

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

IEEE Power and Energy Society

Developed by the
Insulated Conductors Committee

IEEE Std 1185™-2019
(Revision of IEEE Std 1185-2010)



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Insulated Conductors Committee
of the
IEEE Power and Energy Society

Approved 7 November 2019

IEEE SA Standards Board

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

Keywords: American wire gauge, AWG, basket grip, bend radius, cable, cable cleats, cable jamming, cable testing, cable ties, cable tray, cmil, conduit, duct bank, ducts, English units, figure 8, galloping, IEEE 1185™, installation, jam ratio, kcmil, luff, metric units, OD, outside diameter, overall diameter, pull back, pull tension, pullby, pulling bend radius, ropes, sidewall bearing pressure, sidewall pressure, slack puller, sleeve, swivel, training bend radius, trench, wire, wire way

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Introduction

This introduction is not part of IEEE Std 1185-2019, 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. Cable failures can lead to power outages and equipment downtime, resulting in inconvenience at best, lost production, or worse, a safety issue. This document provides information to help engineers, technicians, and trades/crafts people avoid potential wire or cable damage during installation, testing, and modification of cable systems at generating stations and industrial facilities. 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.

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), Canadian Electrical Code (CEC) Parts I, II, and III, or other local codes, are available that provide cable system design and installation information. 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, CEC, 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 help maximize cable life and help minimize in-service cable failures.

This revision is a complete rewrite to re-organize the information into a more logical sequence. An attempt has been made to not delete any technical data from the previous edition.

Selected sections have been combined into a comprehensive section (8.2, Securing cable to raceway) that classifies the forces acting on cables, addresses cable design considerations, and provides in-depth information on cable supports and restraints, including a discussion on thermal expansion, a list of cable restraint devices and new calculations. While prior revisions were primarily based on securing vertical cables, this revision greatly expands on protecting cables from the electrodynamic forces that occur during short circuits.

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, is not exceeded. Since most cable pulls are manual pulls and the setup time to monitor pulling tension is significant, pulling tensions are typically only quantitatively monitored when performing long, high tension pulls requiring the use of motorized pulling equipment. When a cable pull into conduit is made manually, the dynamometer reading has to be adjusted after measuring various angles. Due to the complexity of this process, manual cable pulls are seldom quantitatively 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, pull rope selection criteria, pulling attachment methods, and alternative methods to traditional cable pull tension monitoring, etc.

Cable pullbys (i.e., pulling cables into conduits that already contain cables) 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. Measuring the pulling tensions may help but may not prevent cable damage due to pullbys, because the damage can occur from the pull rope or pulled by cable as the pull rope or cable passes over or under 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 the pullby and by 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 [B3] compliments this document for long power cable pulls through duct bank systems and should be considered as additional reference source. Cable installation information can also be found in IEEE Std 576™-2000 [B67] and may also be consulted as an additional reference source.

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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. It covers installation of cable in trays, conduit, duct banks, wire ways, gutters, and other raceway systems. It covers medium voltage power cable, low voltage power cable, control cable, instrumentation cable, coax/triax cable, fiber optic cable, data communications cable, and other specialty cables used in power plant and industrial environments. This document may also be of benefit for the proper installation of wire and cable systems in commercial, governmental, and public facilities when the same or similar wire or cable types and raceways are used.

1.2 Purpose

The purpose of this recommended practice is to provide guidance on how to help prevent ~~for the proper~~ installation damage, which is the single greatest cause of wire and cable failures. Cable failures can lead to power outages and equipment downtime, resulting in inconvenience at best, lost production, or worse, a safety issue. This document provides information for engineers, technicians, and trades/crafts people to avoid ~~in generating stations and industrial facilities so that~~ potential wire or cable damage ~~may be avoided~~ during ~~the~~ installation, ~~and~~ testing, and modification of cable systems at generating stations and industrial facilities ~~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 reduce the ~~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 metric to English ~~vice versa~~ may not be exact.

The user is also cautioned to recognize the difference between force and mass especially within the English system of units since term "pound" (lb) has been often misapplied, which can result in errors in the application of the equations. Attempts have been made within this document to be clear in the terminology to avoid confusion and misapplication of this concept in both the metric and English units. It should also be noted that cable manufacturers give cable weights in SI units using "kg/m" whereas in English the information is provided in terms of "lb/ft-". The metric units are clearly mass per unit length whereas the English units are more ambiguous. In this context, cable weight in English units (~~lb is lbf~~ /ft), ~~which~~ is a weight force per unit length. A pound (force) is equal to pound (mass) on the surface of the Earth, and thus is not multiplied by the gravity constant "g". 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 acceleration due to gravity ~~gravitational~~ constant "g" has been added to the metric equation as applicable, which does not appear in the English equation.

1.4 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{1,2}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

¹The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

²The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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.

