

IEEE Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities

IEEE Power & Energy Society

Sponsored by the
Insulated Conductors Committee

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IEEE Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities

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IEEE Power & Energy Society

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Abstract: Guidance for the proper installation of cable in generating stations and industrial facilities is provided.

Keywords: American wire gauge (AWG), bend radius, cable, cable jamming, cable testing, cable tray, duct bank, ducts, English units, IEEE 1185, installation, jam ratio, kcmil, metric units, outside diameter or overall diameter (OD), pull back, pullby, pulling bend radius, pull tension, sidewall pressure, sleeve, training bend radius, trench, wire

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Introduction

This introduction is not part of IEEE Std 1185-2010, IEEE Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities.

Construction of generating stations and industrial facilities involve the installation of a large number of cables in various raceway types such as conduits, trays, duct banks, trenches, wire ways, direct burial, etc. The majority of these cables are unshielded, and except in duct banks or direct burial, where water may be present, there is usually no uniform continuous ground plane on the outside of the cable to allow effective post-installation voltage testing of the cable. Without a continuous ground plane, effective cable post-installation testing, as well as the ability to detect cable damage prior to placing the cable in service, is limited. Therefore, greater emphasis needs to be placed on wire and cable installation methods and practices to assure proper cable installation and long life.

Previously, cable storage/handling information and installation recommendations were provided in IEEE Std 422™-1986 [B24] and IEEE Std 690™-1984.^a Since IEEE Std 422-1986 has not been updated since its original issue and is now withdrawn, and since IEEE Std 690-2004 [B30] has removed the cable installation information, which were in the Appendices to IEEE Std 690-1984, this revision to IEEE Std 1185-1994 has been developed to capture and update information needed to properly install wire and cable and therefore improve safety and help assure reliable and long lasting service life.

It should be noted that other documents such as cable manufacturer's cable installation manuals, IEEE/IEC/AEIC standards, National Electrical Code® (NEC®) (NFPA 70, 2007 Edition), etc., are available that provide cable system design and installation information.^b It is not the intent of this recommended practice to replace or supersede the other information but to compliment it and as needed provide more detail, or alternate methods and techniques for proper cable installation. It is also not the intent of this document to override the installation requirements outlined in governing documents such as NEC, cable manufacturer's installation manuals or permitting documents, etc. Even though utilities in certain situations may be exempt from requirements of NEC, the utility is not exempt from following good cable installation practices in an effort to maximize cable life and minimize in-service cable failures.

Improved installation methods are also expected to increase confidence in the ability of the installed cable to function in the accident environments for nuclear power generating stations, and increase confidence in cables that improve safety and reliable operation of industrial facilities and cogeneration/fossil plants.

Monitoring pulling tensions is an effective approach to ensuring that the cable pulling limits, such as minimum bend radius, sidewall bearing pressure (SWBP), and conductor strength, are not exceeded. Since most cable pulls are manual pulls and the setup time to monitor pulling tension is prohibitive, pulling tensions are typically only monitored when performing long, high tension pulls requiring the use of motorized pulling equipment. When a manual cable pull into conduit is made, the dynamometer reading has to be adjusted after measuring various angles. Due to the complexity of this process, manual cable pulls are seldom monitored. This document introduces the use of conduit-cable pulling charts and other methods as alternatives to direct monitoring of the pulling tensions. This document also provides cable lubrication methods, conduit-cable pulling charts, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pull tension monitoring, etc.

Cable pullbys are a common practice in the utility industry and often not thoroughly addressed in either cable manufacturer literature or existing industry standards. Some utilities have reported damage to the existing cables in the conduits when executing pullbys (i.e., pulling cables into conduits that already contain cables). Monitoring the pulling tensions may help but may not prevent cable damage due to pullbys, since the damage can occur from the pull rope or pulled by cable as the pull rope or cable passes

^a The numbers in brackets correspond to those of the bibliography in Annex F.

^b Information on references can be found in Clause 2.

over existing cables. Instead of prohibiting the practice of cable pullbys, the cable installation process should be more carefully controlled by evaluating the pullby conditions prior to starting and placing restrictions on the process to avoid cable damage. However, it should be recognized that this is a risky procedure and damaged cables or questionable conditions can result from cable pullby practices.

AEIC CG5-05 [B3] and IEEE P971™ [B18] compliment this document for long power cable pulls through duct bank systems and should be considered as additional reference sources. Cable installation information can also be found in IEEE Std 576™-2000 [B28] and may also be consulted as an additional reference source.

Due to the requirement (IEEE Policy 9.18) to show metric units as the primary measurement unit, the English units are shown for convenience in parentheses after the metric units. The user of this document is cautioned to pay close attention to the units of the equations (metric versus English) and select units accordingly. Conformance to this standard can be achieved using either metric or English units provided the user is consistent when selecting and applying the units. The user is strongly cautioned not to mix units as mixing units can and will result in installation issues. The user is encouraged to select units that are most familiar to the installers so as to minimize the potential for creating installation problems that could go undetected until wire and cable failures occur, which is often years after installation. An attempt was made to keep the significant figures of the metric and English units comparable. However, due the application of rounding principles, the mathematical conversion from English numbers to metric numbers may not be exact.

