Power Cable Installation

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1.0 Introduction

Power cable installation is a critical aspect of any construction project, forming the backbone of electrical systems. Whether in primary distribution systems, industrial plants, commercial facilities, or residential buildings, the proper installation of power cables ensures that electrical energy is delivered safely and efficiently to the intended loads.

A poorly executed installation can lead to energy losses, mechanical damage, overheating, or even electrical faults and fires. Therefore, understanding the principles, standards, and best practices of cable installation is essential for ensuring system reliability, longevity, and compliance with relevant regulations.

There are various methods of installation, each suited to specific environments and operational requirements. Common approaches include, but are not limited to:

1. Direct burial in the ground
2. Raceways
3. Vertical Risers
4. Cable trays
5. Suspension in air
6. Tunnels.

The choice depends on factors like cable type, voltage level, environmental conditions, mechanical protection requirements, and accessibility for maintenance. For example, underground installations may require special consideration for moisture ingress and thermal dissipation, while cable trays demand secure fixing and adequate spacing to prevent overheating. In addition, installation in combustible or non-combustible combustible buildings will have additional requirements set out in building codes related to protection against flame or fire.

In addition to installation method, numerous considerations must be addressed to ensure safety and compliance. These include adherence to national and international standards such as the Canadian Electrical Code (CE Code) and National Building Code (NBC) in Canada and the National Electrical Code (NEC) and the International Building Code (IBC) in the US with regards to proper selection of cable types and sizes, adequate earthing and bonding, thermal performance analysis, and protection against external influences such as fire/flame, chemical exposure, UV, or physical impact. Attention must also be paid to separation from other utilities, bending radii, and allowable pulling tensions during installation. By accounting for these factors, engineers and installers can ensure that power cable systems operate safely, efficiently, and in full compliance with industry regulations throughout their service life.

It is not the intent of this course to be an all-inclusive "how-to" document, rather it is meant to be used as a handy reference to familiarize with common installation methods and considerations when it comes to low and medium voltage cables.

Any information included herein does not supersede the relevant electrical codes and standards that must be adhered to in Canada and the US.

2.0 Industry Guides and Standards

There are various installation codes, standards, and guides related to power cable installation.

2.1 CSA C22.1, Canadian Electrical Code, Part 1

The CSA C22.1, or Canadian Electrical Code (CE Code), Part 1, is Canada's national safety standard for electrical installations and equipment. It establishes a comprehensive set of rules and requirements for electrical work, designed to protect people and property from electrical shock, fire, and other hazards. The CE Code is updated every three years to reflect advances in technology, safety research, and industry practices. Adoption of the code occurs at provincial, territorial, and municipal levels to ensure a consistent standard of electrical safety across the country.

2.2 NFPA 70, National Electrical Code (NEC)

The National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), provides standards for the safe installation of electrical wiring and equipment in the United States. Like the CE Code, the NEC is updated every three years to incorporate new technologies, materials, and safety practices. It is widely adopted by state and local governments, forming the legal foundation for electrical safety in most U.S. jurisdictions.

2.3 Local Electrical Safety Codes (Provincial or State-specific Codes)

Local electrical safety codes are regulations that establish standards for electrical installations and equipment at the provincial or state level. These codes are often based on the CE Code or NEC but may include amendments specific to local conditions or requirements. For example, in Ontario, Canada, the Ontario Electrical Safety Code (OESC) adapts the CE Code to incorporate Ontario-specific rules and practices, ensuring that electrical work meets both national and local safety requirements.

2.4 National, Provincial, and Municipal Building Codes

Building codes establish the minimum standards necessary to ensure the safety, health, and accessibility of buildings. They cover structural integrity, fire protection, and general public safety. Building codes apply to activities such as construction, renovation, demolition, and changes in building use that may introduce new hazards or alter maintenance requirements. By defining these standards, building codes ensure that structures are safe for occupancy and operation.

2.5 EPRI EL-3333, Volume 2 – Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables – Cable User's Guide

This technical report, published by the Electric Power Research Institute (EPRI), provides guidelines for the maximum safe pulling lengths of solid dielectric insulated cables. It assists engineers in designing cable systems that are both cost-effective and reliable, helping to reduce mechanical and electrical stress during installation.

2.6 IEEE 524 – Guide for the Installation of Overhead Transmission Line Conductors

IEEE 524 offers practical recommendations for the stringing of overhead transmission line conductors and overhead ground wires. It addresses the selection of installation methods, equipment, and tools, providing guidance that has been validated through industry practice.

2.7 IEEE 525 – Guide for the Design and Installation of Cable Systems in Substations

IEEE 525 provides substation engineers with recommendations for the selection, application, and installation of metallic and optical cables in power substations. Its guidance focuses on reducing cable failures and maintaining safe, reliable operation over the substation's design life.

2.8 IEEE 576 – Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable in Industrial and Commercial Applications

IEEE 576 provides guidance for the installation, splicing, termination, and field testing of insulated power cable in industrial and commercial settings.

2.9 IEEE 1185 – Recommended Practice for Cable Installation in Generating Stations and Industrial Facilities

IEEE 1185 outlines best practices for the installation of cables in generating stations and industrial facilities. The guide focuses on installation techniques that maximize cable reliability and operational safety in these demanding environments.

2.10 AEIC CG5 – Underground Extruded Power Cables Guide

The AEIC CG5 guide, developed by the Association of Edison Illuminating Companies (AEIC), defines the key pulling parameters for the installation of extruded underground power cables in ducts. Its purpose is to help engineers plan and execute cable installations that minimize mechanical stress and reduce the risk of failure.

2.11 Aluminum Electrical Conductor Handbook

This comprehensive handbook covers the electrical applications of aluminum conductors, including bare, covered, and insulated wire and cable. It includes more than 300 tables and illustrations, making it a valuable reference for engineers, designers, and technicians working with overhead aluminum-based electrical systems.

3.0 Methods of Installation

The methods installation that will be reviewed/discussed are:

3.1 Exposed
3.2 Raceway
3.3 Cable Tray
3.4 Cablebus
3.5 Vertical
3.6 Underground
3.7 Overhead
3.8 Tunnels
3.9 Low Temperature

3.1 Exposed

The exposed wiring method refers to electrical wiring that is visible, rather than being hidden inside walls. This installation method is used for certain situations and certain types of wiring, but requires careful consideration to protect it from physical damage. Approved methods include running wires inside a protective conduit like rigid metal conduit or using surface-mounted raceways, which are often used in workshops or unfinished basements.

3.2 Raceway

A raceway is a channel designed to contain, support, and route wires, cables or busbars. Its main purpose is to keep cables organized and shielded from physical damage, moisture, dust, heat, and other environmental hazards. By enclosing or guiding cables in a defined path, raceways help prevent wear and accidental contact, while also making installations cleaner and safer. They are commonly used in buildings, industrial facilities, and infrastructure projects where multiple cables need to be run in a controlled and reliable manner.

Raceways come in many forms, including conduits, busways, surface mounted, and underfloor, and can be made from materials such as metal, plastic, or composite compounds depending on the application. In addition to protection, raceways simplify future upgrades and troubleshooting by providing a clear, accessible route for adding, removing, or inspecting cables.

Conduit

Conduits, or ducts, are raceway systems specifically used to route and protect electrical power cables in buildings, industrial facilities, and utility installations. See **Figure 1**. They provide a continuous, controlled pathway that shields cables from mechanical damage, moisture, chemicals, and environmental exposure. Conduits are typically round and enclosed, offering high levels of protection for individual or grouped cables and can be selected to to carry multiple power cables over longer distances, including underground or within concrete structures.

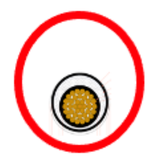
These systems are manufactured from materials such as steel, aluminum, PVC, HDPE, or concrete, with the material choice depending on voltage level, environmental conditions, and installation method. Metallic conduits and ducts offer strong mechanical protection and grounding capability, while non-metallic options provide corrosion resistance and lighter weight. Proper sizing is critical to prevent cable damage during pulling, allow for heat dissipation, and accommodate future cable additions.

In power cable installations, conduits and ducts also play an important role in system reliability and maintenance. They help control cable bending radius, reduce pulling tension, and organize circuits for easier identification and inspection. In underground duct banks, they allow power cables to be replaced or upgraded without major excavation.

Figure 1 – Different types of conduit. Rigid and flexible metallic (Left) non-metallic (Right)

The maximum number of insulated conductors or multi-conductor cables in one conduit or tubing shall be such that the conductor or cable will not result in a greater **conduit fill** than that specified in the relevant electrical code.

All conductors, including the bonding conductor are included in the conduit fill calculation.



Cables used in conduit systems are typically unarmored single/multi-conductors such as RW90, T90/THWN75, XHHW-2 and THHN.

3.3 Cable Tray

A cable tray is a supporting means consisting of troughing/fittings constructed so that insulated conductors and cables may be readily installed or removed after the cable tray has been completely installed, without damage either to the conductors or their covering.

Cable trays are open support systems used to route, support, and organize electrical power cables along defined paths, typically in industrial plants, commercial buildings, and utility facilities. Unlike fully enclosed raceways, cable trays allow cables to be laid in place rather than pulled through, which reduces installation stress and makes inspection, maintenance, and future expansion easier. For power cables, trays provide a practical solution where large cable sizes, high cable counts, or frequent modifications make conduits or ducts less efficient.

There are several types of cable trays, each suited to different applications. See **Figure 2**. Ladder trays are the most common for power cables, offering excellent strength and heat dissipation while supporting heavy loads. Ventilated trough trays provide more continuous cable support with some airflow and are often used for smaller power cables. Solid-bottom trays offer maximum protection from falling debris or dripping liquids but require careful thermal derating due to reduced ventilation. Wire mesh trays are typically used for light-duty applications and smaller cables, rather than medium- or high-voltage power cables.

Figure 2 – Different types of cable trays

Cable tray spacing requirements are typically specified in the relevant electrical code and depend on tray size and positioning. See **Figure 3**.

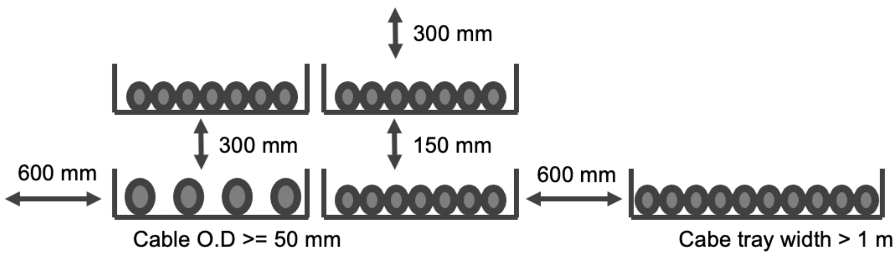


Figure 3 – Example cable tray spacing requirements. Refer to local electrical codes for more.

Cable trays are installed by mounting them on supports such as wall brackets, trapeze hangers, or floor stands, with support spacing determined by tray type, material, and cable weight. Trays may run horizontally or vertically and are often bonded and grounded, especially when metallic. Changes in direction are made using prefabricated fittings (elbows, tees, and reducers) to maintain proper cable bend radius and mechanical support. Expansion joints may be required in long runs to accommodate thermal movement.

When installing power cables in trays, several key considerations apply. Cables should be laid neatly without crossing or twisting, and adequate spacing should be maintained to manage heat dissipation and electromagnetic effects. Cables can also touch, but their maximum allowable ampacity must be derated appropriately. Heavy power cables may need to be installed using rollers and then secured with cleats or ties rated for the cable weight and short-circuit forces. Minimum bend radius must always be respected, particularly at tray fittings and vertical drops. Finally, cable loading should never exceed the tray's rated capacity, and future capacity should be considered to avoid overcrowding and thermal issues over the life of the installation.

Cables used in cable trays are typically either armoured, like Teck90 or Type MC, or unarmored with a Tray Cable (TC) rating. The reason for this is that armoured products and TC rated cables pass additional mechanical damage (crush and impact) and flame (FT4) tests.

3.4 Cablebus

A cablebus is an assembly of insulated conductors or cables, or both, with fittings and conductor terminations in a completely enclosed, ventilated, or non-ventilated protective metal housing. See **Figures 4** and **5**.

Figure 4 – Cablebus construction

Figure 5 – Cablebus installed outdoors (left) and indoors (right)

Cablebus systems are designed to CSA C22.2 No. 273 and are an integrated power distribution solution that combines insulated conductors, continuous aluminum or steel enclosures, and built-in spacing to carry high electrical loads safely and efficiently. One of the key benefits of a cablebus is its free-air cable rating. Because the conductors are installed with controlled spacing and exposed to airflow within a ventilated enclosure, heat is dissipated more effectively than in conduit or duct systems. This improved thermal performance allows cables to operate at higher ampacities without excessive derating, making cablebus ideal for demanding power applications.

Cablebus is particularly well suited for high current loads while maintaining reduced power losses. The optimized conductor spacing and symmetrical phase arrangement help minimize resistance, skin effect, and proximity effect, improving overall electrical efficiency. In addition, the close grouping and enclosure design provide inherent EMF suppression, reducing external magnetic fields and improving safety and compatibility with nearby equipment. These characteristics make cablebus a strong alternative to traditional bus duct or large parallel cable installations.

From a project perspective, cablebus can be cost efficient and simplifies installation. Factory-assembled sections reduce on-site labor, installation time, and the risk of wiring errors. Compared to multiple conduits or large cable trays with parallel conductors, cablebus requires fewer supports and less coordination during installation. This streamlined approach often results in lower total installed cost, especially for long runs or high-amperage feeders.

Finally, cablebus systems are highly expandable, allowing additional circuits or increased capacity to be added with minimal disruption. Modular sections make it easier to extend runs, reroute pathways, or upgrade capacity as power demands grow. This flexibility, combined with thermal efficiency and electrical performance, makes cablebus a future-ready solution for industrial plants, data centers, substations, and other high-power installations.

Cables used in a cablebus can be grouped into two groups, < 5kV and > 5 kV.

For **power cables rated below 5 kV**, minimum insulation and environmental performance requirements must be met to ensure safe operation and long-term reliability. These cables must have a minimum temperature rating of 75 °C and adequate moisture resistance, equivalent to RW75 or RW90 thermoset insulation. Alternatively, compliance can be achieved by using an armoured cable suitable for wet locations, which provides both mechanical protection and moisture resistance, or by selecting a cable with a TC (Tray Cable) rating, which is specifically designed for use in cable trays and exposed industrial environments.

For **power cables rated above 5 kV**, more stringent construction and performance standards apply due to higher electrical stresses. These cables must comply with CSA C68.5 or CSA C68.10, which govern medium-voltage power cable design and testing. In addition, the cable must have a non-metallic, sunlight-resistant outer jacket to withstand outdoor exposure. Fire safety and UV durability are critical at these voltage levels, so the cable must also carry a flame test rating of at least FT1 and include a sunlight-resistant marking, such as SR or SUN-RES, printed directly on the jacket.

Proper color identification of conductors is required to ensure safety, correct phase identification, and ease of maintenance. In three-phase systems, phase conductors are identified as Red, Black, and Blue, and these colors may be applied by field marking at terminations or splice locations if not factory colored. The bonding (ground) conductor must be bare, green, or green with a yellow stripe, while the neutral conductor must be white. Consistent color identification reduces the risk of wiring errors, improves troubleshooting efficiency, and supports compliance with electrical codes and best installation practices.

3.5 Vertical

In vertical cable installations **(Figure 6)**, it is essential that conductors are supported in a way that prevents mechanical strain from being transferred to electrical equipment, joints, splices, or terminations. The weight of a vertical cable run can be significant, especially for large power cables, and if this weight is allowed to rest on terminals or connection points, it can lead to insulation damage, loosened connections, or long-term reliability issues. Proper support ensures that the mechanical load of the cable is carried by the raceway or supporting system rather than the electrical connections themselves.

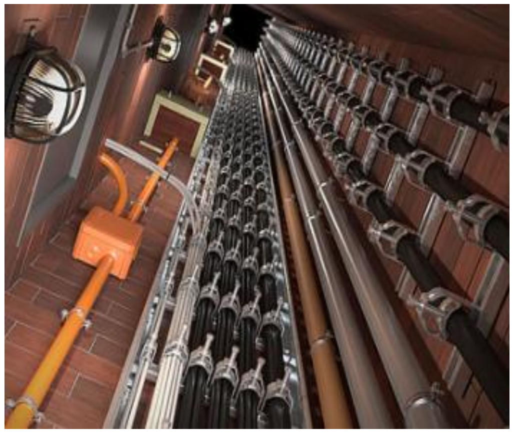


Figure 6 – Vertical installation of cables in shaft

For conductors installed in vertical raceways, support must be provided independently of the terminal connections and at regular intervals throughout the vertical run. These supports are intended to control the downward force caused by gravity and prevent excessive tension on the conductors. Properly spaced supports also help maintain cable alignment, reduce the risk of insulation deformation, and improve safety during both installation and operation. The spacing of supports is determined by the cable type, size, and weight, and must be sufficient to prevent damaging strain over the full height of the installation.

Special considerations apply to armoured and sheathed cables commonly used in vertical applications, such as Type MC, Type AC, TECK90, RA90, and ACWU90. In these installations, the internal conductor assembly must be supported at defined intervals, either through direct mechanical support or by installation methods that effectively relieve vertical tension. This can be achieved by introducing intentional changes in direction, such as bends that create a total change in direction of at least 90 degrees, which help transfer the cable’s weight to the structure. Alternatively, incorporating horizontal sections within the run can provide natural support points, or selecting cables specifically designed to withstand the mechanical demands of vertical installations.

In addition to basic support requirements, installation planning plays a critical role in successful vertical cable systems. The route of the vertical run should be carefully evaluated to identify natural support points such as floors, intermediate landings, or structural members where cable supports can be installed. For long vertical distances, installers should consider dividing the run into manageable sections to limit pulling tension and reduce the risk of conductor stretch or insulation damage during installation. Proper planning also helps ensure that supports are accessible for inspection and maintenance over the life of the system.

Cable pulling and handling practices are especially important in vertical installations. The maximum allowable pulling tension for the conductor and insulation system must not be exceeded, and appropriate pulling equipment, such as tension-limiting devices or cable grips designed for vertical pulls, should be used. More on pulling tension later in this document. For large or heavy cables, staged pulls or top-down installation methods may be required to better control cable weight. Rollers, guides, and protective bushings should be installed at entry and exit points to prevent abrasion and maintain the required bending radius.

Long-term performance and safety considerations must also be addressed. Vertical cables are subject to continuous gravitational stress, thermal expansion and contraction, and in some cases vibration. Proper support and strain-relief methods help prevent conductor creep, armour distortion, and jacket damage over time. Regular inspection of supports, clamps, and termination points is recommended to confirm that the cable remains secure and free from abnormal movement.

When properly designed and installed, vertical cable installations provide reliable performance, minimize maintenance issues, and extend the service life of power cable systems.

3.6 Underground

Underground cable installations are a critical aspect of modern power distribution and transmission networks. Unlike overhead lines, underground cables are less exposed to environmental hazards such as wind, lightning, or ice loading, which improves reliability and safety. However, installing cables underground introduces unique engineering challenges, particularly related to heat dissipation, soil characteristics, current carrying capacity (ampacity), and mechanical protection. Proper planning and design are essential to ensure safe operation, long service life, and optimal performance.

This article provides an in-depth overview of underground cable installations, covering types of installations, thermal considerations, spacing, burial depth, current derating, ampacity calculations, and modern software tools for design.

3.6.1 Types of Underground Cable Installations

Underground power cables can be installed using several methods, each with specific advantages and constraints. The choice of installation type depends on factors such as available space, environmental conditions, soil properties, electrical load requirements, and cost considerations. The most common installation methods include direct burial, duct systems, and concrete-encased duct banks.

3.6.1.1 Direct Buried

Direct burial involves laying the cable directly in the ground, typically in a trench backfilled with soil or sand. This is the simplest and often the most economical installation method.

