Cable Pulling Analysis (CPA)
Spreadsheet Revision 4

DOCUMENTATION
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1.1 Overview

FortisAlberta’s design standards lay down guidelines for calculating underground cable pulling tensions to assure the stated standard limits for tension and side wall bearing pressure (SWBP) are not exceeded in the design of underground electrical systems. The Cable Pulling Analysis (CPA) spreadsheet has been published for use by commercial customers to assist in the design of underground electrical systems. FortisAlberta holds no responsibility or legal obligation through this spreadsheet or documentation. Users must have the calculations verified by a professional Engineer or perform their own calculations in order to calculate the pull tension and resulting pull limitations. Additional limitations such as limitation on pulling equipment may also apply that are not calculated in this version on the CPA.

1.2 References

- Electric Power Research Institute (EPRI) EL333 “Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables” - Volume 1 “Research Data and Cable Pulling Parameters”
- Electric Power Research Institute (EPRI) EL333 “Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables” - Volume 2 “Cable Users Guide” (hereinafter referred to as “EL3333”)
- Pirelli Cables and System Inc, “Pirelli Wire and Cable Engineering Guide” (hereinafter referred to as “Pirelli”).

1.3 CPA Features

**Lubrication**

The CPA allows for reduced coefficients of friction from lubrication based on research performed by American Polywater. The CPA also estimates the volume of lubricant needed, based on an assumed thickness of 0.254 mm.

**Unique Wire Data Entry**

If non-standard cables are used, the CPA allows the user to enter wire data specific to the cable to be used.

**Reel Tension**

CPA permits entry of an allowable reel tension. Reel tension helps prevent surging during the pull. The standard values are 50 lb (222 N) for simple systems and 100 lbs (444 N) for more complex systems. 250 lbs (1112 N) is used for pulling 500 MCM or 750 MCM.

**Method of Cable Attachment**

The CPA allows the user to select what type of grip attachment will be used to pull the cable(s). Standard grips include basket grip, placed either around multiple cables or with one grip per cable. Aluminum Compression (bolting cable directly to the pulling grip) is also included as an additional option for complex pulls. An error note will appear beside
the number of cables selected if the method of cable attachment is not compatible with the cable type or number of cables.

**Groove Snag Potential**
This is mentioned in EL3333. The CPA calculates this as a cautionary result, based on the EL3333 details but adjusted to three levels of “acceptance”. The pulling rope will always, it seems, wear a groove in the bends and this criteria is looking for any potential for the cable to snag in those grooves.

**Pull Box**
The CPA permits a pull box location to be entered as a section and the calculation evaluates both the forward and rear segments accordingly. Maximum tension and SWBP analysis only evaluates on the worse condition from either segment.

**Underground Blocks**
Underground blocks are commonly used in field pulls at the start, end or in pull boxes. They are used to assist in moving cable through bends with minimal addition of friction and tension to the pull.

**Backward Pull Tension**
The CPA can do this with the click of a button. It was felt this might be a feature to assure a cable can be pulled back (for any reason) in a complex system.

**Cable Jam Ratio**
This ratio evaluates the likelihood of a number of cables jamming inside the duct or conduit based on the ratio of diameters.

**Combined Tension of Pull Rope and Cable**
The CPA does not evaluate the effect of both the rope and cable being pulled at the same time and instead calculates the tension when the rope or cable is in full length in contact with the conduit within the system (i.e. maximum loads only). It may be that, if a higher $\mu$ for the pull rope is incorporated later, the combined effect can be analyzed.

**Maximum Allowable Pulling Tension and SWBP**
The CPA calculates the maximum expected pulling tension and resulting SWBP and compares them to the limits listed in Table 4.12 and 4.21. It also performs these calculations for non-standard cables if used.

**Minimum Cross-Sectional Area Used**
The CPA also incorporates (as a designer check) the ratio for cable cross-sectional area to duct area (from Rule 12-1014 and Table 8 of CEC C22). This percentage is based on amperage and temperature considerations for the electrical cable de-rating/heating aspect of design.

**Clearance**
The CPA incorporates the clearance between the cables outside diameter and the inside duct diameter for both round and USEB cables.

**Plan View and Profile**
The CPA automatically generates a plan view and profile of the underground system, as the designer enters each of the system sections. It also calculates the total length of cables required
PART 2   User Information

This part describes, in general terms, the contents and use of the spreadsheet.

Contents

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Sheet 1 ‘CPA’</td>
</tr>
<tr>
<td>2.2</td>
<td>Sheet 2 ‘Sketch’</td>
</tr>
<tr>
<td>2.3</td>
<td>Example of a System</td>
</tr>
<tr>
<td>2.4</td>
<td>Using the Spreadsheet</td>
</tr>
</tbody>
</table>
2.1 Sheet 1 “CPA”

Section 1: Conduit, Conductor and Pulling Apparatus Data

Conduit and conductor input is entered here. Optional values such as Lubrication and Basic Coefficient of Friction can be entered here.

Input

- **Conduit Type** is a drop-down list and contains frequently used conduits. Available conduits types include PVC, DB2, High Density Polyethylene (HDPE) and Trenchless Raceway (TR). Note that the nominal size of conduit is not necessarily the actual conduit I.D. or O.D. and that a different material of the same nominal diameter may have different I.D. or O.D. diameters.
- The **Conductor Type** field is also a drop-down list. The conductor and conduit specifications can be found in Sheet 3 “Data”.

Unique wire data can also be input by clicking on the check box which is right to the Conductor Type field.
• **Number of Cables** should be a positive whole number between one and five, inclusive, as the CPA cannot model more than five cables in one conduit. Enter USEB cable as number of USEB cables (don’t count cables within USEB cable).

• For small systems, “No Lubrication” may be sufficient. However if its final tension is larger than 70% of the maximum allowable tension then lubrication is required.

• **Initial Reel Tension** is the initial tension of the system; in most cases this is the resistance of the reel tension.

Output

• **Conduit I.D.**, inside diameter of the selected conduit, is the Conduit I.D. from Sheet 3 “Data”.

• **Nominal O.D.**, the outer diameter of the selected conductor, is Nominal OD from Sheet 3 “Data”.

• **Per Cable Mass** is the mass of a single selected conductor from Sheet 3 “Data”.

• **Standard Reel Length** is the reel length that the selected conductor generally comes in from Sheet 3 “Data”.

• **Configuration** is the configuration of the cables inside the conduit (see 4.9 Configurations), and is an auto-selection.

• **Weight Correction Factor** is the weight factor of the cables based on configuration (see 4.10 Weight Correction Factors).

• **Total Cables Unit Weight** is total weight of all the cables.

Non-Standard Applications

• In some cases the user may wish to use custom conduits and/or conductors. In order to use custom values sheet 1 “CPA” must first be unprotected. Then custom values can be entered into their respective fields. Another option is to add the conduit and/or conductor specifications to Sheet 3 “Data”. Review with the engineer as required.