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Peter M. Blackford
William G. Bloethe
Kenneth E. Bow
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Altin Dabulla
Chris K. Durland

John M. Fee
Ajit K. Gwal
Charles Hills
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Daniel G. Mainstruck
Arturo J. Maldonado

Nader Moubed
Jan S. Pirrong
Stephen J. Sandberg
Gary Savage
Dhiren Savdharla
Gil Shoshani
Donald Smith
Albert H. Spear III
Michael D. Sweat
William D. Wilkens
Dawn Zhao

*Deceased

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The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
Stan Arnot
Ali Al Awazi
George Ballassi
Radoslav Barac
J. Richard Barker
Farouk Baxter
Michael G. Bayer
Peter M. Blackford
Thomas Blair
William G. Bloethe
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Omar Mazzoni
William McBride
William McDermid
John E. Merando, Jr.
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Gary Michel
James Mitchem
Rachel Mosier
Kimberly Mosley
Jerry Murphy
Michael S. Newman
Allan St. Peter
Christopher Petrola

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1. Overview

1.1 Scope

This recommended practice provides guidance for wire and cable installation practices in generating stations and industrial facilities. This document may also be of benefit for the proper installation of wire and cable in commercial, governmental, and public facilities when similar wire or cable types and raceways are used.

1.2 Purpose

The purpose of this recommended practice is to provide guidance for the proper installation of wire and cable in generating stations and industrial facilities so that potential wire or cable damage may be avoided during the installation and testing process.

1.3 Units of measure

The requirement to show metric units first and if desired English units second in parentheses after the metric units is dictated by IEEE Policy 9.18, and has been implemented in this document even though the customary practice when installing American Wire Gauge (AWG) wire and cable is to use the English

units. The user of this document may choose to use the English units since cables made to AWG sizes are typically installed using English units of measure, even though the metric units are shown first and English units second in parentheses. Conformance to this recommended practice can be achieved using either metric or English units provided the user is consistent when selecting and applying the units. The user is strongly cautioned not to mix units as mixing units can and will result in installation issues. The user is encouraged to select units that are most familiar to the installers so as to minimize potential for creating installation problems that could go undetected until wire and cable failures occur, which is often years after installation. It should also be noted that due to the reversal of the order of metric and English units, an attempt was made to keep the significant figures of the metric and English units comparable. However, due to the application of rounding principles, the mathematical conversion from English to metric and vice versa may not be exact.

The user is also cautioned to recognize the difference between force and mass especially within the English system of units since term “pound” (lb) has been often misapplied, which can result in errors in the application of the equations. Attempts have been made within this document to be clear in the terminology to avoid confusion and misapplication of this concept in both the metric and English units. It should also be noted that cable manufacturers give cable weights in SI units using “kg/m” whereas in English the information is provided in terms of “lb/ft.” The metric units are clearly mass per unit length whereas the English units are more ambiguous. In this context, cable weight in English units is lbf/ft, which is a force per unit length. For clarity equations using cable weight have often been shown as two equations, one for metric and the other for English. Since the metric equation uses cable weight in terms of mass per unit length, the gravitational constant “g” has been added to the metric equation, which does not appear in the English equation.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

NFPA 70, 2007 Edition, National Electrical Code® (NEC®).¹

IEEE Std 1210™, IEEE Standard Tests for Determining Compatibility of Cable-Pulling Lubricants with Wire and Cable.^{2, 3}

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be consulted for terms not defined in this clause.⁴

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maintained space: Power cables installed with a minimum separation distance between each cable to prevent the necessity to apply de-rating factors to the cable ampacity.

NOTE—See item f) in 5.1 for additional information.⁵

mare's tail: Pulling device made of high strength flat fabric braid that is woven around the cable. It usually consists of four straps.

minimum pulling bend radius: The minimum allowable value of the radius of an arc that an insulated conductor, insulated wire, or insulated cable can be bent under tension while the cable is being installed.

minimum training bend radius: The minimum allowable value of the radius of an arc that an insulated conductor, insulated wire, or insulated cable can be bent under no tension for permanent installation.

random fill: Cables installed in trays in a non-spaced, non-grouped configuration.

rolling friction: The resistance to motion developed by sheaves, rollers bearings, etc., after cable movement has begun. *Syn:* **dynamic friction.**

standing friction: The resistance to motion to overcome the inertia or weight and start a cable moving. *Syn:* **static friction.**

3.2 Acronyms and abbreviations

Al	aluminum
AWG	American wire gauge
cmil	circular mils
Cu	copper
EMI/RFI	electromagnetic interference/radio frequency interference
Hi-Pot	high-potential test (usually dc test)
kcmil	one-thousand circular mils
LSZH	low-smoke zero halogen
MAPT	maximum allowable pulling tension
NEC	National Electrical Code ⁶
OD	outside diameter or overall diameter
PPT	projected pulling tension
SAF	slope adjustment factor
SWBP	sidewall bearing pressure, also know as <i>sidewall pressure</i>
TPE	thermoplastic elastomer
XLPE	cross-linked polyethylene
XLPO	cross-linked polyolefin

⁵ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

⁶ Information on references can be found in Clause 2.

4. Cable pulling recommendations

4.1 Distance limitations

The maximum distance a cable may be pulled in a raceway (for example, tray or conduits/ducts), without subjecting it to damage, depends on a combination of the following conditions (see “The Secret to Safe Cable Pulling” [B47]⁷):

- a) Conductor material (Cu or Al)
- b) Size of conductor
- c) Weight of conductor/cable
- d) Number of conductors
- e) Maximum allowable pulling tension (MAPT) (i.e., tensile strength of conductor or jacket, or both)
- f) Maximum allowable sidewall pressure of the cable construction
- g) Cable pulling methods (placed by hand, with pulling eyes, using basket weave grip, etc.)
- h) Size of conduit, duct, or tray
- i) Percentage fill of raceway
- j) Number and configuration (single conductor, triplex, or multi-conductor) of cables to be pulled
- k) Number, location, and radius of bends
- l) Angle and direction of bends (e.g., horizontal or vertical)
- m) Slope of raceway (tray, conduit, or duct)
- n) Coefficient of friction between cable jacket and raceway surface (tray bottom or conduit walls)
- o) Amount and type of lubrication used
- p) Limits of cable pulling and reel handling equipment
- q) Use of any shims, rollers, sheaves, etc., to minimize friction
- r) Amount of reel back-tension from payoff reel
- s) Direction of pull

To determine the maximum pulling length for a cable or bundle of cables, it is necessary to determine the maximum allowable values for both the pulling tension and sidewall pressure. The pulling length is limited by one or both of these factors.

