Prepared by: ABB1

MINIMUM REQUIREMENTS FOR THE DESIGN AND INSTALLATION OF CONDUIT AND INSULATED CABLE

038193

Asset Type:	Electric Distribution	**Function:**	Design and Construction
Issued by:	Lisseth Villareal (LDV2)	**Date:**	11-01-18

Rev. #12: This document replaces PG&E Document 038193, Rev. #11 For a description of the changes, see Page 16.

Purpose and Scope

This document describes the minimum requirements for the design and installation of conduits and pulling insulated cables.

References	Location	Document
Installation of Three-Phase, 600-Amp, Subsurface Sectionalizing Switches	UG-1: Switches	050859
600-Amp Separable Insulated Connectors	UG-1: Terminations	051071
Request for Variance Distribution Standards	D2	TD-2951P-01
Installing Underground Cable in Conduit	TIL	TD-2002P-01
Horizontal Directional Drilling Manual	TIL	TD-4135M
Casings for Highway and Railroad Crossings	TIL	A–70
Casing Insulator and End Seals Selection Chart	TIL	A–73
Modular Wall and Casing Seal	TIL	A–74

Duct System Design

There are many variables involved in designing underground duct systems and installing cables that are peculiar to each installation and cannot be covered in this document. Some of these variables are listed below:

1. Physical requirements of the installation.
2. Limitations of available cable-pulling and reel-handling equipment.
   A. 1,000 pounds maximum for a single grip, 2,000 pounds maximum for two or more grips.
   B. 10,000 pounds maximum for reusable mechanical pulling eyes.
3. Number and radius of sweeps.
   A. Sidewall bearing pressure (1,000 pounds x radius).
4. Deflections, changes in direction, and obstructions encountered during conduit installation.
5. Coefficient of friction (COF) between cable and conduit surfaces.
6. Maximum allowable pulling tension for the cable size under consideration.

Conduit and Substructure Installation

Conduit and substructure installation must comply with the job design and construction documents. When deviation from the original design is required due to field conditions, the originating engineering department must be notified and will determine if the deviation will require additional substructures. Follow the variance request. See Utility Procedure TD-2951P-01.

It is preferred to install conduit around a bio swale. If is not feasible to go around the bio swale, primary and/or secondary conduits under the bio swale must be installed following the requirements below:

1. Option #1
   A. Install conduits with a minimum cover of 48” between the top of the conduit and the bottom of the bio swale.
   B. 6” sand bed below conduit

C. Use Schedule 40 PVC, and install a spare conduit

D. Install conduit 36” past bio swale on each side

E. 6” sand bed on top of conduit

F. Complete trench fill with native dirt

2. Option #2 (if option #1 is not feasible)

A. Install conduits with a minimum cover or 36” between the top of the conduit and the bottom of the bio swale.

B. 6” sand bed below conduit

C. Install Schedule 40 PVC, and install spare conduit

D. Run conduit 3’ past bio swale on each side

E. 6” sand bed on top of conduit

F. 3” Red Slurry Cap

G. Complete trench fill with native dirt

3. Option #3

A. Use horizontal directional drilling (HDD) to install conduits crossing under existing bio swales. For more information about HDD, Refer to TD-4135M.

B. The minimum depth burial for HDD is 48” from the bottom of existing bio swales.

Railroad crossing may require electric conduits installation in a casing via HDD. For information about casing specifications, casing sealing, casing spacers refer to A–70, “Casings for Highway and Railroad Crossings“, A–73 , “Casing Insulator and End Seals Selection Chart“, and A–74 , “Modular Wall and Casing Seal “.

Cable Installation

To minimize the possibility of cable damage during installation, the following design parameters must be followed:

1. The total number of factory bends installed in conduit run for primary cable must not exceed 300 degrees, including the bend at the feed-in location. Only factory bends are allowed.
2. The total number of factory bends installed in conduit runs for secondary cable and services having a maximum length of 200 feet must not exceed 315 degrees, including the bend at the feed in location. If the total length of conduit run exceeds 200 feet, then the total number of factory bends for secondary and service cable must not exceed 300 degrees.
3. The maximum length of any **straight conduit run** (no bends) must not exceed 1,200 feet.
4. The calculated pulling tension for the non-preferred (highest) direction must be used as the limiting pulling tension.
5. When the conduit run includes bends (300 degrees or less), the maximum length of the run must be limited to 800 feet.
6. For secondary, services, and 200-Amp primary applications, the conduit run must not exceed 600 feet if there is a vertical 90 degree bend at both ends of the conduit run.
7. The first 18 inches of conduits leaving any primary underground enclosure must be straight with no factory bends.

To avoid potential burn-through of sweeps, use polyester pulling tape (material code 560154) as the “P-Line” to initiate cable pulling. For further information refer to TD-2002P-01 “Installing Underground Cable in Conduit”.

For each primary cable run, the construction drawing must contain:

1. The calculated pulling tension.
2. A preferred direction of pulling.
3. The maximum allowable pulling tension.

4. A place to record the actual pulling tension and direction of pull.

The tension on the pulling line, as seen on the dynamometer, is dependent on the number of rollers and sheaves used to rig the pulling line and the angle between the line entering and leaving the device. Multiply the calculated pulling tension on the cable by 5% for each 90° bend of the rope.

The pulling equipment specified for a job should be capable of twice the calculated pulling tension. This is recommended due to the following variables:

A. Back tension.
B. Condition of the conduit.
C. Temperature of the conduit, cable, and the ambient air temperature.
D. Increase in friction due to rigging.
E. Static (start/stop) friction.

