.h>
#include <math.h>
#define PI 3.1415927
#define CONSTAN 1.12E7
main(void)
{
 FILE *outfile;
 float PMATRIX[10][10],A2[10][10],B2[10][10],C2[10][10],X[10],Y[10],M[10],TWR[10];
 float COF[3][3],INV[3][3],CPA[3][3],MULT[3][3],INDRE[3][3],INDIM[3][3];
 float IMAG[3][1],VRE[3][1];
 float ANG[3],MAGC[3],IRE[3],IIMAG[3],MAG2[3],AMULTCUR[3],CUR[3];
 float  BIG,RADGRD,S,A,B,RAD,DIRECT,INDIRECT,TEMP,ATMP,DIV,DEL,BTMP,DET1,DET2;
 float MILES,RADDEEN,RADENGD,SUM,DET3,DETS,SUMA,SUMB,MAG,AMULT;
 int A1,B1,NG,NUM,M1,I,J,N,K,KP1,IMAX,AMAX;
 for (N=0;N<=10;N++)
 {
  X[N] = 0.0;
  Y[N] = 0.0;
  M[N] = 0.0;
  TWR[N] = 0.0;
  if(N <=3)
  {
   CUR[N] = 0.0;
   MAGC[N] = 0.0;
   IRE[N] = 0.0;
   IIMAG[N] = 0.0;
   MAG2[N] = 0.0;
   IMAG[N][1] = 0.0;
   VRE[N][1] = 0.0;
   ANG[3] = 0.0;
   for(I=0;I<=3;I++)
   {
    INDRE[N][I] = 0.0;
    INDIM[N][I] = 0.0;
    COF[N][I] = 0.0;
    INV[N][I] = 0.0;
    CPA[N][I] = 0.0;
    MULT[N][I] = 0.0;
   }
  }
  for(J=0;J<=10;J++)
  {
   PMATRIX[N][J] = 0.0;
   A2[N][J] = 0.0;
   B2[N][J] = 0.0;
   C2[N][J] = 0.0;
  }
 }
 if((outfile = fopen("efinduc.dat","wt")) == NULL)
  printf("OUTPUT FILE CAN NOT BE OPENED!!!!!!!!!\n");
 else
```


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```
 {
  fprintf(outfile,"                          ELECTRIC FIELD INDUCTION\n");
  fprintf(outfile,"                         -------------------------\n");
   fprintf(outfile,"THIS PORTION OF THE PROGRAM CALCULATES THE VOLTAGES AND CURRENTS
THAT CAN\n");
   fprintf(outfile,"BE INDUCED ON A DE-ENERGIZED TRANSMISSION LINE THAT PARALLELS AN
ENERGIZED\n");
    fprintf(outfile,"TRANSMISSION LINE. CONDUCTORS 1-2-3 ARE THE ENERGIZED CONDUC-
TORS;\n");
   fprintf(outfile,"CONDUCTORS 4-5-6 ARE THE DE-ENERGIZED CONDUCTORS; SHIELD WIRES (IF
ANY)\n");
  fprintf(outfile,"ARE 7-8-9-10.\n");
  printf("THIS PORTION OF THE PROGRAM CALCULATES THE P AND C MATRIX. ALL INPUTS\n");
  printf("ARE IN THE X-Y CO-ORDINATE SYSTEM. THESE MATRICES ARE USED TO\n");
  printf("CALCULATE ELECTROSTATIC INBALANCE.\n");
  printf("CALCULATE EFFECTIVE RADIUS FOR ENERGIZED BUNDLES \n");
  do
  {
   printf("INPUT RADIUS OF ENERGIZED PHASE CONDUCTORS IN INCHES ");
   scanf("%f",&RADENGD);
  }while(RADENGD <= 0);
  fprintf(outfile,"INPUT DATA:ENERGIZED CONDUCTORS \n");
  fprintf(outfile,"-----------------------------\n");
  fprintf(outfile,"RADIUS OF ENERGIZED PHASE CONDUCTORS: % .3f INCHES \n",RADENGD);
  RADENGD = RADENGD/12;
  do
  {
   printf("ENTER NUMBER OF SUBCONDUCTORS PER BUNDLE ");
   scanf("%d",&N);
  }while((N < 1) || (N > 6));
  fprintf(outfile,"NUMBER OF SUBCONDUCTORS PER BUNDLE: % d\n",N);
  if(N != 1)
  {
   do
   {
    printf("ENTER BUNDLE SPACING IN INCHES ");
    scanf("%f",&S);
   }while(S <= 0);
   fprintf(outfile,"BUNDLE SPACING OF SUBCONDUCTORS: % .3f\n",S);
   fprintf(outfile,"\n");
   S = S/12;
   A = S/(2*sin(PI/N));
   RADENGD = pow(((float)N*RADENGD*(pow(A,N-1))),(float)1/N);
  }
  fprintf(outfile,"INPUT DATA:DE-ENERGIZED CONDUCTORS\n");
  fprintf(outfile,"----------------------------------\n");
  printf("CALCULATE EFFECTIVE RADIUS FOR DE-ENERGIZED BUNDLES IN INCHES\n");
  do
  {
   printf("INPUT RADIUS OF DE-ENERGIZED PHASE CONDUCTORS IN INCHES ");
   scanf("%f",&RADDEEN);
  }while(RADDEEN <=0);
  fprintf(outfile,"RADIUS OF DE-ENRGIZED PHASE CONDUCTORS: % .3f INCHES\n",RADDEEN);
  RADDEEN = RADDEEN/12;
  do
  {
   printf("ENTER NUMBER OF SUB-CONDUCTORS PER BUNDLE ");
   scanf("%d",&N);
  }while((N < 1) || (N > 6));
```

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```
fprintf(outfile,"NUMBER OF SUBCONDUCTORS PER BUNDLE: %d\n",N);
if(N != 1)
{
 do
 {
  printf("ENTER BUNDLE SPACING IN INCHES ");
  scanf("%f",&S);
 }while(RADDEEN <= 0);
 fprintf(outfile,"BUNDLE SPACING OF SUBCONDUCTORS: % .3f INCHES\n",S);