Section 2: Design Data

System section data and system design information is entered here.
i) **Input**

- **Type** of conduit section to be used is selected: The drop-down list includes *Pull Box, Straight, Down, Up, Left, Right, Convex Down, Convex Up, End, Dip* and *Block* (any direction). However, the available section types are dependent on the preceding section (CPA logic). *Convex Up* and *Down* sections begin on an angle of $\theta$ and terminate at an angle of zero. *Convex Down* and *Up* sections begin at an angle of zero and terminate at an angle of $\theta$. For accurate results, sections must be compatible; however in large systems small discontinuities between sections may be acceptable (must turn off logic-check). *Straight* sections may have slopes or grades from $-90^\circ$ to $+90^\circ$ and should match the sections before and after (A $\pm45^\circ$ tolerance is given between slopes and right/left turns to allow for field practices. For straight sections with a grade greater than $\pm45^\circ$ the CPA requires that the conduit be leveled out to $0^\circ$ before putting in a left/right section). An underground cable system may include several segments, separated by pull boxes. Inserting a *Pull Box* represents a section that terminates the preceding segment and a new system segment begins. The CPA results of each segment are analyzed but only the greater result is evaluated in the CPA Section 3.

- **Initial Reel Tension** is the initial tension at the first section or at a selected pull box; in most cases this is the back tension resistance of the reel.

- **Length** is the length of a *Straight* section or *Dip*, when either selected.

- **Grade** is grade of a *Straight* section (as an angle), when it is selected.

- **Angle** is the sweep of a bend when *Down, Up, Left, Right, Convex Down, Convex Up* or *Block* (of the same directions) is selected.

- **Radius** is the inside radius of a bend when *Down, Up, Left, Right, Convex Down, Convex Up, Block* are selected or is the depth of a *Dip* when it is selected.
  - Note that the CPA will automatically determine the bending radius to be used from the minimum allowable radius as defined in CSA C22.1 Rule 12-922. See Section 4.3 on details of how the minimum bending radius is calculated. If the bends are of $90^\circ$, $45^\circ$ or $22.5^\circ$, these are standard manufactured rigid bends and thus the CPA will choose the associated manufactured radius for bends of these types.
  - The bending radius can be overwritten if knowledge of what bends will be used is known. If the user overwrites the cell, that cell will stay as the user defined value unless the “Use Default Radius” button is selected, which will automatically refill all bending radius cells with their original formulas. Also, if the entered value is lower than the minimum allowable radius (based on CSA C22.1 Rule 12-922 or the physical limits on bending radius of the conductor), a red cell will appear below the radius detailing the minimum allowable radius.
• When *Pull Box* is selected, the logic applies the initial reel tension as the new start of the proceeding segment. Sections can be entered or modified as required and the logic permits.

• When *End* is selected, it identifies that the system is ended or the final segment is ended.

**Output**

• The tension required to pull to the end of each section point is *Pull Tension* (see 4.12 Pulling Tension Formulae).

• *SWBP* is the side wall bearing pressure of that specific section of conduit (see 4.2 Maximum Allowable Side Wall Bearing Pressures).

• *Coefficient of Friction* is auto-selected based upon lubrication and high/low shear conditions (see 4.4 Dynamic Coefficients of Friction).

• *Effective Friction* is auto-selected ($k = \mu W$).

**Note:**

• If *Auto-Calc* is disabled the spreadsheet will not perform any calculations. When *Auto-Calc* is enabled the spreadsheet will perform calculations every time any input is changed (a growing or moving bar shows up in the *Progress* cell as calculations proceed and indicates “Done” when calculations are completed).

• If *Logic Check* is enabled all sections are checked for compatibility, otherwise no compatibility checks are performed.

• It is recommended that *Auto Calc* and *Logic Check* are left ‘enabled’ as the speed of calculations is quite rapid. Note if you have gone into either ‘Print Preview’ or ‘View Print Layout’ modes, the calculations may perform very slowly (due to the method in which Excel checks print outlines). To correct this, save, close and re-open the file.

**Section 3: Summary**

Results of the Cable Pull Analysis are summarized. There are no inputs in this section. All the outputs are automatic. Each of the calculation results are compared to the acceptable related criterion and a flag is shown (*Low, Medium, High, OK, Not OK* or *NO* as appropriate)

**Output**

• *Pull Tension* is the calculated maximum pull tension required to pull the cable through the system.

• *Maximum SWBP* is the calculated maximum side wall bearing pressure.
• *Groove Snag Potential* is the potential of snagging occurring (see 4.7 Groove Snag Potential).
• *Jamming Ratio* is the likelihood that the cables will jam between the walls of the conduit (see 4.6 Jamming Conditions).
• The percent cross-sectional area of the conduit that is occupied by cable is *XSect Area Used* (see 4.8 Cross-sectional Area).
• *Clearance* is the minimum calculated clearance the cables have inside the conduit (see 4.10 Cable/Conduit Clearance).
• Maximum Tension Allowance Remaining - See section 4.1 - Maximum Allowable Tension.
• *Volume of Lubricant Needed* - See section 4.5 – Lubrication for calculation.
• If system is un-lubricated and final tension is greater than 70% of the maximum allowable tension then ‘*Lubrication Required*’ will inform the user that lubrication is required.
2.2 Sheet 2 “Sketch”

Overall Summary
This section is an overall summary of the Analysis results from Sheet 1 “CPA”. No entry of data is required here.

Overall Summary:

<table>
<thead>
<tr>
<th>Conduit Type</th>
<th>6&quot; DB2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduit I.D.[mm]</td>
<td>149.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conductor Type</th>
<th>600V 1/0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cables</td>
<td>1</td>
</tr>
<tr>
<td>Nominal O.D.[mm]</td>
<td>25.3</td>
</tr>
<tr>
<td>Per Cable Mass [kg/m]</td>
<td>0.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Single</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubrication</td>
<td>No</td>
</tr>
<tr>
<td>Initial Reel Tension [N]</td>
<td>1112</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight Correction Factor</th>
<th>1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cables Unit Weight [N/m]</td>
<td>7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pull Tension [N]</th>
<th>2649.2</th>
<th>596 lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum SwVB [N/m]</td>
<td>1738.3</td>
<td>119 lb/ft</td>
</tr>
<tr>
<td>Groove Snag Potential</td>
<td>1.1</td>
<td>Low</td>
</tr>
<tr>
<td>Jamming Ratio</td>
<td>4.9</td>
<td>Low</td>
</tr>
<tr>
<td>XSection Area Used [%]</td>
<td>2.8</td>
<td>OK</td>
</tr>
<tr>
<td>Clearance [mm]</td>
<td>117.8</td>
<td>OK</td>
</tr>
</tbody>
</table>

| Maximum Tension Allowance Remaining [%] | 64.8 | OK |
| Cable SwVB Allowance Remaining [%] | 1 | OK |

<table>
<thead>
<tr>
<th>Calculated System Linear Length [m]</th>
<th>2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Length of Cable Needed [m]</td>
<td>2.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume of Lubricant Needed [L]</th>
<th>No Lubrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubrication Required</td>
<td>OK</td>
</tr>
</tbody>
</table>
Sketches of system are drawn to scale, based on the data entered in Sheet 1 ‘CPA’ for sections.

*Plan View* is the system as seen from an aerial point of view where \( x \) applies.

*Profile View* is the system as seen from the side, where \( y \) applies.

