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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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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[B24] and IEEE Std 690™-1984.[a] Since IEEE Std 422-1986 has not been updated since its original issue and is now withdrawn, and since IEEE Std 690-2004 [B30] has removed the cable installation information, which were in the Appendices to IEEE Std 690-1984, this revision to IEEE Std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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Steven N. Graham, *Vice Chair*

J. Richard Barker
Michael G. Bayer
Peter M. Blackford
William G. Bloethe
Kenneth E. Bow
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Stephen J. Sandberg
Gary Savage
Dhiren Savdharia
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
Kenneth E. Bow
Steven Brockschink
Kent W. Brown
Vern Buchholz
William Byrd
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Weijen Chen
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David Zaprazny
Theodore Zeiss
Dawn Zhao

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

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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 the application of rounding principles, the mathematical conversion from English to metric and vice verse 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 where as 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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[1] The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org).

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[4] *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at http://shop.ieee.org/.

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 *sidewall pressure*
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:

a) 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.

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

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)

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

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):

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

where

α = the angle of the inclined section of conduit from horizontal
g = gravitational constant (9.8 m/s^2)

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.

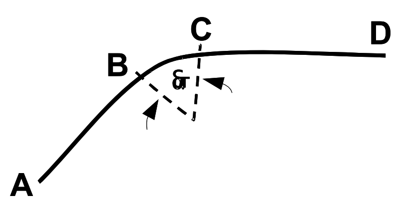


Figure 1—Expected pulling tension around horizontal bend for conduit or duct runs containing horizontal bends

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):

$$K' = W_c \times K_o \tag{5}$$

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

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

$T = n \times K' \times L \times W$ for straight pulls (6b) 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):

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

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).

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

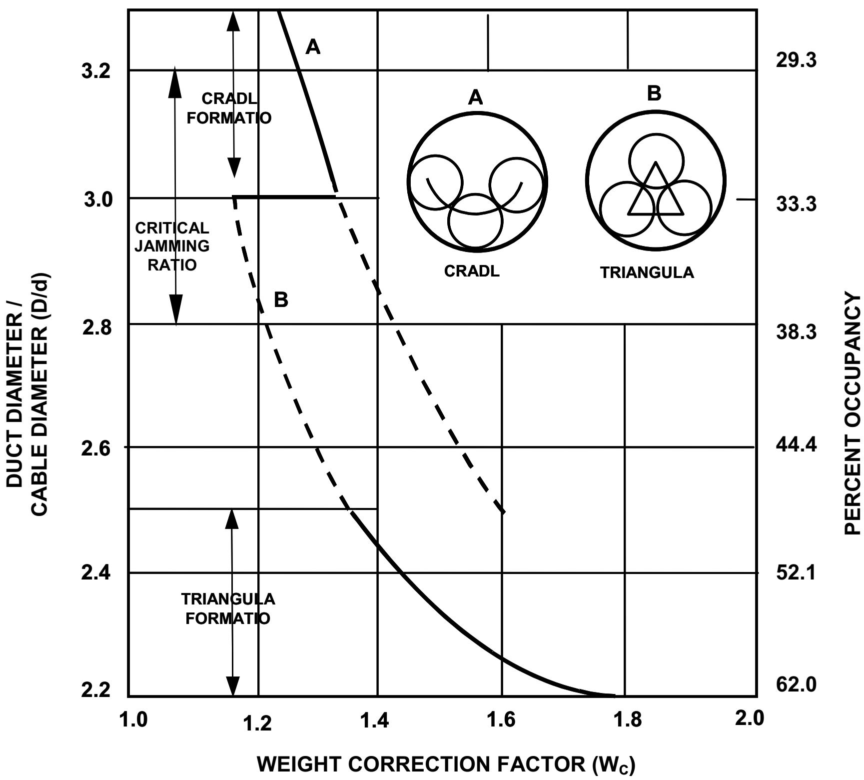
Cables with a D/d ratio between 2.5 and 3.0 may assume either arrangement. Calculations should utilize a value of W_c based on the cradled configuration.

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

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

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.

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

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:

$$P = \frac{T}{R_b} \tag{9a}$$

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

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

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

$$P = \frac{W_c \times T}{2R_b} \tag{9c}$$

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 handing 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: % fill = ∑ cable area ÷ cross-sectional area × 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: % fill = ∑ cable area ÷ internal conduit area × 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 360º 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]):

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

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/s^2)
K_o = basic coefficient of friction (typical value between 0.5 to 1.0; see IEEE Std 525™-2007 [B26])

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

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.

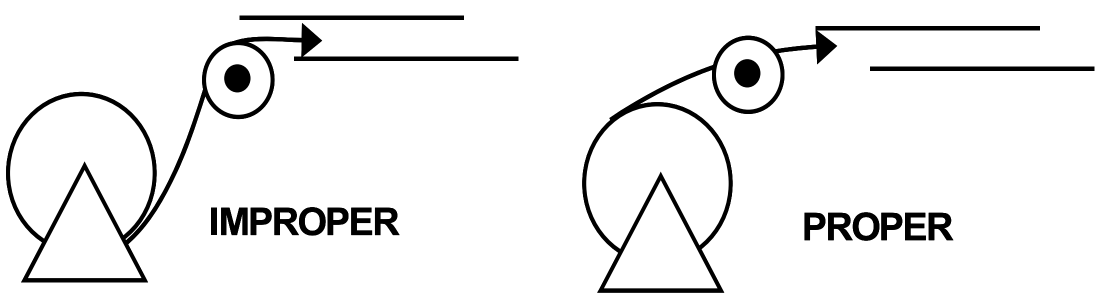


Figure 3—Payoff reel positioning

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:

$$S = \sqrt{\frac{8 \times H \times T}{W \times g}} \qquad \text{(11a) metric}$$

where

S = distance between rollers, m
H = height of top of rollers above tray surface, m
T = tension, N
W = mass per unit length of cable, kg/m
g = gravitational constant (9.8 m/s^2)

$$S = \sqrt{\frac{8 \times H \times T}{W}} \qquad \text{(11b) English}$$

where

S = distance between rollers, ft
H = height of top of rollers above tray surface, ft
T = tension, lbf
W = weight per unit length of cable, lbf/ft

Use of this equation requires an estimate of tensions along the cable tray route. Field experience has shown that it is not practical to use many different roller spacings in the same pull. The installer should have as many rollers as necessary in place to prevent excess sag and drag. Often an installation requires that the sheave/roller apparatus be attached and suspended. The support structure shall have adequate mechanical strength to handle the tensions applied to the cable when making the pull. Cable tray systems are not usually designed to be the support structure for sheaves or rollers. See Figure 4.

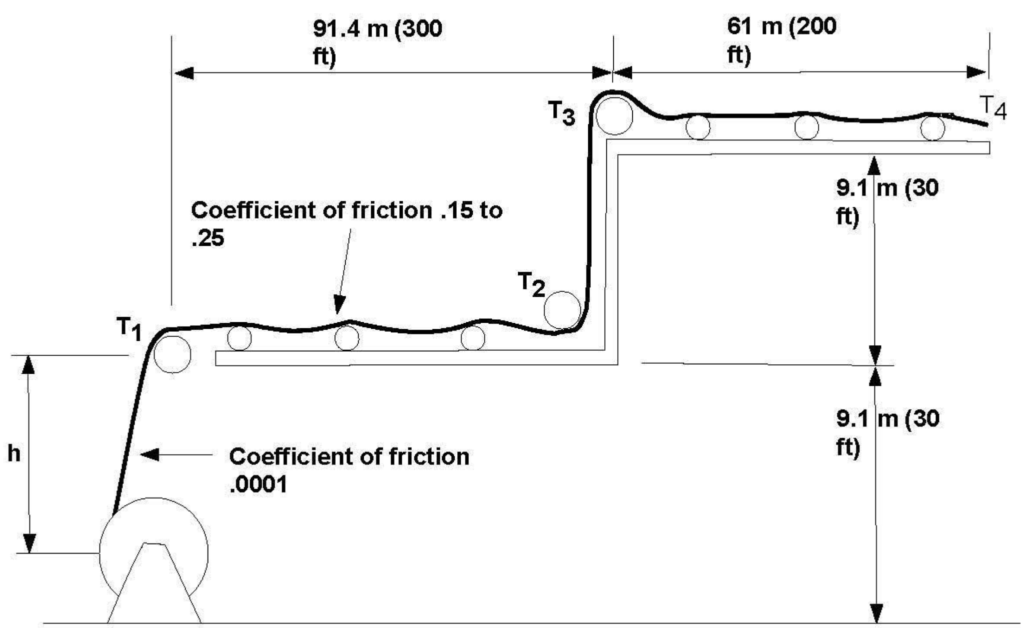


Figure 4—Example of cable tray with cable supported by rollers during pull

6.5 Sheave arrangement

Damage may occur to cable while being installed in tray or into a conduit if the maximum sidewall pressures are exceeded. Sidewall pressure, force per unit length of radius, is exerted on a cable when it is pulled around a sheave. Where change in the direction of the cable pull is made, conveyor sheaves can be employed. Conveyor sheaves are multi-sheave devices bound together by a rigid metal frame to form an arc of various degrees. Due to the small diameter of individual sheaves, it is recommended that each conveyor sheave have a minimum of one sheave for every 20º of bend as shown in Figure 5.

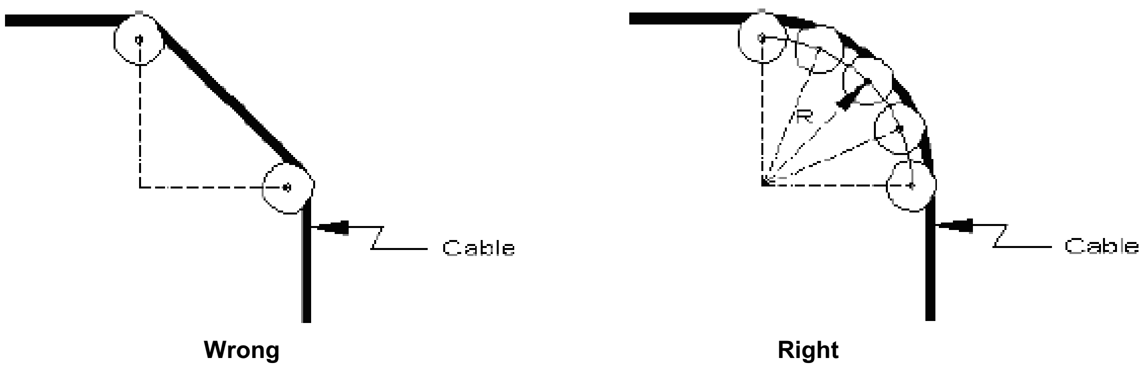


Figure 5—Conveyor sheave arrangement

The conveyor sheaves shall be properly sized with radii sufficiently large to satisfy the maximum allowable sidewall pressure limits and minimum bending radii requirements. Alignment of the conveyor sheaves to accept the cable should be made prior to the actual pull, by applying tension to the pulling rope and aligning the rope in the center of the sheaves. Slight adjustments during the pull may be required. The sheaves and the individual sheaves of conveyor sheaves should be free turning and well lubricated.

Since the sheaves are assumed to be frictionless, the tension out of the sheave is considered to be the same as the tension into the sheave. However, the cable generates a moment of force in its effort to conform to the shape of the sheaves. From practical experience, this force or tension is typically between 445 N to 667 N (100 lbf to 150 lbf) for single conductor copper cables 500 kcmil or larger or for single conductor aluminum cables 750 kcmil or larger. This force should be added to the total tension calculations. By using Equation (9a), the calculation of the SWBP coming out of a sheave can be determined as shown in Equation (12).

$$P = T/R_s \tag{12}$$

where

P = sidewall bearing pressure, N/m (lbf/ft)
T = tension out of sheave, N (lbf)
R_s = radius of sheave, m (ft)

By placing a sheet of plywood or some other rigid, flat-surfaced material over the tray at a bend, the sheave can be placed on top of the plywood and over the existing cable. This flat-surfaced material not only protects the existing cable but provides support to the sheave. In addition to lubricating the bearings on rollers and sheaves, the cable itself can be lubricated by swabbing the surface as it comes off the reel. Ensure the lubricants are compatible with the cable jacket. Any rollers or sheaves with sharp edges or protrusions should be repaired or replaced prior to beginning the pull.

6.6 Assist pulls in cable trays

Maximum pulling tension or sidewall pressure limits can often limit the length that a cable can be pulled. When using conventional pulling techniques (i.e., one cable puller), these types of pulls often require splices or the use of a technique of pulling in two directions by back feeding a significant portion of the cable.

To install a long length of cable without splices or back feeding, an assist puller (also called *cable pusher* or *cable feeder*) can be used. This method is accomplished by using another tugger and pull line in a straight tray section of the pull. The straight section usually needs to be at least 15 m to 30 m (50 ft to 100 ft) in length.

The pulling line is attached to the cable by using a mare's tail. The mare's tail should cover at least 0.6 m to 1 m (2 ft to 3 ft) of the cable surface. Friction tape should be applied over the cable beneath the mare's tail to provide a better gripping surface. The friction tape also acts as a bedding layer. The maximum pulling tension allowed on the mare's tail is a function of the cable design. To obtain the MAPT, the cable manufacturer should be contacted.

The mare's tail is attached to a pulling rope that runs the length of the straight tray section to the assist puller. As the assist cable puller begins to pull, slack is produced just ahead of the assist puller. When slack cable is sufficient, the lead (main) puller is then started to pull the slack cable to its position. Coordination is essential to keep just enough slack in front of the assist puller. Too much slack could cause over bending or damage to the cable.

When the mare's tail approaches the assist puller, the pull is stopped, the mare's tail grip is removed, the assist pulling rope restrung in the straight section of the tray, the mare's tail is reinstalled to the cable and another length of cable can be pulled. This process is repeated until the lead end of the cable reaches the lead puller.

The assist pull is used to pull slack to that point of the pull. By pulling slack, the pulling tension and sidewall pressure from that point on are greatly reduced. The lead or main puller will have a lesser load to pull, thereby reducing pulling tensions and sidewall pressures. Good two-way communications at each puller location is essential so that each portion of the pull is coordinated.

7. Conduit-cable pulling charts

7.1 General

The majority of cable pulls in conduit systems are manual pulls. Monitoring pull tensions for manual pulls is time consuming, difficult and unreliable. The traditional guidance given to pulling crews is to limit the pull to no more than three or four 90° conduit bends between pull points. Experience has shown that excessive cable tensions may occur unless limits are also established for the conduit length.

Another approach is to use conduit-cable pulling charts in conjunction with proper cable installation methods. The use of these charts eliminates the need on many cable pulls to explicitly monitor pull tension or to provide a written record for comparing allowable and actual measured pulling tensions. The conduit-cable pulling charts address the cable pulling limits and when followed allow for a satisfactory cable installation. This includes allowable conductor strength, SWBP, and jacket strength limits. Cable jamming is not addressed in the pulling charts and should be checked separately as discussed in 4.8.

The conduit-cable pulling charts may also be used as guides when establishing the maximum distance between pull points during the layout of the conduit systems. This ensures that an appropriate number of pull points are installed. Conduit pulling charts should not be used when pulling cables with mixed sizes into a conduit such as often done in gang pulls of low-voltage power, control, and instrument cable.

7.2 Cable types and raceway configurations

The maximum "effective" conduit length shown in the conduit-cable pulling charts depends on conduit size and cable type. The conduit-cable pulling charts in Annex A, Table A.1 through Table A.12, are based on the following conditions:

a) The radius of conduit bends is assumed to be equal to or greater than those specified in the NEC, Chapter 9 Table 2 Exception "Radius of Conduit Bends."

b) The cable constructions are assumed to conform to ICEA/NEMA cable standards shown in Annex F (AEIC CG5-05 [B3], *Guidelines for Installation of Cable in Cable Trays* [B14], ICEA/ANSI S-94-649-2004 [B15], NEMA/ANSI WC 57-2004 [B37], NEMA/ANSI WC 58-2008 [B38], NEMA/ANSI WC 70-2009 [B39], NEMA/ANSI WC 71-1999 [B40], NEMA/ANSI WC 74-2006 [B41], and UL-4-2004 [B48]) as applicable.

   Smallest conductor sizes for the various cable types are: two pair 18 AWG for instrument cable, single conductor 14 AWG for control cable, and single conductor 12 AWG for low-voltage power cable. Conductor material is copper. The cable's outer jacket is a polymeric (non-metallic) covering and is not armored or lead-sheathed. Cable pulling calculations are necessary for armored or lead sheathed cables.

c) The cable SWBP limits vary with cable construction and cable supplier. Charts for two different SWBP limits were developed for each class of cable (power, control and instrumentation). In the absence of specific cable manufacturer SWBP data, charts for control and power cable using SWBP = 7300 N/m (500 lbf/ft) of bend radius and instrument cable using SWBP = 4400 N/m (300 lbf/ft) of bend radius should be used.

d) Conduit-cable fill does not exceed the NEC (Chapter 9, Table 1) fill limits of 53% for one cable, 31% for two cables, or 40% for three or more cables.

e) The ratio of conduit diameter (D) and cable diameter (d), for a pull of three cables of equal size, does not fall into the critical cable jamming ratio (D/d) between 2.8 and 3.2 (see 4.8).

f) The proper cable lubrication techniques as discussed in Clause 10 are followed. Charts for two values of effective coefficient of friction (K') were developed (0.3 and 0.5). The effective coefficient of friction is the coefficient of friction multiplied by the weight correction factor. The coefficient of friction varies with cable jacket material, conduit material, and length of conduit. In the absence of test data, charts based on $K' = 0.5$ should be used. Technical papers (AEIC CS8-07 [B4], IEEE Committee Report [B17], and Kommers [B35]) should be used to obtain the coefficient of friction and the weight correction factor.

g) The pull charts shown in Annex A do not apply to pullbys and pullbacks.

h) The lead cable puller stops the pull if abrupt and unexpected change in pulling resistance is encountered.

7.3 Use of conduit-cable pulling charts

The maximum effective conduit length given in the conduit-cable pulling charts presented in Annex A, Table A.1 through Table A.12, should be used as a limitation in cable pulling. If the conditions of the pull are not consistent with the assumptions described in 7.2, or the actual conduit length exceeds the maximum effective conduit length shown in the charts, specific analysis or monitoring of the cable pulling tensions should be made using the pulling tension equations given in 4.5 and 4.6. If control and power cables are pulled together in the same conduit, the pulling charts for power cable should be used.

In order to use the charts, the distance between pull points has to be measured. If some of the conduit sections are not horizontal, an effective conduit length needs to be developed. The effective conduit length and the total degrees of bend in the pull are compared to the charts. The effective conduit length is developed as shown in Table 3.

