PDHonline Course E122 (4 PDH)

Conduit System Design

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Course Content

When designing conduit and duct systems, a conduit size must be selected. Conduit shall be sized so cables can be pulled through it without damaging the cable jacket or insulation and so adequate cooling exists when the cables are energized. The NEC limits conduit fill to 40%, meaning the sum of the cross-sectional areas of all cables in a conduit cannot exceed 40% of the cross-sectional area defined by the conduit inside diameter. The rationale for the 40% fill rule is based on a quantity called the *jam ratio*. If the cables jam in the conduit during pulling, the likelihood of cable damage is high. The jam ratio for three single conductor cables of the same diameter is defined as the ratio of the conduit inside diameter to the single conductor cable outside diameter, as shown in Eq. 1.

$$j = \frac{ID_{conduit}}{OD_{cable}} \qquad \text{Eq. 1}$$

Jamming cannot occur if the jam ratio is greater than 3.0, and normally does not occur when the jam ratio is less than 2.8. Jam ratios between 2.8 and 3.0 should be avoided, since this is a "danger zone" where jamming is likely to occur. Consider three equal-sized cables in a conduit sized to the NEC 40% fill limit. The jam ratio can be calculated as follows:

$$A_{cables} = 3\,\pi\left(\frac{OD_{cable}}{2}\right)^2 = \frac{3\,\pi}{4}\left(OD_{cable}\right)^2 \qquad \text{Eq. 2}$$

$$A_{conduit} = \pi\left(\frac{ID_{conduit}}{2}\right)^2 = \frac{\pi}{4}\left(ID_{conduit}\right)^2 \qquad \text{Eq. 3}$$

$$\frac{3\,\pi}{4}\left(OD_{cable}\right)^2 = 0.40\left(\frac{\pi}{4}\right)\left(ID_{conduit}\right)^2 \qquad \text{Eq. 4}$$

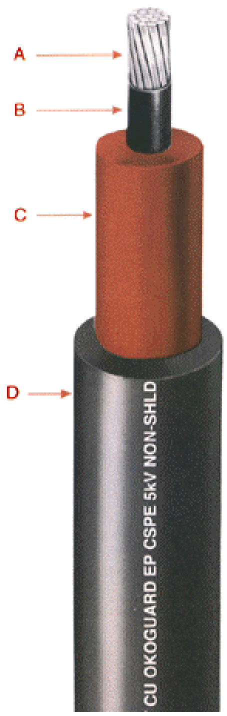
$$\left(OD_{cable}\right)^2 = \frac{0.40}{3}\left(ID_{conduit}\right)^2 = 0.133\left(ID_{conduit}\right)^2 \qquad \text{Eq. 5}$$

$$OD_{cable} = \sqrt{0.133\,(ID_{conduit})^2} = 0.365\,ID_{conduit} \qquad \text{Eq. 6}$$

$$j = \frac{ID_{conduit}}{0.365\,ID_{conduit}} = 2.740 \qquad \text{Eq. 7}$$

This jam ratio is slightly less than the 2.8 threshold. To avoid jam ratios in the "danger zone," conduit fills between 1/3.0 (or 33.3%) and 1/2.8 (or 35.7%) should be avoided.

A minimum bending radius must be determined according to the cables being pulled. *Shielded* cables contain a metallic layer just beneath the jacket to distribute evenly the electric field gradient throughout the insulation. This shield is sometimes provided in the form of a thin copper tape, or *tape shield*, which is grounded, usually at one of the cable terminations. Another shielding option is a *concentric neutral*, in which strands of copper conductor are placed just beneath the jacket. These strands are used for the neutral in a four-wire system. Typically, in three-phase circuits, each cable has enough copper strands in its concentric neutral to make up one-third of the system neutral. Tape-shielded cables require a separate neutral conductor in addition to the phase conductors. Shielding is required with power cables above 5 kV, is optional with the 5kV class, and is seldom used with cables below 5 kV. Control and instrumentation cable is often shielded to prevent voltages from being induced on the conductor.



A - Conductor
B - Semiconductor layer
C - Ethylene propylene rubber (EPR) insulation
D - Jacket

FIGURE 1
Unshielded Cable
Photo courtesy of The Okonite Co.