IEEE Std 1210TM, IEEE Standard Tests for Determining Compatibility of Cable-Pulling Lubricants with Wire and Cable, ^{3,4 2,3}

NFPA 70®, ^{2017 2007} Edition, National Electrical Code® (NEC®).^{5†}

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online: Glossary of Terms & Definitions* should be consulted for terms not defined in this clause. ^{6 4}

[†] ~~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/>).~~

^{3,2} ~~IEEE publications~~ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>), 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

^{4,3} The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

⁵ NFPA publications are published by the National Fire Protection Association (<https://www.nfpa.org/>).

⁶ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

[†] ~~The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.~~

gutter: An enclosure made of sheet metal (metallic auxiliary gutter) or a flame-retardant, non-metallic materials (non-metallic auxiliary gutter) used to supplement wiring spaces in electrical equipment such as distribution centers, switchgear, switchboards, meter centers, etc. The enclosure has hinged or removable covers for ease of wire/cable installation and for protection to the wires inside. The enclosure is designed for conductors to be laid out or set in place after the enclosures have been installed.

luffing: The process of pulling slack cable in a midway point of a cable pull to reduce tension and minimize side wall pressure on the cable

maintained space: A method of installation in power cable trays that provides spacing between adjacent cables and allows for air circulation to avoid having to de-rate the cables for ampacity. Cables without maintained spacing are considered installed in a random fill manner.

~~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 g) in 4.3 5.1 for additional information⁷⁵

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.

⁷⁵Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

rolling friction: The resistance to motion when pulling around a bend ~~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

CPE chlorinated polyethylene

CSPE chlorosulfonated polyethylene (a.k.a. Hypalon™)

Cu copper

EMI/RFI electromagnetic interference/radio frequency interference

EPDM ethylene propylene diene monomer

EPR ethylene propylene rubber

HMWPE high-molecular-weight polyethylene

~~EMI/RFI~~ ~~electromagnetic interference/radio frequency interference~~

Hi-Pot high-potential test ~~(usually dc test)~~

kcmil one-thousand circular mils

LAN local area network

LSZH	low smoke zero halogen
MAPT	maximum allowable pulling tension
NBR	nitrile butadiene rubber (a.k.a. polychloroprene or Neoprene™)
NEC	National Electrical Code ⁶
NESC	National Electrical Safety Code
OD	outside diameter or overall diameter
OSHA	Occupational Safety and Health Administration
PE	polyethylene
PPE	personal protective equipment
PPT	projected pulling tension
PVC	polyvinyl chloride
SAF	slope adjustment factor
SR	silicone rubber
SWBP	sidewall bearing pressure (a.k.a. ~~also know as~~ sidewall pressure)
TP	thermoplastic
TPE	thermoplastic elastomer
TRXLPE	tree-retardant cross-linked polyethylene
TS	thermoset
UV	ultraviolet
XLPE	cross-linked polyethylene

XLPO cross-linked polyolefin

4. Planning the pull

4.1 Cable storage, handling, and re-reeling

Cables ~~Cable reels~~ should be stored on reels that are in an upright position on their flanges and handled in such a manner so as to help prevent ~~deterioration of and~~ physical damage to the reel and deterioration of ~~or~~ the cable. 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. Normally cable is stored in a sheltered area such as a warehouse with ~~During indoor storage,~~ both ends of the cable ~~should be~~ sealed against moisture or contamination. Cold or heat shrinkable end ~~End~~ caps are the preferred method of sealing. In the past, tape has been used to seal cable ends, but it is no longer ~~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 help prevent inadvertent damage, which can occur due to ~~from~~ contact between the ~~with~~ flanges of adjacent reels. When cables are not immediately planned for installation, the cable ~~consideration~~ should be protected ~~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 should ~~shall~~ be stored on pallets or on plywood in order to keep the reels off the ground or on a flat ~~flat~~, solid (properly drained) concrete or gravel surface to help ~~ground to~~ prevent reels from sinking into the earth ~~ground or on pallets or plywood to keep it off the ground~~. The cable ends should ~~shall~~ be sealed with end caps to help prevent moisture intrusion. The cable should be covered with an opaque covering to help reduce ~~minimize~~ cable degradation due to direct 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 properly seal cable ends ~~properly~~ may result in condensation, moisture, or water inside the cable. If this condition is detected, then the cable should be dried out before use by either applying ~~pulling~~ a vacuum to ~~on~~ the cable or purging the cable with dry nitrogen. Consult the cable manufacturer for more information on the recommended method for inspecting, detecting, and remedying moisture ingress ~~how to inspect, detect and remedy these conditions~~.

Often, cable is re-reeled at the job site to accommodate ~~accommodate~~ cable pulling setup space limitations or to make handling easier. Whenever cable is re-reeled, care should ~~shall~~ be taken so ~~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~~ [B80 ~~B36~~] for information about minimum allowable drum diameters.^s

Cable reels can be easily damaged by improper forklift handling during transit and handling or on the jobsite during installation or storage. Cable damage caused by improper handling is often not visible and can be several layers below the surface. The following figures are illustrative examples of proper and improper methods of cable reel handling.

Figure 1, Figure 2, and Figure 3 show the proper handling of cable reels using a forklift.