Field measurements in congested areas can be difficult. Some latitude in the accuracy of the measurement of the conduit length and total degrees of bend is permitted. Conduit length measurements and total conduit angle measurements should be made or conservative estimates should be used. The slope adjustment factor (SAF) can be taken from either Equation (13) or from Table 4 for specific combinations of effective coefficient of friction and slope angles. SAF, for use in Table 3, adjusts the measured length of sloped sections of conduits to arrive at an effective conduit length. Equation (13) is derived from Equation (3a) and Equation (3b).

$$\mathrm{SAF} = \frac{\sin\theta + K'\cos\theta}{K'} \qquad (13)$$

where

SAF = the slope adjustment factor, used in Table 4
θ = the angle (in degrees) of the slope from horizontal
K' = the effective coefficient of friction

Table 3—Development of effective conduit length—chart comparison

Type of conduit section	Effective conduit length
Horizontal conduit	As measured
Conduit sweep	Need not be included
Vertical conduit—Up	As measured multiplied by: 2 for K' = 0.5 and 3.3 for K' = 0.3
Vertical conduit—Down	Not included; L = 0
Slope—Down	As measured
Slope—Up	As measured multiplied by SAF from Equation (13) or Table 4

Table 4—Slope adjustment factor

Slope angle (°)	Effective coefficient of friction (K')	
	0.5	0.3
15	1.5	1.8
30	1.9	2.5
45	2.1	3.1
60	2.2	3.4
90	2.0	3.3

7.4 Bend correction adjustment

The conduit-cable pulling charts are based on the conduit bends being located at the end of the cable pull. This results in conservative values. If the conduit bends are distributed throughout the conduit run, as is typical, then the user needs to consider one of the following:

a) Performing a detailed cable pulling calculation using the pulling equations. Many computer software programs are available to perform this calculation. This is the recommended approach.

b) Applying bend correction (BendCorr) adjustment factors to the maximum effective conduit length shown in the charts. These adjustment factors are discussed in Annex D.

Examples illustrating the use of the conduit-cable pulling charts are included in Annex B.

7.5 Methodology

The conduit-cable pulling charts are influenced by cable construction, allowable cable fill inside conduits, coefficient of friction, location and number of conduit bends, radius of conduit elbows, and SWBP. If project-specific information is available, it may be desirable to develop new charts. The methodology used to develop the conduit-cable pulling charts is presented in Annex C.

7.6 Pulling tension

MAPTs have been provided in the conduit-cable charts to aid in selecting rope size, pulling machine capacity, pull rope attachment method, and number of workers for manual pulls. In most cases actual tension will be significantly less than the maximum values in the charts. This is due to the conservative basis used in developing the maximum effective conduit lengths. Using MAPT from the charts, Equation (14) can be used to arrive at a projected pulling tension (PPT). The BendCorr factor in Equation (14) can be obtained from Annex D, Table D.1 and Table D.2, or conservatively assumed to be equal to 1.

$$\text{PPT} = \text{MAPT} \times \frac{L'}{L} \times \frac{Fill'}{Fill} \times \text{BendCorr} \qquad (14)$$

where

PPT = the projected pulling tension, N (lbf)
MAPT = the maximum allowable pulling tension, N (lbf) (Annex A, Table A.1 through Table A.12)
L' = the effective conduit length, m (ft)
L = the maximum length of conduit, m (ft) (from Annex A, Table A.1 through Table A.12)
BendCorr = the distribution of conduit bends. This varies from 0.25 to 1; decreasing as the conduit bend is located nearer to the front of the pull (see Annex D, Table D.1 and Table D.2)
$Fill'$ = the percentage of cable fill of conduit after the cable pull
$Fill$ = the chart maximum conduit-cable fill, which is 40%

The use of 40% is conservative and envelopes the case when only one or two cables are pulled into a conduit. The calculations were checked and determined to be based on the maximum NEC fill requirements of 53% for one cable, 31% for two cables, and 40% for three or more cables depending on whichever case provided the maximum fill for the conduit size being considered.

8. Cable pulling attachment methods

8.1 General

There are several types of pulling attachments commonly referred to as *pulling eyes* or *pulling grips*, which are available for connection to the cable. Upon request, most cable manufacturers will supply pulling eyes on the ends of large power cable. Basket-type pulling grips, compression-type pulling eyes, wedge-type pulling eyes, mare’s tails, and other types of accessories are described as follows.

8.2 Woven mesh pulling grips

Woven mesh pulling grips also referred to as *socks*, *basket grips*, etc., are held to the cable by friction and the pulling tension of the pull. For correct application, the grips are selected based on the cable's outer diameter, installed by compressing the grip enough to insert the cable, releasing the compression onto the surface of the cable, and then securely banding or taping down the trailing end. Remove grips by releasing the bands or tape and again compressing the grip enough to slide it off the cable. A backup or push-pull action during the pull should be avoided, because unless securely banded and taped, the grip could loosen enough to pull off. When pulling a large number of cables through conduit or duct with a basket grip, it may be necessary to apply friction tape between the layers of cables particularly when cables in the bundle center are not in contact with the grip. Application of friction tape between the cable and the grip will reduce the potential of the basket indenting the cable jacket or insulation. The cable under the basket should be cut off and discarded after the pull.

8.3 Compression-type pulling eyes

Compression-type pulling eyes are supplied with an eye-bolt or a threaded stud for single or multi-conductor power cables. The eyes or studs and wall thickness of the aluminum barrel are sized to withstand tensions in excess of the appropriate manufacturer's recommended maximum pulling tensions. The cable end of the pulling eye is factory drilled to accommodate the particular combination of cables to be pulled. Install the cable by stripping it down to the bare conductors, inserting it into the barrel (or barrels if multi-conductor), and crimping it with manufacturer recommended crimping tool.

8.4 Wedge-type pulling eyes

Wedge-type pulling eyes are used for high-tension pulling applications of power cables. The advantages of the wedge-type pulling eyes are reduced field hardware requirements and reusability of the devices. The stripped power cable is pushed through a reusable steel trailing fitting and an aluminum wedge is inserted between the strand layers. When the wedge and cable are fully tapped into the trailing fitting, the wedge effect yields mechanical integrity equivalent to the compression-type or lead-wiped pulling eyes.

8.5 Mare's tails

Mare's tails grip cables over a 1.5 m to 6.1 m (5 ft to 20 ft) section of jacket. Mare's tails are often used to luff or slack-pull extra length of cable into a manhole or pull box for splicing. Ordinary rope, with half-hitches or flat nylon slings, is sometimes used for the same purpose. Aramid rope eyes with four flat long straps are also available. The straps are installed around the cable to form a basket. The flat straps do not stretch or dig into the cable as rope does. With proper application of mare's tails, pulling tensions up to the limits of the cable can be applied without causing damage to the cable underneath the mare's tail.

8.6 Swivels

Swivels are sometimes used between the pull rope and the grip devices to prevent cables from twisting during the pull. Swivels are recommended for use in high-tension pulling applications. Two common types of swivels are the space swivel and the ball-bearing swivel. Swivels should be selected that will swivel under the anticipated load conditions. Swivels that do not swivel under high load conditions should never be used.

Care should be exercised to avoid rapid changes in tension because swivels have been known to fail in an explosive like manner under extreme conditions of rapid tension changes. This can occur even with ball-bearing swivels.

9. Pull rope and tape selection

9.1 General

A variety of constructions and materials are available for use in pulling cables through conduits and trays. Common materials include natural and synthetic fibers and steel tapes. Rope/tape performance is also considerably influenced by its construction. See A-D Technologies Bull-Line Pull Tape Guide [B2] for more information on tape bull lines.

a) Natural fibers: Inexpensive rope made from natural vegetable fibers including manila, sisal, and cotton. Its main disadvantage is that it is subject to rot and mildew in wet or damp environments.

b) Polyester: Strong, synthetic rope/tape with excellent abrasion resistance; lower stretch, and elasticity; and higher loading characteristics than nylon ropes/tapes. Available in many specially designed finishes (including prelubricated woven polyester tapes) for improving handling and longer life.

c) Aramid: These ropes/tapes have been engineered for applications where low weight, high strength, good abrasion resistance and excellent bending capability are important to a successful pull.

d) Nylon: First synthetic fiber rope/tape to be made and still a popular choice due to its low cost. It has a high elasticity modulus, which allows a nylon rope to absorb sudden shock loads that would break other rope types. It has good resistance to abrasion and typically lasts five times longer than natural fiber ropes. It is rot-proof, and not damaged by oils, gasoline, grease, marine growth, and most non-acid chemicals.

e) Polypropylene: A lightweight, strong rope/tape and used most of any ropes/tapes. It is rot-proof and unaffected by water, oils, gasoline, and most chemicals. It is available in monofilament (smooth surface) fibers or multifilament (velvety appearance and touch) fibers. Newer polypropylene ropes/tapes are available with greater strengths and higher abrasion resistance characteristics.

f) Steel: 3.2 mm (1/8 in) and 6.4 mm (1/4 in) tape width steel tapes have maximum design strength of 1700 N (400 lbf).

9.2 Guidelines for pull rope and tape selection

Pull rope constructions include single and multi-stranded, plaited, single-braid, double braid and parallel core. Selection of a pulling rope should be based on required pulling tension, lubricant compatibility, rope size, rope flexibility, and rope abrasion characteristics and the degree of expected rope stretch under tension. When selecting a pull rope, consideration should also be given to conduit material, expected cable pulling tension, and the application, as well as the cost. The best choice is one with high tensile strength and low stretch characteristics, such as a double-braided composite rope. Choose a rope that has the capacity to handle four times the capacity of the puller being used. Table 5 and Table 6 summarize the different rope characteristics that should be considered for rope selection.

Use of steel tapes or ropes should be avoided for plastic conduit. Testing has shown that steel pull ropes can wear grooves in plastic conduit elbows. The cables being pulled may then be damaged by these grooves. It is recommended that *rigid metal conduit* (steel) or FRPE (fiberglass) elbows be used to prevent this.

Synthetic ropes are used on long pulls with a capstan on a winch truck or self-powered winches. They are also used for manual pulling of short runs, for removing old cable, and for pullbys into conduit.

Pull ropes are rated in terms of maximum and minimum breaking strength, working load, percentage of elongation versus load, and stored energy. The ratio of maximum breaking strength to working load ranges from 4:1 to 7:1 with rope material and construction.

The rope working load rating should not be exceeded. However, transient tensions 10% above the working load rating are generally permitted. In order to provide a margin of safety and account for rope aging, the working load rating of the rope should be 1.5 times the projected cable pulling tension.

9.3 Precautions

Pull ropes should be checked prior to each pull for signs of aging or wear, including frayed strands and broken yarns. A heavily used rope will often become compacted or hard, indicating reduced strength. If there is any question regarding the rope's condition, it should not be used. Visual inspection cannot accurately and precisely determine residual rope strength.

Rope should be stored in a clean dry place, out of direct sunlight, and away from extreme heat. Some synthetic ropes, particularly polypropylene and aramid fiber ropes, may weaken by prolonged exposure to ultraviolet (UV) rays.

Improper pull rope selections can damage the conduits or cause galloping to occur during the pull. In high-tension pulls, stretching the pull rope may occur and the cables themselves may stop moving. To start the cable moving again the pulling tension increases dramatically and the cable tends to jump forward in the process. This is called *galloping* and is to be avoided as it generates unexpectedly high tension. Ropes with low elasticity at the expected high tensions should be used.

Table 5—Pull rope/tape characteristics

Rope characteristic	Importance to pull rope applications
Working load rating	Pulling tension should not exceed the rope's/tape's working load rating.
Abrasion characteristic	In a pullby or when pulling cable through plastic conduit, the pull rope/tape should not abrade the existing cables or conduit.
Suitability in wet area	Pulls through underground ducts are generally considered wet. Hemp (natural fiber, cotton, sisal, manila) rope/tape will rot if not properly dried out after the pull.
Compatibility with lubricants	Some lubricants can degrade the life of the pull rope/tape.
Energy absorption capability	If a rope/tape breaks during the pull, ropes/tapes with higher energy absorption capability present a greater personnel hazard.
Sunlight resistance	During pulls in outdoor areas, the pull rope/tape may sometimes be left in the sun for extended periods of time.
Percentage of elongation or stretch	In high-tension pulling applications, excessive stretching of the rope/tape is a major contributor to galloping and to personnel hazard if the rope/tape breaks.
Heat sink properties	In high-tension pulling applications, rope/tape friction against the conduit can produce a substantial amount of heat. If the rope/tape cannot dissipate the heat and the coefficient is high, plastic conduit could soften and melt.

WARNING

Personnel should never stand in line with rope/tape under tension. If a rope/tape breaks, it can recoil with lethal force.

Table 6—Rope and tape fiber selection guide- typical characteristics)

Fiber type	Composite double braid rope (polyester outer jacket and nylon inner core)	Twisted yellow polypropylene rope	Woven polyester tape	Spiral wrapped light-duty poly twine	Manila rope	Solid braid nylon rope	Three strand polypropylene rope
Strength **Diameter range [mm (in)]**	9.5 to 25.4 (3/8 to 1)	4.8 to 9.5 (3/16 to 3/8)	12.7 to 19.0 (1/2 to 3/4)	N/A	6.4 to 76.0 (1/4 to 3)	3.2 to 12.7 (1/8 to 1/2)	6.4 to 51.0 (1/4 to 2)
Tensile strength range [N (lbf)]	22 250 to 186 900 (5 000 to 42 000)	3200 to 10 860 (720 to 2440)	5560 to 26 700 (1250 to 6000)	935 (210)	2400 to 256 320 (540 to 57 600)	2540 to 23 500 (570 to 5300)	5560 to 2 314 000 (1250 to 52 000)
Characteristics	— High strength, low stretch — Excellent UV, chemical, and abrasion resistance — Factory spliced pulling eye at each end	— Lightweight — Economical — High chemical resistance — Easily spliced	— High tensile strength, low stretch — Printed sequential footage markings — Easily blown through conduits and ducts	— Will not rot or mildew — Can be left in conduit for future use — Ships in plastic pail for ease of use and storage	—Holds knots well —Low stretch —absorbs water —Poor resistance to rot and mildew —Good UV resistance	—Good UV resistance —Excellent rot and mildew resistance —Very good abrasion resistance	—Economical —Very light —Low stretch —High chemical resistance
Applications	Heavy-duty cable pulling line	Cable pulling line	Cable pulling tape	Cable pulling twine	General purpose rope	Blocks, pulleys, winches, and general tie-downs	General purpose rope

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10. Cable lubrication

10.1 General

Whenever cable is pulled through conduit or ducts, lubrication is necessary to reduce pulling tension. The cable lubricant will reduce the coefficient of friction between the cables and the raceway and any cables that the raceway may contain. This reduced coefficient of friction enables the proper installation of cable in raceway systems that otherwise might not be achieved within the design limits.

The conduit should be cleaned to remove any extraneous debris, inspected for sharp edges at the ends, and prelubricated prior to beginning the cable pull to maximize the effectiveness of the lubricant. The lubricant should be applied at all accessible points along the pull. Additionally, the cable and the pull rope should be lubricated during the cable installation.

The pulling lubricant should be compatible with the cable and the pulling rope and should not harden or set up during the cable installation process. Cable lubricants should not support combustion, give off toxic gases, or harden up after the pull is complete. Lubricants that do not set up or harden after the pull are desirable to allow cable to be pulled out or removed at a later time. Lubricant compatibility with cable insulation and jacket materials should be verified before usage. If in doubt, lubricant compatibility tests should be performed or the cable manufacturer's approval should be obtained. Refer to IEEE Std 1210, which identifies tests for determining compatibility of lubricants with wire and cable. Since some pulling lubricants can degrade the performance and life of pull ropes/tapes, the pull ropes/tapes should be periodically inspected and replaced as needed. Consult the lubricant manufacturer for information regarding the compatibility of the lubricant with the rope selected.

With the development of new materials for jackets such as low-smoke zero halogen (LSZH), thermoplastic elastomer (TPE), cross-linked polyolefin (XLPO), etc., (refer to IEEE Std 532™-2007 [B27] for information on jacket types) more attention needs to be paid to the selection and application of pulling lubricants. In addition, lubricant compatibility should be considered, because in one study (Fee [B11]) some lubricants have been shown to cause long-term jacket degradation of physical properties. Some of the newer jackets have a very smooth surface such that the pulling lubricant flows off the jacket like water. There also have been cases where the pulling process wipes the jacket clean of the pulling lubricant by the end of the pull, effectively causing the cable at the end of the run to be unlubricated. Cable installers need to be aware of these cases, so that the proper lubricant for the jacket is selected and so that extra lubricant is applied before and during the pull, and especially at any intermediate pull points. Another sign of a potential problem is when cable pulling crew reports higher than expected pulling tensions, which may be caused by a "lack of sufficient lubrication." When these conditions are reported, adding lubricant throughout the pull may lower the pull tensions if the cause was insufficient lubrication at some points of the pull. If the pulling tension is not reduced after adding extra lubricant, a more serious condition exists that needs further investigation.

10.2 When to use lubricant

All cables installed in or removed from conduit or duct that are intended to be repulled, that are longer than 4.5 m (15 ft), or that have one or more bends that total 90º or more, should be lubricated except when the cable can be pushed through the entire length of the conduit. Prelubrication of existing cables and the conduit or duct is important for pullback and pullby installations. It is especially important to prelubricate conduits and ducts when pulling old cables out of a conduit or duct (when reusing the conduit or duct is anticipated) as most new pulling lubricants contain a substantial amount of water, which helps loosen the existing cables, soften any old lubricants and lower the tension needed to remove the existing cables.

When pulling cables during low ambient temperatures or pulling heavy cables in general, the user should consider the use of pulling lubricants that maintain viscosity at low temperatures and high bearing pressures. Incorrect lubrication type or excessive lubrication can be detrimental by increasing the pulling tensions when temperatures are low.

10.3 Lubricant quantity

The recommended quantity of cable lubricant is dependent on the size and length of the conduit system. Experience indicates that a satisfactory quantity of lubricant for an average cable pull can be determined from Equation (15a) and Equation (15b):

$$Q = 0.00073 \times C_L \times D \qquad \text{L} \qquad \text{(15a) metric}$$

$$Q = 0.0015 \times C_L \times D \qquad \text{gal (US)} \qquad \text{(15b) English}$$

where

Q = the quantity of pulling lubricant needed, L (gal [US])
C_L = the measured length of conduit, m (ft)
D = the nominal diameter of the conduit, mm (in)

The calculated quantity of pulling lubricant is the amount required for a straight pull into a new conduit. The appropriate quantity for use on any given pull can vary upwards from this recommendation by 50%, depending on the condition of the pull. The following factors require increased cable lubricant quantity:

a) Cable weight and jacket hardness (increase quantity for stiff, heavy cable)
b) Conduit type and condition (increase quantity for old, dirty, or rough conduits)
c) Conduit fill (increase quantity for high percent conduit fill)
d) Number of bends (increase quantity for pulls with more than one bend)
e) Pulling environment (increase quantity for high temperatures or water in the conduit)

Some lubricating systems pump or spray the lubricant all the way through the conduit as well as onto the cable. The amount of lubricant pumped is generally controlled by the various system components such as pump pressure, spray nozzle size, fill of the conduit to be lubricated, and the viscosity of lubricant.