No changes or entries can be made to the sketches in this sheet.
2.3 Example of a System

To better familiarize the user with the preceding technical parameters and formulae, a detailed set of calculations is presented for a sample installation. The numerical example, which follows, has been specifically devised to illustrate the application of each of the pulling tension equations and is taken from the example in EL 3333.

ii) Cable Pull Information

<table>
<thead>
<tr>
<th>Conductor Information</th>
<th>EL 3333 Data</th>
<th>CPA Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 kcmil x 3</td>
<td>500 MCM x 3</td>
<td></td>
</tr>
<tr>
<td>1.86 in</td>
<td>47.2 mm</td>
<td></td>
</tr>
<tr>
<td>1.68 lb/ft</td>
<td>2.5 kg/m</td>
<td></td>
</tr>
<tr>
<td>6.065 in</td>
<td>154 mm</td>
<td></td>
</tr>
<tr>
<td>100 lb</td>
<td>445 N</td>
<td></td>
</tr>
</tbody>
</table>

[Diagram of the system with measurements]
2.4 Using the Spreadsheet
1) Open the CPA spreadsheet and enable the macros.

2) Fill out Sheet 1 section 1.
   a. Select conduit type. From the conduit O.D it can be deduced that the conduit is 6” PVC. If the conduit is too small for the conductors then an error message will require a smaller conductor to be chosen or a larger conduit must be chosen to proceed.
   b. Select conductor type. If the conductor size/conduit size is not compatible, the same error message will appear for action by the designer - in order to proceed.
   c. Enter the number of cables to be pulled (3).
   d. Configuration is auto-selected
   e. Select whether or not lubrication is to be used.
   f. Select initial reel tension (445 N)
   g. Select method of cable attachment, if different than default.
   h. At this point section 1 should look something like this:
3) Fill out Sheet 1 Section 2.

**Section 2: Design Data**

<table>
<thead>
<tr>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Down</td>
<td>Straight</td>
<td>Right</td>
<td>Dip</td>
<td>Straight</td>
<td>Convex Down</td>
<td>End</td>
</tr>
<tr>
<td>Initial Real Tension [N]</td>
<td>469.2</td>
<td>1001.9</td>
<td>1942.5</td>
<td>2326.3</td>
<td>2495.9</td>
<td>3167.1</td>
<td>3167.1</td>
</tr>
<tr>
<td>Length [m]</td>
<td>22.9</td>
<td>30.5</td>
<td>7.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade [°]</td>
<td>90</td>
<td>0</td>
<td>90</td>
<td>0</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radius [m]</td>
<td>1.83</td>
<td>3.81</td>
<td>0.91</td>
<td>1.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pull Tension [N]</td>
<td>150.4</td>
<td>41.0</td>
<td>242.6</td>
<td>20.5</td>
<td>41.0</td>
<td>90.0</td>
<td>90.0</td>
</tr>
<tr>
<td>SWBP [N/mm²]</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>Effective Friction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- a. From system design information and profile and plan view design drawings, enter the system section data. Sections 1, 2 and 3 are a 90° down bend, followed by a straight section, and then a horizontal right bend, respectively (Note: In the plan view above, the horizontal bend appears to be a left bend due to the view being flipped, it is however a right bend). Enter length for straight & angle for bends.
- b. The next section is a Dip. Enter Dip depth as the Radius and the distance between beginning and end of the Dip as the Length (section 4).
- c. A straight section and a 45° convex down bend follow the Dip (Sections 5 and 6).

<table>
<thead>
<tr>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight</td>
<td>Convex Down</td>
<td>Straight</td>
<td>Down</td>
<td>Up</td>
<td>Straight</td>
<td>End</td>
</tr>
<tr>
<td>7.62</td>
<td>0</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.81</td>
<td>-45</td>
<td>1.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2495.9</td>
<td>3167.1</td>
<td>3031.1</td>
<td>3773.8</td>
<td>4814.3</td>
<td>5327.4</td>
<td>5327.4</td>
</tr>
<tr>
<td>41.0</td>
<td>900.0</td>
<td>29.0</td>
<td>1072.4</td>
<td>1368.0</td>
<td>29.0</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
</tbody>
</table>

- d. A straight Section follows the convex down and has a grade of -1:1 (-45°). Upon selecting a straight section the following error message should appear in this case (this occurs because the default grade of straight section is zero). To proceed, a grade of -45° must be selected by clicking ‘Ok’ (section 7).
e. A 45° down bend follows the straight section and is followed by a 45° up bend. Upon selecting a down section the following error message should appear in this case (This occurs because the default bend angle is 90°). To proceed, a grade of -45° must be selected by clicking ‘Ok’. This will need to be done for both Sections 8 and 9.

f. Section 10 is a straight conduit with a grade of 45° (upwards).

g. A 45° convex up bend follows section 10. Another error message should occur in this case. To proceed, a grade of -45° must be selected by clicking ‘Ok’.

h. The final section is a level straight (section 12). For section 13 select ‘End’ to confirm system end. The system can be broken into segments by selecting a ‘pull box’ at an appropriate location and revising the before and after sections as needed.
4) Summary of results and sketch (sheet 2 ‘Sketch’) for this example.

This sketch should match the intended design profile in the project file and in this case, it matches the sketch shown in Section 2.3 for ‘Plan’ and ‘Profile’ (side).
PART 3 CPA Limitations

3.1 All design tools and methods incorporate certain assumptions, calculations and design details that may or may not be realized during the actual construction. A certain amount of conservatism is employed in order that the design tool can be used as a reasonable prediction for the engineering of underground cable installation for the majority of applications.

3.2 The CPA is based on cable, conduit and pulling equipment data and calculations provided by FortisAlberta standards at the time of publication. These may vary with time and it is up to the user to ensure compliance with code.

3.3 Field practices and actual pulling methods will vary from site to site and between contractors. Contractors must be aware of the limitations posed by their equipment and the appropriate degree of wear and tear maintenance that is provided by them. Any limitations caused by this aspect may affect the size of system that can be installed. Cleanliness of the cable, conduit and pulling equipment is critical to the pull results. The conduit in particular must be kept free of debris or foreign objects prior to the pull.

3.4 All bend calculations, excluding horizontal bends, reference angles from the vertical axis. Therefore all non-horizontal bends either start or end level. More specifically Down and Convex Up bends must end level, and Convex Down and Up bends must begin level.

3.5 CPA is unable to analyze actual conduit strength. Therefore, CPA may indicate that a pull is safe, however in actual reality the conduit may collapse under very high tension loads around bends.

3.6 Specific details of lubricant used, including manufacturer’s recommended co-efficient of friction values (dynamic and static) under cable pulling pressures, should be reviewed for compatibility with the CPA values. Extreme weather conditions at time of installation can also affect the pulling requirements.

3.7 Specific details of cable maximum allowable tensions for cable based on allowable stress and data from manufacturers should be reviewed for compatibility with the CPA values. Individual limits are possible.

3.8 Specific details of allowable tensions for all items of pulling apparatus i.e. rope, equipment, eye and grip should be reviewed for compatibility with the CPA values.
3.9 It should be ensured that the minimum bend radius specified by the CPA matches those specified by all applicable codes and standards.

3.10 Review Rule 12-1014 and Table 8 of CEC C22, which specifies the maximum cable cross-section area to that of the duct.

3.11 Field tests and tension measurements have not been adequately tested nor documented to compare actual cable pulls to the CPA spreadsheet predictions.