(New)

Figure 1-Lift reel with both flanges

^sThe numbers in brackets correspond to those of the bibliography in Annex H ~~F~~.



(New)

Figure 2-Lift reel using pallet



(New)

Figure 3-Lift reel under bottom flange

Figure 4, Figure 5, and Figure 6 show improper handling of cable reels.



(New)

Figure 4-00 not nail into reel flanges



(New)

Figure 5-00 not stack material on the top of the reel



(New)

Figure 6-00 not lift reels by the top flange

Staging or storing cable in a figure eight configuration should be avoided. The small cross-sectional area created by crisscrossed cables results in discrete pressure points where maximum sidewall bearing pressures (SWBPs) can be exceeded when cables are stacked in a figure eight configuration. See 6.11 for more information on this subject.

4.1.1 ~~Installation of~~ Specialty cables

~~14.1 General~~

While the bulk of the cable in generating station and industrial applications ~~has been~~ will be conventional power, control, and instrumentation cable, the handling and storage ~~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 more ~~increasingly~~ frequent use. This group includes, but is not limited to, category data cable, coaxial cable, tri-axial cable, twin-axial cable, Ethernet cable, and telephone cable. For installation of fiber optic cables, which 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 TM [B74]. For installation information regarding Ethernet cables see ANSI/TIA-1005-A [B26]. For installation information regarding communication cables, refer to IEEE Std 789TM 2004 [B70–[B32].

The high-frequency performance requirements provided by many specialty cables depend upon close manufacturing tolerances to provide ~~ensure~~ uniform impedance as a function of length. The user is recommended to use handling ~~should ensure that installation~~ techniques that ~~utilized~~ do not distort the cable or alter the relative position of cable components because ~~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-crosstalk~~ 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.

14.9 ~~Storage and handling of specialty cables~~

Specialty cables should be adequately protected prior to installation so ~~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. Like all other cables, both ends of the specialty ~~cables-on-reels~~ should be sealed to protect the cable against moisture ingress. Cold or heat shrinkable end caps are the preferred method of sealing. Tape has been used in the past to seal cable ends, but is not the preferred method due to ~~its limited durability.~~

Specialty cable should always be stored indoors. However, when temporary outdoor storage is necessary especially when being installed in duct banks, trenches, or by direct burial, the reels should ~~reels shall~~ be protected from ultraviolet (UV) light damage through the use of light-weight, opaque reel covers. Storage should be on flat, solid, well-drained surfaces. Whether stored indoors or outdoors ~~out~~, reels should be blocked to help prevent inadvertent damage from contact with flanges of adjacent reels. When such cables are not immediately planned for installation, the cable consideration should be protected ~~given to protecting the cable~~ by the application of wood lagging or other suitable materials across the reel flanges.

4.1.2 Armored cable

The National Electrical Code® (NEC®) (NFPA 70® 2017 Edition)⁹ defines armored cables as Type AC (Article 320) and Type MC (Article 330). Per the NEC Type AC, Armored Cable is a "fabricated assembly of insulated conductors in a flexible interlocked metallic armor", and Type MC, Metal Clad Cable is a "factory assembly of one or more insulated circuit conductors with or without optical fiber members enclosed in an armor of interlocking metal tape, or a smooth or corrugated metallic sheath".

Armored cable, as referred to in this document, is anyone of the following cable configurations:

a) Aluminum interlocked armor

⁹Information on references can be found in Clause 2.

b) Galvanized steel interlocked armor

c) Continuous smooth or corrugated aluminum armor

d) Continuously welded smooth or corrugated metallic armor with or without an overall non-metallic jacket

e) Served galvanized steel wire armor (not recognized as type MC)

f) Flat metal tape helically applied armor (not recognized as type MC)

Even though armored cables are protected by a metallic sheath, the storage and handling requirements including the use of end caps on both ends of the cable discussed above should be followed for both armored and non-armored cables. Cold or heat shrinkable end caps are the preferred method of sealing. If an armored cable does not have an overall jacket, then the cable ends should be sealed to an underlying core jacket.

4.2 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. Most cable manufacturers have installation procedures or manuals (see Anaconda-Ericsson, Inc. [B5], Anixter Inc. [B6], CABLEC [B29], General Cable [B47], Nexans Cabling Solutions [B81], Okonite Cable [B84], RSCC Wire and Cable [B86], Southwire Power [B88], etc.) that provide helpful information for cable installation in cold temperatures. As a general guideline, cable should not be installed when temperatures are less than the cold bend temperature rating of the cable plus 15°C (27°F), that is, minimum installation temperature = cold bend temperature rating + 15°C (27°F). Installation Manual [B44]. If ambient temperatures are expected to be below -10°C (14°F) in the 24 h ~~hours~~ preceding cable handling and installation activities, the cable should be warmed to room temperature, 20°C (68°F), for at least 24 h ~~hours~~ before work activities begin. During cold weather installations, cable lubricants should ~~shall~~ be used that are suitable for the ambient temperatures. In addition, to avoid damage to ~~pulling~~ the cable due to cold bending, the cable should be pulled ~~more~~ slowly and steadily to completion (~~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 should ~~shall~~ be followed. For further information contact the cable manufacturer.