⇐ FIGURE 2

A - Conductor
B - Inner semiconductor layer
C - Ethylene propylene rubber (EPR) insulation
D - Outer semiconductor layer
E - Tape shield
F - Jacket

FIGURE 3 ⇒

A - Conductor
B - Inner semiconductor layer
C - Ethylene propylene rubber (EPR) insulation
D - Outer semiconductor layer
E - Concentric neutral
F - Jacket

FIGURE 2
Copper Tape
Shielded Cable
Photo courtesy of The Okonite Co.

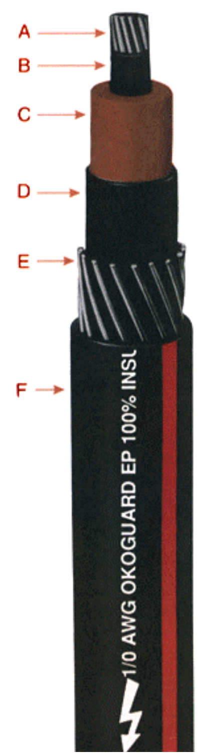


FIGURE 3
Concentric Neutral
Shielded Cable
Photo courtesy of The Okonite Co.

Unless otherwise specified by the cable manufacturer, a minimum bending radius of five times the cable outside diameter can be assumed for unshielded cables. Shielded cables are assumed to have a minimum bending radius of 12 times the cable outside diameter. Of course, using information from the manufacturer is preferable to these rules of thumb. Bending the cable at a radius less than the minimum bending radius can damage the insulation, leading to cable failure.

If more than the four 90° bends allowed by the NEC are required in the raceway, *pullboxes* such as the one shown in Fig. 4 should be installed.

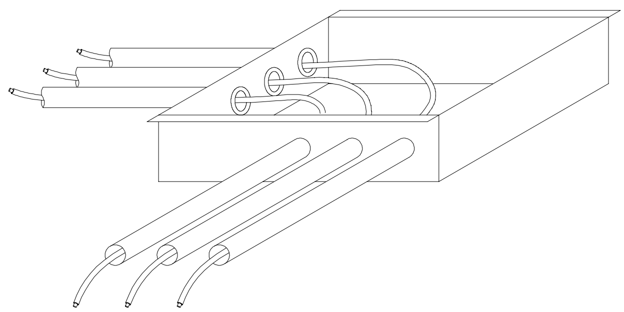


FIGURE 4
Pullbox in Conduit Raceway

A pullbox is a piece of hardware with a removable cover that is inserted in the conduit raceway. Cable is pulled into the pullbox and out through the removable cover. Then the cable is pulled back into the conduit to the next pullbox or to the end of the raceway. This effectively allows a long pull with many bends to become two or more shorter pulls with fewer bends.

The pullbox shown in Fig. 4 shows a 90° change of direction in the conduit. Pullboxes also can be built for straight-through pulls, or for U-pulls where a 180° change in direction is needed. Sizing of pullboxes is governed by the NEC.

The width of a pullbox for a straight-through pull is determined by the size of the largest conduit and by the space required by the locknuts and bushings, which secure the conduit to the box. The length cannot be less than eight times the diameter of the largest conduit.

When an angle or U-pull is required, the minimum length requirement used for straight pulls also determines the minimum width. Additionally, the inside length of the pullbox cannot be less than six times the largest conduit plus the sum of the diameters of all additional conduits entering the box. In the case of an angle pull, the diagonal distance between the centers of the conduits where they enter and exit the box must be at least six times the conduit diameter. The wall of the pullbox with the most conduit penetrations must be used to size the box. Examples of pullbox sizing are shown in Fig. 5.