Key considerations for direct burial include:

Trench Depth and Width: Trench depth depends on voltage level, mechanical protection requirements, and regulatory codes. Low-voltage cables might be buried at depths of 0.6–0.9 meters, whereas high-voltage cables (69 kV and above) may require depths of 1.0–1.2 meters or more. The width of the trench must allow for cable separation and installation of protective bedding material.

Bedding and Backfill Material: Sand or fine soil is commonly used for bedding to prevent mechanical damage. Proper compaction is critical to avoid voids that could affect thermal dissipation.

Thermal Considerations: Directly buried cables rely on the surrounding soil to dissipate heat. The thermal resistivity of the soil significantly impacts the cable's ampacity. Highly resistive soil (dry, sandy) reduces heat transfer, requiring derating of current carrying capacity.

3.6.1.2 Underground Ducts

Ducted systems involve placing cables inside conduits or ducts, which are then buried underground. This method offers flexibility and additional protection.

Duct Materials: Common materials include PVC, HDPE, and sometimes metallic ducts for EMI shielding.

Installation Flexibility: Ducts allow for easier replacement or addition of cables without re-excavation. This is especially advantageous in urban areas or congested corridors.

Thermal and Spacing Considerations: Ducts affect heat dissipation differently than direct burial. Air-filled ducts provide less heat transfer than soil, which may require spacing between cables or forced cooling in high-load situations. Moisture ingress in ducts can improve thermal conductivity, but standing water must be avoided.

3.6.1.3 Concrete-Encased Duct Banks

Concrete-encased duct banks are commonly used in high-density urban installations or where additional mechanical protection is required, such as under roads or pavements.

Structure: Cables are laid in ducts or directly in conduits within a reinforced concrete structure. Concrete provides mechanical protection, chemical resistance, and additional fire safety.

Spacing and Layout: The thermal interaction between adjacent cables is significant. Proper spacing and orientation of cables within the duct bank are critical to avoid overheating.

Thermal Effects: Concrete has relatively high thermal conductivity, which improves heat dissipation compared to dry soil. However, large masses of concrete can also trap heat, requiring careful thermal modeling.

3.6.2 Burial Depth

The depth at which cables are buried is determined by a combination of mechanical protection requirements, local codes, and thermal considerations:

Mechanical Protection: Deeper burial protects against accidental excavation or traffic loads.

Thermal Impact: Deeper burial increases soil thermal resistance slightly, which can reduce ampacity.

Typical Depths:

1. Low-voltage distribution cables: 0.6–0.9 m
2. Medium-voltage distribution cables: 0.9–1.2 m
3. High-voltage transmission cables: 1.2–1.5 m or more

3.6.3 Heat Dissipation and Soil Thermal Resistivity

A critical factor in underground cable installation is heat dissipation. Electrical current flowing through a cable generates heat due to resistive losses. Unlike overhead lines, which cool naturally through air circulation, underground cables rely on surrounding materials for heat removal. The ability of soil, concrete, or duct materials to dissipate heat is quantified by thermal resistivity (ρ), measured in °C·cm/W or m·K/W.

Soil Thermal Resistivity: Moist, compacted soils generally have lower resistivity (0.8–1.2 °C·m/W), allowing efficient heat dissipation. Dry, sandy, or rocky soils can have resistivities exceeding 2 °C·m/W, which restricts current carrying capacity.

Temperature Rise: Cables are rated for a maximum conductor temperature, often 90 °C for XLPE insulation. If heat is not adequately dissipated, conductor temperature can exceed this limit, leading to insulation degradation and reduced service life.

Mitigation: Soil backfill with high thermal conductivity materials (e.g., sand or bentonite) is commonly used. Moistening soil around cables can also improve heat transfer.

3.6.4 Cable Spacing Considerations

Proper spacing between cables is essential to reduce mutual heating and ensure long-term reliability. Spacing depends on:

Phase Arrangement: In three-phase systems, symmetrical arrangements minimize mutual heating and optimize cooling.

Horizontal vs. Vertical Separation: Vertical separation can improve heat dissipation in trenches or duct banks, as the top cables receive more airflow or soil contact.

Thermal Analysis: IEEE 835 provides tables for recommended spacing to maintain rated ampacity, accounting for mutual heating. Software tools now allow precise modeling of spacing effects using steady-state or transient methods.

Inadequate spacing can lead to overheating, insulation degradation, and premature cable failure.

3.6.5 Ampacity Derating

Current derating is the practice of reducing the rated current of a cable to account for installation conditions that impede heat dissipation. Several factors affect derating:

Burial Depth: Shallow burial may reduce soil insulation but exposes cables to ambient air effects. Deeper burial increases thermal resistance and reduces ampacity.

Cable Spacing: Closely spaced cables increase mutual heating, requiring derating. For example, three-phase circuits installed in proximity may need a 10–20% reduction in current.

Number of Circuits: Multiple circuits in the same trench or duct bank amplify heating effects, further reducing allowable current.

Soil Conditions: High thermal resistivity soils require significant derating.

Ambient Temperature: Elevated ground temperatures reduce cable ampacity.

Derating ensures cables operate within safe thermal limits, preventing insulation failure and ensuring reliable service.

3.6.6 Ampacity Calculations

Ampacity is the maximum current a cable can carry continuously without exceeding its thermal limits. Several methods exist for calculating ampacity, including:

3.6.6.1 IEEE 835 / Neher-McGrath Method

The Neher-McGrath method, formalized in IEEE 835, is the standard approach for steady-state ampacity calculations. It considers:

1. Cable construction and insulation properties
2. Conductor temperature rating
3. Soil thermal resistivity and backfill properties
4. Burial depth and spacing
5. Number of circuits and mutual heating effects

The Neher-McGrath method is particularly important for multi-cable installations, where mutual heating and soil variability have a significant impact.

3.6.6.2 IEC 60287 Method

The IEC 60287 standard provides similar ampacity calculation methods, widely adopted internationally. It uses empirical and analytical formulas to account for:

1. Thermal resistivity of surrounding materials

2. Cable construction
3. Installation type (direct burial, duct, or concrete encased)
4. Layering and spacing of cables

IEC 60287 provides a standardized approach to thermal and electrical design.

3.6.6.3 Software Tools for Ampacity Calculations

Modern engineering relies on software tools that implement both steady-state and transient ampacity calculations. Key features include:

1. **Steady-State Methods:** Use Neher-McGrath or IEC formulas to calculate maximum continuous current under normal operating conditions.
2. **Transient Methods:** Simulate short-term events, such as overloads or emergency currents, allowing for temporary ampacity above the steady-state rating.
3. **Thermal Modeling:** 3D modeling of cable layouts, soil layers, and concrete structures to accurately predict temperature rise and optimize spacing.
4. **Integration with Load Flow Analysis:** Ensures cable sizing matches network requirements and prevents unnecessary oversizing.

Popular software packages include CYMCAP, ETAP, and SKM PowerTools.

3.6.7 Design Considerations for Different Installation Methods

3.6.7.1 Direct Buried Cables

Considerations:

- Ensure soil thermal resistivity is measured at the site, preferably using ASTM D5334.
- Use thermal backfill material to improve heat transfer.
- Verify minimum trench width and depth according to code.
- Consider derating for multiple cables in the same trench.

3.6.7.2 Underground Ducts

Considerations:

- Select ducts with appropriate thermal conductivity and mechanical strength.
- Maintain spacing between cables to minimize mutual heating.
- Include provisions for water drainage to prevent standing water in ducts.
- Ampacity calculations must account for reduced heat transfer in air-filled ducts.

3.6.7.3 Concrete-Encased Duct Banks

Reinforced concrete provides excellent mechanical protection but affects thermal dissipation.

Considerations:

- Ensure proper spacing and orientation of cables within the bank.
- Use high-thermal-conductivity concrete or additives to improve heat dissipation if necessary.
- Consider emergency overload scenarios and transient thermal effects.

3.6.8 Key Standards and Guidelines

1. IEEE 835: Standard for calculating ampacity of underground cables using Neher-McGrath method.
2. IEC 60287: International standard for determining continuous current ratings of cables.
3. ASTM D5334: Standard test method for thermal resistivity of soil.
4. IEEE 142 (Green Book): Grounding and soil considerations in power systems.
5. National Electrical Codes (NEC/CEC): Guidelines for minimum burial depth, spacing, and mechanical protection.

3.6.9 Summary and Best Practices

Underground cable installations are complex engineering undertakings that require careful consideration of mechanical protection, heat dissipation, soil conditions, spacing, burial depth, and ampacity. Key takeaways include:

Choose the Appropriate Installation Method: Direct burial is simple and cost-effective; ducts allow flexibility; concrete-encased banks provide mechanical protection in critical locations.

Consider Thermal Conditions: Soil thermal resistivity, concrete conductivity, and ambient temperature significantly impact ampacity. Use proper backfill and moisture control where necessary.

Account for Derating: Multiple circuits, close spacing, and high-resistivity soils require current derating to maintain safe operating temperatures.

Optimize Spacing and Burial Depth: Proper arrangement minimizes mutual heating and ensures mechanical protection.

Use Standards and Software Tools: IEEE 835 and IEC 60287 methods, along with modern software, allow precise ampacity calculations, both in steady-state and transient conditions.

Plan for Long-Term Reliability: Correct installation and thermal management extend cable life, reduce maintenance costs, and enhance safety.

3.7 Overhead

Although underground cable systems are often preferred in urban or environmentally sensitive areas, there are many situations where underground installation is not feasible, practical, or economical. Factors such as high installation costs, rocky or mountainous terrain, permafrost, high water tables, flood-prone areas, long-distance transmission requirements, or the need for rapid deployment often make overhead systems the only realistic option.

Overhead installations also offer significant operational advantages. Conductors are naturally cooled by ambient air through convection and radiation, allowing higher current ratings compared to underground cables of similar size. Overhead lines are easier to inspect, maintain, repair, uprate, and expand. For long-distance transmission, rural distribution, and temporary or expandable networks, overhead systems remain the dominant solution worldwide.

This document provides a comprehensive technical overview of overhead installations of bare conductors and service entrance cables, including commonly used conductor types such as ACSR, AAC, AASC, ASC, NS75, and line wire. It covers conductor characteristics, stringing practices, sag and tension calculations, creep behavior, rated tensile strength, environmental loading (wind and ice), pole selection, long-span considerations, and special design considerations for coastal and corrosive environments.

3.7.1 Common Types of Overhead Conductors

3.7.1.1 ASC/AAC (Aluminum Stranded Conductor / All Aluminum Conductors)

ASC/AAC are made entirely of aluminum strands (1350 alloy) without any steel reinforcement.

Advantages:

1. High electrical conductivity
2. Light weight

Limitations:

1. Lower tensile strength compared to ACSR
2. Limited span capability
3. Not corrosion-resistant

Applications:

1. Urban distribution networks where spans are relatively short.

3.7.1.2 AASC/AAAC (Aluminum Alloy Stranded Conductor / All Al Alloy Conductor)

AASC/AAAC is manufactured from high-strength aluminum alloy (6101/6201) instead of 1350 aluminum.

Advantages:

1. Higher tensile strength than ASC/AAC.
2. Excellent resistance to corrosion
3. Improved sag performance compared to ASC/AAC

Limitations:

1. Slightly lower electrical conductivity than ASC/AAC
2. Higher cost than ASC/AAC

Applications:

AASC is widely used in coastal, industrial, and corrosive environments, as well as for medium-span distribution lines where improved mechanical strength is required without introducing a steel core.

3.7.1.3 ACSR (Aluminum Conductor Steel Reinforced)

ACSR is one of the most widely used conductors for overhead transmission and distribution systems due to its high strength-to-weight ratio.

Construction: One or more layers of aluminum strands around a galvanized steel core

Advantages:

1. High rated tensile strength (RTS)
2. Excellent performance for long spans
3. Good balance between electrical conductivity and mechanical strength

Limitations:

1. May be too heavy for long crossings/spans
2. Not corrosion-resistant unless an anti-oxidant is applied on the steel core.

Applications:

1. Medium- and high-voltage transmission
2. Long rural and river-crossing spans

The steel core carries most of the mechanical load, while the aluminum strands carry the current.

3.7.1.4 NS75 and Polyethylene (PE) Covered Line Wire

NS75 and PE Covered Line Wire are typically used for secondary distribution, service drops, and short-span applications.

NS75: Aluminum alloy conductor designed for moderate strength and flexibility and carry a voltage rating (600V).

PE Covered line wire: Smaller-gauge aluminum or copper conductors used for service entrances and low-voltage circuits

These conductors prioritize ease of handling and installation rather than long-span capability.

3.7.2 Installation Considerations

A thorough understanding of the behavior of overhead conductors under tension is essential for the safe and reliable design and installation of overhead power lines.

Overhead conductors are continuously subjected to mechanical forces resulting from their own weight and characteristics, environmental loading, and temperature changes. If these forces are not properly accounted for during design, excessive sag, overstressing of conductors, or structural failures can occur.

Factors that affect line design:

1. Conductor characteristics (i.e. stress-strain relationship)
2. Temperature variations (current loading & ambient)
3. Ice & wind loading
4. Span lengths

Conductor characteristics, particularly the stress–strain relationship, play a central role. Different conductor types exhibit varying elastic and plastic behavior under load, which directly affects sag, tension, and long-term creep performance. Understanding these properties is essential for selecting suitable conductors and establishing safe operating tensions.

Temperature variations are another critical factor. Changes in ambient temperature and conductor temperature due to current loading cause thermal expansion and contraction of the conductor. As temperature increases, conductor tension decreases and sag increases; conversely, lower temperatures increase tension and reduce sag. Design calculations must consider both maximum operating temperatures and minimum ambient temperatures to ensure adequate clearances and prevent excessive mechanical stress.

Ice and wind loading significantly impact overhead line performance, especially in regions with severe weather conditions. Ice accumulation increases conductor weight and diameter, while wind adds horizontal forces. Together, these loads increase tension and place additional stress on both conductors and support structures.

Span length also directly affects sag and tension. Longer spans result in greater sag and higher mechanical loads, requiring careful optimization of conductor type, tension levels, and structure selection.

Sag and tension parameters can be determined using graphical methods or numerical calculations. Historically, graphical methods were widely used; however, modern computer programs now greatly simplify and accelerate the analysis process. These tools allow engineers to model multiple loading scenarios, temperature conditions, and conductor behaviors accurately, leading to safer and more efficient overhead line designs. Sag and tension will be discussed in the upcoming sections.

3.7.3 Stringing Practices for Overhead Conductors

Stringing is the process of installing conductors on poles or structures prior to final sagging and clipping-in.

3.7.3.1 Pre-Stringing Preparation

Before stringing begins:

1. Poles or towers must be set, framed, and aligned
2. Insulators, crossarms, and hardware must be installed
3. Stringing blocks (travelers) are mounted
4. Clearance checks are performed at road crossings, rivers, and railways

Proper planning minimizes conductor damage and safety risks.

3.7.3.2 Slack Stringing vs Tension Stringing

Slack stringing:

1. Conductor is pulled loosely and allowed to touch the ground
2. Suitable for short spans and low-voltage lines

Tension stringing:

1. Conductor is pulled under controlled tension
2. Prevents ground contact
3. Required for high-voltage lines, long spans, and sensitive terrain

Tension stringing is preferred for ACSR, AASC, and ASC conductors to prevent strand damage and ensure accurate sag control.

3.7.4 Sag and Tension Calculations

3.7.4.1 Sag Fundamentals

Sag is the vertical distance between the lowest point of the conductor and the straight line connecting two support points.

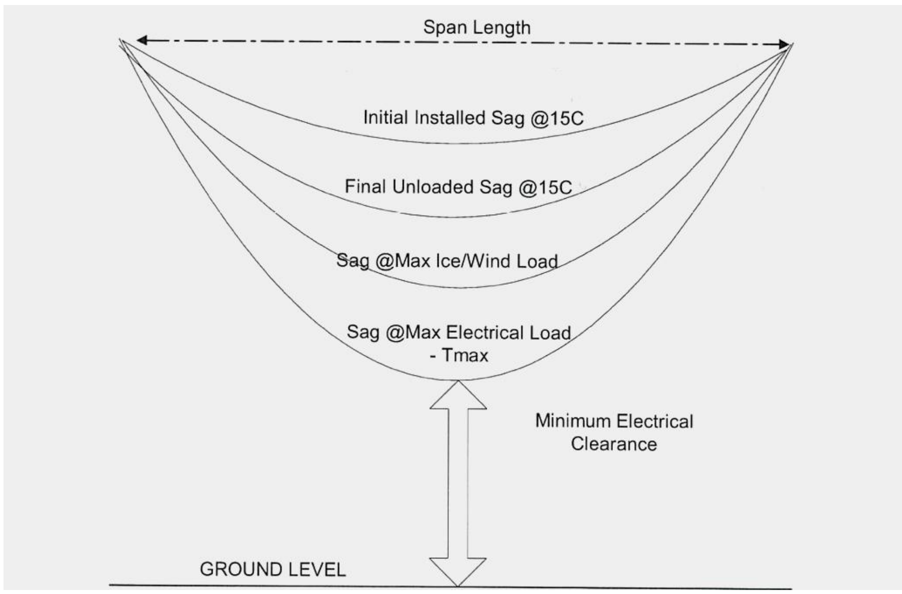


Figure 7 – Catenary variation with conductor temperature, ice & wind loads, and time after installation, where Tmax is the maximum conductor temperature

Sag depends on:

1. Span length
2. Conductor weight
3. Tension
4. Ambient and conductor temperature
5. Wind and ice loading

Insufficient sag can overstress conductors and structures, while excessive sag can violate clearance requirements.

3.7.4.2 Sag & Tension Relationship

Sag and tension are inversely related:

- Increasing tension reduces sag
- Reducing tension increases sag

Designers must find a balance that ensures:

1. Adequate ground clearance

2. Acceptable mechanical loading
3. Long-term reliability

3.7.4.3 Temperature Effects

As conductor temperature increases:

1. Thermal expansion occurs
2. Tension decreases
3. Sag increases

3.7.4.4 Ruling Span Concept

In an overhead line, a typical "line section" can consist of as few as one and as many as 40 or 50 suspension spans (depending on the design philosophy) between dead-end strain structures.

If all of the spans were the same length and subject to the same temperature, wind and ice loading, then the sag and tension calculation would apply to all spans equally and there would be very little movement of the suspension devices between spans. This however, is rarely the case and it becomes a complex task to analyze each span separately.

As an alternate to the exact solution for sag & tension in a line section of varying spans, the sag & tension calculations can be performed for a single "ruling" span.

This is possible because of the efficient tension equalization that occurs naturally at suspension points. The ruling span tension variation with ice and wind loading, time and conductor temperature is essentially the same as the tension variation for any span of the line section.
Alternatively to the equation described below, the ruling span is estimated by taking the average span length plus two thirds of the difference between the maximum span and the average span.

3.7.4.5 Conductor Elongation

Conductor elongation is a fundamental concept in the mechanical design of overhead lines. As conductors are placed under tension and exposed to temperature changes, they experience changes in length that directly affect sag, tension, and long-term line performance. Conductor elongation occurs through three primary mechanisms:

1. Elastic elongation
2. Plastic elongation
3. Thermal elongation

Each behaves differently and must be considered in sag-tension calculations and line design. See **Figure 8.**

Elastic elongation occurs when a conductor stretches under applied tension but returns to its original length once the load is removed. This behavior follows Hooke's Law, meaning the elongation is proportional to the applied stress as long as the material remains within its elastic limit. Elastic elongation is immediate and fully reversible. In overhead lines, elastic elongation governs short-term changes in conductor length caused by variations in mechanical loading, such as wind or ice. During normal operation, conductors are designed to remain within the elastic range to avoid permanent deformation.

Plastic elongation occurs when the applied stress exceeds the elastic limit of the conductor material, resulting in permanent, non-recoverable stretching. In overhead conductors, plastic elongation is closely associated with creep, which is the gradual, time-dependent permanent elongation that occurs under sustained tension, even if stresses are below the ultimate tensile strength. Plastic elongation increases sag over the life of the line and must be accounted for during design to ensure that long-term clearances remain adequate. Different conductor types exhibit different plastic elongation behavior; for example, all-aluminum conductors typically experience more creep than steel-reinforced conductors.

