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IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in Industrial and Commercial Applications

Sponsor

Petroleum and Chemical Industry Committee
of the
IEEE Industrial Applications Society

Approved 21 September 2000

IEEE-SA Standards Board

Abstract: A guide for installing, splicing, terminating, and field proof testing of cable systems in industrial and commercial applications is provided. It is not intended to be a design document, although many of the problems of installation can be avoided by designing cable layouts within the installation limits of this recommended practice.

Keywords: jamming, minimum bending radius, pulling lubricants, pulling tension, sidewall pressure, splicing

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Introduction

(This introduction is not a part of IEEE Std 576-2000, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in Industrial and Commercial Applications.)

This document has been generated to provide guidance for installation of electrical cable systems in industrial and commercial applications. It has long been recognized that the majority of cable failures are a result of mechanical damage during installation. The use of this document should reduce the possibility of electrical failure in a cable system. There are many specific details involved in the installation of cable systems that are subject to differences of opinion. This document covers only the major problem areas.

This document will be revised from time to time to incorporate the latest information available.

This document was prepared by the Cable Installation Working Group of the Petroleum and Chemical Industry Committee of the Industry Applications Society of IEEE. At the time this Recommended Practice was completed, Working Group P576 had the following membership:

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IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in Industrial and Commercial Applications

1. Overview

1.1 Scope

This recommended practice provides a guide for installing, splicing, terminating, and field proof testing of cable systems in industrial and commercial applications. It is not intended to be a design document, although many of the problems of installation can be avoided by designing cable layouts within the installation limits of this recommended practice.

1.2 Purpose

The purpose of this recommended practice is to provide a uniform guide of installation limits that will avoid premature cable failure due to improper installation and mechanical damage during installation. It is intended to provide a reference that can be specified for cable installations.

2. References

This recommended practice should be used in conjunction with the following publications:

Accredited Standards Committee C2-1997, National Electrical Safety Code® (NESC®).[1]

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[1] The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

AEIC CS8-00, Specifications for Extruded Dielectric Shielded Power Cables Rated 5 than 46 kV.[2]

AIEE Paper 53-389, Pipe-Line Design for Pipe Type Feeders, R. C. Rifenburg, published December 1953.[3]

ANSI Std C2-1997, National Electrical Safety Code.[4]

IEEE Std 48-1996, IEEE Standard Test Procedures and Requirements for Alternating Current Cable Terminations 2.5 kV Through 765 kV.[5]

IEEE Std 400-1991, IEEE Guide for Making High-Direct-Voltage Test on Power Cable Systems in the Field.

IEEE Std 404-1993, IEEE Standard for Cable Joints for Use with Extruded Dielectric Cable Rated 5000 V Through 138 000 V and Cable Joints for Use with Laminated Dielectric Cable Rated 2500 V Through 500 000 V.

IEEE Std 442-1981 (Reaff 1996), IEEE Guide for Soil Thermal Resistivity Measurements.

IEEE Std 1242-1999, IEEE Guide for Specifying and Selecting Power, Control, and Purpose Cable for Petroleum and Chemical Plants.

IEEE P1493, Draft Guide for the Evaluation of Solvents Used for Cleaning Electrical Cables and Accessories.[6]

NFPA 70-1999, National Electrical Code® (NEC®).

3. Definitions

3.1 electrical connection: The point at which two or more electrical conductors are joined together to establish electrical continuity.

3.2 jamming: The wedging of cables in a conduit when three cables lie side by side in a flat plane.

3.3 minimum bending radius: The minimum radius to which an insulated cable can be permanently bent that will not result in mechanical damage to the cable. In a bend, the radius is measured to the inside curve of the cable, not to the centerline of the cable.

3.4 sidewall pressure: The pressure exerted on an insulated cable as the result of the cable's being pulled around a bend during installation.

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[2] AEIC publications are available from the Association of Edison Illuminating Companies. 600 N, 18th Street, P.O. Box 2641, Birmingham, Al. 35291-0992, USA (http://www.acic.org/). AEIC publications are also available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112-5704, USA (http://global.ihs.com/).

[3] AIEE...

[4] ANSI publications are available from the Sales Department, American National Standards Institute. 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[5] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[6] This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information on obtaining a draft, contact the IEEE.

3.5 weight: In non-technical work and often in engineering, weight is commonly used as a synonym for mass. In this document, however, it is used as in physics, to refer to the apparent force of gravity on a object. Like other force quantities, it is expressed in newtons in the International System (SI) and in pounds-force in the inch-pound system.

3.6 weight correction factor: A dimensionless factor (≥ 1) by which cable tensions and sidewall pressure are adjusted due to different cable arrangements, when cable is pulled around bends or in conduit. For example, for three cables in a triangular configuration in conduit, the top cable does not touch the conduit, but its weight will cause increased tensions and sidewall pressures for the other two cables.

4. Pulling tensions

4.1 Maximum pulling tension on cable

4.1.1 Pulling eye attachment

With pulling eye attached to copper conductors, the maximum pulling tension should not exceed 0.008 times circular-mil area (C_m). With pulling eye attached to aluminum conductors, the maximum pulling tension should not exceed 0.006 times circular-mil area (C_m).

$$\left.\begin{aligned} T_m &= 0.008 \times n \times C_m \quad \text{(copper)} \\ T_m &= 0.006 \times n \times C_m \quad \text{(aluminum)} \end{aligned}\right\} \tag{1}$$

where

T_m is the maximum tension, lbf,

n is the number of conductors,

C_m is the circular mil area of each conductor,

or

$$\left.\begin{aligned} T_m &= 0.036 \times n \times C_m \quad \text{(copper)} \\ T_m &= 0.027 \times n \times C_m \quad \text{(aluminum)} \end{aligned}\right\} \tag{1a}$$

where

T_m is the maximum tension, N,

n is the number of conductors,

C_m is the circular mil area of each conductor.

Maximum limitation for this calculation is 22 240 N (2268 kgf) (5000 lbf) for single conductor (1/C) cables and 44 480 N (4536 kgf) (10 000 lbf) for three multi-conductor cables. This limitation is due to unequal distribution of tension forces when pulling multiple conductors.

4.1.1.1 Cable manufacturer

Consult the cable manufacturer for maximum allowable/recommended pulling tension.

4.1.1.2 Tension gauge

When the calculated pulling tension is close to (or within 10% of) the maximum pulling tension, the use of a tension gauge during the pulling is recommended.

4.1.2 Cable grip over lead sheath

With cable grip over lead sheath, with commercial lead, the maximum pulling tension on the lead sheath should not exceed 10.33 N/mm^2 (1500 lbf/in^2).

4.1.3 Cable grip over non-leaded cable

With cable grip over non-leaded cable, the maximum pulling tension should not exceed 4400 N (1000 lbf) and may not exceed the maximum tension as given in Equation (1).

4.2 Maximum pulling lengths

The maximum permissible pulling length, L_m, for one straight section is given by

$$L_m = \frac{T_m}{wfW_c} \tag{2}$$

where

T_m is the maximum tension in kgf (lbf),

w is the weight of cable(s) kg/m (lb/ft),

f is the coefficient of dynamic friction,

W_c is the weight correction factor.

W_c is 1.0 if there is one cable per duct; for more than one cable per duct see Figure 1.

4.3 Small conductor cables

In the case of small conductors where the permissible load is limited by 0.008 times the total circular-mil area of the conductors, the permissible load on the sheath may be added to that permitted on the conductor if the conductor and sheath are joined securely to the pulling eye.

4.4 Pulling tension requirements in duct and conduit

4.4.1 Straight run of cable

For a straight run of cable, the tension is given by the following equation:

$$T = LwfW_c \tag{3}$$

where

T is the pulling tension in kgf (lbf),

L is the length of duct in m (ft),

w is the weight of cable(s) in kg/m (lb/ft),

f is the coefficient of dynamic friction between cable(s) and duct or conduit surface,

W_c is the weight correction factor:

One cable per duct, $W_c = 1.0$

Three cables per duct, W_c is taken from Figure 1 or 5.2.

4.4.2 Curved duct sections

For curved duct sections, the following equation applies:

$$T_o = T_i e^{fa} \tag{4}$$

where

T_o = tension coming out of the bend (N) (lbf),

T_i = tension at the end of a straight section entering a bend (N) (lbf),

a = angle of bend in radians,

f = coefficient of dynamic friction.

Equation (4) is a commonly used approximation in lieu of the exact bend equation.

4.4.2.1 Values of e^{fa}

The values for e^{fa} are given in Table 1 for various values of f. The coefficient of friction is a function of the side wall bearing pressure and appropriate values of e^{fa} should be chosen to reflect this. As sidewall bearing pressure increases, the coefficient of friction decreases. Values of friction from high sidewall pressures may approach 0.1.