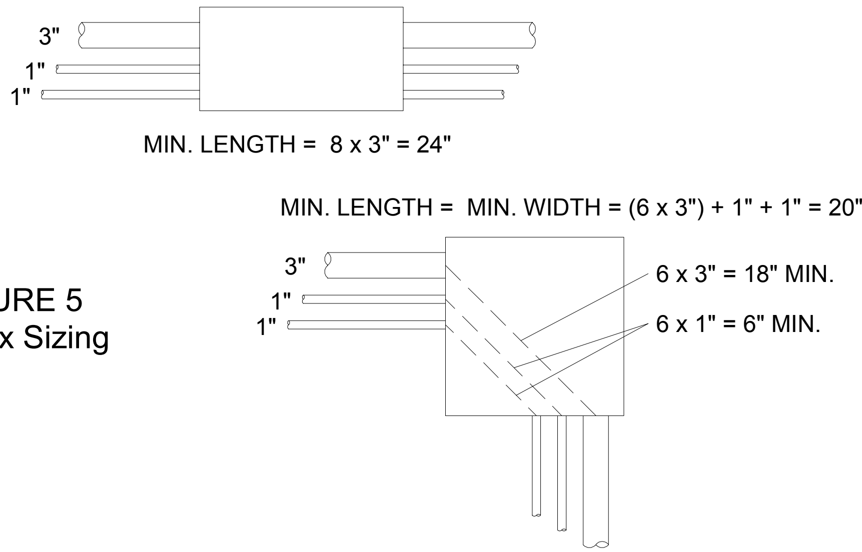


FIGURE 5
Pullbox Sizing

Pulling cables through a conduit raceway requires skill and care. A variety of basket grips and pulling eyes are available to attach the pulling rope to the cable(s). Proper pulling grip selection depends on the required pulling tension, and is crucial to prevent cable and equipment damage and injury to installation personnel. Two particular quantities must be calculated before cable is pulled into conduit and carefully monitored during the pulling process. These quantities are *pulling tension* and *sidewall pressure*. Pulling tension is the tensile force that must be applied to the cable to overcome friction as the cable is pulled through the raceway. Sidewall pressure is the crushing force applied to the cable by the conduit in the radial direction as the cable is pulled around a bend. Exceeding the maximum allowable pulling tension is seldom a problem for large power cable since that maximum value is usually quite large (in the thousands of pounds). Control and instrument cables, however, tend to have much lower maximum allowable pulling tensions. It is not uncommon to exceed the maximum allowable pulling tension for these types of cables in long raceways. Sidewall pressure is usually the controlling factor when designing conduit raceways for large power cables.

When calculations show that the maximum allowable pulling tension for a cable or group of cables will be exceeded, several measures can be taken to reduce the required pulling tension. One is to reduce the coefficient of friction between the conduit and the cable. Various types of lubricants exist for this purpose, each reducing the coefficient of friction to a specific value. The coefficient of friction can range from more than 0.5 for dry cable to less than 0.2 for well-lubricated cable. Suitable lubricants include wire soaps, waxes, and synthetic polymer compounds. Many installers prefer the polymer compounds because the soaps and waxes leave a residue on the cable which can be messy and, in some cases, combustible. If the calculated tensions are unacceptably high, it may be necessary to select a different lubricant with a lower coefficient of friction to reduce the required pulling tension to an acceptable value.

If the coefficient of friction cannot be reduced sufficiently, reducing the length or changing the direction of the pull may be successful. Installing pullboxes in the raceway can reduce the length of the pull. Cable is pulled from pullbox to pullbox, so if a pullbox is installed midway in a 300 foot run of conduit, the installation becomes two pulls of 150 feet each. If the conduit is encased in an underground duct bank, a *manhole* is needed to serve as a pull point. Unless the geometry of the raceway is symmetric, different tensions will be required to pull cable from end A to end B and from end B to end A. Pulling calculations should be done for pulling in both directions to determine which direction of pull will require the lesser tension.

When more than one cable is pulled in a conduit, a *weight correction factor* (w_c) is needed to account for the additional friction forces that exist between the cables. The most common case is to install three cables of the same size in a conduit for a three-phase power circuit. The weight correction factor depends on whether the cables are arranged in a triangular or cradled configuration. An illustration of these two configurations is shown in Fig. 6.

FIGURE 6
Cradled and Triangular Configurations

In the triangular configuration, the top cable may experience very little tension compared to the other two. In the cradled configuration, the middle cable experiences more friction forces than the other two cables. To be conservative, assume that the total required tension is distributed equally between two of the three cables.

Weight correction factors for cradled and triangular configurations are calculated using the formulas shown in Eqs. 8 and 9, respectively.

$$w_c = 1 + \frac{4}{3}\left(\frac{OD_{cable}}{ID_{conduit} - OD_{cable}}\right)^2 \qquad \text{(cradled)} \qquad \text{Eq. 8}$$

$$w_c = \frac{1}{\sqrt{1 - \left(\frac{OD_{cable}}{ID_{conduit} - OD_{cable}}\right)^2}} \qquad \text{(triangular)} \qquad \text{Eq. 9}$$

Pulling Tension

Pulling tension is the tensile force that must be applied to the cable to overcome friction as the cable is pulled through the raceway. The tension required to pull a cable or group of cables through a straight section of conduit is expressed in Eq. 10.