4.2 Reel position

Pulling tension will be increased when the cable is pulled incorrectly off of the reel. Turning the reel and feeding slack cable to the tray, conduit, or duct entrance will reduce the pulling tension and may change a difficult pull to an easy one. See 6.3 for more information on reel setup.

⁷ The numbers in brackets correspond to those of the bibliography in Annex F.

4.3 Bend locations

The location of bends in the raceway system has a large influence on the direction of pulling cables. Whenever a choice is possible, pull the cable so that bends are closest to the reel. It is less desirable to pull a cable out of a bend at or near the end of a long run. When this is not possible and a bend is at or near the end of the cable run, be cognizant that pull tensions might be higher than if the cable were pulled in the opposite direction.

4.4 Minimum bend radius

In order to prevent cable installation damage and for long-term reliability, adherence to the manufacturer's minimum pulling and training bend radius values is necessary. Minimum pulling bend radius values apply when cable is pulled, producing tension and sidewall pressure. Depending on the pulling tension, a larger than the minimum pulling bend radius value may be required to limit the sidewall pressure to a value below the manufacturer's maximum limits. Subclauses 4.5 to 4.10 discuss the relationships between pulling tension, sidewall pressure, and bend radius. Minimum trained bend radius numbers are applicable to when the cable/wire is under no tension and is bent into final position for long-term use. As shown in Table 1, non-shielded, non-armored cables typically have minimum trained bend radius multipliers that vary between 4 to 8 times the *outside diameter* (OD) of the cable. Per Table 2, shielded and armored cable can vary from 7 to 15 times the cable OD based on factors such as the cable construction and armor type. The bend radius values are measured from the inner surface of the cable and not from the cable center axis. Consult the cable manufacturer for specific bend radius values prior to beginning any cable pulling activities.

Table 1—Minimum trained bend radius for non-shielded or non-armored cable

Non-shielded, non-armored cable	Minimum cable bend radius = multiplier × OD of cable		
	OD of cable in mm (in)		
Thickness of insulation mm (mils)	< 25 mm (< 1 in)	25 mm to 51 mm (1 in to 2 in)	> 51 mm (> 2 in)
< 4.3 (169)	4	5	6
4.3 (169) to 7.9 (310)	5	6	7
> 7.9 (310)	N/A	7	8

Table 2—Minimum trained bend radius for shielded or armored cable

Shielded or armored power and control cable	Minimum cable bend radius = multiplier × OD of cable
Type of shield or armor	Multiplier
Tape shield	12
Wire shield	8
Interlocked armor	7
Corrugated welded armor	7
Smooth welded armor	10 to 15
Extruded aluminum armor	10 to 15

4.5 Maximum allowable pulling tension

The MAPT should be determined from the cable manufacturer recommendations or from the following information:

- Pull tension based on pulling by conductor such as with pulling eye [see Equation (1)]:

$$T_{\max} = K \times n \times A_c \quad (1)$$

where

$T_{\max}$	= maximum pulling tension N (lbf)
A_c	= conductor area square mm (circular mils)
n	= number of conductors
K	= 70.2 MPa (0.008 lbf/cmil) for soft annealed copper
K	= 52.7 MPa (0.006 lbf/cmil) for 3/4 hard aluminum (alloy 1350-H16)

When

- 1) Maximum limitation for 1/C cables is 22 250 N (5000 lbf).
 - 2) Maximum limitation for 3/C cables is 44 500 N (10 000 lbf) due to the uneven distribution of forces.
 - 3) Maximum pull tension limitations shown in items 1) and 2) above are conservative, See AEIC CG5-05 [B3]. Consult manufacturer if higher pulling tension values are required.
 - 4) This formula does not apply to thermocouple, fiber optic, or specialty cable types. See Clause 14 for information regarding specialty cable.
- b) Pull tension based on pulling by use of a basket grip applied over the cable jacket:
- Non-shielded jacketed cables—8900 N (2000 lbf)
- Shielded jacketed cables—4450 N (1000 lbf)

When

- 1) Do not exceed tension limits of item a) above.
 - 2) Basket grip tensions shown above do not apply to armored or lead-sheathed cables; cables without an outer jacket; or specialty cable types such as thermocouple, coaxial/triaxial, or fiber optic cables. Consult cable manufacturer for these types.
- c) Tension forces for paralleled or cradled cables are assumed to be evenly distributed among the three conductors only when pulling in a straight line. Since most pulls involve bends, the forces are not evenly distributed, and it is conservative to assume that tension forces are shared by only two conductors. Therefore, the number of conductors [value of n in Equation (1)] is equal to two for the paralleled or cradled cable case.
- d) For triplexed cables, the value of n can remain as 3 since due to the cabling of the conductors, the pulling force will distribute evenly. A factory assembled triplexed cable should be treated the same as a multiconductor cable with regard to pulling tension, sidewall pressure, and weight correction factor.