4.3 Raceway types and ~~cable~~ fill recommendations

4.3.1 Trays

A cable tray is a raceway type that is made up of a single unit, or an assembly of units, forming a structural system used to route cables. Cable trays come in various widths, heights, and configurations; for example, ladder or ventilated trough, solid bottom, and basket type. Cables of all voltage classes can be installed in cable trays provided the appropriate installation conditions for the voltage classes are followed. Specific requirements for tray installation, maximum fill criteria and allowable ampacities can be found in the NEC, Article 392. For additional information regarding the design of cable tray systems see IEEE Std 422TM [B63]. Some general guidelines are listed below, as follows:

- a) The maximum allowable cable weight that can be supported within a tray should be based on ~~the analysis of~~ the analysis of the tray and its 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, specialty, and fiber optic cables may be mixed in the same tray on a random fill basis when electromagnetic interference/radio frequency interference (EMI/RFI) issues among the cables are not a concern.

- d) Low voltage power, control, ~~and instrumentation cables~~, specialty, and fiber optic cables are secured to tray rungs in ~~in trays are generally installed on~~ a random fill manner, but should be installed in as neat and uniform manner as possible. However, they are normally ~~randomfill basis, and are~~ not layered in neat rows ~~or and~~ secured in place like maintained space cables. This results in cable crossings and void areas, which take up some of the tray's ~~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. The cable tray fill limit for random filled trays is calculated to be a percentage of cable tray usable cross-sectional area. A ~~Generally, a~~ 30% to 40% fill for power and control cable and 40% to 50% fill for instrumentation, specialty, and fiber optic cables will generally ~~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 ~~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 tray systems. See NEC, Article 392.22 for cable tray fill criteria. ~~areas/1.167 shall be less than or equal to the tray width."~~
- e) The percent fill of a tray is the sum of the cable cross-sectional areas divided by the tray cross-sectional area times 100%; thus % fill = $\sum \text{cable cross-sectional area} \div \text{tray cross-sectional area} \times 100\%$.
- f) Where single conductor low voltage non-shielded cables ~~conductors~~ are used in trays for ~~two- or three-wire~~ power circuits, these conductors should be securely bound in circuit groups (triangular, triplex, bundled, etc.) to help prevent excessive movements due to conductor-to-conductor fault -current electromagnetic forces and to reduce ~~minimize~~ inductive heating effects in tray sidewalls and bottom.

g) ~~Where~~ ~~When~~ single conductor shielded medium voltage power cables sizes 1 4/0 AWG and larger are installed in trays, the conductors may be arranged in single layer with cables touching, a single layer with cables touching, in a single layer with maintained space (usually one full cable diameter spacing between conductors (maintained space), or in ~~a~~ triangular, triplex, or quadraplex configurations bound together in circuit groups configuration where the sum of the cable diameters does not exceed the tray width. See NEC, Article 392.22 for provides-detailed guidance regarding cable foreable installation and cable ampacity, respectively.

h) Information on ampacity for cables installed in cable trays without maintained spacing and various cable tray fill depths can be found in NEC, Article 392.80 and ANSI/NEMA WC 511CEA P-54-440 [BI6].

a) ~~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 = $\sum \text{cable area} \div \text{cross-sectional area} \times 100\%$.~~

4.3.2 Conduits, wire ways, and ducts

Conduits, wire ways, and ducts are common terms for enclosed raceways. Wire ways, which are usually rectangular, are sheet metal troughs with hinged or removable covers for routing and protecting electrical wires and cables. Conduits and ducts are tubular conveyances for protecting and routing electrical wires and cables. The term "duct" is typically used for underground raceways while the term "conduit" is normally used inside a building. More detailed guidelines are as follows:

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. These fill limits are applicable for power, control, instrument, specialty, and fiber optic cables ~~and instrument cable~~, and have been used for both conduits and ducts. Even though these fill limits are widely accepted and have been used for years, exceptions exist for instances where the conduit/duct path is short, straight, or where the cable can be pushed through the conduit or duct by hand. For more information regarding the design of conduit and ducts see IEEE Std 422 [B63].

- 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 conductor/cable areas divided by the useable conduit or duct area times 100% ~~thus, For example:~~ $\% \text{ fill} = \frac{\sum \text{conductor/cable area}}{\text{internal conduit area}} \times 100\%$.

4.3.3 Troughs, gutters, and sleeves

Gutters are metal or plastic enclosures used to route and protect conductors or cables in meter centers, load distribution centers, switchboards, motor control centers, and other similar cabinets or panels. These items are used as a part of a complete assembly of electrical equipment to supplement wiring space by enclosing conductors and cables that are used as feeders or branch circuit conductors. Gutters are not designed or certified to enclose bus bars, switches, over current devices, or other equipment. Section 12-1900 of the Canadian Electric Code [B32] limits the length that gutters are allowed to extend beyond the equipment that they support to a maximum of 2.0 m (6.6 ft). In addition, the CEC requires gutters to be supported throughout their entire length at intervals not more than 1.5 m (5 ft). NEC, Article 366.30 requires that metal auxiliary gutters be supported and secured throughout their entire length at intervals not exceeding 1.5 m (5 ft). For nonmetallic gutters the interval is not to exceed 900 mm (3 ft) and at each end or joint, and in no case the distance between supports exceed 3 m (10 ft).