Combinations of the above could increase the actual pulling tension to twice (or more) of the calculated tension. Attention should be paid to minimizing these factors.

Cable Design

1. No more than one set of 600-Amp separable connectors is allowed in any one enclosure. One set means three 600-amp separable assemblies. Figure 1 below shows one 600-Amp separable assembly.
2. No more than three 600-Amp elbows are allowed in any one 600-Amp separable connectors.
3. No more than one set of 200-Amp taps (piggy-backed) off of a set of 600-Amp separable connectors is allowed
   A. A 200-Amp tap from a 600-Amp separable must be made with a load-break reducing tap plug (RTP) and a 200-Amp load-break elbow receptacle, as shown in Document 051071, "600-Amp Separable Insulated Connectors". See Figure 1.
   B. Only one such connection is allowed between two 600-Amp main line switches.

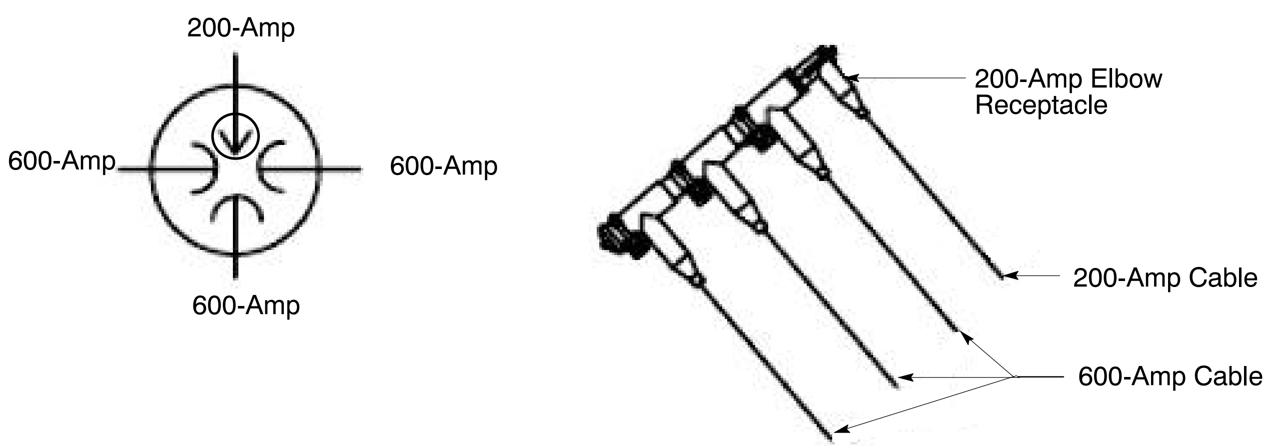


Figure 1
Allowed 600-Amp Separable Splice Assembly

4. Only one set of 600-Amp separable connectors is allowed between two 600-Amp main-line switches.
5. No more than four-ways of cable on a 600-Amp subsurface switch is allowed.
   A. A way is a conduit run from point A to point B. It can be one, two or up to three cables.
   B. It is not allowed to tap off (piggy-back) 600-Amp elbows on top of the other 600-Amp elbows on the same switch bushing at any time. See Note 8 under Cable and Equipment in Document 050859
   C. It is not allowed to tap off (piggy-back) 200-Amp taps off subsurface switches.
   D. Subsurface switch bushings that are rated at 600-Amps may be converted to 200-Amps by using a bushing extension and a 600/200-Amp tap/plug.
   E. 200-Amp taps that utilize 600-Amp bushing extensions are not considered piggy-back.

F. SCADA installation on 600-Amp subsurface switch is exempt from requirement 5 . However, whenever possible install SCADA on 600-Amp subsurface switches with no 200-Amp tap (piggy-backed).

6. No more than four-ways of cable on a 200-Amp pad-mounted or subsurface junction is allowed.

7. It is not permissible to use 1/0 cable adapters with 600-Amp separable connectors to make a 200-Amp tap. See Figure 2 on Page 4. Material code for the 1/0 cable adapters is still active to be used for replacement of existing facility only.

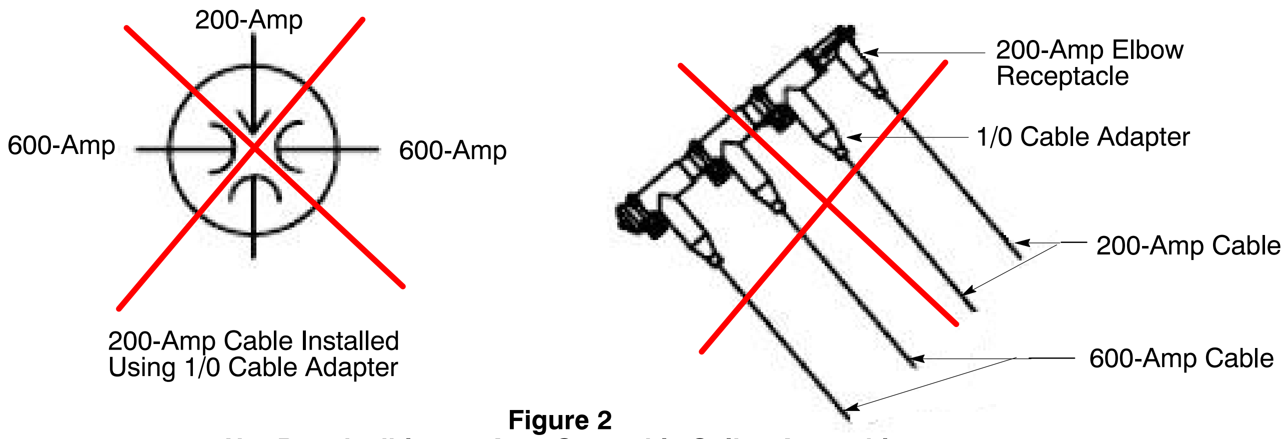


Figure 2
Not Permissible 600-Amp Separable Splice Assembly

8. When necessary, use one of the following two options to establish additional 200-Amp tap from existing mainline cables that already has 600-Amp separable with connectors one existing 200-Amp tap.

