Important Notice

IEEE Guide for Installation Methods for Generating Station Cables

Sponsor

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Abstract: Installation methods to improve cable installation practices in generating stations are provided. These include cable lubrication methods, conduit-cable pulling charts, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pulling tension monitoring. This guide supplements IEEE Std 422-1986 and IEEE Std 690-1984, which provide specific cable installation limits. This guide may also be of benefit to cable pulling crews in commercial and industrial facilities when similar cable types and raceways are used.
Keywords: cable lubrication techniques, cable pullback, cable pullby, cable pulling tension limiting methods, conduit-cable pulling charts, pull rope attachment methods, pull rope selection criteria

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Introduction

(This introduction is not a part of IEEE Std 1185-1994, IEEE Guide for Installation Methods for Generating Station Cables.)

Construction of generating stations involves the installation of a large number of cables in conduits, trays, and duct banks. The majority of these cables are unshielded. Except in duct banks, where water may be present, there is usually no continuous ground plane on the outside of the cable insulation to allow effective post-installation voltage testing of the cable.

Since the effectiveness of post-installation testing of cable is limited, more emphasis should be placed on the method of installing the cable. IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations, and IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class IE Circuits in Nuclear Power Generating Stations, provide recommended cable installation limits, e.g., allowable conductor strength, sidewall bearing pressure, pulling tension equations, etc. In many situations, detailed installation methods are needed to complement these installation limits. These include cable lubrication methods, conduit-cable pulling charts, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pulling tension monitoring.

Improved installation methods are also expected to increase confidence in the ability of the installed cable to function in the accident environments of power generating stations.

Monitoring pulling tensions is an effective approach to ensuring that the cable pulling limits, such as sidewall bearing pressure and conductor strength, are not exceeded. However, for many cable pulls the setup time to monitor the tension is prohibitive. Most of the cable pulls are manual pulls. When a manual cable pull in 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 guide introduces the use of conduit-cable pulling charts and other methods as alternatives to direct monitoring of the pulling tensions.

Cable pullby is a common practice in the industry though not addressed in either cable manufacturer literature or existing industry standards. Some utilities have reported damage to the existing cables in the conduits when pulling cables into conduits that already contain cables, i.e., cable pullbys. Monitoring the pulling tensions may not prevent this cable damage, since the damage can occur from the pull rope as the pull rope or cable passes over existing cables. Instead of prohibiting the practice of cable pullbys, installation methods with modifying restrictions are provided to control the process. However, it should be recognized that this is a risky procedure and damaged cables or questionable conditions can result from such pullby operations.

AEIC G5-90, Underground Extruded Power Cable Pulling Guide, will complement this guide for long power cable pulls through duct bank systems and should be considered as an additional reference source. Work is in progress under IEEE P971, Guide for Distribution Cable Installation Methods in Duct Systems.

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Contents

CLAUSE PAGE

1. Overview 1

1.1 Scope 1
1.2 Purpose 1

2. References 1

3. Definitions 2

4. Conduit-cable pulling charts 3

4.1 General 3
4.2 Cable types and raceway configurations 4
4.3 Use of conduit-cable pulling charts 4
4.4 Bend correction adjustment 6
4.5 Examples 6
4.6 Methodology 6
4.7 Pulling tension 6

5. Cable pulling attachment methods 19

5.1 General 19
5.2 Basket-type pulling grips 19
5.3 Compression-type pulling eyes 19
5.4 Wedge-type pulling eyes 19
5.5 Mare's tails 19
5.6 Swivels 20

6. Pull rope selection 20

6.1 General 20
6.2 Guidelines for pull rope selection 20
6.3 Precautions 20

7. Lubrication techniques 22

7.1 When to use lubricant 22
7.2 Lubricant quantity 22
7.3 Methods of lubricating conduit systems 23
7.4 Cable jacket lubrication 23
7.5 Lubrication procedure 23
7.6 Clean up and safety 24

8. Tension limiting methods 24

8.1 General 24
8.2 Limiting size of pulling crew 24
8.3 Dynamometer 24
8.4 Break link 25

9. Cable pullbys 25

9.1 General 25
9.2 Conditions for potentially successful pullbys 25
9.3 Installation practices 26
9.4 Post-pullby testing 27

10. Pullbacks 27

10.1 General 27
10.2 Cable inspection 28
10.3 Installation practices 28

11. Bibliography 29

ANNEX

A (normative) Examples—Use of conduit-cable pulling charts 30

B (normative) Methodology—Conduit-cable pulling charts 35

C (normative) Bend correction factor—Conduit-cable pulling charts 39

IEEE Guide for Installation Methods for Generating Station Cables

1. Overview

1.1 Scope

This guide provides installation methods to improve cable installation practices in generating stations. Some specific limits in cable installation are covered in IEEE Std 422-1986[1] and IEEE Std 690-1984 and are not within the scope of this guide.

This guide may also be of benefit to cable pulling crews in commercial and industrial facilities when similar cable types and raceways are used.

1.2 Purpose

The purpose of this guide is to improve cable pulling practices in generating stations by:

a) Establishing alternative methods of limiting and monitoring cable pulling tensions to prevent cable damage from excessive pulling tension
b) Introducing the use of cable pull charts that address cable pulling limits including sidewall bearing pressure, and relationship of conduit length and total conduit bends
c) Establishing safe guidelines for pulling cables into conduits containing cables (pullbys)
d) Providing practical guidance in lubrication techniques, pull rope attachment methods, and pull rope selection
e) Facilitating good conduit system layout to permit the safe installation of cables in most raceways without the need for difficult monitoring or costly, rigorous calculations

2. References

This guide shall be used in conjunction with the following references.

ANSI/NEMA WC 55-1992 (ICEA S-82-552), Instrumentation Cables and Thermocouple Wire.[2]

ANSI/NEMA WC 57-1990 (ICEA S-73-532), Standard for Control Cables.

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[1]Information on references can be found in clause 2.
[2]NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

ANSI/NFPA 70-1993, National Electrical Code (NEC).[3]

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[4]

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

IEEE Std 422-1986, IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations (ANSI).

IEEE Std 690-1984, IEEE Standard for the Design and Installation of Cable Systems for Class IE Circuits in Nuclear Power Generating Stations (ANSI).

NEMA WC 3-1992 (ICEA S-19-81), Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 5-1992 (ICEA S-61-402), Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 7-1993 (ICEA S-66-524), Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

NEMA WC 8-1993 (ICEA S-68-516), Ethylene-Propylene-Rubber Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

3. Definitions

The following definitions are provided to describe terms used in this guide. For definitions of other terms, see IEEE Std 100-1992.

3.1 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.

3.2 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.

NOTE—Cable pullback is normally performed to allow relocation of a portion of a conduit system or to avoid pullbys during the installation of additional cables.

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

3.4 control cable: Cable used in a control function application, e.g., interconnection of control switches, indicating lights, relays, solenoids, etc. Generally the cable construction is 600 V or 1000 V, single or multiple conductors, typically in wire sizes 14 AWG (2.08 mm^2), 12 AWG (3.31 mm^2), 10 AWG (5.26 mm^2), 9 AWG (6.63 mm^2), or 8 AWG (8.37 mm^2).

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

[3]ANSI/NFPA publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA, and also from Publications Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3.6 galloping: The sudden surging and stopping action of cables during high-tension pulls when excessive stretching occurs in the pull rope.

3.7 instrument cable: Cable used for instrument applications where the cable construction is generally 300 V, twisted pairs or triads, in wire sizes 16 AWG (1.31 mm^2) or 18 AWG (0.823 mm^2). For the purposes of this document, coaxial, triaxial, and fiber optic cables are not considered instrument cable because of differences in cable installation limits.

3.8 low-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 600 V or 2000 V in sizes ranging from 14 AWG (2.08 mm^2) to 2000 kcmil (1010.0 mm^2).

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

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

3.11 medium-voltage power cable: Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 5000–46 000 V in sizes ranging from 8 AWG (8.37 mm^2) to 2000 kcmil (1010.0 mm^2).

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

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

4. Conduit-cable pulling charts

4.1 General

The majority of generating station cable pulls in conduit systems are manual pulls. Monitoring the pull tensions for manual pulls is 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.

A preferred 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 provide a written record for comparing allowable and actual measured pulling tensions. The conduit-cable pulling charts address the cable pulling limits outlined in IEEE Std 422-1986 and IEEE Std 690-1984. This includes allowable conductor strength, sidewall bearing pressure, and jacket strength limits. Cable jamming is not addressed in the pulling charts and should be checked separately as discussed in 4.2 item e).

The conduit-cable pulling charts may also be used as guides in 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.