 fprintf(outfile,"\n");
 S = S/12;
 A = S/(2*(sin(PI/N)));
 RADDEEN = pow(((float)N*RADDEEN*(pow(A,N-1))),(float)1/N);
}
printf("READ IN CO-ORDINATES OF ALL CONDUCTORS. THE ENERGIZED CONDUCTORS\n");
printf("ARE TO BE 1-2-3 AND THE DE-ENERGIZED CONDUCTORS 4-5-6.\n");
printf("THE SHIELDS WIRES (IF ANY) ARE TO BE 7-8-9-10\n");
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER HORIZONTAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("IN FEET ");
  scanf("%f",&X[I]);
 }while(X[I] < 0);
}
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("AT TOWER IN FEET ");
  scanf("%f",&Y[I]);
 }while(Y[I] < 0);
}
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("AT MIDSPAN IN FEET ");
  scanf("%f",&M[I]);
 }while(M[I] < 0);
}
do
{
 printf("ENTER NUMBER OF SHIELD WIRES ");
 scanf("%d",&NG);
}while((NG < 0) || (NG > 4));
fprintf(outfile,"INPUT DATA:SHIELD WIRES\n");
fprintf(outfile,"-----------------------\n");
fprintf(outfile,"NUMBER OF SHIELD WIRES: %d\n",NG);
do
{
 printf("ENTER RADIUS OF SHIELD WIRES IN INCHES ");
 scanf("%f",&RADGRD);
}while(RADGRD <= 0);
fprintf(outfile,"RADIUS OF SHIELD WIRES: % .3f INCHES\n",RADGRD);
fprintf(outfile,"\n");
```


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```
for(I=1;I<=NG;I++)
{
 do
 {
  printf("ENTER HORIZONTAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
  printf("IN FEET ");
  scanf("%f",&X[I+6]);
 }while(X[I+6] < 0);
}
for(I=1;I<=NG;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
  printf("AT TOWER IN FEET ");
  scanf("%f",&Y[I+6]);
 }while(Y[I+6] < 0);
}
for(I=1;I<=NG;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
  printf("AT MIDSPAN IN FEET ");
  scanf("%f",&M[I+6]);
 }while(M[I+6] < 0);
}
RADGRD = RADGRD/12;
NUM = NG + 6;
for(J=1;J<=NUM;J++)
{
 TWR[J] = Y[J];
 Y[J] = (Y[J] + (2* M[J]))/3;
}
/*CALCULATE THE DIAGONAL ELEMENTES OF THE P MATRIX*/
for(N=1;N<=NUM;N++)
{
 if(N<=3)
  RAD = RADENGD;
 else
  if(N>=7)
   RAD = RADGRD;
  else
   RAD = RADDEEN;
 PMATRIX[N][N] = (log(2.0*(Y[N]/RAD)))*(CONSTAN/377);
}
/*CALCULATE THE OFF DIAGONAL ELEMENTS. FIRST CALCULATE THE DISTANCE */
/*BETWEEN THE ENERGIZED CONDUCTORS AND THE DE-ENERGIZED CONDUCTORS  */
/*AND THE CALCULATE THE DISTANCES BETWEEN THE CONDUCTORS AND THEIR  */
/*IMAGES.                                                           */
for(A1=1;A1<=NUM;A1++)
 for(B1=1;B1<=NUM;B1++)
 {
  if(A1 != B1)
  {
   DIRECT = pow((pow((X[A1] - X[B1]),2.0)+pow((Y[A1]-Y[B1]),2.0)),0.5);
   INDIRECT = pow((pow((X[A1]-X[B1]),2.0)+pow((Y[A1]+Y[B1]),2.0)),0.5);
   /*CALCULATE THE OFF DIAGONAL ELEMENTS*/
   PMATRIX[A1][B1] = log(INDIRECT/DIRECT)*(CONSTAN/377);
```

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```
    }
   }
  fprintf(outfile,"                          POTENTIAL CO-EFICIENTS\n");
  fprintf(outfile,"                          ----------------------\n");
  printf("                       POTENTIAL CO-EFICIENTS\n");
  for(A1=1;A1<=NUM;A1++)
  {
   for(B1=1;B1<=NUM;B1++)
   {
    printf("PMATRIX ( %d , %d ) IS % E\n",A1,B1,PMATRIX[A1][B1]);
    fprintf(outfile,"PMATRIX ( %d , %d ) IS % E\n",A1,B1,PMATRIX[A1][B1]);
   }
   printf("\n");
   fprintf(outfile,"\n");
  }
  RADENGD = RADENGD * 12;
  RADDEEN = RADDEEN * 12;
  RADGRD = RADGRD * 12;
  printf("CONDUCTOR       HORIZONTAL       VERTICAL         MIDSPAN         \n");
  printf("NUMBER          CO-ORDINATE      CO-ORDINATE      CO-ORDINATE     \n");
  printf("                (FEET)           (FEET)           (FEET)          \n");
   fprintf(outfile,"CONDUCTOR          HORIZONTAL          VERTICAL             MIDSPAN
\n");
   fprintf(outfile,"NUMBER             CO-ORDINATE        CO-ORDINATE        CO-ORDINATE
\n");
  fprintf(outfile,"               (FEET)           (FEET)           (FEET)          \n");
  for(A1=1;A1<=NUM;A1++)