Thermal elongation is caused by changes in conductor temperature rather than mechanical stress. As temperature increases, conductors expand; as temperature decreases, they contract. Thermal elongation is reversible and occurs continuously in response to ambient temperature changes and current loading. In overhead lines, thermal elongation is a major contributor to daily and seasonal variations in sag. Designers must consider both maximum operating temperatures and minimum ambient temperatures to prevent excessive sag during hot conditions and excessive tension during cold conditions.

Together, elastic, plastic, and thermal elongation define how a conductor behaves under real operating conditions. Properly accounting for all three ensures safe clearances, controlled mechanical loading, and long-term reliability of overhead line systems.

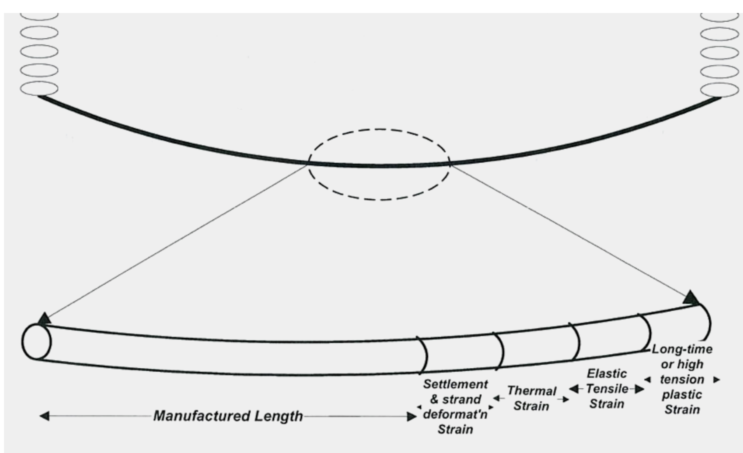


Figure 8 – Conductor elongation behavior

3.7.4.6 Conductor Creep

Creep is the permanent elongation of a conductor caused by sustained mechanical stress over time.

Creep Characteristics by Conductor Type

Creep results in increased sag over the service life of the line and varies based on conductor type and size.

1. ACSR: Lowest creep due to steel core
2. AASC/AAAC: Moderate creep
3. ASC/AAC: Highest creep

See **Figure 9** for an example of a creep elongation curve.

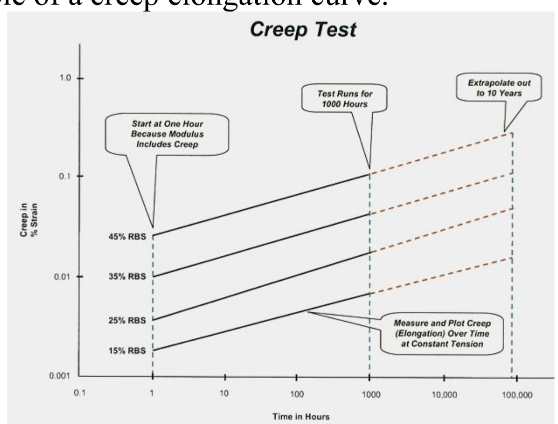


Figure 9 – Creep elongation curves resulting from a series of tests at different tension levels, all at room temperature

Design Considerations

Engineers account for creep by:

1. Applying creep correction factors
2. Using ruling span calculations
3. Designing for final (long-term) sag conditions

Ignoring creep can lead to clearance violations years after installation.

3.7.4.7 Stress-Strain Curves

Stress-strain curves model the elongation behavior (elastic and inelastic) of a specific conductor construction. See **Figure 9.** These curves consider:

1. **Thermal elongation:** Reversible linear elongation due to temperature change.
2. **Elastic elongation:** Reversible linear elongation due to tension change.
3. **Plastic elongation:**

a. **Strand settlement & deformation (initial plastic elongation)**: Rapid irreversible plastic elongation under initial loading due to a combination of strand settlement, deformation, and rapid (< 1 hour) metallurgical creep of aluminum wires.
b. **Short-time, high-tension plastic elongation (design loading plastic elongation):** Rapid irreversible plastic elongation which occurs as the result of high conductor tensions due to wind and ice loads.
c. **Long-time "metallurgical" creep elongation (creep plastic elongation):** Relatively slow, irreversible plastic elongation which occurs due to persistent moderate tension over the life of a transmission line.

3.7.4.8 Stress-Strain and Creep Testing

A 13 m manufactured sample of conductor is placed in a testing device to precisely tension and measure strain from virtually no load to the rated breaking strength of the conductor. The conductor is subjected to an initial load of about 2% RTS in order to straighten it. Afterward, the sample is subjected to a series of loads as follows :

- 30% of RTS for 30 minutes and release to initial load.
- 50% of RTS for 60 minutes and release to initial load.
- 70% of RTS for 60 minutes and release to initial load.

An increasing load is applied until strand breakage occurs. Typical results are shown in **Figure 10**.

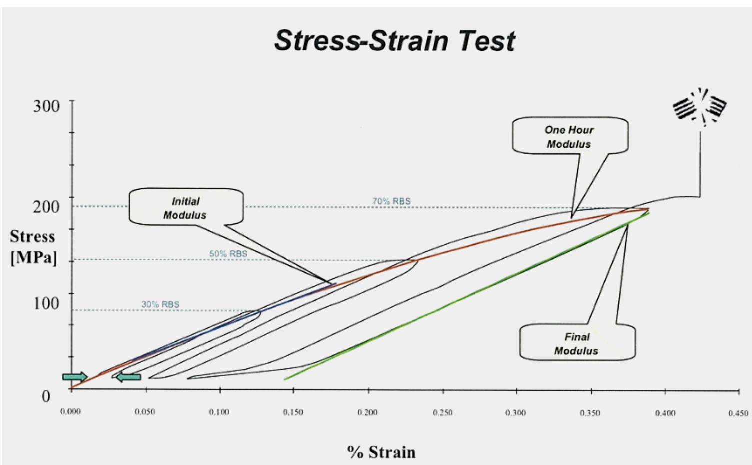
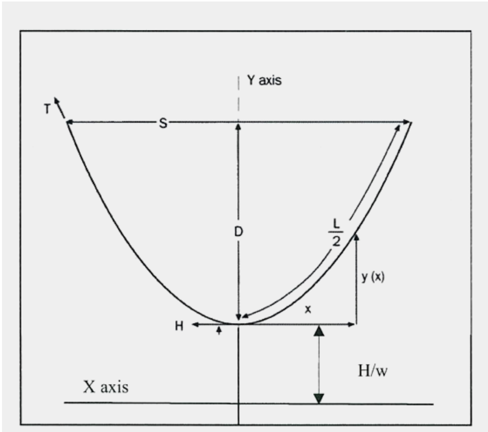


Figure 10 – Example stress-strain curve

3.7.4.9 Sag & Tension (S&T) Calculations

An overhead conductor suspended between two supports naturally forms a catenary curve, which is the true mathematical shape assumed by a flexible, uniform cable under its own weight. See **Figure 11**. The catenary accurately describes the relationship between sag, tension, span length, and conductor weight. In practical engineering applications, particularly for relatively short spans and moderate sag, the catenary curve is often approximated by a parabolic curve to simplify calculations. However, for long spans, large sags, or critical installations such as river crossings, the full catenary formulation is used to ensure accuracy.



$$y(x) = \frac{H}{w} \cdot \left[\cosh\left(\frac{w \cdot x}{H} \right) - 1 \right] \cong \frac{w \cdot x^2}{2 \cdot H}$$

Sag, D, is found by substituting x= S/2

$$D = \frac{H}{w} \cdot \left\{ \cosh\left(\frac{w \cdot S}{2 \cdot H} \right) - 1 \right\} \cong \frac{w \cdot S^2}{8 \cdot H}$$

Figure 11 – Catenary curve

H / w *is referred to as the* CATENARY CONSTANT

Sag and tension calculations must consider several variables, including conductor weight, span length, initial stringing tension, ambient temperature, current loading, wind pressure, and ice accumulation. As conductor temperature increases, thermal expansion reduces tension and increases sag. Conversely, low temperatures and environmental loads increase tension and reduce sag, potentially approaching mechanical design limits.

Calculations are typically performed for multiple loading conditions, such as everyday operating conditions, maximum temperature, and extreme weather scenarios. The goal is to maintain sufficient ground and structure clearances while keeping conductor tension within allowable limits, usually expressed as a percentage of the conductor's rated tensile strength.

Historically, sag and tension were determined using graphical methods based on catenary curves. Today, numerical methods and computer programs are widely used, allowing engineers to quickly evaluate multiple spans, loading cases, and conductor behaviors.

Example S&T Calculation

The following sample calculations are made using 403mm^2, 26/7 ACSR (403-A1/S1A 26/7) "Drake" conductor. If not otherwise specified, the properties of the conductor, the assumed span length, and the horizontal component of tension, H, are:

1. Aluminium area = 402.8 mm^2
2. Total area (aluminium and steel core) = 468.5 mm^2
3. Weight per unit length = 15.97 N/m
4. RTS = 140 kN
5. Span length = 300 m
6. Horizontal component of tension = 20% of RTS = 28 kN.
7. Conductor temperature = 15^{o}C

Under these conditions the sag of the span, according to equation 2, is:

$$D = \frac{28000}{15.97} \cdot \left\{ \cosh\left[\frac{15.97 \cdot 300}{2 \cdot 28000} \right] - 1 \right\} = 6.420m$$

Using the approximate parabolic equation, the sag is:

$$D = \frac{15.97 \cdot 300^2}{8 \cdot 28000} = 6.417m$$

In this particular case, the difference is calculated sag is only 3 mm. Since it is unlikely that the sag can be measured with an accuracy of less than 100 mm, the difference is negligible.

Typical S&T Calculation Results

Results from the stress-strain curve are built into a software program such as PLS-CADD for a range of conductor sizes and types. The tension limits and other governing factors are entered as design constraints.

The output is a table showing the relationship between sag, tension, and temperature for a given conductor and ruling span. See **Table 1.**

Conductor DRAKE 26/7 ACSR Area = 468.6 sq. mm. OD = 28.14 mm Bare Wt = 15.96 N/m Span = 300 m RTS = 140119 N									
Loading Case				Final			Initial		
Temp °C	Ice mm	Wind N/m2	Weight N/m	Sag m	Tension N	RTS %	Sag m	Tension N	RTS %
-20	12.5	380	36.377	9.26	44386	31.7	9.26	44386	31.7
-40	0	0	15.966	7.25	24818	17.7	6.92	25996	18.6
0	0	0	15.966	8.61	20938	14.9	8.13	22146	15.8
15	0	0	15.966	9.08	19847	14.2	8.57	21018	15.0*
25	0	0	15.966	9.39	19200	13.7	8.86	20340	14.5
50	0	0	15.966	10.13	17805	12.7	9.56	18864	13.5
75	0	0	15.966	10.62	17001	12.1	10.23	17636	12.6
100	0	0	15.966	10.99	16425	11.7	10.88	16601	11.8

Table 1 – Typical S&T calculation results

3.7.5 Rated Tensile Strength

Rated Tensile Strength (RTS) is the maximum mechanical load a conductor can withstand.

Typical Design Limits

Sag & tension calculations are normally done numerically with multiple ice and wind loading, and temperature limits considered simultaneously that take into consideration the thermal, elastic, and plastic elongation components of the conductor.

To avoid failure under high ice and wind loading, the conductor's initial unloaded tension at the time of construction is usually limited to a modest value as shown in **Table 2**.

The difference between initial and final sags is estimated on the basis of plastic creep elongation calculations. As the initial installed tension increases, sag decreases. Operating too close to RTS increases the risk of conductor failure and fatigue.

Initial unloaded tension at 15°C [%RTS]	Max. design tension under ice and wind load [%RTS]	Max. design tension under ice and wind load [kN]	Initial Sag at 15°C [m]	Final Sag at 100°C [m]
10	22.6	31.6	12.9	14.6
15	31.7	44.4	8.6	11.0
20	38.4	53.8	6.4	9.4
25	43.5	61.0	5.1	8.4

Table 2 – S&T for maximum ice and wind load and for high temperature shown as a function of initial stringing tension for a 300 m span of Drake ACSR.

RTS and Conductor Selection

1. **ACSR:** Highest RTS, ideal for long spans
2. **AASC / AAAC:** Balanced RTS
3. **ASC / AAC:** Lower RTS
4. **NS75 and Covered Line Wire:** Suitable for short spans

RTS directly influences allowable span length and pole spacing.

3.7.6 Wind and Ice Loading Effects

Wind Loading

Wind applies horizontal forces that:

- Increase conductor tension
- Cause conductor blowout
- Increase pole and crossarm loading

Design wind speeds are defined by regional standards.

Ice Loading

Ice accumulation **(Figure 12)**:

- Increases conductor weight
- Increases sag and tension
- Amplifies wind loading effects

Ice thickness assumptions vary by climate zone and must be included in sag-tension calculations.

Figure 12 – Heavy radial ice buildup on a relatively small bare overhead conductor

3.7.7 Pole and Structure Selection

Pole Types

1. Wood poles:
    a. Most common for distribution
    b. Economical and easy to install
2. Steel poles:
    a. High strength
    b. Used for long spans and transmission
3. Concrete poles:
    a. Durable and fire-resistant
    b. Excellent for coastal environments

Pole Class and Height

Pole selection depends on:
1. Span length
2. Conductor tension
3. Environmental loads
4. Clearance requirements

Higher pole classes provide greater strength but increase cost.

3.7.8 Long-Span and Special Applications

Long Spans

Long spans occur at:

- Rivers
- Valleys
- Highways and railways

Design considerations include:

- High-RTS conductors (ACSR or AASC)
- Taller structures
- Precise sag-tension modeling

Vibration and Galloping

Long spans are susceptible to:

- Aeolian vibration
- Galloping under ice and wind
- Mitigation measures include:
- Stockbridge dampers
- Spacer-dampers

3.7.9 Coastal and Corrosive Environment Considerations

Corrosion Risks

Salt spray accelerates corrosion and steel cores in ACSR are vulnerable if moisture penetrates.

Mitigation Strategies

- Use AASC/AAAC or ACSR with “no-ox” (antioxidant coating) on steel core.
- Use corrosion-resistant hardware
- Increase inspection frequency

3.7.9 Standards and Design Practices

Overhead line design is governed by:

1. IEEE overhead line design guides
2. CSA standards (Canada)
3. NESC and utility-specific criteria

These standards define loading cases, safety factors, and clearances.

3.7.10 Summary and Best Practices

1. Select conductor type based on span, RTS, and environment
2. Perform accurate sag-tension and creep calculations
3. Account for wind and ice loading
4. Choose appropriate pole materials and classes
5. Use proper stringing and tensioning methods
6. Plan for long-term mechanical and environmental effects

Overhead installation of bare conductors and service entrance cables including, ASC/AAC, AASC/AAAC, ACSR, NS75, and covered line wire remain a critical and cost-effective solution where underground installation is impractical. From conductor selection and stringing practices to sag-tension calculations, creep behavior, rated tensile strength, and environmental loading, every design decision influences safety, reliability, and service life.

By applying established engineering standards and selecting the appropriate conductor for each application, overhead systems can provide durable, high-capacity power delivery for many decades, even in challenging environments.

3.8 Tunnels

While underground direct burial and overhead installations are common methods for power cable systems, there are many scenarios where tunnels provide the most practical, safe, and reliable solution. Tunnels are underground passages designed to house power cables, communication cables, and associated infrastructure. They are commonly used in dense urban environments, power plants, substations, industrial facilities, transportation corridors, and utility crossings where space is limited, reliability is critical, and future expansion is anticipated.

Cable tunnels are often chosen when:

- Multiple circuits must be installed in a confined corridor
- Future cable additions or replacements are expected
- Continuous access for inspection and maintenance is required
- Surface disruption must be minimized

Although tunnel construction involves higher upfront civil costs, the long-term benefits—including accessibility, reduced outage duration, and improved asset management—often justify their use.

3.8.1 Types of Tunnels

Tunnels vary in size, construction, and function depending on application.

3.8.1.1 Utility Tunnels

Utility tunnels are designed to carry multiple services, including:

1. Power cables
2. Communication cables
3. District heating pipes
4. Water and gas lines

These tunnels are common in large cities and campuses and require careful segregation and safety planning.

3.8.1.2 Dedicated Cable Tunnels

Dedicated cable tunnels are constructed solely for electrical infrastructure. They typically house medium- and high-voltage power cables and are designed with optimized layouts for thermal performance. Dedicated cable tunnels are common in transmission networks and power plant connections.

3.8.1.3 Transportation and Infrastructure Tunnels

Cables may also be installed within:

- Road tunnels
- Rail tunnels
- Metro and subway systems

In these cases, cables must meet additional fire, smoke, and safety requirements due to public access.

3.8.2 Cable Support and Installation Methods

Cable Trays and Ladder Systems

Cables in tunnels are most commonly installed on:

- Cable trays
- Ladder racks
- Cleated supports

These systems provide:

- Mechanical support
- Defined spacing
- Accessibility for inspection

Materials include galvanized steel, aluminum, or stainless steel depending on corrosion risk.

Wall-Mounted Brackets and Racks

In narrower tunnels, cables may be installed on wall-mounted brackets in either single-layer or multi-layer arrangements with vertical or horizontal stacking. Proper anchoring and load calculations are critical.

Floor-Laid Installations

In some cases, cables are laid directly on the tunnel floor with protective covers. This is less common due to reduced ventilation and a higher fire and mechanical damage risk.

3.8.3 Heat Dissipation in Cable Tunnels

Unlike direct-buried cables, tunnel-installed cables do not rely on soil for heat dissipation. Instead, heat transfer occurs through:

- Natural convection to tunnel air
- Forced ventilation (if present)
- Radiation to tunnel walls
- Conduction through cable supports

This makes tunnel installations thermally unique and highly dependent on ventilation design.

Tunnel Air Temperature

Ambient tunnel temperature is often higher than surface ambient temperature due to:

- Limited airflow
- Heat generated by cables
- Heat from adjacent infrastructure

Design ambient temperatures must be conservatively selected.

Heat Accumulation Risks

Without adequate ventilation, tunnels can experience:

- Progressive temperature rise
- Reduced cable ampacity
- Accelerated insulation aging

3.8.4 Cable Spacing and Grouping

Spacing between cables is critical to control mutual heating. Factors influencing spacing:

- Number of circuits
- Cable diameter
- Load profile
- Ventilation effectiveness

Insufficient spacing leads to higher conductor temperatures and ampacity derating.

3.8.5 Current Derating in Tunnels

Cables installed in tunnels typically require derating due to:

- Elevated ambient temperature
- Limited heat dissipation
- Multiple closely spaced circuits

Derating factors may exceed those for direct burial or duct installations if ventilation is inadequate.

3.8.6 Ampacity Calculations for Tunnel Installations

IEEE 835 / Neher–McGrath Method

The Neher–McGrath method, formalized in IEEE 835, can be adapted for tunnel installations by:

- Replacing soil thermal resistivity with equivalent thermal resistance to air
- Accounting for ventilation rate
- Modeling mutual heating

Although originally developed for buried cables, it remains a foundational steady-state method.

IEC 60287 Method

IEC 60287 provides specific guidance for cables installed:

- In air
- On trays
- In tunnels and galleries

It accounts for:

- Convection and radiation heat transfer
- Cable spacing
- Grouping factors

IEC methods are widely used internationally for tunnel design.

Steady-State vs Transient Analysis

Steady-state analysis: Determines continuous ampacity

Transient thermal analysis:

- Evaluates short-term overloads
- Models emergency loading scenarios
- Assesses cooldown time

Transient analysis is especially important for tunnel systems where ventilation response time matters.

3.8.7 Fire Safety and Protection

Fire risk is one of the most critical considerations in cable tunnels.