4.6 Expected pulling tension

The expected pulling tension of one cable in a straight section of conduit or duct may be calculated from Equation (2). This formula does not consider slope or prior tension.

$$T = L \times W \times K_o \times g \quad (2a) \text{ metric}$$

where

T	= total pulling tension, N
L	= length of conduit runs, m
W	= mass of cable(s) per unit length, kg/m
K_o	= basic coefficient of friction
g	= gravitational constant (9.8 m/s ²)

$$T = L \times W \times K_o \quad (2b) \text{ English}$$

where

T = total pulling tension, lbf
 L = length of conduit runs, ft
 W = weight of cable(s) per unit length, lbf/ft
 K_o = basic coefficient of friction

The expected pulling tension of a cable in an inclined section of conduit or duct may be calculated from Equation (3):

$$\text{Upward } T = W \times g \times L (K_o \cos \alpha + \sin \alpha) + (\text{prior tension}) \quad (3a) \text{ metric}$$

$$\text{Upward } T = W \times L (K_o \cos \alpha + \sin \alpha) + (\text{prior tension}) \quad (3b) \text{ English}$$

$$\text{Downward } T = W \times g \times L (K_o \cos \alpha - \sin \alpha) + (\text{prior tension}) \quad (3c) \text{ metric}$$

$$\text{Downward } T = W \times L (K_o \cos \alpha - \sin \alpha) + (\text{prior tension}) \quad (3d) \text{ English}$$

where

α = the angle of the inclined section of conduit from horizontal
 g = gravitational constant (9.8 m/s²)

For conduit or duct runs containing horizontal bends, the expected pulling tension around a bend can be determined referring to Figure 1 and assuming the pull from A to D as shown in Equation (4):

$$T_C = T_B e^{K_o \sigma} \quad (4)$$

where

T_C = tension out of the bend N (lbf)
 T_B = tension into the bend N (lbf)
 e = natural logarithm base (approximately 2.72)
 K_o = basic coefficient of friction
 σ = angle of bend (radians) where 1 degree = 0.01745 radians

T_B is determined for the pull by the straight-length method previously given.

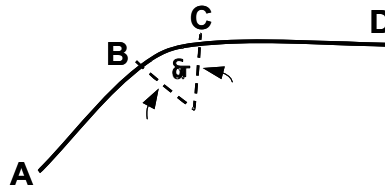


Figure 1—Expected pulling tension around horizontal bend for conduit or duct runs containing horizontal bends

The basic coefficient of friction typically ranges from 0.3 (for properly lubricated cables pulled into smooth, clean conduits) to 0.5 (for lubricated cables pulled into rough or dirty conduits). Other factors such as jacket material, conduit material, ambient temperature, stranding (flexibility) of the conductor, etc., may influence the actual friction factor experienced. The use of a different coefficient of friction may be substantiated by comparison of the actual versus calculated pulling tension.

4.7 Weight correction factor

When more than one cable is pulled into a conduit or duct, the pulling tension is not simply a direct multiple of a single cable pull. Because of the wedging action between cables and conduit/duct, even in a straight pull, the effect is to produce a sidewall pressure, which is treated as an increase in the basic coefficient of friction (K_o) and is called the weight correction factor (W_c). The effective coefficient of friction, K' , is shown in Equation (5):

$$K' = W_c \times K_o \quad (5)$$

The pulling tension for “ n ” cables then becomes, as shown in Equation (6):

$$T = n \times K' \times L \times W \times g \quad \text{for straight pulls} \quad (6a) \text{ metric}$$

$$T = n \times K' \times L \times W \quad \text{for straight pulls} \quad (6b) \text{ English}$$

The additional tension imposed by a bend is calculated the same way as for a one-cable pull except that K_o is replaced by K' .

W_c for single conductor cable, multiple conductor jacketed, or triplex construction in a duct is unity. W_c for a dual cable pull is typically determined utilizing the formula for three cables in a triangular configuration shown below.

For the case of three cables, Figure 2 can be used to determine W_c when the ratio of the conduit/duct inside diameter and cable outside diameter (D/d) is known. Alternatively, W_c may be determined using Equation (7).

For D/d ratios above 3.0, cables tend to form a cradle configuration. W_c for this arrangement may be calculated using Equation (7a):

$$W_c = 1 + \frac{4}{3} \left[\frac{d}{D-d} \right]^2 \quad (7a)$$

where

- W_c = weight correction factor
- D = inside diameter of the conduit, mm (in)
- d = outside diameter of the cable, mm (in)

Up to a D/d ratio of 2.5, cables are constrained into a triangular configuration. W_c for this arrangement may be calculated using Equation (7b).