$$T = w_c \mu L W \qquad \text{Eq. 10}$$

where T = pulling tension in pounds
w_c = weight correction factor (dimensionless)
μ = coefficient of friction (dimensionless)
L = length of straight section of conduit in feet
W = weight of cable in pounds per foot

The tension required to pull a cable through a horizontal bend is shown in Eq. 11.

$$T_o = T_i e^{w_c \mu \theta} \qquad \text{Eq. 11}$$

where T_o = tension out of the bend in pounds
T_i = tension coming into the bend in pounds
e = natural logarithm base
w_c = weight correction factor (dimensionless)
μ = coefficient of friction (dimensionless)
θ = bend angle in radians

When pulling cable through a vertical bend, the tension is calculated as for a horizontal bend, then the cable weight in the vertical section is either added (if the cable is pulled uphill) or subtracted (if the cable is pulled downhill) from the required tension. When pulling cable downhill, a negative tension can be calculated. This indicates that brakes must be applied to the cable supply reel to prevent the cable from spooling too quickly.

Sometimes physical constraints require that the cable be pulled in one specific direction. If no such constraints exist, an attempt should be made to pull the cable in the direction requiring the lesser pulling tension.

Sidewall Pressure

Sidewall pressure is the crushing force applied to the cable by the conduit in the radial direction as the cable is pulled around a bend. It is a function of pulling tension and bending radius of the conduit, and differs according to the arrangement of the cables in the conduit. Three-conductor cables, as shown in Fig. 7, behave like three single conductor cables lying in a triangular configuration.

A - Conductor
B - Inner semiconductor layer
C - Ethylene propylene rubber (EPR) insulation
D - Extruded semiconducting EPR insulation screen
E - Phase identification tape
F - Copper grounding conductor
G - Uncoated copper shield
H - Fillers and binder tape
J - Jacket

FIGURE 7
Three-Conductor Cable
Photo courtesy of The Okonite Company.

The formulas to calculate sidewall pressure for various cable arrangements when the conduit bend radius is r are shown in Eqs. 12 through 14.

$$P = \frac{T_o}{r}$$ (one single-conductor cable) Eq. 12

$$P = \frac{3w_c - 2}{3}\left(\frac{T_o}{r}\right)$$ (three single-conductor cables cradled) Eq. 13

$$P = \frac{w_c}{2}\left(\frac{T_o}{r}\right)$$ (three single-conductor cables triangular or one three-conductor cable) Eq. 14

Sidewall pressure is typically the controlling factor in raceway design for large power cable. Sufficiently large conduit bending radii must be used, and pulling tension may need to be limited to values well below the maximum allowable pulling tension for the cable to keep the sidewall pressure below the maximum allowed by the cable.

Design Examples

Consider the conduit raceway layout shown in Fig. 8.

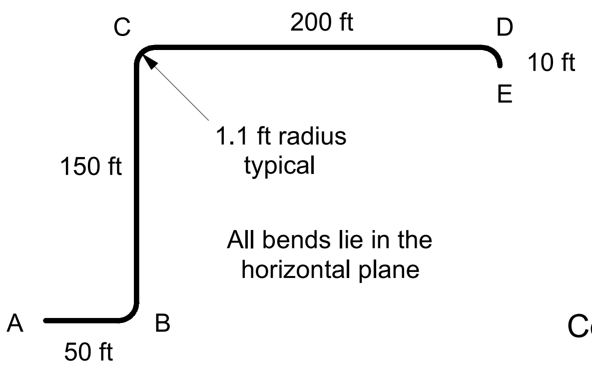


FIGURE 8
Conduit Design Example #1

All bends lie in the horizontal plane. Three single-conductor 500 kcmil tape-shielded 5 kV power cables need to be pulled through the conduit. The cable has a 1.10-inch outside diameter and weighs 1.83 pounds per foot. A coefficient of friction of 0.25 is anticipated. The raceway can be designed as follows:

First, the conduit must be sized. The cross-sectional area of the three cables is

$$A_{cables} = 3\left[\pi\left(\frac{1.10}{2}\right)^2\right] = 2.851\ in^2 \qquad \text{Eq. 15}$$