4.2 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 tables 3 through 14 are based on the following conditions:

a) The radius of conduit bends are assumed to be equal to or greater than those specified in the National Electrical Code (NEC) (ANSI/NFPA 70-1993) table 346-10 Exception “Radius of Conduit Bends (inches).”

b) The cable constructions are assumed to conform to one of the following:

   1) ANSI/NEMA WC 55-1992 (ICEA-S-82-552)
   2) ANSI/NEMA WC 57-1990 (ICEA-S-73-532)
   3) NEMA WC 3-1992 (ICEA-S-19-81)
   4) NEMA WC 5-1992 (ICEA-S-61-402)
   5) NEMA WC 7-1993 (ICEA-S-66-524)
   6) NEMA WC 8-1993 (ICEA-S-68-516)

   Smallest conductor sizes for the various cable types are: two pair 18 AWG (0.823 mm^2) for instrument cable, single conductor 14 AWG (2.08 mm^2) for control cable, and single conductor 12 AWG (3.31 mm^2) for low-voltage power cable. Conductor material is copper. The cable outer sheath is not armored or lead sheathed. Cable pulling calculations are necessary for armored or lead sheathed cables.

c) The cable sidewall bearing pressure (SWBP) limits vary with cable construction and cable supplier. Charts for two different SWBP limits were developed. In the absence of specific cable manufacturer SWBP data, charts for control and power cable using SWBP = 500 lbf/ft (7297 N/m) of bend radius and instrument cable using SWBP = 300 lbf/ft (4378 N/m) of bend radius should be used.

d) Conduit-cable fill does not exceed the NEC fill limits of 53% for one cable, 3% 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 jamming ratio D/d between 2.8 and 3.1 (see IEEE Std 422-1986).

   When three cables are pulled into a conduit, it is possible for the center cable to be forced between the two outer cables while being pulled around a bend if the D/d ratio approaches a value of 3.0. Up to a ratio of 2.5, the cables are constrained into a triangular configuration. However, as the value approaches 3.0, jamming of the cables could occur, and the cables could freeze in the conduit, causing serious cable damage. To allow for tolerances in cable and conduit sizes and for ovalness in the conduit at a bend, the D/d ratios between 2.8 and 3.1 should be avoided.

f) The proper cable lubrication techniques as discussed in clause 7 are followed. Charts for two values of effective coefficient of friction (K') were developed (0.35 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 [B2][5], [B4], and [B5] should be used to obtain the coefficient of friction and the weight correction factor.

g) The limitations given for pullbys in clause 9 are adhered to.

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

4.3 Use of conduit-cable pulling charts

The maximum effective conduit length given in the conduit-cable pulling charts presented in tables 3 through 14 should be used as a limitation in cable pulling. If the conditions of the pull are not consistent with

[5]The numbers in brackets correspond to those in the bibliography in clause 11.

the assumptions described in 4.2, or the effective 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 IEEE Std 422-1986 or IEEE Std 690-1984.

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 has to be developed. The effective conduit length and the total degrees of angle in the pull are compared to the charts. The effective conduit length is developed as shown in table 1.

Field measurements in congested areas of a generating plant 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 should be within 2% and total conduit angle measurements should be within 15°. The slope adjustment factor (SAF) can be taken from either equation (1) or from table 2 for specific combinations of effective coefficient of friction and slope angles. SAF, for use in table 1, adjusts the measured length of sloped sections of conduits to arrive at an effective conduit length.

$$SAF = \frac{\sin\theta + K'\cos\theta}{K'} \qquad (1)$$

where

SAF is the slope adjustment factor, used in table 1
θ is the angle (in degrees) of the slope from horizontal
K' is the effective coefficient of friction

Table 1—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 2.9 for K' = 0.35
Vertical conduit—Down	Not included; L = 0
Slope—Down	As measured
Slope—Up	As measured multiplied by *SAF* from equation (1) or table 2

Table 2—Slope adjustment factor (SAF)

Slope angle (°)	Effective coefficient of friction (K')	
	0.5	0.35
15	1.5	1.7
30	1.9	2.3
45	2.1	2.7
60	2.2	2.9

4.4 Bend correction adjustment

The conduit-cable pulling charts are based upon all of the conduit bends 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 user may consider one of the following:

a) Performing a detailed cable pulling calculation using the pulling equations listed in IEEE Std 422-1986 or IEEE Std 690-1984. 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 C.

4.5 Examples

Examples illustrating the use of the conduit-cable pulling charts are included in annex A.

4.6 Methodology

The conduit-cable pulling charts are influenced by cable construction, allowable cable fill in conduits, coefficient of friction, location and number of conduit bends, radius of conduit elbows, and SWBP. Some may find it desirable to develop new charts using project-specific information. The methodology used to develop the conduit-cable pulling charts is presented in annex B.

4.7 Pulling tension

Maximum allowable pulling tensions (MAPT) have been provided in the 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 (2) can be used to arrive at a projected pulling tension (PPT). The BendCorr factor in equation (2) can be obtained from tables C.1 and C.2, or conservatively assumed to be equal to 1.

$$PPT = MAPT \cdot \frac{L'}{L} \cdot \frac{Fill'}{Fill} \cdot BendCorr \qquad (2)$$

where

PPT	is the projected pulling tension, lbf (N)
MAPT	is the maximum allowable pulling tension, lbf (N) (from tables 3 through 14)
L'	is the effective conduit length, ft (m)
L	is the maximum length of conduit, ft (m) (from tables 3 through 14)
BendCorr	is the distribution of conduit bends. This varies from 0.25 to 1, decreasing as the conduit bends are located at the front of the pull (see tables C.1 and C.2)
Fill'	is the percentage of cable fill of conduit after the cable pull
Fill	is the chart maximum conduit-cable fill, which is 40%

Table 3a—Control cable—Conduit-cable pulling chart
SWBP = 500 lbf/ft and *K*′ = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	935	631	288	131	89	60	66
1.0	754	509	232	106	71	48	132
1.5	483	326	149	68	46	31	310
2.0	327	221	101	46	31	21	353
2.5	251	169	77	35	24	16	386
3.0	200	135	62	28	19	13	478
3.5	173	117	53	24	16	11	551
4.0	142	96	44	20	13	9	583
5.0	138	93	43	19	13	9	895
6.0	120	81	37	17	11	8	1124
NOTE—Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size.							

Table 3b—Control cable—Conduit-cable pulling chart
SWBP = 7297 N/m and *K*′ = 0.5

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	284.9	192.4	87.7	40.0	27.0	18.2	293.6
2.5	229.8	155.2	70.7	32.2	21.8	14.7	587.1
3.8	147.1	99.3	45.3	20.7	13.9	9.4	1379.8
5.1	99.7	67.3	30.7	14.0	9.4	6.4	1569.3
6.4	76.5	51.7	23.6	10.7	7.3	4.9	1717.4
7.6	61.0	41.2	18.8	8.6	5.8	3.9	2125.3
8.9	52.6	35.5	16.2	7.4	5.0	3.4	2451.3
10.2	43.2	29.2	13.3	6.1	4.1	2.8	2592.3
12.7	42.1	28.5	13.0	5.9	4.0	2.7	3980.5
15.2	36.7	24.8	11.3	5.1	3.5	2.3	4999.6
NOTE—Minimum one single conductor 2.08 mm^2 or one multiple conductor 2.08 mm^2 conductor size.							

Table 4a—Control cable—Conduit-cable pulling chart SWBP = 1000 lbf/ft and *K′* = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	935	631	288	131	89	60	152
1.0	935	631	288	131	89	60	270
1.5	935	631	288	131	89	60	601
2.0	654	442	201	92	62	42	706
2.5	502	339	155	70	48	32	772
3.0	400	270	123	56	38	26	956
3.5	345	233	106	48	33	22	1102
4.0	284	192	87	40	27	18	1166
5.0	277	187	85	39	26	18	1790
6.0	241	162	74	34	23	15	2247
NOTE—Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size							

Table 4b—Control cable—Conduit-cable pulling chart SWBP = 14 593 N/m and *K′* = 0.5

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	284.9	192.4	87.7	40.0	27.0	18.2	677.4
2.5	284.9	192.4	87.7	40.0	27.0	18.2	1201.0
3.8	284.9	192.4	87.7	40.0	27.0	18.2	2672.4
5.1	199.3	134.6	61.4	28.0	18.9	12.8	3138.1
6.4	153.0	103.3	47.1	21.5	14.5	9.8	3434.3
7.6	122.0	82.4	37.6	17.1	11.6	7.8	4250.1
8.9	105.3	71.1	32.4	14.8	10.0	6.7	4901.7
10.2	86.5	58.4	26.6	12.1	8.2	5.5	5186.4
12.7	84.3	56.9	25.9	11.8	8.0	5.4	7961.9
15.2	73.3	49.5	22.6	10.3	6.9	4.7	9994.7
NOTE—Minimum one single conductor 2.08 mm^2 or one multiple conductor 2.08 mm^2 conductor size.							