There is no maximum established fill limit for troughs or sleeves because ~~Since~~ these raceway types are normally straight and short ~~(i.e., less than 0.6 m [2 ft])~~ in length, and the cables are either placed into them or pushed through them. For gutters, NEC, Article 366.22 (A) states that "the sum of the cross sectional areas of all contained conductors and cables at any cross section of a gutter shall not exceed 20 percent of the interior cross-sectional area of gutter." ~~, there is no maximum established fill limit in general use.~~

4.3.4 Duct banks ~~bank cable pulls~~

~~16.1 General~~

Many of the same considerations for installing cables ~~given~~ in conduit ~~Clause 6~~ apply to installing cables in underground duct bank systems. However, there are unique installation considerations for underground duct banks that need to be considered. When ~~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 deenergized. However, after plant startup and during retrofit work, vaults, duct banks, hand holes, and manholes often contain other cables that are energized and cannot always ~~may not~~ be de-energized during the new work ~~current~~ activity. Work ~~Working~~ under these conditions requires an added level of caution and extra safety measures to be considered and included in the planning prior to performing this type of 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, with other nearby energized cables. 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. The minimum bending radius and maximum sidewall pressure requirements, for the cables being installed in these raceway types should not be violated. For information regarding the design of duct bank systems see IEEE Std 422 [B63].

There are many potential problems when working in a manhole/vault environment. Duct banks, hand holes, manholes, and vaults are often below ground and may accumulate standing ~~Manholes are belowground creating~~ water, which requires ~~conditions, such as~~ pumping the water out and disposing of contaminated discharge. Vaults and manholes are considered confined spaces that require special permits and extra safety precautions ~~needs to be dealt with~~. The ~~manhole~~ atmosphere in confined spaces requires monitoring ~~shall be monitored~~ for oxygen, toxic gases ~~gasses~~, and explosive gases ~~gasses~~. Work in confined space areas requires that personnel not work alone but in a minimum of pairs, with emergency rescue devices readily ~~shall be~~ available to ~~safely~~ ~~extract injured~~ personnel should an accident happen. Also, ~~manholes are often located where traffic and other above ground obstructions restrict the available work space.~~

It is ~~normally~~ considered an unsafe practice to have personnel in the "exit pulling" manhole during a cable the pull because. ~~When~~ pulling tensions can become ~~are~~ high, and if a the rapid release of tension from a failure of the pulling line, block, or cable grip fails, a rapid release of cable tension can create a missile hazard in that manhole. Blowing a "pig" through the duct when cleaning the duct can also result in a hazard in the exit the manhole. ~~In general~~ It is usually 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 should an equipment failure occur.

WARNING

Personnel should never stand in the exit manhole during a pull because high pulling tension can create a missile hazard if a pull line, block, or cable grip should fail.

4.3.5 Direct burial

Direct burial is a technique used for routing cable without a conduit or duct bank in which the cable is in direct physical contact with earth. The cable should be buried below the frost line. For direct buried cables, bedding sand or a bed of soil, a physical barrier on top, and a marker tape are recommended. As an example, this method is often used for parking lot lighting where the consequences of interruption due to future digging are minimal. This method should not be used in areas of heavy vehicular (truck) traffic or where there is a high density of underground infrastructure. When the direct burial method is used in areas of heavy truck traffic, proper design/calculations for dissipation of load, protection via concrete cap, etc. is necessary to preclude cable damage. When cable is laid in an open trench, precautions should be taken to lay the cable on bedding sand or a bed of soil that does not contain debris or sharp rocks and to cover the cable with similar soil. It is recommended that the cable be designed or rated for direct burial. Cable trenching machines are available that slice an opening in the surface, feed the cable into the opening, and cover the opening in one step, also known as "plowing". Caution must be exercised when using this technique to verify that the area is clear of other buried cable or utilities to avoid damaging these in service items.

4.3.6 Trenches

A trench is a term used for two different types of installations. The first, an open trench, is a form of direct burial in which an excavation or depression in the ground is generally deeper than it is wide (as opposed to a gully, or ditch), and narrow compared to its length. The second is a trench, made typically of concrete although other materials may be available, which is a long narrow ditch with concrete on the sides, has an open bottom for water drainage, and is covered by a removable steel or concrete lid. Trench covers are available in both man-rated and vehicle-rated types. The advantage of the concrete trench is the ability to remove the cover to inspect, repair, or replace damaged cable or to add new cable as conditions warrant. Cost and schedule may be disadvantages to the concrete trench design depending on the length, capacity, construction materials, and labor. Another disadvantage of trenches is that, over time, they usually accumulate water and dirt in them. However, trenches can be sloped and designed to overcome this issue.