10.4 Methods of lubricating conduit systems

Several methods may be employed to lubricate conduit systems. Three possible methods are as follows:

a) Lubricant can simply be pumped or packed into the conduit before the pull. This method is most effective when a mandrel or spreader is attached in front of the cable grip to push and spread the lubricant.
b) Bags (or front-end packs) of lubricant are available that are pulled (or pushed) in front of the cable, which deposit the lubricant as the cable is pulled.
c) Pulling or lubricating ropes with tubular cores and leading spray nozzles are available that spray lubricant throughout the conduit as the rope is pulled through the conduit. When such ropes are

used to pull the cable, the maximum pulling tension may be more limited than when using a conventional pulling rope. When used as a lubricating rope only, it is attached to the pull rope.

WARNING

To prevent injury in the event of cable galloping, caution should be exercised when applying lubricant by hand. Hands and fingers should be kept away from the conduit or duct opening.

10.5 Cable jacket lubrication

Lubricant should be placed on the cable jacket as the cable enters the conduit or duct. There are a number of ways to accomplish this, including the following:

a) Specialty systems are available that continuously or intermittently pump lubricant to a special spray collar on the feeder tube mouth.

b) High-viscosity gel lubricants can be piled into the feeder tube. The cable simply runs through them and gets completely coated with lubricant.

c) Lubricant can be placed directly on the cable jacket by hand.

10.6 Lubrication procedure

The following procedures have been found to result in adequate lubrication throughout the conduit and minimum pulling tensions.

a) One-half to two-thirds of the lubricant should be placed into the conduit in front of the cable. The lubricant can be pumped into the conduit or conduit-sized bags can be inserted in front of the cable as previously discussed in 10.4. A duct swab or lubricant spreader should be used to evenly spread the lubricant throughout the conduit during the pull. The lubricant should be applied at all points of the pull. For long pulls, a lubricated swab should be pulled through the conduit prior to starting the cable pull. Unlubricated sections increase cable tension.

b) The remaining quantity of lubricant should be applied to the cable as it enters the conduit. Automatic applicators or lubricant pumps can be used to apply the lubricant to the cable. A majority of the lubricant should be applied to the front half of the cable.

c) When intermediate manholes exist and the cables are pulled straight through, the lubricant should be proportioned among the segments of the run. Steps a) and b) above should be followed, but each segment should be treated as if it were the beginning of a run.

10.7 Safety and cleanup

Cable lubricants are by definition slippery substances. Lubricant spills should be cleaned up or covered with an absorbent material as soon as they occur as the lubricant presents a safety hazard.

Most commercial cable lubricants are water based. Appropriate precautions should be taken when working around energized cables as discussed in other places in this document.

11. Tension-limiting methods

11.1 General

In order to ensure that the cable installation process does not damage the cable conductor, the insulation, the shield or jacket, and the pulling tensions should be limited. The tension can be effectively limited by the following:

a) Restricting the number of workers utilized for hand pulling

b) Monitoring the actual tension applied and stopping the pull if the tension is too high

c) Limiting the amount of tension available by using a break link or breakaway swivel

Once the required installation tension has been determined (via calculation or by the use of a cable pulling chart) one of the three tension-limiting methods discussed above can be employed.

11.2 Limiting size of pulling crew

The number of workers pulling on the cable should be limited to the minimum number needed. One approach is to limit the number of workers based upon the MAPT, as follows:

One worker: For cable pulls where the MAPT is 445 N (100 lbf) or less.

Two workers: For cable pulls where the MAPT is between 445 N (100 lbf) to 1335 N (300 lbf) and the conduit/duct nominal trade size is metric designator 21 (3/4 in) or larger.

Three workers: For cable pulls where the MAPT is greater than 1335 N (300 lbf) and the minimum conduit nominal trade size is metric designator 103 (4 in) for single cable pulls or nominal trade size metric designator 129 (5 in) for multiple cable pulls.

11.3 Dynamometer

Whenever a cable installation is planned that has a pulling tension within 80% of the MAPT, that utilizes mechanical pulling devices, or that requires more than three workers to pull the cable, a dynamometer or tension gauge should be used to monitor the tension. If the cable is hand pulled or laid in the tray, monitoring the pull tension is typically not done due to the remote possibility of breaking or stretching a conductor.

During a pull, galloping may be experienced. Galloping is usually the result of excessive stretching of the pull rope and the inability of the puller to sustain a constant tension on the pulling eye of the cable(s). Galloping can be minimized by proper lubrication and pull rope selection.

Dynamometer readings may spike as the head of the cable passes around bends within the conduit or duct run. These spikes are typically limited to the head and do not affect the remainder of the cable. The tension measured after the cable head clears the bend is the tension actually experienced by the cable.

11.4 Break link

The use of a break link or *breakaway* swivel can be very effective in limiting the amount of tension that can be applied during installation. When a preestablished tension is reached, the swivel breaks and the pull rope separates from the cable(s).

Breakaway swivels should only be used on pulls where the installation tension is expected to be very low, and the cable can be easily removed if the swivel breaks. If the swivel breaks during a high-tension pull, it will probably be impossible to remove the cable without severe abuse or damage to the cable.

12. Cable pullbys and pushbys

12.1 General

The term *pullby* is used to describe the practice of pulling cables in conduits that are already occupied by other cables. Pullbys are *not* a generally recommended practice because of the risk of causing non-observable damage to the existing cables. Do not use pullbys unless all other design/installation options have been evaluated and determined to be impracticable. However, certain circumstances may at times require their use. These circumstances include design changes requiring added cables not initially foreseen, a lack of space to install additional conduits, or pulling schedules based on system groupings rather than on plant zones.

The term *pushby* is used to describe the practice of hand pushing a cable through a short length of straight conduit, nipple, sleeve, or wire way. Pushbys are preferable to pullbys due to the smaller potential for cable damage to occur during the process. Since pullbys have the potential for doing more cable damage, the balance of this subclause will discuss pullbys.

The intent of this subclause is not to encourage the practice of pullbys, but rather to provide guidelines that will minimize the possibility of damaging the existing cables when a pullby is found to be necessary. Where possible, other alternatives (such as bulk pulls, installation of new conduits, or pullback of existing cables followed by a bulk pull of both initial and new cables) should be implemented.

12.2 Conditions for successful pullbys

The following are generally accepted conditions for achieving a successful pullby:

a) Conduit fill prior to the pullby should be less than 20% (cable area to conduit area). Cable fill after pulling should not exceed 35% for three or more cables and 25% for two cables.

b) When performing a pullby where there will be three cables of the same size in the conduit following the pull, the cables should not be within the cable critical jam ratio, if there are bends in the pull.

c) When evaluating a possible pullby, the compatibility of the jacket materials of the existing and pullby cables should be considered.

   Jackets of woven fiber are generally regarded as too abrasive to be considered candidates for pullbys (for the existing cable or the new cable) if polymer jacketed cables are also involved.

   Also, consideration should be given to the cut-through resistance and the thermal endurance of the jackets of the installed cables especially when soft, rubber-like jacketed cables are being installed over those with thermoplastic jackets. This factor is very significant when the length of cable being installed results in a long duration pull. This may result in heat buildup, softening, and cut-through of the thermoplastic jacket, exposing and damaging the primary insulation.

d) Published coefficients of friction are generally based on the installation of cables into empty conduits (AEIC CG5-05 [B3], Kommers [B35], and Fee [B11]). Many users have assumed a coefficient of friction as high as 0.75 for a pullby. This is likely to be conservative for most jacket combinations provided that all cables are well lubricated. Lubrication is critical since the coefficient of friction between unlubricated, soft, rubber-like jackets can easily exceed 1.0.

e) Consideration should be given to the construction of the existing cables within the conduit prior to the pullby. Certain constructions are susceptible to damage by the sidewall pressures that develop during the pulling of new cables. Silicone rubber and some ethylene-propylene-rubber (EPR) insulations are softer than cross-linked polyethylene (XLPE) insulation and may be more susceptible to cut-through. Electrical characteristics of air dielectric coaxial cables may be significantly altered if crushed. Users considering pullbys involving these insulation materials and cable constructions may need to invoke additional restrictions and should consult the cable manufacturer for further guidance.

f) Consideration should be given to the length of cable being pulled through any segment. This may be well in excess of the actual length of the segment itself since any number of additional conduit segments may follow. Pullby damage is understood to be a function both of the forces exerted on the existing cables and the duration of those forces. As a rule of thumb, for pulls having equal expected sidewall pressures, the severity of the pullby increases in direct proportion to the length of the cable being pulled past a given point.

g) The existing raceway should be evaluated to assess the difficulty of the pullby. Expected pull tensions and sidewall pressures should be calculated to ensure that damaging forces will not be encountered. As stated previously, the coefficient of friction in a pull tension calculation should be adjusted to account for the presence of the existing cables. As in the case of original pulls, the most favorable pullbys will be those with bends closest to the feed point rather than the pull point. Also, where vertical sections are encountered, downward pulls are preferred.

12.3 Installation practices

a) The most important consideration for cable pullbys is establishing a clear path to avoid interference with existing cables during the pull. One technique is to install a fish line or pull rope by manual rodding. This permits the pulling crew to “feel” their way through the conduit. An experienced “rodder” can usually avoid paths between existing cables.

   Under no circumstances should an existing rope or fish tape left in the conduit from a previous pull be used. Rope pulled in with the cables is probably twisted with the original set of cables and if used would cut into the original cables. Metal fish tapes should also not be used because they may cut or otherwise damage the existing cable.

b) Non-conducting rods should be used to minimize the risk to personnel safety in the event that the existing installed cables are damaged and an energized conductor is exposed. Prior to installation, existing cables already installed in the conduit shall be de-energized to prevent accidental shock to personnel or inadvertent equipment operation should cable damage occur. When the intended pullby is easy (i.e., short length of pull, low fill, and few degrees of bend) and involves low energy circuits (instrumentation or control), the pullby may be performed without de-energizing the existing circuits, providing safety precautions are followed.

c) The pulling rope diameter should range between 10 mm and 19 mm (3/8 in to 3/4 in). The rope should be flexible and nonabrasive such as double-braided polyester. Under no circumstance should steel ropes be used.

d) Manual or automatic lubrication of the pull rope, interior of the conduit, and existing cables will significantly reduce the abrasive friction and SWBP on the existing cables as well as the cables to be installed.

e) Normally, swivels should not be used. However, small bullet-nosed, break3away swivels are available and may be helpful when pulling machines are used.

f) Great care should be taken to cover sharp edges of all pulling equipment hardware, either by taping or preferably with heat-shrinkable sleeves. Leading edges should not be blunt or sharp, but rather cone- or bullet-shaped to provide a streamlined profile to ease their passage through the duct.

g) Pull tensions should be monitored and limited regardless of whether machine pulling is used or the cable is pulled by hand. This can be through the use of a dynamometer, a calibrated break-link, or a restricted number of cable pullers. Pull tension should be limited to 1780 N (400 lbf) or the maximum allowable based on conductor strength unless the cable manufacturer indicates otherwise. Restricting the number of workers utilized for hand pulling to no more than two people provides the significant advantage of being more apt to notice the presence of a cable snag.

   A pulling machine has the advantage of maintaining a constant, even pull, which is conducive to smooth, successful pulls. Even so, an experienced cable pulling observer should be stationed at the pulling end and be in communication contact with the other members of the crew.

h) The pull rope, break-link, new cable, and any other pulling hardware should be closely observed as each emerges from the conduit at each pull point for evidence of possible damage being inflicted on the existing cables. Indications of cable damage include discoloration of the pull rope or the presence of small pieces of jacket material.

12.4 Post pullby cable testing

Following a pullby normal post-installation testing should be performed on both the existing cables and the recently pulled cables. This is to address the inherent risk to the existing cables.

13. Pullbacks

13.1 General

The term *pullback* is used to describe situations in which cables have to be pulled out of conduits and then pulled back in. This may result from the relocation or temporary removal of equipment or the raceway system, from a design change requiring a revision to the routing of the cable, or to permit installation of additional cables in lieu of a pullby. Caution should be exercised to prevent damage to the cables during the pullback operation. This is particularly important when aged cables are involved.

Due to the uncertainty of the coefficient of friction for pullbacks, accurate estimations of the pull tensions and SWBPs cannot be made and pulling charts are not applicable. When the entire circuit is being removed such that an option exists regarding the direction of the pullout, the normal considerations should be made for determining the direction of pull (i.e., location of bends and elevation changes with respect to the pull points).

The intent of the following subclauses is to provide guidelines that will minimize the possibility of cable damage.

13.2 Cable inspection

Cables considered for potential pullback should be evaluated for the effects of age degradation. The stresses resulting from gripping, pullback, and repulling can be detrimental to cables that are degraded as a result of heat, moisture, chemicals, or radiation aging. If the condition of cables is unknown, inspection should be undertaken to determine whether existing cable replacement is necessary before being repulled.

13.3 Installation practices

a) A significant factor in achieving a successful pullback is the lubrication of the installed cables prior to initiation of the pullback, which can be done by pumping or blowing lubricant into the conduit. In order to loosen the bond between the cables and the conduit wall, it may be necessary to allow the lubricant time to soak in; twenty-four hours is a typical soak time. Exposed sections of cable should be lubricated prior to pulling them out of the conduit. Use of commercial solvents to loosen the jacket from the conduit may degrade the jacket and render it unacceptable for the repull.

b) Care should be exercised when gripping cables in preparation for pullback. This is particularly important when aged cables are involved. Caution should be taken to avoid violating the minimum bend radius when using a gripping device with a small contact area. Metallic basket-weave grips should not be used for pullbacks. Instead, luffing grips, mare's tails, or the equivalent should be used.

c) The pullback operation involves the handling of cables that may have been aged to some degree and have already undergone the stress of initial installation. Care should be given to ensure that the minimum cable bend radius is maintained, especially at conduit entry and exit points. If the cable is coiled (figure eight preferred) for short-term storage following the pullback, it should be trained with as large a radius as practical and not less than the minimum cable trained bend radius, as recommended by the cable manufacturer.

d) Prior to performing pullbacks, terminal lugs for 6 AWG cable and larger should be removed and terminal lugs for 8 AWG cable and smaller should be taped to prevent damage to other cables and to ensure that the lugs do not hamper the cable removal process or scar the conduit leaving burrs, which may jeopardize the cables during the repull operation.

e) Prior to beginning the pullback activity, fire stops, moisture seals, and cable supports installed in the conduit should be removed. In no case should the cables be pulled through these devices. Care should be taken during the seal removal process and only blunt instruments should be utilized so as not to inflict damage to the cables.

f) Tension should be monitored during the pullback operation and limited to 2225 N (500 lbf) or the maximum allowable based on conductor strength, whichever is less.

g) Following the pullback, a 100% inspection of the removed cables should be performed to look for evidence of jacket or insulation damage. Any evidence of jacket cracking may indicate that significant aging has occurred. Such cables should not be reinstalled. Remaining sealant materials should be carefully removed from the jackets to facilitate inspection.

h) When performing a pullback and the subsequent repull, cables frequently are outside of their raceway while the raceway is being reworked or a bulk pull is being prepared. While this work is underway, it is important that the cables be adequately protected. Care should be taken to ensure that the cables are not left exposed in high-traffic areas where the potential for inadvertent damage is significant. When cables are temporarily coiled and suspended following a pullback, an adequate support area should be provided such that the support does not cut into the jacket. During the time that the cables are exposed, they should be protected from nearby or overhead work, such as welding or grinding.

i) Before the repull is begun, swabbing the conduit is recommended to remove any debris that may have accumulated in the conduit or any other foreign matter on the conduit walls. Installation practices employed during the repull phase will be the same as those for a normal cable pull, with additional care taken to ensure that the cables are liberally lubricated. Special attention should be taken at conduit entry and exit points to ensure that the maximum bend radius is provided and to avoid developing a high sidewall pressure at a conduit bushing or fitting.

j) Following the bulk repull, the cable's normal post-installation testing (Clause 18) should be followed except that high-potential testing on medium-voltage cables should be conducted at maintenance levels only.

14. Installation of specialty cables

14.1 General

While the bulk of the cable in generating station and industrial applications will be conventional power, control, and instrumentation cable and thus subject to the guidance provided elsewhere in this document, the installation of certain specialty cables warrants additional attention due to their construction, to their application requirements and their increasingly frequent use. This group includes, but is not limited to, category data cable, coaxial cable, tri-axial cable, twin-axial cable, and telephone cable. Installation of fiber optic cables also warrants special attention, but is outside the scope of this document. For installation guidance of fiber optic cables, the user should refer to IEEE Std 1428™-2004 [B32].

The high-frequency performance requirements provided by many specialty cables depend upon close manufacturing tolerances to ensure uniform impedance as a function of length. The user should ensure that installation techniques utilized do not distort the cable or alter the relative position of cable components since such changes create impedance anomalies. Such anomalies increase attenuation, cross-talk and signal reflection. Improper installation may also distort the cable's shielding system, which can increase cross-talk and in general reduce the overall signal-to-noise ratio.

The following guidance is general. Users should consult their cable manufacturer for specific applications and for guidance for cable types not addressed by this document.

14.2 Bend radius

High-performance specialty cables should be carefully installed to ensure that their allowable bend radius is not violated during pulling or training activities. Bends that are too tight may distort the cable cross section and alter the impedance at that point and may also reduce the shielding effectiveness for certain designs. Bend radius factors given in Table 7 are provided in multiples of the cable's OD.

Table 7—Minimum training bend radius factors

	Minimum training radius (no tension) = multiplier × OD of cable	Minimum pulling radius (under tension) = multiplier × OD of cable
Category cable, 4-pair, unshielded	4	8
Category cable, 4-pair, with overall shielded	10	14
Category cable, 6-pair, unshielded	8	12
Category cable, 6-pair, shielded	10	14
Coax, twin-axial, tri-axial	8	12
Telephone (aluminum/polyester foil tape shielded)	10	20
Telephone (braid shielded)	10	20

14.3 Cable pulling lubricants

Installation of specialty cables should be performed with the application of a lubricant designed for use on electrical cables. The tension reduction provided by such lubricants is important to ensure that high forces do not occur, which could result in distortion of the cable or violation of the cable jacket. Either form of degradation could adversely impact the performance of specialty cables.

General guidance in the selection and application of lubricants is given in Clause 10. Generally, the use of a low-viscosity lubricant will result in the lowest pull tensions for lightweight specialty cables.

Compatibility of the lubricant with the cable jacket should be verified in accordance with IEEE Std 1210.

14.4 Methods of gripping specialty cable

Most specialty cables have small copper or alloy conductors with insufficient cross-sectional area to permit direct pulling by the conductor. Thus, such cables should be installed by using basket-weave grips over the completed cable. Pulling on the conductor may result in excessive conductor elongation, conductor kinking, or conductor breakage.

When installing pre-terminated cables, consideration should be given to the protection of connectors and to the avoidance of an excessive diameter build-up in this area. Special grips are available for this task.

Since specialty cables are subject to severe performance degradation for twists and kinks, swivels between the grip and the pull rope should be used.