Table 5a—Control cable—Conduit-cable pulling chart
SWBP = 500 lbf/ft and *K*′ = 0.35

Conduit size (in)	Maximum effective conduit length (ft) Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45°	90°	180°	270°	315°	360°	
0.75	1502	1141	659	380	289	219	152
1.0	1212	921	531	307	233	177	218
1.5	776	589	340	196	149	113	310
2.0	526	399	230	133	101	77	353
2.5	403	307	177	102	78	59	386
3.0	322	244	141	81	62	47	478
3.5	278	211	122	70	53	41	551
4.0	228	173	100	58	44	33	583
5.0	222	169	97	56	43	32	895
6.0	193	147	85	49	37	28	1124

NOTE—Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size.

Table 5b—Control cable—Conduit-cable pulling chart
SWBP = 7297 N/m and *K*′ = 0.35

Conduit size (cm)	Maximum effective conduit length (m) Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45°	90°	180°	270°	315°	360°	
1.9	457.8	347.8	200.7	115.9	88.0	66.8	677.4
2.5	369.4	280.6	161.9	93.4	71.0	53.9	968.3
3.8	236.4	179.6	103.6	59.8	45.4	34.5	1379.8
5.1	160.2	121.7	70.2	40.5	30.8	23.4	1569.3
6.4	123.0	93.4	53.9	31.1	23.6	18.0	1717.4
7.6	98.0	74.5	43.0	24.8	18.8	14.3	2124.8
8.9	84.6	64.3	37.1	21.4	16.3	12.4	2451.3
10.2	69.5	52.8	30.5	17.6	13.4	10.1	2592.3
12.7	67.7	51.5	29.7	17.1	13.0	9.9	3980.5
15.2	58.9	44.7	25.8	14.9	11.3	8.6	4999.6

NOTE—Minimum one single conductor 2.08 mm^2 or one multiple conductor 2.08 mm^2 conductor size.

Table 6a—Control cable—Conduit-cable pulling chart
SWBP = 1000 lbf/ft and *K′* = 0.35

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	1502	1141	659	380	289	219	152
1.0	1502	1141	659	380	289	219	270
1.5	1502	1141	659	380	289	219	601
2.0	1051	798	461	266	202	153	706
2.5	807	613	354	204	155	118	772
3.0	643	489	282	163	124	94	956
3.5	555	422	243	140	107	81	1102
4.0	456	346	200	115	88	67	1166
5.0	444	338	195	112	85	65	1790
6.0	387	294	170	98	74	56	2247

NOTE—Minimum one single conductor 14 AWG or one multiple conductor 14 AWG conductor size.

Table 6b—Control cable—Conduit-cable pulling chart
SWBP = 14 593 N/m and *K′* = 0.35

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	457.8	347.8	200.7	115.9	88.0	66.8	677.4
2.5	457.8	347.8	200.7	115.9	88.0	66.8	1201.0
3.8	457.8	347.8	200.7	115.9	88.0	66.8	2672.4
5.1	320.3	243.4	140.4	81.0	61.6	46.8	3138.1
6.4	245.9	186.8	107.8	62.2	47.3	35.9	3434.3
7.6	196.1	149.0	86.0	49.6	37.7	28.6	4250.1
8.9	169.2	128.5	74.2	42.8	32.5	24.7	4901.7
10.2	139.0	105.6	60.9	35.1	26.7	20.3	5186.4
12.7	135.4	102.9	59.4	34.3	26.0	19.8	7961.9
15.2	117.8	89.5	51.7	29.8	22.6	17.2	9994.7

NOTE—Minimum one single conductor 2.08 mm^2 or one multiple conductor 2.08 mm^2 conductor sizes

Table 7a—Power cable—Conduit-cable pulling chart SWBP = 500 lbf/ft and *K′* = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	613	414	189	86	58	39	170
1.0	408	276	126	57	39	26	218
1.5	168	113	52	24	16	11	310
2.0	165	112	51	23	16	11	353
2.5	139	94	43	20	13	9	386
3.0	96	65	30	13	9	6	478
3.5	86	58	27	12	8	6	551
4.0	67	45	21	9	6	4	583
5.0	65	44	20	9	6	4	895
6.0	55	37	17	8	5	4	1124
NOTE—Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size.							

Table 7b—Power cable—Conduit-cable pulling chart SWBP = 7297 N/m and *K′* = 0.5

Conduit size (cm)	Maximum effective conduit lengtH (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	187.0	126.2	57.5	26.2	17.7	12.0	757.5
2.5	124.5	84.1	38.3	17.5	11.8	8.0	968.3
3.8	51.1	34.5	15.7	7.2	4.8	3.3	1379.8
5.1	50.4	34.0	15.5	7.1	4.8	3.2	1569.3
6.4	42.4	28.6	13.0	5.9	4.0	2.7	1717.4
7.6	29.3	19.8	9.0	4.1	2.8	1.9	2125.3
8.9	26.3	17.7	8.1	3.7	2.5	1.7	2451.3
10.2	20.4	13.8	6.3	2.9	1.9	1.3	2592.3
12.7	19.9	13.5	6.1	2.8	1.9	1.3	3980.5
15.2	16.8	11.4	5.2	2.4	1.6	1.1	4999.6
NOTE—Minimum one single conductor 3.31 mm^2 or one multiple conductor 3.31 mm^2 conductor size.							

Table 8a—Power cable—Conduit-cable pulling chart
SWBP = 1000 lbf/ft and *K′* = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	1227	828	378	172	116	79	341
1.0	817	552	252	115	77	52	436
1.5	335	226	103	47	32	21	620
2.0	331	223	102	46	31	21	706
2.5	278	188	86	39	26	18	772
3.0	192	130	59	27	18	12	956
3.5	172	116	53	24	16	11	1102
4.0	134	90	41	19	13	9	1166
5.0	131	88	40	18	12	8	1790
6.0	110	75	34	15	10	7	2247
NOTE—Minimum one single conductor 12 AWG or one multiple conduct or 12 AWG conductor size.							

Table 8b—Power cable—Conduit-cable pulling chart
SWBP = 14 593 N/m and *K′* = 0.5

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	374.0	252.5	115.1	52.5	35.4	23.9	1515.4
2.5	249.0	168.1	76.7	34.9	23.6	15.9	1937.1
3.8	102.1	69.0	31.5	14.3	9.7	6.5	2759.5
5.1	100.8	68.1	31.1	14.2	9.6	6.5	3138.1
6.4	84.8	57.2	26.1	11.9	8.0	5.4	3434.3
7.6	58.5	39.5	18.0	8.2	5.5	3.7	4250.1
8.9	52.5	35.4	16.2	7.4	5.0	3.4	4901.7
10.2	40.8	27.5	12.6	5.7	3.9	2.6	5186.4
12.7	39.9	26.9	12.3	5.6	3.8	2.6	7961.9
15.2	33.6	22.7	10.4	4.7	3.2	2.2	9994.7
NOTE—Minimum one single conductor 3.31 mm^2 or one multiple conductor 3.31 mm^2 conductor size.							

Table 9a—Power cable—Conduit-cable pulling chart SWBP = 500 lbf/ft and *K′* = 0.35

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	31°	360°	
0.75	986	749	432	249	190	144	170
1.0	656	499	288	166	126	96	218
1.5	269	205	118	68	52	39	310
2.0	266	202	117	67	51	39	353
2.5	223	170	98	57	43	33	386
3.0	154	117	68	39	30	23	478
3.5	138	105	61	35	27	20	551
4.0	108	82	47	27	21	16	583
5.0	105	80	46	27	20	15	895
6.0	89	67	39	22	17	13	1124

NOTE—Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size.

Table 9b—Power cable—Conduit-cable pulling chart SWBP = 7297 N/m and *K′* = 0.35

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	300.5	228.3	131.7	76.0	57.8	43.9	757.5
2.5	200.0	152.0	87.7	50.6	38.4	29.2	968.3
3.8	82.1	62.4	36.0	20.8	15.8	12.0	1379.8
5.1	81.0	61.6	35.5	20.5	15.6	11.8	1569.3
6.4	68.1	51.7	29.9	17.2	13.1	9.9	1717.4
7.6	47.0	35.7	20.6	11.9	9.0	6.9	2124.8
8.9	42.2	32.1	18.5	10.7	8.1	6.2	2451.3
10.2	32.8	24.9	14.4	8.3	6.3	4.8	2592.3
12.7	32.0	24.3	14.0	8.1	6.2	4.7	3980.5
15.2	27.0	20.5	11.9	6.8	5.2	3.9	4999.6

NOTE—Minimum one single conductor 3.31 mm^2 or one multiple conductor 3.31 mm^2 conductor size.

Table 10a—Power cable—Conduit-cable pulling chart
SWBP = 1000 lbf/ft and *K*′ = 0.35

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	1972	1498	864	499	379	288	341
1.0	1313	997	576	332	252	192	436
1.5	539	409	236	136	104	79	620
2.0	532	404	233	135	102	78	706
2.5	447	340	196	113	86	65	772
3.0	309	234	135	78	59	45	956
3.5	277	210	121	70	53	40	1102
4.0	215	163	94	54	41	31	1166
5.0	210	160	92	53	40	3	1790
6.0	177	135	78	45	34	26	2247
NOTE—Minimum one single conductor 12 AWG or one multiple conductor 12 AWG conductor size.							

