

INSTALLATION PRACTICES FOR CABLE RACEWAY SYSTEMS

**ISO 9000-1994
CERTIFIED**



**THE
OKONITE
COMPANY**

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INSTALLATION PRACTICES

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INTRODUCTION

The Okonite Installation Practices Manual has been developed to aid in the proper design and installation of cable raceway systems. In determining the best possible design and installation, many parameters must be considered and weighed against each other. These parameters and installation techniques are explained within this manual. A raceway system should be designed with a knowledge of proper installation techniques so as not to create a situation which would cause these techniques to be disregarded. A system designed without regard for the installation methods may be virtually impossible to install.

The manual is divided into five parts: Part I explains the recommended procedures which should be pursued when determining the correct conduit or duct size for a given cable or group of cables. Tables are included as a handy aid which should eliminate some routine calculations.

Part II described the limitations and pertinent formulas required to design an allowable pull for a cable raceway system. Pulling devices and cable pulling parameters are explained along with their limitations which must not be exceeded when a properly designed system is desired. Again, tables are included for ease of calculation. Pulling precautions are listed so that the designer is alerted to these limitations during design.

Several examples of typical duct pulls are included in Part III. Examples include horizontal as well as vertical runs. Each example is calculated in two different pulling directions. In some examples, large differences in tension are demonstrated depending upon the direction chosen.

Part IV describes in greater detail the choices and considerations to be made when a cable raceway system is designed. Conduit bends, risers, junction boxes, manholes, conduits and cable trays are among those topics examined. Both the cable designer and installer should be aware of options and potential problem areas when the best possible, most economical cable raceway system is desired.

INSTALLATION PRACTICES FOR CABLE RACEWAY SYSTEMS

Installation methods and procedures are described in Part V. Correct procedures for conduit installation including feeding and pulling cables are included. Precautions and prohibitions are stated to make the installation as problem-free as possible.

SAFETY

The discussions and cable handling recommendations in this manual, must be supported using appropriate safety rules, procedures and regulations. Cable handling requires various techniques and tools to prep the cable for pulling, splicing and terminating. During installation, cables are moving, the cable weight is being supported and conveyed, cable reels are turning and pulling lines and equipment are under mechanical tensions. Installation crews are expected to be trained in work safety habits and cable handling techniques. All equipment, manual as well as motor driven, must be in proper working order.

METHODS for DETERMINING
CONDUIT SIZES

Conduits or ducts should be of adequate size as determined by the maximum recommended percentage fill of conduit area. The following tables express the limitations as specified by the National Electrical Code.

For groups or combinations of cables, the National Electrical Code requires that the conduit or duct be of such size that the sum of the cross-sectional areas of the individual cables will not be more than the percentage of the interior cross-sectional area of the conduit or duct as shown in the following tables:

Table 1
Maximum Cable Cross-Sectional Areas as a
Percentage of Internal Conduit or Duct Area

	Number of Cables		
	1	2	3 or More
Max % Fill	53	31	40

Table 2
Dimensions of Conduit

Nominal Conduit Inches	Internal Diameter Inches	Area Square Inches
1/2	0.622	0.30
3/4	0.824	0.53
1	1.049	0.86
1 1/4	1.386	1.50
1 1/2	1.610	2.04
2	2.067	3.36
2 1/2	2.469	4.79
3	3.068	7.38
3 1/2	3.548	9.90
4	4.026	12.72
5	5.047	20.00
6	6.065	28.89

Table 3
Maximum Allowable Diameter (in inches) of
Individual Cables in Given Size of Conduit
(Based on % Fill Requirements in Table 1)

Non-Metallic Jacket Cable
— All Cables of Same Outside Diameter

Nominal Size Conduit	Number of Cables Having Same O.D.			
	1	2	3	4
1/2	0.453	0.244	0.227	0.197
3/4	0.600	0.324	0.301	0.260
1	0.763	0.412	0.383	0.332
1 1/4	1.010	0.542	0.504	0.436
1 1/2	1.173	0.633	0.588	0.509
2	1.505	0.812	0.754	0.653
2 1/2	1.797	0.970	0.901	0.780
3	2.234	1.206	1.128	0.970
3 1/2	2.583	1.395	1.296	1.121
4	2.930	1.583	1.470	1.273
5	3.675	1.985	1.844	1.595
6	4.416	2.385	2.215	1.916

Example: For 3-1/C cables where the O.D. of 1/C is 1.47", use column "3", the conduit size must be 4" or larger.

For quick selection of correct conduit size (three single or multiconductor cables) refer to Appendix 2.

DESIGN LIMITS AND FORMULAE

Pulling Tension Limits

1. Pulling Eyes & Bolts

The maximum pulling tension on copper conductors or for full hard aluminum shall not exceed .008 times the circular mil (CM) area when pulled with a pulling eye attached to each conductor. The maximum tension on 3/4 hard aluminum conductors shall not exceed .006 times the CM area with a pulling eye attached to each conductor.

Eq. 1: $T_m = .008 \times n \times \text{CM}$ for copper or full
hard aluminum

$T_m = .006 \times n \times \text{CM}$ for 3/4 hard aluminum
conductors

NOTE: In pulling three single conductors of equal size that are not triplexed, a value of n equal to 2, rather than 3, should be used since two of the conductors may sustain the total pulling tension. When more than three single conductors of equal size are pulled in parallel, the maximum tension should be limited to 60% of value determined by the equation, with n representing the total number of conductors.

When pulling conductors of different sizes, consult manufacturer.

When pulling using a pulling eye, the maximum tension for a 1/C cable should not exceed 6000 lbs. The maximum tension for 2 or more conductors shall not exceed 10000 lbs.

2. Basket Grip

The maximum tension on copper or aluminum conductors shall not exceed 1000 lbs. per grip or the value calculated by Eq. 1 above, whichever is smaller. The limit applies to a single conductor cable, a multiconductor cable with common overall jacket, two or more twisted cables, or paralleled cables with one basket grip applied to the single cable or to the group.

NOTE: Same as note under "Pulling Eye".

3. Other Pulling Devices

For pulling limitations using devices other than pulling eyes and basket grips, the manufacturer of these devices should be consulted. However, the limitations of Equations 1 and 2 above should not be exceeded.

4. Sidewall Pressure

- (a) The sidewall pressure (P) in general is defined as the tension out of a bend expressed in pounds divided by the inside radius of the bend expressed in feet. Equation 2a and 2b are for the “worst case” cable.

Eq. 2: $P = \frac{T_o}{r}$ (One Single Cable or Multi-Conductor)

2a: $P = \frac{(3c - 2)}{3} \frac{T_o}{r}$ (Three Single Cables -Cradle Configuration)

2b: $P = \frac{cT_o}{2r}$ (Three Single Cables -Triangular Configuration)

P = Sidewall pressure, lbs per foot of radius

T_o = Tension (leaving the bend), pounds

c = Weight correction factor (Eq. 5 and 6)

r = Inside radius of conduit in feet (Table 4).

Table 4
Rigid Conduit and Elbow Data

Conduit Size	Area in Sq. In.	Conduit ID in inches	Elbow Centerline Radius in Inches								
			Std.	12	15	18	24	30	36	42	48
			Inside Radius - feet								
1/2	0.30	0.622	0.33								
3/4	0.53	0.824	0.34								
1	0.86	1.049	0.44	0.96	1.21	1.46	1.96	2.46	2.96	3.46	3.96
1 1/4	1.50	1.380	0.55	0.94	1.19	1.44	1.94	2.44	2.94	3.44	3.94
1 1/2	2.04	1.610	0.62	0.93	1.18	1.43	1.93	2.43	2.93	3.43	3.93
2	3.36	2.067	0.71	0.91	1.16	1.41	1.91	2.41	2.91	3.41	3.91
2 1/2	4.79	2.469	0.77		1.15	1.40	1.90	2.40	2.90	3.40	3.90
3	7.38	3.068	0.96			1.37	1.87	2.37	2.87	3.37	3.87
3 1/2	9.90	3.548	1.10			1.35	1.85	2.35	2.85	3.35	3.85
4	12.72	4.026	1.17				1.82	2.33	2.83	3.33	3.83
5	20.00	5.047	1.79					2.29	2.79	3.29	3.79
6	28.89	6.065	2.25						2.75	3.25	3.75

- (b) The maximum sidewall pressure that modern cables can withstand without causing incipient damage is based on the number of cable pulled together and the size of the conductors. These recommended limits are tabulated in Table 5.

Table 5
Maximum Sidewall Pressure - P_{MAX}
(lbs per ft. of radius)

Power Cables	Conductor Size	
	≤ 8AWG	> 8AWG
One Single Cable	300	500
Two or More single conductors (parallel or plex)	500	1000
Multiconductor (under common jacket)	500	1000
Multiconductor Control Cable	All Sizes	
One Cable	500	
Two or More Cables	1000	
Instrument Cable		
Single Pair	300	
Multipair	500	

5. Minimum Bending Radii for Installation

- (a) Provided the maximum sidewall pressures have not been exceeded, the following shall be the minimum bending radii for installation and training of cable.

Table 6
Cables Without Metallic Shielding or Armor*

Thickness of Conductor Insulation	Overall Diameter of Cable - Inches		
	1.000 and less	1.001 to 2.001	2.001 and over
inch	Minimum Bending Radius as a Multiple of Cable Diameter		
0.169 and less	4	5	6
0.170 - .310	5	6	7
0.311 and over	—	7	8

*For 2.4 kV non shielded cables the minimum bending radius multiplier is 8 per NEC 300.34.

Table 7
Cables With Metallic Shielding or Armor

	Power	Control
Minimum Bending Radius as a Multiple of Cable Diameter		
Armored, flat tape or wire type	12	12
Armored, smooth aluminum sheath, up to		
0.75 inches cable diameter.	10*	10*
0.76 to 1.5 inches cable diameter	12	12
over 1.5 inches cable diameter.	15	15
Armored, corrugated sheath or		
interlocked type	7***	7
with shielded single conductor	12	12
with shielded multi-conductor	**	**
Non-armored, flat or corrugated		
tape shielded single conductor	12	12
tape shielded multi-conductor	7	7
LCS with PVC jacket	15	15
Non-armored, flat strap shielded	8	—
Non-armored, wire shielded.	see table 6	—
Non-armored, concentric neutral	8	
*with shielded conductors 12		
** 12 times single conductor diameter or 7 times overall cable diameter whichever is greater.		
*** Also applies to 2.4kV non-shielded cables.		
LCS = longitudinally applied corrugated shield		

6. Jam Ratio (Three Single Conductors)

Jam Ratio is defined for three single conductors of equal diameter as the ratio of the conduit ID to the single conductor cable OD. The reason for concern with the jam ratio is that damage could occur to one or more of the conductors due to their jamming (wedging) in the pipe. Jamming is not likely to occur when D/d > 3.2 and normally does not occur when D/d < 2.8. A 40% conduit fill gives a jam ratio of 2.74. The critical range of the ratio of the conduit diameter to the cable diameter to avoid is 2.8 to 3.2.