  {
   printf(" %d            % .2E       % .2E       % .2E\n",A1,X[A1],TWR[A1],M[A1]);
      fprintf(outfile,"  %d                      %  .2E             %  .2E             %
.2E\n",A1,X[A1],TWR[A1],M[A1]);
  }
  fprintf(outfile,"\n");
  /*REDUCE PMATRIX BY PARTITIONING */
  while((NUM-6) > 0)
  {
   M1 = NUM -1;
   for(I=1;I<=M1;I++)
    for(J=1;J<=M1;J++)
        PMATRIX[I][J]  =  PMATRIX[I][J]  -  PMATRIX[I][NUM]  *  PMATRIX[NUM][J]  /  PMA-
TRIX[NUM][NUM];
   NUM = NUM - 1;
  }
  /*MATRIX INVERSION BY ELIMINATION WITH PARTIAL PARTITIONING*/
  /*ORIGINAL MATRIX = A, INVERSE = B                          */
  /*LET A = PMATRIX AND B = CMATRIX                           */
  for(N=1;N<=6;N++)
   for(M1=1;M1<=6;M1++)
    A2[N][M1] = PMATRIX[N][M1];
  /*VERIFY THAT A IS NON-SINGULAR ROWS ONLY                   */
  for(I=1;I<=6;I++)
  {
   BIG = 0;
   for(J=1;J<=6;J++)
   {
    TEMP = A2[I][J];
    if(TEMP > BIG)
     BIG = TEMP;
   }
```


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```
 if(BIG == 0)
 {
  printf("PMATRIX INVERSE IS NOT DEFINED \n");
  fprintf(outfile,"PMATRIX INVERSE IS NOT DEFINED\n");
  exit(0);
 }
}
for(I=1;I<=6;I++)
 for(J=1;J<=6;J++)
 {
  if(I == J)
   B2[I][J] = 1;
  else
   B2[I][J] = 0;
 }
/*LOCATE MAXIMUN MAGNITUDE A[I][D] ON OR BELOW MAIN DIAGONAL */
DEL = 1;
for(K=1;K<=6;K++)
{
 if(K != 6)
 {
  IMAX = K;
  AMAX = abs(A2[K][K]);
  KP1 = K + 1;
  for(I=KP1;I<=6;I++)
  {
   if(AMAX < abs(A2[I][K]))
   {
    IMAX = I;
    AMAX = abs(A2[I][K]);
   }
  }
  /*INTERCHANGE ROWS IMAX AND K IF IMAX NOT EQUAL TO K        */
  if(IMAX != K)
  {
   for(J=1;J<=6;J++)
   {
    ATMP = A2[IMAX][J];
    A2[IMAX][J] = A2[K][J];
    A2[K][J] = ATMP;
    BTMP = B2[IMAX][J];
    B2[IMAX][J] = B2[K][J];
    B2[K][J] = BTMP;
   }
   DEL = -DEL;
  }
 }
 DEL = A2[K][K] * DEL;
 /*DIVIDE PIVOT ROW BY ITS MAIN DIAGONAL                     */
 DIV = A2[K][K];
 for(J=1;J<=6;J++)
 {
  A2[K][J] = A2[K][J]/DIV;
  B2[K][J] = B2[K][J]/DIV;
 }
 /*REPLACE EACH ROW BY LINEAR COMBINATION WITH PIVOT ROW     */
 for(I=1;I<=6;I++)
 {
  AMULT = A2[I][K];
```

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```
    if(I != K)
    {
     for(J=1;J<=6;J++)
     {
      A2[I][J] = A2[I][J] - AMULT * A2[K][J];
      B2[I][J] = B2[I][J] - AMULT * B2[K][J];
     }
    }
   }
  }
  printf("                ADMITTANCE MATRIX \n");
  printf("\n");
  fprintf(outfile,"                                ADMITTANCE MATRIX \n");
  fprintf(outfile,"                                -----------------\n");
  fprintf(outfile,"\n");
  for(I=1;I<=6;I++)
  {
   for(J=1;J<=6;J++)
   {
    printf("CMATRIX ( %d , %d ) IS % E\n",I,J,B2[I][J]);
    fprintf(outfile,"CMATRIX ( %d , %d ) IS % E\n",I,J,B2[I][J]);
   }
   printf("\n");
   fprintf(outfile,"\n");
  }
  printf("\n");
  for(I=1;I<=6;I++)
   for(J=1;J<=6;J++)
    C2[I][J] = B2[I][J];
  /*CALCULATE ELECTROSTATICALLY INDUCED VOLTAGES                    */
  /*CHECK IF SUB-MATRIX C, ROWS 4-6 AND COLUMNS 4-6 IS NON-SINGULAR */
  /*CHECK IF ANY ROWS OR COLUMNS ARE ALL ZEROS                      */
  for(I=4;I<=6;I++)
  {
   BIG = 0;
   for(J=4;J<=6;J++)
   {
    TEMP = C2[I][J];
    if(TEMP != BIG)
     BIG = TEMP;
   }
   if(BIG == 0)
   {
    printf("THE SUB-MATRIX INVERSE IS NOT DEFINED           \n");
    fprintf(outfile,"THE SUB-MATRIX INVERSE IS NOT DEFINED           \n");
    exit(0);
   }
  }
  for(I=4;I<=6;I++)
  {
   BIG = 0;
   for(J=4;J<=6;J++)
   {
    TEMP = C2[J][I];
    if(TEMP != BIG)
     BIG = TEMP;
   }
   if(BIG == 0)
   {
```


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```
  printf("THE SUB-MATRIX INVERSE IS NOT DEFINED          \n");
  fprintf(outfile,"THE SUB-MATRIX INVERSE IS NOT DEFINED          \n");
  exit(0);
 }
}