   A. Install a pad-mounted switch, such as PMI-9 or equivalent. This installation is preferred. See Figure 3 below.

   B. Install an additional 600-Amp separable connectors with 600-Amp 3-Way Switch, 3-Way Switched subsurface switch. See Figure 4.

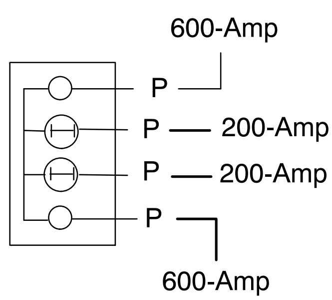


Figure 3
Pad-Mounted PMI-9 Interrupter (Switch-Interrupter-Interrupter-Switch)

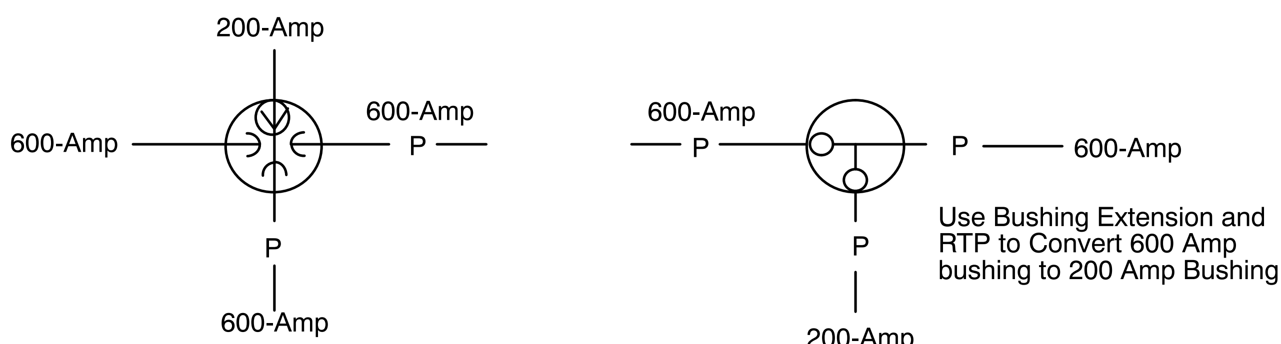


Figure 4
600-Amp 3-Way Switch, 3 Way Switched Subsurface Switch

9. Locate the protection devices as close as possible to the mainline tap when designing 200-Amp taps off the 600-Amp mainline. See examples in Figure 5, Figure 6, and Figure 7 on Page. 5