Table 1—Values of e^{fa}

Bend angle in degrees	Value of e^{fa}			
	$f = 0.1$	$f = 0.2$	$f = 0.35$	$f = 0.5$
15	1.03	1.05	1.10	1.14
30	1.05	1.11	1.20	1.3
45	1.08	1.17	1.32	1.48
60	1.11	1.23	1.44	1.69
75	1.14	1.3	1.58	1.92
90	1.17	1.37	1.73	2.19
105	1.2	1.44	1.90	2.5
120	1.23	1.52	2.08	2.85

4.4.2.2 Typical values for coefficient of friction

Table 2 gives typical values of the low sidewall bearing pressure dynamic coefficient of friction with properly applied pulling lubricant. The actual values may be obtained from the lubricant manufacturer for the specific type of lubricant used. The coefficient of friction for high sidewall bearing pressure may be a lower value.

Table 2—Typical coefficients of dynamic friction with adequate cable lubrication during full[a]

Cable exterior	Type of conduit		
	M	PVC	FIB
PVC—polyvinyl chloride	0.40	0.35	0.5
PE—low density HMW polyethylene	0.35	0.35	0.5
CSPE—chlorosulphonated polyethylene	0.50	0.5	0.7
XLPE—cross-linked PE	0.35	0.35	0.5
Nylon	0.40	0.35	0.5
CPE—chlorinated polyethylene	0.50	0.5	0.7
PCP—polychloroprene	0.50	0.5	0.7

Conduit codes:
M = metallic, steel or aluminum
PVC = polyvinyl chloride, thin wall or schedule 40
FIB = fiber conduit—Orangeburg or Nocrete
[a]These represent conservative values for use in lieu of more exact information.

4.4.2.3 Minimizing pulling tension

In order to minimize the pulling tension on the cable(s), the cable should be fed into the duct run from the end nearest the bend.

4.5 Check list prior to pulling cable

a) Be sure there is adequate clearance between duct or conduit diameter and cable diameter. The "percent fill" requirements should not be exceeded.

b) Use adequate lubrication of the proper type to reduce friction in conduit and duct pulls. The grease and oil type lubricants used on lead sheathed cables should not be used on non-metallic sheathed cables. There is a number of commercially available wire pulling compounds that are suitable for use with non-leaded cables.

c) Avoid sharp bending of the cable at the first pulley in overhead installations by locating the pay-off reel far enough away from the first pulley that the lead-in angle is kept relatively flat.

d) After installation, check to determine that end seals are still intact and have not been damaged to the point where water could enter. Apply suitable end seals to help protect against damage if the cable will be subjected to immersion or rain. This is particularly important if there will be a delay of some time between the pulling operation and splicing and terminating.

e) Be sure to check the maximum tension limits of the cable pulling accessories (cable grips, pulling eyes, swivels, pull rope, etc.). They should have a capacity equal to or greater than the tension limits that are required to pull the cable.

4.6 Methods of gripping cables for pulling

In general, insulated cables may be gripped either directly by the conductors or by a basketweave pulling grip applied over the cables. The method used depends on the anticipated maximum pulling tension. When pulls are low tension, a basketweave grip is used. High tension pulls will require connecting to the conductor either by means of pulling eyes or by forming a loop with the conductor itself. In some instances, it is desirable to use a grip over the outer covering in addition to the conductor connection to prevent any slippage of one with respect to the other.

4.6.1 Non-metallic sheathed cables

The smaller sizes of non-metallic sheathed cables are usually gripped directly by the conductors by forming them into a loop to which the pull wire or rope can be attached. The insulation on each conductor is removed before the loop is formed. Larger sizes are more easily handled by applying a pulling grip over the cable or cables, provided the pull is not too severe.

If more than one cable is involved, the ends should be bound together with friction tape before applying the grip overall. Long, hard pulls will necessitate the use of pulling eyes.

4.6.2 Lead sheathed cables

Pulling eyes for lead sheathed cables can be applied either at the factory or in the field. They must be wiped or sealed by other suitable means to the lead sheath to prevent the entrance of moisture. For shorter pulls a basketweave grip may be applied over the lead sheath or over the jacket if one is present over the lead sheath.

4.6.3 Metal clad cables

In pulling metal clad cable it is necessary to grip the armor and the conductors. This can be accomplished in a number of ways. One method requires that a portion of the armor be removed. Friction tape is then applied over the armor and down over the conductors, and a long basketweave grip is applied in such a way that it grips both the armor and the conductors. Another method requires that two holes be drilled through the cable (armor and conductors) at right angles to each other and that a loop be formed by passing steel wires through the holes and out over the end of the cable. A third approach would be to use a pulling eye and a grip together, the grip being applied over the armor to prevent its slipping back. The armor is not a tension member. Be certain pulling load is taken by the conductors.

5. Sidewall pressure

The sidewall pressure in general is expressed as the tension out of a bend expressed in newtons (pounds) divided by the inside radius of the bend expressed in meters (feet). Equation 5 is for one cable. Equations 5a and 5b are for the "worst case" condition with three single cables.

$$P = \left[\frac{T_o}{r}\right] \quad \text{(one single cable)} \tag{5}$$

$$P = \left[\frac{3W_c - 2}{3}\right]\frac{T_o}{r} \quad \text{(three single cables—cradle configuration)} \tag{5a}$$

$$P = \left[\frac{W_c}{2}\right]\frac{T_o}{r} \quad \text{(three single cables—triangular configuration)} \tag{5b}$$

where

P is the sidewall pressure, N/m (lbf/ft) of radius,

T_o is the tension (leaving the bend), N (lbf),

W_c is the weight correction factor,

r is the inside radius of conduit in m (ft).

5.1 Sidewall pressure limitations

One of the limitations to be considered in the installation of electrical cables is sidewall pressure. The sidewall pressure is the force exerted on the insulation and sheath of the cable at a bend point when the cable is under tension, and is normally the limiting factor in an installation where cable bends are involved.

When installing single-conductor cables, or multiconductor cables in duct or conduit, the sidewall pressure acting on the cable at a bend is the ratio of the pulling tension out of the bend to the radius of the bend, as defined in Equations 5, 5a, and 5b.

The normal maximum sidewall pressure per meter (foot) of radius is as given in Table 3. However, in order to minimize cable damage because of excessive sidewall pressure, the installer should check the cable manufacturer's recommendation for each type of cable to be installed.

Although the normal maximum allowable sidewall pressure is as stated in Table 3, specific installation procedures and specific cable constructions may cause this maximum to be increased or decreased.

Table 3—Maximum sidewall pressure, P_{max}, in newtons per meter of bending radius (pounds force per foot of bend radius)

Cable type	Maximum sidewall pressure	
	lbf/ft	**N/m**
600 V nonshielded multiconductor control	500	7300
600 V and 1 kV single conductor		
Size 8 and smaller	300	4400
Size 6 and larger	500	7300
5 to 15 kV power cable	500	7300
25 and 35 kV power cable	300	4400
Interlocked armored cable (all voltage classes)	300	4400
Instrumentation cable—single pair	300	4400
Instrumentation cable—multipair	500	7300

5.2 Weight correction factor calculations

The weight correction factor for one cable (single or one multiconductor) is $W_c = 1.0$. For three single conductor cables in a duct or conduit the equations for determining the weight correction factor are as follows:

a) For a cradled configuration

$$W_c = 1 + \frac{4}{3}\left[\frac{d}{D-d}\right]^2 \tag{6}$$

b) For a triangular configuration

$$W_c = \frac{1.0}{\sqrt{1 - \left[\frac{d}{D-d}\right]^2}} \tag{7}$$

where

W_c is the weight correction factor,

D is the I.D. of duct,

d is the O.D. of single conductor cable.

The configuration of three single-conductor cables in a conduit is determined by the ratio of the conduit inner diameter, D, to the outer diameter, d, on one of the single cables (D/d ratio).

For cradles, $D/d > 2.5$. For triangular, $D/d < 2.5$.

A graph of the above weight correction factors is given in Figure 1. For more detail refer to AIEE paper 53-389.