3.12 The system modeling within the CPA is limited to 14 sections. The CPA permits the use of pull boxes to split a system into 2 or 3 segments for evaluation.
PART 4        Technical Information

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4.1 Maximum Allowable Tension

The CPA checks if the maximum tension in the cable exceeds the maximum allowable tension. The maximum allowable tension is the minimum of one of two values. The first value is the cable tension limit as follows:

\[ T_{\text{max}} = C_{TC} C_A N \]

*Where* \( T_{\text{max}} = \text{Maximum pulling tension} \)
\( C_{TC} = \text{Conductor tension constant} \)
\( C_A = \text{Conductor area (circular mils)} \)
\( N = \text{Number of conductors in cable or cable bundle} \)

Use the applicable value for the conductor tension constant, \( C_{TC} \):

- 0.011 lb/cmil for copper conductor cables
- 0.008 lb/cmil for aluminium stranded conductor cables
- 0.006 lb/cmil for aluminium solid conductor cables

The second value is the pulling grip tension limits seen in Table 4.11 below (applies to basket grips only).

<table>
<thead>
<tr>
<th>Type of Cable</th>
<th>Maximum Pulling Tension, In lbs.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PE, XLP Insulated</td>
</tr>
<tr>
<td></td>
<td>Single Cables</td>
</tr>
<tr>
<td>Unshielded, with or without jacket *</td>
<td>2,000</td>
</tr>
<tr>
<td>Concentric Wire, &quot;URD&quot;, with or without jacket **</td>
<td>10,000</td>
</tr>
</tbody>
</table>

* These tension limits apply to USEB 90, 600 V cable (1/0, 4/0, 300 MCM, #4 AL) in the CPA
** These tensions limits apply to the 25 kV cable (#1 AL, 500 MCM, 750 MCM) in the CPA

Table 4.12 was constructed using the weaker tension of the two for different cables and pulling methods. Note that if aluminum compression (bolting directly to the cable) is used, only the cable tension limit given by the formula will apply as Table 4.11 is not applicable if a grip is not used.
### Table 4.12: Recommended Maximum Pulling Tensions

<table>
<thead>
<tr>
<th>Description</th>
<th>Single Cable</th>
<th>Three Cables</th>
<th>Single Cable</th>
<th>One Grip on Three Cables</th>
<th>Three Grips, One Grip per Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 Kcmil Al.</td>
<td>6,000</td>
<td>12,000</td>
<td>6,000</td>
<td>5,000</td>
<td>12,000</td>
</tr>
<tr>
<td>500 Kcmil Al.</td>
<td>4,000</td>
<td>8,000</td>
<td>4,000</td>
<td>5,000</td>
<td>8,000</td>
</tr>
<tr>
<td>#1 Al Solid</td>
<td>502</td>
<td>1,004</td>
<td>502</td>
<td>1,004</td>
<td>1,004</td>
</tr>
<tr>
<td>300MCM, 600V</td>
<td>4,800</td>
<td>n/a</td>
<td>2,000</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>4/0 Alu 600V</td>
<td>3,886</td>
<td>n/a</td>
<td>2,000</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>1/0 Alu 600V</td>
<td>1,690</td>
<td>n/a</td>
<td>1,690</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>#4 Alu 600V</td>
<td>334</td>
<td>n/a</td>
<td>334</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

The CPA will compare the applicable tension limit from Table 4.12 with the maximum pull tension calculated in the cable to check if it exceeds the maximum allowable tension. There are some additional rules to follow when using either of these tension limits:
- If using one basket grip on each cable and pulling 3 or more cables, maximum allowable tension from Table 4.11 will be that of a single cable (Concentric or USEB) multiplied by 2.
- If USEB cable is used, N=2 (for simplicity, use this even for multiple USEB cables)
- For multiple round cables (non-USEB), N = number of cables – 1.

### 4.2 Maximum Allowable Side Wall Bearing Pressure (SWBP)

SWBP is a value of force per unit length of the bending radii. The current maximum Side Wall Bearing Pressures that a cable can withstand are shown in Table 4.21 below:

These values are taken from [EL 3333](#) (Table A-8).

<table>
<thead>
<tr>
<th>Type of Cable</th>
<th>PE, XLPE insulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric wire, with encapsulating jacket *</td>
<td>2,000</td>
</tr>
<tr>
<td>Wire shielded &amp; jacketed **</td>
<td>1,500</td>
</tr>
</tbody>
</table>

* These tension limits apply to USEB 90, 600 V cable (1/0, 4/0, 300 MCM, #4 AL) in the CPA
** These tensions limits apply to the 25 kV cable (#1 AL, 500 MCM, 750 MCM) in the CPA

SWBP is the vector sum of forces acting on the conduit and is defined as

\[
SWBP = \frac{T}{r} + \tilde{W} \quad [N/m]
\]

Where \( T \) is the outgoing tension [N], \( r \) is inside radius of the bend [m], and \( \tilde{W} \) is the total unit weight of all cables [N/m]. SWBP is directly proportional to the normal force acting on the cable. In straight lengths, only \( |\tilde{W}| \) acts as a
SWBP. In conduit bends, $|\vec{W}|$ is negligible compared to $\left|\frac{T}{\rho}\right|$; however,

$$|\vec{r}| \to \infty \Rightarrow \left|\frac{T}{\rho}\right| \to 0 \Rightarrow SWBP_{\text{oneCable}} = |\vec{W}| \cos \theta$$

Where $\theta$ is the grade [radians]. For derivations see Side Wall Bearing Pressure Formulae, Appendix A.

SWBP for straight sections is taken as the cable’s total weight per unit length. For bends, SWBP is calculated based on configuration:

- **iii) Single**
  $$SWBP_{\text{oneCable}} = \frac{T}{r} \text{ [N/m]}$$

- **(ii) Two-Point Contact (Double/Triangular)**
  $$SWBP_{\text{twoPoint}} = \frac{W \cdot T}{2r} \text{ [N/m]}$$

- **(iii) Three-Point Contact (Cradled/Diamond)**
  $$SWBP_{\text{threePoint}} = \frac{(W_c - \frac{2}{3})T}{r} \text{ [N/m]}$$

- **(iv) Four-Point Contact (Four-Point Cradle)**
  $$SWBP_{\text{fourPoint}} = \frac{2}{r} \left[ W \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right) - \frac{1}{4} \left( 1 - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \right] \frac{T}{r} \text{ [N/m]}$$

### 4.3 Minimum Bending Radius

If a power cable is bent in a radius, which is too severe, the cable structure may be damaged. Field experience and laboratory tests have been used to establish the minimum bending radii for various cable designs.

The static bending radius is the minimum bending radius when there is no tension in the cable. The dynamic bending radius is the minimum bending radius of a cable when it is being pulled under tension around a bend. As cable tension increases, the minimum bending radius it can handle decreases.