4.3.7 Raceway support types

The type of support device to be utilized is dependent upon whether the raceway is conduit, tray, or free air (~~shaft~~). The support should be designed and installed to carry the maximum cable load considering the seismic zone where the facility is located. Engineering usually produces typical support details applicable to most plant areas for the installer to use; however sometimes special support details are needed due to unique installation situations. See 8.2 for more information relative to cable supports.

4.4 Planning activities

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

- a) For long conduit or duct bank pulls, preplan the direction of cable pulls by performing cable pulling calculations in both directions.
- b) Plan to have sufficient cable, pulling lubricants, and cable pulling accessories (shims, sheaves, rollers, ropes, etc.) available prior to performing any work.

- c) Plan duct inspection and cleaning activities sufficiently in advance of cable pulling activities in order to determine the suitability of the ducts for use.
- ~~e) 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 space inspection and test activities ~~spaces such as manholes, vaults, and duct bank openings~~ for combustible and toxic gases, water, and energized cables sufficiently in advance to make necessary preparations ~~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. This should also help ensure the pulling equipment can be located to support the planned pull. Sometimes physical constraints will only allow pulling from one direction.
- g) For installing cables in trays, walk down the tray route to assure it is complete, contiguous, and does not contain debris or foreign material.

~~6. Cable installation recommendations~~

~~6.1.1 Pre installation considerations~~

- h) Avoid routing cables near lube oil reservoirs, lube oil conditioners, hydraulic oil storage areas, etc., since potential leakage of petroleum products can affect cable jacket, shield, and insulation materials ~~material.~~
- i) 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.

- j) Avoid routing cables in areas subject to damage due to future maintenance activities. If it ~~is~~ required to run cables through these areas, proper physical protection will need to ~~and shielding shall~~ be provided.
- k) As required under NEC, Article 300.8, "raceways or cable trays containing electric conductors shall *not* contain any pipe, tube, hose, or equal for steam, water, air, gas, drainage, or any service other than electrical", see NEC Article 300.8
- l) 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.

4.5 Pre-installation activities for duct banks

4.5.1 General

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

- a) If possible, 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 toxic ~~toxicity~~ and combustible gases ~~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 [conduits/ducts](#) with [boring and cleaning mandrels followed by a test mandrel with](#) ~~and~~ soft covering. [A boring mandrel dislodges and removes the debris not removed by the rodding operation and re-bores a duct to remove duct blisters, roots, concrete stalactites, etc. The cleaning mandrel is normally used after the rodding operation to provide a clear and clean duct for cable pulling. Inspect and repair, as necessary, each duct and conduit prior to starting any cable pulling activities.](#)
- 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. [Test mandrels are used to determine the duct bend radii of the duct system, to check ducts for out of roundness, and to check surface roughness in preparation for cable pulling.](#) A borescope 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 [conduits/ducts](#) and let ~~it~~-soak for 24 ~~h~~ [hours](#) before [pulling](#) existing cables ~~are pulled out~~ [during cable replacement activities](#) ~~and replaced~~. The use of power lubrication equipment is the most effective technique as it forces the lubricant further into the [conduit/duct](#) and covers the interior of the [conduit/](#) duct and cable more thoroughly.
- j) Inspect existing cables that are being removed to identify installation damage that may be a clue to the [conduit/duct's](#) inner condition. ~~Repeat the above steps as necessary.~~
- [k\) Review safety requirements that must be adhered to before beginning work in enclosed spaces such as manholes or vaults.](#)
- ~~k) Consult IEEE P971™ [B18] for more information regarding precautions to be taken before beginning work in a manhole or vault.~~

- 1) ~~Because~~ ~~Since~~ manholes and vaults are considered confined spaces, comply with [Occupational Safety and Health Administration \(OSHA\)](#) and other applicable safety codes and standards before entry.

WARNING

Always monitor air inside manholes and vaults for combustible and toxic gases, ventilate prior to entering manholes and vaults, and use appropriate personal protective equipment (PPE).

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. If any of the conditions noted above are extreme, a new cable route may need to be designed.

For duct bank systems that were constructed of concrete-asbestos (transite), pulling cables, cleaning ducts, and removing cables is difficult because the duct absorbs moisture, "swells", and becomes "friable". This is a particular concern because it is constructed with asbestos. It is recommended to avoid disturbing concrete asbestos duct banks and cables therein, and looking for another route for new cables.