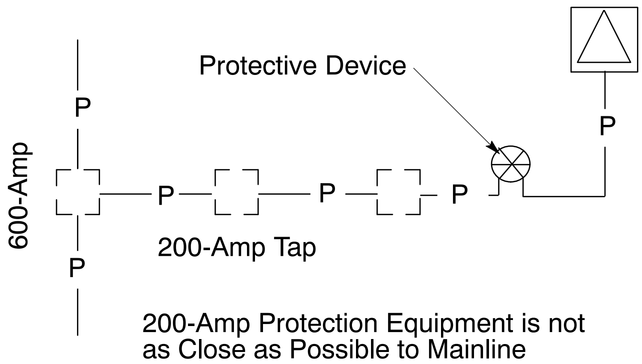


Figure 5
Bad Design

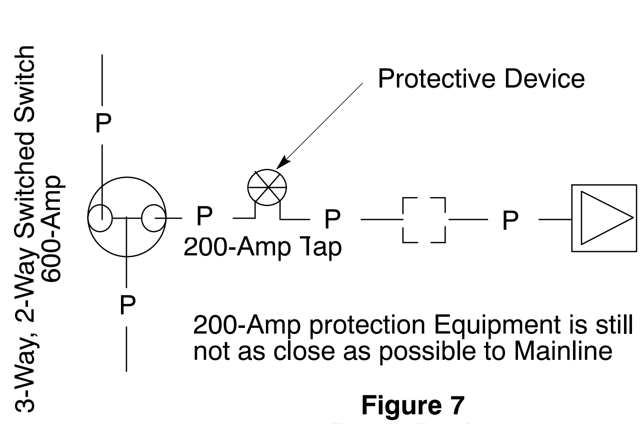


Figure 7
Better Design

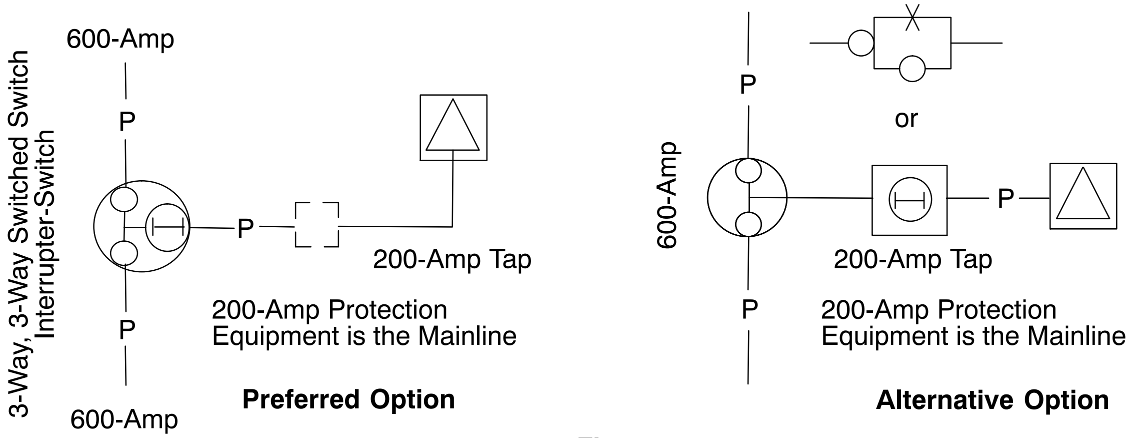


Figure 6
Best Design

Cable Installation

1. Cable manufacturers' warranties require the use of approved pulling practices and equipment.
2. Before starting any cable installation or removal operation, all employees must be thoroughly familiar with the safe operation of the equipment and methods to be used.
3. Provide a reliable means of communications between feed-in and pull-out locations before and during the entire operation.
4. Provide an adequate number of employees to safely install or remove the cable.
5. The conduit must be cleared of dirt, rocks, or other debris before starting the cable installation.
6. The practice of attaching the pulling rope to a vehicle and then driving the vehicle to pull in or remove cable may damage the cable and is prohibited.
7. All cable must be lubricated (pre-lubed) before installing (see Table 4 and Table 5 on Page 7).
8. The use of a dynamometer or inline tensiometer to monitor the pulling tension during cable installation is **recommended** for cable pulls where the calculated pulling tension is less than 50% of the maximum allowable pulling tension for the cable being installed.
9. The use of a dynamometer or inline tensiometer to monitor the pulling tension during cable installation is **required** for cable pulls where the calculated pulling tension is equal to or greater than 50% of the maximum allowable pulling tension for the cable being pulled.

10. All locations where the actual pulling tensions exceed the calculated tensions by more than 25% must be reported to the originating engineering department and analyzed to determine the cause of the difference. The information will be used to improve the design parameters as well as PG&E's cable-pulling practices.
11. The minimum radius bend that an insulated cable can be subjected to cannot exceed the results of the OD of the cable times the multiplier shown in Table 1 on Page 6.

Table 1 Minimum Allowable Cable-Bending Radius Multiplier

Type of Cable	Multiplier
P&L or PL&N	10
15 and 22 kV XLP-PVC	12
5–35 kV CONC-PVC, LLDPE Encap, or EPR-CONC-PE	8
600 V XLP and EPR&N	5 (500 kcmil and larger)
	4 (less than 500 kcmil)

12. The recommended amount of cable lubricant depends only on the size and length of the conduit system.

    The appropriate quantity for use on any given pull can vary from this recommendation depending on the complexity of the pull. Consider the following factors:

    A. Cable weight and jacket hardness (increase quantity for stiff, heavy cable).
    B. Conduit type and condition (increase quantity for old, dirty, or rough conduits).
    C. Conduit fill (increase quantity for conduit fills of 50% or greater).
    D. Number of bends (increase quantity for pulls with several bends).
    E. Pulling environment (increase quantity for high temperatures).
13. Front-end packs are conduit-sized polyethylene bags of lubricant. The packs are attached to the winch line, ahead of the cable, and are manually opened as they enter the conduit, pre-lubing the conduit. Codes for front-end packs are in listed Table 2.

Table 2 Pulling Lubricant

Description	Code
Front-End Pack 2" and 3" Conduit	500118
Front-End Pack 4", 5", and 6" Conduit	500117
Pourable Lubricant, 2.5-Gallon Container	500031
Pourable Lubricant, 5-Gallon Container	500099

14. Cable lubricant LZ type must be used when 500 kcmil and 750 kcmil Cu 15kV EPR flat strap with low smoke zero halogen (LSZH) jacketed cable is pulled through conduits. For more information regarding LSZH cable refer to Document 039955.
    Note: The use of standard pulling lubricant will have a negative impact on the physical integrity of the cable's LSZH jacket.

Table 3 Pulling Lubricant to be Used With LSZH Cable

Description	Code [1]
Lubricant, Squeezable Quart	500060

[1] 12 quarts is the minimum order quality.

15. Table 4 and Table 5 on Page 7 indicate the approximate amount of pulling lubricant for various cable pulls. Same tables apply for the lubricant LZ type.