14.5 Maximum allowable pulling tension

As stated in 14.4, pull tension is typically applied to specialty cables through the use of a basket-weave grip installed over the cable's outer jacket. Maximum pulling tension is therefore calculated based on the cable jacket material, its thickness and the overall cable diameter. Equation (16) (see Vartanian and Sandler [B49]) is used to calculate the MAPT using a basket-weave grip:

$$T_{\mathrm{mc}} = \pi \times Y_{\mathrm{m}} \times t_{\mathrm{j}} \times (d_{\mathrm{j}} - t_{\mathrm{j}}) \qquad (16)$$

where

T_{mc} = MAPT, N (lbf)
Y_m = maximum jacket tensile yield stress, MPa (lbf/in^2) (see Table 9)
t_j = jacket or sheath thickness, mm (in)
d_j = jacket or sheath OD, mm (in)
π = 3.1416

For specialty coaxial, tri-axial, and twin-axial cables, the user should consider the cross-sectional area of the conductors and the braids even though the pulling is always done by the use of a basket-weave grip.

Table 8 provides typical numbers for common coaxial cables.

Table 8—Typical maximum allowable pull tension, basket-weave grip[a]

Cable type	Typical diameter mm (in)	Maximum pull tension, basket-weave grip N (lbf)
RG 6 Type	8.4 (0.332)	270 (60)
RG 8 Type	10.3 (0.405)	356 (80)
RG 11 Type	10.3 (0.405)	535 (120)
RG 58 Type	5.0 (0.195)	90 (20)
RG 59 Type	6.1 (0.242)	115 (25)
RG 62 Type	6.1 (0.242)	135 (30)
RG 114 Type	10.3 (0.405)	645 (145)

[a]Cable manufacturers should be consulted if the planned pull requires pull tension values in excess of the tensions given in Table 8.

Table 9—Jacket material stress values

Jacket material	Material stress (Y_m) [a]	
	MPa	lbf/in^2
CPE (chlorinated polyethylene)	6.89	1000
CSPE (chlorosulfonated polyethylene) (general purpose)	6.89	1000
CSPE (chlorosulfonated polyethylene) (heavy duty)	10.34	1500
LSZH (low-smoke zero halogen) polyolefin	6.89	1000
NBR/PVC (acrylonitrile-butadiene rubber and polyvinyl chloride) (heavy duty)	6.89	1000
PCP (polychloroprene) (general purpose)	6.89	1000
PCP (polychloroprene) (heavy duty)	10.34	1500
PE (polyethylene)	6.89	1000
PVC (polyvinyl chloride) (general purpose)	6.89	1000
SR (silicone rubber)	3.45	500
TPE (thermoplastic elastomer)	6.89	1000
XLPE (cross-linked polyethylene)	6.89	1000
XLPO (cross-linked polyolefin)	6.89	1000

[a] For purposes of this table material stress is the yield tensile value.

Maximum pull tension formula for coax cables using a basket-weave grip is as shown in Table 8 and may be calculated according to Equation (17):

$$T_{MC} = T_C + T_B \quad (17a)$$
$$T_C = K \times n_c \times A_c \quad (17b)$$
$$T_B = K \times n_b \times A_b \quad (17c)$$

where

T_{MC} = MAPT, N (lbf)
T_C = maximum pulling tension, N (lbf) based on conductor
T_B = maximum pulling tension, N (lbf) based on braid ends
A_c = one strand conductor area, square mm (circular mils)
A_b = one braid end circular area, square mm (circular mils)
n_c = number of conductor strands
n_b = number of braid ends
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)

MAPT for 4-pair category cables is limited to 115 N (25 lbf).

14.6 Sidewall pressure

For power and control cable SWBP criteria has always been known to be a limiting parameter for cable installation. Even though specialty cables are often not rated for SWBP by their manufacturers, it is still a limiting parameter during cable installation. Manufacturers of specialty cables frequently limit installation forces by specifying an allowable bend radius under tension and an allowable pulling tension. Such data can be evaluated to determine an inferred maximum allowable SWBP (i.e., tension divided by radius).

Special caution should be used when installing cables with foamed and spacer-maintained (air dielectric) insulation systems since these are readily susceptible to crush induced damage.

Typical values of SWBP are given in Table 10 for solid and foam dielectric coax, twin-axial, and tri-axial cables.

Table 10 —Typical maximum values of allowable sidewall bearing pressure[a]

Cable type	Typical max SWBP N/m (lbf/ft)
Coax, twin-axial, tri-axial (foam dielectric)	2200 (150)
Coax, twin-axial, tri-axial (solid dielectric)	3000 (200)

[a] Cable manufacturers should be consulted if the planned pull requires SWBPs to exceed those given in Table 10.

14.7 Pulling specialty cables

Aside from the above limitations and guidance, the actual pulling of specialty cables differs little from techniques applied to pulling control or instrumentation cables. Special care should be exercised to ensure that the cables do not twist or kink at any time when feeding off of the reel, feeding into the conduit or during pullout at condulets, boxes, hand-holes and manholes. Such kinks and twists can be especially detrimental to the performance of specialty cable.

To ensure that SWBP is not violated; cables should enter their raceway on-axis. When this cannot be directly achieved, rollers and sheaves should be provided.

Cable should be fed from the reel rather than pulled from the reel in order to minimize back-tension.

14.8 Post-installation considerations

As with conventional power, control, and instrumentation cables, specialty cables should be adequately supported when long vertical drops are encountered to ensure that the unsupported load does not damage the conductor, distort the cable at the top of the run, or result in a violation of bend radius at the top of the run. However, specialty cables are frequently of a conductor size not specifically addressed by the guidance in the NEC. In no case should the installation exceed the maximum support interval listed in the NEC unless the above concerns have been addressed by alternate analysis. Supports at the top or interval point of a drop may be provided by grips. Care should be exercised to ensure that the application of the grip does not distort the cable and that the minimum bend radius requirements are maintained. Other methods of support may be acceptable provided they are backed-up by suitable testing or analysis.

Care should be exercised in the application of tie wraps to specialty cables installed in open raceways and in panels. Excessive tie-wrap pressure can distort the underlying dielectric and adversely affect the cable's performance. Tie-wrap guns should generally not be used. Tie wraps should not indent the cable's outer jacket.

When terminating twisted pairs of specialty cables, maintain the manufacturer's twist as close to the termination/connector point as possible. This practice minimizes the affect of the termination on the overall cable performance. For category cabling, pair twists should be maintained to within the distance specified in Table 11.

Table 11 —Category wire termination

Cable type	Maintain pair twist to within, mm (in)
Category 3	76 (3)
Category 5	25 (1)
Category 5e and 6	13 (0.5)

14.9 Storage and handling of specialty cables

Specialty cables should be adequately protected prior to use to ensure that their High-performance requirements have not deteriorated. Such cables are typically more susceptible to degradation during storage than ordinary power and control cables because of their construction.

Both ends of the cables on reels should be sealed to protect the cable against moisture ingress. End caps are the preferred method of sealing. Tape has been used to seal cable ends, but is not the preferred method due to its limited durability.

Specialty cable should be stored indoors. When outdoor storage is necessary, reels shall be protected from UV damage through the use of light-weight, opaque reel covers. Storage should be on flat, solid, well-drained surfaces. Whether stored indoors or out, reels should be blocked to prevent inadvertent damage from contact with flanges of adjacent reels. When such 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.

15. Installation of armored cable

15.1 General

Armored cable as used in this document means any one of the following metal clad (MC) cable configurations: aluminum interlocked armor, galvanized steel interlocked armor, continuous smooth or corrugated extruded aluminum armor, or continuously welded smooth or corrugated metallic armor with or without an overall non-metallic jacket. Whenever Type MC cable is installed, the recommended practices of Article 330 of the NEC shall govern. Also see IEEE Std 635™-2003 [B29] for more information on armored cables.

Type MC cable may be installed in any raceway (tray, conduit, ducts, duct banks, etc.), in open runs, as direct buried, or attached to a messenger on an aerial cable. Although variations of metallic armored cables offer additional degrees of life-long mechanical protection versus non-armored cables, certain unique and sometimes more limiting installation constraints should be considered when selecting armored cables. The advantage of using an armored cable is the physical protection afforded to the insulated conductors and the fact that it can be installed without the need for raceway. The disadvantages are that it requires a larger bend radius, and is often stiff and difficult to handle.

For more details regarding installation of a particular armored cable, consult the specific armored cable manufacturer's installation information.

15.2 Bend radius

Armored cables should be carefully installed to ensure that their allowable bend radius is not violated during pulling or training activities. Bends that are too tight may distort the armor and compromise the geometry of the cable core insulation. Bend radius factors given in Table 12 are provided in multiples of the cable's OD.

The recommended minimum bend radius for armored cables while under pull tension is larger than for non-armored cables of the same conductor size, with the same number of conductors and configuration. It is important to reiterate that the recommended minimum pulling bend radius, which is measured to the inner cable surface of the bend, may actually need to be further restricted to a larger limit because of cable SWBPs as discussed elsewhere in this document.

Table 12—Comparative minimum bend radius factors

Cable type	Minimum training radius as a multiple of OD (no tension) [a]	Minimum pulling radius as a multiple of OD (under tension) [a]
Unarmored cables, 25 mm (1.0 in) OD and less	4	7
Unarmored cables, greater than 25 mm (1.0 in) to 50 mm (2 in) OD	5	8
Unarmored cables, greater than 50 mm (2 in) OD	6	9
Type MC interlocked armor or continuous corrugated armor	7	10
Type MC smooth sheath, 19 mm (0.75 in) OD and less	10	12
Type MC smooth sheath, greater than 19 mm (0.75 in) to 38 mm (1.5 in) OD	12	14
Type MC smooth sheath, greater than 38 mm (1.5 in) OD	15	18
Braided stainless steel or braided bronze armor	8	10
Served wire armor or flat armor	12	14
Overall shielded cables (with or without MC smooth sheath), 38 mm (1.5 in) OD and less	12	14
Overall shielded cables (with or without MC smooth sheath), greater than 38 mm (1.5 in) OD	15	18
Cables with individually shielded conductors (unarmored)	7 × OD of cable	10 × OD of cable
Cables with individually shielded conductors (armored)	7 × OD of cable or multiplier for armor, whichever is greater	10 × OD of cable or multiplier for armor, whichever is greater

[a] For cable that is not round, the OD to be used is the circumscribing diameter.

15.3 Cable pulling lubricants

Installation of jacketed armored cables in conduit should be performed with the application of a lubricant designed for use on electrical cables. The tension reduction provided by such lubricants is important to ensure that high forces do not occur, which could distort the armor or damage the jacket or conductors within.

General guidance in the selection and application of lubricants is given in Clause 10. Compatibility of the lubricant with the cable jacket should be verified in accordance with IEEE Std 1210.

15.4 Methods of gripping

Armored cable should be gripped not only on the external armor or jacket, but also on the core conductors. This is the preferred method to pull any type of armored cable. One method of achieving this dual grip is to remove a portion of the armor and then tape over the armor and down over the core conductors. A long basket-weave grip can then be applied such that it grips both the armor and the conductors. Another approach is to use a pulling eye for the core conductors and a grip over the armor to prevent it from slipping back. This latter approach provides the greater strength. The helically wrapped interlocked armor tapes also require a more restricting linear tension limit than other cable types to prevent armor separation or core withdrawal. As with all pulled cables, the “spoil” length under and near the grip area should be cut off and not used after pulling.

15.5 Maximum allowable pulling tension

As identified in 15.4, pull tension is typically applied through the use of a basket-weave grip installed over the cable’s outer jacket or armor. If interlocked armor is manufactured and tested to meet UL-4 [B48] requirements, 1335 N (300 lbf) would be the corresponding tension limit for the tape armor itself. The corresponding core withdrawal or slippage is 133.5 N (30 lbf) for a 3 m (10 ft) long sample. Unless cable tension is limited by manually pulling with multiple installers, the cable should be gripped on core conductors as well as the external armor or jacket.

Cable manufacturer should be consulted if the planned pull requires pull tension values in excess of the tensions given above.

15.6 Sidewall pressure

The use of SWBP as a limiting parameter during cable installation is somewhat unique to the utility industry. A typical SWBP limit for armored cables is 4400 N/m (300 lbf/ft) of bend radius.

The cable manufacturer should be consulted if the planned pull requires the SWBP to exceed that given above.

15.7 Pulling armored cables

Aside from the previous limitations and guidance, the actual pulling of armored cables differs little from techniques applied to pulling non-armored cables.

To ensure that SWBP is not violated; cables should enter their raceway on-axis. When this cannot be directly achieved, rollers and sheaves should be provided.

15.8 Post-installation considerations

As with conventional power, control, and instrumentation cables, armored cables should be adequately supported when long vertical drops are encountered to ensure that the unsupported load does not damage the integrity of the armor, distort the armor at the top of the run, or result in a violation of bend radius at the top of the run. In general, respecting specific guidelines provided in the NEC is the best practice for armor types covered. In no case should the installation exceed the maximum support interval listed in the NEC unless the above concerns have been addressed by alternate analysis. Supports at the top or interval point of a drop may be provided by grips. Care should be exercised to ensure that the application of the grip does not distort the cable and that the minimum bend radius requirements are maintained. Other methods of support may be acceptable provided they are backed-up by suitable testing or analysis.

15.9 Storage and handling of armored cables

Even though armored cables are protected by a metallic sheath, the storage and handling requirements of 4.2 should be followed. If an armored cable does not have an overall jacket, the ends shall be sealed to an underlying core jacket.

16. Duct bank cable pulls

16.1 General

Many of the same considerations given in Clause 6 apply to installing cables in underground duct bank systems. However, there are unique installation considerations for underground duct banks that are addressed in this clause.

Most cable pulls in vaults, duct banks, and manholes at generation stations are done prior to plant startup when other cables in the same location are usually de-energized. However, after plant startup and during retrofit work, vaults, duct banks, and manholes often contain other cables that are energized and may not be de-energized during the current activity. Working under these conditions requires an added level of caution and extra safety measures to be considered prior to performing any work in the vaults, duct banks, or manholes. These pulls often have the same problems as conduit pulls, plus the added difficulty of having to work in an enclosed or confined space at one or both ends. When the size of the manhole opening does not allow the setup of the pulling rig or the cable reel at the duct opening, extra rigging is required to guide both the pulling rope and the cable from outside the manhole into the duct or conduit.

There are many potential problems when working in a manhole environment. Manholes are belowground creating water conditions, such as pumping the water out and disposing of contaminated discharge that needs to be dealt with. The manhole atmosphere shall be monitored for oxygen, toxic gasses, and explosive gasses. Emergency rescue devices shall be available to safely extract injured personnel. Manholes are often located where traffic and other aboveground obstructions restrict the available work space.

It is normally considered unsafe to have personnel in the "pulling" manhole during the pull. When pulling tensions are high, the rapid release of tension from a failure of the pulling line, block, or cable grip can create a missile hazard in the manhole. In general it is necessary to have personnel in the "feeding" manhole to apply lubricant to the cable as it enters the conduit, because the pulling tensions at this location are not high enough to cause personnel injury.

16.2 Planning activities

The following planning activities should be considered prior to performing any work in these areas:

a) Preplan the direction of cable pulls by performing cable pulling calculations in both directions.

b) Have sufficient cable, pulling lubricants, and cable pulling accessories (shims, sheaves, rollers, ropes, etc.) available prior to performing any work.

c) Plan to thoroughly clean ducts with the mandrel and inspect and repair as necessary each duct prior to starting any cable pulling activities.

d) Plan to check and re-check confined spaces such as manholes, vaults, and duct bank openings for combustible and toxic gases, water, and energized cables prior to any personnel entry.

e) Plan to check cable clearances by doing jamming calculations, bend radius calculations. and sidewall pressure calculations prior to any cable pulling.

f) Plan the cable setup area to be sure that it is of sufficient size to accommodate the equipment needed.

16.3 Pre-installation activities

16.3.1 General

The following pre-installation activities should be performed before pulling any new cable in these areas:

a) Turn off all existing energized cables and ground all de-energized phase conductors at the load end to be sure that there are no residual charges built up on cable shields or sheaths.

b) Monitor the air inside manholes and vaults for toxicity and combustible gasses.

c) Ventilate manholes and vaults and re-check air for toxicity and combustible gas levels.

d) Dewater manholes and vaults.

e) Wear appropriate protective clothing including rubber gloves, boots, respirators, harnesses, etc., when entering manholes and vaults.

f) Inspect the entrance of all ducts for evidence of sharp edges; inspect existing cables for evidence of cable deterioration; identify any spare ducts; and in general examine the condition of the manhole or vault.

g) Bore, rod, and thoroughly clean all empty ducts with a mandrel and soft covering.

h) Upon removal of the mandrel inspect the soft covering. Evidence of damage to the soft covering such as tears or rips indicate sharp edges or obstructions inside the duct and should be further investigated before pulling cable into the duct. Normally the boring and rodding activities are repeated until the mandrel with a soft covering shows no signs of damage. A boroscope may also be used to examine the inside of the duct to locate the sharp edges and obstructions inside the duct or to confirm that the sharp edges have been removed.

i) Lubricate existing cables and ducts and let it soak for 24 hours before existing cables are pulled out and replaced. The use of power lubrication equipment is the most effective technique as it forces the lubricant further into the duct and covers the interior of the duct and cable more thoroughly.

j) Inspect existing cables that are being removed to identify installation damage that may be a clue to the duct's inner condition. Repeat the above steps as necessary.

k) Consult IEEE P971™ [B18] for more information regarding precautions to be taken before beginning work in a manhole or vault.

l) Since manholes and vaults are considered confined spaces, comply with OSHA and other applicable safety codes and standards before entry.

16.3.2 Duct damage

The kinds of duct damage that could be encountered include the following:

a) Silt and debris in spare ducts left over from original construction.

b) Protrusions into ducts at joints from concrete, tree roots, broken PVC ducts, earth settlement, etc.

c) Collapsed or oval shaped ducts due to poor construction practices or heavy equipment driving over the top of the duct bank.

d) Ducts misaligned at joints due to earth settling or poor installation practices.

e) Too small bend radius for the new cable to be installed.

When any of the above conditions is present, duct bank rework or repair is required before pulling cable.

16.3.3 Manhole damage

The kinds of manhole or vault damage that could be encountered include the following:

a) Manhole lid or seal damaged.
b) Broken or rusted ladder rungs, ladder supports or loose anchor bolting.
c) Corrosion of cable racks, trays, or metallic conduit.
d) Broken rungs and sharp edges on trays or conduit.
e) Degradation, deterioration, or evidence of rodent damage to cable.
f) Evidence of electrical arcing from existing cables to racks, trays, ducts, other metallic objects.

When any of these conditions are present, manhole or vault repair or replacement is required before pulling cable.

16.4 Cable installation precautions

The following installation precautions should be observed:

a) Ventilate and retest the vault or manhole prior to entering. For information on the proper methods of artificial or natural ventilating manholes, see IEEE P971 [B18].
b) Use suitable pulling eyes, basket grips and ropes for the size and weight of the cable being pulled.
c) Never pull cables into a duct with existing cables due to the potential for cable damage.
d) Due to the potential for cable damage, avoid pulling cables of different types and sizes together in the same duct; however sometimes a ground conductor of a different size is pulled with the phase conductors.
e) Prelubricate ducts with copious amounts of a lubricant that is compatible with the cable jacket, see Clause 10 for additional information on lubrication.
f) Lubricate each cable with more lubricant as it enters the duct, see Clause 10 for additional information on lubrication.
g) Monitor cable pulling tensions during the pull (see 11.3).
h) Avoid starts, stops and jerking the cable during the pull as this leads to cable galloping.