4.5.3 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\) Corrosion of metallic cable clamps or metallic portions thereof](#)
- e) Broken rungs and sharp edges on trays or conduit
- f) Degradation, deterioration, or evidence of rodent damage to cable
- g) Evidence of electrical arcing from existing cables to racks, trays, ducts, other metallic objects-
- [h\) Loose connections or corrosion at the ground wire terminal point inside the manhole or vault](#)

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

4.5.4 Cable installation precautions

The following installation precautions should be observed:

- a) Ventilate and retest the vault or manhole [for toxic gases](#) 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\) Use suitable sized shims, sleeves, rollers, etc. to avoid violating the cable minimum bend radius, maximum pulling tensions, or maximum sidewall pressures.](#)

- d) [Avoid pulling](#) ~~Never pull~~ cables into a duct with existing cables due to the potential for cable damage.
- e) Due to the potential for cable damage, avoid pulling cables of different types and sizes together in the same [conduit](#)/duct; however, sometimes a ground conductor of a different size is pulled with the phase conductors. [When a separate ground conductor is pulled in with single phase conductors, it is recommended to use an insulated ground conductor to avoid a bare ground conductor from doing damage, such as scraping the insulated phase conductors during the installation process. Unless the ground conductor is the same size as the phase conductors being pulled, it should not be part of the cable conductors being pulled on. The ground wire should only "go along for the ride". Its weight contribution should be included in the total cable weight when performing pulling calculations.](#)
- f) Pre-lubricate ducts with copious amounts of a lubricant that is compatible with the cable jacket; ~~see Clause 10 for additional information on lubrication.~~
- g) Lubricate each cable with more lubricant as it enters the duct; ~~see Clause 10 for additional information on lubrication.~~
- h) Monitor cable pulling tensions during the pull ~~(see 11.3).~~
- i) Avoid starts, stops, and jerking the cable during the pull as this leads to cable galloping.
- j) [Pre-warm cable when pulling cable in cold temperatures \(See 4.2\).](#)

4.5.5 [Cable](#) rigging activities

Rigging, including bull wheels and skids, should be carefully selected [so](#) ~~to ensure~~ that cable pulling tensions, sidewall pressures, and bending radius limits are not exceeded. Pulling rigs should be properly braced to [help](#) 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 44500 N (10 000 lbf) will apply 89 000 N (20 000 lbf) of tension to a block with a 0° angle or 63000 N (14 140 lbf) at a 90° angle ([see Figure 7](#)) ~~6~~.

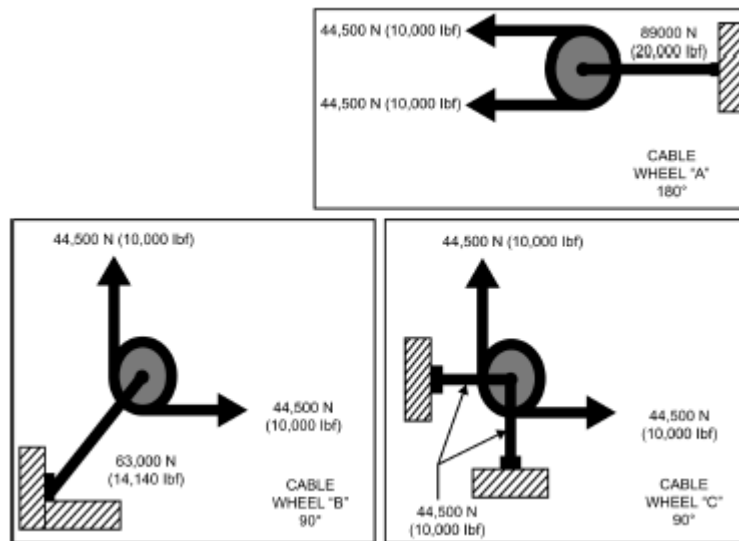
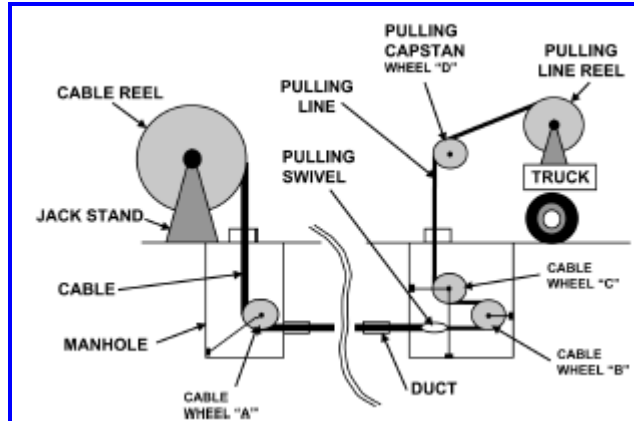


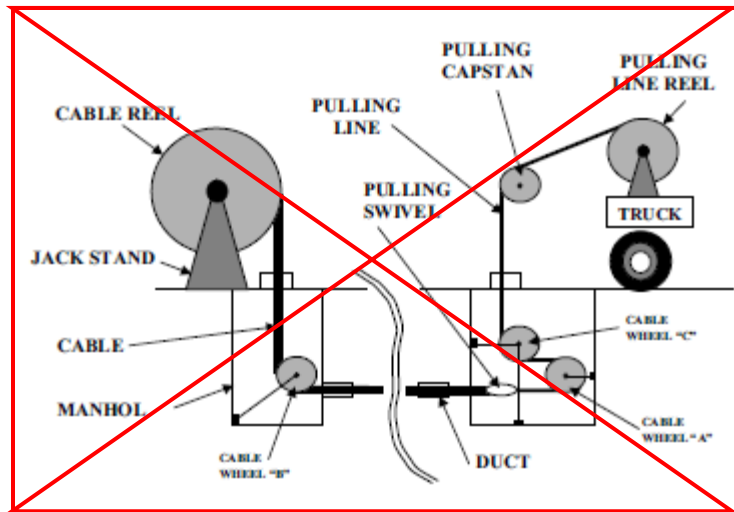
Figure 7-Wheel setup comparisons

The rigging should be set up to bring sufficient cable into the manhole for splicing. Stopping a pull to later pull (luffing) ~~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 pulling (luffing) slack cable back into the manhole.