Table 10b—Power cable—Conduit-cable pulling chart
SWBP = 14 593 N/m and *K*′ = 0.35

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	601.1	456.6	263.5	152.0	115.5	87.8	1515.4
2.5	400.2	303.9	175.4	101.2	76.9	58.4	1937.1
3.8	164.2	124.7	72.0	41.5	31.5	24.0	2759.5
5.1	162.1	123.1	71.0	41.0	31.2	23.7	3138.1
6.4	136.2	103.5	59.7	34.5	26.2	19.9	3434.3
7.6	94.1	71.4	41.2	23.8	18.1	13.7	4250.1
8.9	84.4	64.1	37.0	21.3	16.2	12.3	4901.7
10.2	65.6	49.8	28.7	16.6	12.6	9.6	5186.4
12.7	64.1	48.7	28.1	16.2	12.3	9.4	7961.9
15.2	54.1	41.1	23.7	13.7	10.4	7.9	9994.7
NOTE—Minimum one single conductor 3.31 mm^2 or one multiple conductor 3.31 mm^2 conductor size.							

Table 11a—Instrument cable—Conduit-cable pulling chart
SWBP = 300 lbf/ft and *K′* = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	875	591	269	123	83	56	117
1.0	588	397	181	83	56	38	152
1.5	376	254	116	53	36	24	217
2.0	265	179	81	37	25	17	247
2.5	196	133	60	28	19	13	270
3.0	157	106	48	22	15	10	334
3.5	136	92	42	19	13	9	386
4.0	112	76	34	16	11	7	408
5.0	109	74	34	15	10	7	626
6.0	95	64	29	13	9	6	787
NOTE—Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table 11b—Instrument cable—Conduit-cable pulling chart
SWBP = 4378 N/m and *K′* = 0.5

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	266.7	180.1	82.1	37.4	25.3	17.1	518.6
2.5	179.3	121.0	55.2	25.2	17.0	11.5	677.9
3.8	114.6	77.4	35.3	16.1	10.9	7.3	965.7
5.1	80.7	54.5	24.8	11.3	7.6	5.2	1098.2
6.4	59.8	40.4	18.4	8.4	5.7	3.8	1201.8
7.6	47.8	32.3	14.7	6.7	4.5	3.1	1487.4
8.9	41.4	27.9	12.7	5.8	3.9	2.6	1716.0
10.2	34.1	23.0	10.5	4.8	3.2	2.2	1814.8
12.7	33.3	22.5	10.3	4.7	3.2	2.1	2786.2
15.2	28.9	19.5	8.9	4.1	2.7	1.8	3498.8
NOTE—Minimum two pair 0.823 mm^2 or one pair 1.31 mm^2 conductor size							

Table 12a—Instrument cable—Conduit-cable pulling chart
SWBP = 500 lbf/ft and *K′* = 0.5

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	875	591	269	123	83	56	117
1.0	840	567	259	118	80	54	218
1.5	537	363	165	75	51	34	310
2.0	378	255	116	53	36	24	353
2.5	280	189	86	39	27	18	386
3.0	224	151	69	31	21	14	478
3.5	194	131	60	27	18	12	551
4.0	160	108	49	22	15	10	583
5.0	156	105	48	22	15	10	895
6.0	135	91	42	19	13	9	1124
NOTE—Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table 12b—Instrument cable—Conduit-cable pulling chart
SWBP = 7297 N/m and *K′* = 0.5

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	266.7	180.1	82.1	37.4	25.3	17.1	518.6
2.5	256.1	172.9	78.8	35.9	24.3	16.4	968.3
3.8	163.7	110.6	50.4	23.0	15.5	10.5	1379.8
5.1	115.2	77.8	35.5	16.2	10.9	7.4	1569.3
6.4	85.4	57.7	26.3	12.0	8.1	5.5	1717.4
7.6	68.3	46.1	21.0	9.6	6.5	4.4	2125.3
8.9	59.1	39.9	18.2	8.3	5.6	3.8	2451.3
10.2	48.8	32.9	15.0	6.8	4.6	3.1	2592.3
12.7	47.6	32.1	14.7	6.7	4.5	3.0	3980.5
15.2	41.2	27.8	12.7	5.8	3.9	2.6	4999.6
NOTE—Minimum two pair 0.823 mm^2 or one pair 1.31 mm^2 conductor size							

Table 13a—Instrument cable—Conduit-cable pulling chart
SWBP = 300 lbf/ft and *K′* = 0.35

Conduit size (in)	Maximum effective conduit length (ft) — Total degrees of conduit bend						Maximum allowable pulling tension (lbf)
	45°	90°	180°	270°	315°	360°	
0.75	1406	1068	617	356	270	205	117
1.0	945	718	414	239	182	138	152
1.5	604	459	265	153	116	88	217
2.0	425	323	187	108	82	62	247
2.5	315	240	138	80	61	46	270
3.0	252	192	111	64	48	37	334
3.5	218	166	96	55	42	32	386
4.0	180	137	79	46	35	26	408
5.0	176	133	77	44	34	26	626
6.0	152	116	67	38	29	22	787

NOTE—Minimum two pair 18 AWG or one pair 16 AWG conductor size

Table 13b—Instrument cable—Conduit-cable pulling chart
SWBP = 4378 N/m and *K′* = 0.35

Conduit size (cm)	Maximum effective conduit length (m) — Total degrees of conduit bend						Maximum allowable pulling tension (N)
	45°	90°	180°	270°	315°	360°	
1.9	428.5	325.5	187.9	108.4	82.4	62.6	518.6
2.5	288.1	218.8	126.3	72.9	55.4	42.1	677.9
3.8	184.2	139.9	80.7	46.6	35.4	26.9	965.7
5.1	129.7	98.5	56.8	32.8	24.9	18.9	1098.2
6.4	96.1	73.0	42.1	24.3	18.5	14.0	1201.8
7.6	76.8	58.4	33.7	19.4	14.8	11.2	1487.4
8.9	66.4	50.5	29.1	16.8	12.8	9.7	1716.0
10.2	54.9	41.7	24.0	13.9	10.5	8.0	1814.8
12.7	53.6	40.7	23.5	13.5	10.3	7.8	2786.2
15.2	46.4	35.2	20.3	11.7	8.9	6.8	3498.8

NOTE—Minimum two pair 0.823 mm^2 or one pair 1.31 mm^2 conductor size

Table 14a—Instrument cable—Conduit-cable pulling chart
SWBP = 500 lbf/ft and *K*′= 0.35

Conduit size (in)	Maximum effective conduit length (ft)						Maximum allowable pulling tension (lbf)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
0.75	1406	1068	617	356	270	205	117
1.0	1350	1026	592	342	260	197	218
1.5	863	656	378	218	166	126	310
2.0	608	462	266	154	117	89	353
2.5	451	342	198	114	87	66	386
3.0	360	274	158	91	69	53	478
3.5	312	237	137	79	60	45	551
4.0	257	195	113	65	49	38	583
5.0	251	191	110	63	48	37	895
6.0	217	165	95	55	42	32	1124
NOTE—Minimum two pair 18 AWG or one pair 16 AWG conductor size							

Table 14b—Instrument cable—Conduit-cable pulling chart
SWBP = 7297 N/m and *K*′ = 0.35

Conduit size (cm)	Maximum effective conduit length (m)						Maximum allowable pulling tension (N)
	Total degrees of conduit bend						
	45°	90°	180°	270°	315°	360°	
1.9	428.5	325.5	187.9	108.4	82.4	62.6	518.6
2.5	411.5	312.7	180.4	104.1	79.1	60.1	968.3
3.8	263.1	199.9	115.3	66.6	50.6	38.4	1379.8
5.1	185.2	140.7	81.2	46.8	35.6	27.0	1569.3
6.4	137.3	104.3	60.2	34.7	26.4	20.0	1717.4
7.6	109.7	83.4	48.1	27.8	21.1	16.0	2124.8
8.9	94.9	72.1	41.6	24.0	18.2	13.9	2451.3
10.2	78.4	59.5	34.4	19.8	15.1	11.4	2592.3
12.7	76.5	58.1	33.5	19.3	14.7	11.2	3980.5
15.2	66.3	50.3	29.0	16.8	12.7	9.7	4999.6
NOTE—Minimum two pair 0.823 mm^2 or one pair 1.31 mm^2 conductor size							

5. Cable pulling attachment methods

5.1 General

Several types of pulling attachments, commonly referred to as pulling eyes or pulling grips, are available for connection to the cable. Upon request, most cable manufacturers will supply pulling eyes on the ends of large power cable. Pulling eyes, wedge-type pulling harnesses, compression pulling bolts, and other types of accessories are described below for reference.