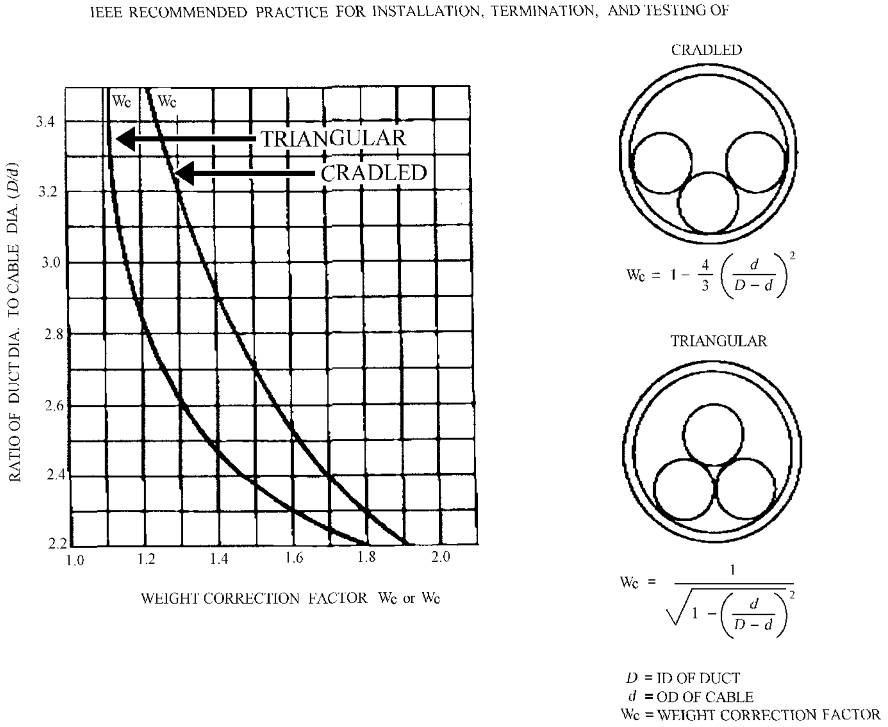

Figure 1—Occupancy factors

6. Jamming

Jamming is the wedging of three or more cables when pulled in a conduit.

Jamming can occur with cables in a conduit when three cables lie side by side in a flat plane. The cables will become wedged in the conduit and pulling damage will occur. This may occur when pulling around bends or when the cable twists. For one or two conductors or for a multiconductor with an overall jacket, jamming is not applicable. For four or more conductors the cable should still be evaluated as three conductors, because this is the pattern into which they will most likely move. Cabling or triplexing will eliminate jamming.

6.1 Computation of ratio

A check should be made by computing the ratio between the conduit inside diameter, *D*, and a single conductor overall diameter, *d*, to evaluate the potential for jamming. Because bending a cylinder produces an oval cross section in the bend, 1.05*D* should be used for the conduit inside diameter in these limitations:

If $1.05D/d$ is larger than 3.2, jamming is not probable.

If $1.05D/d$ is between 2.8 and 3.2, jamming is probable.

If $1.05D/d$ is less than 2.6, jamming is not probable, but clearance should be checked.

D is the inside diameter of conduit or duct.

d is the cable overall diameter.

6.2 Jam ratio

The critical range of the jam ratio to avoid is 2.8 to 3.2.

7. Recommended bending radii for cables

The minimum values for the radii of thermoplastic and thermosetting cables for permanent training during installation are given in this section. These limits do not apply to conduit bends, sheaves, or other curved surfaces around which the cable may be pulled under tension while being installed. Larger radii bends may be required for such conditions (see Clause 5).

In all cases the minimum radius specified refers to the inner surface of the cable and not to the axis of the cable.

7.1 Cables without metallic shielding or armor

The minimum bending radii for both single and multiple conductor cable without lead sheath and without metallic shielding or armor except portable cables are shown in Table 4.

Table 4—Minimum bending radius of single and multiconductor cable without metallic shield or armor as a multiple of cable diameter

Insulation thickness		**Overall diameter of cable**		
		2.54 cm and less	**2.55 to 5.08 cm**	**5.09 cm and over**
mm	**mil**	**(1.00 in and less)**	**(1.01 to 2.0 in)**	**(2.01 in and over)**
3.9 and less	155 and less	4	5	6
39.4 to 80	156 to 318	5	6	7
81 and over	316 and over		7	8

7.2 Cables with metallic armor

The minimum bending radii of all interlocked armored, flat-tape armored, wire armored, and corrugated sheathed cables, both single and multiple conductor, are shown in Table 5.

Table 5—Minimum bending radius of power and control cables with metallic sheath or armor as a multiple of cable diameter[a]

Type of cable	Minimum bending radius
Interlocked armor	7
Flat-tape armor	12
Wire armor	12
Corrugated sheath	7
Lead sheath	12

[a] Applies to non-shielded cable only.

7.3 Shielded cables

The minimum bending radius for all cables with metallic shield is 12 times the diameter of the individually shielded conductors or 7 times the overall diameter, whichever is greater.

For multiconductor or multiplexed single-conductor cables having individually shielded conductors, the minimum bending radius is 12 times the diameter of the individually shielded conductor or 7 times the overall diameter, whichever is greater.

7.4 Portable cables

The minimum bending radii for single and multiconductor portable cables during installation and handling are shown in Table 6.

Table 6—Minimum bending radius of single and multiconductor non-metallic portable cable as a multiple of cable diameter[a]

Type of cable	Minimum bending radius
0–5 kV	6
Over 5 kV	8
Control cable (7 conductors and over)	20

[a] For flat twin cables, the minor diameter should be used to determine the bending radius.

8. Minimum installation temperature

When installing cables under cold ambient conditions, various insulations and jacket materials become brittle and cables may be damaged if worked at too low a temperature. Table 7 gives the recommended minimum temperatures for handling and installing cables. It should be noted that these are typical values for standard compound materials; minimum temperatures will vary with special compound designs and requirements as specifications dictate.

Table 7—Recommended minimum temperature for handling and installing cables

Type of insulation or jacket	Minimum temperature for installation
PVC	−10 °C
PCP	−20 °C
CSPE	−20 °C
CPE	−20 °C
XLPE	−40 °C
PE	−40 °C
EPR	−40 °C

8.1 After installation

After the cables are installed they may be subjected to additional lowering of temperature without harm. The danger of damage comes from unreeling, bending, pulling, or accidental hits that could shatter the insulation or jacket.

8.2 Storage prior to installation

The cable to be installed at low temperatures, or that which has been stored at temperatures below the minimum installation temperature, should be heated up to the minimum installation temperature before installation.

This should be done by keeping the cable in heated storage for at least 24 hours prior to installation.

9. Direct burial

This clause discusses installation practices that should be considered when installing direct burial cable. The purpose of this section is not to be totally exhaustive, but to provide sound installation suggestions and recommendations.

9.1 Trenching

The width of trench should be large enough to accommodate the cables to be installed with sufficient separation between cables. Minimum depth of trench should be as defined in the latest edition of the National Electrical Code® (NEC®) (NFPA 70-1999). Minimum depths are as follows:

	Inches	Centimeters
600 V and below	24	60.9
Over 600 V to 22 kV	30	76.2
Over 22 kV to 40 kV	36	91.4
Over 40 kV	42	106.7

The minimum cover requirements (depths) listed above may be reduced by 15.2 cm (6 in) for installations where a 5.1 cm (2 in) thick concrete pad or equivalent in physical protection is placed in the trench above the cables. For full details, refer to Articles 300-5 and 300-50 of the NEC.

The above distances are measured between the top surface of direct buried cable and finished grade. It is recommended that direct buried cables be installed below the frost line.

One method of preparing the trench for cable installation is to pour 7.6 cm to 15.2 cm (3 to 6 in) of sand in the bottom of the trench to act as a cushion for the cable. If sand is not available, rock-free screened fill may be used.

Another method is to pour a 7.6 cm (3 in) concrete seal slab in the bottom of the trench, and then cover it with 7.6 cm (3 in) of sand. Cable spacers could also be installed with this method at reasonable distances.

Refer to the NEC, Article 300-5 for 0 to 600 V and Article 300-50 for over 600 V. Also refer to Article 310-7.

9.2 Installation

After trenching, the cables may be installed by one of the following methods:

a) The cable reel may be suspended directly over the trench, or alongside, and the cable laid in place as it is payed off the reel.
b) The cable reel may be set up at one end of the trench and the cable pulled into place.
c) It may be feasible to use a combination of both a) and b).

Cables should be installed with slack to allow for earth movement due to freezing, drying, or settling.

Direct buried cables can be installed in single or multiple layers. Where multiple layers are used there should be sufficient spacing between layers. It is recommended that lean concrete (1 to 1 mixture, sand to cement) be used as the backfill material between the layers. This type of backfill provides the rigidity for maintaining the space between cables on the same layer and the spacing between layers. It also has good thermal conductivity properties that can yield higher ampacity for cables in the duct bank.

It is acceptable and economically feasible to install power cables and communication cables in a common trench with defined separation. As a general rule, a 30 cm (1 ft) minimum separation is suggested for working distance. Additional separation may be required due to electromagnetic interference between power and communication cables.