Typical duct bank cable pull set-ups are shown in Figure ~~87~~ and Figure 9. Three-wheel pulley assemblies, shown in (Figure 8) are often used when pulling cables because ~~since~~ they are smaller and more practical for areas of limited space. However, it should be recognized that a three-wheel pulley assembly does ~~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.

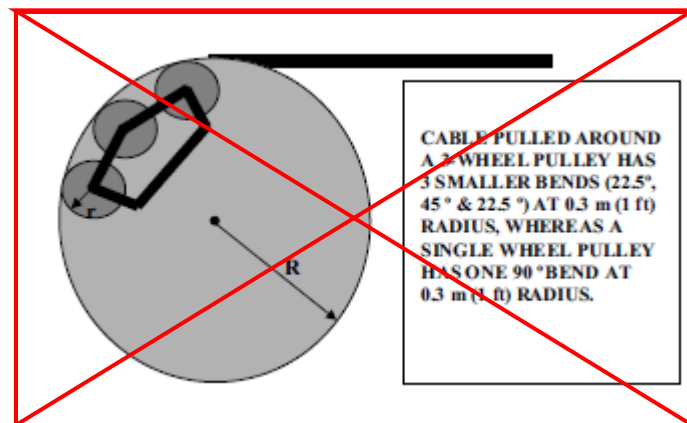


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Figure 8-Duct bank pull setup-Example 1



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Figure 8—Three-wheel pulley example

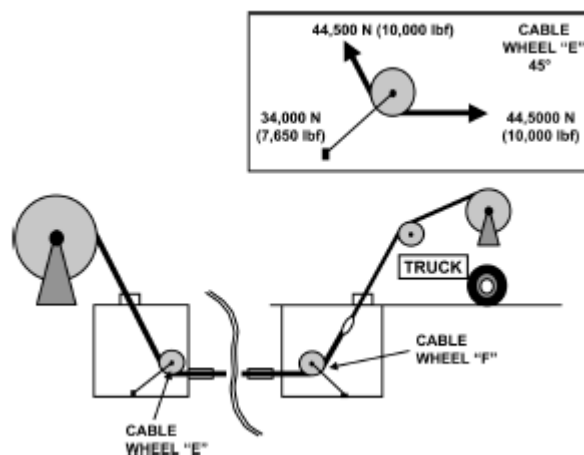


Figure 9—Duct bank pull setup—Example 2

4. Cable pulling recommendations

4.6 Distance limitations

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

- a) Conductor material (copper Cu or aluminum 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 SWBP ~~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 in degrees 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 ~~reduce~~ minimize friction
- r) Amount of reel back-tension from payoff reel
- s) Direction of pull

For more information see pulling guides from equipment manufacturers and installation guides from cable manufactures; such as Anaconda-Ericsson, Inc. [B5], Anixter Inc. [B6], General Cable [B47], Nexans Cabling Solutions [B81], Okonite [B84], Southwire Power [B88], RSCC Wire and Cable [B86], CABLEC [B29].

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. See 4.10, 4.11, and 4.14 for more information on these subjects.

4.7 Reel position and reel back tension

Pulling tension will be increased when the cable is pulled incorrectly off of the reel. Turning the reel and feeding slack cable into ~~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.~~

~~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 (1)¹⁰. For more information ~~)(see the~~ IEEE Committee Report entitled "Recommended Practice on Specific Aspects of Cable Installation in Power Generating Stations" [B31]; ~~[B17]);~~

¹⁰Equation (1) courtesy Committee Report [B30].

$$\begin{aligned} T_r &\approx K_o \times W \times L \times g \quad (\text{metric}) \\ T_r &\approx K_o \times W \times L \quad (\text{English}) \end{aligned} \quad (1)$$

(New)

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

(Deleted)

where:

T_r is the =tension from cable reel, N (metric), lbf (English)

W is the weight =mass per unit length of cable, kg/m (metric), lbf/ft (English)

L is the =length of cable, m (metric), ft (English)

g is the acceleration due to gravity =gravitational constant (9.8 m/s^2) (metric)

K_o is the =basic coefficient of friction (both: typical value between 0.5 to 1.0)

for more information ;see IEEE Std 525™ [B65], Fee and Quist [B44], and Weitz [B93 26])

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

(Deleted)

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])