5.2 Basket-type pulling grips

Basket-type pulling grips work on the principle of the chinese-finger puzzle and are referred to as socks, basket grips, etc. They are installed by compressing the grip enough to insert the cable and then securely banding or taping down the trailing end. They are removed 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, 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. Cable ends should be visually inspected for damage. The cable section under the basket should be discarded after all high-tension pulls and if any visual deformation is found after low-tension pulls.

5.3 Compression-type pulling eyes

Compression-type pulling eyes are supplied with an eye bolt or a threaded stud for single or multiconductor power cables. The eyes or studs and wall thickness of the aluminum barrel are sized to withstand tensions in excess of the ICEA S-19-81, ICEA S-61-402, ICEA S-66-524, ICEA S-68-516, ICEA S-73-532, and ICEA S-82-552 maximum pulling tensions. The barrel side of the cable is factory drilled to accommodate the particular combination of cables to be pulled. The cable is installed by stripping it down to the bare conductors, inserting them into the barrel (or barrels if multiconductor), and crimping them with powered crimping tools and a hydraulic pump.

5.4 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.

5.5 Mare's tails

Mare's tails grip cables over a 5–20 ft (1.5–3.1 m) section of jacket to luff or slack-pull extra length of cable into a manhole or pullbox for splicing. Ordinary rope, with half-hitches or flat nylon slings, is sometimes used for the 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.

5.6 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 explode under extreme conditions of rapid tension changes. This can occur even with ball-bearing swivels.

6. Pull rope selection

6.1 General

A variety of rope constructions and materials are available and in use for pulling cables through conduits and trays. Common rope materials include: steel, coated steel, hemp, polyester, kevlar/aramid, nylon, and polypropylene. In addition to the properties of the fibers used in the rope, rope performance varies considerably with its construction. Rope constructions include: three-strand, plaited, single braid, double braid, and parallel core.

6.2 Guidelines for pull rope selection

Pull ropes should be selected on the basis of required pulling tension, compatibility with lubricant, degree of stretch under tension, and for pullbys: size, flexibility, and low abrasion. Table 15 summarizes the importance of the different rope characteristics that should be considered when selecting a rope. One rope material or construction will not necessarily meet all applications on a job site.

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 vs. 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 supplier's 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 aging of the rope, the working load rating of the rope should be 1.5 times the projected cable pulling tension.

When selecting a pull rope, consideration should be given to conduit material, expected pulling tension, and cable pullby, as well as cost. Use of steel ropes should be avoided for plastic conduit. Testing has shown that steel pull ropes can wear grooves in plastic conduit. The cables being pulled may then jam in the grooves.

Typical working load rating and use recommendations for pull ropes are provided in table 16.

6.3 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. No type of visual inspection can accurately and precisely determine residual strength.

Table 15—Evaluation of pull rope characteristics

Rope characteristic	Importance to pull rope applications
Working load rating	Pulling tension should not exceed the rope's working load rating.
Abrasion characteristic	In a pullby or when pulling cable through plastic conduit, the pull rope should not abrade the existing cables or conduit.
Suitability in wet area	Pulls through underground ducts are generally considered wet. Hemp rope will rot if not properly dried out after the pull.
Compatibility with lubricants	Some lubricants can degrade the life of the pull rope.
Energy absorption capability	If a rope breaks during the pull, ropes with higher energy absorption capability present a greater personnel hazard.
Sunlight resistance	During pulls in outdoor ducts, the pull rope 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 is a major contributor to galloping and to personnel hazard if the rope breaks.
Heat sink properties	In high-tension pulling applications, rope friction against the conduit can produce a substantial amount of heat. If the rope cannot dissipate the heat and the coefficient is high, plastic conduit could melt.

Table 16—Typical working load and recommended use for pull ropes

	Working load, lbf (N)						
Size, in (cm) / Rope material	1/4 * (0.64)	3/8 (0.95)	1/2 (1.27)	5/8 (1.59)	3/4 (1.91)	1.0 (2.54)	Recommended use
Double-braided polyester	374 (1663.6)	792 (3552.8)	1320 (5871.4)	2200 (9785.6)	2684 (11 938.4)	4400 (19 571.2)	Cable pullbys* and high-tension pulling applications
Three-strand polyester	149 (662.8)	334 (1485.6)	640 (2846.7)	1130 (5026.2)	1610 (7161.3)	2820 (12 543.4)	Low-tension cable pulls
Hemp	54 (240.2)	122 (542.7)	264 (1174.3)	496 (2206.2)	695 (3091.4)	1160 (5159.7)	Generally not recommended except for indoor and empty conduit
Three-strand nylon	124 (551.6)	278 (1236.5)	525 (2335.2)	935 (4158.9)	1420 (6316.2)	2520 (11 209)	Low-tension cable pulls

* 1/4 in (0.64 cm) size should not be used for cable pullbys.

Rope should be stored clean, dry, out of direct sunlight, and away from extreme heat. Some synthetic rope, particularly polypropylene, polyethylene, and aramid, may be weakened by prolonged exposure to ultraviolet (UV) rays.

CAUTION

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

Improperly selected pull rope can damage the conduits or cause galloping to occur during the pull. In high-tension pulls, stretching of the pull rope may occur and the cables themselves may stop moving. The pulling tension increases dramatically to start the cable moving 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.

7. Lubrication techniques

Generally, 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 could not be achieved within the design limits.

The conduit should be 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 has to be compatible with the cable and the pulling rope; therefore, cable insulation and jacket compatibility tests should be performed or the cable manufacturer's approval should be obtained. Pulling lubricant can degrade the performance and the life of the pulling rope and the cable. The pull rope manufacturer should be consulted when selecting the pulling lubricant.

In addition to proper lubrication practices, the pull should be made quickly and stops should be avoided. Adjust the pulling speed to eliminate surging, if necessary. The kinetic coefficient of friction is less than the static coefficient of friction.

7.1 When to use lubricant

All cables installed in or removed from conduit or duct that are longer than 5 ft (1.5 m), or that have 90° or more of conduit bends should be lubricated except when the cable can be pushed into the conduit. Prelubrication of existing cables and the conduit or duct is especially important for all pullby installations.

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

7.2 Lubricant quantity

The recommended quantity of cable lubricant is dependent on the size and length of the conduit system. Experience indicates that equation (3) predicts a satisfactory quantity for an average cable pull.

$$Q = 0.0015 \times CL \times D, \quad \text{gal} \tag{3a}$$

$$Q = 0.00116 \times CL \times D, \quad \text{L} \tag{3b}$$

where

Q is the quantity of pulling lubricant needed, gal (L)
CL is the measured length of conduit, ft (m)
D is the nominal diameter of the conduit, in (cm)

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 several bends)
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 pumped quantity is generally controlled by the various system components such as pump pressure, spray nozzle, size of lubricant conduit, and viscosity of lubricant.

7.3 Methods of lubricating conduit systems

Several methods may be employed to lubricate conduit systems. Three possible methods are listed below.

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. They 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.

7.4 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.

NOTE—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.

7.5 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 discussed in 7.3. A duct swab or lubricant spreader should be used to evenly spread the lubricant throughout the conduit during the pull. The lubricant should be 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.

7.6 Clean up and safety

Cable lubricants are by definition slippery substances. Spills in foot traffic areas should be cleaned up or covered with sand.

Most commercial cable lubricants are water based. Appropriate precautions should be taken when working around energized cables as discussed in 9.3.

8. Tension limiting methods

8.1 General

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

a) Restricting the number of workers utilized for hand pulling
b) Monitoring the actual tension induced and stopping the pull if the tension is too high
c) Limiting the amount of tension available by using a break link or break-away 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 above can be employed.

8.2 Limiting size of pulling crew

The maximum number of workers pulling on the cable should be limited. One approach is to limit the number of workers based upon the maximum allowable pulling tension, as presented below.

One worker: For cable pulls where the maximum allowable pulling tension is 100 lbf (444.8 N) or less.

Two workers: For cable pulls where the maximum allowable pulling tension is 101 lbf (449.2 N) to 300 lbf (1334.3 N) and the conduit/duct size is 3/4 in (1.9 cm) or larger.

Three workers: For cable pulls where the maximum allowable pulling tension is 301 lbf (1338.8 N) or greater and the minimum conduit size is 4 in (10.2 cm) for single cable pulls or 5 in (12.7 cm) for multiple cable pulls.

8.3 Dynamometer

Whenever a cable installation is planned that utilizes mechanical pulling devices or requires more than three workers to pull the cable, a dynamometer should be used to monitor the tension.

During a mechanical 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. Spikes that occur as the head of the cable passes through a bend in the conduit are 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.

8.4 Break link

The use of a break link or break-away swivel can be very effective in limiting the amount of tension that can be applied during installation. When a pre-established tension is reached, the swivel breaks and the pull rope is separated from the cable(s).

Break-away swivels should only be utilized 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.