9.3 Backfill

An additional layer of sand, or lean concrete approximately 15.2 cm (6 in) thick, should be poured and hand tamped after the cables are installed and before backfilling. The thermal resistivity of the backfill material is highly dependent on the material itself and its water content, and will affect the cable ampacity. Consult IEEE Std 442-1981 for soil thermal resistivity measurement procedures. Treated wood planks or a concrete slab [approximately 7.6 cm (3 in) thick] may be installed on top of this if additional protection is warranted. The trench should then be backfilled with the remaining excavated material to grade.

Backfill containing large rocks, sharp objects, corrosive material, scrap wood, or trees should not be used. If treated wood planks are used above the cable for mechanical protection, they should not be in direct contact with the cables and should not be treated excessively with preservatives that could be harmful to the cables.

9.4 Protection

Where cables run under railroads, or paved or non-paved roads, cables should be run through rigid conduit or pipe sleeves. Cable ampacity derating should be considered as temperatures will be higher here than where directly buried.

Marking strips and warning signs should be installed to readily identify the direct buried cable trench.

10. Cable tray installation

The same limitations of pulling tensions, sidewall pressures, and minimum bending radius apply for cable in trays as for cable in conduit. Attention must be given to the length of runs, the number of turns, and the size of sheaves used for pulling cable around these turns to accommodate changes in direction. Sheaves are often used as rollers in horizontal sections and for bends, either concave upward or concave downward, in connecting horizontal and vertical sections of tray. If trays are stacked vertically without sufficient clearance the installation of such "rollers" can be difficult if not impossible. The recommended clearance between trays is 30 cm (12 in) minimum. Heavier cables should be installed on the top tray. The use of trapeze hangers involving two vertical members for the hanger, one on each side of the tray, makes it impossible to lay cable into the tray and the cable must be pulled into place. The use of cantilevered supports should be given careful consideration, especially where placement of sheaves and pulling of cable is difficult.

10.1 Cable sheaves and cable sheave assemblies

As indicated in other sections of this standard, it is often necessary to pull around bends in a cable tray. Excessive sidewall pressure can result in damage to the cable. Sidewall pressure can be minimized by the use of a large radius sheave. Unfortunately, use of large radius sheaves is often impractical since they cannot be rigged in congested tray runs. Even if they can fit, they are often unavailable. To alleviate this problem, multiple smaller sheaves are placed on a radius. This device is known as a radius-type cable sheave assembly.

Precautions should be taken when using a radius-type cable sheave assembly to prevent damage due to excessive sidewall pressure around the individual sheaves. Each individual sheave should have an inside radius of at least 3.17 cm (1.25 in). The assembly should consist of at least one sheave per 20° of bend. The practice of using a three-sheave assembly to make a 90° bend should be avoided.

10.2 Use of rollers and sheaves

The proper use and location of rollers and sheaves will greatly reduce the tension required to pull cable into the tray. All rollers and sheaves need to be properly maintained and lubricated to provide the lowest coefficient of friction possible.

10.2.1 Roller mounting

Rollers should be mounted over the tray and supported by the side members of the tray, properly spaced to prevent the cable from touching the bottom of the tray.

The rollers or sheaves should be free turning with a low coefficient of friction.

Where the tray changes direction sheaves should be employed with radii sufficiently large to satisfy both maximum allowable sidewall pressure limits and minimum bending radii requirements.

10.2.2 Spacing of rollers

The maximum required spacing of rollers along the cable tray route will vary with the cable weight, the tension in the cable, the cable construction, and the height of the rollers above the tray bottom. Near the end of the pull, where the tension is approaching the maximum value, the spacing can be greater than at the beginning of the pull, where the tension is a minimum.

If vertical clearance permits, roller mounting brackets can be fashioned to provide considerable sag clearance between cable and tray, thus extending maximum allowable spacing between rollers.

If one assumes a perfectly flexible cable construction, Equation (8) can be used as an approximation in determining the spacing interval.

$$s = \sqrt{\frac{8hT}{w}} \tag{8}$$

where

s is the distance between rollers in m (ft),

h is the height of top of roller above tray bottom in m (ft),

T is the tension in kgf (lbf),

w is the weight of cables in kg/m (lb/ft).

The height should be taken as the distance from the top surface of the roller on which the cable bears to the upper surface of the tray bottom. This equation will give a conservative result, particularly for armored cable, assuming the value of T is correctly calculated.

In general it is not practical to establish a large number of different spacings along the tray route. It is recommended that a maximum number of three different intervals be used and then only for the longer runs. It is also recommended that surplus rollers be available should the calculated spacing prove to be excessive. Whenever possible, a length of cable should be used to determine maximum spacing permissible in the absence of tension. This will serve as a check against the equation, and provide a means for adjusting the calculation of the total number of rollers required.

10.3 Pulling tension calculations

The calculated pulling tension is the total tension of all segments of the cable pull: this includes tension at the cable reel, horizontal and vertical sections, including adders for all bends. These pulling tension calculations are based on the conditions of Clause 4 being met.

10.3.1 Horizontal sections

The pulling tension for horizontal sections of tray can be calculated as follows:

$$T = Lwf \tag{9}$$

where

T is the pulling tension in kgf (lbf),

L is the total length of cable in m (ft),

w is the weight of cables in kg/m (lb/ft),

f is the coefficient of dynamic friction.

Field data indicate that an effective coefficient of 0.15 will account for the low rolling friction coefficients of well designed rollers and sheaves in good operating condition.

The coefficient of friction is very dependent on condition and spacing of rollers and sheaves. The specific coefficient of friction for each installation should be verified.

The coefficient of dynamic friction can be verified by measuring the pulling tension of a known straight length and solving for f in Equation 9.

Another method to confirm the friction at a bend is to measure the tension in and out of the bend and to calculating f from Equation 4.

Both of these methods require pulling with an in-line tension measuring device.

10.3.2 Tension at cable reel

Since cable trays are elevated above floor level, it is common practice to mount the cable reel or reels at floor level and feed the cable up to and on the cable tray in making an installation. Unless cable slack is provided at the reel, either by manpower or by a drive mechanism, tension will be developed in the cable as it is removed from the reel. This tension should be taken into account in calculating the total tension developed during installation. The following equation is recommended:

$$T_r = 25w \tag{10}$$

where

T_r is the tension in cable at reel in kgf (lbf).

w is the weight of cables in kg/m (lb/ft).

or

$$T_r = 7.5w \tag{10a}$$

where

T_r is the tension in cable at reel in N,

w is the weight of cables in N/m.

This equation is based on the tension required to pull 15.2 m (50 ft) of cable in a straight, horizontal section of conduit assuming an effective coefficient of friction (basic coefficient friction of 0.5 multiplied by a weight correction factor of 1.0). This equation is a close approximation of the tensions typically observed.

10.3.3 Tension in vertical section

If cable reel is mounted at floor level directly below the starting point of the cable tray installation, the tension developed between reel and tray must be included in the calculation and is given by the following:

$$T_w = wL \tag{11}$$

where

T_w is the tension due to cable weight in kgf (lbf),

w is the weight of cables in kg/m (lb/ft),

L is the length of cable between reel and tray in m (ft).

If the cable reel is mounted above floor level, as on the bed of a truck, this component of tension can be reduced. In some cases the cable may be mounted below the tray but at some distance from the starting point of the pull. Theoretically a more sophisticated method could be employed to calculate this component of tension. However, the complexity of the procedure and the uncertainty of parameters does not warrant such an approach. It is recommended that the tension be calculated as though the cable were in a vertical configuration, with the height taken as the vertical distance between cable reel and tray.

10.3.4 Tension for an inclined section

Tension pulling up on an inclined tray section will increase as the incline rises at a rate dependent on a incline angle θ. Cumulative pulling tension will increase, remain unchanged, or decrease when pulling down an incline.

The tension pulling up, T_{up}, is expressed as:

$$T_{up} = LW(f \cos\theta + \sin\theta) \tag{12}$$

The tension pulling down, T_{dn}, is expressed as:

$$T_{dn} = LW(f \cos\theta - \sin\theta) \tag{13}$$

where

T_{up} is the pulling up tension in kgf (lbf),

T_{dn} is the pulling down tension in kgf (lbf),

L is the length of inclined cable in m (ft),

w is the weight of cables in kg/m (lb/ft),

f is the coefficient of dynamic friction,

θ is the straight section angle from horizontal.

10.3.5 Tension at bends in cable tray

Unlike cables pulled around bends in conduit or duct, bends around free turning sheaves are not treated as tension multipliers. A multiplying effect does not occur since the surface of the sheave(s) turns with the cable. The coefficient of friction, f, for a free turning, well-lubricated sheave is assumed to approach zero. Therefore, e^{fa} is essentially unity.

Although no multiplying effect is assumed at bends in tray installations, an increase in tension is sometimes necessary to account for the force required to bend the cable around the sheave.