Table 4 Pulling Lubricant Needed for 2”, 3”, and 4” Conduit

Pull Length (feet)	2” Conduit			3” Conduit			4” Conduit		
	Gallons Needed	Number of Front-End Packs	Pourable (gallons)	Gallons Needed	Number of Front-End Packs	Pourable (gallons)	Gallons Needed	Number of Front-End Packs	Pourable (gallons)
100	0.25	1	0	0.50	2	0	0.50	1	0
200	0.50	2	0	1.00	2	0.50	1.00	2	0
300	1.00	2	0.50	1.25	2	0.75	2.00	2	1.00
400	1.25	2	0.75	1.75	2	1.25	2.50	2	1.50
500	1.50	2	1.00	2.25	3	1.50	3.00	2	2.00
600	1.75	3	1.00	2.75	3	2.00	3.50	3	2.00
700	2.00	4	1.00	3.25	4	2.25	4.00	4	2.00
800	2.50	4	1.50	3.50	4	2.50	5.00	4	3.00
900	2.75	4	1.75	4.00	4	3.00	5.50	4	3.50
1,000	3.00	4	2.00	4.50	4	3.50	6.00	4	4.00

Table 5 Pulling Lubricant Needed for 5” and 6” Conduit

Pull Length (feet)	5” Conduit			6” Conduit		
	Gallons Needed	Number of Front-End Packs	Pourable (gallons)	Gallons Needed	Number of Front-End Packs	Pourable (gallons)
100	1.00	2	0	1.00	2	0
200	1.50	3	0	2.00	2	1.00
300	2.50	2	1.50	2.50	3	1.00
400	3.00	2	2.00	3.50	3	2.00
500	4.00	2	3.00	4.50	3	3.00
600	4.50	3	3.00	5.50	4	3.50
700	5.50	4	3.50	6.50	4	4.50
800	6.00	4	4.00	7.00	4	5.00
900	7.00	4	5.00	8.00	6	5.00
1,000	7.50	5	5.00	9.00	6	6.00

Formulas and Parameters

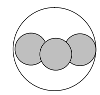
Notes

1. The formulas and parameters used in this document are widely used in the utility industry. The parameters that must be checked are: **Conduit Fill, Cable Configuration, Minimum Bending Radius, Cable Jamming Potential, Cable Clearance, Maximum Pulling Tension, and Sidewall Bearing Pressure Limits.**
2. Cable Jamming

   Jamming is a condition that may occur if the sum of the cable diameters is about equal to the inside diameter of the conduit. It will typically occur at bends when one cable is forced between the other two cables and wedges them against the inner wall of the conduit. Jam ratios between 2.8 to 3.1 should be avoided to prevent the possibility of the cables jamming at a sweep. Use the formula given below to calculate jam ratio.
3. Jam Ratio Formula

   J = 1.05 D/d

   Where:
   J = Jam ratio
   D = Conduit inside diameter (inches)
   d = Cable nominal diameter (inches), one cable

   Check the probability of jamming using the formula: J = 1.05 D/d
   1.05*J = (p) probability of jamming

   - If the value J is less than 2.5, jamming is unlikely to occur.
   - If the value J is Between 2.6 and 3.1, jamming is very possible.
   - If the value J is greater than 3.1, jamming is unlikely to occur.

   The 1.05 factor is to account for the oval shape of the bends in the section view.
4. Coefficient of Friction

   A coefficient of friction value of 0.30 is recommended for lubricated PVC or PE conduits.
5. Minimum Bending Radius

   The multipliers for determining the minimum cable bending radius for commonly used cables are listed in Table 1 on Page 6.
6. Percent Conduit Fill

   Conduit fill is the percentage of area inside the conduit taken up by the cable(s).

   A. The recommended maximum percentage of conduit fill is shown in Table 6 on Page 14.

   B. The total combined percent conduit fill ratio of PG&E electric supply cable and fiber optic cable (FOC) must not exceed 75%.

   C. For new construction, the conduit is usually sized for the next-larger size of cable.

Formulas and Parameters (continue)

Table 6 Recommended Maximum Conduit Fill

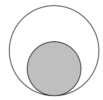
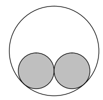
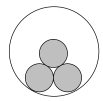
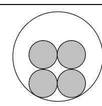
Number of Cables	Example	Percent of Total Internal Area of Conduit to Be Filled by Cable
1		60
2		40
3		55
4		55

Table 7 Percent Fill for Common Cable/Conduit (DB 120) Combinations

	Type of Cable	2”	3”	4”	5”	6”
600 V	1/0 Triplex	15%	7%	–	–	–
	4/0 Triplex	24%	11%	–	–	–
	350 kcmil Triplex	–	18%	11%	–	–
	750 kcmil Triplex	–	32% [1]	19%	13%	9%
	1,000 kcmil Triplex	–	–	25%	17%	–
	1/0 Quadruplex	20%	9%	–	–	–
	4/0 Quadruplex	–	15%	9%	–	–
	350 kcmil Quadruplex	–	24%	15%	10%	–
	750 kcmil Quadruplex	–	–	27%	18%	13%
	1,000 kcmil Quadruplex	–	–	35%	24%	16%
15 kV	3-#2 AWG, Cu-EPR	–	21%	13%	–	–
	3-350 kcmil, Cu-EPR	–	–	26%	17%	12%
	3-500 kcmil, Cu-EPR	–	–	31%	20%	14%
	3-750 kcmil, Cu-EPR	–	–	42%	28%	19%
	3-1,100 kcmil, Cu-EPR	–	–	–	38%	26%
25 kV	1-1/0, Al-EPR	32%	–	–	–	–
	3-1/0, Al-EPR	–	–	27%	–	–
	3-600 kcmil, Al-EPR	–	–	–	38%	26%
	3-1,100 kcmil, Al-EPR	–	–	–	47%	34%
	3-1,100 kcmil, Cu-EPR	–	–	–	48%	34%

[1] Although percent fill is less than 55%, it is difficult to pull 750 kcmil triplex in 3” conduit. It is acceptable to pull 750 kcmil triplex in existing 3” conduit . New construction should use 4” conduit.