The minimum static and dynamic bending radii are shown in Table 4.31 and 4.32 for different conductors.
Table 4.31: 25 kV Primary Cable, Physical Properties

<table>
<thead>
<tr>
<th>Description</th>
<th>Conductor Size in cmil</th>
<th>Jacket Material</th>
<th>Cable O.D. (inch)</th>
<th>Weight One Cable lb/ft</th>
<th>Minimum Static Bending Radius</th>
<th>Minimum Dynamic Bending Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 Kcmil Al.</td>
<td>750,000</td>
<td>LLDPE</td>
<td>1.93</td>
<td>2.148</td>
<td>16</td>
<td>36</td>
</tr>
<tr>
<td>500 Kcmil Al.</td>
<td>500,000</td>
<td>LLDPE</td>
<td>1.837</td>
<td>1.665</td>
<td>15</td>
<td>24</td>
</tr>
<tr>
<td>#1 Al Solid</td>
<td>83,690</td>
<td>LLDPE</td>
<td>1.169</td>
<td>0.552</td>
<td>9</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 4.32: USEB 90, 600V Secondary Cable Physical Properties

<table>
<thead>
<tr>
<th>Description</th>
<th>Conductor Size in cmil</th>
<th>Jacket Material</th>
<th>Insulation Diameter (inch) [X]</th>
<th>Major Dimension (inch) [Y]</th>
<th>Minor Dimension (inch) [Z]</th>
<th>Weight One Cable lb/ft</th>
<th>Minimum Static Bending Radius (inch)**</th>
<th>Minimum Dynamic Bending Radius (inch)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 Kcmil USEB</td>
<td>300,000</td>
<td>PVC</td>
<td>0.712</td>
<td>1.840</td>
<td>1.128</td>
<td>1.412</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>4/0 Kcmil USEB</td>
<td>211,600</td>
<td>PVC</td>
<td>0.592</td>
<td>1.505</td>
<td>0.913</td>
<td>0.931</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>1/0 Kcmil USEB</td>
<td>105,600</td>
<td>PVC</td>
<td>0.452</td>
<td>1.199</td>
<td>0.747</td>
<td>0.538</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>#4 AWG RW90</td>
<td>41,740</td>
<td>PVC</td>
<td>0.649</td>
<td>0.181</td>
<td>5</td>
<td>18</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

* Where the recommended bending radius is calculated as 8 x cable O.D. for single conductor cables.
** Where the recommended bending radius is calculated as 5 x cable Major Dimension for USEB 90 cables, with the exception for the #4 AWG RW90 which is a single conductor cable therefore the minimum bending radius for this cable will be 8 x cable O.D.
O.D. (outside diameter over one cable) is measured over the cable jacket. For USEB 90 cables consider using the Major Dimension for bending purposes.
*** Minimum Dynamic Bending Radius calculated based on maximum tension per conductor and maximum SWBP.

To calculate the minimum bending radii for dynamic conditions, use the following formula:

\[ MBR = \left( \frac{T_e}{SWBP_{MAX}} \right) \times 12 \text{ inches} \]

Where:  
\( MBR \) = Minimum bending radius (inches)  
\( T_e \) = Pulling tension per cable as it leaves the bend (pound-force)  
\( SWBP \) = Maximum Sidewall Bearing Pressure (pounds per foot of bend radius) as per Table 4.21.

The dynamic radii in Tables 4.31 and 4.32 above are calculated using maximum pulling tension values from Table 4.12. However, the minimum dynamic radii are unique for each system as they depend on the pulling tension in the cable, which depends on system configuration and parameters.

**NOTE:** The dynamic minimum bending radius can be calculated to be less than the static minimum bending radius, HOWEVER, one must use the greater of the two values when considering dynamic conditions. So if the dynamic minimum bending radius
calculated is lower than the static minimum bending radius, then the static minimum bending radius takes precedence.

### 4.4 Coefficients of Friction

American Polywater has done extensive research on coefficients of friction of cables being pulled through ducts. Static coefficients of friction resulting from that research are seen below in Table 4.4 and are used in the CPA.

<table>
<thead>
<tr>
<th>Conduit</th>
<th>Cable Jacket</th>
<th>COF Lubricated</th>
<th>COF Un-Lubricated</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>LLDPE</td>
<td>0.25</td>
<td>0.3</td>
</tr>
<tr>
<td>Steel</td>
<td>LLDPE</td>
<td>0.49</td>
<td>0.68</td>
</tr>
<tr>
<td>HDPE</td>
<td>LLDPE</td>
<td>0.23</td>
<td>0.38</td>
</tr>
<tr>
<td>PVC</td>
<td>PVC</td>
<td>0.15</td>
<td>0.56</td>
</tr>
<tr>
<td>Steel</td>
<td>PVC</td>
<td>0.22</td>
<td>0.55</td>
</tr>
<tr>
<td>HDPE</td>
<td>PVC</td>
<td>0.25</td>
<td>0.56</td>
</tr>
</tbody>
</table>

The dynamic (or effective) coefficient of friction used in the CPA is calculated as the static coefficient of friction multiplied by the weight correlation factor (section 4.11).

### 4.5 Lubrication

Lubrication is an important factor in cable pulling. Whether or not a cable is lubricated can have a large impact on the final results. In some cases a pull may not require lubrication; however a non-lubricated cable pull cannot exceed 70% of the allowable maximum tension. The limit of 70% is established as a Fortis criterion. CPA will show lubrication as required in this case.

To calculate the volume of lubricant needed, the CPA uses the following method.

\[
V_{L(cable)} = n\left[\pi (t + r)^2 - \pi r^2\right] \cdot \frac{L}{1000}
= n\left[\pi (t^2 + 2tr + r^2 - r^2)\right] \cdot \frac{L}{1000}
\]

\[
V_{L(cable)} = \frac{n \cdot \pi \cdot L}{1000} (t^2 + 2tr) \text{ Liters, where } t \text{ is thickness of lubricant in meters; } r \text{ is the OD radius of cable in meters; } L \text{ is the length of single cable in meters; } n \text{ is the number of cables, and } V_{L(cable)} \text{ is the volume of lubricant in m}^3. \text{ (1000 Liters = 1 m}^3) \]

\[
V_T = (V_{L(cable)}) + (V_{L(ropes)})
\]
Section 1.02
Section 1.03 \[ V_T \] is the total volume of lubrication required, including that added to the pull rope.
\[ V_{L(ropes)} = d_{rope} \times L \times t / 1000 \] Liters where \( d_{rope} \) is OD of the pull rope; \( L \) is length of pull rope (assumed same as the system length or single cable) and \( t \) is thickness of lubricant.

The application of lubricant is not well controlled in the field and \( V_L \) assumes a nominal thickness of 0.254 mm. No allowance is included in the calculation for liberal use or any waste of lubricant. Reasonable application of lubricant is critical to the validity of the lubrication coefficient of friction used in the calculations.

4.6 Jamming Conditions

When three cables are pulled in parallel in a duct, there is a possibility of wedging action developing in bends. The cables changing from a triangular configuration to a cradled configuration as they are pulled in through the bend causes this. This change in configuration will force the two outer cables further apart. If the diameter of the duct is too small to accommodate this wider configuration, the cables will become jammed in the bend.

Jamming is likely if the ratio of the inside diameter of the duct to the cable diameter is within a certain range. Potential of Jamming is critical if 3 to 5 cables are being pulled. If a cable is jammed inside a conduit the force required to pull the cable will be very large and may exceed the maximum tensile strength of the cable or equipment being used. The conditions for jamming are stated in Pirelli (Page 37) and EL 3333 (2-2) and outline the following conditions for jamming. Currently the CPA follows the Pirelli Criteria except that it considers a jam ratio between 2.8 and 3.0 to be high.