This tension adder is usually necessary for heavy, less flexible cable. Experience has indicated that a 667 to 889 newtons (150 to 200 pounds) adder is typical for a 3/C, rated 15 kV, 500 kcmil copper conductor, metallic sheathed cable.

For longer pulls having several bends, this adder could become significant especially with respect to sidewall pressure limitations.

NOTE—The above is based on the use of multiroller sheave where the coefficient of friction is approaching zero. If this is not the case, then the tension adder for a bend will be a multiplier as used for calculating tension of a conduit bend.

10.4 Intermediate assist tugging

To reduce sidewall pressure and/or tension in order to extend the distance of a pull through cable tray, often the installer will employ a method known as assist tugging. This involves the use of an additional tugger attached to the cable via a tow rope and mare's tail or split basket grip at some intermediate point in the run, usually the longest straight section available. To safely distribute the pulling stresses on the cable, a commercial mare's tail is recommended; otherwise, the area of the cable under the grip should be wrapped with several layers of friction tape. A constant tension not in excess of 80% of the limit specified in 4.1.3 is applied to the cable until the cable reaches the end of the straight tray section, at which time the pull is halted and the assist tugger attachment moved back to the opposite end of the section and the pull continued. A high level of communications between all personnel involved in an installation of this type must be maintained to prevent damage to the cable.

10.5 Hints on installation

a) Pull cable with a tension measuring device. Monitor pulling tension during pull.
b) Attach cable to pull line with swivel.
c) Make sure the jacket or armor is attached so there is no separation or push back.
d) Drum end of cable should be free from reel.
e) Apply back tension on reel to avoid slack and prevent overrun of cable from reel.
f) Do not start and stop pull. Pull at a slow constant speed.
g) Rig sheaves at bends so they can be adjusted to fit cable movement during pull.
h) Have personnel stationed at sufficiently close intervals and at bends to monitor cable movement during pull.
i) Have extra rollers and sheaves immediately available for use if needed.

11. Aerial cable installation

Aerial cable consists of insulated cable bound to and supported by a messenger. The messenger type and size will vary greatly depending upon the specific application requirement.

Typical messenger characteristics are given in Table 8.

Table 8—Messenger characteristics

Nominal messenger		EHS copper clad				Aluminum clad steel				EHS galvanized steel				Stainless steel-type 316			
Size		Weight		Breaking strength		Weight		Breaking strength		Weight		Breaking strength		Weight		Breaking strength	
(in)	(cm)	(lbf/ft)	(kg/m)	(lbf)	(N)	(lbf/ft)	(kg/m)	(lbf)	(N)	(lbf/ft)	(kg/m)	(lbf)	(N)	(lbf/ft)	(kg/m)	(lbf)	(N)
1/4	0.635					0.104	0.158	6301	28026	0.121	0.188	6650	29579	0.135	0.201	7650	34027
5/16	0.79	0.204	0.303	9196	40903	0.165	0.248	10020	44568	0.208	0.308	11200	49817	0.212	0.318	11900	52931
3/8	0.98	0.324	0.482	13980	61782	0.385	0.572	15930	70856	0.273	0.406	15400	68499	0.286	0.414	16200	72087
7/16	1.11	0.409	0.608	16890	78126	0.433	0.644	19060	84778	0.399	0.594	20800	92518	0.416	0.619	23400	104083
1/2	1.27	0.515	0.766	20460	91006	0.486	0.723	22730	101103	0.517	0.769	26900	119654	0.535	0.796	30200	134329
9/16	1.43	0.650	0.967	24650	109643	0.546	0.812	27030	120229	0.671	0.998	35000	155680				

Aerial cable consists basically of two types, preassembled self-supporting and field supported spun. Each of these requires different methods of installation.

11.1 Preassembled self-supporting aerial cable

This type of cable is always pulled by the messenger.

The pulling line is fastened to the messenger with a swivel connection. The cable end should be tapered and tightly bound to the messenger to prevent slippage on the messenger and to facilitate easy passing through the pulleys.

All pulleys should be large enough to allow ample clearance around the cable so that there is no possibility of the binder tape catching against the frame of the pulley.

A minimum diameter of 25 cm (10 in) for the inside of the pulley and 2.5 cm (1 in) clearance on all sides is recommended.

Where there are obstructions between poles that must be avoided, a temporary messenger may be used to install additional pulleys to prevent the cable from catching and dragging where space is limited.

Where the cable must change direction, a multisheave radius roller assembly should be used. For large diameter heavy cables, a large radius 1.2 to 1.5 m (4 to 5 ft) multiroller sheave is recommended.

During pulling, the tension on the reel must be controlled to maintain a reasonable sag between poles. The sag should be controlled to prevent dragging of the cable on the ground or other obstructions. The tension on the cable leaving the reel should be kept to the minimum allowed by the sag requirements.

A cable will sometimes rotate or twist as it goes through a pulley. This twist can usually be removed by temporarily halting the pull and having line personnel untwist the cable. Once the cable passes through the pulley the tendency for the cable to twist is greatly reduced.

Upon completion of the pull the messenger should be tensioned at 25% higher than the final tension and then loosened. This will equalize the tension in all the spans. The final tension should not exceed 50% of the rated breaking strength of the messenger under the assumed ice loading and wind loading (heavy loading) at 60 °F. Normal sag should be about 1.5 to 2% of the span length. It is recommended that the cable be left a minimum of 24 hours before splicing. This will allow uneven tensions to equalize throughout the length.

11.2 Field supported aerial cable

In this type of cable installation, the selected messenger is installed and the insulated cable is pulled along the messenger on rollers and attached to the messenger using spinning wire or other means such as lashing rods, cable rings, cable blocks, or other special attachment methods.

The messenger is installed and tensioned to the desired tension prior to installing the pulley rollers. The desired final tension must take into account the total installed weight of cable, messenger, and lashing.

Since the cable is installed by pulling on the conductor, the installation procedures and limits for pulling tensions, sidewall pressure, and minimum bending radius as given in Clauses 4, 5, and 7 of this recommended practice apply.

11.2.1 Roller and sheaves

The proper use and location of rollers and sheaves will greatly reduce the required tension to pull cable. All rollers and sheaves need to be properly lubricated and aligned to provide the lowest possible friction.

All bends should be made with multiroller radius type sheaves. Rollers on straight pulls should be spaced to avoid excessive sag between rollers. Normally a 3.3 m (10 ft) spacing is used.

11.2.2 Pulling tension calculations

Since the cable is being installed on rollers the pulling tensions will be the same as stated in 10.3 of this recommended practice.

11.3 Sag and tension calculations for aerial cables

The sag and tension are based on the formulas for a parabola which are approximately the same as for a true catenary for small deflections. The formula is as follows:

$$T = \frac{s^2 w}{8d} \tag{14}$$

where

T is the horizontal tension in messenger kgf (lbf)[7],

s is the span length in m (ft),

w is the weight of cable assembly, including messenger, in kg/m (lbf/ft),

d is the sag in m (ft).

The total tension in the messenger at the support is the horizontal tension plus the vertical component due to the dead load. The vertical component has been neglected.

11.4 Determination of ice and wind loading

Ice and wind loading are determined by geographical location. The USA is divided into three districts for which standard loading conditions are specified in the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-1997). The ice and wind loadings should be calculated as given in the NESC.

11.5 Installation equipment

The equipment and hardware required for aerial cable application and installation is unique for the specific use. Preassembled and field-spun aerial cable require different installation techniques and hardware.

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[7] Use 50% of messenger breaking strength for heavy loading and 25% of breaking strength for normal loading.

The installer should become familiar with the available equipment and make sure that it is suitable for the particular installation application.

12. Pulling lubricants

It is recommended that an adequate quantity of a suitable lubricant be used in pulling cables to reduce friction. The commonly used lubricants are shown in Table 9.

Table 9—Pulling lubricants

Lubricant	**Cable coverings**					
	PCP	**PVC**	**XLP & PE**	**CSPE**	**CPE**	**Lead**
Soap flakes and water	+	+	+	+	+	+
Bentonite—dry or with water	+	+	+	+	+	+
Grease	O	O	O	O	O	+
Commercially available lubricants						
Soap-based paste	+	+	+	+	+	+
Water/wax emulsions	+	+	X	+	+	+
Polymer-based aqueous solutions	+	+	+	+	+	+

+ means OK to use,
X means check with lubricant manufacturer,
O means not recommended,
Allow all commercially available lubricants to dry prior to energizing circuits.

For more detail on compatibility refer to IEEE P1493.

Various commercial lubricants designed specifically for pulling cables are available. Commercial lubricants are designed to be compatible with different types of jacketing material. The choice of a specific commercial lubricant should be coordinated with the lubricant manufacturer to ensure compatibility with the cable jacket material.

Extreme conditions of high and low temperature affect lubricant performance. If pulling under these conditions, the lubricant used should be reviewed with the lubricant manufacturer.