16.5 Rigging activities

Rigging, including bull wheels and skids, should be carefully selected to ensure that cable pulling tensions, sidewall pressures, and bending radius limits are not exceeded. Pulling rigs should be properly braced to prevent movement. The pulling ropes, blocks, tackles, bracing, and shackles should have a rating sufficient to meet the tension demands of the cable pull. For example, a pulling rope with a tension of 44 500 N (10 000 lbf) will apply 89 000 N (20 000 lbf) of tension to a block with a 0^{o} angle or 63 000 N (14 140 lbf) at a 90^{o} angle. See Figure 6.

Typical duct bank cable pull set-ups are shown in Figure 7 and Figure 9. Three-wheel pulley assemblies (Figure 8) are often used when pulling cables since they are smaller and more practical for areas of limited space. However, it should be recognized that they do not provide as smooth of a bend as a single-wheeled pulley of a larger size and can create a higher sidewall pressure on the cables being pulled.

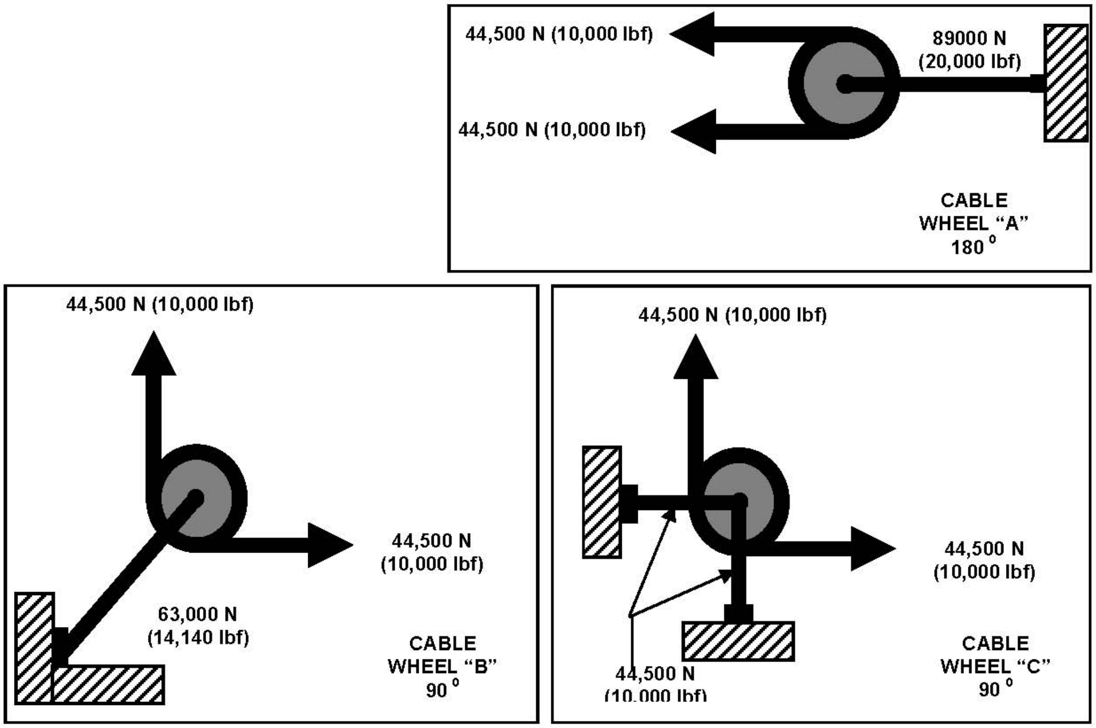


Figure 6—Wheel setup comparisons

The rigging should be set up to bring sufficient cable into the manhole for splicing. Stopping a pull to luff additional cable into the manhole works against standing friction rather than rolling friction, which can greatly increase the cable's pulling tension. For the same reason if the cable is pulled through manholes, cable guides should be set up to position the cable as it goes through this manhole, rather than luffing slack cable back into the manhole.

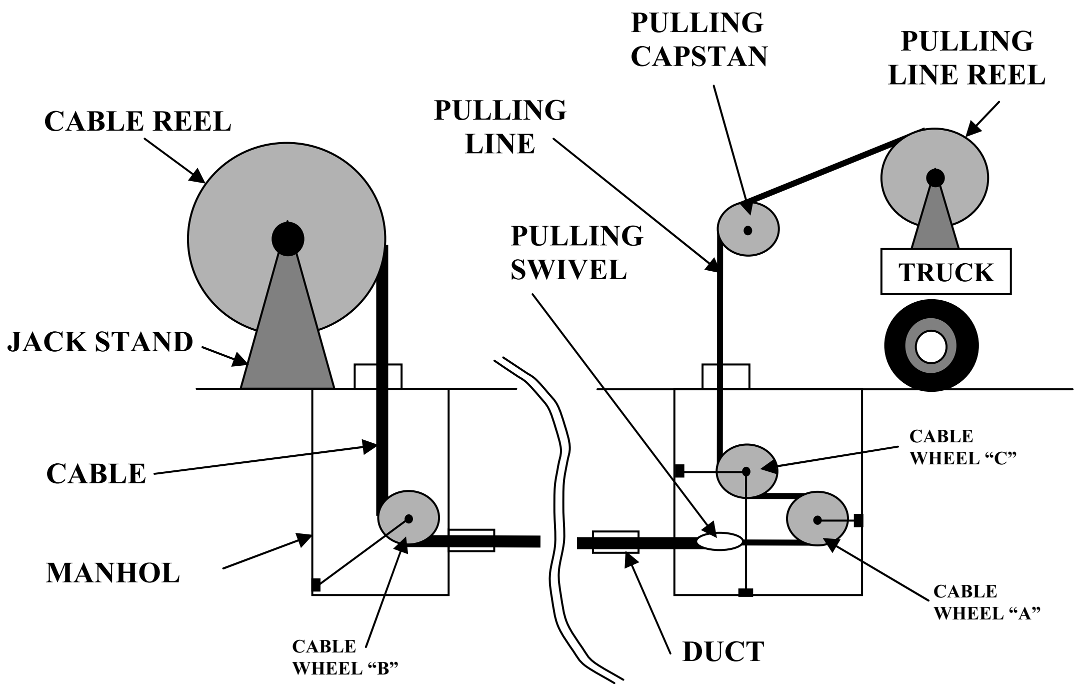


Figure 7—Duct bank pull setup—Example 1

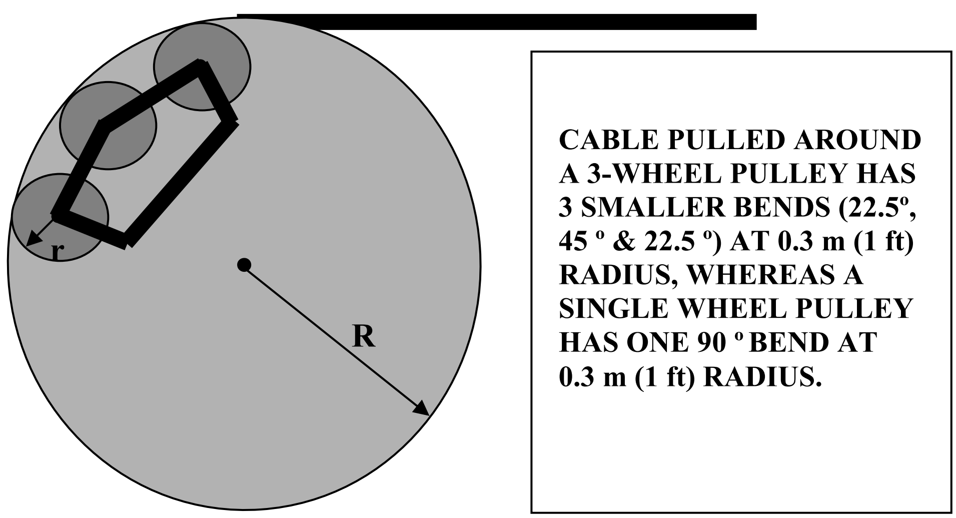


Figure 8—Three-wheel pulley example

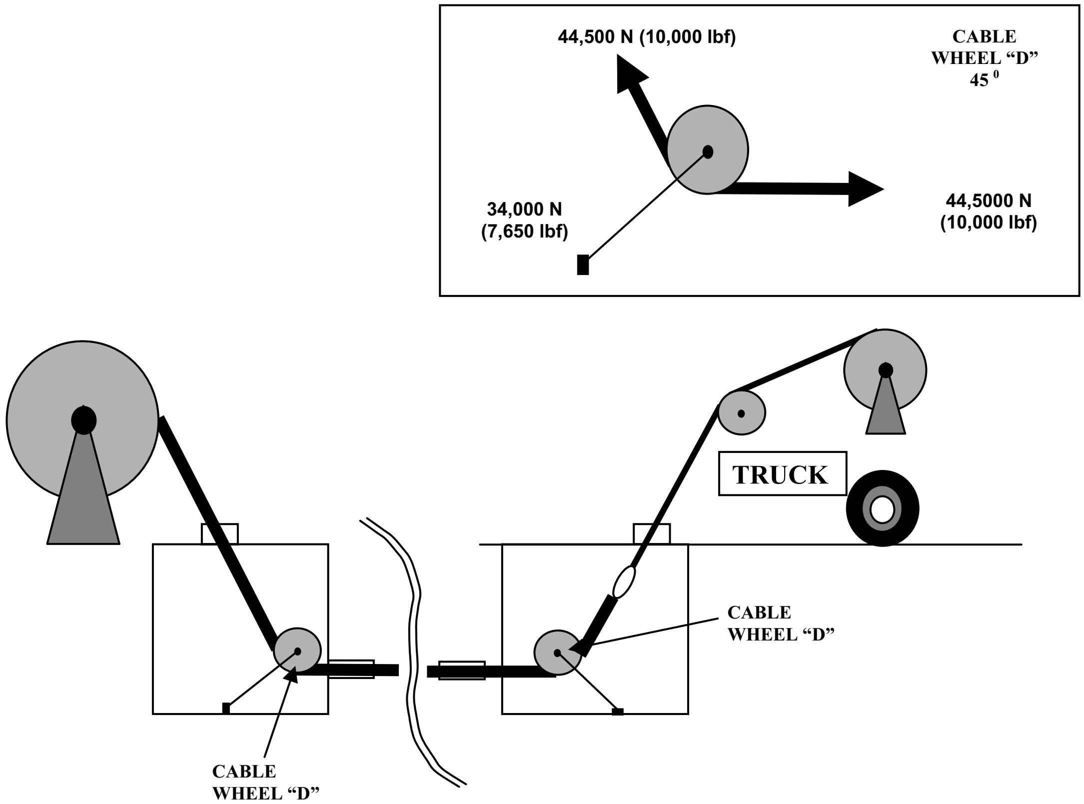


Figure 9—Duct bank pull setup—Example 2

17. Vertical cable support

17.1 General

Conductors in vertical raceways require some type of support to prevent strain at lugs and terminations, crushing of the insulation, shield or jacket, or elongation of the conductor. Cable supports are used to transfer the tensile forces on the load bearing components of the cable to a support structure without physical damage to the cable. This force transfer is dependent upon many variables, the most important of which is the coefficient of friction between the cable jacket and the supporting device.

17.2 Cable classifications

The effect of the forces on a long vertical cable drop and those clamping forces associated with the support of the cable should be evaluated. The significance of those forces will differ according to the type of cable under consideration, its materials and its application.

a) *Medium-voltage power cables* are rated above 2000 V, are subject to thermal expansion due ampacity loading, are usually shielded, may be single or multi-conductor, are covered with polymeric jacket or armor or both, and are attached to support structures by fasteners.

b) *Low-voltage power cables* are rated 2000 V and below, may be subject (but not always subject) to thermal expansion due to ampacity loading, may be single or multi-conductor construction, with larger sizes individually attached to supports by fasteners, and in smaller sizes are bundled and attached to supports by fasteners.

c) *Control, instrument, communication and specialty cables* are low-voltage multi-conductor cables that are not subject to thermal expansion due to ampacity since they do not carry appreciable currents. They are usually attached to support structures in bundles with fasteners.

17.3 Forces

The forces on the supports/cables can be classified as follows:

a) Axial forces are due to the weight of the cable. These forces act to elongate the conductor and pull the conductor from its connector or terminal block.

b) Tangential forces by the raceway system inflict sidewall pressures on the cable. These forces typically occur at or near the top of the run where the cable transitions from vertical to horizontal. While the greatest concern is for those transitions over a sharp edge or other small radius raceway feature, the user should also evaluate bearing pressures that exist at the top of a long drop for standard radius tray and conduit sections. The forces developed at transition points are proportional to its radius of curvature, length of the drop, and weight of the cable and inversely proportional to the cable's diameter. These forces act to crush the cable and its constituent materials.

c) Tangential forces, which result from the application of cable supporting devices and are necessary to restrict the movement of the cable as the result of gravity, thermal expansion, or short circuit, act to crush the cable and its constituent materials.

d) Electrodynamic forces, which result from the interaction of the magnetic field produced by the fault current in one conductor with the magnetic fields produced by fault currents in adjacent conductors, are of a very short duration, of a high intensity and if not sufficiently restrained, can be damaging to the cables, surrounding equipment, and personnel.

While seismic forces are a concern, these forces are more applicable to the raceway system, since the natural frequency of the cable is low.

17.4 Thermal considerations

All cables will experience some degree of thermal expansion and contraction in the axial direction due to changes in ambient temperature. For typical generating station ambient temperatures, the magnitude of the change due to ambient alone will not be significant and the forces produced by the growth will generally be insufficient to overcome friction in any horizontal section above the transition point. Large power cables that carry appreciable load currents and are unrestrained may produce sufficient thermal expansion to overcome those frictional forces. As the cable changes load it may "ratchet" its way over the transition point. When the load is removed the contraction forces may not be sufficient to return the cable to its original position. Repeated cycling can build up significant tension on the cable above the transition point and significant crushing forces at the transition point.

17.5 Raceway

The type of support device to be utilized is dependent upon whether the raceway is conduit, tray, or free air (shaft).

17.6 Environment

Cable outer covering and fastener materials need to be selected to be compatible with the environment.

17.7 Support devices

These devices, such as basket-weave grips, tie wraps, clamps, cleats, conduit fittings, etc., have specific applications depending upon the raceway and cable configurations, and have specific loading capabilities that are a function of their orientation to the support structure. Support device material should be compatible with the support structure and with the cable covering.

17.8 Support locations

Care should be taken to ensure that the cable is secured in the horizontal raceway immediately before the vertical bend to prevent ratcheting and buildup of tensions in the cable by load cycling. Supports should be located at the top of a vertical raceway and at additional points in the vertical section.

17.9 Standards for vertical cable support spacing

NEC Article 300 Table 300.19(A), Spacings for Conductor Supports, is a prevalent reference in the U.S. relative to vertical cable support spacing (see Table 13). Research to establish the basis for the primary U.S. standard, NEC Table 300.19(A) did not reveal the existence of any supporting documentation. NEMA/ANSI WC 58-2008 (ICEA S-75-381) [B38], NEMA/ANSI WC 70-2009 (ICEA S-95-658) [B39], and NEMA/ANSI WC 74-2006 (ICEA Std S-93-639) [B41] address the issue of conductor strength for cables for use in vertical riser, bore holes, and shafts in mines and similar applications.

Table 13—Typical cable support distances per NEC Section 300.19 [B1]

Conductor size	Maximum distance for aluminum conductors		Maximum distance for copper conductors	
(AWG/kcmil)	m	ft	m	ft
AWG #18 to AWG #8	30	100	30	100
AWG #6 to AWG 1/0	60	200	30	100
AWG 2/0 to AWG 4/0	55	180	25	80
4/0 AWG to 350 kcmil	41	135	18	60
Over 350 kcmil to 500 kcmil	36	120	15	50
Over 500 kcmil to 750 kcmil	28	95	12	40
750 kcmil and over	26	85	11	35

17.10 Calculating vertical cable support spacing and forces

The standards referenced in 17.9 provide recommended safety factors based on conductor cross-sectional area, the weight being supported, and the conductor material. For a given conductor material and unit weight, the safety factor "F" limits the unsupported length of vertical drop before a support would be required and establishes the interval between subsequent supports. Evaluation of the formula for common cables sizes utilized in generating station applications shows that such applications are rarely limited by conductor strength alone given the limited vertical drops that are typical of such facilities. Exceptions to this general rule may include certain feeder cables in pumped storage facilities and "down-comer" conductors used in lightning protection of tall stacks and cooling towers.

$$F = \frac{A \times T}{W \times L \times \mathrm{g}} \qquad \text{(18a) metric}$$

where

F = factor of safety (not less than 7)
A = area of (3) conductors, mm^2
W = mass per unit length of cable, kg/m
T = tensile strength of conductors, MPa
L = length of cable, m
g = gravitational constant (9.8 $\mathrm{m/s}^2$)

$$F = \frac{A \times T}{W \times L} \qquad \text{(18b) English}$$

where

F = factor of safety (not less than 7)
A = area of (3) conductors, in^2
W = weight per unit length of cable, lbf/ft
T = tensile strength of conductors, $\mathrm{lbf/in}^2$
L = length of cable, ft

Where typical values of *T* for various materials with concentric round conductors are shown, as follows:

Soft annealed copper	165 MPa (24 000 $\mathrm{lbf/in}^2$)
3/4 hard aluminum (alloy 1350-H16)	117 MPa (17 000 $\mathrm{lbf/in}^2$)

The source of the formula for safety factor and values for *T* shown above is NEMA/ANSI WC 74-2006, Section 17.10 (ICEA S-93-639) [B41].

Consult manufacturer when using conductors that are compressed or compacted strand as the process of compressing and compacting the strands increases the values of *T*.

The support spacing intervals based on conductor strength appear to be conservative. Comparing the results of Equation (18) with the intervals given in the NEC, we see that conductor strength is not the primary concern.

Stainless steel tie-wraps or cable clamps may also be used to support the cable. The spacing of the supports can be calculated using the Equation (19).

$$S = \frac{D \times L \times P}{W \times \mathrm{g}} \qquad \text{(19a) metric}$$

where

S	= tie wrap spacing, m
D	= diameter of the cable, mm
L	= length of the clamp or tie-wrap along the cable axis, mm
W	= mass of a unit length of cable, kg/m
P	= maximum pressure the tie wrap exerts on the cable, MPa Consult tie wrap manufacturer for the pressure a tie wrap can exert on a cable.
g	= gravitational constant (9.8 m/s^2)

$$S = \frac{D \times L \times P}{W} \qquad \text{(19b) English}$$

where

S	= tie wrap spacing, ft
D	= diameter of the cable, in
L	= length of the clamp or tie-wrap along the cable axis, in
W	= weight of a unit length of cable, lbf/ft
P	= maximum pressure the tie wrap exerts on the cable, lbf/in^2 Consult tie wrap manufacturer for the pressure a tie wrap can exert on a cable.