The required cross-sectional area of the conduit to yield a 40% fill, which is the maximum fill allowed by the NEC, is

$$A_{conduit(40\%)} = \frac{2.851}{0.40} = 7.128\ in^2 \qquad \text{Eq. 16}$$

The corresponding diameter to this cross-sectional area is

$$ID_{conduit(40\%)} = \sqrt{\frac{4\ (7.128)}{\pi}} = 3.013\ in \qquad \text{Eq. 17}$$

This indicates that a nominal 3-inch conduit can be used. Before settling on a 3-inch conduit, the jam ratio must be checked. The jam ratio in the 3-inch conduit is

$$j_{3"} = \frac{3}{1.10} = 2.727 \qquad \text{Eq. 18}$$

This value is close to the "danger zone" of $2.8 \le j \le 3.0$ where jamming can occur. Before the engineer can allow this jam ratio and proceed with the design of the raceway, another issue must be addressed. When a conduit is bent, a slight flattening occurs, transforming the circular cross-section of the conduit into an ellipse. The major axis of the ellipse is typically 5% larger than the diameter of the circular cross-section. This enlarged effective diameter yields a different jam ratio in the bends of the raceway. This jam ratio is

$$j_{3''-\text{bends}} = \frac{1.05\ (3)}{1.10} = 2.864 \qquad \text{Eq. 19}$$

This jam ratio is in the "danger zone." Since jamming is most likely to occur in a bend, this conduit size should not be selected. The next larger nominal conduit size is 3½ inches. The cross-sectional area of a 3½-inch conduit is

$$A_{\text{conduit}(3\text{-}1/2'')} = \pi \frac{(3.5)^2}{4} = 9.621 \text{ in}^2 \qquad \text{Eq. 20}$$

The percent fill for the 3½-inch conduit is

$$\%\,\text{fill} = \frac{2.851}{9.621} = 29.6\% \qquad \text{Eq. 21}$$

Next, the jam ratios are checked for the 3½-inch conduit.

$$j_{3\text{-}1/2''} = \frac{3.5}{1.10} = 3.182 \qquad \text{Eq. 22}$$

Since jamming cannot occur when j > 3, this jam ratio is acceptable. Now, the jam ratio is checked in the bends, allowing for a 5% elongation of the conduit's inside diameter.

$$j_{3\text{-}1/2''-\text{bends}} = \frac{1.05\ (3.5)}{1.10} = 3.341 \qquad \text{Eq. 23}$$

This jam ratio is also acceptable, so a 3½-inch conduit will be used.

A minimum bending radius must now be determined for the conduit. The minimum bending radius of the cable is 12 times its outside diameter, or

$$r_{\min} = 12\ (1.10) = 13.2 \text{ in} \qquad \text{Eq. 24}$$

This radius will be assumed for all conduit bends, but may have to be increased if the maximum allowable sidewall pressure is exceeded.

The last term to be calculated before the pulling calculations can be performed is the weight correction factor. Because of the high jam ratio, a cradled cable configuration is assumed.

$$w_c = 1 + \frac{4}{3}\left(\frac{1.10}{3.5 - 1.10}\right)^2 = 1.28 \quad \text{Eq. 25}$$

Now the pulling calculations can be done. First, the calculations will be done to pull the cables from point A to point E. The tension required to pull the cables from point A to point B, using Eq. 10, is

$$T_{A\text{-}B} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) = 87.84 \text{ lb} \quad \text{Eq. 26}$$

Note the multiplier of 3 to account for three cables being pulled. The tension required to pull the cables through bend B, using Eq. 11, is

$$T_B = 87.84\ e^{(1.28)(0.25)(\pi/2)} = 145.20 \text{ lb} \quad \text{Eq. 27}$$

The tension required to pull the cables from point B to point C is

$$\begin{aligned} T_{B\text{-}C} &= (3)\,(1.28)\,(0.25)\,(150)\,(1.83) + T_B \\ &= 263.52 + 145.20 = 408.72 \text{ lb} \end{aligned} \quad \text{Eq. 28}$$

The tension required to pull the cables through bend C is

$$T_C = 408.72\ e^{(1.28)(0.25)(\pi/2)} = 675.66 \text{ lb} \quad \text{Eq. 29}$$

To pull the cables through the next straight section, C to D, the required tension is

$$\begin{aligned} T_{C\text{-}D} &= (3)\,(1.28)\,(0.25)\,(200)\,(1.83) + T_C \\ &= 351.36 + 675.66 = 1027.02 \text{ lb} \end{aligned} \quad \text{Eq. 30}$$