/*CALCULATE SUB-MATRIX DETERMINANT                          */
DET1 = C2[4][4]*(C2[5][5]*C2[6][6]-C2[5][6]*C2[6][5]);
DET2 = C2[4][5]*(C2[5][4]*C2[6][6]-C2[5][6]*C2[6][4]);
DET3 = C2[4][6]*(C2[5][4]*C2[6][5]-C2[5][5]*C2[6][4]);
DETS = DET1-DET2+DET3;
/*CALCULATE CO-FACTORS OF SUBMATRIX                         */
COF[1][1] = +(C2[5][5]*C2[6][6]-C2[5][6]*C2[6][5]);
COF[1][2] = -(C2[5][4]*C2[6][6]-C2[5][6]*C2[6][4]);
COF[1][3] = +(C2[5][4]*C2[6][5]-C2[5][5]*C2[6][4]);
COF[2][1] = -(C2[4][5]*C2[6][6]-C2[4][6]*C2[6][5]);
COF[2][2] = +(C2[4][4]*C2[6][6]-C2[4][6]*C2[6][4]);
COF[2][3] = -(C2[4][4]*C2[6][5]-C2[4][5]*C2[6][4]);
COF[3][1] = +(C2[4][5]*C2[5][6]-C2[4][6]*C2[5][5]);
COF[3][2] = -(C2[4][4]*C2[5][6]-C2[4][6]*C2[5][4]);
COF[3][3] = +(C2[4][4]*C2[5][5]-C2[4][5]*C2[5][4]);
/*CALCULATE ADJOINT OF CO-FACTORS                           */
for(I=1;I<=3;I++)
 for(J=1;J<=3;J++)
  INV[I][J] = (1/DETS)*COF[J][I];
/*RE-DEFINE SUB-MATRIXES                                    */
for(I=4;I<=6;I++)
 for(J=1;J<=3;J++)
 {
  K = I - 3;
  CPA[K][J] = C2[I][J];
 }
/*MULTIPLY SUB-MATRIX AND INVERSE                              */
for(I=1;I<=3;I++)
 for(J=1;J<=3;J++)
 {
  SUM = 0;
  for(K=1;K<=3;K++)
   SUM = SUM + (-1)*INV[I][K]*CPA[K][J];
  MULT[I][J] = SUM;
 }
/*INPUT ENERGIZED LINE VOLTAGES AND ANGLES; EXPAND INTO REAL AND        */
/*IMAGINARY COMPONENTS. THIS LEVEL OF BASIC IS NOT CAPABLE OF COMPLEX   */
/*ALGEBRA, SO WE MUST PLAY GAMES TO GET WHAT WE WANT...ASSUME POSITIVE  */
/*SEQUENCE EXCITATION                                                   */
printf("ENTER PHASE TO PHASE MAGNITUDE OF ENERGIZED LINES (VOLTS) ");
scanf("%f",&MAG);
fprintf(outfile,"PHASE TO PHASE MAGNITUDE OF ENERGIZED LINES: % .3f VOLTS\n",MAG);
for(I=1;I<=3;I++)
{
 printf("ENTER REFERENCE ANGLE OF LINE %d IN DEGREES ",I);
 scanf("%f",&ANG[I]);
 fprintf(outfile,"REFERENCE ANGLE OF LINE %d IN DEGREES: % .3f\n",I,ANG[I]);
}
printf("\n");
printf("\n");
fprintf(outfile,"\n");
for(I=1;I<=3;I++)
{
 VRE[I][1] = (MAG/(sqrt(3)))*cos(ANG[I]*PI/180);
```

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--```,,`-`-`,,`,,`,`,,`---

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```
   IMAG[I][1] = (MAG/(sqrt(3)))*sin(ANG[I]*PI/180);
  }
  for(I=1;I<=3;I++)
  {
   J = 1;
   SUMA = 0.0;
   SUMB = 0.0;
   for(K=1;K<=3;K++)
   {
    SUMA = SUMA + MULT[I][K]*VRE[K][J];
    SUMB = SUMB + MULT[I][K]*IMAG[K][J];
   }
   INDRE[I][J] = SUMA;
   INDIM[I][J] = SUMB;
  }
  /*CALCULATE MAGNITUDE OF INDUCED VOLTAGES                                */
  for(I=1;I<=3;I++)
  {
   J = 1;
                                                          MAG2[I]                    =
(float)sqrt((float)pow((float)INDRE[I][1],(float)2.0)+pow(INDIM[I][1],2.0));
  }
  printf("\n");
  printf("\n");
  printf("VOLTAGES INDUCED ON (UNGROUNDED) DE-ENERGIZED CONDUCTORS \n");
   fprintf(outfile,"             VOLTAGES INDUCED ON (UNGROUNDED) DE-ENERGIZED CONDUC-
TORS\n");
  fprintf(outfile,"           ------------------------------------------------------
\n");
  fprintf(outfile,"\n");
  printf("\n");
  printf("CONDUCTOR              INDUCED VOLTAGE(VOLT)              MAGNITUDE OF VOLT-
AGE\n");
  printf("\n");
  fprintf(outfile,"CONDUCTOR             INDUCED VOLTAGE(VOLT)             MAGNITUDE OF
VOLTAGE\n");
  fprintf(outfile,"\n");
  for(A1=1;A1<=3;A1++)
  {
   B1 = 3 + A1;
      printf("%d                              %  E  +J  %  E                       %  E
\n",B1,INDRE[A1][1],INDIM[A1][1],MAG2[A1]);
     fprintf(outfile,"%d                          %  E  +J  %  E                    %  E
\n",B1,INDRE[A1][1],INDIM[A1][1],MAG2[A1]);
  }
  printf("\n");
  printf("\n");
  fprintf(outfile,"\n");
  printf("FOR MAINTENANCE OPERATIONS ON THE DE-ENERGIZED CONDUCTORS, THE\n");