Using this formula it can be shown that a three conductor, 250 kcmil cable that weighs 4990 kg/1000 m (3350 lbf/1000 ft), that has an OD of 45 mm (1.75 in) and a maximum tie wrap pressure of 6.89 kPa (1.0 lbf/in^2) would require supports at 7.9 m (26 ft) intervals if secured by 140 mm (5.5 in) long clamps.

Research into the basis for the tables confirms that the support spacing for cables in long vertical drops given in the subject standards is primarily based on historical (common) practice as opposed to readily available calculated documentation that verifies their validity. In the absence of widespread failures attributed to unsupported vertical drop, it is doubtful that such documentation will be rigorously developed unless it is driven by the nuclear industry.

The literature shows that certain high-stress installation configurations, such as bends, vertical runs, and overhangs can impose additional mechanical stress on the cables and potentially contribute to cable failure. While some work has been done to investigate these phenomena, questions still remain as to the severity of this problem; therefore, this issue is unresolved.

17.11 Design considerations

a) Control and instrumentation cables are typically lightly loaded (i.e., low currents) and have negligible linear expansion; therefore, only the hanging weight needs be considered for spacing of supports in vertical drops.

b) Long horizontal runs of cable coming into a vertical drop should have an expansion loop at the top of the drop to eliminate the long horizontal length of cable from the linear expansion equation.

c) Since linear expansion of vertical cable is subject to gravity, all expansion will occur at the bottom of the drop.

d) Since linear expansion of a vertical cable down does not equal linear contraction up, the cable will see an increased tensional force.

e) Individual single cables in a multi-conductor cable will be longer than the linear length of the overall cable by a factor tied to the lay length of the cable in the bundle.

f) Some or all of the linear expansion in a multi-conductor cable or triplexed cable will be taken up by changing lay length or spacing.

17.12 Devices

There are several types of support devices available in the industry. Some are designed specifically for this purpose and some are designed for other functions but can be adapted without modification for use as a support. Application of each type is dependent on the specific installation.

a) Cable tie wraps—Usually made of nylon or stainless steel, are the most economical choice for vertical tray support applications. Tie wraps are available in a wide range of lengths and tensile strength ratings, and can be supplied for applications in adverse environmental conditions such as high temperature, corrosive gasses, ultraviolet light, and nuclear radiation areas. Tension limits for locking plastic ties are a function of their width and thickness.

b) Wire mesh grips—The principal advantage of this more expensive support is that the lifting forces are more evenly distributed over the cable's outer covering. Wire mesh grips are made of metal materials such as bronze, galvanized steel, and stainless steel and can be used for conduit installations. Basket-weave grips can provide more than 4450 N (1000 lbf) on cable insulation or jacket, but exceeding 4450 N (1000 lbf) may damage cable.

The force from the cable to the support is largely dependent upon the coefficient of friction between the cable jacket and the supporting device. For those applications having a coefficient of friction higher than 0.25, the maximum load based on the strength of load bearing components can be determined by the Equation (20), which was derived from Equation (1):

$$F_{\max} = K \times CM \qquad (20)$$

where

$F_{\max}$ = maximum allowable total force per grip, N (lbf)
K_{cu} = 35.137 MPa (0.004 lbf/cmil) for soft annealed copper
K_{al} = 26.353 MPa (0.003 lbf/cmil) for 3/4 hard aluminum alloy (1350-H16)
CM = total sq mm (cmil) area of all load bearing components

Compressive forces necessary to secure the cable in a wire mesh grip tend to force the wires into the cable jacket. The greater the supported weight, the greater the tendency depending on the parameters shown in the relationship in Equation (21):

$$F_{\max} = \frac{k' \times d \times D \times P_{\max}}{D_{\mathrm{List}}^{2}} \qquad \text{(21a) metric}$$

where

$F_{\max}$ = maximum allowable total force per grip, N
d = diameter of the wire used in the grips, mm
D = diameter of one cable, mm
D_{List} = smallest rated cable diameter for which the cable grip is designed, mm
$P_{\max}$ = maximum pressure under the grip wires MPa
k' = 90.322×10^3 mm^2 (for metric units)

$$F_{\max} = \frac{k'' \times d \times D \times P_{\max}}{D_{\mathrm{List}}^{2}} \qquad \text{(21b) English}$$

where

F_{max}	= maximum allowable total force per grip, lbf
d	= diameter of the wire used in the grips, in
D	= diameter of one cable, in
D_{List}	= smallest rated cable diameter for which the cable grip is designed, in
P_{max}	= maximum pressure under the grip wires lbf/in^2
k''	= 140 in^2 (for English units)

c) Conduit fittings—These fittings are typically made of iron, steel, or aluminum; are suitable for single cable installations; and for special applications can be used to provide a seal at the conduit/equipment.

d) Universal struts—The tension on the vertical cable provided by universal struts is a function of the grommet material, rubber, porcelain, or wood and retaining bolt.

e) Clamps—The tension on the vertical cable provided by cable clamps is a function of clamp material (metal, rubber, etc.) and pressure (cable deformation). Excessive pressure can damage cable.

f) Cleats—Since the tension on the vertical cable provided by cleats is diameter sensitive, cleats do not support significant tension. Typical support lengths are as follows:

   1) 12.7 mm O.D. and less = 406 mm (0.5 in O.D. and less = 16 in)

   2) 12.7 mm to 38.1 mm = 508 mm (0.5 in to 1.5in = 20 in)

   3) 38.1 mm to 63.5 mm = 914 mm (1.5 in to 2.5in = 36 in)

   4) 63.5 mm and up = 1219 mm (2.5 in and up = 48 in)

g) Braided "mare's tail" grips—Braided weave grips can provide more than 4450 N (1000 lbf) on cable insulation or jacket, but exceeding 4450 N (1000 lbf) in a short distance may damage cable. To reduce the strain on the cable, the grips can be made longer.

h) Conductor connections—Use the strength of the conductor as the holding force at the terminal lug or pulling eye.

i) Preformed grips—Short distance plastic devices that depend on friction between grip and cable OD for holding.

18. Acceptance testing of installed cables

18.1 General

Before cable acceptance or maintenance testing is performed, consult the cable manufacturer to obtain their recommendations in addition to 18.2. The primary purpose of testing at this stage (after installation and before placing into service) is to verify that major cable damage did not occur during transportation, storage, handling, or installation. After cable has been placed in service, cable testing, if performed, shall be done at a reduced voltage level, typically 80% of the factory test voltage level.

Safety precautions shall be followed during all phases of testing.

18.2 Recommendations

a) For medium- and low-voltage power cables, insulation resistance tests should be performed to measure the insulation resistance between any possible combination of conductors in the same cable and between each conductor and ground, with all other conductors in the same cable grounded. The test voltage should be a minimum of 500 V dc. The minimum acceptable insulation resistance is calculated with Equation (22):

$$R = (V + 1) \times \frac{305}{L} \qquad \text{(22a) metric}$$

where

R = insulation resistance, megohms
V = rated voltage in kilovolts, kV
L = cable length, m
305 = unit length of cable, megohms–m/kV

$$R = (V + 1) \times \frac{1000}{L} \qquad \text{(22b) English}$$

where

R = insulation resistance, megohms
V = rated voltage in kilovolts, kV
L = cable length, ft
1000 = unit length of cable, megohms–ft/kV

b) It is recommended that only shielded medium-voltage power cables be high potential (Hi-Pot) tested in accordance with applicable IEEE, ICEA, NEMA or AEIC standards. For testing of medium-voltage cables refer to IEEE Std 400™-2001 [B20], IEEE Std 400.1™-2007 [B21], IEEE Std 400.2™-2004 [B22], and IEEE Std 400.3™-2006 [B23]. If medium-voltage cable has been placed in service, the Hi-Pot test voltage level used should be at the maintenance level only. If a new piece of medium-voltage cable has been spliced to an existing medium-voltage cable and the entire length is being Hi-Pot tested, the test voltage should be at the maintenance level only.

c) Insulation resistance testing of control, instrumentation, and prefabricated cable assemblies is recommended after installation. Cable manufacturers' recommendations should always be followed.

d) Consult the cable manufacturer for acceptance testing of fiber optic, specialty cables, and other cables not discussed in this clause.

Annex A

(normative)

Conduit-cable pulling charts

Table A.1a—Conduit-cable pulling chart for control cable SWBP = 500 lbf/ft and *K′* = 0.5

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
¾	935	631	288	131	89	60	66
1	754	509	232	106	71	48	132
1 ½	483	326	149	68	46	31	310
2	327	221	101	46	31	21	353
2 ½	251	169	77	35	24	16	386
3	200	135	62	28	19	13	478
3 ½	173	117	53	24	16	11	551
4	142	96	44	20	13	9	583
5	138	93	43	19	13	9	895
6	120	81	37	17	11	8	1124
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.1b—Conduit-cable pulling chart for control cable SWBP = 7300 N/m and *K′* = 0.5

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
21	285.0	192.3	87.8	39.9	27.1	18.3	293.7
27	229.8	155.1	70.7	32.3	21.6	14.6	587.4
41	147.2	99.4	45.4	20.7	14.0	9.4	1379.5
53	99.7	67.4	30.8	14.0	9.4	6.4	1570.9
63	76.5	51.5	23.5	10.7	7.3	4.9	1717.7
78	61.0	41.1	18.9	8.5	5.8	4.0	2127.1
91	52.7	35.7	16.2	7.3	4.9	3.4	2452.0
103	43.3	29.3	13.4	6.1	4.0	2.7	2594.4
129	42.1	28.3	13.1	5.8	4.0	2.7	3982.8
155	36.6	24.7	11.3	5.2	3.4	2.4	5001.8
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.2a—Conduit-cable pulling chart for control cable SWBP = 1000 lbf/ft and *K′* = 0.5

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
¾	935	631	288	131	89	60	152
1	935	631	288	131	89	60	270
1 ½	935	631	288	131	89	60	601
2	654	442	201	92	62	42	706
2 ½	502	339	155	70	48	32	772
3	400	270	123	56	38	26	956
3 ½	345	233	106	48	33	22	1102
4	284	192	87	40	27	18	1166
5	277	187	85	39	26	18	1790
6	241	162	74	34	23	15	2247
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.2b—Conduit-cable pulling chart for control cable SWBP = 14 600 N/m and *K′* = 0.5

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
21	285.0	192.3	87.8	39.9	27.1	18.3	676.4
27	285.0	192.3	87.8	39.9	27.1	18.3	1201.5
41	285.0	192.3	87.8	39.9	27.1	18.3	2674.5
53	199.3	134.7	61.3	28.0	18.9	12.8	3141.7
63	153.0	103.3	47.2	21.3	14.6	9.8	3435.4
78	121.9	82.3	37.5	17.1	11.6	7.9	4254.2
91	105.2	71.0	32.3	14.6	10.1	6.7	4903.9
103	86.6	58.5	26.5	12.2	8.2	5.5	5188.7
129	84.4	57.0	25.9	11.9	7.9	5.5	7965.5
155	73.5	49.4	22.6	10.4	7.0	4.6	9999.2
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.3a—Conduit-cable pulling chart for control cable SWBP = 500 lbf/ft and *K′* = 0.3

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
¾	1823	1440	899	561	443	350	152
1	1470	1162	725	453	358	283	218
1 ½	941	744	464	290	229	181	310
2	638	504	314	196	155	123	353
2 ½	490	387	241	151	119	94	386
3	390	308	192	120	95	75	478
3 ½	337	266	166	104	82	65	551
4	277	219	136	85	67	53	583
5	270	213	133	83	66	52	895
6	235	185	116	72	57	45	1124
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.3b—Conduit-cable pulling chart for control cable SWBP = 7300 N/m and *K′* = 0.3

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
21	555.7	438.9	274.0	171.0	135.0	106.7	676.4
27	448.1	354.2	221.0	138.1	109.1	86.3	970.1
41	286.8	226.8	141.4	88.4	69.8	55.2	1379.5
53	194.5	153.6	95.7	59.7	47.2	37.5	1570.9
63	149.4	118.0	73.5	46.0	36.3	28.7	1717.7
78	118.9	93.9	58.5	36.6	29.0	22.9	2127.1
91	102.7	81.1	50.6	31.7	25.0	19.8	2452.0
103	84.4	66.8	41.5	25.9	20.4	16.2	2594.4
129	82.3	64.9	40.5	25.3	20.1	15.8	3982.8
155	71.6	56.4	35.4	21.9	17.4	13.7	5001.8
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.4a—Conduit-cable pulling chart for control cable SWBP = 1000 lbf/ft and *K′* = 0.3

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
¾	1823	1440	899	561	443	350	152
1	1823	1440	899	561	443	350	270
1 ½	1823	1440	899	561	443	350	601
2	1275	1008	629	393	310	245	706
2 ½	979	774	483	301	238	188	772
3	781	617	385	240	190	150	955
3 ½	674	532	332	207	164	129	1102
4	553	437	273	170	135	106	1166
5	539	426	266	166	131	104	1790
6	469	371	231	144	114	90	2247
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.4b—Conduit-cable pulling chart for control cable SWBP = 14 600 N/m and *K′* = 0.3

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
21	555.7	438.9	274.0	171.0	135.0	106.7	676.4
27	555.7	438.9	274.0	171.0	135.0	106.7	1201.5
41	555.7	438.9	274.0	171.0	135.0	106.7	2674.5
53	388.6	307.2	191.7	119.8	94.5	74.7	3141.7
63	298.4	235.9	147.2	91.7	72.5	57.3	3435.4
78	238.0	188.1	117.3	73.2	57.9	45.7	4249.8
91	205.4	162.2	101.2	63.1	50.0	39.3	4903.9
103	168.6	133.2	83.2	51.8	41.1	32.3	5188.7
129	164.3	129.8	81.1	50.6	39.9	31.7	7965.5
155	143.0	113.1	70.4	43.9	34.7	27.4	9999.2
Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table A.5a—Conduit-cable pulling chart for power cable SWBP = 500 lbf/ft and *K′* = 0.5

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
¾	613	414	189	86	58	39	170
1	408	276	126	57	39	26	218
1 ½	168	113	52	24	16	11	310
2	165	112	51	23	16	11	353
2 ½	139	94	43	20	13	9	386
3	96	65	30	13	9	6	478
3 ½	86	58	27	12	8	6	551
4	67	45	21	9	6	4	583
5	65	44	20	9	6	4	895
6	55	37	17	8	5	4	1124
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.5b—Conduit-cable pulling chart for power cable SWBP = 7300 N/m and *K′* = 0.5

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
21	186.8	126.2	57.6	26.2	17.7	11.9	756.5
27	124.4	84.1	38.4	17.4	11.9	7.9	970.1
41	51.2	34.4	15.8	7.3	4.9	3.4	1379.5
53	50.3	34.1	15.5	7.0	4.9	3.4	1570.9
63	42.4	28.7	13.1	6.1	4.0	2.7	1717.7
78	29.3	19.8	9.1	4.0	2.7	1.8	2127.1
91	26.2	17.7	8.2	3.7	2.4	1.8	2452.0
103	20.4	13.7	6.4	2.7	1.8	1.2	2594.4
129	19.8	13.4	6.1	2.7	1.8	1.2	3982.8
155	16.8	11.3	5.2	2.4	1.5	1.2	5001.8
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.6a—Conduit-cable pulling chart for power cable SWBP = 1000 lbf/ft and *K′* = 0.5

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
¾	1227	828	378	172	116	79	341
1	817	552	252	115	77	52	436
1 ½	335	226	103	47	32	21	620
2	331	223	102	46	31	21	706
2 ½	278	188	86	39	26	18	772
3	192	130	59	27	18	12	956
3 ½	172	116	53	24	16	11	1102
4	134	90	41	19	13	9	1166
5	131	88	40	18	12	8	1790
6	110	75	34	15	10	7	2247
Minimum one single conductor 12 AWG or one multiple conduct or 12 AWG conductor size							

Table A.6b—Conduit-cable pulling chart for power cable SWBP = 14 600 N/m and *K′* = 0.5

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
21	374.0	252.4	115.2	52.4	35.4	24.1	1517.5
27	249.0	168.2	76.8	35.1	23.5	15.8	1940.2
41	102.1	68.9	31.4	14.3	9.8	6.4	2759.0
53	100.9	68.0	31.1	14.0	9.4	6.4	3141.7
63	84.7	57.3	26.2	11.9	7.9	5.5	3435.4
78	58.5	39.6	18.0	8.2	5.5	3.7	4254.2
91	52.4	35.4	16.2	7.3	4.9	3.4	4903.9
103	40.8	27.4	12.5	5.8	4.0	2.7	5188.7
129	39.9	26.8	12.2	5.5	3.7	2.4	7965.5
155	33.5	22.9	10.4	4.6	3.0	2.1	9999.2
Minimum one single conductor 12 AWG or one multiple conduct or 12 AWG conductor size							

Table A.7a—Conduit-cable pulling chart for power cable SWBP = 500 lbf/ft and *K'* = 0.3

Conduit trade size	Maximum effective conduit length (ft) — Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45º	90º	180º	270º	315º	360º	
¾	1196	945	590	368	291	230	170
1	796	629	393	245	194	153	218
1 ½	327	258	161	101	79	63	310
2	323	255	159	99	78	62	353
2 ½	271	214	134	83	66	52	386
3	187	148	92	58	46	36	478
3 ½	168	133	83	52	41	32	551
4	131	103	64	40	32	25	583
5	128	101	63	39	31	25	895
6	108	85	53	33	26	21	1124
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.7b—Conduit-cable pulling chart for power cable SWBP = 7300 N/m and *K'* = 0.3

Conduit metric designator	Maximum effective conduit length (m) — Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45º	90º	180º	270º	315º	360º	
21	364.5	288.0	179.8	112.2	88.7	70.1	756.5
27	242.6	191.7	119.8	74.7	59.1	46.6	970.1
41	99.7	78.6	49.1	30.8	24.1	19.2	1379.5
53	98.5	77.7	48.5	30.2	23.8	18.9	1570.9
63	82.6	65.2	40.8	25.3	20.1	15.8	1717.7
78	57.0	45.1	28.0	17.7	14.0	11.0	2127.1
91	51.2	40.5	25.3	15.8	12.5	9.8	2452.0
103	39.9	31.4	19.5	12.2	9.8	7.6	2594.4
129	39.0	30.8	19.2	11.9	9.4	7.6	3982.8
155	32.9	25.9	16.2	10.1	7.9	6.4	5001.8
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.8a—Conduit-cable pulling chart for power cable SWBP = 1000 lbf/ft and *K′* = 0.3

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
¾	2392	1890	1180	737	582	460	341
1	1593	1258	786	490	387	306	435
1 ½	654	516	322	201	159	126	620
2	645	510	318	199	157	124	706
2 ½	542	428	267	167	132	104	772
3	374	296	185	115	91	72	956
3 ½	336	265	166	103	82	65	1102
4	261	206	129	80	63	50	1166
5	255	202	126	79	62	49	1790
6	215	170	106	66	52	41	2247
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.8b—Conduit-cable pulling chart for power cable SWBP = 14 600 N/m and *K′* = 0.3