7. Sidewall Bearing Pressure (SBP)

   Sidewall pressure is exerted on a cable as it is pulled around a bend. **The following limits are recommended:**

   A. SBP = 500 pounds/foot for one solid dielectric cable (XLPE or EPR insulation).

   B. SBP = 1,000 pounds/foot for two or more solid dielectric cables (XLPE or EPR insulation).

   C. SBP = 300 pounds/foot for PILC (lead) cables.

Formulas and Parameters (continued)

8. Weight Correction Factor

   This is an important factor to calculate because when you pull two or more cables in a conduit, the sum of the forces developed between the cables and the conduit is always greater than the sum of the individual cable weights. When you have three single cables of equal diameter and weight, you can expect a higher weight factor for the cradled position than the triangular position. Assume that the cables will sit in the cradled position (unless you are pulling triplexed cables from a single reel), because this will yield a higher and therefore more conservative pulling tension calculation.

   For one or two cables

   $$w_{single} = 1$$

   For three cables in a cradled configuration
   Where 3 > J > 2.5

   $$w_{cradled} = 1 + 4/3\ (d/D - d)^2$$

   For three cables in a triangular configuration
   Where J < 2.5

   $$w_{triangular} = 1 \div \sqrt{1 - (d/D - d)^2}$$

   For four cables (quadruplex) in a diamond configuration
   Where J < 3.0

9. Maximum Allowable Pulling Tension

   The maximum allowable pulling tension is the lesser of the allowable tension on the pulling device and the maximum pulling tension that can be applied to the conductors.

   Definition of symbols:
   w = Weight Correction Factor
   f = Coefficient of Friction
   W = Cable Weight, pounds per foot
   L = Length of conduit run, in feet

10. Equations to calculate pulling tension formulas

    A. Tension, Horizontal Straight Section

    $$T_{out} = wfWL + T_{in}$$

    B. Tension, Natural or Factory Bend Section (except for “D” below)

    $$T_{out} = T_{in}\cosh(wf\theta) + \sinh(wf\theta) \times \sqrt{T_{in}^2 + (WR)^2}$$

    Where: $\sinh(wf\theta) = (e^{wf\theta} - e^{-wf\theta}) / 2$
    $\cosh(wf\theta) = (e^{wf\theta} + e^{-wf\theta}) / 2$

    And θ = Angle of bend, in radians
    R = Sweep radius
    e = 2.718

    C. Tension, inclined and Vertical Straight Section

    (1) Pulling up a Straight Section

    $$T_{out} = WL(\sin(\theta) + wf\cos(\theta)) + T_{in}$$

    Where: θ = Angle of incline

    (2) Pulling down a Straight Section (utilize equation for horizontal straight section)

    $$T_{out}\ wfWL + T_{in}$$

Formulas and Parameters (continued)

D. Tension, Convex Bend at Top of Incline, Upward Pull

$$T_{out} = T_{in}\, e^{wf\theta} + (WR / (1 + (wf) 2)) [2wfe^{wf\theta} \sin\theta + (1 - w^2 f^2)(1 - e^{wf\theta} \cos\theta)]$$

Where: θ = Angle of bend (same as angle of slope)

R = Sweep radius

e = 2.718

11. When cable is pulled through a conduit bend or around a sheave, sidewall bearing pressure (SBP) develops between the cable wall and the bend or sheave. This pressure has a dramatic effect on the sizing of the conduit system, because it relates directly to the radii of bends, pulling tension and cable's weight.

For single cable:

$$SBP = T \div R$$

For 3 cables in cradled configuration:

$$SBP = [(3w_{cradled} - 2) T] \div 3R$$

For 3 cables in triangular configuration:

$$SBP = (w_{triangular} T) \div 2R$$

For 4 cables in diamond configuration:

$$SBP = (w_{diamond} - 1) (T \div R)$$

12. It is necessary to have adequate clearance between the uppermost cable and the top of the conduit to ensure a safe and easy pull. For straight pulls, a clearance of 1/4" is safe. For pulls that include bends, a clearance of 1/2" to 1" is needed. Use the outside diameters of the circumscribing circle listed on Document 039955 to determine cable clearances.

Determining Pulling Tension for Sections Containing Sweeps

Example

Given:

- Conduit layout as shown in Figure 8.
- Conduit size 6 inch, 6.11”.
- Size of cables: three 1/C 1,100 kcmil Al. EPR-CONC-Encap PE, 25 kV.
- Weight of cable = 3 x 2.36 lbs. = 7.08 pounds/foot.
- Coefficient of Friction = 0.30

Find:

- If cable can be pulled without damage.
- Best direction of pull.
- What type of pulling attachment can be used.

1. The first step is to calculate conduit fill in percent:

   d = 2.05” from Document 039955.

   D = 6.11” From Table 10-3 of the *Electric Design Manual.*

   r = d/2 = 1.025”

   Cable Area = $3\pi\ (d/2)^2$ or Cable Area = $3\pi r^2$

   Cable Area = 9.902 in ^{2}

   Conduit Area = $\pi\ (D/2)^2$

   Conduit Area = 29.321 in ^{2}

   Conduit Fill = (Cable Area/Conduit Area)*100%

   Conduit Fill = 33.771%

   This is less than the 55% percent conduit fill allowed.