9. Cable pullbys

9.1 General

The term “pullby” is used to describe the practice of pulling cables in conduits that are already occupied by cables. Pullbys are not a generally recommended practice because of their risk of causing non-observable damage to the existing cables. However, practical circumstances may at times dictate their use. This includes design changes requiring added cables not initially foreseen, a lack of space to install additional conduits, or pulling schedules based on mechanical system groupings rather than on plant zones.

The intent of this clause 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.

9.2 Conditions for potentially 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 four or more cables and 30% for two or three 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 critical jam ratio.

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

   Jackets of woven glass fiber, woven asbestos fiber, or woven aramid fiber are generally regarded as too abrasive to be considered as candidates for a pullby (for the initial 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 [B2, B6]. 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 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 tension and sidewall pressure should be calculated to ensure that damaging forces will not be encountered. As noted previously, the coefficient of friction in 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.

9.3 Installation practices

a) The most important consideration in cable pullby 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 not be used because they may cut or otherwise damage the cable.

b) Nonconducting 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 should be de-energized to prevent accidental shock to personnel or inadvertent equipment operation should cable damage occur. Where the intended pullby is easy (short length of pull, low fill, and low degrees of bend) and involves low energy circuits (instrumentation or control), consideration may be given to performing the pullby without de-energizing, but with the proper safety precautions.

c) The pulling rope diameter should range between 3/8 in (0.95 cm) and 3/4 in (1.9 cm). 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 bearing pressure on the existing cables as well as the cables to be installed.

e) Normally, swivels should not be used. However, small bullet-nosed, break-away 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 tension should be monitored or limited regardless of whether hand or machine pulling is used. 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 the lesser of 400 lbf (1779.2 N) 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 their 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 good 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. Possible indications include discoloration of the pull rope or the presence of small pieces of jacket material.

9.4 Post-pullby testing

Following a pullby that requires more than one worker to pull the cable, normal post-installation testing as outlined in IEEE Std 422-1986 and IEEE Std 690-1984 should be performed on both the initial cables and the recently pulled cables. This is to address the inherent risk to the initial cables. High potential testing on medium-voltage cables should be conducted at maintenance levels in accordance with IEEE Std 400-1991.

10. Pullbacks

10.1 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 relocation or temporary removal of equipment, a design change requiring change in routing of 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 sidewall bearing pressures 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.

10.2 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 embrittled as a result of either heat or radiation aging. If the condition of cables is unknown, inspection should be undertaken to determine whether cable replacement is necessary.

10.3 Installation practices

a) A significant factor in achieving a successful pullback is the relubrication of the installed cables prior to initiation of the pullback. This can be accomplished 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 some time to soak in. Exposed sections of cable should be lubricated prior to their being pulled back into 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 allowable 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 dynamic handling of cables that may have been aged to some degree and have already undergone the stress of 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 bending radius, as discussed in IEEE Std 422-1986 and IEEE Std 690-1984.

d) Prior to performing pullbacks, terminal lugs for 6 AWG (13.3 mm^2) cable and larger should be removed and terminal lugs for 8 AWG (8.37 mm^2) 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) Fire stops, moisture seals, and cable supports installed in the conduit have to be removed prior to pullback. In no case should the cables be pulled through the seal. 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 the lesser of 500 lbf (2224 N) or the maximum allowable based on conductor strength.

g) Following the pullback, a 100% inspection of the cables removed 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 the 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.

i) 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 as outlined in IEEE Std 422-1986 and IEEE Std 690-1984 should be followed except that high potential testing on medium-voltage cables should be conducted at maintenance levels only.

11. Bibliography

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[B3] IEEE Committee Report, "Recommended Practice on Specific Aspects of Cable Installation in Power-Generating Stations," *IEEE Transactions on Power Delivery*, vol. 4, no. 3 p. 1504, July 1989.

[B4] Kommers, T. A., "Electric Cable Installations in Raceways," *IEEE Transactions on Industry Application*, vol. IA-16, no. 6, Nov./Dec. 1980.

[B5] Rifenburg, R. C., "Pipeline Design for Pipe Type Feeders," *AIEE Transactions on Power Apparatus and Systems*, vol. 8, Dec. 1953.

[B6] Weitz, Gene C., "Coefficient of Friction Measurement Between Cable and Conduit Surfaces Under Varying Normal Loads," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-014, no. 1, p. 19, Jan. 1985.

Work is in progress under IEEE P971, Guide for Distribution Cable Installation Methods in Duct Systems.[6]

[6]For more information, contact the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

Annex A
Examples—Use of conduit-cable pulling charts

(normative)

This annex provides three examples of the use of the conduit-cable pulling charts in tables 3 through 14.

A.1 Example #1

Control cables are being pulled into a 3 in (7.6 cm) conduit laid out as shown in figure A.1. The properties of the pulling lubricant and the details of the sidewall bearing pressure (SWBP) capability of the cable are not known. The appropriate table is table 3, in which SWBP = 500 lbf/ft (7297 N/m) and *K′* = 0.5. Utilizing table 1, the effective conduit length for each section can be determined, as shown in table A.1.

The total effective conduit length is 25 ft (7.6 m) and the total degrees of bend is 270. From table 3, the maximum effective conduit length is found to be 28 ft (8.6 m). Since the effective conduit length is less than the maximum value shown in table 3, the cables can be pulled into the conduit. Use of the bend correction (BendCorr) method (discussed in 4.4 and annex C) is not necessary in this example.

If three or six cables of identical construction 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.

Table 3 provides a maximum allowable pulling tension (MAPT) of 478 lbf (2125.3 N); 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 × 478 lbf = 717 lbf (1.5 × 2125.3 N = 3188 N). From table 16, a 3/8 in (0.95 cm) diameter double-braided polyester rope or a 5/8 in (1.59 cm) diameter three-strand polyester rope can be used. Figure A.2 illustrates the use of equation (2)—projected pulling tension (PPT)—which could be applied in this example also.

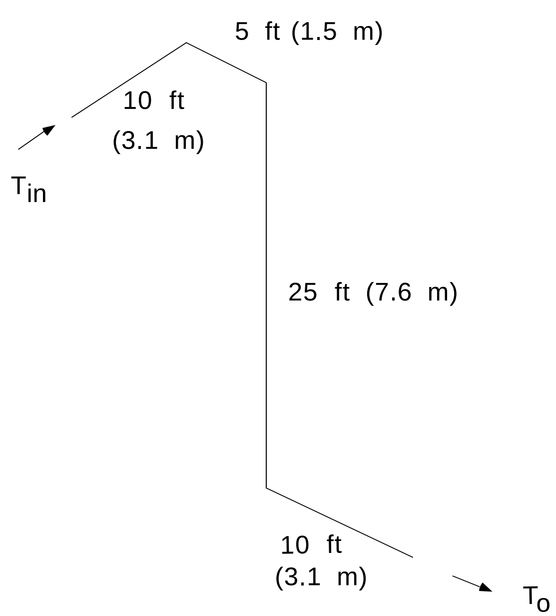

Figure A.1—Isometric of conduit layout—Example #1

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

Section type	Angle (°)	Measured conduit length, ft (m)	Effective conduit length, ft (m)
Straight horizontal		10 (3.0)	10 (3.0)
Horizontal bend	90		
Straight horizontal		5 (1.5)	5 (1.5)
Bend down	90		
Vertical down		25 (7.6)	0
Bend down	90		
Straight horizontal		10 (3.0)	10 (3.0)
End of pull (totals)	270		25 (7.6)

A.2 Example #2

Control cables are being pulled into a 3 in (7.6 cm) conduit laid out as shown in figure A.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 1000 lbf/ft (14 593 N/m) and the effective coefficient of friction (K') for the type of lubricant and cable jacket material is 0.35. The appropriate table is table 6, in which SWBP = 1000 lbf/ft (14 593 N/m) and K' = 0.35. Utilizing table 1, the effective conduit length for each section can be determined, as shown in table A.2.

The total effective conduit length is 127.5 ft (38.9 m) and the total degrees of bend is 270. From table 6, a maximum conduit length of 163 ft (49.6 m) is found. Since the effective conduit length is less than the maximum value shown in table 6, 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 4.4 and annex C) is not necessary in this example.

Table 6 provides an MAPT of 956 lbf (4250.1 N); 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 × 956 lbf = 1434 lbf (1.5 × 4250.1 N = 6375.15 N). From table 16, a 5/8 in (1.59 cm) diameter double-braided polyester rope or a 3/4 in (1.91 cm) diameter three-strand polyester rope can be used.

Alternately, the PPT from equation (2) 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 follows:

$$PPT = 956 \cdot \frac{127.5}{163} \cdot \frac{20}{40} \cdot 1 = 374, \mathrm{lbf} \qquad \text{(A.1a)}$$

$$PPT = 4250.1 \cdot \frac{38.9}{49.7} \cdot \frac{20}{40} \cdot 1 = 1667, \mathrm{N} \qquad \text{(A.1b)}$$

where

L' = 127.5 ft (38.9 m)
L = 163 ft (49.7 m)
BendCorr = 1 (conservatively picked)
Fill' = 20%
Fill = 40%

For a PPT of 374 lbf (1667 N), a 3/8 in (0.95 cm) diameter double-braided polyester rope could be used. Three workers will be necessary to pull the cable.