Large quantities of polymeric insulation increase fire load and bundled cables can propagate fire rapidly. Some fire mitigation measures include using fire-resistant or low-smoke, halogen-free (LSZH) cables. Using fire barriers and fire stops and compartmentalizing tunnels. Fire detection and suppression systems also become important.

Tunnel-specific fire and safety regulations must be followed.

3.8.8 Mechanical and Structural Considerations

Cables in tunnels can be heavy, and so the installation must account for static load on supports and dynamic load during installation. Thermal expansion and contraction is also important to consider. Cables expand with temperature and so adequate slack must be provided. Supports must also allow controlled movement.

3.8.9 Maintenance and Accessibility

One of the major advantages of tunnel installations is accessibility. Benefits include:

- Visual inspection without excavation
- Thermal monitoring
- Easier repairs and replacements

However, tunnels require:

- Ongoing ventilation system maintenance
- Drainage and moisture control
- Structural inspections

3.8.10 Environmental and Moisture Considerations

Tunnels are prone to water ingress, condensation and high humidity. Mitigation measures include adequately designed drainage systems, moisture-resistant materials, and corrosion-resistant supports.

3.8.11 Summary and Best Practices

1. Select tunnel type and layout early in the design
2. Optimize cable spacing and support arrangement
3. Design ventilation for worst-case loading
4. Apply appropriate derating factors
5. Use steady-state and transient ampacity analysis
6. Integrate fire safety and maintenance access

Cable installation in tunnels represents a highly engineered solution for modern power systems where reliability, accessibility, and capacity are paramount. Unlike direct-buried or overhead installations, tunnel systems rely heavily on air-based heat dissipation, ventilation design, and careful cable arrangement. Factors such as spacing, grouping, ambient temperature, ventilation effectiveness, and fire protection have a direct impact on cable ampacity, safety, and long-term performance.

3.9 Low Temperature Installations

Installing power cables in low-temperature environments presents unique mechanical and material challenges that must be carefully managed to prevent damage and ensure long-term reliability. At low temperatures, cable components such as insulation, jackets, and the conductors themselves exhibit changes in mechanical behavior, including increased stiffness and reduced flexibility. If these effects are not properly addressed during handling and installation, the risk of cracking, deformation, or permanent damage to the cable increases significantly.

To mitigate these risks, cables intended for cold-weather service must meet specific design, material selection, and testing requirements, and installers must follow specialized handling and installation practices. This section provides an overview of cold-temperature cable performance, relevant testing standards, and best practices for power cable installation in low-temperature conditions.

3.9.1 Cold-Temperature Design and Testing Requirements

Cables designed for use in cold climates are required to meet cold bend and cold impact performance criteria, often tested at temperatures as low as -40°C. These tests are intended to verify that the cable's insulation and jacket materials can withstand mechanical stress at low temperatures without cracking or breaking.

Cold Bend Test

The cold bend test evaluates the cable's ability to withstand bending at low temperatures. A cable sample is conditioned at a specified low temperature (typically at -40°C) for a defined period. The cable is then bent around a mandrel of a specified diameter. The cable is then inspected for cracks, splits, or other damage.

Passing this test demonstrates that the cable maintains sufficient flexibility at low temperatures under controlled conditions.

Cold Impact Test

The cold impact test assesses resistance to sudden mechanical shocks. Cable samples are conditioned at the specified low temperature. A defined weight is dropped onto the cable from a fixed height. The cable is then inspected for cracks or mechanical failure.

This test simulates accidental impacts that may occur during handling or installation in cold environments.

Limitations of Laboratory Testing

While cold bend and cold impact tests provide valuable information about cable performance, it is important to recognize that these tests are conducted under carefully controlled laboratory conditions. In the field, cables may experience:

- Uneven temperatures along their length
- Wind chill effects
- Localized stress concentrations
- Handling methods that differ from test conditions

As a result, passing laboratory tests does not eliminate the need for caution during cold-weather installation.

3.9.2 Low-Temperature General Handling Guidelines

Many cables that pass cold bend and impact tests at -40°C may be handled and installed at temperatures below -10°C, provided that appropriate care is taken. At these temperatures, cable materials become stiffer and less forgiving, increasing sensitivity to mechanical stress. Key general precautions include, but are not limited to:

1. Minimizing flexing of the conductor and cable overall
2. Avoiding rapid or abrupt bending
3. Increasing the minimum bend radius beyond standard requirements
4. Reducing pulling speed
5. Avoiding sudden impacts and shock loads
6. Preconditioning the cable

7. Maintaining cable temperature during installation
8. Taking extra care near minimum bend radius

These measures reduce stress on insulation and jacket materials that are more brittle at low temperatures.

These are general guidelines. Always follow the manufacturer's recommendations.

Minimizing Flexing

Excessive flexing increases the risk of microcracks in insulation and jackets, particularly at points of stress concentration such as terminations, entry points, and bends. During cold-weather installation:

- Plan cable routes carefully to minimize unnecessary handling.
- Avoid repeatedly repositioning or re-bending the same section of cable.
- Use rollers, guides, or supports to control cable movement.

Slow and Controlled Bending

When bending is unavoidable, conductors should be bent slowly and deliberately. Slow bending allows stresses to distribute more evenly through the cable materials. Sudden bending can cause localized strain that exceeds material limits. Mechanical aids should be used to guide bends rather than relying on manual force alone.

Increased Minimum Bend Radius

At low temperatures, the minimum allowable bend radius should be increased beyond the standard value specified for normal installation conditions. A larger bend radius reduces strain on insulation and jacket layers. This is especially important near terminations, splices, and entry points into equipment.

As a general practice, increasing the bend radius by 25-50% in cold conditions is often recommended, unless otherwise specified by the manufacturer.

Reduced Pulling Speed

Cable pulling speeds should be significantly reduced in cold conditions. Slower pulling minimizes dynamic stress and frictional heating. Sudden starts and stops should be avoided. In addition, pulling tension should be continuously monitored to ensure it remains well below maximum allowable limits.

Mechanical pulling equipment should be operated smoothly, with careful coordination between pulling and feeding crews.

Avoiding Sudden Impacts and Shock Loads

At low temperatures, cable jackets and insulation are more susceptible to cracking due to impact. Installers should:

- Avoid dropping cables or allowing them to strike hard surfaces.
- Prevent tools, rollers, or equipment from impacting the cable.
- Ensure cable reels are handled gently and secured properly during pay-off.

Extra care is required when cables are routed over edges, into trays, or through penetrations.

Preconditioning the Cable

One of the most effective mitigation measures is preconditioning the cable prior to installation. The cable should be exposed to a temperature of approximately +15°C for at least 24 hours before installation. This allows the insulation and jacket materials to regain flexibility.

Preconditioning can be achieved by storing the cable in a heated warehouse, trailer, or enclosure.

If only part of the cable length can be preconditioned, installers should prioritize sections where bending or termination will occur.

Maintaining Cable Temperature During Installation

Where possible, steps should be taken to maintain the cable temperature during installation:

- Install cables immediately after removal from a warm storage area.
- Use insulated covers or thermal blankets during transport to the installation site.
- Avoid leaving cable exposed to extreme cold for extended periods prior to pulling.

Extra Care Near Minimum Bend Radius

The area near the minimum bend radius is particularly vulnerable in cold installations.

- Bends should be gradual and well-supported.
- Avoid bending the cable near rigid supports or terminations.
- Ensure sufficient straight length is available before and after bends.

Failure to observe these precautions can result in hidden damage that may not become apparent until the cable is energized.

3.9.3 Inspection and Quality Control

Cold-weather installations should include enhanced inspection procedures:

- Visually inspect cables for jacket cracking, whitening, or surface irregularities.
- Pay close attention to high-stress areas such as bends, terminations, and pulling points.
- Document installation temperatures and handling practices for future reference.

Any cable suspected of damage should be evaluated and, if necessary, removed from service before energization.

3.9.4 Long-Term Reliability Considerations

Damage incurred during cold-weather installation may not result in immediate failure but can significantly reduce cable service life. Microcracks and material degradation can lead to:

- Moisture ingress
- Accelerated insulation aging
- Partial discharge activity
- Premature failure under normal operating conditions

Adhering to cold-temperature installation best practices from the manufacturer helps ensure that cables achieve their full intended lifespan.

3.9.5 Summary and Best Practices

Installing cables in low-temperature environments requires careful planning.

- Cables must meet cold bend and cold impact requirements, often tested at –40°C.
- Laboratory tests do not replace the need for cautious field handling.
- Cables may be installed below –10°C with appropriate care.
- Flexing should be minimized, bending should be slow, and bend radii should be increased.
- Installation below -10°C requires preconditioning the cable to approximately +15°C for 24 hours.
- Pulling speeds should be reduced, and sudden impacts avoided.
- Extra care is required near minimum bend radius and termination points.

4.0 A Deeper Dive: Underground Medium Voltage Installations

4.1 Pulling Recommendations

4.1.1 Bending Radius

Bend radius shall be sufficiently large to ensure that no damage is done to the cable while pulling and during final training. Field experience and lab tests have been used to establish the minimum bend radius for various cable designs.

The allowable minimum bending radius for unarmoured medium voltage cables, for final training, can be calculated using a factor (F) as follows:

1. Single cables:
   a. $R_{min} = F \times OD$
2. Three single cables:
   a. $R_{min} = F \times (2.155 \times OD)$

a. Four single cables:
   a. $R_{min} = F \times (2.414 \times OD)$

where,

R_{min} = minimum allowable bending radius
F = multiplication factor for the cable design
OD = overall single cable diameter

The recommended minimum bend radius for the final training of **shielded single conductor cables or single conductor assemblies** utilize the following "F" factors shown in **Table 3**.

Table 3 – F factors for shielded single conductor cables or single conductor assemblies

Type of shield	F for single cable	F for assemblies of single cable
Concentric neutral	8	5
Tape shield	12	12/7*
Wire shield	8	8/5**
Combination tape and wire	12	7
Lead sheath	12	12/7*

* Radius is the greater of:
a. 12 times the individual shielded conductor diameter; or
b. 7 times the overall cable diameter.

** Radius is the greater of:
a. 8 times the individual shielded conductor diameter; or
b. 5 times the overall cable diameter.

The recommended minimum bend radius for the final training of **shielded multi-conductor armoured cables** are shown in **Table 4**.

Construction	Minimum bend radius as a multiple of cable OD
Armoured cable with individually shielded conductors	7
Armoured cable with an overall shield	12

Table 4 – Recommended minimum bend radius for shielded multi-conductor armoured cables

The recommended minimum bend radius **during cable pulling** is generally 1.5 - 2x that for final training.

Note: Non-shielded cables are generally more flexible and can handle tighter bends than shielded cables. In shielded cables, excessive bending can cause a copper tape shield or metal armour to separate or buckle, potentially damaging the insulation beneath. This kind of damage is often hidden by the cable's outer jacket, making it difficult to detect during inspection. Additionally, any electrical discharge issues resulting from shield damage may be temporarily obscured by the inherent design of the cable's components delaying the detection of faults at commissioning.

4.1.2 Sidewall Bearing Pressure

Sidewall bearing pressure (SWBP) is a radial force per unit length exerted on a cable being pulled through a bend. The pressure is caused by the tension and weight of the cable and can be the most restrictive factor in many installations. It is calculated as follows:

1. Single cable
    a. SWBP = T/R
2. Three single conductor cables, triangular
    b. SWBP = W_c x T / (2R)
3. Three single conductor cables, cradled
    a. SWBP = $(3W_c - 2)$ x T / (3R)

where,
SWBP = sidewall bearing pressure in Newtons/metre
T = the tension at the bend exit, in Newtons
R = bend radius, in metres
W_c = weight correction factor (see Section 4.4.6)

Maximum SWBP limits are given in **Table 5**.

Table 5 – Maximum SWBP for different types of MV cables

Cable construction type	Maximum SWBP	
	N/m	lb/ft
TR-XLPE or EPR insulation, concentric neutral wire or tape shield, unarmoured LLDPE or PVC jacket	29185 [a]	2000 [a]
TR-XLPE or EPR insulation, concentric neutral wire or tape shield, aluminum interlocked armour, LLDPE or PVC jacket	4400	300
TR-XLPE or EPR insulation, concentric neutral wire or tape shield, continuously corrugated and welded aluminum sheath, LLDPE or PVC jacket	7290	500

[a] SWBP should be reduced to 21890 N/m or 1500 lb/ft when the jacket is not applied tightly to the core.
Exceeding the maximum allowable SWBP may result in crushing damage to the cable. High anticipated SWBP values could be lowered by increasing the cable duct bend radius. Note – the inside radius of the duct bend should be used when calculating the SWBP.

4.1.3 Pulling Tension

Maximum pulling tension that can be applied to a given cable is dictated by the physical limitations of the cable, the methods of attachment and the design of the installation.
Tension limits using pulling grips is shown in **Table 6**.
Table 6 – Tension limits using pulling grips

	Maximum Tension*		
		Triplexed and Parallel Cables	
	Single Cable	One grip on three cables	One grip per cable
TR-XLPE insulation, Wire Shield, With or Without Encapsulating Jacket – 5 to 46 kV	10,000	5,000	20,000
TR-XLPE insulation, Longitudinally Applied Copper Tape Shield, LLDPE jacket			
15, 25 and 35 kV	8000	4,000	16,000
46 kV	4,000	2,500	8,000
TR-XLPE insulation, CN or Copper Tape Shield, LLDPE or PVC overlaid jacket – 5 to 46 kV	10,000	5,000	20,000

*The conductor must be large enough to handle the tensions listed above
Maximum stress on the cable conductor should not exceed those shown in **Table 7**.

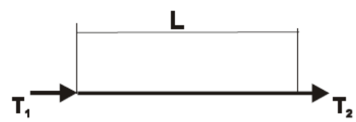
Metal	Temper	lb/cmil
Copper	Soft (annealed)	0.008
Aluminum	Hard	0.008
Aluminum	¾ Hard	0.006 to 0.008
Aluminum	½ Hard	0.003 to 0.004
Aluminum	Soft	0.002 to 0.004

Table 7 – Maximum stress on the cable conductor

The cable under the grips plus an additional 1 meter should be cut off after pulling is complete.
The following formulae may be used to determine pulling tensions for a specific cable installation:
Variables

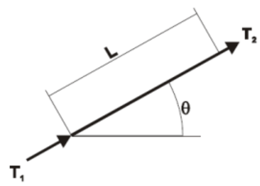
T_{in} (T_1) = tension into a section (N)
T_{out} (T_2) = tension out of a section (N)
Wc = weight correction Factor
W = weight
K = coefficient of dynamic friction
L = section length

Straight Pull



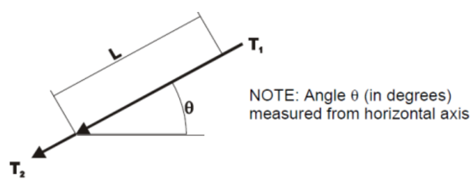
$$T_2 = T_1 + WKWcL$$

Slope – Upwards



$$T_2 = T_1 + LW(\sin\theta + KWc\cos\theta)$$
(θ in degrees)

Slope – Downwards



$$T_2 = T_1 - LW(\sin\theta - KWc\cos\theta) \qquad \text{8-3}$$

Horizontal Bend

$T_2 = T_1 e^{(k)(Wc)(\theta)}$ (Simplified) (θ in radians)

Vertical Concave Up Bend

Pulling Up:

$$T_{out} = T_{in}e^{w\mu\theta} - \left(\frac{WR}{(1+(w\mu)^2)}\right)\left[(2w\mu\sin(\theta)) - (1-(w\mu)^2)\left(e^{w\mu\theta} - \cos(\theta)\right)\right]$$

Pulling Down:

$$T_{out} = T_{in}e^{w\mu\theta} - \left(\frac{WR}{(1+(w\mu)^2)}\right)\left[\left(2w\mu\, e^{w\mu\theta}\sin(\theta)\right) + (1-(w\mu)^2)\left(1 - e^{w\mu\theta}\cos(\theta)\right)\right]$$

Vertical Concave Down Bend

Pulling Up:

$$T_{out} = T_{in}e^{w\mu\theta} + \left(\frac{WR}{(1+(w\mu)^2)}\right)\left[\left(2w\mu\, e^{w\mu\theta}\sin(\theta)\right) + (1-(w\mu)^2)\left(1 - e^{w\mu\theta}\cos(\theta)\right)\right]$$

Pulling Down:

$$T_{out} = T_{in}e^{w\mu\theta} + \left(\frac{WR}{(1+(w\mu)^2)}\right)\left[(2w\mu\sin(\theta)) - (1-(w\mu)^2)\left(e^{w\mu\theta} - \cos(\theta)\right)\right]$$

4.1.4 Pulling Speed

Typical pulling speeds are 3 to 15 metres a minute. When operating at the higher end of this range, it's important to ensure that the cable doesn't recoil if the pulling process is paused or completed. This can be mitigated by equipping the reel stands with braking mechanisms. Additionally, faster pulling speeds can increase frictional heat, particularly in bends, which may accelerate wear in ducts made of materials like PVC, polyethylene, or fiber.

4.1.5 Pulling Direction

The tension needed to pull a cable can vary greatly depending on the direction of the pull. It is generally easier to pull from the end with more bends or from the uphill side. It is always a good idea to calculate the pulling tension from both directions to determine the better option and to allow for flexibility at the job site.

4.1.6 Pulling Calculations Procedure

1. Select cable; determine its outside diameter and its weight per foot.
2. Determine the duct type, and size it to handle the required number of cables per duct.
3. Calculate the jam ratio, clearance factor and weight correction factor.
4. Look up the maximum allowable tension, SWBP and minimum bending radius for the cable under consideration.
5. Look up both low and high SWBP friction factors for given cable, conduit, and lubrication types.
6. Consider accessibility and the limitations of pulling equipment and hardware.
7. Design the duct / manhole system if an existing system is not being used.
8. Calculate the tension and SWBP for each section. As the calculation proceeds from one duct section to the next, the existing tension for a given section, T2, becomes the entering tension T1, for the next section. Check to see if the allowable tension or SWBP limit has been exceeded.
9. Angles are expressed in degrees when tension calculations involve trigonometric functions (sin, cos), such as uphill or downhill slopes. Angles are expressed in radians when tension calculations involve exponential functions, such as conduit bends.

4.2 Cable Installation Recommendations

4.2.1 Cable Spacing

Attention should be given to cable spacing to prevent electromagnetic interference with other circuits and mutual heating between cables, and general safety, especially for larger cables requiring additional supports. Derating may be required for cables installed in close proximity to one another or to other heat generating sources.

4.2.2 Distance Limits

The maximum distance a cable can be safely pulled through a raceway, such as a cable tray or conduit, depends on several factors. These include the conductor's material, size, and weight; the number and configuration of conductors; and the maximum allowable pulling tension and sidewall bearing pressure. Other important considerations are the pulling method, raceway size and fill, bend characteristics, slope, friction between the cable and raceway, lubrication, equipment limitations, and the direction of the pull. Designing with these variables in mind helps prevent cable damage and ensures a successful installation.

4.2.3 Bend Locations

The placement of bends in a raceway system greatly affects the preferred cable pulling direction. When possible, it's best to pull the cable with the bends located near the reel, rather than pulling it out of a bend at the end of a long run.

4.2.4 Reel Set-up, Orientation, and Position

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

Positioning of the payoff reel can also be critical. The closer the payoff is to the raceway elevation, as well as the more in line it is, the less tension due to cable weight and direction change will be added to the overall tension of the pull. To reduce cable payoff reel tension, follow the natural curvature of the cable on the reel and feed the cable into the raceway in as straight and level manner as possible. See **Figure 13**.