Some pulling lubricants will negatively impact the flame resistance of the cable. Consult the lubricant manufacturer if this is a concern (e.g., if the cable being pulled through a conduit section is going to end up in a cable tray).

13. Splicing

These general guidelines are offered for splicing cables 5000 V and higher. However, because of the variety of cables and methods of splicing, they are not intended as a detailed set of instructions. Most manufacturers have instructions for specific cable constructions and the type of splice being used, and these instructions are to be followed. There are many different splices available, such as: pre-molded rubber, heat shrink, cold shrink, resin, and tape. This section will cover the basic requirements for splicing insulated copper or aluminum conductors up to 69 kV (using any of the above methods): shielded and non-shielded; single and three conductor; thermoset, thermoplastic, or paper insulated; lead, thermoset, or thermoplastic covered and/or jacketed. It is recommended that whichever method of splicing is chosen, it meets the requirements of IEEE Std 404-1993.

The objective is to make a joint in a power cable that is electrically equivalent to the cable. To achieve this objective, the following conditions are necessary to properly prepare the cable and install the joint:

a) Tools should be in first class condition—clean, dry and sharp.

b) Strict adherence to instructions, dimensions, cleanliness, and freedom from contamination are to be followed.

c) The materials used in the fabrication of the joint must be compatible with the cable materials and be new and clean.

d) The materials used for rejacketing the splice should be suitable for the environment.

13.1 Solid dielectric insulated cable

13.1.1 Removal of cable jacket and shield

a) The non-metallic jacket should be removed by ring cutting and slitting. In this case, it will be necessary to cut further than halfway through the jacket. Extreme care must be exercised in sheath and jacket removal not to damage the underlying layers. Also, extreme caution on removing the extruded semiconducting material from the cable should be exercised. The ring cutting should not go into the insulation.

b) The length of the jacket removed should be in accordance with the manufacturer's instructions for the splice being used.

c) The metallic shield and semiconducting layer of the cable should be removed in accordance with the manufacturer's instructions for the splice being used. It is very important to remove all of the semiconducting material from the cable insulation and to not leave any cuts or gouges in the exposed cable insulation. Sometimes an abrasive cloth is required to remove all of the semiconducting material from the cable insulation. The abrasive cloth must contain no conductive particles and should have a fine grit of between 100 and 150, with 120 normally being used. The exposed cable insulation surface should be cleaned with an cable cleaner approved by the cable manufacturer.

13.1.2 Placing connectors

a) Connectors are available in several types, among which are welded, soldered, compression, and indent. Most types are suitable for copper conductor with thermosetting insulation. When compression or indent type connectors are used with aluminum conductors, the connectors should contain an oxide inhibitor compound.

b) Remove the cable insulation from each cable end a distance as specified in the manufacturer's instructions. The distance will typically be half the connector length plus an additional length for growth of the connector. Copper connectors will grow very little, but aluminum connectors will grow more.

13.1.3 Preparation of joint for insulation

a) If a pre-molded rubber, heat shrink, or cold shrink splice is being used, the components must be slid over the conductor on the cable before the connector is compressed on the conductor.

b) For most tape splices and some other splices, it is necessary to "pencil" the factory-applied cable insulation. The pencil length should be approximately six times the thickness of the cable insulation. The pencil can be applied with either a penciling tool or a knife and abrasive cloth. The pencil surface should be as smooth as possible without gouges or cuts. The pencil and the exposed cable insulation should then be cleaned with a cleaner approved by the cable manufacturer.

c) Once the cable has been prepared to the splice manufacturer's specifications, and any parts requiring parking have been placed on the cable, the connector should be crimped or otherwise connected to the cable. Any sharp burrs occurring on the connector should be removed. If oxide inhibitor is used all residual inhibitor compound must be removed.

13.1.4 Insulating the joint

a) If a pre-molded rubber splice is being used, it can now be properly positioned on the cable. This shields the connector, insulates the joint, and continues the cable insulation shield across the splice. Silicone grease provided with the splices must be liberally used.

b) If a heat shrink resin or cold shrink splice is being used, it can now be positioned and installed as per manufacturer's instructions to shield the connector, insulate the joint and continue the splice insulation shield to the cable insulation shield on both sides of the splice.

c) If a tape method is used to insulate the joint, the manufacturer's instructions should be followed. The conductor shield will be installed over the connector and slightly onto the pencil, using semiconducting tape. Apply the semiconducting tape as smoothly as possible so there are no abrupt dimensional changes. Over this use high-voltage insulating rubber tape. Stretch the tape to a minimum of 80% of its original width while wrapping with smooth half-lapped layers. Continue installing the tape to the dimensions as specified by the manufacturer.

13.1.5 Shielding of the insulated joint

a) Pre-molded, heat shrink and cold shrink joints typically have a semiconducting layer on the outside of the splice. This layer overlaps the cable semiconducting layer on both sides and shields the joint.

b) Resin and tape splices for shielded cable joints typically require a layer of semiconducting tape installed with a 2.5 cm (1 in) overlap onto the cable semiconducting layer on both sides of the splice.

c) The cable metallic shield is then continued over the joint. The joint metallic shielding should match the fault current capacity of the cable shield. If an external ground is to be attached to the cable shield at this joint, care must be taken to keep water out of the splice. Where the ground exits the splice and the protective covering, mastic or some similar material must be used to keep moisture from running down the ground into the splice. If the ground leaving the splice is not a solid strap or solid bare conductor, the ground must be solder blocked either at the factory or in the field to prevent moisture ingress through the strands of the external ground.

13.1.6 Protective covering

The cable and splice metallic shield should be insulated and protected from cable jacket to cable jacket with a covering suitable for the environment. The covering of a joint should be of a material similar to the cable jacket. All sharp points should be removed before any jacket is installed. For cold shrink and heat shrink jackets, they should be positioned to overlap the cable jacket and installed as per manufacturer's instructions. For a tape cover, the covering tape should be applied in half-lapped layers to a thickness equal to or slightly greater than the cable jacket and onto the existing cable jacket for approximately 3.7 cm (1.5 in) on each end. For cables with a moisture-impervious layer, rejacketing should employ a moisture-impervious layer also.

13.2 Lead sheathed cable

There are several types of lead sheathed cables. Some cables with extruded insulation have lead sheaths. These cables will not be discussed here. This section will refer specifically to oil impregnated paper insulated cables with a lead sheath. Special consideration must be given to these cables in removal of the lead sheath and making of the joint. Environmental and health considerations must be taken into account when dealing with these cables.

13.2.1 Removal of the sheath

The joint manufacturer's installation instructions should be followed to determine the amount of lead sheath to remove. The lead sheath is then ring cut at this location, about halfway through the lead. Typically the lead is then removed by using a "chipping knife" and a hammer. The chipping operation is begun at the cable end and worked toward the ring cut. The chipping knife is held parallel to the paper insulation and shield and does not damage or nick the papers. The lead is then torn off at the cutback point, leaving the end of the remaining lead slightly "belled". For most splices, the lead is ideally not belled, but they can handle whatever belling occurs during removal of the lead sheath.

13.2.2 Making the lead joint

The joint can be insulated by any one of several different methods.

a) The joint can be taped or insulated with a poured hot compound. In either of these cases, a lead sleeve is typically slid over the joint, centered, and the ends of the sleeve beaten down snugly against the cable sheath. Scrape all wiping surfaces clean, and apply stearine flux to the wiping surfaces and paper pasters to limit the wiping area. Make the wipes by pouring molten lead onto the wipe area. As the solder becomes plastic on cooling, the solder is worked by wiping with a cloth pad. This process is continued until a leakfree, tight joint is effected at each end of the lead sleeve. Tape is applied before this lead sleeve is installed. The hot compound is poured after the sleeve is installed, by cutting two notches into one end of the sleeve. The hot compound is poured into the lower notch, while the upper one is used as a vent. Once the compound is poured, the notches must be soldered back closed.

b) Pre-molded, heat shrink and cold shrink joints can also be used on PILC cable, after a means of stopping the oil is applied. By stopping the oil from leaking out of the cable, the cable is effectively transformed into a polymeric equivalent cable and can then be treated as such. The same basic components associated with each means of insulating a joint on a shielded polymeric cable can now also be used on this PILC cable with the oil stop system on it. In all cases, follow manufacturer's instructions.

14. Terminating

Cable terminations are required when connecting insulated shielded power cables to other conductors such as a bus bar or uninsulated overhead lines. When a shielded power cable is ended or terminated, and the outer cable shield is stopped on the cable insulation, there is a very high concentration of stress at this point. These terminations must contain a method of controlling this high stress (stress cone or stress grading material), an outer non-tracking surface, and a means of providing an environmental seal to prevent moisture ingress. There are many different types of terminations available, such as pre-molded rubber, heat shrink, cold shrink, and tape. It is recommended that whichever method of terminating is chosen, it meets the requirements of IEEE Std 48-1996.