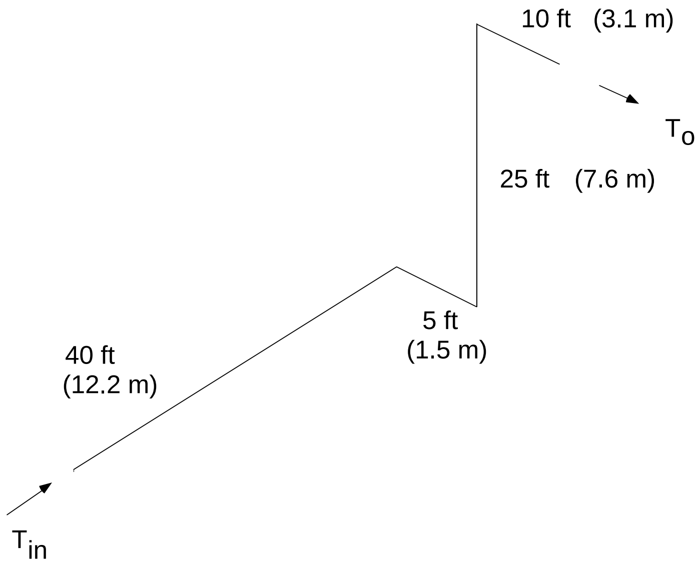

Figure A.2—Isometric of conduit layout—Example #2

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

Section type	Angle (°)	Measured conduit length, ft (m)	Effective conduit length, ft (m)
Straight horizontal		40 (12.2)	40 (12.2)
Horizontal bend	90		
Straight horizontal		5 (1.5)	5 (1.5)
Bend—Up	90		
Vertical—Up		25 (7.6)	25 × 2.9 = 72.5 ft 7.6 × 2.9 = 22.1 m
Bend—Up	90		
Straight horizontal		10 (3.1)	10 (3.1)
End of pull (totals)	270		127.5 (38.9)

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.

   1) $L1/L$ = 40/127.5 = 30%
   2) $L2/L$ = 5/127.5 = 3%
   3) $L3/L$ = (72.5 + 10)/127.5 = 65%

b) Reviewing the conduit configurations in figure C.1, select the configuration with a $L1/L$ ratio that is equal to or larger than the calculated ratio of 30%. 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 C.2, the BendCorr factor for 270° is 0.67. Incorporating this lower BendCorr, PPT is recalculated below:

$$PPT = 956 \cdot \frac{127.5}{163} \cdot \frac{20}{40} \cdot 0.67 = 251, \text{lbf} \qquad \text{(A.2a)}$$

$$PPT = 4250.1 \cdot \frac{38.9}{49.7} \cdot \frac{20}{40} \cdot 0.67 = 1114, \text{N} \qquad \text{(A.2b)}$$

A.3 Example #3

Control cables are being pulled into a 3 in (7.6 cm) conduit laid out as shown in figure A.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 500 lbf/ft (7297 N/m) and the K' for the type of lubricant and cable jacket material is 0.35. The appropriate table is table 5, in which SWBP = 500 lbf/ft (7297 N/m) and K' = 0.35. Utilizing table 1, the effective conduit for each section can be determined, as shown in table A.3.

The total effective conduit length from table A.3 is 112.5 ft (34.3 m) and the total degrees of bend is 270. From table 5, a maximum effective conduit length of 81 ft (24.8 m) is found. Since the effective conduit length is greater than the maximum value shown in table 5, additional evaluation is necessary before this conduit section can be used.

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

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

   1) $L1/L$ = 20/112.5 = 18%
   2) $L2/L$ = 10/112.5 = 9%
   3) $L3/L$ = (72.5 + 10)/112.5 = 73%

b) Reviewing the conduit configurations in figure C.1, select the configuration whose $L1/L$ ratio is equal to or larger than the calculated ratio of 18%. 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 C.2, the BendCorr factor for 270° is 0.67.

c) The maximum effective conduit length can be adjusted upwards to 81.0/0.67 = 121.0 ft (24.8/ 0.67 = 37.0 m).

The new maximum effective conduit length of 121 ft (37.0 m) is greater than the measured effective conduit length of 112.5 ft (34.3 m) from table A.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 in IEEE Std 422-1986 should be used for such a calculation.

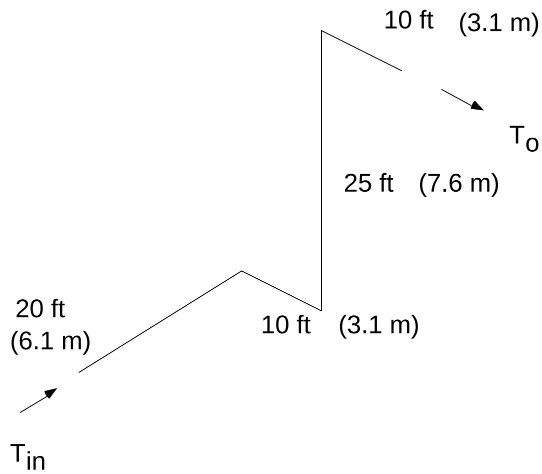

Figure A.3—Isometric of conduit layout—Example #3

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

Section type	Angle (°)	Measured conduit length, ft (m)	Effective conduit length, ft (m)
Straight horizontal		20 (6.1)	20 (6.1)
Horizontal bend	90		
Straight horizontal		10 (3.1)	10 (3.1)
Bend—Up	90		
Vertical—Up		25 (7.6)	25 × 2.9 = 72.5 ft 7.6 × 2.9 = 22.1 m
Bend—Up	90		
Straight horizontal		10 (3.1)	10 (3.1)
End of pull (totals)	270		112.5 (34.3)

Annex B
Methodology—Conduit-cable pulling charts

(normative)

This annex describes the methodology used to develop the conduit-cable pulling charts in tables 3 through 14.

B.1 Pulling tension calculation

The charts conservatively assume that all conduit bends are located at the end of the pull, as shown in figure B.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 B.1—Conduit layout—Chart development

The pulling tension, T_o, at the end of the conduit system (point E) for a horizontal conduit system (see IEEE Std 422-1986) is:

$$T_o = L \cdot W_c \cdot N \cdot K' \cdot e^{K' \cdot A}\text{, lbf} \quad \text{(B.1a)}$$

$$T_o = L \cdot W_c \cdot 0.009807 \cdot N \cdot K' \cdot e^{K' \cdot A}\text{, N} \quad \text{(B.1b)}$$

where

- T_o is the cable tension out of the conduit, lbf (N)
- L is the conduit length not including the length of the elbows, ft (m)
- A is the sum of the angle of conduit bends, rad
- K' is the effective coefficient of friction
- W_c is the weight of the individual cable, lbm/ft (g/m)
- N is the number of cables in the conduit

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:

$T_{B'}$	=	$L\,(W_c)\,N\,(K')$	horizontal, lbf	(B.2a)
$T_{B'}$	=	$L\,(W_c)(0.009807)\,N\,(K')$	horizontal, N	(B.2b)
$T_{B''}$	=	$-L\,(W_c)\,(N)$	vertical down, lbf	(B.3a)
$T_{B''}$	=	$-L\,(W_c)\,(0.009807)\,(N)$	vertical down, N	(B.3b)
$T_{B'''}$	=	$L\,(W_c)\,(N)$	vertical up, lbf	(B.4a)
$T_{B'''}$	=	$L\,(W_c)\,(0.009807)\,(N)$	vertical up, N	(B.4b)
$T_{B''''}$	=	$-L\,(W_c)\,N\,(\sin\theta - K'\,(\cos\theta))$	slope down, lbf	(B.5a)
$T_{B''''}$	=	$-L\,(W_c)\,(0.009807)\,N\,(\sin\theta - K'\,(\cos\theta))$	slope down, N	(B.5b)
$T_{B'''''}$	=	$L\,(W_c)\,N\,(\sin\theta + K'\,(\cos\theta))$	slope up, lbf	(B.6a)
$T_{B'''''}$	=	$L\,(W_c)\,(0.009807)\,N\,(\sin\theta + K'\,(\cos\theta))$	slope up, N	(B.6b)

where

θ is the angle of the slope

The correction factor used in table 1 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 $e^{K' \cdot A}$ for horizontal conduit bends is based on $T_{in} > 10\,R(W_c)N$. 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.