To pull through bend D, the required tension is

$$T_D = 1027.02\ e^{(1.28)(0.25)(\pi/2)} = 1697.76 \text{ lb} \quad \text{Eq. 31}$$

Pulling through the final straight section, D to E, requires

$$\begin{aligned} T_{D\text{-}E} &= (3)\,(1.28)\,(0.25)\,(10)\,(1.83) + T_D \\ &= 17.58 + 1697.76 = 1715.34 \text{ lb} \end{aligned} \quad \text{Eq. 32}$$

A total tension of 1715.34 pounds is required to pull the cables from point A to point E. Next, the pulling calculations are redone, this time pulling from point E to point A. The calculations are as follows:

$$T_{E\text{-}D} = (3)\,(1.28)\,(0.25)\,(10)\,(1.83) = 17.58 \text{ lb} \quad \text{Eq. 33}$$

$$T_D = 17.58\ e^{(1.28)(0.25)(\pi/2)} = 29.07 \text{ lb} \quad \text{Eq. 34}$$

$$T_{D\text{-}C} = (3)\,(1.28)\,(0.25)\,(200)\,(1.83) + T_D = 351.36 + 29.07 = 380.43 \text{ lb} \quad \text{Eq. 35}$$

$$T_C = 380.43\, e^{(1.28)(0.25)(\pi/2)} = 628.89 \text{ lb} \quad \text{Eq. 36}$$

$$T_{C\text{-}B} = (3)\,(1.28)\,(0.25)\,(150)\,(1.83) + T_C = 263.52 + 628.89 = 892.41 \text{ lb} \quad \text{Eq. 37}$$

$$T_B = 892.41\, e^{(1.28)(0.25)(\pi/2)} = 1475.25 \text{ lb} \quad \text{Eq. 38}$$

$$T_{B\text{-}A} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) + T_B = 87.84 + 1475.25 = 1563.09 \text{ lb} \quad \text{Eq. 39}$$

Pulling the cables from point E to point A requires only 1563.09 pounds of tension. Since less tension is required to pull the cables from point E to point A than in the other direction, the preferred pulling direction is from point E to point A. Sometimes, due to physical constraints, it is more difficult or even impossible to pull in one particular direction. If this is the case, the cables need to be pulled in the more feasible direction. If no pulling constraints exist, the direction requiring the lesser pulling tension should be chosen.

Now that it has been determined that the cables will be pulled from point E to point A, sidewall pressures are calculated at each bend. A maximum allowable sidewall pressure of 500 pounds per foot of radius is determined to be

$$P_{max} = (1.10)\,(500) = 550 \text{ lb / ft} \quad \text{Eq. 40}$$

Due to the large jam ratio, a cradled cable configuration is assumed. The following calculations determine the sidewall pressures at each bend:

$$P_D = \frac{3\,(1.28) - 2}{3}\left(\frac{29.07}{1.10}\right) = 16.21 \text{ lb/ft} \quad \text{Eq. 41}$$

$$P_C = \frac{3\,(1.28) - 2}{3}\left(\frac{628.89}{1.10}\right) = 350.65 \text{ lb/ft} \quad \text{Eq. 42}$$

$$P_B = \frac{3\,(1.28) - 2}{3}\left(\frac{1475.25}{1.10}\right) = 822.56 \text{ lb/ft} \quad \text{Eq. 43}$$

The sidewall pressure at bend B is in excess of the maximum allowable. This can be remedied by increasing the bend radius of bend B. The minimum bend radius as to not violate the sidewall pressure limit can be calculated as follows:

$$r_{min} = \frac{(822.56)\,(1.10)}{550} = 1.65\text{ ft} = 19.74\text{ in} \qquad \text{Eq. 44}$$

So, if a 20-inch bend radius is used at bend B, the sidewall pressure there becomes

$$P_{B(20")} = \frac{(3)\,(1.28) - 2}{3}\left(\frac{1475.25}{1.65}\right) = 548.38\text{ lb/ft} \qquad \text{Eq. 45}$$

If only bend B is enlarged to a 20-inch bend radius and the other bends remain at a 13.2-inch bend radius, it is critical that the cables be pulled from point E to point A. Pulling in the reverse direction would violate the maximum sidewall pressure limit at the last bend, probably damaging the cables in the process. To safeguard against pulling the cables in the wrong direction, the engineer may choose to use 20-inch bend radii at all bends. If physical constraints allow for the larger bend radii, using a 20-inch bend radius at each bend is advisable.