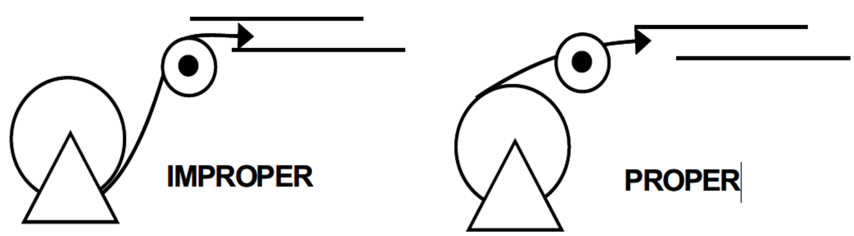


Figure 13 – Reel setup example

4.2.5 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. This tension force can be approximated by:

$T_r \approx K_o \times W \times L \times g$

Where,

T_r = tension from cable reel, N

W = mass per unit length of cable, kg/m

L = length of cable, m
g = gravitational constant (9.8 m/s^2)
K_o = basic coefficient of friction (typical value between 0.5 to 1.0, see IEEE 525)
To control the pulling force, use powered reel drives, motorized payoff stands, or sufficient manpower. Freewheeling reels and long vertical drops should be avoided. A payoff system with braking helps control back-tension, which can increase significantly through bends or over vertical distances.

Ideally, one person should manage the reel while another feeds the cable into the raceway. Reel back-tension should always be accounted for when calculating pulling tension.

4.2.6 Pulling Lines and Duct Wear

The utility industry uses various types of pulling lines, and their diameter significantly affects duct wear. Thinner lines increase wear due to higher pressure per unit area. Surface texture also matters, for example coarse braided fiber or stranded steel ropes wear ducts faster than smooth, nylon-jacketed lines.

Additionally, duct materials vary in durability; PVC, polyethylene, and bituminized fiber wear more quickly than transite, fiberglass, or steel.

4.2.7 Surging

Surging is a complex issue that can cause unexpectedly high pulling tensions, even under seemingly steady conditions. It's more common with elastic pulling lines and cables with neoprene jackets. The main cause, is the difference between static and dynamic friction between the cable and duct. When this difference is large, the cable tends to stick and then suddenly slip, repeating the cycle.

Since surging is difficult to predict, engineers should consult manufacturers, refer to friction data, and apply higher safety factors when designing cable pulls.

4.2.8 Slack Pulling

Slack pulling is a method used to create extra cable length—typically in a manhole for splicing—by stopping and restarting the pull. This is often done with split grips that can be repositioned along the cable. However, this technique is not recommended, as the grip may compress and damage the cable. Since the affected section usually can't be removed, it may lead to future cable failure.

4.2.9 Looping

Looping or flaking involves pulling cable out of one duct in a manhole, looping it above ground, and feeding it into another duct on the opposite side. While sometimes used, this method is not recommended, as it increases the risk of cable damage if not done with great care.

4.2.10 Lubricants

There are three main types of cable-pulling lubricants:

1. soap-based,
2. clay-based, and
3. gel types.

Some newer formulations can significantly reduce friction. Interestingly, lubricants tend to perform better under high sidewall pressure in bends than under low pressure.

Cold temperatures can also raise friction levels, and water-based lubricants may lose effectiveness if frozen.

4.2.11 Assist Pulls

Maximum pulling tension and sidewall pressure often limit how far a cable can be pulled using a single puller. To avoid splices or back feeding, an assist puller (also called a cable pusher or feeder) can be used in a straight tray section, typically 15–30 meters long. The pulling line is attached to the cable using a mare's tail, which should grip 0.6–1 meter of the cable, with friction tape underneath for better hold. The assist puller creates slack ahead of the main puller, reducing overall tension and sidewall pressure.

Coordination between pullers is essential to maintain proper slack and avoid cable damage. As the mare's tail reaches the assist puller, the setup is reset and repeated until the cable reaches the main puller.

4.3 Pulling Methods and Consideration

4.3.1 Attachment Methods

General

There are several types of cable pulling attachments, commonly known as pulling eyes or pulling grips, used to connect to the ends of power cables during installation. These attachments include:

1. **Basket-type pulling grips**: Flexible mesh grips that wrap around the cable and tighten under tension.
2. **Compression-type pulling eyes**: Rigid fittings crimped or compressed onto the cable end.
3. **Wedge-type pulling eyes**: Use a wedge mechanism to grip the cable securely.
4. **Mare's tails**: A bundle of wires or strands used to distribute pulling force and reduce stress on the cable.

Each type is designed to suit different cable sizes, pulling conditions, and installation methods.

Basket-type (woven mesh) pulling grips

Woven mesh pulling grips—also known as socks or basket grips—hold onto the cable using friction and the tension applied during pulling. To install them properly, the grip is compressed to fit over the cable, then released to grip the surface tightly. The trailing end should be securely banded or taped to prevent the grip from loosening or slipping off, especially during push-pull actions.

When pulling multiple cables through a conduit, friction tape may be needed between cable layers to ensure a firm hold, particularly for cables not directly touching the grip. Applying friction tape between the grip and cable also helps prevent the grip from damaging the cable jacket or insulation. After the pull, the section of cable under the grip should be cut off and discarded.

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 appropriate manufacturer's recommended maximum pulling tensions. The cable end of the pulling eye is factory drilled to accommodate the particular combination of cables to be pulled. Install the cable by stripping it down to the bare conductors, inserting it into the barrel (or barrels if multiconductor), and crimping it with manufacturer recommended crimping tool.

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.

Mare's tails

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

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.

4.3.2 Pulling Rope

Types of Pull Ropes

A variety of constructions and materials are available for use in pulling cables through conduits and trays. Common materials include natural and synthetic fibers and steel tapes. Rope/tape performance is also considerably influenced by its construction. The different types of pull ropes include:

1. **Natural fibers:** Inexpensive rope made from natural vegetable fibers including manila, sisal, and cotton. Its main disadvantage is that it is subject to rot and mildew in wet or damp environments.
2. **Polyester:** Strong, synthetic rope/tape with excellent abrasion resistance; lower stretch, and elasticity; and higher loading characteristics than nylon ropes/tapes. Available in many specially designed finishes (including prelubricated woven polyester tapes) for improving handling and longer life.
3. **Aramid:** These ropes/tapes have been engineered for applications where low weight, high strength, good abrasion resistance and excellent bending capability are important to a successful pull.
4. **Nylon:** First synthetic fiber rope/tape to be made and still a popular choice due to its low cost. It has a high elasticity modulus, which allows a nylon rope to absorb sudden shock loads that would break other rope types. It has good resistance to abrasion and typically lasts five times longer than natural fiber ropes. It is rot-proof, and not damaged by oils, gasoline, grease, marine growth, and most non-acid chemicals.
5. **Polypropylene:** A lightweight, strong rope/tape and used most of any ropes/tapes. It is rot-proof and unaffected by water, oils, gasoline, and most chemicals. It is available in monofilament (smooth surface) fibers or multifilament (velvety appearance and touch) fibers. Newer polypropylene ropes/tapes are available with greater strengths and higher abrasion resistance characteristics.
6. **Steel:** 3.2 mm (1/8 in) and 6.4 mm (1/4 in) tape width steel tapes have maximum design strength of 1700 N (400 lbf).

Pull Rope Selection

Selection of a pulling rope should be based on required pulling tension, lubricant compatibility, rope size, rope flexibility, and rope abrasion characteristics and the degree of expected rope stretch under tension. When selecting a pull rope, consideration should also be given to conduit material, expected cable pulling tension, and the application, as well as the cost. The best choice is one with high tensile strength and low stretch characteristics, such as a double-braided composite rope. Choose a rope that has the capacity to handle four times the capacity of the puller being used.Use of steel tapes or ropes should be avoided for plastic conduit. Testing has shown that steel pull ropes can wear grooves in plastic conduit elbows. See **Table 8** and **9.**

Rope Characteristic	Considerations
Working load rating	The pulling force applied during installation must always remain within the rated working load of the rope or tape.
Abrasion resistance	During cable pulls, especially through plastic conduit, the pull rope or tape should not cause abrasion or damage to the conduit or existing cables.
Suitability for wet environments	Underground duct pulls are typically considered wet conditions. Natural fiber ropes such as hemp, sisal, or manila may deteriorate or rot if not properly dried after use.
Compatibility with lubricants	Certain pulling lubricants may chemically degrade or shorten the service life of some rope or tape materials.
Energy absorption capability	If a rope or tape fails during a pull, materials with high energy absorption can create a greater safety hazard due to stored energy release.
Resistance to sunlight (UV exposure)	In outdoor installations, pull ropes or tapes may be exposed to direct sunlight for extended periods and should be resistant to ultraviolet degradation.
Elongation or stretch characteristics	In high-tension pulling operations, excessive elongation can lead to instability, galloping, and increased safety risks if the rope or tape breaks.
Heat dissipation properties	In high-tension pulls, friction between the rope or tape and conduit can generate significant heat.

Table 8 – Pull Rope Characteristics and Considerations

Fiber Type	Composition	Typical Woven Construction	Minimum Bend Radius	Typical Breaking Strength*	Key Characteristics	Typical Applications
Polypropylene	Single or multiple polypropylene yarns	Woven or braided	Large	Low to moderate	Lightweight, good chemical resistance, floats on water, lower strength and heat resistance	Light-duty pulling, general-purpose use
Nylon	Nylon filaments	Woven or braided	Medium	High	Very high strength, excellent abrasion resistance, good elasticity, higher stretch under load	Heavy-duty pulling, long pulls where shock loading may occur
Polyester	Polyester filaments	Woven or braided	Medium	High	High strength with lower stretch than nylon, good abrasion resistance, good chemical stability	Cable pulling where controlled elongation is important

Aramid	Aramid fibers	Braided	Small	Very high	Extremely high tensile strength, very low stretch, excellent heat resistance, sensitive to bending fatigue	High-tension pulls, limited elongation applications
UHMWPE (High-Modulus Polyethylene)	Ultra-high molecular weight polyethylene fibers	Braided	Small	Very high	Extremely high strength-to-weight ratio, very low stretch, excellent abrasion resistance, lightweight	Long-distance or high-load cable pulling
Flat Poly Tape	Polypropylene or polyester fibers	Flat woven tape	Large	Moderate	Wide surface area reduces friction and pressure, flexible, easy to handle	Conduit and duct pulling, general cable installation
Three-Strand Polypropylene Rope	Twisted polypropylene strands	Three-strand lay	Large	Low to moderate	Economical, lightweight, floats, higher stretch, lower abrasion resistance	General-purpose pulling, non-critical installations

Table 9 – Rope and Tape Selection Guide

4.3.3 Lubrication

General

Lubrication is essential when pulling cables through conduit or ducts, as it reduces friction and pulling tension, helping ensure proper installation within design limits. Before pulling, the conduit should be cleaned, inspected for sharp edges, and prelubricated. Lubricant should be applied at all accessible points, including the cable and pull rope.

The lubricant must be compatible with the cable and rope, and should not harden, support combustion, or release toxic gases. Compatibility should be verified—refer to IEEE Std 1210 for testing guidelines. Newer cable jackets like LSZH, TPE, and XLPO may shed lubricant easily, requiring extra application during the pull. If pulling tensions are higher than expected, it may indicate insufficient lubrication. Adding more lubricant can help, but if tensions remain high, further investigation is needed.

Pre-lubrication of existing cables and the conduit or duct is important for pullback and pullby installations. It is especially important to pre-lubricate conduits and ducts when pulling old cables out of a conduit or duct (when reusing the conduit or duct is anticipated) as most new pulling lubricants contain a substantial amount of water, which helps loosen the existing cables, soften any old lubricants and lower the tension needed to remove the existing cables.

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

Methods

There are several ways to lubricate conduit systems during cable pulls:

1. **Pre-lubrication:** Lubricant is pumped or packed into the conduit before pulling. Using a mandrel or spreader ahead of the cable grip helps distribute it evenly.
2. **Lubricant packs:** Bags of lubricant are pulled or pushed ahead of the cable, releasing lubricant as the cable moves through.
3. **Lubricating ropes:** These ropes have spray nozzles that apply lubricant throughout the conduit during the pull. If used to pull the cable directly, they may limit the maximum pulling tension. When used only for lubrication, they're attached to the main pull rope.

Quantity

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

$$Q = 0.00073 \times C_L \times D$$

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

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

1. Cable weight and jacket hardness (increase quantity for stiff, heavy cable)
2. Conduit type and condition (increase quantity for old, dirty, or rough conduits)
3. Conduit fill (increase quantity for high percent conduit fill)
4. Number of bends (increase quantity for pulls with more than one bend)
5. Pulling environment (increase quantity for high temperatures or water in the conduit)

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

Procedure

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

1. One-half to two-thirds of the lubricant should be placed into the conduit in front of the cable. The lubricant can be pumped into the conduit or conduit-sized bags can be inserted in front of the cable as previously discussed. A duct swab or lubricant spreader should be used to evenly spread the lubricant throughout the conduit during the pull. The lubricant should be applied at all points of the pull. For long pulls, a lubricated swab should be pulled through the conduit prior to starting the cable pull. Unlubricated sections increase cable tension.
2. 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.
3. 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.

Cleanup

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

4.3.4 Tension-Limiting Methods

General

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

a. Restricting the number of workers utilized for hand pulling
b. Monitoring the actual tension applied and stopping the pull if the tension is too high
c. Limiting the amount of tension available by using a break link or breakaway swivel
d. Once the required installation tension has been determined (via calculation or by the use of a cable pulling chart) one of the three tension-limiting methods discussed above can be employed.

Size of pulling crew

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

a. **One worker:** For cable pulls where the MAPT is 445 N (100 lbf) or less.
b. **Two workers:** For cable pulls where the MAPT is between 445 N (100 lbf) to 1335 N (300 lbf) and the conduit/duct nominal trade size is metric designator 21 (3/4 in) or larger.
c. **Three workers:** For cable pulls where the MAPT is greater than 1335 N (300 lbf) and the minimum conduit nominal trade size is metric designator 103 (4 in) for single cable pulls or nominal trade size metric designator 129 (5 in) for multiple cable pulls.

Dynamometer

When using mechanical pulling devices or more than three workers, a dynamometer or tension gauge should be used to monitor pulling tension. For hand-pulled cables or tray installations, tension monitoring is usually unnecessary due to the low risk of damage.

Galloping, or jerky cable movement, can occur if the pull rope stretches too much or the puller can't maintain steady tension. This can be reduced with proper lubrication and rope selection. Tension spikes may happen as the cable head moves through bends, but these usually affect only the head. The tension after the head clears the bend reflects the actual force on the cable.

Break links or Breakaway Swivels

Break links or breakaway swivels are useful for limiting pulling tension during cable installation. When the preset tension is exceeded, the swivel breaks, disconnecting the pull rope from the cable. These devices should only be used in low-tension pulls where the cable can be easily retrieved if the swivel breaks. In high-tension scenarios, a broken swivel may make cable removal difficult and risk damaging the cable.

4.3.5 Cable Pull-bys and Push-bys

General

Pullby refers to pulling cables through conduits that already contain other cables. This method is generally discouraged due to the risk of hidden damage to existing cables. It should only be used when no other installation options are feasible, such as unexpected design changes, space limitations, or scheduling constraints.

Pushby, on the other hand, involves manually pushing a cable through short, straight sections like sleeves or nipples and is preferred due to lower risk of damage. While pullbys are not recommended, if necessary, guidelines should be followed to minimize harm. Alternatives like bulk pulls, installing new conduits, or pulling back existing cables for a combined pull should be considered first.

Installation practices

The most important consideration for cable pullbys is establishing a clear path to avoid interference with existing cables during the pull. One technique is to install a fish line or pull rope by manual rodding. This permits the pulling crew to “feel” their way through the conduit. An experienced “rodder” can usually avoid paths between existing cables. Under no circumstances should an existing rope or fish tape left in the conduit from a previous pull be used. Rope pulled in with the cables is probably twisted with the original set of cables and if used would cut into the original cables. Metal fish tapes should also not be used because they may cut or otherwise damage the existing cable.

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

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

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

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

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.

Pull tensions should be monitored and limited regardless of whether machine pulling is used or the cable is pulled by hand. This can be through the use of a dynamometer, a calibrated break-link, or a restricted number of cable pullers. Pull tension should be limited to 1780 N (400 lbf) or the maximum allowable based on conductor strength unless the cable manufacturer indicates otherwise. Restricting the number of workers utilized for hand pulling to no more than two people provides the significant advantage of being more apt to notice the presence of a cable snag.
A pulling machine has the advantage of maintaining a constant, even pull, which is conducive to smooth, successful pulls. Even so, an experienced cable pulling observer should be stationed at the pulling end and be in communication contact with the other members of the crew.

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

4.3.6 Cable Pullbacks

Pullback refers to removing cables from a conduit and reinstalling them, often due to equipment relocation, design changes, or to allow new cables to be added instead of performing a pullby. Extra care is needed to avoid damaging cables, especially older ones.

Since friction levels during pullbacks are unpredictable, tension estimates and standard pulling charts aren’t reliable. If the entire circuit is being removed, choose the pull direction based on typical factors like bend locations and elevation changes. The following guidelines aim to reduce the risk of cable damage during pullback operations.

A successful pullback starts with proper lubrication of the cables, ideally by pumping or blowing lubricant into the conduit and allowing it to soak for about 24 hours. Avoid using commercial solvents, as they may damage the cable jacket. Exposed cable sections should also be lubricated before removal.

Use appropriate gripping tools like luffing grips or mare’s tails—never metallic basket grips—to avoid damaging the cable, especially aged ones. Maintain the minimum bend radius during handling and storage, using figure-eight coils with adequate support. Remove terminal lugs (6 AWG and larger) or tape smaller ones to prevent damage during removal.

Before pulling, remove fire stops, seals, and supports using blunt tools to avoid cable damage. Monitor tension during the pullback and keep it below 2225 N (500 lbf) or the cable’s rated limit. After removal, perform a full inspection for jacket or insulation damage. Damaged or aged cables should not be reused.

During repull prep, protect cables from physical damage and nearby work like welding or grinding. Ensure they’re not left exposed in high-traffic areas and are properly supported to avoid jacket stress.

Before starting a repull, it's important to swab the conduit to remove debris or residue. Standard cable installation practices apply, but extra care should be taken to liberally lubricate the cables. Pay close attention to entry and exit points to maintain proper bend radius and avoid high sidewall pressure at fittings.
After the repull, follow standard post-installation testing procedures. For medium-voltage cables, limit high-potential testing to maintenance levels only.

4.4 Conduit Installations

4.4.1 Cable Configuration

When pulling three cables in a duct, cable configuration/positioning becomes important since it affects the weight distribution of the cables, and subsequently, jamming. The configuration of the cables is governed by the ratio of the inner diameter of the duct to the nominal diameter of the cable, known as the Jam Ratio (J). The Jam Ratio can be calculated as shown in Section 6.c. Based on field experience, and several industry studies, the following can be expected for 3 cables in a duct (See **Figure 14**):

If $J < 2.4$, cables are triangular
If $2.4 < J < 2.6$, cables tend toward triangular
If $2.6 < J < 2.8$, cables are either triangular or cradled
If $2.8 < J < 3.0$, cables tend toward cradled
If $J > 3.0$, cables are cradled

Note: Jamming can occur when $2.8 < J < 3.0$.

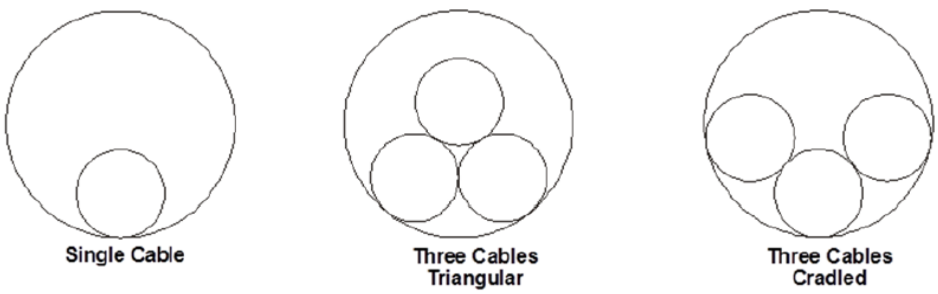


Figure 14 – Cable configuration in duct

If the sidewall bearing pressure, SWBP, is greater than 1000 lb/ft. and if $2.6 < J < 3.0$, the cables tend to form a cradled configuration in a bend.

The cradled configuration is the most conservative and should be assumed when it is not clear which configuration will be encountered.

4.4.2 Cable Clearance

For conduit installations, it is necessary to calculate the cable clearance, C, to help ensure that the cable(s) will physically fit inside the duct. See **Figure 15**. An adequate clearance also accommodates the pulling eye or cable grip used in the pull.
For 3-conductor pulls, it is only necessary to calculate the clearance for the triangular configuration since cradled cables tend to change to a triangular formation before the fit becomes too tight.

From field experience, the minimum clearance is 0.5 inches. A lesser clearance of 0.25 inches may be acceptable for straight runs.

Cable Clearance (C) can be calculated as follows:

a. Single Cable

$C = D - d^*$

b. Three Cable Pull (based on triangular configuration)

$C = D/2 - 1.366d^* + 0.5(D-d^*)(1-(d^*/(D-d^*))^2)^{0.5}$

where,
D = inside diameter of duct
$d^* = 1.05d$
d = nominal cable diameter

Note: the nominal cable diameter, d, has been increased by 5% to allow for variations in cable and duct dimensions as well as ovality of the duct at bends.

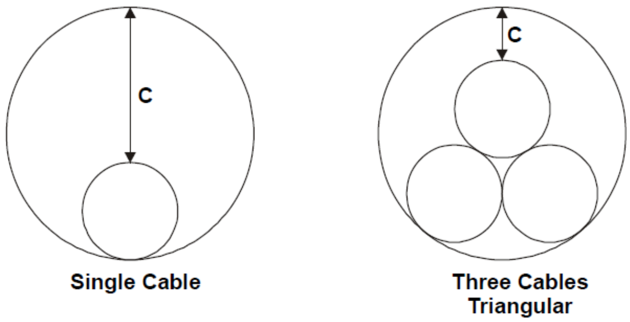


Figure 15 – Cable clearance

4.4.3 Jamming

The Jam Ratio (J), is defined as the ratio of the inside diameter of the duct (D) to the cable diameter (d).

$J = D/d$

Jamming can occur when this ratio gets close to 3.0, where one of the cables in a 3c pull may slip between the other two cables, particularly in bends. Jamming is generally not an issue for straight runs.

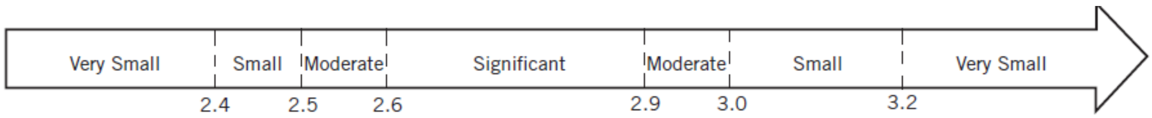


Figure 16 – Jamming probabilities using Jam Ratio

4.4.4 Conduit Fill

Conduit fill is the % of the area inside the conduit taken up by the conductors or cables.

Consult the relevant electrical code for rules on allowable conduit fill %.

4.4.5 Coefficient of Friction

The coefficient of friction (CoF) plays a critical role in cable pulling operations, influencing the force needed to initiate and maintain cable movement. The CoF depends on the materials in contact with each other. There are two types of CoF:

. Static (higher, needed to start motion); and

a. Dynamic (lower, needed to sustain motion).

Most calculations use the dynamic coefficient since cable pulls are typically continuous. However, if a pull is interrupted, restarting requires higher tension due to the static friction. Cables pulls should be started and/or restarted slowly. **Table 10** shows typical values for dynamic CoF at 24C.

Table 10 – Typical CoF for different duct types and cable outer coverings

Duct Type	Conductor or Cable Outer Covering					
	PE		PVC		XLPE	
	1c	3c	1c	3c	1c	3c
PVC	0.40	0.60	0.50	0.60	0.40	0.60
PE	0.25	0.85	0.30	0.45	0.45	0.55
Steel	0.50	0.50	0.65	0.65	0.60	0.65
Fiber	0.25	0.60	0.40	0.45	0.30	0.65
Transite	0.70	0.70	0.70	0.70	0.70	0.70

Puling lines may have higher coefficients of friction which may affect the maximum tension in the early stages of the pull. Pulling line manufacturers should be contacted for this information.

4.4.6 Weight Correction

The weight correction factor (W_c) is used to account for the weight distribution of the individual cables when pulling multiple cables and can be calculated as follows:

. Single cable in a conduit:

$W_c = 1$

. Three single cables in cradled configuration:

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

. Three single cable in triangular configuration:

$$W_c = \frac{1}{\sqrt{1-\left(\frac{d}{D-d}\right)^2}}$$

. Four cables

$W_c = 1.4$

4.5 Duct Bank Installations

4.5.1 General

While many principles and recommendations in this document apply, underground duct bank installations present unique challenges.

Cable pulls in vaults, duct banks, and manholes often occur in confined spaces and, post-startup, may involve energized cables—demanding heightened safety protocols. Issues include limited access, water management, hazardous atmospheres, and restricted workspaces.

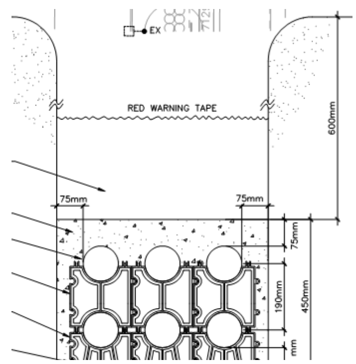


Figure 17 – Typical duct bank detail

Pulling operations must avoid placing personnel in high-tension zones due to hazards, while feeding points require lubrication and careful handling. Rigging complexity increases when access is limited, emphasizing the need for thorough planning and risk mitigation.

4.5.2 Planning

Before starting work in confined underground spaces, the following planning steps are critical:

- **Cable Pull Strategy:** Perform pulling calculations in both directions to determine optimal routing.
- **Material Readiness:** Ensure all cables, lubricants, and accessories (e.g., rollers, ropes, sheaves) are on-site.
- **Duct Preparation:** Clean and inspect ducts thoroughly using a mandrel; repair as needed.
- **Safety Checks:** Monitor confined spaces for hazardous gases, water intrusion, and energized cables before entry.
- **Clearance Verification:** Conduct jamming, bend radius, and sidewall pressure calculations to confirm safe cable passage.
- **Site Setup:** Confirm that the cable setup area can accommodate all necessary equipment.

4.5.3 Installation precautions

To ensure safe and effective cable installation in manholes and vaults, observe the following:

a. **Ventilation & Air Testing:** Ventilate and retest air quality for toxic and combustible gases before entry.
b. **Proper Equipment:** Use pulling eyes, grips, and ropes suited to the cable's size and weight.
c. **Avoid Shared Ducts:** Never pull new cables into ducts with existing ones; avoid mixing cable types unless necessary (e.g., ground conductors).
d. **Lubrication Protocol:** Pre-lubricate ducts with compatible lubricant; apply additional lubricant as cables enter.
e. **Tension Monitoring:** Continuously monitor pulling tensions to prevent damage.
f. **Smooth Pulling:** Avoid starts, stops, and jerking to prevent cable galloping and mechanical stress.

4.5.4 Rigging

Proper rigging is essential to ensuring safe and efficient cable installation. Key precautions include:

a. **Rigging Selection:** Use bull wheels, skids, and pulling rigs designed to stay within cable tension, sidewall pressure, and bend radius limits.
b. **Secure Setup:** Brace pulling rigs to prevent movement during operation.
c. **Rated Equipment:** Ensure ropes, blocks, tackles, shackles, and bracing are rated to handle expected pulling tensions. For example, a 10,000 lbf rope can exert up to 20,000 lbf on a straight block.
d. **Pulley Choice:** Use three-wheel pulley assemblies in tight spaces, but be aware they may increase sidewall pressure compared to larger single-wheel pulleys.

Figure 18 shows some examples of cable pull set-ups.

Figure 18 – duct bank pull example set ups

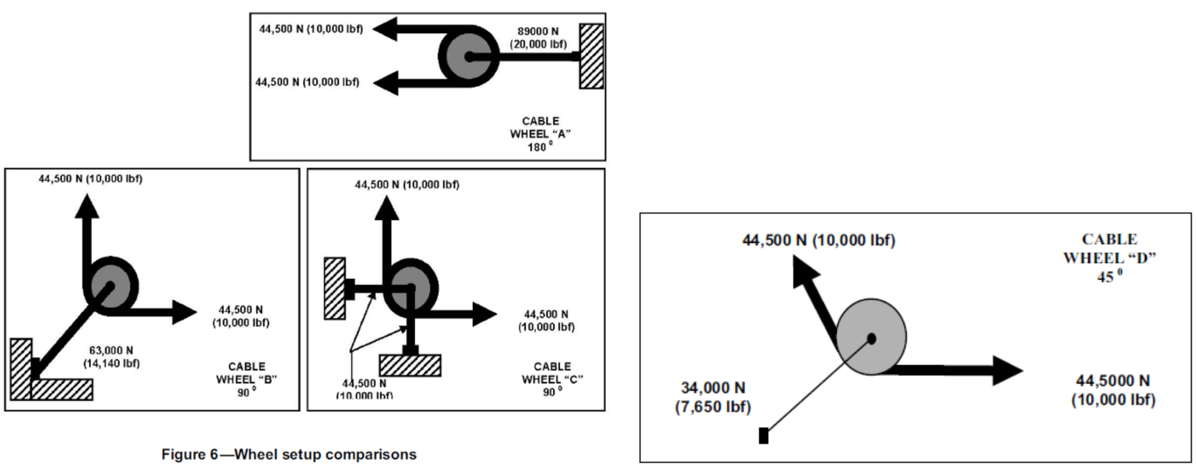
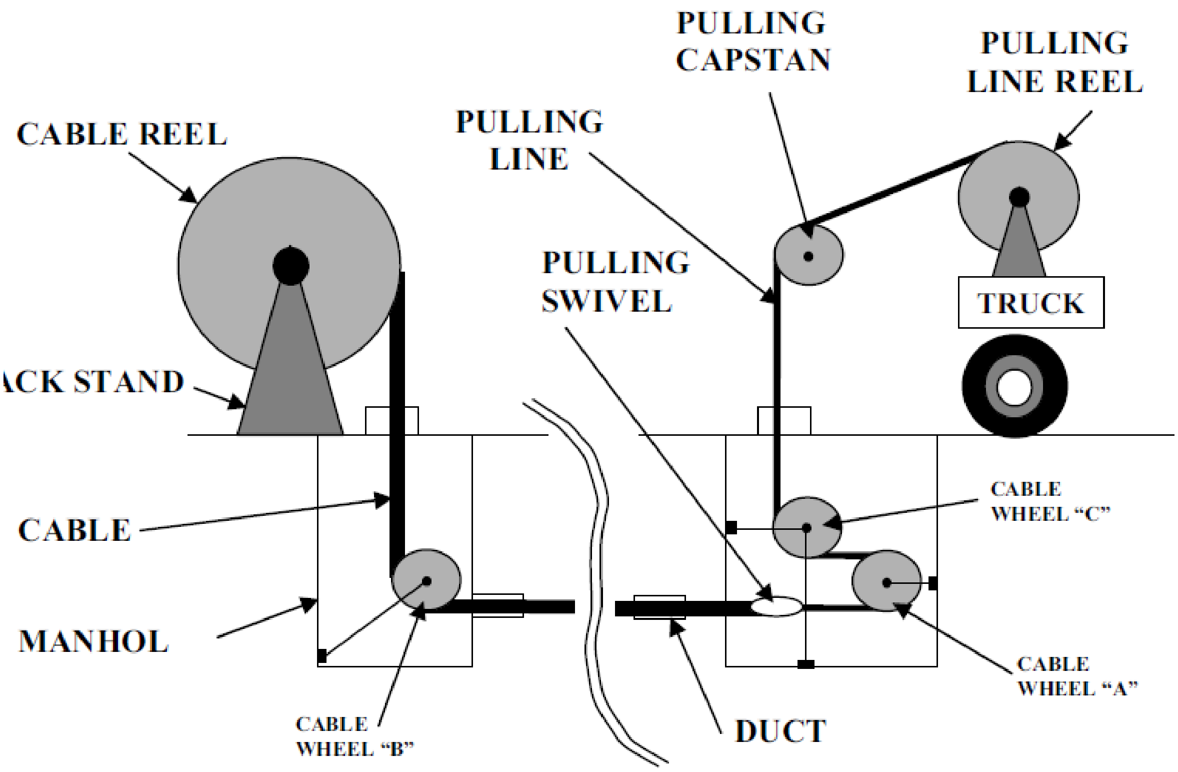


Figure 6—Wheel setup comparisons



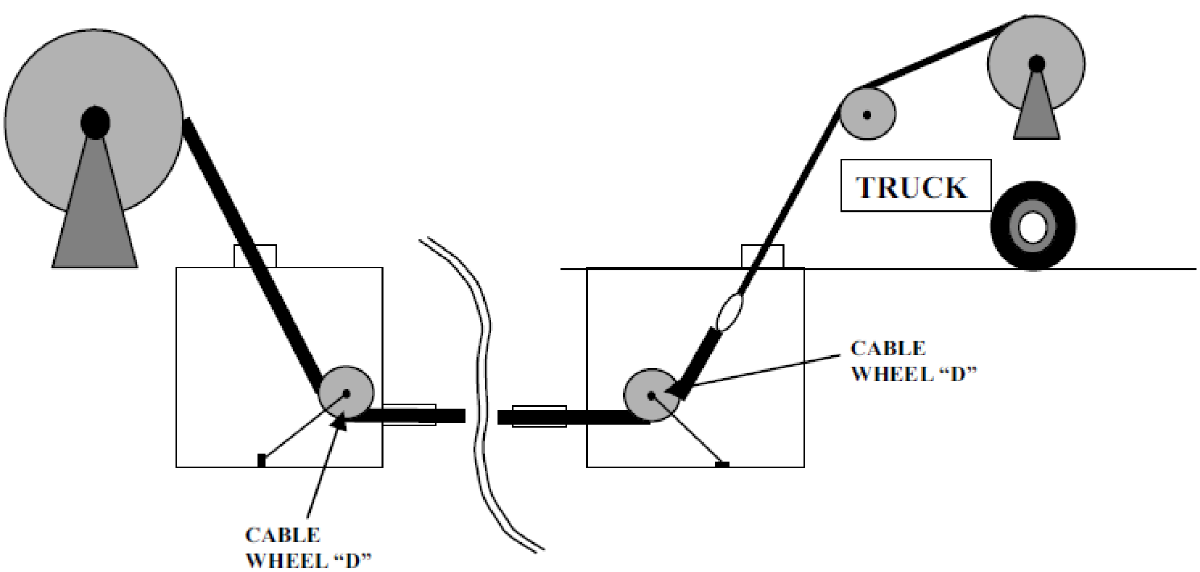


Figure 18 – duct bank pull example set ups (continued)

4.6 Direct Burial Installations

4.6.1 General

Direct burial installation of medium voltage (MV) cables requires selecting direct-burial-rated cable, ensuring adequate burial depth according to local codes, and installing warning tape or "marker tape" in the trench above the cable to alert future excavators. Proper installation also involves careful handling, sealing exposed ends, and protecting the cable from mechanical damage, especially at transition points where it emerges from the ground.

The NEC and CE Code provide rules regarding direct burial of electrical cables.

4.6.2 Burial Depth

The depth of burial must be sufficient to protect the cable from damage imposed by expected surface usage.

4.6.3 Trenching

The bottom of the trench should be smooth, undisturbed, well-tamped earth or sand. When excavation is in rock or rocky soils, the cable should be laid on a protective layer of well-tamped backfill. Backfill within 4 inches of the cable should be free of materials that may damage the cable. Backfill should be adequately compacted. Machine compaction should not be used within 6 inches of the cable.
A protective covering above the cable will warn excavators of the presence of an underlying cable.

4.6.4 Trenchless

Trenchless installation method, or cable plowing, is method where a specialized plow with a vibration blade creates a narrow slit in the ground to bury cables in a single pass.

This method should not result in damage to the cable from rocks or other solid materials. The design of cable plowing equipment and the plowing of cable should not damage the cable by exceeding bend, sidewall pressure, cable tension, or other allowable limits.

5.0 A Deeper Dive: Overhead Installations

5.1 Conductor Handling

In any overhead bare conductor installation, priority should be given to protecting the conductor surface from mechanical damage. The conductor should be handled in a manner that prevents abrasion, scratching, or deformation, as surface damage can compromise both mechanical strength and long-term performance. Conductors should never be dragged along the ground or allowed to come into contact with rough or abrasive surfaces such as rocks, fences, or guardrails.

Overhead conductors should remain on their original shipping reels until installation. Rewinding conductors from one reel to another in the field is not recommended, as it increases the risk of surface damage, improper tensioning, and uneven winding. Proper reel handling and storage practices are essential to maintaining conductor integrity prior to installation.

Reels should always be stored and handled in an upright position with the flanges vertical. Storage surfaces should be paved, compacted, or otherwise stable to prevent the reel from sinking or tipping. For extended storage periods, reels should be supported using wood blocking or similar cribbing to keep the reel flanges elevated above the ground and protected from moisture and corrosion. Under no circumstances should reels be laid on their side or transported in that position, as this can damage the reel structure and the conductor itself.

5.2 Stringing Methods

A variety of installation methods have been successfully used for overhead conductor construction, each suited to different line types, conductor sizes, and project requirements. Common conductor stringing methods include tension, semi-tension, layout, and slack stringing. All of these methods can be suitable for distribution line installation when applied correctly and under appropriate conditions.

For larger, multilayer conductor constructions—particularly those used in transmission applications—greater control of conductor tension and handling is required during installation. In these cases, tension-controlled stringing methods are generally preferred, as they minimize contact with the ground and reduce the risk of conductor damage. Tension stringing provides consistent control over mechanical forces in the conductor, which is especially important for conductors with multiple layers over a core or central wire.

Industry standards and best practices typically recommend the tension stringing method for conductors with more complex constructions, as well as for applications where maintaining conductor integrity is critical. This method helps ensure uniform tension, proper alignment, and reduced mechanical stress during installation.

Each stringing method has its own advantages and limitations depending on terrain, span length, access constraints, and conductor type. A clear understanding of these installation approaches allows installers and engineers to select the most appropriate method for a given project, balancing efficiency, safety, and long-term performance.

5.2.1 Tension Method

The tension stringing method involves pulling the overhead conductor into its final position while maintaining controlled mechanical tension throughout the installation process. This method provides precise control of the conductor and helps prevent contact with the ground or other obstacles that could cause surface damage.

In a typical setup, a pulling device such as a winch is positioned at one end of the line section, while a tensioning unit is placed at the opposite end. The conductor reel is positioned on the payout side of the tensioning equipment. A pulling line, which may be a steel wire rope or a high-strength synthetic rope, is first installed through the stringing blocks mounted on each structure along the line route.

Once the pulling line is in place, it is connected to the end of the conductor after the conductor has been routed through the tensioning equipment. As the pulling operation begins, the conductor is drawn through the stringing blocks and along the line path toward the pulling equipment. Throughout this process, controlled back-tension is applied to the conductor to maintain a consistent and safe tension level.

Maintaining proper tension ensures that the conductor remains elevated, avoiding contact with terrain, vegetation, or existing structures. This significantly reduces the risk of mechanical damage and is especially important for larger or more complex conductor constructions. The back-tension applied during stringing is generated and regulated by the tensioning equipment itself, rather than by the conductor reel, which functions solely as a supply source.

5.2.2 Semi-Tension Method

This installation method is similar in principle to tension stringing, but with reduced control over conductor tension. In this approach, the conductor is pulled directly from the pay-off reel and guided into the spans without the use of a dedicated tensioning device. Limited ground clearance is maintained by applying a light and controlled braking force to the pay-off reel during the pulling operation.

Because the conductor is drawn directly from the reel, careful attention must be given to the braking force applied. Only the minimum amount of braking necessary to prevent excessive slack should be used. Applying excessive braking can introduce high mechanical stresses into the conductor, potentially damaging the outer strands or causing deformation. In addition, excessive braking forces can be transmitted back to the reel, increasing the risk of reel damage or structural failure.

This method may be suitable for shorter spans, smaller conductors, or distribution-level installations where tension requirements are relatively low. However, it provides less precise control of conductor tension compared to full tension stringing and requires experienced personnel to ensure safe and proper handling.

5.2.3 Layout Method

This installation approach is similar to the slack stringing method but uses a mobile payout system to distribute the conductor along the line route. In this method, the leading end of the conductor is secured at the starting point, and the conductor reel is mounted on a vehicle or trailer. As the vehicle moves along the line section, the conductor is paid out directly beneath the spans.

Once the conductor has been laid out along the route, it is progressively lifted and placed into stringing sheaves or rollers installed on each structure. This process allows the conductor to be positioned without being pulled under significant tension during payout.

This method is typically used for shorter spans, light conductors, or distribution-level installations where ground access is readily available. While it can be efficient in accessible terrain, the conductor may come into contact with the ground during payout, which increases the risk of surface damage if proper precautions are not taken.

Careful coordination of vehicle speed and payout control is essential to prevent kinks, excessive slack, or uneven distribution of the conductor. Adequate ground protection and clean right-of-way conditions are important to minimize abrasion or contamination. When applied under suitable conditions, this method can provide a practical and economical approach to overhead conductor installation.

5.2.4 Slack Method

This installation method involves mounting the conductor reel on fixed stands or jacks, allowing it to rotate freely with only minimal braking applied. The braking force is used solely to prevent reel overrun, backlash, or the formation of loops during payout, and should not introduce significant tension into the conductor.

The conductor is attached to a vehicle, which then travels along the line route, pulling the conductor from the reel as it moves past each structure. As the conductor is paid out, it is lifted and positioned into stringing sheaves installed at each structure. These devices, commonly known as travelers, blocks, dollies, or stringing sheaves, support and guide the conductor during installation.

The vehicle continues along the entire line section until the required length of conductor has been distributed. Throughout the process, careful control of vehicle speed and reel rotation is essential to ensure smooth payout and to prevent excessive slack or sudden loading. This method is generally suited to shorter spans and lighter conductors, particularly in distribution applications where access conditions are favorable.

When properly executed, this approach provides a simple and efficient means of installing overhead conductors while minimizing equipment requirements. However, attention to handling practices and ground conditions remains important to avoid damage to the conductor surface during installation.

5.3 Tension Equipment

Bullwheel tensioners create controlled tension in overhead conductors through friction between the conductor and the bullwheel surface. To increase friction and distribute contact forces more evenly, multi-groove bullwheel designs are commonly used. These designs increase the total area of contact between the conductor and the tensioner, allowing for better control of tension while reducing localized wear on the conductor surface.

To guide the conductor smoothly through multiple grooves, bullwheel tensioners typically use two wheels arranged in tandem. This configuration allows the conductor to wrap around the grooves without excessive bending or twisting. Two common mechanical arrangements—often referred to as offset and tilted configurations—are used to transition the conductor from one wheel to the other while maintaining proper alignment and contact.

Bare aluminum overhead conductors are generally manufactured with a right-hand lay on the outer strand layer. To accommodate this construction and prevent strand disturbance or damage, bullwheel tensioners must be designed to match the conductor lay direction. Proper orientation ensures that the conductor seats correctly in the grooves and maintains stable contact during stringing.

Conductors should typically be routed through all available grooves on the bullwheel to maximize friction and ensure uniform tension control. Proper entry and exit paths through the tensioner help maintain smooth conductor movement and reduce the risk of slippage or uneven loading.

5.3.1 Offset Multi-Groove Bullwheel Tensioner

An offset multi-groove bullwheel tensioner is shown in **Figure 19**. In this configuration, both the front and rear bullwheels are oriented vertically, with the wheels laterally offset by approximately half the width of a groove. This offset allows the conductor to transition smoothly from one bullwheel to the other while maintaining proper alignment within the grooves.

Proper sizing of the bullwheel grooves is critical to ensure safe and effective operation. The groove radius must closely match the conductor diameter to provide adequate support and prevent localized deformation. In addition, the bullwheel diameter measured at the bottom of the grooves must be sufficient to limit bending stresses in the conductor as it passes through the tensioner.

This type of multi-groove bullwheel tensioner has a long history of successful use in overhead conductor installations. When properly designed and operated, it provides reliable tension control while minimizing mechanical stress and surface damage to the conductor.

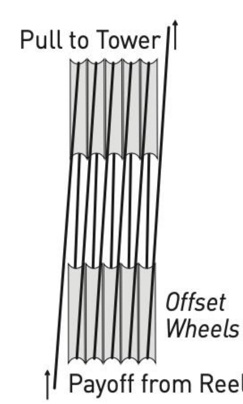


Figure 19 - Offset Multi-Groove Bullwheel Tensioner

5.3.2 Tilted Multi-Groove Bullwheel Tensioner

Figure 20 shows another commonly used bullwheel tensioner configuration in which the grooves at the top of the two bullwheels are aligned, while one of the wheels is slightly tilted. This arrangement allows the conductor to enter and exit each groove along a straight path, promoting smooth travel through the tensioner.

By maintaining straight-line alignment, this design reduces side contact between the conductor and the groove walls. Minimizing sidewall contact helps prevent abrasion and reduces the risk of loosening or disturbing the outer conductor strands during stringing.

As with other bullwheel tensioner designs, proper sizing of the groove radius is essential to ensure adequate conductor support and minimize localized stress. The diameter of the bullwheel measured at the bottom of the grooves must also be sufficient to limit bending forces as the conductor passes through the tensioner.

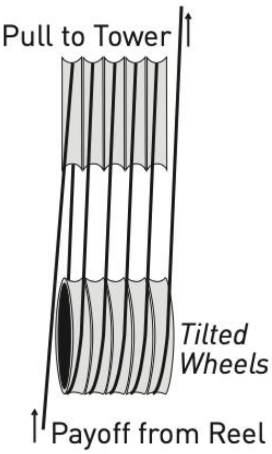


Figure 20 - Tilted Multi-Groove Bullwheel Tensioner

When correctly designed and operated, this tensioner configuration provides effective tension control while protecting conductor integrity, making it well suited for overhead conductor installation applications.

5.3.3 Motorized Bullwheel Tensioner

Bullwheel tensioners can be equipped with motorized hydraulic systems to provide controlled braking and generate the necessary back tension during conductor stringing. These hydraulic systems allow operators to precisely regulate the tension applied to the conductor, helping to maintain proper alignment and prevent contact with the ground or other obstacles.

It is important to operate the hydraulic system correctly. If not carefully controlled, the system can unintentionally push the conductor forward rather than applying back tension, which may create slack, uneven loading, or damage to the conductor. Proper training and monitoring of the hydraulic controls are essential to ensure the tensioner functions as intended and protects the conductor during installation.

5.4 Bullwheel and Sheave Dimensions and Lining Material

When selecting a bullwheel tensioner or stringing sheave, the two most critical dimensions to consider are the groove radius and the diameter at the bottom of the groove. Groove depth is also a useful measurement. See **Figure 21**. These dimensions determine how well the conductor is supported and how much bending stress is applied as it passes through the equipment.

In contrast, the overall diameter measured at the top of the groove is not a critical factor and has minimal impact on conductor performance during stringing. Ensuring the groove radius and bottom diameter are properly matched to the conductor helps protect the strands, reduce the risk of surface damage, and maintain safe tension control throughout the installation process. Recommended dimensions for bullwheel tensioners including diameter, groove radius, and depth are provided in IEEE Standard 524.

To prevent scratching or marking the surface of the conductor during stringing, bullwheel grooves should be lined with protective material. Common lining materials include urethane or molded nylon segments, which provide a smooth surface for the conductor to pass over while maintaining proper friction for tension control. Properly lined bullwheels help preserve conductor integrity and reduce the risk of damage during installation.

In addition, regular inspection of stringing sheaves is essential to ensure safe and damage-free conductor installation. Worn, torn, or damaged linings should never be used, as a degraded groove lining can prevent the conductor from tracking properly and can cause uneven pressure along its surface.
Stringing sheaves should roll smoothly as the conductor is pulled through. If a sheave bounces, jerks, or fails to maintain a constant rotational speed, it is likely due to faulty bearings. In such cases, the pull should be stopped immediately, and the defective sheave must be replaced before continuing.

Protective linings made of urethane or neoprene are commonly used and have proven effective for bare overhead conductors. For multilayer or sensitive conductors, bare metal sheaves should be avoided, as direct contact can scratch or damage the conductor surface. Using properly lined sheaves helps preserve conductor integrity, ensures smooth stringing, and reduces the risk of long-term performance issues.

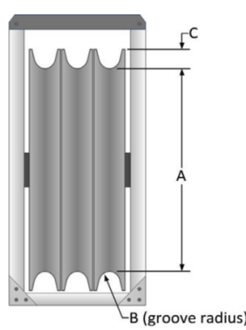


Figure 21 – Stringing sheave dimensional measurements where: A = groove diameter, B = groove radius, C = groove depth.

5.5 Stringing Operations

5.5.1 Conductor Grips

A variety of conductor grips and tie-down devices are available for use in overhead line installation. It is important to consult the grip manufacturer to ensure that the selected grip is appropriate for the conductor's diameter, type, and anticipated tension during pulling, sagging, or dead-ending operations. Proper selection helps maintain safe handling and prevents conductor damage.

There are two primary categories of mechanical grips. The first type, including Klein (Chicago) and Crescent styles, features an open-sided rigid body with opposing jaws and a swing latch that pinches the conductor between the jaws. The second type, often called the pocketbook, come-along, suitcase, or four-bolt grip, has a body with a bail that folds completely around the conductor. Bolts are then tightened to secure the conductor within the clamp.

For tension stringing, woven wire grips, also known as basket, wire mesh, or sock grips, are commonly used. These grips fit over the conductor and attach to a suitably sized swivel link to allow smooth movement during pulling. To prevent the grip from slipping off the conductor, it is recommended to secure the open end of the grip with two punch-lock steel bands. Protective tape can be applied over the steel bands to prevent abrasion or damage to bullwheel tensioners and stringing sheave linings.

5.5.2 Bottom-End Conductor Attachment to Reel

The conductor end at the bottom of the reel must be properly secured to the reel to provide a stable attachment point during manufacturing and payout. However, this attachment should never be used as an anchor or tension point during stringing operations.

During conductor payout, the stringing process must be stopped before the reel is completely emptied. At that point, any required back tension should be transferred to a proper anchor or tensioning device rather than relying on the conductor end attached to the reel.

The reel-mounted conductor end is not designed to act as a brake or end-stop and cannot safely resist the forces generated in a "run-out" scenario. Treating it as such could result in conductor damage, reel failure, or safety hazards. Proper tension control and transfer to dedicated equipment are essential to ensure safe and effective conductor installation.

5.5.3 Stringing Setup

Figure 22 illustrates a typical setup for a conductor stringing operation. For optimal performance and safety, the pay-off reel, tensioner, first stringing sheave, and the initial span beyond the break-over structure should be aligned as straight as possible. Proper alignment helps minimize bending stresses on the conductor and reduces excessive loading on both the structure and the sheave.

Industry best practices recommend maintaining a ratio of three to one (3:1) between the horizontal distance to the first structure and the vertical height to the first stringing sheave. This ratio corresponds to an upward conductor angle of approximately 20 degrees and helps limit vertical loads on the structure while controlling pressure on the sheave.

Additionally, the pay-off reel should be positioned a sufficient distance from the bullwheel tensioner, typically 40-50 feet, to allow smooth conductor payout and proper tension control during the stringing process. Following these alignment and spacing guidelines helps ensure safe, efficient, and damage-free installation of overhead conductors.

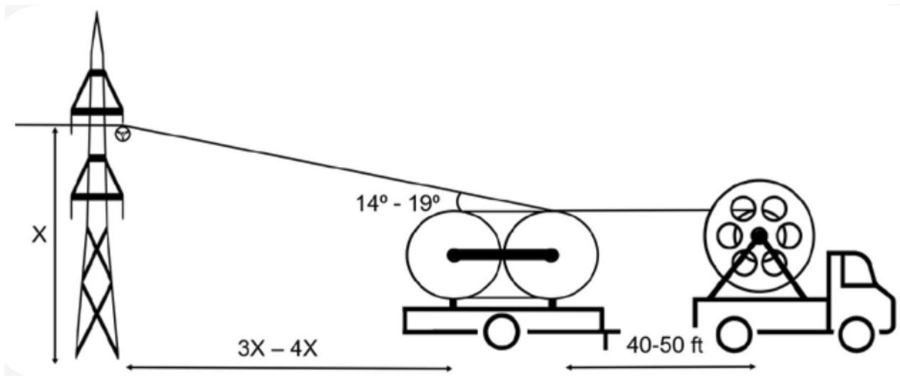


Figure 22 – Typical Stringing Setup Equipment Alignment

5.5.4 Pay-off Brake Tension

IEEE Standard 524 recommends that the brake tension on the pay-off reel be set only high enough to prevent the reel from overrunning as the conductor is pulled into the tensioner. The pay-off brake tension must be carefully monitored throughout the stringing operation.

As the reel becomes partially empty, the brake tension should be gradually reduced to prevent excessive force from being applied to the conductor. If the brake tension is too high, it can deform or distort the reel flanges, potentially causing permanent damage to the reel. Excessive tension may also pull the conductor into the underlying wraps on the reel, where it could become wedged or damaged.

5.5.5 Angle Changes and Sheave Supports

An angle is any change in line direction or elevation along the route. When a pull involves multiple angles or significant elevation changes that could create excessive stress on the conductor, it is often necessary to divide the installation into separate pulls to reduce the risk of damage.

If it is not feasible to relocate equipment to minimize the total angle change, additional measures should be taken to reduce conductor stress and protect its integrity. This includes properly supporting stringing sheaves at angles, as outlined in recommended practices for sheave support, to ensure smooth conductor travel.

For angles that may pose a potential problem, it is standard practice to have construction personnel stationed at the angle structure during stringing. These personnel can observe the conductor as it passes through the sheave or block, allowing any damage or abnormal behavior to be detected immediately. Prompt corrective action can then be taken to prevent further damage and ensure a safe, efficient installation.

The stringing sheave in a static condition will hang plumb (vertical). When tension is applied to the pulling line/ conductor, the angle in the line will cause the sheave to swing left or right of plumb, depending on the direction of the line change.

For significant angle changes, the stringing sheave should be supported by means of a sling to allow the conductor to roll along in the bottom of the groove.

When the line tension pulls the sheave to one side, the conductor can ride up on the edge of the groove. This off-center position generates a torsional force that can cause the conductor to rotate clockwise or counter-clockwise, depending on which side of the sheave it is riding. Such rotation can increase the risk of strand damage or surface marks.

To maintain proper conductor alignment, it is recommended to support stringing sheaves at angles. Supporting the sheave keeps it in the correct orientation relative to the conductor, helping the conductor track through the center of the groove. Simple methods such as using a rope, chain, or hoist can be used, particularly for heavier sheaves, to hold them at the proper angle during pulling.

Properly supporting sheaves in this manner minimizes torsional forces on the conductor, reduces the potential for strand damage, and helps ensure a smooth and controlled installation. This practice is especially important at directional or elevation changes where the risk of off-center tracking is greatest.

5.5.6 Time in Stringing Sheaves

As recommended by IEEE Standard 524, conductors should be sagged within 24 hours of installation.

Leaving conductors sitting in sheaves can lead to damage, since they are unsecured and may slip out during high winds. Low-tension spans can also result in excessive sag, causing conductors to clash against each other.

When temporarily securing a conductor, the holding tension should be kept as low as possible and well below the final sagging tension. Maintaining low tension and sagging the line promptly within the 24-hour window reduces the need to rely on short-term creep correction curves for later adjustments. These curves estimate conductor elongation based on assumed tension, temperature, and time, and their accuracy diminishes as the time between installation and sagging increases.

5.5.7 Pre-Tensioning

In some installations, although not commonly practiced, conductors may be pre-stretched prior to sagging. Pre-tensioning is performed when it is desirable to sag the conductor based on its final operating conditions. Typically, the conductor is pulled to 50–60% of its rated tensile strength and held under this load for at least one hour.

The exact pre-tension value is calculated for each specific installation and ambient temperature to ensure proper elongation before final sagging. After the pre-tension period, the tension is reduced to the final sagging tension for the line. Pre-tensioning is generally applied only to selected spans rather than the entire line.

It is important that stringing sheaves, support structures, and associated hardware are rated to safely withstand the applied pre-tension forces. Proper equipment selection and adherence to calculated tension values help prevent conductor or hardware damage while achieving accurate final sag.

5.5.8 Sagging

Conductor sagging is performed using sag-tension tables to determine the proper sag or tension for the conductor at a specific temperature. It is important to measure the conductor temperature at the time of sagging, using a conductor thermometer positioned on or near the conductor. The thermometer should be installed in advance to allow the conductor temperature to stabilize before measurements are taken.

Once the temperature is known, the conductor is tensioned to achieve the correct sag or tension. Common methods for applying and verifying tension include the (1) Stopwatch Method, (2) Transit Method, and (3) Dynamometer method.

Stopwatch Method

The stopwatch method measures the time it takes for a conductor to swing between two points to determine sag.

In this method, a rope or line attached to the conductor is given a sharp jerk to create a vibration wave. The time it takes for the wave to travel along the span and return multiple times is measured. Typically, observing three to five return waves provides an accurate determination of the sag.

The measurement is then used in the below equation to calculate the conductor's sag based on span length, wave travel time, and conductor properties.

$$D = 48.3\left(\frac{t}{2n}\right)^2$$

Where,
D = conductor sag, inches
t = time, seconds
n = number of return waves

Transit Method

This method uses a surveyor's transit or optical instrument to measure conductor position relative to reference points.

The transit method for conductor sagging includes three primary approaches:

1. Calculated angle of sight
2. Calculated target
3. Horizontal line of sight.

The selection of the most appropriate method depends on the terrain, span length, and conductor profile along the right-of-way.

For tall structures on flat terrain with relatively short spans, the calculated target or horizontal line of sight methods are generally the most effective, providing accurate sag measurements with minimal setup. On the other hand, for steep slopes, long spans, or spans with large sag, the calculated angle of sight method is preferred, as it accounts for variations in elevation and allows for precise positioning of the conductor along the span.

Dynamometer Method

This method directly measures the tension in the conductor with a calibrated dynamometer.

A dynamometer is placed in-line with the sagging equipment to directly measure the tension in the conductor providing an immediate and accurate reading of conductor tension, allowing the installer to achieve the desired sag.

For best results, the conductor line should have a minimal number of sheaves between the dynamometer and the span being measured, as additional sheaves can introduce friction and affect accuracy. This method is particularly effective for smaller conductors, shorter spans, or ruling spans consisting of only one or two spans. Proper use of the dynamometer method ensures precise tension control and accurate sag placement in overhead line construction.

Selecting the appropriate method depends on the equipment available, span length, and desired accuracy. Proper use of these methods ensures that the conductor is installed with the correct sag and tension for safe and reliable operation.

5.5.9 Sag Adjustments

When sagging overhead conductors, all tension adjustments should be completed within one hour to ensure accuracy and minimize conductor movement. It is recommended to check the sag at multiple locations along the line, preferably in level sections with similar span lengths, to verify consistency. For bundle or multi-conductor installations, all conductors should be sagged simultaneously to maintain proper alignment and phase spacing. Once the sagging tension is set, it should not be readjusted.

In cases where conductors have remained in stringing sheaves and were not sagged within 24 hours, conductor creep may occur. To account for this, estimated creep correction curves, which consider factors such as tension, temperature, and time, can be applied to adjust the final sag. While these curves provide guidance, their accuracy decreases as the time between installation and sagging increases, making timely sagging the preferred practice in accordance with IEEE Standard 524.

5.5.10 Clipping

Ideally, conductors should be clipped into place within 24 hours after the line has been sagged. Once the line tension is set, it should not be adjusted, as conductor creep will begin immediately. According to IEEE Standard 524, the total time that conductors remain in the stringing sheaves, from initial installation to final clipping, should not exceed 72 hours, as longer durations may lead to damage to the conductor or the sheaves.

Following sagging, the installation of dampers, spacers, and spacer-dampers should be completed as soon as possible. Early installation of these devices helps protect the conductors from mechanical vibration, galloping, or contact between bundled conductors, ensuring safe and reliable operation of the overhead line.

6.0 A Deeper Dive: Cable Tray Installation

6.1 General

When pulling cable into cable trays the same approach should be used for cable installed into conduit. Care must be given to the run lengths, number of cable turns, and cable sheave size to ensure the cable's maximum pulling tension, minimum bending radius, and maximum allowable sidewall pressure are not exceeded, subjecting the cable to possible damage.

6.2 Roller Spacing and Mounting

Roller Spacing

Roller spacing will vary with:

a. Cable weight
b. Cable tension
c. Cable construction
d. Roller height above the tray

Spacing of the rollers should be adequate to prevent the moving cable from touching or rubbing against the cable tray. The rollers should be placed to keep the cable in a fairly level position. The tension is significantly greater as the cable approaches the end of the pull allowing for more distance between rollers. Field experience shows that normally rollers should be spaced between 3 m to 5 m apart. The objective is to reduce drag and tension.

Roller spacing can be calculated as follows:

$$S = \sqrt{\frac{8 \times H \times T}{W \times g}}$$

where

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

Using this equation requires estimating cable tensions along the cable tray route. In practice, varying roller spacing throughout a pull isn't feasible, so enough rollers should be used to minimize sag and drag. When rollers or sheaves must be suspended, the support structure must be strong enough to handle pulling forces since cable trays are generally not designed to support this equipment. See **Figure 23** for an example of a cable tray installation setup.

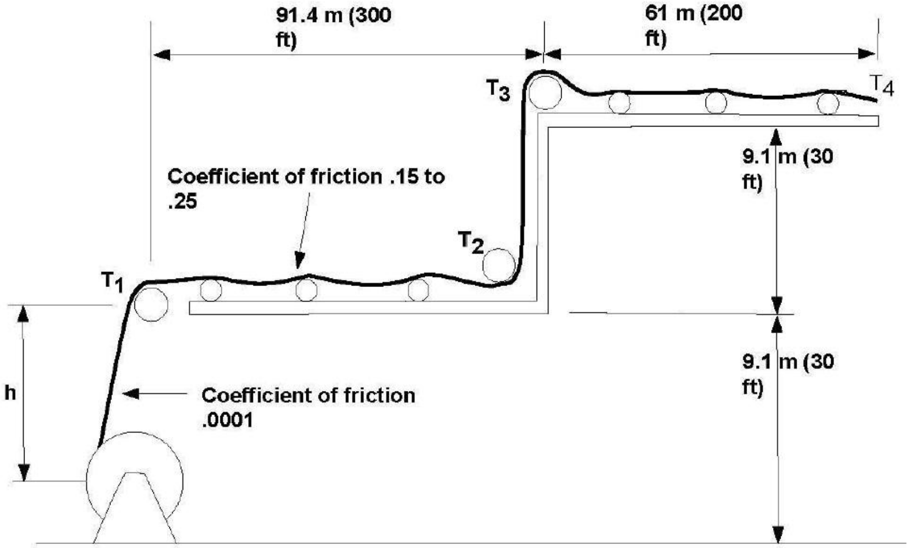


Figure 23 – Example cable tray setup

Roller Mounting

Rollers must be properly spaced to prevent the cable from touching the tray and must be free-turning.

When the tray changes direction, vertically or horizontally, sheave radii must be large enough to meet the minimum bending and maximum allowable sidewall pressure limits.

6.3 Sheave Arrangement

Exceeding maximum sidewall pressure during cable installation in trays or conduits can cause damage. To manage direction changes, conveyor sheaves can be used. See **Figure 24**. These consist of multiple small sheaves in a rigid frame forming an arc. It's recommended to use at least one sheave for every 20° of bend to minimize stress on the cable.

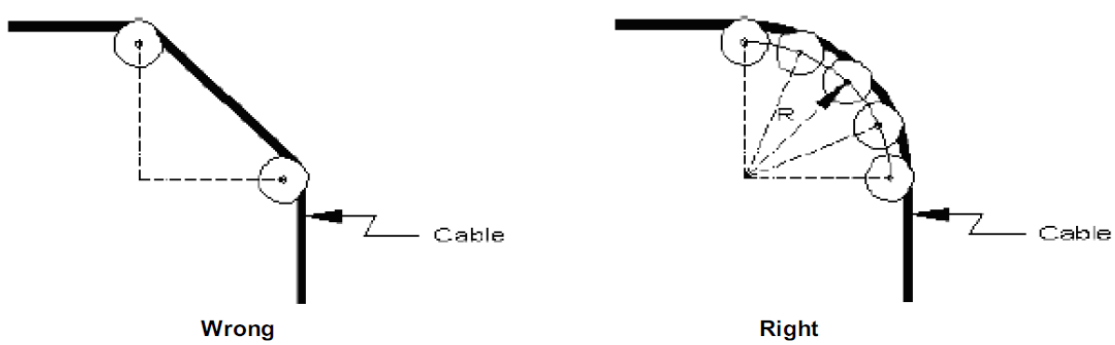


Figure 24 – Conveyor sheave arrangement

Conveyor sheaves must be properly sized to meet sidewall pressure and minimum bend radius requirements. Before pulling, align the sheaves by tensioning the pulling rope and centering it within the sheaves; minor adjustments may be needed during the pull. All sheaves should turn freely and be well-lubricated. Although sheaves are assumed frictionless—meaning input and output tension are equal—the cable still exerts a bending force. Calculation of SWBP out of a sheave can be determined using the following formula:

$$P = T/R_s$$

where

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

To protect existing cables and support the sheave during a pull, place a rigid, flat surface like plywood over the tray at bends and position the sheave on top. Lubricate both the cable as it comes off the reel and the bearings of rollers and sheaves—ensuring the lubricant is compatible with the cable jacket. Inspect all rollers and sheaves beforehand, and repair or replace any with sharp edges or damage.

6.4 Tension in Bends

If the sheaves in the bends in cable trays are well-maintained, they will not have the multiplying effect on tension that bends in conduit have. The sheaves will turn with the cable, allowing the coefficient of friction to be assumed zero. This results in the commonly-used approximation for conduit bend equation $e^{wK\Phi}$, becoming one. Even though cable tray bends produce no multiplying effect, it is essential for heavier cables to include the force required to bend the cable around the sheave.

A 200-pound adder per bend should be used for a three-conductor 500 kcmil copper conductor armored cable. If the sheaves are not well-maintained, the bend will have a multiplying effect. The tension in the pull must then be calculated using the same equations used for installations in conduit.

6.5 Tension entering Cable Tray

Because the tension entering the cable tray is rarely zero, it is critical that the tension required to remove the cable from the reel be used to calculate the total tension for the installation.

Many times it is difficult to know the location of the reel of cable until the cable is being installed. The following equations are used to approximate the tension entering the cable tray and can be used to determine how critical the reel position will be for the cable pull.

6.6 Feeding Off Reel Horizontally

When the cable reel can be elevated so that the cable can be pulled directly into the tray, the following equation should be used to approximate the tension required to remove the cable from the reel:

$$T_{reel} = 25W \text{ pound}$$

where: T_{reel} = tension, in pounds

W = total cable assembly weight, in pounds/foot

6.7 Feeding Off Reel Vertically

When the cable reel must be positioned directly below the cable tray the following equation should be used to approximate the tension required to pull the cable into the tray:

$$T = WL \text{ pounds}$$

where: W = total cable assembly weight, in pounds/foot

L = straight vertical section length, in feet

The tension can now be approximated for pulling the cable into the tray from a horizontal position when the reel is placed directly under the tray. To estimate the tension entering the cable tray when the reel must be placed away from and below the entrance to the tray, use the equation for feeding off the reel vertically where the height (L) is the vertical distance between the reel and cable tray. To allow for bending forces as the cable comes off the reel, the minimum tension added should be 25W.

7.0 A Deeper Dive: Armoured Cable Installation

7.1 General

Armored cables may employ aluminum or galvanized steel interlocked armor, and smooth or corrugated extruded or welded metallic armor, and can come with or without a non-metallic jacket. These cables offer enhanced mechanical protection and can be installed in raceways, open runs, direct burial, or aerial configurations.

Advantages:

1. Superior physical protection for conductors
1. Can be installed without raceways

Limitations:

1. Requires larger bend radius
2. Stiffer and more difficult to handle
1. Subject to specific installation constraints

7.2 Bend Radius

Armored cables should be carefully installed to ensure that their allowable bend radius is not violated during pulling or training activities. Bends that are too tight may distort the armor and compromise the geometry of the cable core insulation.

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

7.3 Methods of gripping

To prevent damage during installation, armored cables should be gripped on both the external armor/jacket and the core conductors. Recommended methods include:

1. **Dual-Grip Method:** Remove a section of armor, tape over it and the conductors, then apply a long basket-weave grip to secure both layers.
2. **High-Strength Method:** Use a pulling eye for the conductors and a separate grip over the armor to prevent slippage—this offers superior strength.

Important Considerations:

a. Interlocked armor requires lower tension limits to avoid separation or core withdrawal.
b. Always discard the “spoil” length near the grip area after pulling, as it may be compromised.

8.0 A Deeper Dive: Vertical Installation

8.1 General

Vertical cable runs require proper support to prevent mechanical stress at terminations, insulation damage, or conductor elongation. Cable supports must transfer tensile forces to the structure without harming the cable. This transfer depends heavily on the coefficient of friction between the cable jacket and the support device, making material compatibility and design critical to safe and effective installation.

To prevent tension buildup and ratcheting from load cycling, cables must be firmly secured in the horizontal raceway just before the vertical bend. Additional supports should be placed at the top of the vertical raceway and at intervals along the vertical section to maintain cable integrity and prevent strain on terminations.

Vertical support devices include basket-weave grips, tie wraps, clamps, cleats, and conduit fittings.

8.2 Forces

Understanding the forces acting on cables is critical for safe and reliable installation:

- **Axial Forces:** Caused by the cable's weight, these pull downward, risking elongation and disconnection at terminations.
- **Tangential Forces (Raceway-Induced):** Occur at vertical-to-horizontal transitions, especially over tight bends. These sidewall pressures can crush cable insulation and jackets.
- **Tangential Forces (Support-Induced):** Result from cable supports resisting gravity, thermal expansion, or fault movement. These also exert crushing pressure on the cable.
- **Electrodynamic Forces:** Short-duration, high-intensity forces from fault current interactions between conductors. If unrestrained, they can damage cables, equipment, and pose safety risks.
- **Seismic Forces:** Generally affect the raceway system more than the cable due to the cable's low natural frequency.

Calculation of Forces:

$$F = \frac{A \times T}{W \times L \times g}$$

where

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

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

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

8.3 Thermal Expansion

All cables expand and contract axially with temperature changes. While ambient temperature shifts typically cause minimal movement, large power cables under load can expand enough to overcome friction in horizontal sections above vertical transitions. This can lead to a ratcheting effect, where the cable gradually shifts downward during load cycles but doesn't fully retract when cooled.

Over time, this can result in tension buildup above the transition point and crushing forces at the bend, potentially damaging the cable and its insulation.

8.4 Support Spacing

Vertical runs of armoured or sheathed cable shall have the internal conductor assembly supported at intervals not exceeding those specified in local Codes, or by

- incorporating a bend or bends equivalent to a total of not less than 90° at intervals not exceeding the distances specified in local Codes;
- installation of a horizontal run of the cable not less than the length of the vertical run; or
- use of cable that is specifically designed for vertical runs.

8.5 Calculation of support spacing

$$S = \frac{D \times L \times P}{W \times g}$$

where

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

9.0 Cable Termination

9.1 General

A medium voltage (MV) cable termination is a specialized connection that secures the end of an MV power cable to electrical equipment, providing crucial electrical performance, mechanical strength, environmental durability, and safety. It can be performed using hot (heat shrink) or cold (cold shrink) methods, both requiring specific cable preparation and installation of components like stress relief and sealing mastic.

9.2 Heat Shrink Terminations

Involves using a heat source (like a heat gun) to shrink specialized tubing and components onto the cable for a tight, insulated seal and proper electric field distribution. See **Figure 25**.

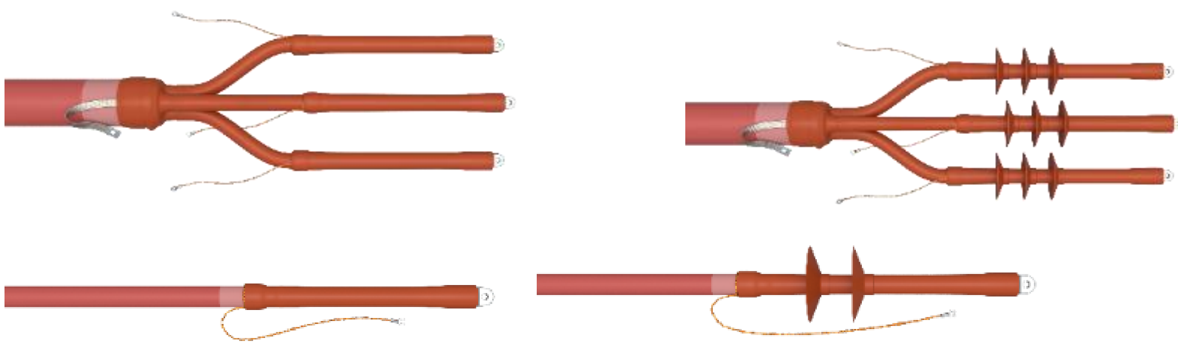


Figure 25 – Example of heat shrink terminations. Indoor (left) and outdoor (right).

9.3 Cold Shrink Terminations

Uses components that are pre-expanded and held on a removable core. Once installed, the core is pulled out, allowing the material to naturally contract and shrink tightly onto the cable without the need for a heat source. See **Figure 26**.

Figure 26 – Example of cold shrink terminations. Indoor (top) and outdoor (bottom).

9.4 Pre-Moulded Terminations

Consists of factory-engineered, slip-on termination components with built-in features for a precise and straightforward installation process.

Figure 26 – Example of pre-moulded terminations. Indoor (left) and outdoor (right).

9.5 Procedure

The cable preparation process is critical. The accessory imitates the structure of the cable, layer by layer, and provides a safe and reliable transition when terminating the cable at the end of the line.

Termination procedures should follow the termination kit manufacturer's recommendations. General steps are described below:

1. **Cable Preparation:** The cable's outer jacket, shielding, and insulation are carefully stripped according to the termination kit's specifications.
2. **Stress Control:** Stress control mastic or a semi-conductive tube is applied to manage electric field stress at the cable's end, ensuring safe operation.
3. **Component Installation:** The appropriate termination components (like silicone tubes, anti-tracking tubes, and rain sheds) are applied.
4. Lugs and Connectors: Cable lugs or connectors are secured to the exposed conductor, typically through crimping.
5. **Sealing:** Sealant and mastic are used to protect against moisture ingress.
6. **Testing:** After installation, acceptance tests such as continuity, insulation resistance, and withstand testing are performed to verify the termination's integrity and performance.

10.0 Cable Splicing

10.1 General

A splice joins two or more conductors using a suitable connector, followed by re-insulation, re-shielding, and re-jacketing with compatible materials over a properly prepared surface. See **Figure 27**. While typically avoided, splicing is often necessary due to:

1. Limited cable reel lengths or conduit routing constraints
2. Cable failures or post-installation damage
3. Taps into existing cables (e.g., tee or wye splices)

Splices must match the cable's rating to avoid derating and ensure system reliability. Modern splicing technologies often make splicing the most economical and practical solution.

Figure 27 – Example splice

10.2 Procedure

The general procedure for splicing is as follows:

1. **Surface Preparation:** Clean and prep the cable ends thoroughly.
2. **Conductor Connection:** Use suitable connectors to join conductors securely.
3. **Re-insulation:** Apply insulation materials compatible with the original cable.
4. **Re-shielding:** Restore shielding to maintain electrical performance.
5. **Re-jacketing:** Protect the splice with a durable outer jacket.

Refer to splice kit manufacturer for more specific/detailed procedures.

The most critical factor in splice reliability is the skill and care of the installer. Despite advancements in splicing products, proper technique and attention to detail remain essential for long-term performance.

11.0 Cable Removal

Removal of cables is sometimes required for replacement, repair, or disposal. Removing cable from old ducts is often more difficult than installing new ones due to:

1. **Debris & Silt Accumulation:** These can obstruct removal and increase friction.
2. **Dried Lubricant:** Hardened lubricant can bond cable to duct surfaces, raising friction beyond levels seen in dry installations.
3. **Tension Limits:** Even if the cable is being scrapped, pulling tensions must stay within the cable's tensile strength to avoid equipment damage.
4. **Limited Friction Data:** Static and dynamic friction coefficients during removal are not well-documented, making tension prediction difficult.

If excessive tensions are expected. flooding the duct with water can aid removal. Introducing water can reduce friction, loosen debris, and lower the cable's effective weight via buoyancy.

12.0 Cable Purging

The following is a recommended procedure for purging water from insulated conductors. See **Figure 28**.

1. Remove end caps on cables not installed. Remove splices, terminations and connectors on installed cables. The strands must be open to allow unrestricted flow of the dry nitrogen gas.
2. At the cable end where the water is present, attach a clear plastic bag. Secure the bag with tape or clamps. Make a small vent hole by cutting one corner of the bag. This bag will inflate during purging to indicate that nitrogen is flowing.
3. At the other cable end, attach the dry nitrogen supply as shown in the below diagram. Dry nitrogen is available from a welding gas supplier. Apply a few layers of insulating tape over the cable insulation where the hose assembly is to be attached to ensure good sealing between the insulation and the hose assembly.
4. Apply not more than 15 psig of pressure. Depending on the size, type and length of conductor being purged, it will take a few minutes before the dry nitrogen gas begins to escape and push out water at the exhaust end. Apply gas until water or moisture is no longer visible. To detect moisture, if not visible, sprinkle one tablespoon of Anhydrous Cupric Sulphate crystals in the bag. The crystals turn blue when exposed to moisture. If the crystals remain white, the purging process can be terminated.

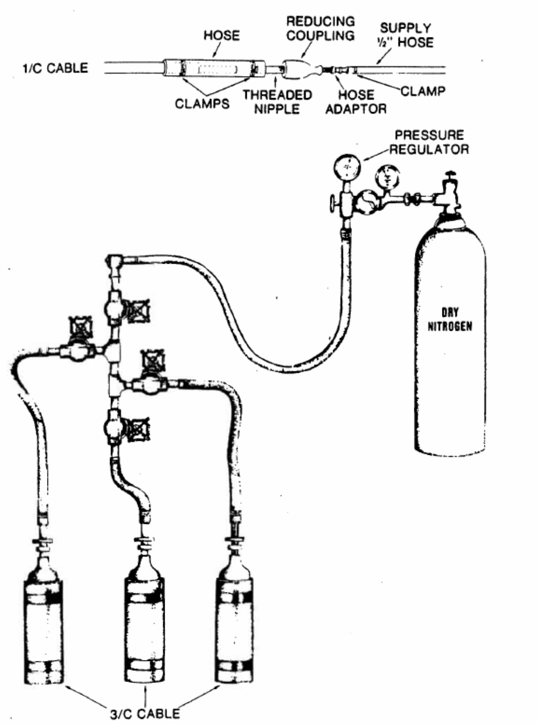


Figure 28 – Cable purging example set-up

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