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45º	90º	180º	270º	315º	360º	
21	729.1	576.1	359.7	224.6	177.4	140.2	1517.5
27	485.5	383.4	239.6	149.4	118.0	93.3	1935.8
41	199.3	157.3	98.1	61.3	48.5	38.4	2759.0
53	196.6	155.4	96.9	60.7	47.9	37.8	3141.7
63	165.2	130.5	81.4	50.9	40.2	31.7	3435.4
78	114.0	90.2	56.4	35.1	27.7	21.9	4254.2
91	102.4	80.8	50.6	31.4	25.0	19.8	4903.9
103	79.6	62.8	39.3	24.4	19.2	15.2	5188.7
129	77.7	61.6	38.4	24.1	18.9	14.9	7965.5
155	65.5	51.8	32.3	20.1	15.8	12.5	9999.2
Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size							

Table A.9a—Conduit-cable pulling chart for instrument cable SWBP = 300 lbf/ft and *K′* = 0.5

Conduit trade size	Maximum effective conduit length (ft) — Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45º	90º	180º	270º	315º	360º	
¾	767	518	236	108	73	49	102
1	504	340	155	71	48	32	131
1 ½	322	218	99	45	31	21	186
2	227	153	70	32	22	15	212
2 ½	168	114	52	24	16	11	232
3	134	91	41	19	13	9	287
3 ½	116	79	36	16	11	7	331
4	96	65	30	13	9	6	350
5	94	63	29	13	9	6	537
6	81	55	25	11	8	5	674
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.9b—Conduit-cable pulling chart for instrument cable SWBP = 4400 N/m and *K′* = 0.5

Conduit metric designator	Maximum effective conduit length (m) — Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45º	90º	180º	270º	315º	360º	
21	233.8	157.9	71.9	32.9	22.3	14.9	453.9
27	153.6	103.6	47.2	21.6	14.6	9.8	583.0
41	98.1	66.4	30.2	13.7	9.4	6.4	827.7
53	69.2	46.6	21.3	9.8	6.7	4.6	943.4
63	51.2	34.7	15.8	7.3	4.9	3.4	1032.4
78	40.8	27.7	12.5	5.8	4.0	2.7	1277.2
91	35.4	24.1	11.0	4.9	3.4	2.1	1473.0
103	29.3	19.8	9.1	4.0	2.7	1.8	1557.5
129	28.7	19.2	8.8	4.0	2.7	1.8	2389.7
155	24.7	16.8	7.6	3.4	2.4	1.5	2999.3
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.10a—Conduit-cable pulling chart for instrument cable SWBP = 500 lbf/ft and K' = 0.5

Conduit trade size	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
¾	875	591	269	123	83	56	117
1	840	567	259	118	80	54	218
1 ½	537	363	165	75	51	34	310
2	378	255	116	53	36	24	353
2 ½	280	189	86	39	27	18	386
3	224	151	69	31	21	14	478
3 ½	194	131	60	27	18	12	551
4	160	108	49	22	15	10	583
5	156	105	48	22	15	10	895
6	135	91	42	19	13	9	1124
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.10b—Conduit-cable pulling chart for instrument cable SWBP = 7300 N/m and K' = 0.5

Conduit metric designator	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
21	266.7	180.1	82.0	37.5	25.3	17.1	520.7
27	256.0	172.8	78.9	36.0	24.4	16.5	970.1
41	163.7	110.6	50.3	22.9	15.5	10.4	1379.5
53	115.2	77.7	35.4	16.2	11.0	7.3	1570.9
63	85.3	57.6	26.2	11.9	8.2	5.5	1717.7
78	68.3	46.0	21.0	9.4	6.4	4.3	2127.1
91	59.1	39.9	18.3	8.2	5.5	3.7	2452.0
103	48.8	32.9	14.9	6.7	4.6	3.0	2594.4
129	47.5	32.0	14.6	6.7	4.6	3.0	3982.8
155	41.1	27.7	12.8	5.8	4.0	2.7	5001.8
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.11a—Conduit-cable pulling chart for instrument cable SWBP = 300 lbf/ft and *K′* = 0.3

Conduit trade size	Maximum effective conduit length (ft) — Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45º	90º	180º	270º	315º	360º	
¾	1495	1181	737	460	364	287	102
1	983	777	485	303	239	189	131
1 ½	628	497	310	193	153	121	186
2	442	350	218	136	108	85	212
2 ½	328	259	162	101	80	63	232
3	262	207	129	81	64	50	287
3 ½	227	179	112	70	55	44	331
4	187	148	92	58	46	36	350
5	183	144	90	56	44	35	537
6	158	125	78	49	38	30	674
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.11b—Conduit-cable pulling chart for instrument cable SWBP = 4400 N/m and *K′* = 0.3

Conduit metric designator	Maximum effective conduit length (m) — Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45º	90º	180º	270º	315º	360º	
21	455.7	360.0	224.6	140.2	110.9	87.5	453.9
27	299.6	236.8	147.8	92.4	72.8	57.6	583.0
41	191.4	151.5	94.5	58.8	46.6	36.9	827.7
53	134.7	106.7	66.4	41.5	32.9	25.9	943.4
63	100.0	78.9	49.4	30.8	24.4	19.2	1032.4
78	79.9	63.1	39.3	24.7	19.5	15.2	1277.2
91	69.2	54.6	34.1	21.3	16.8	13.4	1473.0
103	57.0	45.1	28.0	17.7	14.0	11.0	1557.5
129	55.8	43.9	27.4	17.1	13.4	10.7	2389.7
155	48.2	38.1	23.8	14.9	11.6	9.1	2999.3
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.12a—Conduit-cable pulling chart for instrument cable SWBP = 500 lbf/ft and *K'* = 0.3

Conduit trade size	Maximum effective conduit length (ft) — Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45º	**90º**	**180º**	**270º**	**315º**	**360º**	
¾	1707	1348	842	525	415	328	117
1	1638	1294	808	504	399	315	218
1 ½	1047	828	517	322	255	201	310
2	737	583	364	227	179	142	353
2 ½	547	432	270	168	133	105	386
3	437	345	215	134	106	84	478
3 ½	378	299	186	116	92	73	551
4	312	246	154	96	76	60	583
5	304	241	150	94	74	59	895
6	264	208	130	81	64	51	1124
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table A.12b—Conduit-cable pulling chart for instrument cable SWBP = 7300 N/m and *K'* = 0.3

Conduit metric designator	Maximum effective conduit length (m) — Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45º	**90º**	**180º**	**270º**	**315º**	**360º**	
21	520.3	410.9	256.6	160.0	126.5	100.0	520.7
27	499.3	394.4	246.3	153.6	121.6	96.0	970.1
41	319.1	252.4	157.6	98.1	77.7	61.3	1379.5
53	224.6	177.7	110.9	69.2	54.6	43.3	1570.9
63	166.7	131.7	82.3	51.2	40.5	32.0	1717.7
78	133.2	105.2	65.5	40.8	32.3	25.6	2127.1
91	115.2	91.1	56.7	35.4	28.0	22.3	2452.0
103	95.1	75.0	46.9	29.3	23.2	18.3	2594.4
129	92.7	73.5	45.7	28.7	22.6	18.0	3982.8
155	80.5	63.4	39.6	24.7	19.5	15.5	5001.8
Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Annex B

(informative)

Use of conduit-cable pulling chart examples

This annex provides three examples of the use of the conduit-cable pulling charts in Annex A, Table A.1 through Table A.12.

B.1 Example #1

Control cables are being pulled into a 3 in trade size (metric designator size 78) conduit laid out as shown in Figure B.1. The properties of the pulling lubricant and the details of the SWBP capability of the cable are not known. The appropriate table is Annex A, Table A.1 (use Table A.1a or Table A.1b depending on the units), in which SWBP = 7300 N/m (500 lbf/ft) and $K' = 0.5$. Utilizing Table 3, the effective conduit length for each section can be determined, as shown in Table B.1.

The total effective conduit length is 7.6 m (25 ft) and the total degrees of bend are 270. From Annex A, Table A.1, the maximum effective conduit length is found to be 8.5 m (28 ft). Since the effective conduit length is less than the maximum value shown in Table A.1, the cables can be pulled into the conduit. Use of the bend correction (BendCorr) method (discussed in 7.4 and Annex D) is not necessary in this example.

If three or six cables of identical construction were being pulled into the conduit, a cable jam ratio would have to be calculated to ensure that a critical jam ratio condition did not exist.

Table A.1 provides a MAPT of 2127 N (478 lbf); therefore, a standard basket pulling-grip can be used. The minimum allowable working load of pull rope is 1.5 times the maximum allowable pulling tension: 1.5 × 2127.1 N = 3190.7 N (1.5 × 478 lbf = 717 lbf). From Table 6, a 9.5 mm (3/8 in) diameter double-braided polyester rope or a 16 mm (5/8 in) diameter three-strand polyester rope can be used. Figure B.2 illustrates the use of Equation (14)—PPT—which could be applied in this example also.

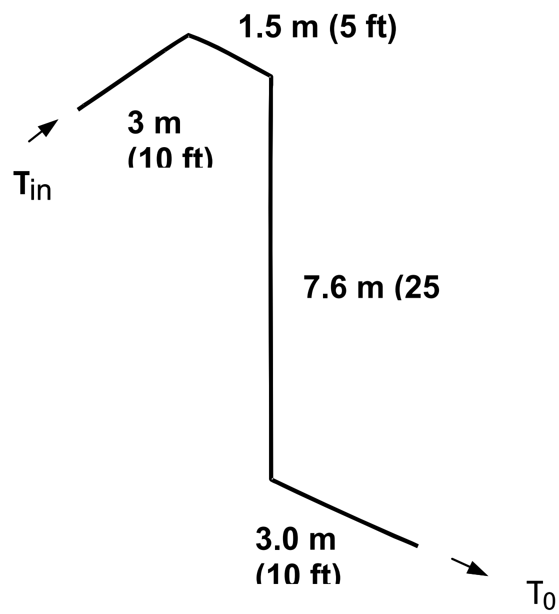


Figure B.1—Isometric of conduit layout—Example #1

Table B.1—Effective conduit length and degrees of bend—Example #1

Section type	Angle (º)	Measured conduit length, m (ft)	Effective conduit length, m (ft)
Straight horizontal		3 (10)	3 (10)
Horizontal bend	90		
Straight horizontal		1.5 (5)	1.5 (5)
Bend down	90		
Vertical down		7.6 (25)	0
Bend down	90		
Straight horizontal		3 (10)	3 (10)
End of pull (totals)	270		7.6 (25)

B.2 Example #2

Control cables are being pulled into a metric designator size 78 (3 inch trade size conduit) laid out as shown in Figure B.2. The cable fill in the conduit is 20%. The properties of the pulling lubricant and the SWBP capability of the cable have been obtained from the lubricant and cable manufacturers. The SWBP is 14 600 N/m (1000 lbf/ft) and the effective coefficient of friction (*K′*) for the type of lubricant and cable jacket material is 0.3. The appropriate table is Annex A, Table A.4 (use Table A.4a or Table A.4b depending on the units), in which SWBP = 14 600 N/m (1000 lbf/ft) and *K′* = 0.3. Utilizing Table 3, the effective conduit length for each section can be determined, as shown in Table B.2.

The total effective conduit length is 42.0 m (137.8 ft) and the total degrees of bend are 270. From Table A.4, a maximum conduit length of 73.2 m (240 ft) is found. Since the effective conduit length is less than the maximum value shown in Table A.4, the cables can be pulled into the conduit. If three cables were being pulled into the conduit, the cable jam ratio would have to be calculated to ensure that a critical jam ratio condition did not exist. Use of the BendCorr method (discussed in 7.4 and Annex D) is not necessary in this example.

Table A.4 provides an MAPT of 4250 N (955 lbf); therefore, a standard basket pulling grip can be used. The minimum allowable working load of pull rope is 1.5 times the MAPT; 1.5 × 4250 N = 6375 N (1.5 × 955 lbf = 1432.5 lbf). From Table 6, a 16 mm (5/8 in) diameter double-braided polyester rope or a 19 mm (3/4 in) diameter three-strand polyester rope can be used.

Alternately, the PPT from Equation (14) could be used to reduce the MAPT, thus enabling the use of a smaller pull rope and a better prediction of the pull tension. The existing cable fill in the conduit is 20%. This is calculated as shown in Equation (B.1):

$$\mathrm{PPT} = 4250 \times \frac{42.0}{73.2} \times \frac{20}{40} \times 1 = 1219.3 \qquad \mathrm{N} \qquad \text{(B.1a)}$$

$$\mathrm{PPT} = 955 \times \frac{137.8}{240} \times \frac{20}{40} \times 1 = 274.2 \qquad \mathrm{lbf} \qquad \text{(B.1b)}$$

where

L'	= 42.0 m (137.8 ft)
L	= 73.2 m (240 ft)
BendCorr	= 1 (conservatively picked)
Fill'	= 20%
Fill	= 40%

For a PPT of 1219.3 N (274.2 lbf), a 9.5 mm (3/8 in) diameter three-strand polyester rope could be used. Three workers will be necessary to pull the cable. This pull should be made in the opposite direction to that of example B.1.

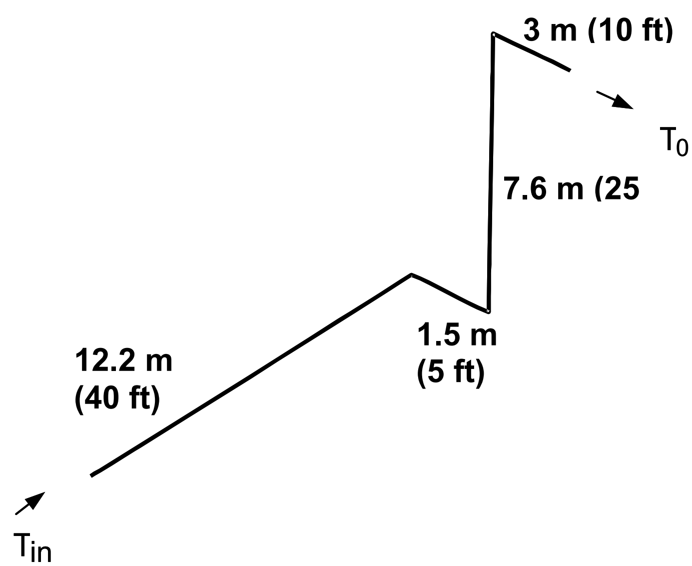


Figure B.2—Isometric of conduit layout—Example #2

Table B.2—Effective conduit length and degrees of bend—Example #2

Section type	Angle (º)	Measured conduit length m (ft)	Effective conduit length m (ft)
Straight horizontal		12.2 (40)	12.2 (40)
Horizontal bend	90		
Straight horizontal		1.5 (5)	1.5 (5)
Bend—Up	90		
Vertical—Up		7.6 (25)	7.6 × 3.33 = 25.3 m (25 × 3.33 = 83.3 ft)
Bend—Up	90		
Straight horizontal		3 (10)	3 (10)
End of pull (totals)	270		42.0 (137.8)

BendCorr could be calculated, further reducing the PPT. This calculation is performed as follows:

a) Express $L1$, $L2$, and $L3$ as a percentage of the total conduit length, L.

Metric:

1) $L1/L = 12.2/42.0 = 29\%$

2) $L2/L = 1.5/42.0 = 4\%$

3) $L3/L = (25.3 + 3)/42.0 = 67.4\%$

English:

4) $L1/L = 40/137.8 = 29\%$

5) $L2/L = 5/137.8 = 4\%$

6) $L3/L = (83.3 + 10)/137.8 = 67.7\%$

b) Reviewing the conduit configurations in Figure D.1, select the configuration with a $L1/L$ ratio that is equal to or larger than the calculated ratio of 29%. This would be configuration II, III, or IV ($L1/L$ of 33%, 50%, and 50%, respectively). There is little difference between the BendCorr factors for these configurations. Since $L2/L$ is very small, select configuration III ($L2/L$ =0). From Table D.2, the BendCorr factor for 270° is 0.67. Incorporating this lower BendCorr, PPT is recalculated as shown in Equation (B.2):

$$\text{PPT} = 4250 \times \frac{42.0}{73.2} \times \frac{20}{40} \times 0.67 = 816.9 \quad \text{N} \qquad \text{(B.2a)}$$

$$\text{PPT} = 955 \times \frac{137.8}{240} \times \frac{20}{40} \times 0.67 = 183.7 \quad \text{lbf} \qquad \text{(B.2b)}$$

B.3 Example #3

Control cables are being pulled into a 3 in trade size (metric designator size 78) conduit laid out as shown in Figure B.3. The cable fill in the conduit is 10%. The properties of the pulling lubricant and the SWBP capability of the cable have been obtained from the lubricant and cable manufacturers. The SWBP is 7300 N/m (500 lbf/ft) and the K' for the type of lubricant and cable jacket material is 0.3. The appropriate table is Annex A, Table A.3 (use Table A.3a or Table A.3b depending on the units), in which SWBP =

7300 N/m (500 lbf/ft) and K' = 0.3. Utilizing Table 3, the effective conduit for each section can be determined, as shown in Table B.3.

The total effective conduit length from Table B.3 is 37.4 m (123.3 ft) and the total degrees of bend are 270. From Table A.3, a maximum effective conduit length of 36.6 m (120 ft) is found. If the effective conduit length was found to be greater than the maximum value shown in Table A.3, additional evaluation would be necessary before this conduit section can be used. The methodology for the evaluation follows.

The maximum effective conduit length can be adjusted upwards by determining the BendCorr factor, from Annex D, as follows:

a) Express $L1$, $L2$, and $L3$ as a percentage of the total conduit length, L.

   Metric:

   1) $L1/L$ = 6.1/37.4 = 16.3%
   2) $L2/L$ = 3/37.4 = 8.0%
   3) $L3/L$ = (25.3 + 3)/37.4 = 75.7%

   English:

   4) $L1/L$ = 20/123.3 = 16.2%
   5) $L2/L$ = 10/123.3 = 8.1%
   6) $L3/L$ = (83.3 + 10)/123.3 = 75.7%

b) Reviewing the conduit configurations in Figure D.1, select the configuration whose $L1/L$ ratio is equal to or larger than the calculated ratio of 16.3%. This would be configuration II, III, or IV. There is little difference between the BendCorr factors of these configurations. Since $L2/L$ is very small, select configuration III ($L2/L$ =0). From Table D.2, the BendCorr factor for 270° is 0.67.

c) The maximum effective conduit length can be adjusted upwards to 36.6/ 0.67 = 54.6 m (120.0/0.67 = 179.1 ft).

The new maximum effective conduit length of 54.6 m (179.1 ft) is greater than the measured effective conduit length of 37.4 m (123.3 ft) from Table B.3. In many cases, it is more difficult to use BendCorr to adjust the maximum effective conduit length than it is to calculate the pulling tension, and therefore, this is not the preferred approach. The pulling tension equations and cable pulling limits should be used for such a calculation.