Next, consider the conduit raceway layout shown in Fig. 9.

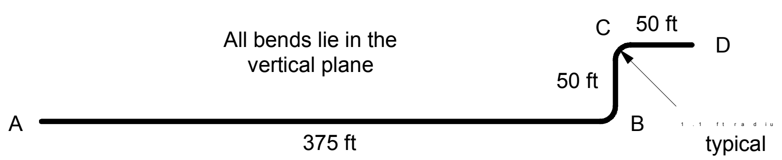


FIGURE 9
Conduit Design Example #2

All bends lie in the vertical plane. As in the last example, three single-conductor 500 kcmil tape-shielded 5 kV power cables will be pulled through the conduit. The cable outside diameter, weight, and coefficient of friction are 1.10 inches, 1.83 pounds per foot, and 0.25, respectively. The same conduit sizing procedure as used in Example #1 determines a 3½-inch conduit size. A minimum bend radius of 13.2 inches and a weight correction factor of 1.28 also will be used.

First, the required tension to pull the cables from point A to point D is calculated.

$$T_{A\text{-}B} = (3)\,(1.28)\,(0.25)\,(375)\,(1.83) = 658.80\text{ lb} \qquad \text{Eq. 46}$$

$$T_B = 658.80\; e^{(1.28)(0.25)(\pi/2)} = 1089.07\text{ lb} \qquad \text{Eq. 47}$$

To determine the tension required to pull the cable uphill through the vertical section B-C, the weight of the cables in that section is added to the tension as calculated by Eq. 10.

$$T_{B\text{-}C} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) + 1089.07 + (3)\,(50)\,(1.83)$$
$$= 87.84 + 1089.07 + 274.50 = 1451.41 \text{ lb} \quad \text{Eq. 48}$$

Note that the cables must be supported by special hangers in the vertical section of conduit to prevent damage to the cables caused by supporting their own weight.

$$T_C = 1451.41\, e^{(1.28)(0.25)(\pi/2)} = 2399.33 \text{ lb} \quad \text{Eq. 49}$$

$$T_{C\text{-}D} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) + 2399.33$$
$$= 87.84 + 2399.33 = 2487.17 \text{ lb} \quad \text{Eq. 50}$$

A total of 2487.17 pounds is required to pull the cables from point A to point D. Next, the tension calculations are redone, this time pulling the cables in the reverse direction.

$$T_{D\text{-}C} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) = 87.84 \text{ lb} \quad \text{Eq. 51}$$

$$T_C = 87.84\, e^{(1.28)(0.25)(\pi/2)} = 145.21 \text{ lb} \quad \text{Eq. 52}$$

The weight of the cables in vertical section C-B is subtracted from the tension as calculated by Eq. 10, since the cables are being pulled downhill.

$$T_{C\text{-}B} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) + 145.21 - (3)\,(50)\,(1.83)$$
$$= 87.84 + 145.21 - 274.50 = -41.45 \text{ lb} \quad \text{Eq. 53}$$

The negative tension indicates that the cable reel must be braked during installation. Assume a braking force sufficient to provide the equivalent of 50 feet of horizontal pulling tension (87.84 lb) developed at the entrance to bend B.

$$T_{\text{entering B}} = (3)\,(1.28)\,(0.25)\,(50)\,(1.83) = 87.84 \text{ lb} \quad \text{Eq. 54}$$

$$T_B = 87.84\, e^{(1.28)(0.25)(\pi/2)} = 145.21 \text{ lb} \quad \text{Eq. 55}$$

$$T_{B\text{-}A} = (3)\,(1.28)\,(0.25)\,(375)\,(1.83) + 145.21$$
$$= 658.80 + 145.21 = 804.01 \text{ lb} \quad \text{Eq. 56}$$

When pulling the cables from point D to point A, only 804.01 pounds of tension is required.

The last step of the design is to verify that the sidewall pressure is less than the 550 pounds per foot of bend radius maximum. The tension out of each bend is the same (145.21 lb), so the sidewall pressure, assuming a cradled cable configuration, is

$$P_C = P_B = \frac{3\,(1.28) - 2}{3}\left(\frac{145.21}{1.10}\right) = 80.97\,\text{lb/ft} \qquad \text{Eq. 57}$$

This value is well below the maximum allowable sidewall pressure, so a 1.10-foot bending radius is acceptable.