$$W_c = \frac{1}{\sqrt{1 - \left[\frac{d}{D-d} \right]^2}} \quad (7b)$$

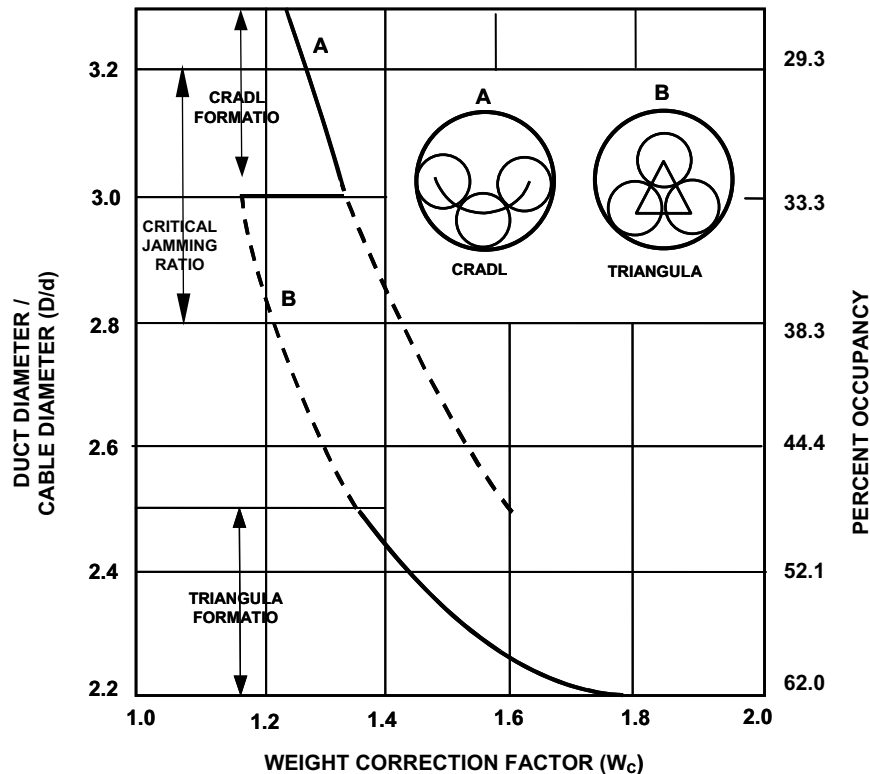
Cables with a D/d ratio between 2.5 and 3.0 may assume either arrangement. Calculations should utilize a value of W_c based on the cradled configuration.

Four cables pulled into a conduit or duct will assume the diamond configuration. W_c for this arrangement may be calculated using Equation (7c).

$$W_c = 1 + 2 \left[\frac{d}{D - d} \right]^2 \quad (7c)$$

When more than four cables are being pulled together or when multiple cables of differing sizes are being pulled together a W_c of 1.4 may be assumed.

Even though the National Electrical Code® (NEC®) (NFPA 70, 2007 Edition) allows a 40% conduit fill ratio for three cables in a single conduit, caution should be observed when approaching the fill limit as practical experience demonstrates that as the fill ratio is approached, the probability of cable jam occurring increases as well as the likelihood of cable damage during the pull.



Between the dashed portion of curve “A” (cradle) and the dashed portion of curve “B” (triangular) is an area where either formation may exist.

Figure 2—Weight correction factor and cable jam ratio for three cables
(see IEEE Std 422™-1986 [B24], Okonite Cable Installation Manual [B44])

4.8 Cable jamming

Cable jamming is the wedging of three cables in the bend of a conduit. This occurs when the center cable is forced between two outer cables causing the cables to *freeze* in the conduit/duct. Serious cable damage will occur if the pull continues.

The jam ratio is defined as the conduit/duct inside diameter divided by the cable OD and expressed by the formula shown in Equation (8). To allow for tolerances in cable and conduit sizes, and for non-circularity

or oval shape in the conduit at the bend, the D/d ratio (critical jam ratio) between 2.8 and 3.2 should be avoided (see Figure 2).

For fewer than three cables, for a single multi-conductor cable with an overall jacket, or for cables triplexed by a cable manufacturer, cable jamming is not possible. Cable jamming is not applicable to cable pulled into trays or troughs.

$$\text{Jam Ratio (JR)} = \text{Conduit ID} / \text{Cable OD} \quad \text{or} \quad \text{JR} = D/d \quad (8)$$

4.9 Maximum allowable sidewall pressure

Sidewall pressure is the radial force exerted on the insulation and sheath of a cable at a bend point when the cable is under tension. For single conductor, multiple conductor, or triplexed power and multiconductor control cables, the maximum allowable sidewall pressure ranges from 7300 N/m (500 lbf/ft) of radius to 14,600 N/m (1000 lbf/ft) of radius depending on the cable materials. For instrumentation cable the maximum allowable sidewall pressure ranges from 4380 N/m (300 lbf/ft) to 7300 N/m (500 lbf/ft) of radius depending on cable materials and construction. For armored cable the maximum allowable sidewall pressure is typically 4380 N/m (300 lbf/ft) of radius or lower. Always follow the manufacturers' recommendations regarding maximum allowable sidewall pressure because insulation and jacketing materials and cable configurations also factor into the maximum allowable sidewall pressure values.

4.10 Expected sidewall pressure

The sidewall pressure acting upon a cable at any bend may be estimated from Equation (9):

For single conductor or one cable:

$$P = \frac{T}{R_b} \quad (9a)$$

For three cables in cradle formation where center cable presses hardest:

$$P = \frac{1}{3} (3W_c - 2) \frac{T}{R_b} \quad (9b)$$

For three cables in triangular formation where pressure is divided equally between two bottom cables:

$$P = \frac{W_c \times T}{2R_b} \quad (9c)$$

where

- P = sidewall bearing pressure on the cable(s) in N/m (lbf/ft)
- T = total pulling tension in N (lbf)
- R_b = radius of bend in m (ft)
- W_c = weight correction factor

The cable manufacturers' recommendations should be followed for all cable configurations not covered by the formulas in this clause.

4.11 Cable cold temperature limits for handling and installation

Low ambient temperatures can create cable handling and pulling difficulties, which vary based on the cable construction and specific installation configuration. Generally handling or pulling cables in low ambient temperatures below -10°C (14°F) can cause damage to the cable's sheathing, jacketing, or insulation (see Okonite Cable Installation Manual [B44]). If ambient temperatures are expected to be below -10°C (14°F) in the 24 hours preceding cable handling and installation activities, the cable should be warmed to room temperature, 20°C (68°F), for at least 24 hours before work activities begin. During cold weather installations, cable lubricants shall be used that are suitable for the ambient temperatures. In addition, pulling the cable more slowly and completing the installation including cable training on the same day are necessary to assure an undamaged installation. In all cases, the cable manufacturer's recommendations on minimum ambient temperature limits during handling or installation shall be followed. For further information contact the cable manufacturer.