EL3333 Criteria
\[
J = \frac{D_{D}}{d} < 2.9 \text{ to be OK}
\]
\[
J = \frac{D}{1.03d} > 3.1 \text{ to be OK}
\]

Both criteria must be satisfied to indicate low possibility of jamming.

Pirelli Criteria
\[
J = \frac{D}{d} \text{ is cable O.D., and } D \text{ is conduit I.D}
\]

<table>
<thead>
<tr>
<th>Jam Ratio</th>
<th>Potential</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>( J &lt; 2.4 )</td>
<td>Low</td>
<td>Triangular</td>
</tr>
</tbody>
</table>
2.4 ≤ J < 2.6
Moderate
Triangular

2.6 ≤ J < 2.8
Moderate
Triangular or Cradled

2.8 ≤ J < 3.0
High
Cradled

J ≥ 3.0
Low
Cradled

SWBP Effect
Jamming potential ratio with a range 2.8 to 3.1 is more likely if the SWBP is greater than 14594 N/m (though this is not taken into consideration in the CPA).

4.7 Groove Snag Potential

A major concern when pulling cables through a conduit is the physical condition of the conduit, particularly at the bends. Generally pulling rope is much coarser than the cable it is pulling and therefore the pulling rope may produce a groove in the conduit wall as it is pulled. As the cable passes over this groove it may snag and the force required to pull a snagged cable may exceed the tensile strength of the cable or equipment being used. The Groove Snag Potential (GSP) ratios are cautionary indicators of the potential to snag. ‘Low’ or ‘Moderate’ potential is usually OK but caution on cable and/or pull wire selection should be exercised if potential is shown as ‘High’.

Where ratio \( GSP = \frac{d}{d_{\text{pullRope}}} \), \( d \) is cable O.D., and \( d_{\text{pullRope}} \) is pull rope O.D.

<table>
<thead>
<tr>
<th>SWBP lbs/ft</th>
<th>GSP ratio</th>
<th>Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1000</td>
<td>( GSP \leq .9 )</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>(.9 &lt; GSP \leq 1 )</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>( GSP &gt; 1 )</td>
<td>Low</td>
</tr>
<tr>
<td>≥ = 1000</td>
<td>( GSP \leq 1 )</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>( GSP &gt; 1 )</td>
<td>Low</td>
</tr>
</tbody>
</table>

4.8 Cross-Sectional Area

The total cross-sectional area of the conductors cannot exceed the values specified by Table 4.81, derived from Rule 12-1014 and Table 8 of CEC C22 (in relation to any cable amperage limitations).

<table>
<thead>
<tr>
<th>Number of Conductors or Multi-conductor Cables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Over 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors or multi-conductor cables</td>
<td>53</td>
<td>31</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>
The percentage of area filled can be calculated by the following:

\[
A_{\text{conductors}} = n \cdot \frac{d^2}{2} \quad \Rightarrow \quad \%A = \frac{A_{\text{conductors}}}{A_{\text{conduit}}} = \frac{n \cdot \left(\frac{d}{2}\right)^2}{\frac{D^2}{2}} = \frac{nd^2}{D^2}
\]

\[
\therefore \quad \%A = \frac{nd^2}{D^2} \pi
\]

Where \(d\) is the cable O.D., \(D\) is the conduit I.D., and \(n\) is the number of cables.

For USEB cables, cross sectional area can be calculated as follows:

\[
\%\text{fill} = \left[ \frac{\left(\frac{\pi Z^2}{4} + Z(Y - Z)\right)N}{\pi r^2} \right] \times 100
\]

Where:

- \(Z\) = Cable minor dimension (inches)
- \(Y\) = Cable major dimension (inches)
- \(r\) = Inside radius of the conduit or duct (inches)
- \(N\) = number of cables

### 4.9 Cable/Conduit Clearance

Clearance is defined as the distance between the highest point of the highest conductor and the conduit directly above that conductor. Pirelli (Page 37) and EL 3333 (2-1, 2-2) recommends that a clearance of at least 12.7 [mm] be maintained throughout the cable pull. The calculations for cable clearance for different configurations are shown below. See the next section for a description of cable configurations.

For derivations see Clearance Formulae, Appendix A.

Where \(d\) is the cable O.D., mm; \(D\) is the conduit I.D, mm; and \(C\) is the clearance based on configuration, mm.

Acceptance is when \(C \geq 12.7\) [mm] and non-acceptance when \(C < 12.7\) [mm].

\(d\) = Nominal cable O.D. \(\times 1.05\)

i) One Cable

\[
C = D - d
\]
ii) Two Cable

Cradle configuration

\[ C = \frac{1}{2} \left( D^2 - d^2 \right)^{\frac{1}{2}} + \frac{1}{2} \left( D^2 - 2 \cdot d \cdot D \right)^{\frac{1}{2}} - \frac{1}{2} d \]

Section 1.04 Three Cables

Three cables may be arranged in a cradled or triangular configuration; however triangular has a stacked cable and therefore will have less clearance and will be used to calculate the systems clearance.

\[ C = \frac{1}{2} D - \left( \frac{1}{2} + \sin \frac{\pi}{3} \right) d + \frac{1}{2} \left( D - d \right) \left( 1 - \left( \frac{d}{D - d} \right)^2 \right)^{\frac{1}{3}} \]

Triangular configuration

i) Four Cables

Four cables may be arranged in a cradled or diamond configuration; diamond has less clearance and therefore will be used to calculate the CPA clearance.

\[ C = (D - d) - \frac{2d^2}{(D - d)} \]

Diamond configuration

i) Five Cables

Five cables are assumed to be in a four-point cradle with the fifth cable resting on top of the two middles cables. Therefore the clearance will be equal to that of a triangular configuration clearance given for the Three Cables above.

USEB Cables

The formulas mentioned above are appropriate for round cables, For USEB cables the following is used to calculate clearance:

\[ C = D - Y' \]

Where: \( C \) = Clearance (inches)
\( D \) = Inside diameter of duct (inches)
\( Y' = 1.05 \times \) cable major dimension (\( Y \)) (inches)

4.10 Configurations

There are several cable configurations that must be considered in order to create an accurate model of cable pulling. In specific situations cables will have a tendency to assume certain configurations.

The primary goal of the CPA is to generate practical tension and SWBP estimates. Cable configurations have a significant effect on the tension and SWBP calculations. In
general, an increase in the points of contact produces an increase in the force required to overcome friction and SWBP.

In order to produce a comprehensive model of cable pulling tensions, the configuration of cables within the conduit is assumed to be as noted below:

Some configurations are more probable under certain conditions than others. Conditions for cable configurations can be found in EL 3333 (2-3, 2-4). However, neither reference considers more than four cables; furthermore, four cable configurations are always assumed to be of diamond configuration which is generally not the case. When the number of cables exceeds four, an approximation may be the only practical approach. Cable configurations are dependent on conduit I.D. and cable O.D. only, and are given by the following criteria. Where $d$ is the cable O.D., $D$ is the conduit I.D. and $n$ is the number of cables.

$n = 3$: If $\frac{D}{d} < 2.4$ then cable configuration will be assumed triangular. Value of 2.4+ will be assumed cradled.

$n = 4$: If $\frac{D}{d} < 3$ then cable configuration will be diamond. Value of 3+ will be assumed cradled.

$n = 5$: will be assumed as a four point cradle configuration.

4.11 Weight Correction Factor

A weight correction factor ($W_c$) is a dimensionless constant that simplifies the total normal weight of many cables into a single weight force and some are shown in EL3333. Where $d$ is the cable O.D. and $D$ is the conduit I.D. For derivations of formulae below see Weight Correction Formulae, Appendix A. The following assumes all the cables in one conduit are of equal size and weight.
i) Single-Point Contact
The weight correlation for a single cable is one. The total weight force is equal to a single normal force and hence $W_c = 1$

Two-Point Contact

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

Three-Point Contact (Cradled and Diamond Configuration)

$$W_{c\,(cradled)} = \left(1 + 4\left(\frac{d}{D-d}\right)^2\right)^{1/3}$$

$$W_{c\,(diamond)} = 1 + 2\left(\frac{d}{D-d}\right)^2$$

Four-Point Contact (Four-Point Cradle)

$$W_c = \frac{2\left(a_0 + a_1\left(\frac{d}{D-d}\right)^2 - 8\left(\frac{d}{D-d}\right)^4 + 1\right)}{\left(1 - \left(\frac{d}{D-d}\right)^2\right)^{1/2}}$$

Where $a_0 = \frac{w_{inside\,Cables}}{w_{all\,Cables}} = \frac{1}{4}$ and $a_1 = \frac{w_{outside\,Cables}}{w_{all\,Cables}} = \frac{1}{4}$

Five cables may be approximated by placing the fifth cable on the bottom two cables;

where $a_0 = \frac{w_{inside\,Cables} + \frac{1}{2}w_{top\,Cables}}{\sum w_{all\,Cables}} = \frac{1 + \frac{1}{2}}{5} = \frac{3}{10}$ and $a_1 = \frac{w_{outside\,Cables}}{\sum w_{all\,Cables}} = \frac{1}{5}$

4.12 Pulling Tension Formulae and Section Descriptions

The formulas used in CPA to calculate pulling tension are given by EL 3333. For each section, the outgoing tension, $T_2$, is calculated based on the incoming tension, $T_1$. For each subsequent section, $T_1$ is $T_2$ from the previous section. Where $T_2$ is outgoing tension, $T_1$ is incoming tension; $R$ is radius of the bend; $\theta$ is grade of straight pipe or angle of bend [radians]; $k = \mu W_c$ is effective coefficient of friction; $L$ is the length of the section and $W$ is total unit weight [N/m].
H refers to Horizontal i.e. along or parallel to the nominal level ground and V refers to Vertical i.e. 90° down from the ground level.

Straight Section (CPA “straight”)

\[ T_2 = T_1 + WL [\sin \theta + k \cos \theta] \]

Note for \( \theta = 0^\circ \) (i.e. level straight), \( T_2 = T_1 + WLk \)

iv) Concave Down Bend Section (CPA “Down”)

\[ T_2 = T_1 e^{k\theta} - \frac{RW}{1 + k^2} \left[ 2ke^{k\theta} \sin \theta + \left( 1 - k^2 \right) \left( 1 - e^{k\theta} \cos \theta \right) \right] \]

Note for normal full bend, \( \theta = 90^\circ \) & \( T_2 = T_1 e^{\frac{\pi k}{2}} \left[ 2ke^{\frac{\pi k}{2}} \sin \theta + \left( 1 - k^2 \right) \left( 1 - e^{\frac{\pi k}{2}} \cos \theta \right) \right] \)

Convex Down Bend Section (CPA “convex down”)

\[ T_2 = T_1 e^{k\theta} + \frac{RW}{1 + k^2} \left[ 2k \sin \theta - \left( 1 - k^2 \right) \left( e^{k\theta} - \cos \theta \right) \right] \]
Note for normal full bend, $\theta = 90^\circ$ & $T_2 = T_1 e^{\frac{\pi k}{2}} + \frac{RW}{1 + k^2} \left[ 2k - \left( 1 - k^2 \right) \left( e^{\frac{\pi k}{2}} \right) \right]$

Concave Up Bend Section (CPA “Up”)

$$T_2 = T_1 e^{k\theta} - \frac{RW}{1 + k^2} \left[ 2k \sin \theta - \left( 1 - k^2 \right) \left( e^{k\theta} - \cos \theta \right) \right]$$

Note for normal full bend, $\theta = 90^\circ$ & $T_2 = T_1 e^{\frac{\pi k}{2}} - \frac{RW}{1 + k^2} \left[ 2k - \left( 1 - k^2 \right) \left( e^{\frac{\pi k}{2}} \right) \right]$

Convex Up Bend Section (CPA “convex up”)

$$T_2 = T_1 e^{k\theta} + \frac{RW}{1 + k^2} \left[ 2ke^{k\theta} \sin \theta + \left( 1 - k^2 \right) \left( 1 - e^{k\theta} \cos \theta \right) \right]$$

Note for normal full bend, $\theta = 90^\circ$ & $T_2 = T_1 e^{\frac{\pi k}{2}} + \frac{RW}{1 + k^2} \left[ 2ke^{\frac{\pi k}{2}} + \left( 1 - k^2 \right) \right]$

Horizontal Bend Section (CPA ‘Left” or “Right”)
‘Right’ is shown in this example: \( T_2 = T_1 \cosh k\theta + \sinh k\theta \sqrt{t_1^2 + (RW)^2} \)

Note for normal ground level bend, \( \theta = 90^\circ \) & \( T_2 = T_1 \cosh \frac{\pi}{2} + \sinh \frac{\pi}{2} \sqrt{T_1^2 + (RW)^2} \)

Dip Section (CPA “Dip”)

\[
\theta = \frac{4D}{L} \quad T = T_1 e^{k\theta} + \frac{L^2W}{4D} \left[ e^{k\theta} - 1 \right]
\]

If \( T \leq \frac{L^2W}{16D} \) then \( T_2 = T_1 + WL \), else \( T_2 = T_1 e^{k\theta} + \frac{L^2W}{16D} \left[ e^{4k\theta} - 2e^{3k\theta} + e^{k\theta} - 1 \right] \)

If a Dip is used, L is entered as approximate length and D is entered as 0.6m minimum.

Block Section

If underground blocks are used, \( T_2 = T_1 \times 1.15 \) (estimated value from field practices).