Eq. 3: J.R. = $\frac{\text{Conduit ID}}{\text{Cable OD}}$

(See Table 4 for conduit ID)

7. Pulling Tension Calculations

(a) Straight Section — For a straight section, the pulling tension is equal to the length of the straight run multiplied by the weight per foot of the cable, the coefficient of friction, and the weight correction factor.

Eq. 4: $T = L w f c$

T = Total Pulling Tension of Straight Run in lbs.

L = Length of Straight Run in feet.

w = Weight of Cable in lbs. per ft.

f = Coefficient of Friction

c = Weight Correction Factor

Coefficient of friction

Dry cable or ducts:	0.5
Well lubricated cable or ducts:	0.35

Weight correction factor —

This takes into account the added frictional forces that exist between triangular or cradle arranged cables resulting in a greater pulling tension than when pulling a single cable.

Values of c: (For Three Single Conductors — same diameter & weight)

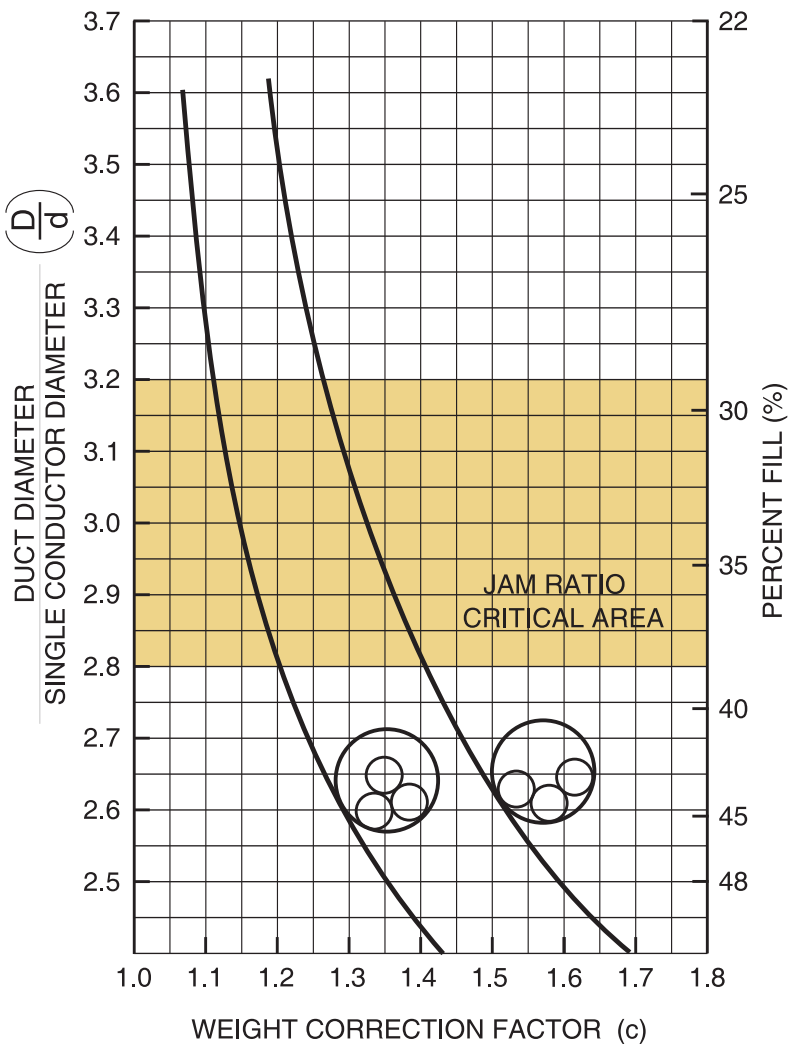
Eq. 5: Cradled: $c = 1 + \frac{4}{3} \left[\frac{d}{D - d} \right]^2$

Eq. 6: Triangular: $c = \frac{1}{\sqrt{1 - \left[\frac{d}{D - d} \right]^2}}$

D = Conduit I.D.

d = Single conductor cable O.D.

Weight Correction Factors
3 Single Conductors in Duct



For 40% fill and less, cables are likely to be in cradled configuration.

Triplexed cables assure the triangular configuration.

(b) Tension Out of a Horizontal Bend

Eq. 7: $T_o = T_{in} e^{cfa}$

T_o = Tension out of bend

T_{in} = Tension coming into bend

c = weight correction factor (see above)

f = Coefficient of friction (see above)

a = angle of change of direction in radians
produced by the bend

This is a simplified equation which ignores the weight of the cable. It is very accurate where the incoming tension at a bend is equal to or greater than 10 times the product of cable weight per foot times the bend radius expressed in feet.

Eq. 8: $T_{in} < 10 w r$ (terms are all defined above)

If T_{in} is less than $10wr$, the following equation should be used for precise calculations. (These cases occur where light tensions enter large radii bends.)

Eq. 9: $T_o = T_{in} \frac{e^{cfa} + e^{-cfa}}{2} + \sqrt{(T_{in})^2 + (wr)^2} \left(\frac{e^{cfa} - e^{-cfa}}{2} \right)$

In general, factory bends, both standard and sweep elbows, will not require use of equation 9.

Values of e^{cfa} For Conduit of Raceway Bends				
cf	30°	45°	60°	90°
0.30	1.17	1.27	1.37	1.60
0.35	1.20	1.33	1.45	1.74
0.40	1.23	1.37	1.52	1.88
0.50	1.30	1.48	1.69	2.20
0.60	1.37	1.60	1.88	2.57
0.85	1.48	1.80	2.20	3.25

8. Pulling Precautions

- (a) The direction of pulling cable can make a very substantial difference in pulling tensions and sidewall pressures depending on the exact configuration of conduit and bends.
- (b) The limitation of four (4) ninety degree bends or equivalent per the National Electrical Code cannot be completely relied upon to guarantee safe maximum pulling tensions and sidewall pressures. Pulling tensions should be calculated in both directions to verify that pulling limitations have not been exceeded.
- (c) The minimum allowable bending radius will be determined by the largest radius required to meet either the minimum training value or minimum allowable radius due to sidewall pressure during or after installation.
- (d) The effect of sidewall pressure must be considered when cables are hanging down vertically around a conduit bend. Supporting the cable around tight radius bends, such as condulets, should be avoided. Considerable pressure can be exerted by the total weight of the cable in the vertical portion and sidewall pressures in this region should be limited to 120 lbs./ft. of bend radius under static loading.
- (e) Although rather complex formulas have been developed for bends in a vertical plane, little accuracy is sacrificed in using equations 7 or 9 for calculating tensions out of these bends.

9. Installing Cable in Tray

As indicated in Part IV, SYSTEM CONSIDERATIONS, similar design limits for maximum allowable pulling tensions, sidewall pressures, and minimum allowable bending radii apply to cables installed in cable tray as described for cables installed in conduits.

Based on field data, a simplified method for calculating pulling tensions and sidewall pressures may be used for cables to be installed in tray if the following assumptions are satisfied.

- 1. Rollers are mounted over the tray and supported by the shoulders of the tray, properly spaced to prevent the cable from touching the bottom of the tray.
- 2. The rollers or sheaves are free turning with a low coefficient of friction.

3. Where the tray changes direction sheaves are employed with radii sufficiently large to satisfy maximum allowable sidewall pressure limits and minimum bending radii requirements.
- (a) If these conditions are met the pulling tension for horizontal sections of tray can be calculated as follows:

$$T = Lwf$$

L = total length of run

w = weight of cable per foot (all conductors)

f = coefficient of friction = 0.15

NOTE: Field data indicates that an effective coefficient of 0.15 will account for the low rolling friction coefficients of well designed and lubricated rollers and sheaves in good operating condition.

This equation will not account for tension developed when the cable changes elevation, as in a vertical section, nor will it account for the tension that may be developed in pulling cable from a reel. These tensions must be calculated separately.

For changes in elevation the methods illustrated in Part III, EXAMPLE CALCULATIONS, may be used. For pulling on a slope the coefficient, f, of 0.15 applies if the conditions outlined in (1) through (3) are satisfied. For vertical sections the weight of the cable, w, applies.

- (b) Tension at Cable Reel:

Since cable trays are elevated above floor level, it is common practice to mount the cable reel or reels at floor level and feed the cable up to and on the cable tray in making an installation. Unless cable slack is provided at the reel either by manpower or by a drive mechanism, tension will be developed in the cable as it is removed from the reel. This tension should be taken into account in calculating the total tension developed during installation. The following equation is recommended:

$$T_r = 25 w$$

T_r = tension in cable at reel

w = weight of cable per foot (all conductors)

This equation is based on the tension required to pull 50 feet of cable in a straight, horizontal section of conduit assuming

an effective coefficient of friction (basic coefficient of friction (f) multiplied by the weight correction factor (c) of 0.5).

(c) Tension in Vertical Section:

If cable reel is mounted at floor level directly below the starting point of the cable tray installation, the tension developed between reel and tray must be included in the calculations and is given by the following:

$$T_w = wL$$

T_w = tension due to cable weight

w = weight of cable per foot (all conductors)

L = length of cable between reel and tray

If the cable reel is mounted above floor level, as on the bed of a truck, this component of tension can be reduced. In some cases the cable may be mounted below the tray but at some distance from the starting point of the pull. Theoretically a more sophisticated method could be employed to calculate this component of tension. However, the complexity of the procedure and the uncertainty of parameters does not warrant such an approach. It is recommended that the tension be calculated as though the cable were in a vertical configuration, with the height taken as the vertical distance between cable reel and tray.

(d) Spacing of Rollers:

The maximum required spacing of rollers along the cable tray route will vary with the cable weight, the tension in the cable, the cable construction, and the height of the rollers above the tray bottom. Near the end of the pull, where the tension is approaching the highest value, the spacing can be greater than at the beginning of the pull, where the tension is much lower.

If vertical clearance permits, roller mounting brackets can be fashioned to provide considerable sag clearance between cable and tray, thus extending maximum allowable spacing between rollers.

If one assumes a perfectly flexible cable construction, the following expression can be used as an approximation in determining the spacing interval:

$$s = \sqrt{\frac{8hT}{w}}$$

s = distance between rollers in feet

h = height of top of roller above tray bottom in feet

T = tension in pounds

w = weight of cable per foot

NOTE: The height should be taken as the distance from the top surface of the roller on which the cable bears to the upper surface of the tray bottom.

This equation will give a conservative result, particularly for armored cable, assuming the value of T is correctly calculated.

In general it is not practical to establish a large number of different spacings along the tray route. It is recommended that a maximum number of three different intervals be used and then only for the longer runs. It is also recommended that surplus rollers be available should the calculated spacing prove to be excessive.

Whenever possible, a length of cable should be used to determine maximum spacing permissible in the absence of tension. This will serve as a check against the equation, and provide a means for adjusting the calculation of the total number of rollers required.

(e) Bends in Cable Tray

Unlike cables pulled around bends in conduit or duct, bends around free turning sheaves are not treated as tension multipliers. A multiplying affect does not occur since the surface of the sheave(s) turns with the cable. The coefficient of friction (f) for a free turning, well lubricated sheave is assumed to approach zero. Therefore, e^{cfa} is essential unity. Although no multiplying affect is assumed at bends in tray installations, an increase in tension is sometimes necessary to account for the force required to bend the cable around the sheave.

This tension adder is usually necessary for heavy, less flexible cable. Experience has indicated that a 100 to 150 pound adder is typical for a 3/C 15 kV 500 kcmil copper conductor, metallic sheathed cable. For longer pulls having

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several bends, this adder could become significant especially with respect to sidewall pressure limitations.

EXAMPLE CALCULATIONS

In the following examples it is assumed that rigid conduit is to be installed above grade.

Basic coefficient of friction, f , is assumed to be .35 (for one cable in straight section of lubricated conduit).

Maximum sidewall pressure due to static loading after installation is 120 lbs. per foot of bend radius for the worst case cable.

All bends equal 90 degrees.

Cable Construction

One conductor cable, 500 kcmil copper, .065" insulation, .065" jacket.

Net weight per foot = 1.83 lbs.

OD = overall diameter = 1.10 inches = d

Maximum pulling tension using pulling eye: $.008 \times 500,000 \text{ cmils} = 4000 \text{ lbs./cond.}$ For three conductors: $4000 \times 2 = 8000 \text{ lbs.}$

If basket grips are used, the max. pulling tension is 1000 lbs./conductor for each of 2 conductors. See note on Pg. 3 when pulling more than one conductor.

NOTE: The maximum allowable pulling tension during installation may be limited by the values given for pulling eye or basket grip. However, the maximum tension may be limited by the sidewall pressures developed in pulling cable around a bend. It is the lowest value of tension that will control.

If 3" nominal conduit size is used:

actual ID = 3.068" = D

Add 5% for flattening at bends = 3.221" = D'

Percentage fill = 38.6%

Jam Ratio in conduit = 2.789

Jam Ratio in bend = $D/d = 3.221/1.10 = 2.93$

NOTE: Jam ratio is in the danger area. Use $3\frac{1}{2}$ " conduit if field bending is contemplated. Where triplexed cable is used jamming is not a problem.

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3 1/2" Conduit:

Actual ID = 3.548" = D

Add 5% for flattening at bends = 3.715" = D'

Percentage fill = 28.8% based on actual ID

Jam ratio in conduit = 3.548/1.10 = 3.225

Jam ratio at bend = 3.725/1.10 = 3.386

NOTE: Both jam ratios are acceptable. 3 1/2" conduit will be utilized in the following examples.

Minimum training radius (without static loading) for nonshielded cable = 5 x OD = 5.50". (See Table 6).

If tape shielded cable were being installed, the minimum training radius must be verified. (See Table 7).

Minimum training radius (without static loading) for tape shielded cable = 12 x OD = 12 x 1.10" = 13.2" or 1.1'.

A standard 3 1/2" factory elbow with an inside radius of 1.10' will satisfy the minimum training radius requirements.

NOTE: It may not satisfy either the static loading requirement or the minimum allowable radius due to sidewall pressure during installation. **In all cases the largest radius will control.**

Weight correction factor c: When all three cables ride on the conduit wall during installation, it is termed a cradled configuration. When only two cables ride on the wall of the conduit and the third cable resides on the other two, the arrangement is described as a triangular configuration. For large jam ratios, it is likely that the cables will move in a cradled configuration. In either configuration the pulling tension required will be greater than the sum of the weights when moving in a straight section of conduit, and greater than the tension out of a bend divided by the radius of the bend (T/R) when negotiating a change of direction. Furthermore, the pulling tension is not equally distributed among the three cables; and, therefore, the weight correction factor must be used not only to calculate increased pulling tension due to this fact, but also to take into account the sidewall pressure on the worst case cable. For cradled configurations the middle cable is the worst case. For triangular configurations it is actually two cables, the pair making contact with the conduit.

In these examples a cradled configuration is assumed:

$$c = 1 + \frac{4}{3} \left(\frac{d}{D-d} \right)^2 = 1 + \frac{4}{3} \left(\frac{1.1}{3.548 - 1.1} \right)^2 = 1.269$$

Calculation Examples

Example 1: One conductor - Figure 1

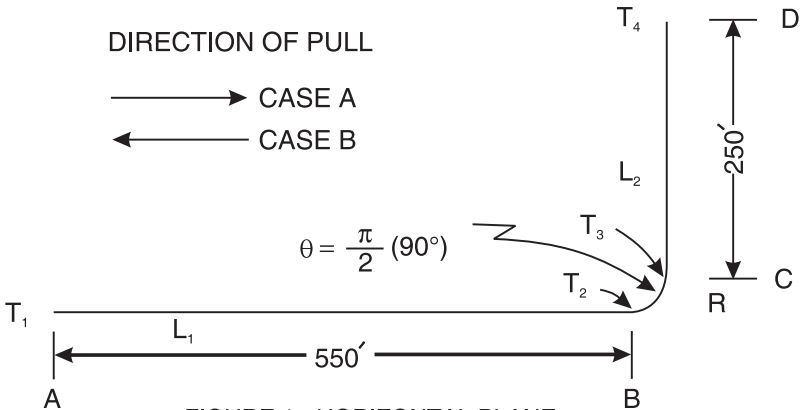


FIGURE 1 - HORIZONTAL PLANE

Case A Pulling from A to D

Maximum Tension will occur at T_4 when Pulling from A to D

$$T_1 = 0 \text{ (Assumed)}$$

$$T_2 = L_1 W f = 550 \times 1.83 \times .35 = 352.3$$

$$T_3 = T_2 e^{fa} = 352.3 e^{.35 \pi/2}$$

$$T_3 = 610.5$$

Minimum Bend Radius r

$$P = T/r \text{ and } r = \frac{T}{P}$$

$$r = \frac{T_3}{500} = \frac{610.5}{500}$$

$r = 1.22 \text{ ft.}$ Inside radius minimum based on sidewall pressure.

Use 18" Sweep Radius (See Table 4.)

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To verify use of the short form tension multiplier at a bend, we test with Eq.8:

Test Is: $T_2 > 10 wr?$

$$w = 1.83 \text{ \#/ft.}$$

$$r = 1.35 \text{ ft. (See Table 4)}$$

$$\text{Is } T_2 > 10 \times 1.83 \times 1.35$$

$$\text{Is } T_2 > 24.7$$

Since $T_2 = 352.3$ it is greater than 24.7 then the short form equation can therefore be used.

$$T_4 = T_3 + L_2 W f = 610.5 + (250 \times 1.83 \times .35)$$

$$T_4 = 770.6 \text{ lbs.}$$

One basket grip or pulling eye can be used.

Case B Pulling from D to A

$$T_4 = 0 \text{ (Assumed)}$$

$$T_3 = 250 \times 1.83 \times .35$$

$$T_3 = 160.13 \text{ lbs.}$$

$$T_2 = T_3 e^{fa} = 160.13 \times e^{fa} = 160.13 \times e^{.35 \pi/2}$$

$$T_2 = 277.48 \text{ lbs.}$$

Minimum Bend Radius based of Sidewall Pressure:

$$r = \frac{T_2}{500} = \frac{277.48}{500} = .55 \text{ ft.}$$

Standard $3\frac{1}{2}$ " elbow is acceptable.

Test: Is $T_3 > 10 Wr?$

$$160 > 10 \times 1.83 \times 1.10$$

$$160 > 20.13$$

$$T_1 = 277.48 + 550 \times 1.83 \times .35$$

$$T_1 = 629.8 \text{ lbs.}$$

Pulling eye or basket grip may be used.

COMMENTS: Case B is the preferred direction since it produces lower maximum tension and permits utilization of a standard factory elbow.

Example 2: Three Cables - Figure 1

Case A Pulling from A to D

$$T_1 = 0 \text{ (Assumed)}$$

$$T_2 = L_1 N W c f$$

Where N = number of cables (or 3)

$$\text{Let } cf=f'=1.269 \times .35 = .444$$

$$T_2 = 550 \times 3 \times 1.83 \times .444 = 1341 \text{ lbs.}$$

$$T_3 = T_2 e^{fa} = 1341 \times e^{.444 \pi/2} = 1341 \times 2.01 = 2695$$

Minimum bend requirement based on sidewall pressure:

$$r = T_3/1000 = 2695/1000 = 2.70 \text{ ft.}$$

A 36" radius is required.

Test: Is $T_2 > 10 W r$?

$$1341 > 10 \times 5.49 \times 2.85$$

$$1341 > 156.5$$

$$T_4 = T_3 + L_2 W f' = 2695 + (250 \times 3 \times 1.83 \times .444)$$

$$T_4 = 3304 \text{ lbs.}$$

Case B Pulling from D to A

$$T_4 = 0 \text{ (Assumed)}$$

$$T_3 = 250 \times 3 \times 1.83 \times .444 = 609.4$$

$$T_2 = 609.4 \times e^{.444 \pi/2} = 1224 \text{ lbs.}$$

Minimum radius requirement based on sidewall pressure:

$$r_{\min} = \left(\frac{1224}{1000} \right) = 1.22$$

A 18" sweep radius is required.

Test: Is $T_3 > 10 W r$?

$$609 > 10 \times 5.49 \times 1.35$$

$$609 > 74.1$$

$$T_1 = 1224 + (550 \times 3 \times 1.83 \times .444) = 2565$$

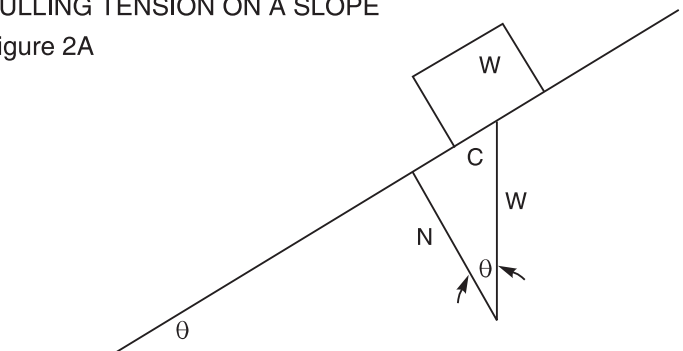
Pulling eye attached to the copper conductors is required.

COMMENTS: Case B is the preferred direction since it produces lower maximum tension and subsequently less sidewall pressure.

INSTALLATION PRACTICES FOR CABLE RACEWAY SYSTEMS

PULLING TENSION ON A SLOPE

Figure 2A



θ = Angle of Slope

W = Weight of Block

N = Normal Force of Slope = $W \cos \theta$

Normal Force Produces a Friction

Force Resisting Motion = $Wf \cos \theta$

NOTE: W & f in this illustration represent L & N W & f in Example 3 respectively.

C = Downward Force Parallel to Slope = $W \sin \theta$

NOTE: This force will increase the tension pulling up the slope and decrease it pulling downward.

$$T_{\text{up}} = W (f \cos \theta + \sin \theta)$$

$$T_{\text{down}} = W (f \cos \theta - \sin \theta)$$

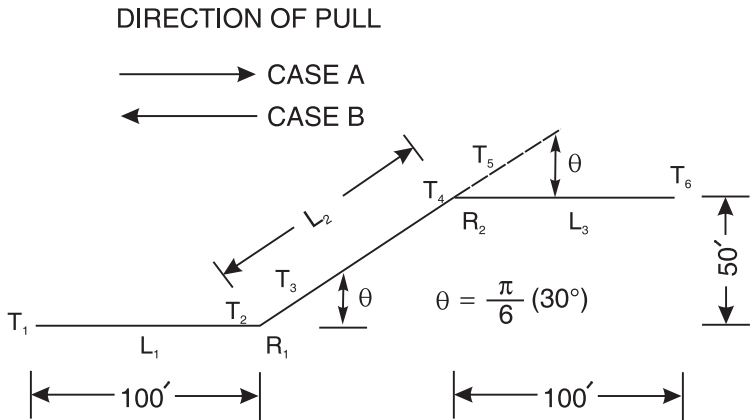


FIGURE 2- VERTICAL PLANE

Example 3: Three Cables - Figure 2

$$L_2 = \frac{50}{\sin \theta} = \frac{50}{0.5} = 100 \text{ ft.}$$

Where $\theta = \frac{\pi}{6}$ and $\sin \frac{\pi}{6} = 0.5$

Case A

$$T_1 = 0 \text{ (Assumed)}$$

$$T_2 = L_1 N W f$$

$$\text{where } f' = cf = 1.269 \times .35 = .444$$

$$T_2 = 100 \times 3 \times 1.83 \times .444$$

$$T_2 = 243.76 \text{ lbs.}$$

$$T_3 = T_2 e^{f'a} = 243.76 e^{.444 \pi/6}$$

$$T_3 = 307.56 \text{ lbs.}$$

Minimum bend radius at R_1 based on sidewall pressure during installation:

$$r_{\min} = \frac{T_3}{1000} = \frac{307.56}{1000} = .31'$$

Minimum bend requirements:

Standard $3 \frac{1}{2}''$ elbow is acceptable.

INSTALLATION PRACTICES FOR CABLE RACEWAY SYSTEMS

Test: Is $T_2 > 10 W r$?

$$244 > 10 \times 5.49 \times 1.10$$

$$244 > 60.39$$

$$T_4 = T_3 + L_2 W (f' \cos \theta + \sin \theta)$$

$$= 307.56 + \left[100 \times 3 \times 1.83 \left(.444 \times \frac{\sqrt{3}}{2} + .5 \right) \right]$$

$$T_4 = 793.16 \text{ lbs.}$$

See Figure 2A for calculating tension developed on a slope

$$T_5 = 793.16 e^{.444 \pi / 6}$$

$$T_5 = 1000.75$$

Minimum bend at R_2 based on sidewall pressure:

$$r_{\min} = \frac{T_5}{1000} = \frac{1000.75}{1000} = 1.0' \text{ minimum}$$

A standard $3\frac{1}{2}"$ elbow is acceptable.

Test: Is $T_4 > 10 W r$?

$$793 > 10 \times 5.49 \times 1.1$$

$$793 > 60.39$$

At R_2 the sidewall pressure from static loading must be considered. If $\sin \theta$ is greater than $f' \cos \theta$ the cables will tend to slide downward therefore a permanent static loading exists and a minimum training radius based on a maximum sidewall pressure limited to 120 lbs. per foot of bend radius for the worst cable must be satisfied.

$$f' \cos \theta = .444 \cos 30^\circ = .385$$

$$\sin \theta = .5$$

$$\text{Static Loading} = (.5 - .385) 100 \times 3 \times 1.83 = 63.14 \text{ lbs.}$$

$$\text{Minimum } r = \left(\frac{3 \times 1.269 - 2}{3 \times 120} \right) 63.14 = .317 \text{ ft.}$$

Sidewall pressure during installation will control. The standard $3\frac{1}{2}"$ elbow is acceptable.

$$T_6 = T_5 + L_3 W f' = 1000.75 + 100 \times 5.49 \times .444$$

$$T_6 = 1244.51 \text{ lbs.}$$

Use a pulling eye or 3 basket grips, one per cable.

Case B

$$T_6 = 0 \text{ (Assumed)}$$

$$T_5 = 100 \times 5.49 \times .444$$

$$T_5 = 243.76 \text{ lbs.}$$

$$T_4 = 243.76 \times e^{.444 \pi/6} = 307.56$$

Minimum bend radius at R_2 based on sidewall pressure:

$$r_{\min} = \left(\frac{307.56}{1000} \right) = .31 \text{ ft. minimum}$$

Standard $3\frac{1}{2}$ " elbow is adequate.

Test: Is $T_5 > 10 W r$?

$$244 > 10 \times 5.49 \times 1.10$$

$$244 > 60.39$$

$$T_3 = T_4 + L_2 W (f' \cos \theta - \sin \theta)$$

$$= 307.56 + 100 \times 3 \times 1.83 \left(.444 \times \frac{\sqrt{3}}{2} - .5 \right)$$

$$T_3 = 244.16$$

Note that the tension has been reduced in this case. This is not always so, depending on the values of f' and θ .

$$T_2 = 244.16 \times e^{.444 \pi/6}$$

$$T_2 = 308.06$$

Minimum bend radius at R_1 based on sidewall pressure:

$$r_{\min} = \frac{308.06}{1000} = .31 \text{ ft.}$$

Standard $3\frac{1}{2}$ " elbow is acceptable.

Test: Is $T_3 > 10 W r$?

$$244 > 10 \times 5.49 \times 1.10$$

$$244 > 60.39$$

$$T_1 = 308.06 + (100 \times 5.49 \times .444)$$

$$T_1 = 551.82 \text{ lbs.}$$

One basket grip or pulling eye can be used.

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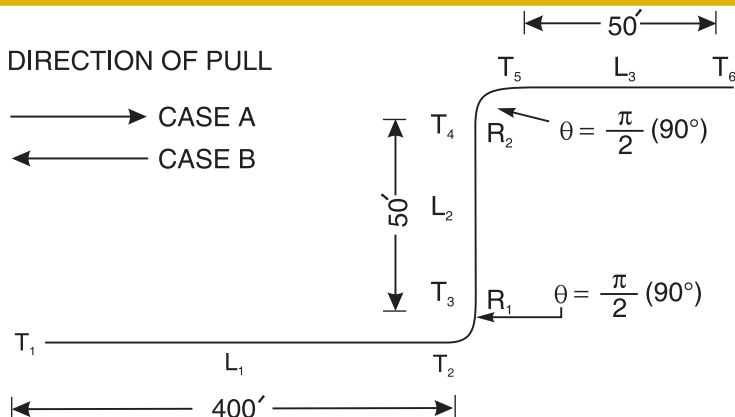


FIGURE 3- VERTICAL PLANE

Example 4: Figure 3

Case A

$$T_1 = 0 \text{ (Assumed)}$$

$$T_2 = L_1 W_f = 400 \times 3 \times 1.83 \times .444$$

$$T_2 = 975.02 \text{ lbs}$$

$$T_3 = T_2 e^{f_a} = 975.02 \times e^{.444 \pi/2}$$

$$T_3 = 1958.81$$

Minimum bend radius at R_1 based on sidewall pressure:

$$r_{\min} = \frac{1958.81}{1000}$$

$$r_{\min} = 1.96 \text{ ft.}$$

A 30° sweep elbow is required.

Test: Is $T_2 > 10 W r$?

$$975 > 10 \times 5.49 \times 2.35$$

$$975 > 129.02$$

$$T_4 = T_3 + L_2 W = 1958.81 + 50 \times 5.49$$

$$T_4 = 2233.31$$

NOTE: In the vertical section the full cable weight is used.

$$T_5 = T_4 e^{f_a} = 2233.31 e^{.444 (\pi/2)}$$

$$T_5 = 4486.72$$

Minimum bend radius at R_2 based on the sidewall pressure:

$$r_{\min} = \left(\frac{4486.72}{1000} \right) = 4.49 \text{ ft.}$$

Test: Is $T_4 > 10 W r$?

$$2233 > 10 \times 5.49 \times 4.49$$

$$2233 > 246.5$$

This requires a special sweep. It must be determined whether this sweep can be accomplished in the field with a standard 10' conduit length.

$$S = r\theta$$

where: s = arc length in feet

r = radius of bend in feet

θ = angle of bend in radians

If a 1' straight section on both ends of a 10' conduit is sufficient for the bending machine $S = 8'$.

$$r = \frac{S}{\theta} = \frac{8}{\pi / 2} = 5.09 \text{ ft.}$$

This would satisfy the minimum radius at R_2 .

If an 18" machine clearance is required at both ends

$S = 7'$ and

$$r = \frac{7}{\pi / 2} = 4.46 \text{ ft.}$$

This would not satisfy the requirements at R_2 .

$$\begin{aligned} T_6 &= T_5 + L_3 W f' \\ &= 4486.72 + 50 \times 5.49 \times .444 \end{aligned}$$

$$T_6 = 4608.6 \text{ lbs.}$$

If the minimum radius of R_2 is satisfied, the cable must be pulled using a pulling eye. Assuming the cable is installed it is now necessary to determine if the forces are in equilibrium.

Friction Force in $L_3 = 50 \times 5.49 \times .444 = 121.88 \text{ lbs.}$

Force required to pull downward around R_2 :

$$= 121.88 e^{.444 \pi / 2} = 244.86 \text{ lbs.}$$

Cable weight in vertical section L_2 :

$$= L_2 W = 50 \times 5.49 = 274.50 \text{ lbs.}$$

$$\text{Net downward force} = 274.50 - 244.86 = 29.64 \text{ lbs.}$$

Based on effective coefficient of friction (f') of .444 the forces are not in equilibrium. Although the static coefficient of friction will be higher than .444 and the net downward force as calculated -29.64 lbs. is not substantial, the cable should be secured at the upper termination by means of basket grips. For such application the maximum load is 400 pounds per cable with one grip attached to

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each cable. Two layers of half lapped tape should be wrapped over the cable jacket to serve as a bedding for the grips, sufficient in length to extend 6" beyond the ends of the grips.

The static load at R_2 must also be examined based on a sidewall pressure limit of 120 pounds per foot of bend radius for the worst case cable.

Cable weight in vertical section $L_2 = 274.50$ lbs.

$$r_{\min} = \left(\frac{3 c - 2}{3 \times P} \right) T = \left(\frac{3 \times 1.269 - 2}{3 \times 120} \right) 274.5$$

$$r_{\min} = 1.38'$$

This is a smaller value than that found for the sidewall pressure during installation. The minimum allowable radius is 4.49 ft.

Case B

$$T_6 = 0 \text{ (Assumed)}$$

$$T_5 = 50 \times 5.49 \times .444$$

$$T_5 = 121.88 \text{ lbs.}$$

$$T_4 = 121.88 e^{.444 \pi/2}$$

$$T_4 = 244.86 \text{ lbs.}$$

Minimum bend radius at R_2 :

$$r_{\min} = \frac{244.86}{1000} = .24 \text{ ft.}$$

$$r_{\min} = .24 \text{ ft. based on sidewall pressure during installation.}$$

The minimum allowable radius is determined by static loading and is 1.38'. See case A. A 24' factory sweep radius may be used.

Test: Is $T_5 > 10 W r$?

$$122 > 10 \times 5.49 \times 1.85$$

$$122 > 101.57$$

$$T_3 = T_4 \text{ minus vertical load} = 244.86 - 274.50$$

$$T_3 = -29.64 \text{ lbs.}$$

During installation it will be necessary to brake the reel. Assume the reel is braked sufficiently to provide the equivalent of 50 feet of horizontal pulling tension, and assume that this net positive tension is developed at the bottom of the vertical section entering R_1 at T_3 .

$$T_3 = L W f' = 50 \times 3 \times 1.83 \times .444$$

$$T_3 = 121.88 \text{ lbs}$$

$$T_2 = T_3 e^{f'a} = 121.88 e^{.444 \pi/2}$$

$$T_2 = 244.86$$

Minimum bending radius at R_1 based on sidewall pressure:

$$r_{min} = \frac{244.86}{1000} = .245 \text{ ft.}$$

Standard $3\frac{1}{2}$ " elbow is acceptable

Test: Is $T_3 > 10 W r$?

$$122 > 10 \times 5.49 \times 1.10$$

$$122 > 60.39$$

$$T_1 = 244.86 + 400 \text{ ft.} \times 5.49 \times .444$$

$$T_1 = 1219.9 \text{ lbs.}$$

A pulling eye or basket grips may be used. Once the cable is installed, the static loading and supports at the upper end will be the same as in Case A.

DIRECTION OF PULL

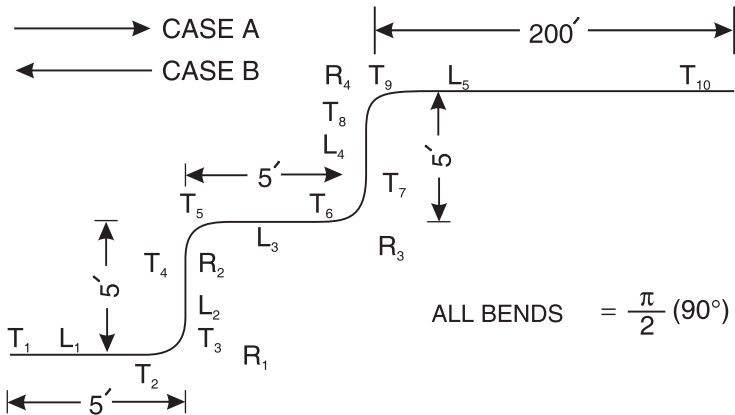


FIGURE 4- HORIZONTAL PLANE

Example 5: Figure 4

Case A

$$T_1 = 0 \text{ (Assumed)}$$

$$T_2 = L_1 W f' = 5 \times 5.49 \times .444$$

$$T_2 = 12.2 \text{ lbs.}$$

$$T_3 = T_2 e^{f'a} = 12.20 e^{.444 \pi/2} = 24.51$$

For this example, involving several short sections, it is convenient to confirm use of the short form equation, $e^{f'a}$, by solving for the

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minimum incoming tension to satisfy $T_{in} > 10 W r$ assuming $R_1 = 1.10$; the inside of a standard $3\frac{1}{2}"$ conduit elbow.

Test: Is $T > 10 \times 5.49 \times 1.10$

$$T_{min} = 60.39 \text{ lbs.}$$

Since the tension at T_2 is only 12.2 lbs. the complete equation is required for a rigorous solution.

$$T_3 = T_2 \left(\frac{e^{f_a} + e^{-f_a}}{2} \right) + \sqrt{T_2^2 + (Wr)^2} \left(\frac{e^{f_a} - e^{-f_a}}{2} \right)$$

$$e^{f_a} = e^{.444 \pi/2} = 2.009$$

$$e^{-f_a} = 1/e^{f_a} = .498$$

$$(Wr)^2 = (5.49 \times 1.1)^2 = 36.47$$

$$T_3 = 12.2 \left(\frac{2.01 + .50}{2} \right) + \sqrt{(12.2)^2 + 36.47} \left(\frac{2.01 - .50}{2} \right)$$

$$T_3 = 25.59$$

This compares with a value of 24.51 based on the simplified equation.

Even though some error is introduced by use of the short form it may be concluded that for short radius bends and relatively light weights of cable, the error is negligible. However, for low incoming tensions and very large bend radii the complete equation should be used.

In calculations for determining minimum bend radii to limit sidewall pressure it is often convenient to determine the maximum allowable tension out of the standard factory bend radius.

From equation 2: $T_o = P r$

for $3\frac{1}{2}"$ conduit $r = 1.1'$

$$P_{Max} = 1000 \text{ from Table 5}$$

$$\text{and } T_o = 1000 (1.1) = 1100$$

$3\frac{1}{2}"$ standard elbow is acceptable.

$$T_4 = T_3 + L_2 W f' = 24.51 + 12.2$$

Note that each 5 foot straight section accumulates 12.2 pounds tension.

$$T_4 = 36.71 \text{ lbs}$$

$$T_5 = T_4 e^{f_a} = 36.71 e^{.444 \pi/2} = 73.75 \text{ lbs.}$$

3 1/2" standard elbow is acceptable.

$$T_6 = T_5 + L_3 W f' = 73.75 + 12.20$$

$$T_6 = 85.95 \text{ lbs}$$

$$T_7 = T_6 e^{f'a} = 85.95 e^{.444 \pi/2}$$

$$T_7 = 172.67 \text{ lbs.}$$

3 1/2" standard elbow is acceptable.

$$T_8 = T_7 + L_4 W f' = 172.67 + 12.20$$

$$T_8 = 184.87 \text{ lbs.}$$

$$T_9 = T_8 e^{f'a} = 184.87 e^{.444 \pi/2} = 371.4 \text{ lbs.}$$

3 1/2" standard elbow is acceptable.

$$T_{10} = T_9 + L_5 W f' = 371.4 + 200 \times 3 \times 1.83 \times .444$$

$$T_{10} = 858.91$$

Cable may be installed with one basket grip or pulling eye.

Case B

$$T_{10} = 0 \text{ (Assumed)}$$

$$T_9 = L_5 W f' = 200 \times 3 \times 1.83 \times .444 = 487.51$$

$$T_8 = 487.51 e^{.444 \pi/2} = 979.41 \text{ lbs.}$$

3 1/2" standard elbow is acceptable.

$$T_7 = 979.41 + 12.2 = 991.61 \text{ lbs.}$$

$$T_6 = 991.61 e^{.444 \pi/2} = 1992.14$$

$$R_3 = \frac{1992.14}{1000} = 1.99 \text{ ft. minimum}$$

A 30" sweep radius is required

Test: Is $T_7 > 10 W r$?

$$1992 > 10 \times 5.49 \times 2.35$$

$$1992 > 129.0$$

$$T_5 = 1992.14 + 12.2 = 2004.34$$

$$T_4 = 2004.34 e^{.444 \pi/2} = 4026.72$$

$$R_2 = \frac{4026.72}{1000} = 4.03 \text{ ft. minimum}$$

A special sweep radius is required.

Test: Is $T_5 > 10 W r$?

$$2004 > 10 \times 5.49 \times 4.03$$

$$2004 > 221.2$$

$$T_3 = 4026.72 + 12.2 = 4038.92$$

$$T_2 = 4038.92 e^{.444 \pi/2} = 8114.19$$

$$R_1 = \frac{8114.19}{1000} = 8.11 \text{ ft. minimum}$$

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These last bends would require a special sweep of extended conduit length and strongly suggests that installing the cable in this direction in one length is not feasible.

Test: Is $T_3 > 10 W r$?

$$4039 > 10 \times 5.49 \times 8.11$$

$$4039 > 445.2$$

In addition to a monumental bend radius requirement the maximum allowable pulling tension of 8000 pounds is exceeded.

$$T_1 = 8114.19 + 12.2 = 8126.39 \text{ lbs.}$$

Example 5 illustrates two interesting and significant points:

1. The direction of pulling cable can make a very substantial difference in pulling tensions and sidewall pressures, depending on the exact configuration of conduit and bends.
2. Case B illustrates that the limitation of four (4) ninety degree bends or equivalent per NEC cannot be relied upon to assure limiting pulling tensions and sidewall pressures to safe values. If the cable is pulled in the Case A direction, several additional bends can be added, assuming 5 foot straight sections between bends, without posing insurmountable problems. For case A the limitation of four ninety degree bends is unduly restrictive. For Case B it is far too generous.

For the five examples given it should be observed that incoming tension at the feed end has been assumed to be zero. The calculations indicate that this is highly desirable to hold the incoming pulling tensions to minimum values. If calculations are made on this assumption, then the installation procedure must assure this condition.

In all the examples the pulls have been completed out of a straight section of conduit. In the practical case, however, a ninety degree bend is frequently encountered at the end of the pull. As has already been shown, in some detail, each change of direction in a conduit run acts as a multiplier of the incoming tension at that point. Consider the effect of a ninety degree bend at the pulling end of Case B, Example 5. The multiplying effects of this bend is 2.009, and with an incoming tension of 8126.39 calculated for T_1 , the tension out of such an additional bend would be 16,325.92 pounds. Avoid the nineties at the ends of the pulls wherever possible.

Example 6: Cable in Tray See Fig. 5

Given a 3/C - 500 kcmil copper 15kV - 133% Level armored cable (Type MV-105 or MC-HL approved for cable tray use)

Approximate OD = 3.60 in

Net Weight per Foot = 8.67 lb.

Minimum Bend Radius: 7 x OD (during installation) or larger to satisfy the maximum allowable sidewall pressure limit. Minimum Bend Radius = 7 x 3.6 in. = 25.2"

Effective Cable Weight: $wf = 8.67 \times .15 = 1.30$ lb. Maximum Sidewall Pressure: 1000 lb. per foot of bend radius for three conductor cable. With a radius of 3 ft. for all sheaves the maximum pulling tension is 3000 lbs.

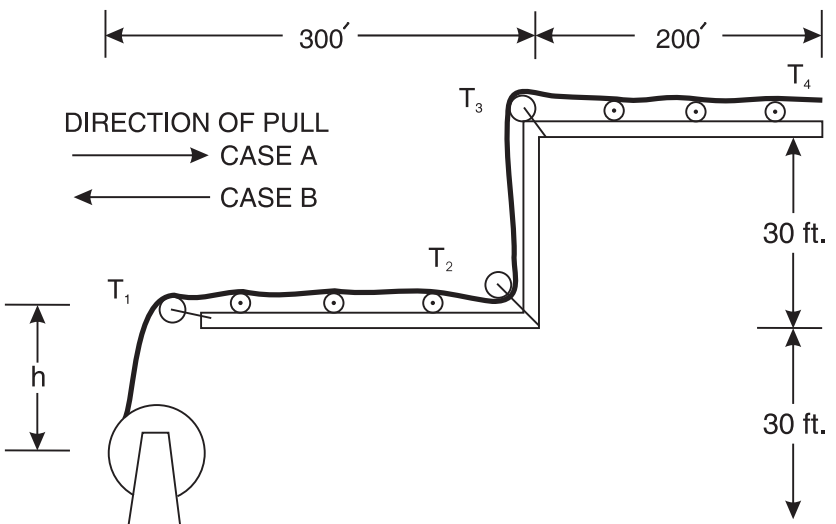


FIGURE 5 - VERTICAL PLANE

NTS

A precise calculation of the effective distance h between cable reel and sheave shown in Fig. 5 could be made at the start of the pull, if reel and sheave dimensions, A-frame or reel jack details are known, and if the mounting height of rollers on the cable tray is established. Even so the actual height will change as successive layers are removed from the reel. In general it is sufficiently

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accurate to treat the cable tray elevation above the floor as h , unless the cable reel is elevated above normal floor mounting height.

The following calculations assume that properly sized sheaves are installed securely in place to accommodate changes in direction along the cable tray route.

Case A

$$T_r = 25w = 25 \times 8.67 \text{ lb.} = 217 \text{ lb.}$$

This assumes that cable is removed from the reel under tension from the pulling end.

$T_a = 125 \text{ lbs.}$ Assumed tension adder for bends.

$T_w = \text{wt/ft of cable times height}$

$$T_1 = T_r + T_w + T_a = 217 + (30 \times 8.67) + 125 = 602 \text{ lb.}$$

$$T_2 = T_1 + (300 \times 1.3) + T_a = 602 + 390 + 125 = 1117 \text{ lb.}$$

$$T_3 = T_2 + T_w + T_a = 1117 + (30 \times 8.67) + 125 = 1502 \text{ lb.}$$

$$T_4 = T_3 + (200 \times 1.3) = 1502 + 260 = 1762$$

Use pulling eye on conductors and install basket grip over metal sheath securely attached to pulling line.

Case B

$$T_r = 25w = 217 \text{ lb.}$$

$$T_4 = T_r + T_w + T_a = 217 + 60 \times 8.67 + 125 = 862 \text{ lb.}$$

$$T_3 = T_4 = 200 \times 1.3 + 125 = 1247 \text{ lb.}$$

$$T_2 = T_3 - T_w + T_a = 1247 - 30 \times 8.67 + 125 = 1112 \text{ lb.}$$

$$T_1 = T_2 + 300 \times 1.3 = 1502 \text{ lb.}$$

Use pulling eyes on conductors and install basket grip over metal sheath securely attached to pulling line.

$$\text{Difference in tension} = 1762 - 1502 = 260 \text{ lb.}$$

Even though the bends are not treated as tension multipliers the direction of pull affects the total tension. In Case A the cable is raised 60 ft. vertically. In Case B the cable is raised a net height of only 30 ft. with respect to pulling tension.

Theoretically the distance around the sheaves should be included in the computation. However, in the practical case the total distance involved is relatively short, and adds little to the total tension.

System Considerations

Introduction

Insulated conductors often fail because of mechanical damage due to improper raceway and terminal design, or to improper installation techniques. There is an ongoing trend toward reduced insulation thickness which makes it increasingly important to observe established limitations on the physical treatment of these cables. It is highly desirable to make these cables damage-proof, but that is beyond the present state of the art, particularly since there are a number of other criteria these cables must satisfy: long service life under voltage stress and heat aging, flame retardance, thermal stability, dielectric strength, are some of the requirements that come to mind. This is to say nothing of the special requirements for nuclear power plants such as radiation resistance and performance during a Loss of Coolant Accident. In achieving these requirements some limits are imposed on the mechanical durability of the cable, and these limits must be recognized.

Cable in Conduit

The maximum allowable limits of pulling tension and sidewall pressure are given in Part II. Equations are also given for calculating the anticipated values when the cable is installed.

Equation 7 of Part II demonstrates that a bend in a conduit run acts as a multiplier of incoming tension. The examples in Part III demonstrate that the direction of pulling can have significant influence on the tensions and sidewall pressures generated.

The total pulling tension in a straight section of conduit may not be shared equally by the cables. In the case of three cables in triangular configuration one cable can get a free ride. Even for the case of cradled configuration the tensions will not be equal since the center cable has a higher effective coefficient of friction than the other two. For three cables in conduit it should be assumed that the total tension is sustained by two of the three cables.

Weight correction factor, c , (Part II - Equations 5 and 6) expresses mathematically the fact that where two or more cables rest in a conduit the sum of the normal forces developed between cables and conduit is greater than the sum of cable weights. This factor, greater than unity, has three significant consequences: (1) it operates to increase the effective weight of the cable in a straight pull, (2) it increases the tension generated in pulling cable around a bend; and (3) it increases the sidewall pressure on the “worst case” cable or cables.

The equations of Part II clearly show that the minimum allowable bend radius will be determined by either the allowable training radius with or without static loading, or by maximum allowable sidewall pressure during installation, whichever of these criteria require the largest radius at each bend. Factory elbows, both standard and sweep elbows, for the various nominal conduit sizes are given in Table 4. This table shows the radius to the inside of the bend, the value to be used in calculating sidewall pressures.

Sizing of Conduit - Jam Ratio

Where three cables of equal diameter are to be installed and the sum of the three diameters are approximately equal to the inside diameter of the conduit one cable can be wedged between the other two and serious cable damage can occur. For the case of three cables of equal diameter it is conventional to express the jam ratio as the ratio of the inside diameter of conduit to the diameter of one cable. Expressed in this way the prospect of jamming increased as the ratio approaches 3. Jamming is still possible for ratios greater than three and it is recommended that jam ratios between 2.8 and 3.2 be avoided in the sizing of conduit. For precisely 40% Code fill the jam ratio is 2.739.

Oversizing of conduit with the consequent increase of jam ratio should be carefully analyzed to avoid the hazardous range. For the installation of more than three cables jamming is still possible. but experience suggests that the case of three cables represents the greatest hazard. Obviously, the cables need not be of the same diameter, and an analysis based on the sum of the three diameters to the inside conduit diameter is then required.

Jamming is not possible when the cables are triplexed by the manufacturer, providing the conduit fill limit is not exceeded.

Layout and Calculations

The layout of cable raceway system and calculations to predict pulling tensions and sidewall pressures should be regarded as two facets of the same design process.

Conduit Bends - Minimum Radii

Factory elbows may not be available to satisfy sidewall pressure limitations. Conduit sweeps, produced in the field may be required, but required bend radii may be prohibitively large. An alternate design should be carefully considered that contemplates the use of a concrete trench under switchgear, motor control centers, and other terminals, sufficiently wide from front to back to allow pulling the cable into the trench with sufficient cable to provide required makeup. The back wall of such a trench can be provided with eyes to accommodate the pulls. Where the required width of the trench is greater than the free standing equipment, a steel cover plate can be used and supports can be provided to hold the cable above the bottom of the trench. In addition to eliminating the sidewall pressure problem at the pulling end, this design can offer attractive economies by elimination of elbows.

Junction Boxes

Care must be given to the sizing and location of junction boxes. It must be remembered that junction boxes are not designed to pull through or pull around. They are intended for junction or splice points. If an enclosure is to be used as a pull box, then careful attention should be given to the box or feeding into the box. If a junction box is installed in a run and then cable is pulled through it, it is possible that the box should have been omitted from the design.

Standard Condulets

In general, these enclosures should be treated with care. Except for the straight through type, cable should never be pulled through them and minimum prescribed bending radii for installed cable must be reviewed. Violations occur regularly in condulets.

Unsupported Cable in Vertical Conduit Risers

Insulated cables are frequently damaged where overhead horizontal conduit runs turn down to terminal enclosures. If condulets are used for the ninety degree turns and the risers are more than a few feet, damage can occur from the cable weight. Junction boxes and wireways can also produce the same kind of damage unless special cable supports are provided in the enclosures. Conduit bushings are not adequate and are not designed for that purpose.

Manholes

Judicious placement of manholes in a duct system is obviously an important criterion for good design. Regrettably manholes are often included in a system which are not required, and sometimes omitted where they are critically needed. The inclusion of an intermediate manhole between Point A and Point B in a duct bank system adds substantially to the cost, complicates cable installation, and can produce cable damage.

The chief cause for inclusion of extra manholes is failure to make pulling tension calculations during the design phase. In the installation phase the installer will be tempted to pull from manhole A through the intermediate manhole to manhole B, and employ a split basket grip or line grip to acquire slack for training the cable in the intermediate manhole. Such a procedure can damage the cable.

Corresponding duct segments, in and out of the manhole, are rarely in true alignment. In pulling the cable through the manhole, failure to align the cable by means of properly sized sheaves can lead to cable damage. Recessed duct entries with flared opening in the concrete by means of bells or wooden plug can sometime alleviate this specific problem. But use of a basket grip or line to provide slack will very frequently exceed the maximum allowable 1000 pound limit, due partly to the fact that an entire section of cable will have to be accelerated from rest, due partly to the fact that static friction is significantly higher than sliding friction, and often due to the length of the cable section.

Whenever an intermediate manhole is included in a straight section of duct bank between two points, A and B, a decision

should be made at the time of design whether this is to be a splice point or a point for feeding the cable in both directions. The intent should be so stated and specified for the installer.

Using the intermediate manhole for a feed point poses problems. The typical manhole will have a 30 inch manhole cover with a clear opening of approximately 29 inches. With care the cable can be fed through the opening from the lead off end to the reel of cable. But feeding the inner end of the cable into the manhole for pulling in another direction will require bending the cable into a radius of $14\frac{1}{2}$ " inches maximum. It is true that cable can be bent temporarily into a tighter radius than the limits specified for permanent in-place training in accordance with the limits for shipment of cables on reels. In no case, however, should this minimum bending radius be violated. And even assuming that this minimum radius can be satisfied, the inner end of the cable will have to be removed from the reel and usually this will involve dragging that portion of the cable over the ground. Damage can occur during this phase of installation and such design should be avoided. A proper splice at the intermediate manhole is preferable to the risk of cable damage.

Manholes are sometimes used for producing a turn in the direction of a duct bank, perhaps most frequently a ninety degree turn. And just as frequently the cable will be pulled through such a manhole and the turn negotiated by means of a sheave installed in the manhole. Recalling the size of a manhole opening and the limitations on sidewall pressure, it is not difficult to imagine that this situation can represent a flagrant abuse of sidewall pressure limitations. Given a standard sheave of 24 inch nominal diameter, the effective inside radius is approximately $9\frac{1}{2}$ inches. The maximum sidewall pressures given by Table 5 in Part II for cable sheaves impose limitations that are frequently violated. Undeniably, these limits place substantial restrictions on the designer and the installer, but the problem should be recognized and anticipated.

In new construction it is often feasible to delay installation of manhole roofs until the cable has been installed. This will facilitate use of sheaves with adequate bend radii, and simplify both feeding and pulling at a manhole.

INSTALLATION PRACTICES FOR CABLE RACEWAY SYSTEMS

As an alternative the cable can be spliced. It is far better to include splices in accessible locations than to damage cable that may reside in the middle of a duct run. Even if a splice is questionable, it is accessible in the manhole and can be repaired without disturbing the cable in duct and without cable replacement, providing sufficient slack is provided in the manhole, and provided manhole design offers adequate space.

An alternative to using manholes for direction change of duct runs is to use sweeping bends of large radii and eliminate the manholes. When non-metallic conduit is used this is easily accomplished at considerable cost saving. Pulling tensions will be increased, but sidewall pressure limitations can be satisfied with the large bend radii, and recognizing that sidewall pressure limitations usually control, judicious elimination of unnecessary manholes represent sound engineering design.

Splicing Cable in Manholes

Splice points in a circuit should be included in the design and specified. In these manholes, slack should be provided for the eventuality of a splice repair. Some electric utilities follow the practice of installing a complete loop of cable per leg on one side of a splice. Splices should be staggered horizontally and be installed with adequate clearance vertically to facilitate not only the original installation but subsequent repair or replacement, should this be necessary. These details should be designed and specified.

Cable Terminations in Enclosures

Economics in the manufacture of switchgear, motor control centers, control devices and a wide variety of related equipment dictate that their enclosures be held to tight limits. The physical space for the installation of such equipment may also conspire to reduce the size of such equipment. The unfortunate result is that all too often the space provided for the termination of cables makes it impossible for the installer to satisfy minimum bending radii for the training of cables into their final, installed configuration. The installer can hardly be held responsible for errors of design, but this does not solve the problem.

Even where physical space will permit larger enclosures the question of space within the enclosure for cable termination can

be overlooked by the designer. Consider the case of switchgear and cable run in conduits below grade. How often the space provided for termination of cables simply does not permit satisfying minimum training radii for the cables. A review of shop drawings at the time of submittal and before manufacture can solve such a problem by insisting on adequate vertical clearance.

Cables in Trays and Ladders

The same limitations of pulling tensions and sidewall pressures apply for cable in tray as for cable in conduit. Attention must be given to the length of runs, the number of turns and the size of sheaves used for pulling cable around these turns to accommodate changes in direction. Sheaves are often used as rollers in horizontal sections and for bends either concave upward or concave downward in connecting horizontal and vertical sections of tray. If trays are stacked vertically without sufficient clearance the installation of such “rollers” can be difficult if not impossible.

The use of trapeze hangers involving two vertical members for the hanger, one on each side of the tray, makes it impossible to lay cable into the tray and the cable must be pulled into place. The use of catilevered supports should be given careful consideration, especially where placement of sheaves and pulling of cable is difficult.

Cable Tray Bends

Pulling sheaves of adequate diameter should be used in pulling cable around bends in cable tray. The minimum allowable diameters should be determined by calculation of sidewall pressures and these values compared with minimum allowable training radii of the cables once they are installed. See Part II Tables 5, 6 & 7 and Part III. The inside radius of a cable tray bend can violate the in-place allowable radius for a cable, even though a sheave of adequate radius was used in the pulling of the cable.

Fastening of Cable in Trays

The use of nylon fasteners for securing cables in cable trays has become popular. Their use is acceptable providing that the tension developed in applying the fastener is not excessive. Torque limiting tools are available for use with the fasteners. Their use should be specified together with a provision in the

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specifications that excessive tension with the consequent deformation of cable will not be permitted.

Cable Sheaves and Cable Sheave Assemblies

As indicated in other sections of this manual, it is often necessary to pull around bends in cable tray or to change direction in a manhole. Excessive sidewall pressure can result in damage to the cable. Sidewall pressure can be minimized by the use of a large radius sheave. Unfortunately, large radius sheaves are often impractical since they may not fit inside a manhole or cannot be rigged in congested tray runs. Even if they can fit, they are often unavailable. To alleviate this problem, multiple smaller sheaves are placed on a radius. This device is known as a radius-type cable sheave assembly.

Precautions must be followed when using a radius type cable sheave assembly to prevent damage due to excessive sidewall pressure around the individual sheaves. Each individual sheave should have an inside radius of at least $1\frac{1}{4}$ inches. The assembly should consist of at least one sheave per 20° of bend. The practice of using a three sheave assembly to make a 90° bend should be prohibited.

Cable Hangers/Saddles

Aerial cables can be supported underneath a messenger with the use of a cable hanger or saddle. The hangers/saddles should be spaced 12" to 20" depending on the cables weight.

Cable Failures

A great many cases of cable failure are directly attributable to damage caused by their installation, occurring either during installation, or as a result of their in-place configuration with subsequent cable breakdown. Very often the damage can be directly attributed to improper raceway design.

Installers as Designers

It is fully recognized that in many instances the installer does the design work; at least the routing and size of raceway, the choice and location of junction boxes, the direction of pulling cable. The installer, for example, is frequently left to his own devices to route a 4-inch feeder conduit that must be installed from point A to point B. Often the stage of construction and the nature of the structure will make such an installation a real challenge that can be hailed

as a triumph in mechanical ingenuity when once accomplished. But the raceway serves no useful purpose if the cable cannot be installed without damage. All too often pulling calculations, if they are made at all, are done after the raceway is installed, a dynamometer is not used, and the cable is worried into place. Hopefully it will survive, but sometimes it does not.

If the conduit installer is to route the conduit, select appropriate fittings, determine the size and location of boxes, and decide the number of splices required, he must be more than a good “pipe man”. He must also be a good cable man, conversant with the necessary limitations imposed on its installation and the methods for predicting whether these limits will be exceeded when the cable is installed. He must recognize that every change of direction in a conduit run increases the pulling tension, and each of these bends or offsets or saddles or “swings” not only increases the tension but also produces a sidewall pressure on the cable, a tension or a pressure or both that may damage the cable.

The installation of conduit in concrete and the installation of overhead exposed conduit represent the worst cases where many changes in direction may occur simply to avoid obstacles. Consider the simple case of two junction boxes surface mounted on the wall of a structure at the same elevation and an exposed conduit must be installed between the boxes. Consider further that two vertical columns lie in the path of the conduit. In standard installation this will involve two bends at each box, one offset per box, and four bends at each column. If the offsets and saddles are held close to the boxes and columns to make the job look aesthetic, one might expect two 45 degree bends at each box and four 60 degree bends at each saddle. This run represents a total angular change of direction of 540 degrees. Such an installation does not satisfy the National Electrical Code where a limitation of four ninety degree bends or their equivalent is specified. But aside from this restriction, which is not a reliable index to pulling tensions and sidewall pressures, consider what might have been done to eliminate all bends in the run. Instead of using standard 4-inch square boxes, suppose that special boxes of adequate depth had been used and that appropriate blocking was placed between the conduit and the wall for supporting the conduit. With such an

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installation a straight conduit run could be achieved from box to box without offsets or saddles.

This is a simple case. Many conduit installations are not so simple. But a competent installer will call for help in those situations where pulling tensions and/or sidewall pressures are likely to be excessive. He will know that the greater the change in direction (the larger the angle) the greater the increase in tension at the bend. He will also know that the smaller the radius of bend the greater will be the sidewall pressure on the cable in that bend. He will, therefore, hold the bends to the minimum, and, where unavoidable, will keep the angle of bend as small as possible and the radius of bend as large as possible.

INSTALLATION

Good design of a raceway system is the first step in the proper installation of cables. But good design alone will not guarantee that the cable will be installed and connected without damage.

Conduit Installation

Adequate reaming of metallic conduit and cleaning to remove cuttings, fillings, and cutting oil are required. Field bending of conduit must provide bends of acceptable radii without undue flattening of the conduit. Conduits should be capped prior to cable installation to avert the presence of dirt and rocks.

Non-metallic ducts in underground installations should be mandreled and swabbed to confirm the integrity of the duct runs prior to installation. Manholes should be cleaned prior to cable installation and the proper location of pulling eyes in the manhole should be confirmed.

Pulling Equipment

The installer should be familiar with all pulling equipment necessary for the cable pull and all safety precautions associated with it.

Suitable pulling equipment, confirmed to be in good working conditions, should be on hand. Hydraulic pulling equipment with smooth, variable speed control is recommended.

The pulling line should be adequately sized to safely pull the cable into the raceway. The pulling line should be high strength, low stretch and abrasion resistant. Polypropylene pulling line is often selected for general use. Manila hemp is satisfactory although it has a lower tensile strength than polypropylene. Ropes made of aramid and some polyesters are also very good. Unstressed nylon is not acceptable due to its high stretch characteristics.

Pulling lines under tension can sometime impart a torque on the cable which may cause cable rotation. The proper use of an adequately sized swivel joint placed between the line and the cable pulling eye/bolt should prevent this condition. Swivels that lock up at prescribed tensions should not be used as they cause the power cables to cross, resulting in possible damage. A torque balance pulling line will also help eliminate cable rotation.

A dynamometer to measure the pulling tensions should be used at the pulling end of the installation and the value recorded for each pull. Three sheave, direct-reading dynamometers are available, but many in general use are not of the direct-reading type. The method for translating the dynamometer reading to actual pulling tension is given in Appendix 1.

Cable in Storage

Proper storage and handling of cable prior to installation is required. Many instances of cable damage occur in moving reels, especially where fork lift trucks are used. Frequently cable is damaged when accidentally dropped from a loading dock or a truck bed.

Setting Up for a Pull

In this phase of the operation it is critical that the correct pulling direction has been determined in conformance with the calculations for pulling tensions and sidewall pressures.

Moving the cable reels into proper positions requires care. Damage has often occurred in this operation, especially if a “pull and cut” method of operation is used for several pulls at different locations. Once the protective covering is removed from a reel, the cable is particularly vulnerable.

For cable on reels, reel jacks or other adequate means must be utilized to support an axle to provide minimal friction. The axle must be properly selected to carry the load with minimal deflection in order to avoid excessive rotational friction between reel and axle. The axle/reel interface should be well greased to reduce reel back tension.

The operation must necessarily include proper procedures for feeding the cable into the conduit. Manhandling the cable, one or more journeymen per reel, may be entirely adequate to feed the cable into the raceway with zero tension at the point of feed.

Often a flexible cable guide or feed in tube is used when pulling cables from above grade, into a manhole and to the underground duct. The guide must be appropriately sized for the cable being pulled and the duct. A properly sized bell adapter and a duct adapter must also be used with the guide to assure the cable is not

damaged either entering or exiting the guide. Cable must be fed into the guide with little or no back tension.

Consider the case of feeding three 500 kcmil cables into a surface mounted junction box thirty feet above the floor. A feed-in tube and properly sized sheaves will be required to do a proper job if the cable reels are set up on the floor below. Pulling the cable from the floor into the box without proper rigging produces considerable tension in the cable at point of conduit entry and will very probably damage the cable at that point. Pipe rollers are frequently used, but in general they are not acceptable. A single 4-inch pipe nipple rotating on a smaller nipple, used as an axle, provides a bending radius well below the minimum training radius for these installed cable, with the rotational friction being relatively high. This is to say nothing of the sidewall pressures that would be generated during installation.

Approved lubrication in ample quantity must be on hand in preparation for the installation.

Pulling equipment must be set in proper position to accommodate the rigging of the dynamometer.

For short, easy runs, pulling by hand may be satisfactory, but for a run of substantial length or one involving several changes of direction, proper pulling equipment is preferred. Pulling by hand moves the cable by jerks and stops, while the application of many hands to the pulling line can damage the cable.

Cable Pulling Devices

Manufacturers can provide a pulling eye or pulling bolt to the leading end of the cable on the reel. These devices usually consist of a long barrel aluminum ferrule which is compressed onto the exposed conductor. A temporary seal is made over the remaining exposed conductor using tape and/or a heat shrink sleeve. This seal is to help prevent water from entering the cable during the pull.

Once the cable has been installed, the pulling attachment is to be immediately removed and the cable cut end resealed with a heat shrink or cold shrink end cap. The use of tape as an end seal is inadequate.

The factory applied pulling device having gone through the rigors of installation, cannot be considered a permanent water tight seal.

Pulling the Cable

It is important that two-way voice communication is available before and during the installation.

Cable should be pulled at constant velocity, not to exceed 50 feet per minute and not to be less than 15 feet per minute.

Do not let the cable on the reel become loose and form loops. Un-tensioned loops transmit back toward the test hole in reel resulting in the cable backing out of the reel. A small amount of tension on the reel minimizes backout. Similarly, the cable at the test hold should not be restricted or covered. If restricted, any looseness in the reel will result in the cable near the drum being forced between the cable above, aka Z-ing.

At the beginning of the pull the angle formed between the two segments of pulling line around the sheave in the dynamometer must be carefully estimated and recorded to accurately translate the dynamometer reading to pull tension. Dynamometer readings should be taken periodically during the pull and recorded.

If basket grips are used, sufficient slack must be pulled to remove at least one foot of cable beyond the inside end of the grip.

At the feed end during the pull, care must be exercised to avoid crossovers in the cable.

Lubricant should be applied liberally and continuously during the pull.

Pulling through manholes should be avoided. Whether the pull is straight through or around a bend the cable can be damaged. In either case slack will be required and getting this slack after the cable is pulled from feed point to pulling point can damage the cable. If sheaves are used in manholes to change direction they must be of proper size. Trolley assemblies consisting of several small diameter sheaves mounted in an assembly given the appearance of increasing the radius of bend, but this is deceptive. Care must be taken so that the apparent overall radius of the

sheave arrangement does not violate any of the criteria for minimum bending radius.

When using these sheave assemblies, the maximum sidewall pressure for the apparent overall radius shall not be exceeded. Even though good quality sheaves are treated as frictionless and tension increase is not imputed to them, extreme care and good judgment must be exercised in their use.

Once the cable is pulled, steps must be taken to protect it. Cable is frequently damaged during this phase of the installation, particularly if it is not trained into final position and terminated or spliced immediately. Consider as one example cable pulled into a pull box above switchgear with sufficient slack to be installed subsequently in riser conduits extending from the top of the switchgear. During this period the relatively long lengths of cable are allowed to hang out the face of the box and over an edge of the box. In order to keep the space below clear, the cable is coiled and tied below the box awaiting a more convenient time for installation in the switchgear. This practice and practices like it have caused damage.

Condulets

The general use of standard condulets should be avoided. The space is limited, the bend radius is small and many cases of damaged cable have occurred in the use of the ninety degree turn type. Cable should never be pulled through these types, nor should substantial lengths of cable in conduit riser be supported by the condulets.

See Part II - Section 8-d for minimum training radii of installed cables under static loading. In no case should cable be hammered into a conduit in order to fasten the conduit cover.

Splicing and Terminating

The mechanics of good splicing and terminating techniques are special subjects not covered in this Guide. However, both splicing and terminating require training the cable into final position. Minimum training radii must be observed. The conduit hickey is not a suitable tool for training cable. Special forming tools can be fashioned or purchased that will produce acceptable radii without cable damage.

Installing Cable in Tray

Many of the recommendations and prohibitions offered with regard to the installation of cable in conduit apply to the installation of cable in tray. Particularly relevant are the admonitions regarding the use of sheaves, and the temporary drooping of cable over sharp edges. (See “System Considerations”)

Where cable is fastened to tray, extreme care must be exercised to avoid deforming the cable under the fasteners. If nylon fasteners are used the tension limiting tools should be used.

Since cable is exposed in cable tray, it is very vulnerable to damage during installation. This damage can be occasioned not only by electrical crews but by other crafts. Protection of cable during construction requires special attention.

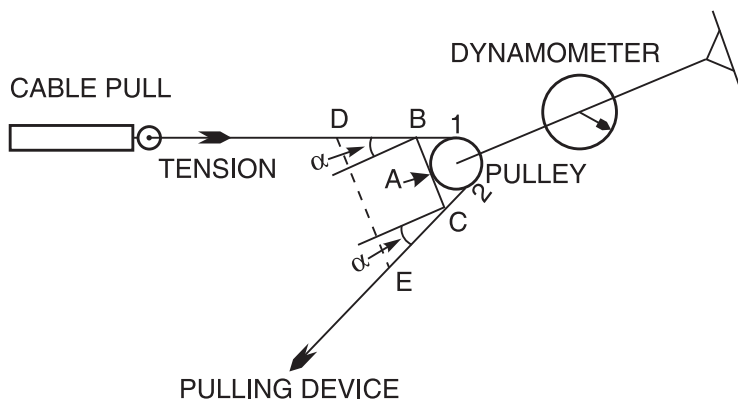
Specific Prohibitions

Do not pull cable into a conduit that already contains conductors.

Do not attempt to remove a portion of the cables in a conduit.

Do not remove cable from a conduit and then reinstall any of that cable in conduit for permanent use.

DYNAMOMETER READING



To Find α

1. Using a wooden stick or other rigid straight object and holding object tangent to pulley at Point "A", measure distance where object crosses pulling lines and let this distance equal BC, with distance B1 = C2. 1 and 2 are point of tangency between the pulling line and the pulley.
2. Starting at Point "B", measure the distance BC along the pulling line and mark this distance "D". Thus, BD = BC.
3. Starting at Point "C" once again measure the distance BC along this side of pulling line. Thus, CE = BC.
4. With Points "D" and "E" suitably marked, measure the distance from "D" to "E" and record DE.

$$\sin \alpha = \frac{DE - BC}{2 BC}$$

Once is known, then tension can be calculated from reading.

$$\text{Tension} = \frac{\text{Meter Reading}}{2 \cos \alpha}$$

NOTE: Dynamometer must be zeroed with pulley assembly attached or else the weight of pulley assembly must be subtracted from meter reading.

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<u>α</u>	<u>Sin α</u>	<u>2 Cos α</u>
0	0	2
11.5	.2	1.96
17.5	.3	1.91
23.6	.4	1.83
30	.5	1.73
36.8	.6	1.60
45	.71	1.41
53.1	.8	1.20
58.2	.85	1.05
64.2	.9	.87

Example:

Assume measure BC = 40 inches

After marking off BD and CE equal to 40 inches

DE is measured to be 84 inches

$$\sin \alpha = \frac{84 - 40}{2(40)} = \frac{44}{80} = .55$$

Interpolating between .5 = 1.73 and .6 = 1.60

Then .55 = 1.665 or 1.67

Assuming meter reading is 2000 lbs, then

$$\text{Tension} = \frac{2000}{167} = 1198 \text{ lbs.}$$

APPENDIX 2

INSTALLATION PRACTICES
FOR CABLE RACEWAY SYSTEMS

CONDUIT SELECTION CHART -
THREE SINGLE OR MULTICONDUCTOR CABLES
Based on 40% Fill and to Avoid the
Jam Ratio of 2.8-3.2

Conduit Size	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6
Conduit I.D.	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	3.548	4.026	5.047	6.065
Area (sq. in.)	0.30	0.53	0.86	1.50	2.04	3.36	4.79	7.38	9.90	12.72	20.00	28.89
Cable Diameter (in.)												
0.000 - 0.193	X											
0.194 - 0.222		X										
0.223 - 0.227	X											
0.228 - 0.256		X										
0.257 - 0.294			X									
0.295 - 0.301			X									
0.302 - 0.326			X									
0.327 - 0.375				X								
0.376 - 0.383				X								
0.384 - 0.430				X								
0.431 - 0.493					X							
0.494 - 0.504					X							
0.505 - 0.575						X						
0.576 - 0.588						X						
0.589 - 0.645						X						
0.646 - 0.738							X					
0.739 - 0.754							X					
0.755 - 0.770							X					
0.771 - 0.882	UNACCEPTABLE SIZES							X				
0.883 - 0.901								X				
0.902 - 0.958								X				
0.959 - 1.096									X			
1.097 - 1.120									X			
1.121 - 1.267									X			
1.268 - 1.296										X		
1.297 - 1.438										X		
1.439 - 1.470										X		
1.471 - 1.576											X	
1.577 - 1.803											X	
1.804 - 1.844											X	

[illegible]