4.12 Cable storage, handling, and rereeling

Cable reels should be stored in an upright position on their flanges and handled in such a manner so as to prevent deterioration of and physical damage to the reel or the cable. During indoor storage, both ends of the cable should be sealed against moisture or contamination. End caps are the preferred method of sealing. In the past, tape has been used to seal cable ends, but is not the preferred method due to its limited durability and non-uniform application by users. Normally cable should be stored indoors. Reels should be blocked to prevent inadvertent damage from contact with flanges of adjacent reels. When cables are not immediately planned for installation, consideration should be given to protecting the cable by the application of wood lagging or other suitable materials across the reel flanges.

When outdoor storage is necessary, the cable shall be stored on flat, solid (properly drained) ground to prevent reels from sinking into the ground or on pallets or plywood to keep it off the ground. The cable shall be sealed with end caps to prevent moisture incursion and shall be covered with an opaque covering to minimize cable degradation due to sunlight and direct exposure to weathering elements.

Cable reels weighing less than 18 kg (40 lb), and smaller than 610 mm (24 in), that can be handled by one person alone, are often shipped and stored flat on their flange for convenience.

Poor storage or failure to seal cable ends properly may result in condensation, moisture, or water inside the cable. If this condition is detected, the cable should be dried out before use by either pulling a vacuum on the cable or purging the cable with dry nitrogen. Consult the cable manufacturer for more information on how to inspect, detect and remedy these conditions.

Often cable is rereeled at the job site to accommodate cable pulling setup space limitations or to make handling easier. Whenever cable is rereeled, care shall be taken to ensure that the minimum cable bend radius is not violated by the use of a cable reel that has a drum diameter that is smaller than twice the minimum cable bend radius for the cable construction. Consult NEMA WC 26-2008 [B36] for information about minimum allowable drum diameters.

5. Raceway cable fill recommendations

5.1 Trays

- a) The maximum allowable cable weight that can be supported within a tray should be based on the analysis of the tray support system.
- b) Cable should be installed no higher than the top of the cable tray side rails for non-covered trays; lower for covered cable trays. Exceptions exist such as at intersections and where cables enter/exit the cable tray over the side rails.
- c) Smaller size cables such as control, instrument, and fiber optic cables may be mixed in the same tray on a random fill basis when EMI/RFI issues among the cables are not a concern.
- d) Low-voltage power, control, and instrumentation cables in trays are generally installed on a random fill basis, and are not layered in neat rows and secured in place like maintained space cables. This results in cable crossings and void areas, which take up much of the tray cross-sectional area. Therefore a percentage fill limit is needed for random filled trays to a predetermined percentage of cable tray usable cross-sectional area. Generally, a 30% to 40% fill for power and control cable and 40% to 50% fill for instrumentation cable will result in a tray loading so that no cable will be installed above the top of the side rails of the cable tray except at intersections and where cables enter or exit the cable tray systems. However, NEC in Article 392 provides detailed criteria for cable tray fill. For example, trays containing 600 V multiconductor cables less than 4/0 AWG, the “sum of the cable areas/1.167 shall be less than or equal to the tray width.”
- e) Where single conductors are used in trays for two- or three-wire power circuits, these conductors should be securely bound in circuit groups to prevent excessive movements due to fault-current electromagnetic forces and to minimize inductive heating effects in tray sidewalls and bottom.
- f) When single conductor medium-voltage power cables sizes 4/0 AWG and larger are installed in trays, the conductors may be arranged single layer with cables touching, a single layer with one full cable diameter spacing (maintained space), or in a triangular configuration where the sum of the cable diameters does not exceed the tray width. NEC Article 392 provides detailed guidance for cable installation and cable ampacity.
- g) The percent fill of a tray is the sum of the cable areas divided by the useable tray cross-sectional area times 100%. For example: $\% \text{ fill} = \sum \text{cable area} \div \text{cross-sectional area} \times 100\%$.

5.2 Conduits, wire ways and ducts

- a) NEC Chapter 9 Table 1 shows conduit cross-sectional fill limits of 53%, 31%, and 40% for one, two, and three or more cables respectively. Even though these fill limits are widely accepted and have been used for years, exceptions exist for instances where the path is short, straight, or where the cable can be pushed through by hand. These fill limits are applicable for power, control, and instrument cable, and have been used for both conduits and ducts.
- b) For wire ways, the sum of the cross-sectional areas of all conductors/cables in the wire way should not be greater than 20% of the interior cross-sectional area of the wire way per NEC Article 376.22(A), Section 620.32.
- c) The percent fill of a conduit or duct is the sum of the cable areas divided by the useable conduit or duct area times 100%. For example: $\% \text{ fill} = \sum \text{cable area} \div \text{internal conduit area} \times 100\%$.

5.3 Troughs, gutters, and sleeves

Since these raceway types are normally straight, short (i.e., less than 0.6 m [2 ft]) in length and cables are either placed into them or pushed through them, there is no maximum established fill limit in general use.