B.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 follows:

$$T_{cond} = 0.008\,(n')\,(N)\,CMA\text{, lbf} \tag{B.7a}$$

$$T_{cond} = 70.5\,(n')\,(N)\,CMA\text{, N} \tag{B.7b}$$

$$T_{swbp} = \text{SWBP}\,(R) \tag{B.8}$$

where

T_{cond} is the maximum allowable tension-conductor strength considerations, lbf (N)
T_{swbp} is the maximum allowable tension-sidewall bearing pressure considerations, lbf (N)
R is the conduit radius, ft (m)
n' is the number of conductors in the cable

N	is the number of cables in the conduit
CMA	is the area of the conductor, cmil (mm^2)
SWBP	is the sidewall bearing pressure limit on the cable, lbf/ft (N/m)

Equation (B.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 20–30% greater than in other cables. Equation (B.7) provides a 100% margin over the yield strength of the conductor. Also, most entries in the chart are sidewall bearing pressure (T_{swbp}) limited rather than conductor strength (T_{cond}) limited. For these reasons, and to maintain consistency with IEEE Std 422-1986 and IEEE Std 690-1984, equation (B.7) is not derated for unequal tension distribution.

Equation (B.8) is for one cable in a pull (source: IEEE Std 422-1986). When applied to a multiple cable pull, results are conservative. For a large number of cables, actual T_{swbp} may be 2–5 times greater than equation (B.8). See [B4].

B.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 $T_o = T_{cond}$.

$$L_{cond} = \frac{0.008 \cdot n' \cdot N \cdot CMA}{K' \cdot e^{(K \cdot A)} \cdot W_c \cdot N}\text{, ft} \tag{B.9a}$$

$$L_{cond} = \frac{70.5 \cdot n' \cdot N \cdot CMA}{K' \cdot e^{(K \cdot A)} \cdot W_c \cdot 0.009807 \cdot N}\text{, m} \tag{B.9b}$$

$$L_{swbp} = \frac{SWBP \cdot R}{K' \cdot e^{(K \cdot A)} \cdot W_c \cdot N}\text{, ft} \tag{B.10a}$$

$$L_{swbp} = \frac{SWBP \cdot R}{K' \cdot e^{(K \cdot A)} \cdot W_c \cdot 0.009807 \cdot N}\text{, m} \tag{B.10b}$$

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) = $n' \cdot CMA/W_c$]. For the specific range of cable construction the following minimum StWt were calculated:

a) Instrument cable: 1 pair 16 AWG (1.31 mm^2) to 12 pair 16 AWG (1.31 mm^2), 2 pair 18 AWG (0.823 mm^2) to 12 pair 18 AWG (0.823 mm^2); StWt = 81 000 cmil/lbm (0.0906 mm^2/g)

b) Control cable: Single conductor (1/C) or multiple conductors (2/C, 3/C, 4/C, 7/C, and 9/C) in sizes 14 AWG (2.08 mm^2) and 12 AWG (3.31 mm^2); StWt = 86 530 cmil/lbm (0.0968 mm^2/g)

c) Power cable: 1/C and 3/C in sizes 12 AWG (3.31 mm^2) to 750 kcmil (400 mm^2); StWt = 130 600 cmil/lbm (0.1462 mm^2/g)

In computing L_{swbp}, N (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, $W = N (W_c)$, 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 B.1.

Table B.1—Maximum cable weight in conduit

Nominal conduit diameter, in (cm)	Instrument cable, lbm/ft (g/m)	Control cable, lbm/ft (g/m)	Power cable, lbm/ft (g/m)
0.75 (1.9)	0.18 (267.87)	0.22 (372.40)	0.38 (565.5)
1.0 (2.5)	0.35 (520.86)	0.39 (580.38)	0.72 (1071.48)
1.5 (3.8)	0.78 (1160.76)	0.87 (1294.70)	2.5 (3720.40)
2.0 (5.1)	1.26 (1875.08)	1.46 (2172.71)	2.88 (4285.90)
2.5 (6.4)	1.86 (1875.08)	2.08 (3095.97)	3.75 (5580.60)
3.0 (7.6)	2.88 (2767.98)	3.22 (4791.88)	6.72 (10 000.43)
3.5 (8.9)	3.84 (5714.53)	4.31 (6413.97)	8.64 (12 857.70)
4.0 (10.2)	4.92 (7321.75)	5.55 (8259.29)	11.76 (17 500.76)
5.0 (12.7)	7.74 (11518.36)	8.74 (13006.52)	18.48 (27 501.20)
6.0 (15.2)	11.22 (16697.16)	12.62 (18780.58)	27.5 (40 924.40)

B.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 C
Bend correction factor—Conduit-cable pulling charts

(normative)

The conduit-cable pulling charts are based on all of 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 4.4 but may be convenient in some cases.

BendCorr factors were developed for five specific conduit configurations. Figure C.1 illustrates these five conduit layout configurations: I, II, III, IV, and V. The BendCorr factors are taken from table C.1 or C.2 after calculating the ratios $L1/L$, $L2/L$, and $L3/L$ 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 C.1 or C.2.

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

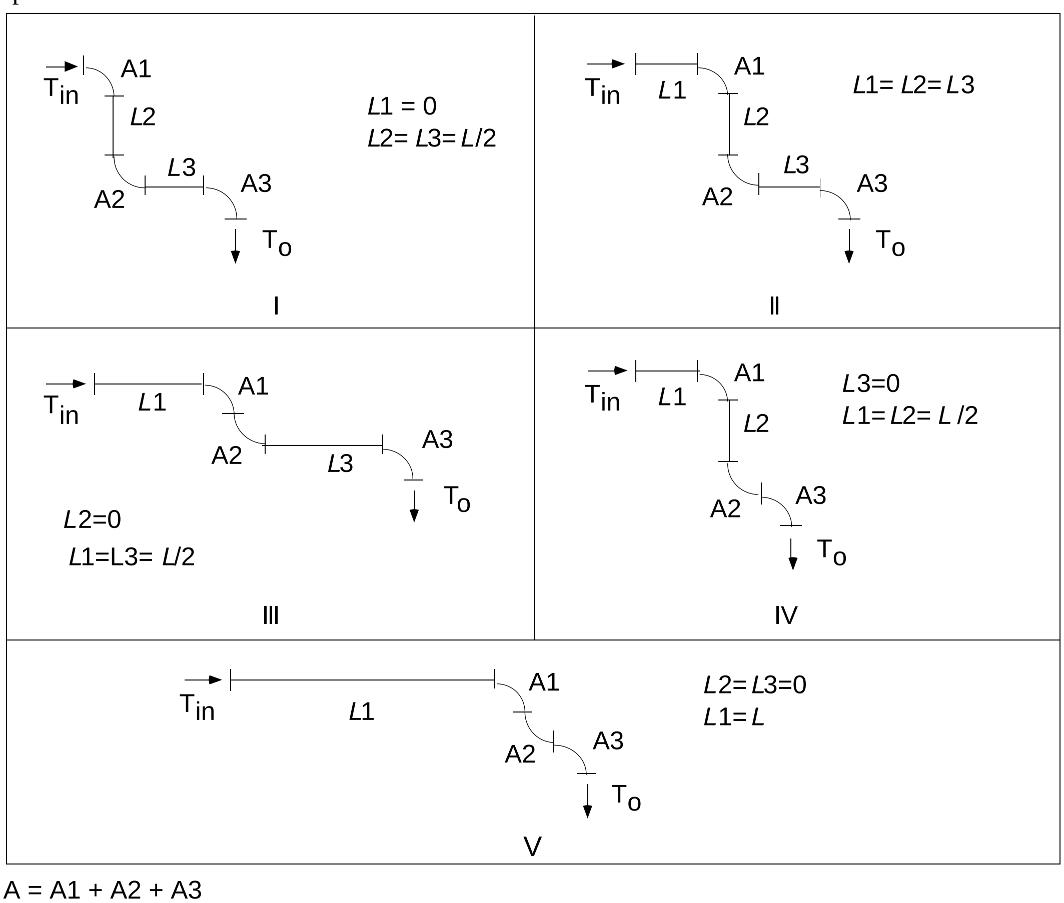

Figure C.1—Conduit layout—BendCorr factor

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

Configuration	Total degrees (A) of conduit bend						Layout
	45°	90°	180°	270°	315°	360°	
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	0.8	0.68	0.6	0.58	0.56	*L*2=0, *L*1=*L*3=*L*/2
IV	0.94	0.88	0.8	0.73	0.7	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*
NOTE— A1 + A2 + A3 = A total degrees of bend							

Table C.2—BendCorr adjustment factor—*K′* = 0.35

Configuration	Total degrees (A) of conduit bend						Layout
	45°	90°	180°	270°	315°	360°	
I	0.87	0.76	0.59	0.46	0.4	0.36	*L*1 =0, *L*2=*L*3=*L*/2
II	0.91	0.84	0.72	0.64	0.6	0.57	*L*1=*L*2=*L*3=*L*/3
III	0.92	0.85	0.74	0.67	0.64	0.62	*L*2=0, *L*1=*L*3=*L*/2
IV	0.96	0.92	0.85	0.79	0.76	0.74	*L*3=0, *L*1=*L*2=*L*/2
V	1	1	1	1	1	1	*L*2=*L*3=0, *L*1=*L*
NOTE— A1 + A2 + A3 = A total degrees of bend							