For nonshielded cable, environmental sealing of the connector to the jacket is advantageous to keep out water, and an outer insulating non-tracking covering will minimize the possibility of a failure due to surface discharge.

These general guidelines are offered for terminating cables. However, because of the variety of cables and methods of terminating, they are not intended as a detailed set of instructions. Most manufacturers have instructions for specific cable constructions and the type of termination being used, and these instructions are to be followed.

The objective is to make a termination in a power cable that is electrically equivalent to the cable. To achieve this objective, the following conditions are necessary to properly install the cable and the termination:

a) Tools are to be in first class condition clean, dry and sharp.
b) Strict adherence to instructions, dimensions, cleanliness, and freedom from contamination are to be followed.
c) The materials used in the fabrication of the termination must be compatible with the cable materials and be new and clean.

14.1 Cable preparation

The removal of the cable jacket and shield, the preparation of the cable end for the termination, and the installation of the lug are all the same operations as for splices. The guidelines for preparing the cable as outlined in 13.1.1, 13.1.2, and 13.1.3 should be followed. For exact removal and installation dimensions, the manufacturer's instructions should be followed for the type of termination selected and the cable being used. Again, note that it is extremely important to remove all of the black semiconducting layer from the actual cable insulation before installing the termination.

14.2 Installation of terminations

a) If a pre-molded rubber termination is being used, it can now be properly positioned on the cable. Follow manufacturer's instructions for installation and environmental sealing of the termination.
b) If a cold shrink or heat shrink termination is being used, it can now be positioned and installed as per manufacturer's instructions. Also, follow the instructions to make sure that the termination is environmentally sealed.
c) If tape is used to make a termination, the manufacturer's instructions should be followed and similar practices should be followed that were outlined in 13.1.4.
d) For methods of terminating shielded cable, some form of stress relief is used, either a stress cone or stress grading material. Proper positioning of these is critical for the termination to perform properly. The high stresses occur where the cable insulation shield ends, and the positioning of the termination is critical relative to the end of the insulation shield. If the termination contains stress grading material, it must be in contact with the insulation shield and extend onto the cable insulation. If the stress grading material is not in contact with the cable shield semiconductor, then the termination will fail.

e) For cable terminations installed within enclosures, it is important that the required minimum air clearances are maintained between phases and ground.

f) Sufficient space should be allowed to properly train cables without exceeding appropriate bending radius.

g) When connecting terminations to insulated bus bar, it is recommended that the exposed metallic connections be reinsulated.

h) The connection from the shield to ground at the cable termination should be of sufficient size to match the shield fault current capability.

15. Electrical connections

Electrical connections are made where conductors must be joined to another conductor or terminated. This process usually involves an electrical connector, a joining process, or a combination of the two. It is always advisable to consult a cable or connector manufacturer when selecting the best connector for a particular application.

15.1 Connector types

Connections may be divided into two general types: (1) thermal and (2) pressure.

15.1.1 Thermal connections

Thermal connections are a joining process that depend on heat to effect attachment. These connections consist of the following types: soldered, silver-soldered, brazed, welded, and thermite-welded.

15.1.2 Pressure connections

Pressure connections utilize pressure to effect attachment. There are three general types of connections that fall under the pressure connections category: (1) mechanical, (2) compression, and (3) wedge.

15.1.2.1 Mechanical connectors

Mechanical connectors are those in which the attachment pressure is applied by screw, cone, or other mechanical parts.

15.1.2.2 Compression connectors

Compression connectors are attached by use of a specially designed compression tool and die. The final shape of the resultant connection area may be indented, cup, hexagon, circular, or oval. A hydraulic compression tool is preferred for connections on cables sized #4/0 or larger.

Consult the connector manufacturer for the correct tool and die to use for each size and type of connector. Different size dies may be required for different connectors intended for the same size cable. This occurrence is mainly due to differences in connector wall thickness, but can also be affected by metallurgy composition.

15.1.2.3 Wedge connectors

Wedge connectors utilize a wedge component and a tapered, C-shaped spring body (C-body) for joining conductors. During installation, the wedge is driven between the two conductors into the

C-body. The C-body is spread and the resultant spring force places high pressure on the conductors, creating a stable electrical connection.

15.2 Contact resistance

Pressure connectors bring two surfaces tightly together to establish a low resistance electrical connection. The qualitative relationship between contact resistance and contact force is shown in Figure 2. The significance of this relationship is that once sufficient force, F_1, at recommended torque, has been applied to establish a safe value of resistance, R_1, considerable relaxation can occur before the resistance starts to rise again. The flatness of the relaxation curve coupled with the long duration for relaxation to occur provides a built-in safety factor.

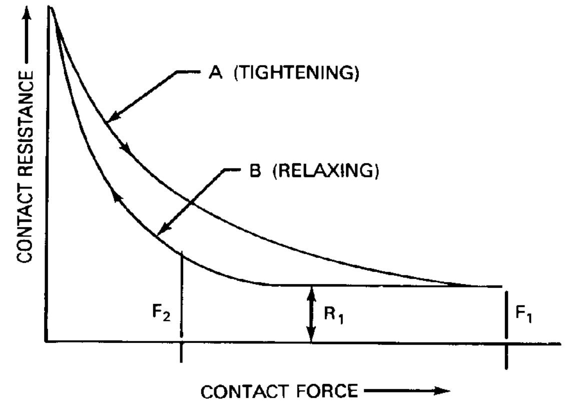

Figure 2—Contact resistance curves

15.3 Clamped connectors

Connectors that mechanically clamp the cable or two flat surfaces together depend on bolts to deliver the connecting force. The bolts must be of sufficient strength and be properly torqued to ensure a good electrical connection.

15.3.1 Torque values

The tightening torque values given in Table 10 may be used where manufacturer's values are unavailable.

Table 10—Recommended tightening torque values for various hardware

Bolt diameter		Nominal torque value			
		Silicon bronze galvanized or stainless steel		Aluminum alloy (lubricated)	
(in)	(cm)	(lb-ft)	(kg-m)	(lb-ft)	(kg-m)
5/16	0.812	15	2.034	—	—
3/8	0.965	20	2.712	12	1.627
1/2	1.27	40	5.424	25	3.390
5/8	1.60	55	7.458	40	5.424
3/4	1.90	80	10.848	70	9.492

15.4 Cable connection to bus bar

When making a flat, bolted connection between a NEMA connector and a bus bar, it is important to use the correct bolt, nut, washer, and torque. Where metals with different coefficients of expansion are involved, the use of stainless steel belleville washers is recommended during thermal expansion and contraction of the electrical joint. Compact design permits their use on NEMA hole spacing and size as well as on other standard connector drilling.

15.4.1 Belleville washers

A belleville washer is a dished washer made of spring steel. These high-loading and low deflection spring washers are useful in maintaining constant contact pressure on flat-contact electrical connections. They are ideal for use on aluminum, aluminum-to-copper, or other connections where continuous clamping pressure is required. On copper-to-copper or aluminum-to-copper connections, silicon bronze or stainless steel hardware can be used. On aluminum-to-aluminum connections, use aluminum or stainless steel hardware with belleville washers.

15.4.2 Proper installation of belleville washers

To properly install a belleville washer, fit the belleville washer onto the bolt with the concave side facing away from the bolt head. Then slide a large flat washer (outside diameter greater than the belleville when fattened) onto the bolt facing the concave side of the belleville washer. Fit this assembly through its intended hole. Fit an additional fat washer over the bolt and secure the assembly with the nut. Figure 3 shows the proper order and orientation of the hardware. Tighten the nut on to the bolt until a sudden, noticeable increase in torque is required to continue and the belleville washer becomes flat. The bolt assembly is complete, and no backing off of the nut is required. The completed connection should have no overlapping washers from one bolt assembly to another to ensure the proper force is being applied to the electrical joint.

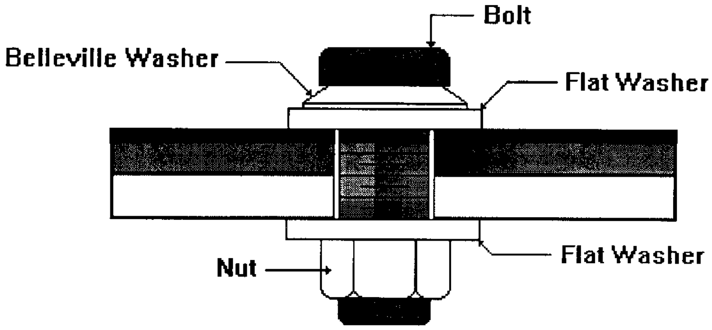

Figure 3—Belleville washer installation

15.5 Thermal expansion

Since the coefficient of thermal expansion (and contraction) of aluminum is greater than that of copper, copper compression connections are suitable only for copper cable and should never be used on aluminum conductors. Aluminum connectors do not experience an objectionable increase in contact resistance. Approved aluminum compression connections are suitable for use with both aluminum and copper cables.

15.6 Joint compounds for aluminum connections

A joint compound (oxide inhibitor) consists of oxide breaking particles suspended in a medium carrier. The particles penetrate the oxide film when pressure is applied and form current-carrying bridges at contact surfaces. The conductor(s) must be carefully prepared and compound properly applied to ensure a reliable connection.

A joint compound should be used on connections involving aluminum as aluminum oxide (a) forms rapidly on exposed aluminum surfaces, (b) is difficult to remove, especially between conductor strands, and (c) is non-conductive. Joint compound is also recommended on copper connections exposed to adverse environmental conditions.

15.7 Connectors for aluminum

Underwriter's Laboratories (UL) has tested and listed connectors approved for use on aluminum cable. Such connections meet or exceed UL performance tests. Approved mechanical and compression UL approved pressure connectors are available. The most satisfactory connections are those specifically designed for aluminum. They are compatible with characteristics of electrical conductivity, creep, corrosion, oxide film, and the coefficient of expansion of aluminum conductors.

15.8 Connection procedures

15.8.1 Materials

There are three possible surface material combinations when making a connection: (1) aluminum to aluminum (Al/Al), (2) aluminum to copper (Al/Cu), and (3) copper to copper (Cu/Cu). There are also two types of surfaces: (1) plated, and (2) unplated.

15.8.2 Surface preparation

When working with plated surfaces, never remove the plating. Clean the surface with a suitable non-abrasive cleaner.

When working with unplated surfaces, remove any oxide film by using a nonwoven abrasive pad, wire brush, or file. On aluminum surfaces, working through a coating of oxide inhibitor will help prevent the reformation of oxide film.

15.8.3 Non-compression connections

After surface preparation;

a) Coat contact surfaces liberally with a joint compound.
b) Select the appropriate hardware for the materials being joined.
c) Tighten the hardware to the recommended torque.

d) Remove excess joint compound.
e) Insulate the joint for the required operating voltage. If the connection is to remain bare, coat with joint compound for corrosion protection.

15.8.4 Compression connectors

Whether copper or aluminum is involved there are two requirements for a good compression connector installation: (1) selecting the correct connector for the application, and (2) using the correct tool and die for the particular connector selected. Long barrel connectors are normally recommended for conductors larger than 4/0 AWG due to their higher mechanical strength. The general installation procedures are as follows:

a) Select a connector approved for the type of cable and intended application. Do not remove any factory applied joint compound from the connector.
b) Remove any conductor insulation, being careful not to nick or cut any conductor strands. Follow the strip length recommendations provided by the connector manufacturer.
c) Prepare the conductor surfaces as per 15.8.2.
d) Insert the conductor all the way into the connector.
e) Make the beginning crimp near the tongue end of a terminal connector or center area of a splice connector.
f) Remove excess joint compound.
g) Insulate the joint according to the cable construction and for the required operating voltage.

16. Field acceptance testing

The practice of testing cables after installation to be certain that no damage has occurred during installation and that the cables are satisfactory for operation has been increasing. This is particularly important where contractors have installed the cable, as an acceptance test insures that the cable systems are satisfactory when turned over to the user.

The type of circuit and voltage, as well as the importance of the circuit, determines the method to be used for testing and the frequency of the testing. For low voltage control cables it is general practice to use an insulation resistance tester for checking the reliability of the circuit. This consists essentially of measuring the insulation resistance of the circuit to determine whether or not it is high enough for satisfactory operation. For higher voltage cables, the insulation resistance tester is not usually satisfactory and the use of high-voltage testing equipment is becoming more common. Even at the lower voltages, high-voltage dc tests are finding increasing favor. The use of high-voltage dc has many advantages over other types of testing.

16.1 Advantages of high-voltage dc acceptance testing

High-voltage direct current testing is intended to detect faults without damaging good insulation. Direct current voltage has no harmful or cumulative effects on the insulation, and as long as the voltage is not high enough to break down good insulation it has no deteriorating effects. This permits the use of high test voltages with direct current. With alternating current, the safe test voltage is limited, as there are secondary effects such as corona discharges that can damage good insulation.

Much more information can be obtained from examination of faults that are broken down with direct current, as the small arc current does not burn up any appreciable quantity of cable. Thus, in general, it is possible to determine the cause of the failure when it is broken down or located with direct current as compared to a service failure.

The equipment needed for high voltage dc testing is much smaller than with alternating current, since the charging current of the cable need not be provided by this equipment, as is the case with alternating current. Long lengths of cable can be tested with relatively small dc equipment. The only influence the length of the circuit has is in the case where the rate of charging the cable may occasionally be limited if a low capacity rectifier tube is used.

16.2 Installation acceptance test voltages

Power cables may be proof-tested with high voltage direct current at the voltages given in Table 11 after installation and before being energized.

Tests should be run for a period of 5 minutes for shielded and nonshielded cables. Generally, the voltage is applied and leakage current is recorded after 15, 30, 45, and 60 seconds and at one-minute intervals thereafter.

Table 11—High voltage installation test

Rated voltage Phase to Phase (kV)	**Conductor size AWG or kcmil (mm^2)**	**Insulation thickness, mils (mm)**		**Maximum dc field test voltages[a] (kV)**			
				During installation		**First 5 years**	
		A	**B**	**A**	**B**	**A**	**B**
5	8–1000 (8.4–507)	90 (2.29)	115 (2.92)	28	36	22	29
	Above 1000 (507)	140 (3.56)	140 (3.56)	28	36	22	29
8	6–1000 (13.3–507)	115 (2.92)	140 (3.56)	36	44	29	35
	Above 1000 (507)	175 (4.45)	175 (4.45)	36	44	29	35
15	2–1000 (33.6–507)	175 (4.45)	220 (5.59)	56	64	45	51
	Above 1000 (507)	220 (5.59)	220 (5.59)	56	64	45	51
25	1–2000 (42.4–1013)	260 (6.60)	320 (8.13)	80	96	64	77
28	1–2000 (42.4–1013)	280 (7.11)	345 (8.76)	84	100	67	80
35	1/0–2000 (53.5–1013)	345 (8.76)	420 (10.7)	100	124	80	99
46	4/0–2000 (107.2–1013)	445 (11.3)	580 (14.7)	132	172	106	138
69	500–2000 (254–1013)	650 (16.5)		192		154	

Column A: 100% insulation. Column B: 133% insulation.

[a] These test voltages are for all EPR circuits. Other values may be dictated by mixed cable circuits with other insulations or thinner insulation walls. Refer to AEIC CS8-00.

16.3 Interpretation of test results

Considerable experience is needed to properly interpret dc test results. One of the most important things to watch in connection with these tests is the shape of the leakage current curves during the test. In general, the leakage current will start at a relatively high value and drop off rather rapidly, becoming constant at some low value. The fact that the current becomes constant and levels off is more important than the actual magnitude of this leakage current. If the current has not dropped down or if, after dropping down, it starts to rise again, a strong indication of trouble on the circuit is evident. It is usually the best practice to continue the test beyond the usual time period or for as long as the current continues to rise, until failure occursorder that the weak spot may be eliminated.

More data on installation proof testing is available from IEEE Std 400-1991. However, this standard is under revision at the time of this writing (June 1999) and will subsequently become an omnibus standard covering all feasible types of test methods including ac and very low frequency. The new title will sbe IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems. The major divisions of the revised standard will be as follows:

a)	IEEE 400	Overview
b)	IEEE 400.1	Direct current (DC)
c)	IEEE 400.2	Very low frequency (VLF)
d)	IEEE 400.3	Partial discharge (PD)
e)	IEEE 400.4	Dissipation factor (DF)
f)	IEEE 400.5	Power frequency (PF)
g)	IEEE 400.6	Oscillating wave (OW)

Annex A

(informative)

Bibliography

[B1] *Engineering Data, Copper and Aluminum Conductor Electrical Cables.* Ramsey, NJ: The Okonite Company.

[B2] ICEA Publication P-79-561, Guide for Selecting Aerial Cable Messengers and Lashing Wires.[8]

[B3] *Installation Practices for Cable Raceway Systems.* Ramsey, NJ: The Okonite Company.

[B4] G. DiTroia, *Connector Theory and Application.* FCI Electrical 1997.

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[8] ICEA publications are available from ICEA, P.O. Box 20048, Minneapolis, MN 55420, USA (http://www.icea.org/).