6. Cable installation recommendations

6.1 General

6.1.1 Pre-installation considerations

- a) Avoid routing cables near lube oil reservoirs, lube oil conditioners, hydraulic oil storage areas, etc., since potential leakage of petroleum products can affect jacket, shield, and insulation material.
- b) Avoid routing cables near hot pipes (even insulated pipes) as the heat from pipes can cause accelerated aging to localized cable areas, which can lead to long-term failure points.
- c) Avoid routing cables in areas subject to damage due to future maintenance activities. If it is required to run cables through these areas, proper protection and shielding shall be provided.
- d) Raceways or cable trays containing electric conductors shall *not* contain any pipe, tube, or equal for steam, water, air, gas, drainage, or any service other than electrical, see NEC Article 300.8
- e) Cables should only be installed in a raceway system that has adequately sized bends, boxes, fittings, and pull points so that the manufacturer's minimum allowable bending radius and sidewall pressure limits are not exceeded.
- f) Suitable pull points (pull boxes, termination boxes, manholes, hand-holes, etc.) shall be installed to avoid over-tensioning the cables during the pull. Whenever there is more than 360° of bend in the conduit/duct run, a cable pulling calculation should be performed to ensure that the cable(s) is not over stressed.
- g) When installing cables in ferrous-metallic conduits or ducts, all phases of a three-phase ac circuit and both legs of a single-phase ac circuit shall be installed in the same conduit, duct, or sleeve to minimize inductive heating.
- h) When installing dc circuit cables between the battery and main switchboard, each leg of the dc circuit should be installed in separate non-magnetic conduits to minimize the possibility of a positive to negative cable short circuit, which could drain the battery.
- i) In outdoor areas, cables normally enter equipment from the bottom. Where cables enter outdoor electrical equipment enclosures from the top, the system should be designed to prevent water from entering the equipment.
- j) Cables in horizontal trays exposed to falling objects should be protected with tray covers. Where covers are used on trays containing power cables, consideration should be given to cable de-rating, ventilation requirements, or both.
- k) When installing new cable in trays with existing cable, the existing cables need to be protected.
- l) Caution shall be used when pulling or terminating cables near energized cable or equipment because of a possibility of a ground potential rise. For additional information and appropriate safety precautions see IEEE Std 80™-2000 [B19], IEEE Std 487™-2007 [B25], and IEEE Std 1590™-2009 [B34].
- m) Cables should not be pulled into conduits, ducts, handholes, manholes, trenches, vaults, or any other raceway that contains standing water. Standing water may be indicative of a defect or fault in

the raceway system. Efforts should be made to remove the water before cable pulling commences. If water removal is not possible because of raceway configuration, consideration should be given to selecting cables suitable for continuous immersion in water.

- n) As noted in 4.12, cable ends should be sealed during cable storage, handling, movement, and at all times prior to pulling. If testing is performed prior to cable pulling, the cable should be resealed until pulling operations begin. Once pulling is complete, the cable should be resealed until it is terminated.

6.1.2 Set-up considerations

- a) Use quality, sturdy stands and spindles to support reels. The use of jack-stands fabricated at the job site in lieu of manufactured stands is not recommended. For more information, see National Electrical Safety Code[®] (NESC[®]) (Accredited Standards Committee C2-2007) [B1].
- b) Set stands up correctly, on a level surface and in line with the pull.
- c) Consider the use of a cable-feeding machine to control the pull and bundle the cable for “gang” pulls requiring multiple reels. This minimizes the number of people required.
- d) Select the proper rope type and size for the job (see 9.2).
- e) Select pulleys, ropes, sheaves, wheels, swivels, etc., that have the same or similar capacity and match them to the capacity of the puller, not the weight of the cable being pulled. Remember the anchoring/mounting point(s) as well, as these points shall be rated for at least the same as the cable puller. Always anchor to a secure wall and not to conduit or tray or their supports.
- f) Select proper grip basket or pulling eye type for the pull being performed.
- g) In order to prevent injury to workers, select tuggers, pullers, winches, and other cable pulling equipment with the latest safety devices and that are rated for the job.

6.1.3 Installation considerations

- a) Cables should be pulled in the direction that minimizes sidewall pressures and pulling tensions.
- b) Cables should only be pulled into clean raceways. Any abrasive or sharp edges, which might damage the cable, should be removed. A mandrel should be pulled through all underground ducts and long conduit runs (e.g., over 15 m [50 ft]) prior to cable pulling. Trenches and manholes should be cleaned, as necessary, prior to pulling cables to remove any sharp edges and debris that could damage the cable during a pull.
- c) Cable should be protected and guided from the cable reel into the raceway by a suitable means, such as a flexible feeder tube or cable protector. The radius of the feeder tube or cable protector should not be less than the minimum bend radius of the cable.
- d) Temporary bracing may be required during pulling to prevent damage to cable trays or conduit, especially when using pulling winches or tuggers.
- e) Pulling winches, tuggers, pull ropes, and other support equipment necessary for a cable pull should be of adequate capacity to ensure a steady continuous pull on the cable.
- f) A swivel should be attached between the pulling eye and the pulling rope. All sharp points of the hardware that attach the cable to the eye, such as bolts and cable clamps, should be thoroughly taped to prevent such projections from catching at conduit ends, joints or bends.
- g) Cables shall not be pulled around sharp corners or obstructions without the use of single-roller or multi-roller sheaves.
- h) Conduit Prelubrication is recommended and should be done in accordance with the pulling lubricant manufacturer’s instructions. Excessive residue from cable pulling lubricants should be

wiped from exposed cables as they are pulled out of a conduit. If not removed, the excessive lubricant tends to drip on the floor and become a “slip and fall” hazard.

- i) The pull should be made smoothly. Stops should be avoided. Adjust the pulling speed to eliminate surging.
- j) Bare wire rope should not be used to pull cable in conduits, ducts, trays, etc. Bare wire rope used for pulling ropes has been known to damage cable, conduit, ducts, or tray during the pulls.
- k) A tension measuring device should be used whenever pulling calculations indicate that the allowable pulling tension or sidewall pressure limits may be approached.
- l) Special care should be exercised during welding, soldering, and splicing operations to prevent damage to adjacent or nearby cables.