  printf("CONDUCTORS WOULD BE GROUNDED AT BOTH ENDS. \n");
  printf("CALCULATE THE AMOUNT OF ELECTROSTATIC DISPLACEMENT CURRENT \n");
  printf("BETWEEN GROUNDS. \n");
  fprintf(outfile,"FOR MAINTENANCE OPERATIONS ON THE DE-ENERGIZED CONDUCTORS, THE CON-
DUCTORS\n");
   fprintf(outfile,"WOULD BE GROUNDED AT BOTH ENDS. CALCULATE THE AMOUNT OF ELECTRO-
STATIC\n");
  fprintf(outfile,"DISPLACEMENT CURRENT BETWEEN GROUNDS.\n");
  fprintf(outfile,"\n");
  for(I=1;I<=3;I++)
```


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```
  {
   J = 1;
   SUMA = 0;
   SUMB = 0;
   N = 3 + I;
   for(K=1;K<=3;K++)
   {
    SUMA = SUMA + C2[N][K]*VRE[K][J];
    SUMB = SUMB + C2[N][K]*IMAG[K][J];
   }
   IRE[I] = SUMA;
   IIMAG[I] = SUMB;
  }
  /*CALCULATE MAGNITUDE OF INDUCED CURRENT                                  */
  for(I=1;I<=3;I++)
   MAGC[I] = (float)sqrt(pow(IRE[I],2.0)+pow(IIMAG[I],2.0));
  printf("\n");
  printf("CONDUCTOR          INDUCED CURRENT(AMPS/MILE)               MAGNITUDE(AMPS/
MILE)\n");
  printf("\n");
  fprintf(outfile,"\n");
  fprintf(outfile,"CONDUCTOR          INDUCED CURRENT(AMPS/MILE)               MAGNI-
TUDE(AMPS/MILE)\n");
  fprintf(outfile,"\n");
  for(A1=1;A1<=3;A1++)
  {
   B1 = A1 + 3;
   printf("%d             % E +J % E           % E \n",B1,IRE[A1],IIMAG[A1],MAGC[A1]);
     fprintf(outfile,"%d                        % E +J % E                    % E
\n",B1,IRE[A1],IIMAG[A1],MAGC[A1]);
  }
  printf("\n");
  printf("\n");
  fprintf(outfile,"\n");
  printf("THIS SECTION CALCULATES THE AMOUNT OF CURRENT INDUCED BETWEEN\n");
  printf("GROUNDS ON THE DE-ENERGIZED CONDUCTOR \n");
  printf("HOW MANY MILES IS EXPOSED BETWEEN GROUNDS ");
   fprintf(outfile,"THIS SECTION CALCULATES THE AMOUNT OF CURRENT INDUCED BETWEEN
GROUNDS ON\n");
  fprintf(outfile,"THE DE-ENERGIZED CONDUCTORS.\n");
  fprintf(outfile,"\n");
  scanf("%f",&MILES);
  printf("\n");
  for(A1=1;A1<=3;A1++)
  {
   B1 = 3 + A1;
   CUR[A1] = MILES*MAGC[A1];
      printf("THE CURRENT IN CONDUCTOR %d IS % E AMPS FOR % .2f MILES OF
LINES\n",B1,CUR[A1],MILES);
    fprintf(outfile,"THE CURRENT IN CONDUCTOR %d IS % E AMPS FOR % .2f MILES OF
LINES\n",B1,CUR[A1],MILES);
  }
  fclose(outfile);
 }
 exit(0);
}
```

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# Annex N

(normative)

## Source code for magnetic field induction program (MFINDUC.C)

```
#include <stdio.h>
#include <math.h>
#define PI 3.1415927
main(void)
{
 FILE *outfile;
 float FREQ,RESEG,RADDEN,RADENGD,S,GMR,GMRDE,GMRGRD,A,RESDE,RGRD,RADGRD,RHO;
 float GMRE,RES,THETA,DIND,RIL,MI,SUMA,SUMB,SUMC,SUMD;
 float D,DD,DI,DV,F,FF,H,K,P1,P2,P3,P4,P5,Q1,Q2,Q3,Q4,Q5,Q6,Q7,W,XGRD,XL;
 float X[10],Y[10],M[10],ANG[3],IRE[3],IIM[3],VRE[3],VCOM[3],MAG[3];
 float P[10][10],ZREAL[10][10],ZIMAG[10][10],Q[10][10];
 int K1,M1,N,NG,NUM,A1,B1,I,J;
 for (N=0;N<=10;N++)
 {
  X[N] = 0.0;
  Y[N] = 0.0;
  M[N] = 0.0;
  for(J=0;J<=10;J++)
  {
   P[N][J] = 0.0;
   Q[N][J] = 0.0;
   ZREAL[N][J] = 0.0;
   ZIMAG[N][J] = 0.0;
  }
  if(N <= 3)
  {
   ANG[N] = 0.0;
   IRE[N] = 0.0;
   IIM[N] = 0.0;
   VRE[N] = 0.0;
   VCOM[N] = 0.0;
   MAG[N] = 0.0;
  }
 }
 if((outfile = fopen("mfinduc.dat","wt")) == NULL)
  printf("OUTPUT FILE CAN NOT BE OPENED!!!!!!!!!\n");
 else
 {
  fprintf(outfile,"                          MAGNETIC FIELD INDUCTION\n");
  fprintf(outfile,"                          ------------------------\n");
  fprintf(outfile,"THIS PROGRAM CALCULATES THE VOLTAGES THAT CAN BE INDUCED ON DE-ENER-
GIZED\n");
   fprintf(outfile,"CONDUCTORS THAT LIE WITHIN THE MAGNETIC FIELD OF ENERGIZED CONDUC-
TORS.\n");
   fprintf(outfile,"CONDUCTORS 1-2-3 ARE THE ENERGIZED CONDUCTORS AND CARRY LOAD CUR-
RENT.\n");
    fprintf(outfile,"CONDUCTORS 4-5-6 ARE THE DE-ENERGIZED CONDUCTORS. THE SHIELD
WIRES\n");
  fprintf(outfile,"(IF ANY) ARE 7-8-9-10.\n");
  fprintf(outfile,"\n");
  printf("            MAGNETIC FIELD INDUCTION\n");
```


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```
printf("\n");
printf("THIS PROGRAM CALCULATES THE VOLTAGES THAT CAN BE INDUCED ON \n");
printf("DE-ENERGIZED CONDUCTORS THAT LIE WITHIN THE MAGNETIC FIELD OF\n");
printf("ENERGIZED CONDUCTORS. CONDUCTORS 1-2-3 ARE THE ENERGIZED CONDUCTORS\n");
printf("AND CARRY LOAD CURRENT. CONDUCTORS 4-5-6 ARE THE DE-ENERGIZED \n");
printf("CONDUCTORS. THE SHIELD WIRES (IF ANY) ARE 7-8-9-10\n");
printf("\n");
fprintf(outfile,"INPUT DATA:ENERGIZED CONDUCTORS\n");
fprintf(outfile,"-----------------------------\n");
do
{
 printf("ENTER SYSTEM FREQUENCY IN HERTZ ");
 scanf("%f",&FREQ);
}while(FREQ <= 0.0);
do
{
 printf("ENTER AC RESISTANCE OF ENERGIZED PHASE COND IN OHMS/MILE ");
 scanf("%f",&RESEG);
}while(RESEG <= 0.0);
printf("CALCULATE GMR OF ENERGIZED PHASE CONDUCTORS IN INCHES \n");
do
{
 printf("INPUT RADIUS OF ENERGIZED PHASE CONDUCTORS IN INCHES ");
 scanf("%f",&RADENGD);
}while(RADENGD <= 0);
fprintf(outfile,"RADIUS OF ENERGIZED PHASE CONDUCTORS: % .3f INCHES\n",RADENGD);
fprintf(outfile,"AC RESISTANCE OF ENERGIZED CONDUCTORS: % .3f OHMS/MILE\n",RESEG);
RADENGD = RADENGD/12;
do
{
 printf("ENTER NUMBER OF SUBCONDUCTORS PER BUNDLE ");
 scanf("%d",&N);
}while((N < 1) || (N > 6));
fprintf(outfile,"NUMBER OF SUBCONDUCTORS PER BUNDLE: %d\n",N);
GMRE = 0.7788*RADENGD;
if(N != 1)
{
 do
 {
  printf("ENTER BUNDLE SPACING IN INCHES ");
  scanf("%f",&S);
 }while(S <= 0);
 fprintf(outfile,"BUNDLE SPACING OF SUBCONDUCTORS: % .3f INCHES\n",S);
 fprintf(outfile,"\n");
 S = S/12;
 RESEG = RESEG/N;
 A = S/(2.0*sin(PI/N));
 GMRE = pow(N*GMRE*pow(A,(float)N-1),(float)1/N);
 RADENGD = pow(N*RADENGD*pow(A,(float)N-1),(float)1/N);
}
fprintf(outfile,"INPUT DATA:DE-ENERGIZED CONDUCTORS\n");
fprintf(outfile,"---------------------------------\n");
do
{
 printf("ENTER AC RESISTANCE OF DE-ENERGIZED PHASE COND IN OHMS/MILE ");
 scanf("%f",&RESDE);
}while(RESDE <= 0.0);
do
{
```

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```
 printf("INPUT RADIUS OF DE-ENERGIZED PHASE CONDUCTORS IN INCHES ");
 scanf("%f",&RADDEN);
}while(RADDEN <=0);
fprintf(outfile,"RADIUS OF DE-ENERGIZED PHASE CONDUCTORS: % .3f INCHES\n",RADDEN);
fprintf(outfile,"AC RESISTANCE OF ENERGIZED CONDUCTORS: % .3f OHMS/MILE\n",RESDE);
RADDEN = RADDEN/12;
do
{
 printf("ENTER NUMBER OF SUB-CONDUCTORS PER BUNDLE ");
 scanf("%d",&N);
}while((N < 1) || (N > 6));
fprintf(outfile,"NUMBER OF SUBCONDUCTORS PER BUNDLE: %d\n",N);
GMRDE = 0.7788*RADDEN;
if(N != 1)
{
 do
 {
  printf("ENTER BUNDLE SPACING IN INCHES ");
  scanf("%f",&S);
 }while(RADDEN <= 0);
 fprintf(outfile,"BUNDLE SPACING OF SUBCONDUCTORS: % .3f INCHES\n",S);
 fprintf(outfile,"\n");
 S = S/12;
 A = S/(2.0*sin(PI/N));
 RESDE = RESDE/N;
 RADDEN = pow(N*RADDEN*pow(A,(float)N-1),(float)1/N);
 GMRDE = pow(N*GMRDE*pow(A,(float)N-1),(float)1/N);
}
printf("READ IN CO-ORDINATES OF ALL CONDUCTORS. THE ENERGIZED CONDUCTORS\n");
printf("ARE TO BE 1-2-3 AND THE DE-ENERGIZED CONDUCTORS 4-5-6.\n");
printf("THE SHIELDS WIRES (IF ANY) ARE TO BE 7-8-9-10\n");
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER HORIZONTAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("IN FEET ");
  scanf("%f",&X[I]);
 }while(X[I] < 0);
}
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("AT TOWER IN FEET ");
  scanf("%f",&Y[I]);
 }while(Y[I] < 0);
}
for(I=1;I<=6;I++)
{
 do
 {
  printf("ENTER VERTICAL CO-ORDINATE OF BUNDLE %d ",I);
  printf("AT MIDSPAN IN FEET ");
  scanf("%f",&M[I]);
 }while(M[I] < 0);
}
do
```


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```
{
 printf("ENTER NUMBER OF SHIELD WIRES ");
 scanf("%d",&NG);
}while((NG < 0) || (NG > 4));
fprintf(outfile,"INPUT DATA:SHIELD WIRES\n");
fprintf(outfile,"----------------------\n");
fprintf(outfile,"NUMBER OF SHIELD WIRES: %d\n",NG);
NUM = NG + 6;
if(NG != 0)
{
 do
 {
  printf("ENTER AC RESISTANCE OF SHIELD WIRES IN OHMS/MILE ");
  scanf("%f",&RGRD);
 }while(RGRD <= 0.0);
 do
 {
  printf("ENTER GMR OF SHIELD WIRES IN FEET ");
  scanf("%f",&GMRGRD);
 }while(GMRGRD <= 0.0);
 do
 {
  printf("ENTER RADIUS OF SHIELD WIRE IN INCHES ");
  scanf("%f",&RADGRD);
 }while(RADGRD <= 0);
 fprintf(outfile,"RADIUS OF SHIELD WIRES: % .3f INCHES\n",RADGRD);
 fprintf(outfile,"AC RESISTANCE OF SHIELD WIRES: % .3f OHMS/MILE\n",RGRD);
 fprintf(outfile,"\n");
 RADGRD = RADGRD/12;
 for(I=1;I<=NG;I++)
 {
  do
  {
   printf("ENTER HORIZONTAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
   printf("IN FEET ");
   scanf("%f",&X[I+6]);
  }while(X[I+6] < 0);
 }
 for(I=1;I<=NG;I++)
 {
  do
  {
   printf("ENTER VERTICAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
   printf("AT TOWER IN FEET ");
   scanf("%f",&Y[I+6]);
  }while(Y[I+6] < 0);
 }
 for(I=1;I<=NG;I++)
 {
  do
  {
   printf("ENTER VERTICAL CO-ORDINATE OF SHIELD WIRE %d ",I+6);
   printf("AT MIDSPAN IN FEET ");
   scanf("%f",&M[I+6]);
  }while(M[I+6] < 0);
 }
}
fprintf(outfile,"SYSTEM FREQUENCY: % .3f HERTZ\n",FREQ);
fprintf(outfile,"\n");
```

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```
fprintf(outfile,"CONDUCTOR       HORIZONTAL      VERTICAL          MIDSPAN \n");
fprintf(outfile,"NUMBER          CO-ORDINATE     CO-ORDINATE       CO-ORDINATE\n");
fprintf(outfile,"                (FEET)          (FEET)            (FEET)\n");
printf("\n");
printf("CONDUCTOR       HORIZONTAL       VERTICAL         MIDSPAN         \n");
printf("NUMBER          CO-ORDINATE      CO-ORDINATE      CO-ORDINATE     \n");
printf("                (FEET)           (FEET)           (FEET)          \n");
for(A1=1;A1<=NUM;A1++)
{
 printf("%d            % .2E       % .2E       % .2E\n",A1,X[A1],Y[A1],M[A1]);
 fprintf(outfile,"%d           % .2E       % .2E       % .2E\n",A1,X[A1],Y[A1],M[A1]);
}
fprintf(outfile,"\n");
for(J=1;J<=NUM;J++)
 Y[J] = (Y[J] + (2* M[J]))/3;
printf("LET RESISTIVITY OF EARTH = 100 OHM-METER IF UNKNOWN \n");
do
{
 printf("ENTER RESISTIVITY OF EARTH IN OHM-METER ");
 scanf("%f",&RHO);
}while(RHO <= 0.0);
fprintf(outfile,"THE RESISTIVITY OF THE EARTH IS % .3f OHM-METERS\n",RHO);
fprintf(outfile,"\n");
/*CALCULATE P & Q */
for(A1=1;A1<=NUM;A1++)
 for(B1=1;B1<=NUM;B1++)
 {
  if(A1 == B1)
  {
   K = 0.8564671*0.001*2*Y[B1]*pow(FREQ/RHO,(float)1/2);
   THETA = 0;
  }
  else
  {
   D = pow((pow(X[A1]-X[B1],2.0)+pow(Y[A1]+Y[B1],2.0)),(float)1/2);
   H = abs(X[A1]-X[B1]);
   K = 0.8564671*0.001*D*pow(FREQ/RHO,(float)1/2);
   F = H/D;
   if (F > 1)
    printf("ERROR !!!");
   THETA = atan(F/(sqrt(1.0-pow(F,2.0))));
  }
  P1 = PI/8-(1/(3*sqrt(2.0)))*K*cos(THETA);
  P2 = (pow(K,2.0)/16)*cos(2.0*THETA)*(0.06728+log(2.0/K));
  P3 = (pow(K,2.0)/16)*THETA*sin(2.0*THETA);
  P4 = pow(K,3.0)*cos(3*THETA)/(45*sqrt(2.0));
  P5 = PI*pow(K,4.0)*cos(4*THETA)/1536;
  P[A1][B1] = P1+P2+P3+P4-P5;
  Q1 = (-0.0386)+((float)1/2*log(2.0/K));
  Q2 = (1/(3*sqrt(2.0)))*K*cos(THETA);
  Q3 = (PI*pow(K,2.0)*cos(2*THETA))/64;
  Q4 = (pow(K,3)*cos(3*THETA))/(45*sqrt(2.0));
  Q5 = (pow(K,4)*THETA*sin(4*THETA))/384;
  Q6 = (pow(K,4)*cos(4*THETA))/384;
  Q7 = log(2.0/K)+1.0895;
  Q[A1][B1] = Q1+Q2-Q3+Q4-Q5-Q6*Q7;
 }
/*CALCULATE THE DIAGONAL ELEMENTS */
for(A1=1;A1<=NUM;A1++)
```


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```
{
 if(A1<=3)
 {
  RES = RESEG;
  GMR = GMRE;
  DI = 2*RADENGD;
 }
 else
 {
  if(A1>=7)
  {
   RES = RGRD;
   GMR = GMRGRD;
   DI = 2*RADGRD;
   XL = XGRD;
  }
  else
  {
   RES = RESDE;
   GMR = GMRDE;
   DI = 2*RADDEN;
  }
 }
 FF = 0.1609347* 0.001;
 W = 2*PI*FREQ;
 ZREAL[A1][A1] = RES+FF*4*W*P[A1][A1];
 ZIMAG[A1][A1] = FF*(2*W*log(2.0*Y[A1]/GMR)+4*W*Q[A1][A1]);
}
/*CALCULATE OFF-DIAGONAL ELEMENTS */
for(A1=1;A1<=NUM;A1++)
 for(B1=1;B1<=NUM;B1++)
 {
  if(A1 != B1)
  {
   DD = pow((pow(X[A1]-X[B1],2.0)+pow(Y[A1]-Y[B1],2.0)),(float)1/2);
   DIND = pow((pow(X[A1]-X[B1],2.0)+pow(Y[A1]+Y[B1],2.0)),(float)1/2);
   ZREAL[A1][B1] = FF*4*W*P[A1][B1];
   ZIMAG[A1][B1] = FF*(2*W*log(DIND/DD)+4*W*Q[A1][B1]);
  }
 }
while(NUM != 6)
{
 M1 = NUM-1;
 DV = pow(ZREAL[NUM][NUM],2.0)+pow(ZIMAG[NUM][NUM],2.0);
 for(I=1;I<=M1;I++)
 {
  RIL = ZREAL[I][NUM];
  ZREAL[I][NUM] = (ZREAL[I][NUM]*ZREAL[NUM][NUM]+ZIMAG[I][NUM]*ZIMAG[NUM][NUM])/DV;
  ZIMAG[I][NUM] = ((-RIL)*ZIMAG[NUM][NUM]+ZIMAG[I][NUM]*ZREAL[NUM][NUM])/DV;
 }
 for(I=1;I<=M1;I++)
  for(J=1;J<=M1;J++)
  {
   ZREAL[I][J] = ZREAL[I][J]-ZREAL[I][NUM]*ZREAL[NUM][J]+ZIMAG[I][NUM]*ZIMAG[NUM][J];
   ZIMAG[I][J] = ZIMAG[I][J]-ZREAL[I][NUM]*ZIMAG[NUM][J]-ZIMAG[I][NUM]*ZREAL[NUM][J];
  }
 NUM = NUM-1;
}
fprintf(outfile,"                                IMPEDANCE MATRIX\n");
```

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```
  fprintf(outfile,"                                ----------------\n");
  fprintf(outfile,"\n");
  printf("                   IMPEDANCE MATRIX \n");
  for(A1=1;A1<=6;A1++)
  {
   for(B1=1;B1<=6;B1++)
   {
    fprintf(outfile,"ZREAL ( %d , %d ) IS % E\n",A1,B1,ZREAL[A1][B1]);
    fprintf(outfile,"ZIMAG ( %d , %d ) IS % E\n",A1,B1,ZIMAG[A1][B1]);
    printf("ZREAL ( %d , %d ) IS % E\n",A1,B1,ZREAL[A1][B1]);
    printf("ZIMAG ( %d , %d ) IS % E\n",A1,B1,ZIMAG[A1][B1]);
   }
   fprintf(outfile,"\n");
   printf("\n");
  }
  fprintf(outfile,"\n");
  fprintf(outfile,"ASSUME THE DE-ENERGIZED CIRCUITS ARE GROUNDED AT ONE TOWER. CALCU-
LATE,\n");
   fprintf(outfile,"FOR DISTANCES AWAY FROM THE TOWER, THE OPEN LOOP VOLTAGES TO
GROUND\n");
  fprintf(outfile,"INDUCED ON THE DE-ENERGIZED PHASE 4-5-6.\n");
  fprintf(outfile,"\n");
  printf("\n");
  printf("ASSUME THE DE-ENERGIZED CIRCUITS ARE GROUNDED AT ONE TOWER.\n");
  printf("CALCULATE, FOR DISTANCES AWAY FROM THE TOWER, THE OPEN LOOP \n");
  printf("VOLTAGES TO GROUND INDUCED ON THE DE-ENERGIZED PHASES 4-5-6.\n");
  do
  {
   printf("ENTER MAGNITUDE OF LOAD CURRENT ON ENERGIZED LINES ");
   scanf("%f",&MI);
  }while(MI <= 0.0);
  fprintf(outfile,"\n");
  fprintf(outfile,"MAGNITUDE OF LOAD CURRENT ON ENERGIZED LINES: % .3f AMPS\n",MI);
  fprintf(outfile,"\n");
  for(I=1;I<=3;I++)
  {
   printf("ENTER REFERENCE ANGLE OF LINE %d IN DEGREES ",I);
   scanf("%f",&ANG[I]);
   fprintf(outfile,"REFERENCE ANGLE OF LINE %d IN DEGREES: % .3f\n",I,ANG[I]);
  }
  fprintf(outfile,"\n");
  for(I=1;I<=3;I++)
  {
   IRE[I] = MI*cos(ANG[I]*PI/180);
   IIM[I] = MI*sin(ANG[I]*PI/180);
  }
  for(I=4;I<=6;I++)
  {
   SUMA = 0.0;
   SUMB = 0.0;
   SUMC = 0.0;
   SUMD = 0.0;
   for(K1=1;K1<=3;K1++)
   {
    SUMA = SUMA+ZREAL[I][K1]*IRE[K1];
    SUMB = SUMB+ZREAL[I][K1]*IIM[K1];
    SUMC = SUMC+ZIMAG[I][K1]*IRE[K1];
    SUMD = SUMD+ZIMAG[I][K1]*IIM[K1];
   }
```


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```
   VRE[I-3] = SUMA-SUMD;
   VCOM[I-3] = SUMB+SUMC;
  }
  /*CALCULATE MAGNITUDE OF THE INDUCED VOLTAGES*/
  for(I=4;I<=6;I++)
   MAG[I-3] = sqrt(pow(VRE[I-3],2.0)+pow(VCOM[I-3],2.0));
  fprintf(outfile,"CONDUCTOR             INDUCED VOLTAGE(V/mi)      MAGNITUDE OF VOLT-
AGE(V/mi)\n");
   printf("CONDUCTOR               INDUCED VOLTAGE(V/mi)       MAGNITUDE OF VOLTAGE(V/
mi)\n");
  for(A1=4;A1<=6;A1++)
  {
   printf("%d               % E +J % E   % E\n",A1,VRE[A1-3],VCOM[A1-3],MAG[A1-3]);
   fprintf(outfile,"%d              % E +J % E   % E\n",A1,VRE[A1-3],VCOM[A1-3],MAG[A1-
3]);
  }
  fclose(outfile);
 }
 exit(0);
}
```

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