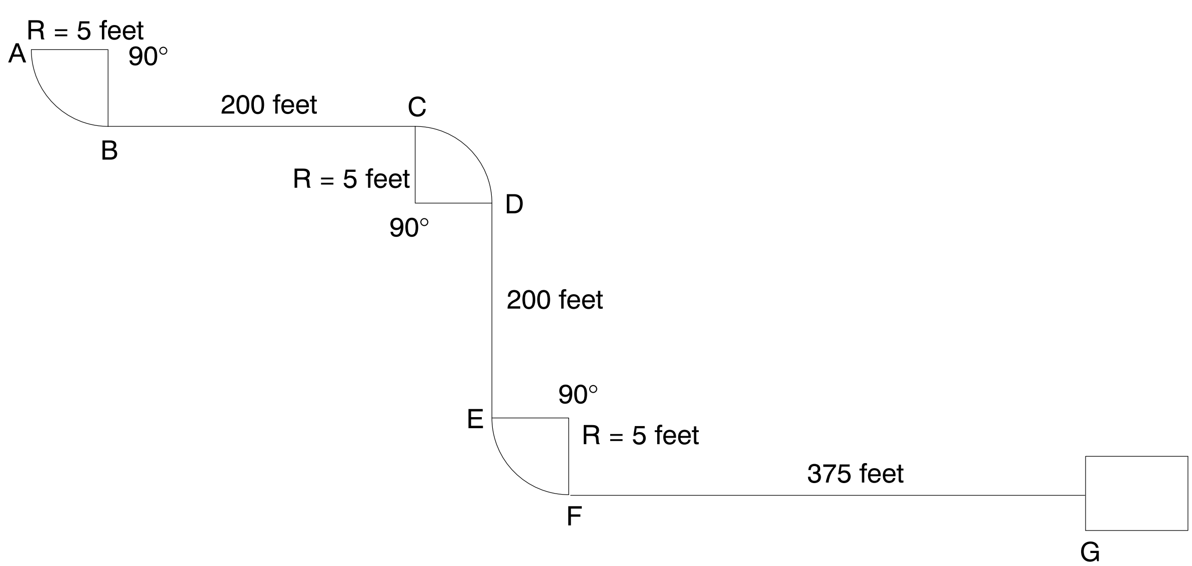


Figure 8
Typical Duct Layout

Determining Pulling Tension for Sections Containing Sweeps (continued)

2. The next step is to calculate the jam ratio to determine the cable configuration and the probabilities of cable jamming.

   $J = D/d = 2.98$

   Since this ratio is larger than 2.5 but less than 3, it is assumed that the cables are going to be in the cradled configuration. Cable clearance does not need to be checked.

   Check the probability of jamming by using the following formula:

   $\mathbf{J = 1.05\ D/d}$

   $\mathbf{J = 1.05*2.98 = 3.13}$

   In this case the probability of jamming is greater than 3.1; therefore, jamming is not expected to happen.

3. The next step is to calculate the weight correction factor for this cable:

   $w_{cradled} = 1 + (4/3)*(d/D-d)^2 = 1.339$

4. We can now proceed to calculate the pulling tensions:

   $T_{in} = 0$ **Tension at A!**

   Tension at B is calculated using the formula for horizontal bend section:

   $W = 7.08$ **lbs/ft** $R_{AB} = 5$ **ft** $f = 0.2$ $\theta = p/2$

   $T_{AB} = T_{in}\cosh(w_{cradled} f\theta) + \sinh(w_{cradled} f\theta)\sqrt{T_{in}^2 + (WR_{AB})^2}$

   $T_{AB} = 0 + (0.674)\sqrt{0 + (35.4)^2}$

   $T_{AB} = 23.85$ **lbs**

   Tension at C is calculated using the horizontal straight section formula:

   $L_{AB} = 200$ **ft** $T_{BC} = w_{cradled} fWL_{AB} + T_{AB}$ $T_{BC} = 568.81 + 23.85 = 593$ **lbs**

   Tension at D is calculated using the formula for horizontal bend section:

   $R_{CD} = 5$ **ft**

   $T_{CD} = T_{BC}\cosh(w_{cradled} f\theta) + \sinh(w_{cradled} f\theta)\sqrt{T_{BC}^2 + (WR_{CD})^2}$

   $T_{CD} = 715.02 + 400.22 = 1{,}115$ **lbs**

   Tension at E is calculated using the pulling down straight section formula.

   $L_{DE} = 200$ **ft** $T_{DE} = wfWL_{DE} + T_{cD}$ $T_{DE} = 568.81 + 1{,}115 = 1{,}684$ **lbs.**

   $T_{EF} = 3{,}165$ **lbs**

   $T_{FG} = 4{,}232$ **lbs**

   Since this tension exceeds the maximum allowable tension of 2,000 lbs. on pulling grips (see Table 8 on Page 15), pulling eyes are needed for this pull (10,000 lbs. limit). Also, the maximum tension on the conductor can be calculated as follows:

   A_C **= Area in cmil** **cmil =** mil^2 N_c **= Number of Conductors**

   S_c **= 0.008 lbs/cmil Maximum Stress on Al or Cu conductors!**

   The area of 1,100 kcmil is: $A_c = 1{,}100{,}000$ **cmil and** $N_c = 3$

   $T_{conductor} = N_c S_c A_c = 26{,}400$ **lbs**

Determining Pulling Tension for Sections Containing Sweeps (continued)

The maximum allowable tension on these cables is the lesser value of the calculated tension on the conductor(s) and the maximum tension on the pulling device. In this case, the 10,000 lbs limit on the pulling eye is the maximum allowable tension. Refer to Table 8 on Page 15 through Table 10 on Page 16 for the maximum allowable tension on PG&E’s cables.