6.1.4 Post-installation considerations

- a) Cables run vertically in trays or conduits shall be adequately supported throughout the vertical run to prevent excessive force on the cable at the top of the run, and slippage of the cable to the bottom of the run. Methods of conduit support and maximum spacing for supports are listed in NEC Section 300.19, Table 300.19(A). Support recommendations for special cables such as armor, fiber optic and coaxial cable should be obtained from the manufacturer. In vertical trays, securing the cable to the tray rungs every 0.6 m to 1.5 m (2 ft to 5 ft) will normally provide adequate support for most cable types. When split blocks are used, they should be spaced 1.8 m to 2.4 m (6 ft to 8 ft) apart. Refer to Clause 17 for more details on vertical cable support.
- b) Sufficient cable slack should be left in each manhole so that the cable can be trained to its final location on racks, hangers, or trays along the sides of the manhole. This slack will need to be temporarily supported until the cable is trained and secured into its final position.
- c) After the cable pull is complete and before cable termination, the cable under the basket grip and 0.9 m (3 ft) behind the pulling eye shall be cutoff and discarded. A greater amount may need to be discarded if inspection of the cable exterior reveals jacket damage that occurred during the pull.
- d) After cable has been installed, cable ends should be resealed until splicing or terminating operations have begun.
- e) Once the cable pull is complete, the manufacturer’s recommendations should be followed for the minimum trained bend radius for both the cable and the individual conductors.
- f) Both ends of each cable should be adequately marked to assure proper identification.

6.2 Reel back-tension

Reel back-tension is the amount of force required to pull the cable off of the reel. The tension required to pull cable from a reel will depend on the cable size, the weight of the first lap of the cable on the reel, the stiffness of the cable, and the type and condition of the reel payoff stand used. For purposes of this recommended practice, the tension force can be approximated for pulling a cable off of the reel in a horizontal position as shown in Equation (10) (see IEEE Committee Report [B17]):

$$T_r \approx K_o \times W \times L \times g \quad (10a) \text{ metric}$$

where

- T_r = tension from cable reel, N
- W = mass per unit length of cable, kg/m
- L = length of cable, m
- g = gravitational constant (9.8 m/s²)
- K_o = basic coefficient of friction (typical value between 0.5 to 1.0; see IEEE Std 525™-2007 [B26])

$$T_r \approx K_o \times W \times L \quad (10b) \text{ English}$$

where

- T_r = tension from cable reel, lbf
- W = weight per unit length of cable, lbf/ft
- L = length of cable, ft
- K_o = basic coefficient of friction (typical value between 0.5 to 1.0; IEEE Std 525-2007 [B26])

To assure proper force for pulling cable off of the reel, a reel drive device such as power reel rollers or motorized payoff stands or adequate manpower should be used. Freewheeling the cable or cable reel during the pull and long vertical distances between the payoff reel and the entrance point of the cable system should be avoided. A payoff system equipped with braking ability will be the most effective in controlling cable back-tension. Tension caused by removal of the cable from a reel or simply the dead weight of the cable traversing a long vertical rise to the entrance point of the system will be magnified as the cable passes through bends in the system. This will shorten the ultimate length of cable that can be pulled without exceeding the cable maximum physical limits. For light gauge or fragile cable, (i.e., LAN/Category or fiber optic cable) practically zero back-tension may be necessary to prevent damaging the cable. To better control tension one person is used to un-reel the cable while another person feeds it into the first raceway component. Payoff reel back-tension should be considered when calculating the total tension developed during the installation.

6.3 Payoff reel orientation

Positioning of the payoff reel can also be critical. The closer the payoff is to the raceway elevation, as well as the more in line it is, the less tension due to cable weight and direction change will be added to the overall tension of the pull. To reduce cable payoff reel tension, follow the natural curvature of the cable on the reel and feed the cable into the raceway in as straight and level manner as possible, as shown in Figure 3.

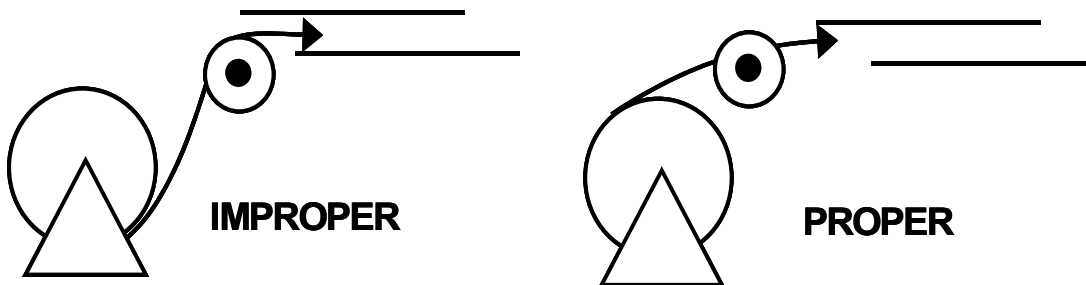


Figure 3—Payoff reel positioning

6.4 Roller spacing and mounting for cable tray installation

Spacing of the rollers should be adequate to prevent the moving cable from touching or rubbing against the cable tray. The rollers should be placed to keep the cable in a fairly level position. The tension is significantly greater as the cable approaches the end of the pull allowing for more distance between rollers. Field experience shows that normally rollers should be spaced between 3 m to 5 m (10 ft to 15 ft) apart. The objective is to reduce drag and tension. Equation (11) can be used to calculate the approximate roller spacing intervals: