

WIRE AND CABLE INSTALLATION GUIDE

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UNITED COPPER INDUSTRIES
Copper Building Wire and Cable Products

Introduction

Cable installations often require pulling the cables through conduit, cable trays, or raceways. This document provides information to aid the installation process to prevent damage to the wire and cable, which may cause service failures or decrease the service life of the product. Prime considerations must be given to pulling tensions and evaluation of all components to assure a successful and trouble free installation.

Cable routing should be considered when designing new installations. When installations are necessary in existing construction, the routing should be inspected thoroughly.

Before installation, be sure the raceway or conduit is sized in accordance with the requirements of the National Electric Code® (NEC). Care should be taken to ensure that no sharp edges exist to protrude into the cable insulation as it is being installed. It is essential to run a clean-out brush through the conduit to remove or loosen up any burrs.

When finished, pull a swab through to clean out foreign objects.

When installing cables in wet underground locations, the cable ends must be sealed to prevent entry of moisture into the conductor strands. These seals should be left intact or remade after pulling if disrupted, until splicing, terminating, or testing is to be done. This practice is recommended to avoid unnecessary corrosion of the conductors and to safeguard against entry of moisture into the conductor strands, which would generate steam under overload, emergency loadings, or short-circuit conditions after the cable is energized.

Another important consideration is to not exceed the maximum allowable tensile strength or the minimum-bending radius of the cable. The force required for pulling a given length can be reduced by the application of a pulling compound on cables in conduit and the use of rollers in cable trays.

The data in this document provides general information relating to maximum allowable pulling tensions for wire and cables under normal conditions. For extraordinary conditions, additional engineering consultations are advisable.

The pulling apparatus must be evaluated as well and the manufacturer's limits must not be exceeded.

Temperature can adversely affect the installation process. Cables must not be installed or rewound when the cable is below the minimum temperatures listed below.

MINIMUM INSTALLATION TEMPERATURE

| Jacket or Insulation Type | Celsius | Fahrenheit |
|---------------------------|---------|------------|
| PVC | -10°C | 14°F |
| XLP | -40°C | -40°F |
| Nylon | -3.9°C | 25°F |

NOTE: Cables stored below these temperatures must be moved to a heated environment. Allow for a twenty-four (24) hour stabilization period before using.

Maximum Cable Tensions during Pulling

Maximum pulling tension of wire and cable is determined by the stress per circular mil area of the metallic conductors (.008 lbs for copper and .006 for aluminum).

Table A lists circular mil area for standard AWG sizes, both solid and concentric stranded conductors as well as weights per foot for copper THHN, XHHW-2 and USE-2.

TABLE A

| Wire Size Conversion to CMA | | Approximate Weight per 1,000 Feet (Pounds) | | |
|-----------------------------|---------|--|-------------|------------|
| Trade Size | CMA | THHN (Cu) | XHHW-2 (Cu) | USE-2 (Cu) |
| 14 AWG | 4,110 | .018 | .021 | .021 |
| 12 AWG | 6,530 | .027 | .029 | .029 |
| 10 AWG | 10,380 | .040 | .045 | .045 |
| 8 AWG | 16,510 | .069 | .070 | .070 |
| 6 AWG | 26,240 | .109 | .115 | .115 |
| 4 AWG | 41,740 | .166 | .164 | .164 |
| 3 AWG | 52,620 | .202 | .206 | .206 |
| 2 AWG | 66,360 | .254 | .235 | .235 |
| 1 AWG | 83,690 | .316 | .320 | .320 |
| 1/0 AWG | 105,600 | .398 | .365 | .365 |
| 2/0 AWG | 133,100 | .488 | .440 | .440 |
| 3/0 AWG | 167,800 | .603 | .620 | .620 |
| 4/0 AWG | 211,600 | .731 | .770 | .770 |
| 250 KCMIL | 250,000 | .903 | .894 | .894 |
| 300 KCMIL | 300,000 | 1.058 | 1.010 | 1.010 |
| 350 KCMIL | 350,000 | 1.211 | 1.231 | 1.231 |
| 400 KCMIL | 400,000 | 1.332 | 1.350 | 1.350 |
| 500 KCMIL | 500,000 | 1.735 | 1.720 | 1.720 |
| 600 KCMIL | 600,000 | 1.990 | 2.028 | 2.028 |
| 750 KCMIL | 750,000 | 2.468 | 2.511 | 2.511 |

Maximum allowable pulling tension on the cable for one (1), two (2) or three (3) conductors can be calculated by the following formula:

$$T_{\max} = S \times N \times CMA$$

Where: T_{\max} = Maximum Tension

S = Maximum Stress per Circular Mil Area (.008 lbs for copper and .006 for aluminum)

N = Number of Conductors

CMA = Circular Mil Area (from Table A)

MAXIMUM PULLING TENSIONS USING FORMULAS AND DATA ABOVE

| Trade Size | Number of Conductors* | | | | | |
|------------|-----------------------|--------|--------|--------|--------|--------|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 14 AWG | 33 | 66 | 99 | 105 | 132 | 158 |
| 12 AWG | 52 | 104 | 157 | 167 | 209 | 251 |
| 10 AWG | 83 | 166 | 249 | 266 | 332 | 399 |
| 8 AWG | 132 | 264 | 396 | 423 | 528 | 634 |
| 6 AWG | 210 | 420 | 630 | 672 | 840 | 1,008 |
| 4 AWG | 334 | 668 | 1,002 | 1,069 | 1,336 | 1,603 |
| 3 AWG | 421 | 842 | 1,263 | 1,347 | 1,684 | 2,021 |
| 2 AWG | 531 | 1,062 | 1,593 | 1,699 | 2,124 | 2,548 |
| 1 AWG | 670 | 1,339 | 2,009 | 2,142 | 2,678 | 3,214 |
| 1/0 AWG | 845 | 1,690 | 2,534 | 2,703 | 3,379 | 4,055 |
| 2/0 AWG | 1,065 | 2,130 | 3,194 | 3,407 | 4,259 | 5,111 |
| 3/0 AWG | 1,342 | 2,685 | 4,027 | 4,296 | 5,370 | 6,444 |
| 4/0 AWG | 1,693 | 3,386 | 5,078 | 5,417 | 6,771 | 8,125 |
| 250 KCMIL | 2,000 | 4,000 | 6,000 | 6,400 | 8,000 | 9,600 |
| 300 KCMIL | 2,400 | 4,800 | 7,200 | 7,680 | 9,600 | 11,520 |
| 350 KCMIL | 2,800 | 5,600 | 8,400 | 8,960 | 11,200 | 13,440 |
| 400 KCMIL | 3,200 | 6,400 | 9,600 | 10,240 | 12,800 | 15,360 |
| 500 KCMIL | 4,000 | 8,000 | 12,000 | 12,800 | 16,000 | 19,200 |
| 600 KCMIL | 4,800 | 9,600 | 14,400 | 15,360 | 19,200 | 23,040 |
| 750 KCMIL | 6,000 | 12,000 | 18,000 | 19,200 | 24,000 | 28,800 |

Caution: Always check the pulling equipment manufacturer's specifications before applying the above tensions. Exceeding the manufacturer's limitations could result in damage to equipment and/or materials as well as personal injury.

For pulling more than three (3) conductors, the maximum allowable tension can be calculated by:

$$T_{\max} = S \times N \times \text{CMA} \times (0.8)$$

Where: T_{\max} = Maximum Tension

S = Maximum Stress per Circular Mil Area (.008 lbs for copper and .006 for aluminum)

N = Number of Conductors

CMA = Circular Mil Area (from Table A)

(0.8) = Factor for Additional Conductors

Maximum Permissible Pulling Length

The maximum length of cable that can safely be pulled through conduit can be calculated with the following formula:

$$L_{\max} = T_{\max} / (W \times C)$$

Where: L_{\max} = Maximum Pulling Length in Feet

T_{\max} = Maximum Tension in Pounds

W = Weight of Cable in Pounds per Foot

C = Coefficient of Friction (if unknown use 0.5)

Pulling Tension Calculations for Straight Section of Conduit

Pulling tensions for a straight section of conduit can be calculated as follows:

$$T_s = L \times W \times f$$

Where: T_s = Pulling Tension at the End of a Straight Section in Pounds

L = Length of Straight Section of Conduit in Feet

W = Weight of Cable in Pounds per Foot

f = Coefficient of Friction (if unknown use 0.5)

Pulling Tension Calculations for Curved or Bent Section of Conduit

$$T_b = T_s \times e^{fa}$$

Where: T_b = Pulling Tension at the End of Curved or Bent Section in Pounds

T_s = Pulling Tension at End of the Straight Section Entering the Bend in Pounds

e = Naperian Log Base 2.718

f = Coefficient of Friction (if unknown use 0.5)

a = Angle of Curve - Radians

VALUES OF e^{fa} FOR COMMON ANGLES

| Angle of Bend | e^{fa} | | | | | |
|---------------|----------|---------|---------|---------|---------|----------|
| | f = 0.7 | f = 0.6 | f = 0.5 | f = 0.4 | f = 0.3 | f = 0.15 |
| 15° | 1.20 | 1.17 | 1.14 | 1.11 | 1.08 | 1.04 |
| 30° | 1.44 | 1.37 | 1.30 | 1.23 | 1.17 | 1.08 |
| 45° | 1.73 | 1.60 | 1.48 | 1.37 | 1.27 | 1.13 |
| 60° | 2.08 | 1.87 | 1.68 | 1.52 | 1.37 | 1.17 |
| 75° | 2.50 | 2.19 | 1.92 | 1.69 | 1.48 | 1.22 |
| 90° | 3.00 | 2.57 | 2.19 | 1.87 | 1.60 | 1.27 |

Maximum Sidewall Pressure at Bends

Tension on the cable during pulling acts horizontally and the weight of the cable acts vertically, resulting in Sidewall Pressure. As a general rule, this sidewall pressure should not exceed 300 pounds per foot of radius. (The tension of a cable as it immediately leaves a bend must not be greater than 300 times the bend radius in feet.)

Below are formulas to calculate the maximum allowable tension at a bend and the actual sidewall pressure.

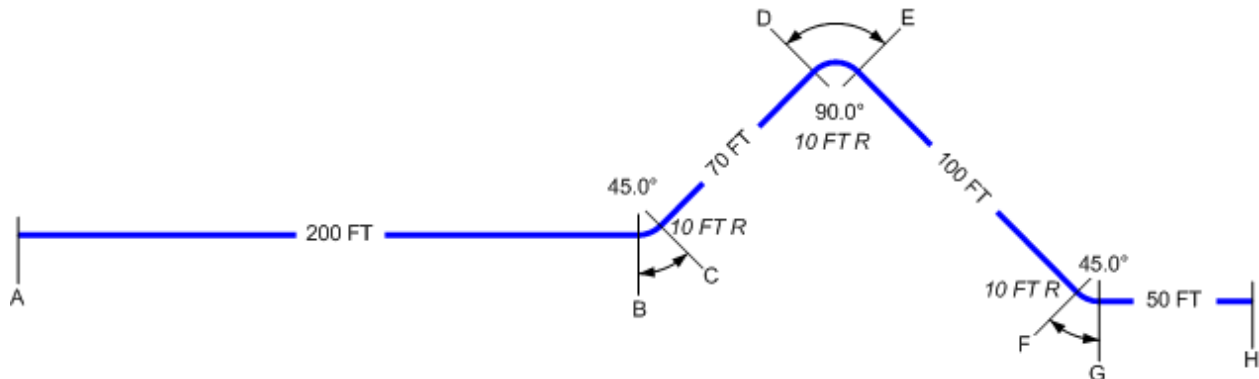
$$T_{b_{max}} = 300 \times r$$

Where: $T_{b_{max}}$ = Maximum Allowable Pulling Tension at Bends in Pounds
 r = Bend Radius in Feet

$$P = T_b / r$$

Where: P = Actual Sidewall Pressure on the Cable in Pounds per Foot
 T_b = Pulling Tension at and of Bend in Pounds
 R = Bend Radius in Feet

EXAMPLE: 500 kcmil THHN, Cable Weight 1.735 lb/ft



Maximum Pulling Tension- T_{max}

$$T_{max} = S \times N \times CMA$$

$$T_{max} = .008 \times 1 \times 500000$$

$$T_{max} = \underline{4,000} \text{ lbs}$$

Pulling from point “H” (feeding in from Point “A”)

Tension at Point “A” = 0 (Zero)

Tension at Point “B” = $(Ts_1) 200' \times 1.735 \times 0.5 = 174 \text{ lb}$

Tension at Point “C” = $(Tb_1) 174' \times 1.48 = 258 \text{ lb}$ $P_{B-C} = 258/10 = 25.8 \text{ lb/ft}$

Tension at Point “D” = $(Ts_2) 258' + [70 \times 1.735 \times .5] = 319 \text{ lb}$

Tension at Point “E” = $(Tb_2) 319' \times 2.19 = 699 \text{ lb}$ $P_{D-E} = 699/10 = 69.9 \text{ lb/ft}$

Tension at Point “F” = $(Ts_3) 699' + [100 \times 1.735 \times .5] = 868 \text{ lb}$

Tension at Point “G” = $(Tb_3) 868' \times 1.48 = 1285 \text{ lb}$ $P_{F-G} = 1,328/10 = 132.8 \text{ lb/ft}$

Tension at Point “H” = $(Ts_3) 1,285' + [50 \times 1.735 \times .5] = 1,328 \text{ lb}$

Pulling from point “A” (Feeding in from point “H”)

Tension at Point “H” = 0 (Zero)

Tension at Point “G” = $(Ts_1) 50' \times 1.735 \times 0.5 = 43 \text{ lb}$

Tension at Point “F” = $(Tb_1) 43' \times 1.48 = 64 \text{ lb}$ $P_{G-H} = 64/10 = 6.4 \text{ lb/ft}$

Tension at Point “E” = $(Ts_2) 64' + [100 \times 1.735 \times .5] = 151 \text{ lb}$

Tension at Point “D” = $(Tb_2) 151' \times 2.19 = 331 \text{ lb}$ $P_{D-E} = 331/10 = 33.1 \text{ lb/ft}$

Tension at Point “C” = $(Ts_3) 331' + [70 \times 1.735 \times .5] = 392 \text{ lb}$

Tension at Point “B” = $(Tb_3) 392' \times 1.48 = 580 \text{ lb}$ $P_{C-B} = 580/10 = 58.0 \text{ lb/ft}$

Tension at Point “A” = $(Ts_3) 580' + [200 \times 1.735 \times .5] = 754 \text{ lb}$

In this example, the cable may be pulled from either direction without exceeding the maximum allowable tension of 4,000 lbs or sidewall tension of 300 lb/ft. It can be seen that feeding the cable into end “H” and pulling from end “A” results in approximately 40% less tension on the cable.

Minimum Bend Radius

Bend radius for placing cable into final position with no tension on the cable, are shown in the following two tables. No published limits are available for bend radius when pulling cable (when the cable is under tension), however United Copper Industries recommends doubling the minimum bend radius shown in these tables when pulling through conduit.

MINIMUM BEND RADIUS FOR NON-METALLIC SHIELDED AND NON ARMORED POWER CABLES

| Total Thickness of Conductor Insulation (Inches) | Outside Diameter of Cable (Inches) | | |
|--|--|-----------------------|------------------|
| | 0 to 1.000 Inches | 1.001 to 2.000 Inches | 2.001 and Larger |
| | Minimum Bending Ratios as a Multiple of Cable Diameter | | |
| 0 to 0.169 | 4 | 5 | 6 |
| 0.169 and Larger | 5 | 6 | 7 |

NOTE: Values taken from ICEA S-95-658

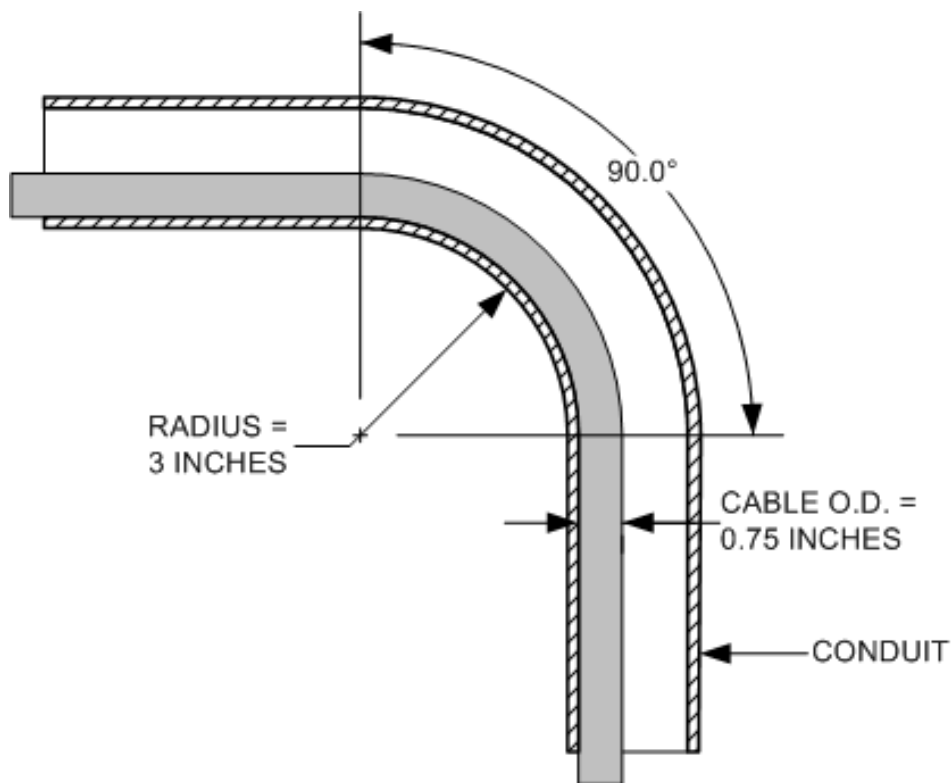
SUGGESTED MINIMUM BEND RADIUS FOR PORTABLE JACKETED CABLES

| Cable Type | Minimum Bend Radius as a Multiple of Overall Cable Diameter |
|---|---|
| Thermoset-Jacketed 0 – 5 kV | 6 |
| Thermoset-Jacketed 5+ kV | 8 |
| Control Cable (7 Conductors and Larger) | 20 |
| Flat-Twin Cables | Use Minor O.D. to Determine Minimum Bend Radius |

Example of Calculating Minimum Bending Radius

For a cable with an outside diameter of .75 inches, the minimum-bending radius is 4 times the cable diameter.

The minimum radius the cable can be bent is 3 inches ($4 \times .75$) or a minimum diameter of 6 inches.



Jam Ratio

Jamming is the wedging of three or more cables when pulled into a conduit. This usually occurs because of crossovers when the cables twist or are pulled around bends. When the combined diameters of three cables roughly equal the interior diameter of the conduit, the cables can line up linearly as they are pulled around the bend. The cables then wedge against the conduit wall as they are forced towards the inside of the bend. The wedged (or jammed) cables are "stuck." To pull jammed cables with enough force to get them through a bend usually ruins the cable by ripping off the jacket or crushing the insulation.

The common technique to avoid jamming is to avoid pulling cables with an unfavorable ratio of cable OD to conduit ID (called Jam Ratio). However, unfavorable jam ratios cover a wide range, and to avoid them completely is not always possible.

The following equation presents the usual calculation of Jam Ratio:

$$\text{Jam Ratio} = \frac{D}{d} \times 1.05$$

Where: D = Interior diameter of conduit

d = Outer diameter of wire

1.05 = Factor included to estimate the oval cross-sections of conduit bends

Generally accepted industry guidelines indicate the highest probability of jamming occurs at jam ratios between 2.6 and 2.9. The Table below provides a general guideline when determining the probability of jamming.

PROBABILITY OF JAMMING

| Ratio | Probability of Jamming |
|------------------|------------------------|
| < 2.4 | Very Small |
| 2.4 – 2.5 | Small |
| 2.5 – 2.6 | Moderate |
| <u>2.6 – 2.9</u> | <u>Significant</u> |
| 2.9 – 3.0 | Moderate |
| 3.0 – 3.2 | Small |
| > 3.2 | Very Small |

Insulation Resistance “MEGGER” Test

Low voltage, non-shielded cables can be tested using a battery powered ohmmeter or a device called a "megger." Hand held ohmmeters generally have outputs from several volts to 24 volts. They are excellent for detecting direct "shorts" such as bolted faults and low resistant measurements in the kilohm (k Ω) range. A "megger" measures resistance in the megohm (M Ω) range using higher voltages than an ohmmeter. Manual or motor-driven meggers are available for a range of fixed dc voltages. Typical fixed dc voltages are 500, 1000, 2500 and 5000 volts.

“2 to 50 Megohm Rule”

Applied dc potential may be 500 or 1000 volts dc with the insulation resistance reading taken at one minute. Generally accepted industry guidelines indicate that megohm readings of less than 50 megohms may be used for deciding when to investigate the cable installation. Readings less than two megohms will most likely indicate damaged insulation. Readings within the 2 to 50 megohm range are usually associated with long circuit lengths, moisture, or contamination. In most cases a 2 to 50 megohm reading does not indicate the insulation quality, therefore 2 to 50 megohms should not be specified as a pass/fail value. Insulation resistance readings should be made and interpreted by experienced testing specialists to determine the condition of the cable's insulation.

Note that it is difficult to obtain accurate insulation resistance measurements in the field. Factory tests are done in a controlled environment with the cable submerged in water to provide an electrical ground. Using factory test values are not recommended.

Summary

- Determine the safest direction of pull based on safe tension levels and sidewall pressure calculations.
- Position payoff reels securely and at a position to minimize pressure.
- Select pulling equipment that provides adequate strength and control.
- Examine conduit, cable tray for obstructions or debris.
- Attach pulling eyes/grips securely and assure proper size.
- Assure ends are sealed when in wet underground sites.
- Apply approved lubricant during pulling.
- Use constant speed and avoid stopping until the pull is completed.
- Monitor both ends of the conduit or raceway during installation.
- After pulling, reseal ends that may have been disrupted.

The information presented here is, to the best of our knowledge, true and accurate. However, since conditions of use are beyond our control, all recommendations or suggestions are presented without guarantee or responsibility on our part. We disclaim all liability in connection with the use of information contained herein or otherwise.

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