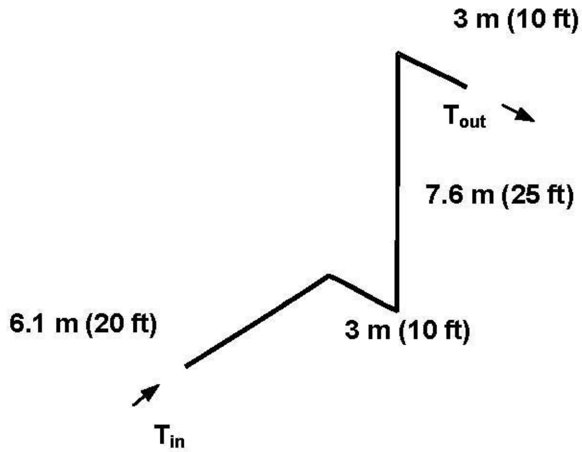


Figure B.3—Isometric of conduit layout—Example #3

Table B.3—Effective conduit length and degrees of bend—Example #3

Section type	Angle (°)	Measured conduit length, m (ft)	Effective conduit length, m (ft)
Straight horizontal		6.1 (20)	6.1 (20)
Horizontal bend	90		
Straight horizontal		3 (10)	3 (10)
Bend—Up	90		
Vertical—Up		7.6 (25)	7.6 × 3.33 = 25.3 m (25 × 3.33 = 83.3 ft)
Bend—Up	90		
Straight horizontal		3 (10)	3 (10)
End of pull (totals)	270		37.4 (123.3)

Annex C

(informative)

Conduit-cable pulling chart methodology

This annex describes the methodology used to develop the conduit-cable pulling charts in Annex A, Table A.1 through Table A.12.

C.1 Pulling tension calculation

The charts conservatively assume that all conduit bends are located at the end of the pull, as shown in Figure C.1. Placing bends at the beginning of the pull reduces pulling tension dramatically. The general design practice of avoiding unnecessary splices may preclude the selection of optimum pulling direction.

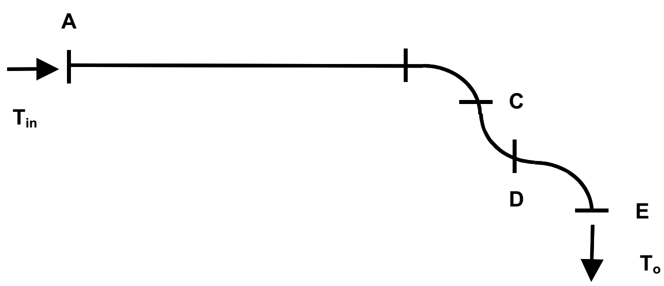


Figure C.1—Conduit layout—Chart development

The pulling tension, $T_{o,}$ at the end of the conduit system (point E) for a horizontal conduit system is shown in Equation (C.1):

$$T_o = L \times W_c \times g \times N \times K' \times e^{K \times A} \quad \text{N} \qquad \text{(C.1a)}$$

$$T_o = L \times W_c \times N \times K' \times e^{K \times A} \quad \text{lbf} \qquad \text{(C.1b)}$$

where

T_o = the cable tension out of the conduit, N (lbf)
L = the conduit length not including the length of the elbows, m (ft)
A = the sum of the angle of conduit bends, rad
K' = the effective coefficient of friction
W_c = the mass (weight) of the individual cable, kg/m (lbf/ft)
N = the number of cables in the conduit
g = gravitational constant (9.8 m/s^2)

For conduits installed vertically or on a slope, correction factors can be applied to actual length, *L,* instead of changing equations. The tension at point B for the various conduit configurations is as shown in Equation (C.2) through Equation (C.6):

$T_{B'}$	=	$L \times W_c \times 9.807 \times N \times K'$	horizontal, N	(C.2a)
$T_{B''}$	=	$-L \times W_c \times 9.807 \times N$	vertical down, N	(C.3a)
$T_{B'''}$	=	$L \times W_c \times 9.807 \times N$	vertical up, N	(C.4a)
$T_{B''''}$	=	$-L \times W_c \times 9.807 \times N \times (\sin\theta\ K' \times \cos\theta)$	slope down, N	(C.5a)
$T_{B'''''}$	=	$L \times W_c \times 9.807 \times N \times (\sin\theta + K' \times \cos\theta)$	slope up, N	(C.6a)
$T_{B'}$	=	$L \times W_c \times N \times K'$	horizontal, lbf	(C.2b)
$T_{B''}$	=	$-L \times W_c \times N$	vertical down, lbf	(C.3b)
$T_{B'''}$	=	$L \times W_c \times N$	vertical up, lbf	(C.4b)
$T_{B''''}$	=	$-L \times W_c \times N \times (\sin\theta - K' \times \cos\theta)$	slope down, lbf	(C.5b)
$T_{B'''''}$	=	$L \times W_c \times N \times (\sin\theta + K' \times \cos\theta)$	slope up, lbf	(C.6b)

where

θ = the angle of the slope in degrees

The correction factor used in Table 3 is the ratio of $T_{B''}/T_{B'}$, etc. For K'= 0.5, the correction for vertical conduit up is $1/K'$ or 2.0.

The use of $e^{K' \times A}$ for horizontal conduit bends is based on $T_{in} > 10 \times R \times W_c \times N$. This condition is satisfied when using standard elbows for rigid steel conduit, intermediate metal conduit (IMC), and electrical metallic tubing (EMT) with the bends placed at the end at the pull.

C.2 Maximum allowable tension

Maximum allowable cable tension is the lesser of conductor strength (T_{cond}), SWBP (T_{swbp}), or pulling grip limitations. Pulling grip limitations can be eliminated by stipulating a different attachment method when the chart's expected pulling tension exceeds the limit of the grip. T_{cond} and T_{swbp} are calculated as shown in Equation (C.7) and Equation (C.8):

$$T_{cond} = 70.5 \times n' \times N \times CMA \quad \text{N} \qquad \text{(C.7a)}$$

$$T_{cond} = 0.008 \times n' \times N \times CMA \quad \text{lbf} \qquad \text{(C.7b)}$$

$$T_{swbp} = \text{SWBP} \times R \quad \text{N or lbf} \qquad \text{(C.8)}$$

where

T_{cond} = the maximum allowable tension-conductor strength considerations, N (lbf)
T_{swbp} = the maximum allowable tension-SWBP considerations, N (lbf)
R = the conduit bend radius, m (ft)
n' = the number of conductors in the cable
N = the number of cables in the conduit
CMA = the area of the conductor, mm^2 (cmil)
SWBP= the sidewall bearing pressure limit on the cable, N/m (lbf/ft)

Equation (C.7) is based on a copper conductor and an equal distribution of tension between cables for multiple cable pulls. For pulls with a large number of cables, the tension may not be distributed equally. Tension distribution in some of the cables may be 20% to 30% greater than in other cables. Equation (C.7) provides a 100% margin over the yield strength of the conductor. Also, most entries in the chart are SWBP (T_{swbp}) limited rather than conductor strength (T_{cond}) limited. For these reasons, and to maintain consistency, Equation (C.7) is not de-rated for unequal tension distribution.

Equation (C.8) is for one cable in a pull. When applied to a multiple cable pull, results are conservative. For a large number of cables, actual T_{swbp} may be 2 to 5 times greater than Equation (C.8). See IEEE Committee Report [B17].

C.3 L_{cond}, L_{swbp}

The pulling charts provide the maximum conduit length between pull points. Typical pull points are at the pull box, conduit bodies, and electrical equipment. The pulling tension out of the conduit, T_o, varies with conduit length and degrees of bend. Maximum allowable conduit length, L_{cond} and L_{swbp}, can be established by setting $T_o = T_{swbp}$ and $T_o = T_{cond}$.

$$L_{cond} = \frac{70.5 \times n' \times N \times CMA}{K' \times e^{(K \times A)} \times W_c \times 9.807 \times N} \quad \text{m} \tag{C.9a}$$

$$L_{cond} = \frac{0.008 \times n' \times N \times CMA}{K' \times e^{(K \times A)} \times W_c \times N} \quad \text{ft} \tag{C.9b}$$

$$L_{swbp} = \frac{\text{SWBP} \times R}{K' \times e^{(K \times A)} \times W_c \times 9.807 \times N} \quad \text{m} \tag{C.10a}$$

$$L_{swbp} = \frac{\text{SWBP} \times R}{K' \times e^{(K \times A)} \times W_c \times N} \quad \text{ft} \tag{C.10b}$$

If it is stipulated that all cables in the conduit have the same number of conductors and the same size conductors, L_{cond} is independent of the number of cables in the conduit. A worst-case L_{cond} therefore occurs when strength to weight ratio (StWt) is a minimum [(StWt) = $n' \times CMA/W_c$]. For the specific range of cable construction the following minimum StWt were calculated:

a) Instrument cable: 1 pair 16 AWG to 12 pair 16 AWG, 2 pair 18 AWG to 12 pair 18 AWG; StWt = 90.6 mm^2/kg (81 kcmil/lb)

b) Control cable: Single conductor (1/C) or multiple conductors (2/C, 3/C, 4/C, 5/C, 7/C, 9/C and 12/C) in sizes 14 AWG and 12 AWG; StWt = 9.68 mm^2/kg (86.53 kcmil/lb)

c) Power cable: 1/C and 3/C in sizes 12 AWG to 750 kcmil; StWt = 146.2 mm^2/kg (130.6 kcmil/lb)

In computing L_{swbp}, $N \times W_c$ is the total weight of cables, W, in the conduit. The maximum number of cables permitted in a conduit using the NEC cable fill criteria was calculated for each cable construction. Total cable weight in a conduit, $W = N \times W_c$, is then compared for each of the different cables to arrive at the maximum total cable weight for a given size conduit. These cable weights are shown in Table C.1.

Table C.1—Maximum cable mass (weight) in conduit

Nominal conduit diameter, English trade size (metric designator)	Instrument cable, kg/m (lb/ft)	Control cable, kg/m (lb/ft)	Power cable, kg/m (lb/ft)
3/4 (21)	0.27 (0.18)	0.37 (0.22)	0.56 (0.38)
1 (27)	0.52 (0.35)	0.58 (0.39)	1.07 (0.72)
1-1/2 (41)	1.16 (0.78)	1.29 (0.87)	3.70 (2.5)
2 (53)	1.88 (1.26)	2.17 (1.46)	4.30 (2.88)
2 –1/2 (63)	1.88 (1.86)	3.10 (2.08)	5.58 (3.75)
3 (78)	2.77 (2.88)	4.72 (3.22)	10.0 (6.72)
3-1/2 (91)	5.71 (3.84)	6.41 (4.31)	12.86 (8.64)
4 (103)	7.32 (4.92)	8.26 (5.55)	17.50 (11.76)
5 (129)	11.52 (7.74)	13.00 (8.74)	27.50 (18.48)
6 (155)	16.70 (11.22)	18.78 (12.62)	40.92 (27.5)

C.4 Maximum effective conduit length

The maximum effective conduit length shown in the conduit-cable pulling charts is the smaller of L_{cond} or L_{swbp}. Since L_{swbp} varies with conduit radius, separate lengths are calculated for different size conduits.

Annex D

(informative)

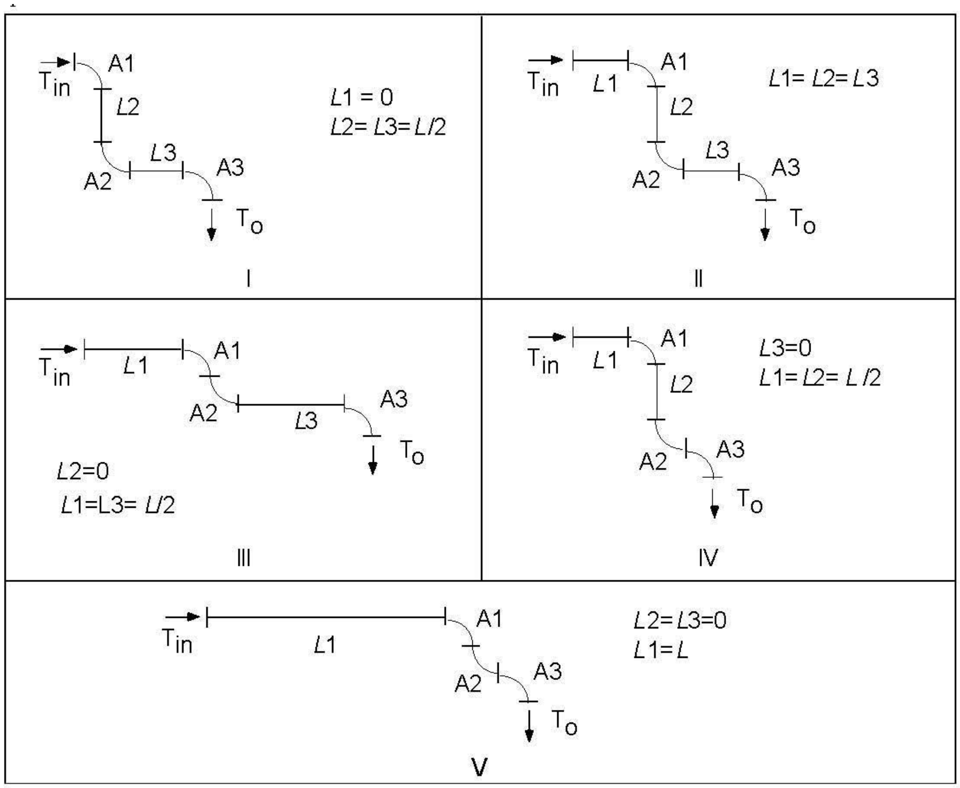
Conduit-cable pulling chart bend correction factor

The conduit-cable pulling charts are based on the conduit bends being located at the end of the cable pull. This results in conservative values. If the conduit bends are distributed throughout the conduit section, as is typical, then the maximum effective conduit length shown in the charts could be increased.

One approach, which takes into consideration conduit bends distributed throughout the conduit, is the use of bend correction (BendCorr) factors. This is not the preferred approach as discussed in 7.4 but may be convenient in some cases.

BendCorr factors were developed for five specific conduit configurations. Figure D.1 illustrates these five conduit layout configurations: I, II, III, IV, and V. BendCorr factors are taken from Table D.1 or Table D.2 after calculating the ratios *L*1/*L*, *L*2/*L*, and *L*3/*L* for the installed conduit system. The user then selects the configuration best matching the installed conduit system. The maximum effective conduit length shown in the conduit-cable pulling charts is increased by dividing the maximum effective conduit length by the BendCorr value shown in Table D.1 or Table D.2.

This method can be used only if the conduit bends divide evenly into the A1, A2, and A3 set of angles. Example B.3 illustrates the use of the BendCorr method.



A = A1 + A2 + A3

Figure D.1—Conduit layout—BendCorr factor

Table D.1—BendCorr adjustment factor—*K′* = 0.5

Configuration	Total degrees (A) of conduit bend						Layout
	45º	**90º**	**180º**	**270º**	**315º**	**360º**	
I	0.82	0.68	0.47	0.33	0.28	0.24	*L*1 =0, *L*2=*L*3≡*L*/2
II	0.88	0.79	0.65	0.55	0.52	0.49	*L*1=*L*2=*L*3≡*L*/3
III	0.88	0.80	0.68	0.60	0.58	0.56	*L*2=0, *L*1=*L*3≡*L*/2
IV	0.94	0.88	0.80	0.73	0.70	0.68	*L*3=0, *L*1=*L*2≡*L*/2
V	1	1	1	1	1	1	*L*2=*L*3=0, *L*1=*L*
A1 + A2 + A3 = A (total degrees of bend)							

Table D.2—BendCorr adjustment factor—*K′* = 0.3

Configuration	Total degrees (A) of conduit bend						Layout
	45º	**90º**	**180º**	**270º**	**315º**	**360º**	
I	0.89	0.79	0.63	0.51	0.46	0.41	*L*1 =0, *L*2=*L*3≡*L*/2
II	0.93	0.86	0.75	0.67	0.64	0.61	*L*1=*L*2=*L*3≡*L*/3
III	0.93	0.87	0.77	0.69	0.67	0.64	*L*2=0, *L*1=*L*3≡*L*/2
IV	0.96	0.93	0.87	0.81	0.79	0.77	*L*3=0, *L*1=*L*2≡*L*/2
V	1	1	1	1	1	1	*L*2=*L*3=0, *L*1=*L*
A1 + A2 + A3 = A (total degrees of bend)							

Annex E

(informative)

Glossary

For the purposes of this document, the following terms and definitions apply. These and other terms within IEEE standards are found in *The IEEE Standards Dictionary: Glossary of Terms & Definitions*.[10]

AWG: American Wire Gauge designation for conductor sizes used primarily in North America. The AWG number is inversely proportional to the cross-sectional area of the conductor.

break link: A weak section of rope connected between the cable pulling attachment and the pull rope that is intended to break when the pulling tension exceeds a certain limit.

cable pullback: The pulling of one or more cables out of a conduit system for the express purpose of repulling the cables into the same conduit.

cable pullby: The pulling of cable(s) into a conduit that already contains one or more cables.

control cable: Cable used in a control function application, e.g., interconnection of control switches, indicating lights, relays, solenoids. Generally the cable construction is 600 V or 1000 V, single or multiple conductors, typically in wire sizes 14 AWG, 12 AWG, 10 AWG, or 8 AWG.

cable jamming ratio: The ratio of conduit inside diameter (D) to cable outside diameter (d) that could result in the cable wedging or jamming in the conduit during the cable pull.

circular mil (cmil): The area of a circle whose diameter is one mil (one mil is one-thousandth of an inch)

$$1 \text{ cmil} = 7.854 \times 10^{-7} \text{ in}^2 \ (5.067 \times 10^{-4} \text{ mm}^2)$$

galloping: Stopping and sudden surging of cable during high-tension pulls when excessive pull rope stretching occurs.

instrument cable: Cable used for instrument applications where the cable construction is generally 300 V, (but may be 600 V) twisted pairs or triads, in wire sizes 16 AWG or 18 AWG. For the purposes of this document, coaxial, tri-axial, fiber optic, telephone, data communication, and other specialty cables are not considered instrument cable.

low-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 600 V to 2000 V in sizes ranging from 14 AWG to 2000 kcmil.

lubricant: Any material applied on the cable or into a conduit to reduce friction and hence tension during cable pulling operations.

luff: Pulling additional cable out of the conduit, using a split grip or mare's tail, to be used to facilitate terminating, racking, etc.

medium-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, having voltage ratings above 2000 V in sizes ranging from 8 AWG to 2000 kcmil.

[10] *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at http://shop.ieee.org/.

power cable: Cable used to supply power to plant auxiliary system devices. The classifications for power cable are: low voltage and medium voltage.

pull rope: A rope, attached to the cable that is used to pull the cable through the conduit system. *Syn:* bull rope; fish tape: pull line.

raceway: Any channel designed for supporting and conveying wire, cable, or bus bars. Raceway consists primarily of but is not limited to tray, conduit, wire ways, ducts, and duct banks.

Annex F

(informative)

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[16] ICEA publications are available from ICEA, P.O. Box 20048, Minneapolis, MN 55420, USA (http://www.icea.org/).
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[18] This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.
[19] The IEEE standards or products referred to in Annex F are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.
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