Reverse Direction Calculations

Tension at F is calculated as follows:

L_{FG} = 375 ft. T_{in} = 0

$T_{GF} = w_{cradled} fWL_{FG} + 0$ = 1,067 lbs

T_{FE} = 2,006 lbs
T_{ED} = 3,422 lbs
T_{DC} = 6,432 lbs
T_{CB} = 7,001 lbs
T_{BA} = 13,158 lbs

Since the pulling tension from G to A is greater (13,158 lbs.) than the pulling tension from A to G (4,232 lbs.), and pulling tension from G to A exceeds the 10,000 lbs maximum allowable tension on the puling eye, cable must be pulled in the direction from A to G.

5. Finally, the sidewall bearing pressure limits need to be checked at the bends.

The pulling tensions at B and D are not very significant, but the tension at F may be a concern in terms of sidewall bearing pressure.

$SBP = [(3w_{cradled} - 2)T_{EF}]/3R_{EF} = [(3*1.339 - 2)*3,165]/15$
SBP = 426 lbs/ft

As we can see, the limit of 1,000 lbs/ft for two or more solid dielectric cables is not exceeded at the bend between points E and F.

However, if any of the limits are exceeded, consider one or more of the following options:

- Increase bend radii.
- Decrease conduit fill.
- Reduce the number of bends.
- Try reverse pull.
- Pull in stages.
- Decrease length of pull.

Maximum Allowable Pulling Tensions for Various Cable Rating, Sizes, and Configurations

Table 8 Maximum Allowable Pulling Tensions for 1/C Aluminum or Copper XLP or EPR Insulated Cables

Cable Rating	Cable Size AWG or kcmil	Maximum Allowable Pulling Tension (lbs.)					
		1/C per Duct		2/C per Duct		3/C per Duct	
		Grip	Pulling Eye	Grip	Pulling Eye	Grip	Pulling Eye
600 V Through 35 kV	#4	334	334	668	668	668	668
	#2	531	531	1,062	1,062	1,062	1,062
	1/0	844	844	1,688	1,688	1,688	1,688
	2/0	1,000	1,065	2,000	2,130	2,000	2,130
	4/0	1,000	1,693	2,000	3,386	2,000	3,386
	250	1,000	2,000	2,000	4,000	2,000	4,000
	350	1,000	2,800	2,000	5,600	2,000	5,600
	500/600	1,000	4,000	2,000	8,000	2,000	8,000
	700	1,000	5,600	2,000	10,000[2]	2,000	10,000[2]
	750	1,000	6,000	2,000	10,000[2]	2,000	10,000[2]
	1,000/1,100	1,000	8,000	2,000	10,000[2]	2,000	10,000[2]
	1,500	1,000	10,000[2]	–	–	–	–

[2] Limited by cable pulling and reel handling equipment.

Table 9 Maximum Allowable Pulling Tensions for 1/C Copper P&L and PL&N Cables

Cable Rating	Cable Size AWG or kcmil	Maximum Allowable Pulling Tension (lbs.)					
		1/C per Duct		2/C per Duct		3/C per Duct	
		Grip	Pulling Eye	Grip	Pulling Eye	Grip	Pulling Eye
1 kV	1/0	–	–	–	–	475	1,265
	250	–	–	–	–	677	3,000
	500	458	3,000	–	–	916	6,000
	750	571	4,500	–	–	1,141	9,000
	1,000	674	6,000	–	–	1,349	12,000
	1,500	897	9,000	–	–	–	–
5 kV	#4	–	–	415	501	415	501
	#2	–	–	460	796	460	796
	2/0	–	–	597	1,600	597	1,600
	250	–	–	725	3,000	725	3,000
	500	512	3,000	–	–	1,025	6,000
	750	631	4,500	–	–	1,262	9,000
15 kV	#4	–	–	653	653	653	653
	#2	–	–	693	796	693	796
	2/0	–	–	733	1,600	733	1,600
	250	–	–	916	3,000	916	3,000
	500	622	3,000	–	–	1,244	6,000
	750	750	4,500	–	–	1,498	9,000
	1,000	700	6,000	–	–	1,400	10,000[1]
	1,500	857	9,000	–	–	–	–
	2,000	1,008	10,000[1]	–	–	–	–
25 kV	#2	–	–	–	–	800	1,060
	250	–	–	–	–	928	3,000
	500	–	–	–	–	1,181	10,000[1]

[1] Limited by cable pulling and reel handling equipment.

Table 10 Maximum Allowable Pulling Tensions for 3/C Copper PL&N Cables, 1/C per DuctRevised

Cable Rating	Cable Size AWG or kcmil	Maximum Allowable Pulling Tension (lbs.)	
		Grip	Pulling Eye
5 kV	#2	464	1,194
	2/0	510	2,400
	250	657	4,500
	500	875	9,000
15 kV	#2	708	1,195
	2/0	840	2,400
	250	866	4,500
	500	1,150	9,000
	750	1,434	10,000[1]

[1] Limited by cable-pulling and reel-handling equipment.

Revision Notes

Revision 12 has the following changes:

1. Added Documents TD-2002P-01, TD-4135M, A-70, A-73, and A-74 to References section on Page 1.
2. Revised text for various notes on Page 2.
3. Revised Notes 1 – 3 on Page 3.
4. Added Note 4 on Page 3.
5. Revised Notes 8 – 9 and Figure 3 on Page 4.
6. Revised Figure 7 on Page 5.
7. Updated Table 7 on Page 9.