Reverse Section

For reverse direction pull (i.e. “Backward” in CPA) the above formulae changes as the sections may change due to the reversed direction that affects directions of gravity (i.e. “up” becomes “down”, “T_1” and “T_2” are reversed, etc). The CPA logic will caution a change if the next section does not fit the normal logic of the previous section.
Appendix A

Basic Engineering For Pulling Underground Cables in Conduits

Contents

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A.1 Configuration Formulae

i) Two-Point Contact

\[ x = \frac{1}{2}(D - d) \]
\[ r = \frac{1}{2}d \]
\[ x \cos \theta = r \rightarrow \cos \theta = \frac{d}{D-d} \]
\[ \sin \theta = \left(1 - \left(\frac{d}{D-d}\right)^2\right)^{\frac{1}{2}} \]

ii) Three-Point Contact

\[ x = \frac{1}{2}(D - d) \]
\[ r = \frac{1}{2}d \]
\[ \cos \alpha = \frac{d \cos \beta}{x} \]
\[ \sin \alpha = 1 - \frac{d \sin \beta}{x} \]
\[ \sin^2 \alpha + \cos^2 \alpha = 1 \]
\[ 1 - 2 \frac{d \sin \beta}{x} + \frac{d^2 \sin^2 \beta}{x^2} + \frac{d^2 \cos^2 \beta}{x^2} = 1 \]
\[ \frac{d^2}{x^2}(\sin^2 \beta + \cos^2 \beta) - 2 \frac{d \sin \beta}{x} = 0 \]
\[ \sin \beta = \frac{d}{2x} = \frac{d}{D-d} \]
\[
\sin^2 \beta + \cos^2 \beta = 1 \\
\cos \beta = 1 - \sin^2 \beta = 1 - \left(1 - \frac{d}{D-d}\right)^2 \Rightarrow \\
\cos \beta = \left(1 - \frac{d}{D-d}\right)^2 \\
\sin \alpha = 1 - \frac{d \sin \beta}{x} = 1 - \frac{d}{x} \left(1 - \frac{d}{D-d}\right)^2 \\
\sin \alpha = 1 - 2 \left(1 - \frac{d}{D-d}\right)^2 \\
\cos \alpha = \frac{d \cos \beta}{x} = \frac{d}{x} \left(1 - \frac{d}{D-d}\right)^2 \\
\cos \alpha = 2 \left(1 - \frac{d}{D-d}\right)^2 \left(1 - \frac{d}{D-d}\right)^2 \\
\]

iii) Four-Point Contact

\[
x = \frac{1}{2} (D-d) \quad \cos \theta = \frac{d}{D-d} \quad \sin \theta = \left(1 - \frac{d}{D-d}\right)^2 \\
2\theta + \delta = \Pi \quad \delta + \phi = \theta \quad \phi = 3\theta - \Pi \\
\cos \phi = \cos(3\theta - \Pi) = -\cos 3\theta = \cos(\theta + 2\theta) = -\left[\cos \theta \cos 2\theta - \sin \theta \sin 2\theta\right] \\
= -\left[\cos^2 \theta - \sin^2 \theta \right] \cos \theta - 2 \sin^2 \theta \cos \theta = -\left[\cos^3 \theta - 3 \cos \theta \sin^2 \theta\right] = -\left[\cos^3 \theta - 3 \cos \theta + 3 \cos^3 \theta\right] \\
= 3 \cos \theta - 4 \cos^3 \theta = 3 \left(d \frac{D-d}{D-2d}\right) \left(1 - \frac{4d}{3(D-d)}\right)^2 \\
\cos \phi = 3 \left(d \frac{D-d}{D-d}\right) \left(1 - \frac{4d}{3(D-d)}\right)^2 \\
\]
\[
\sin \phi = \sin(3\theta - \Pi) = -\sin 3\theta = -\sin(\theta + 2\theta) = -[\sin \theta \cos 2\theta + \cos \theta \sin 2\theta] = -[\sin \theta(1 - 2\sin^2 \theta) + 2\cos \theta \sin \theta]
\]
\[
= -[\sin \theta - 2\sin^3 \theta + 2\sin \theta - 2\sin^3 \theta] = 4\sin^3 \theta - 3\sin \theta = 4 \left(1 - \left(\frac{d}{D-d}\right)^2\right)^{\frac{1}{2}} \left(\frac{1}{4} - \left(\frac{d}{D-d}\right)^2\right)
\]
\[
\sin \phi = 4 \left(1 - \left(\frac{d}{D-d}\right)^2\right)^{\frac{1}{2}} \left(\frac{1}{4} - \left(\frac{d}{D-d}\right)^2\right)
\]
\[
\delta = \Pi - 2\theta
\]
\[
\cos \delta = \cos(-2\theta + \Pi) = -\cos(-2\theta) = -\cos^2 \theta + \sin^2 \theta = -2\cos^2 \theta + 1
\]
\[
\delta = \Pi - 2\theta
\]
\[
\sin \delta = \sin(2\theta + \Pi) = -\sin(-2\theta) = \sin 2\theta = 2\sin \theta \cos \theta = 2 \left(\frac{d}{D-d}\right) \left(1 - \left(\frac{d}{D-d}\right)^2\right)^{\frac{1}{2}}
\]
\[
\sin \delta = 2 \left(\frac{d}{D-d}\right) \left(1 - \left(\frac{d}{D-d}\right)^2\right)^{\frac{1}{2}}
\]

A.2 Clearance Formulae

iv) One Cable

Two Cable
\[ x = \frac{1}{2} (D - d) \quad a = \frac{1}{2} d + x \sin \theta \quad b = \left( \frac{1}{2} D \right)^{\frac{1}{2}} - \left( \frac{1}{2} d \right)^{\frac{1}{2}} = \frac{1}{2} (D^2 - d^2)^{\frac{1}{2}} \quad C = b + \left( x^2 - \left( \frac{d}{2} \right)^2 \right)^{\frac{1}{2}} - \frac{1}{2} d \]

\[ C = \frac{1}{2} (D^2 - d^2)^{\frac{1}{2}} + \frac{1}{2} (D^2 - 2*d*D)^{\frac{1}{2}} - \frac{1}{2} d \]

**Three Cable**

\[ a = \frac{1}{2} (D - d) - \frac{1}{2} (D - d) \sin \theta \quad b = d \sin \frac{\Pi}{3} + \frac{1}{2} d \quad C = D - b - a = D - \left( \frac{1}{2} \frac{D}{2} \right) (D - d) \sin \theta + d \sin \frac{\Pi}{3} + \frac{1}{2} d \]

\[ C = \frac{1}{2} D - \left( \frac{1}{2} + \sin \frac{\Pi}{3} \right) d - \frac{1}{2} D (d - d) \left( 1 - \left( \frac{d}{D - d} \right)^{2} \right)^{\frac{3}{2}} \]

**Four Cable**

\[ a = \frac{1}{2} d + d \sin \beta \quad b = \frac{1}{2} d + \left( d^2 - (d \sin \beta)^2 \right)^{\frac{1}{2}} \]

\[ C = D - \left( \frac{1}{2} d + d \sin \beta + \frac{1}{2} d + \left( d^2 - (d \cos \beta)^2 \right)^{\frac{1}{2}} \right) = D - d + 2d \sin \beta \]

\[ C = (D - d) - \frac{2d^2}{(D - d)} \]
Five Cable

Five cables are assumed to be stacked in a three cable configuration and therefore the clearance is equal to that of three cable configuration.

\[
C = \frac{1}{2} D - \left( \frac{1}{2} + \sin \frac{\Pi}{3} \right) d - \frac{1}{2}(D-d) \left( 1- \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}}
\]

A.3 Weight Correction Factor \((W_c)\) Formulae

Two-Point Contact

\[
\sum F_y = 0 = N_1 \sin \theta - \text{avg} \quad \rightarrow \sum F_x = 0 = N_1 \cos \theta - P \\
N_1 \sin \theta = \text{avg} \\
N_1 \cos \theta = P \\
\rightarrow P = \frac{\cos(\text{avg})}{\sin \theta} \\
N_1 = \frac{\text{avg}}{\sin \theta} \quad \mu(W_{c, \text{avg}}) = \mu(2N_1) \rightarrow W_c = \frac{2a}{\sin \theta}
\]
\[ W_c = 2a \left( 1 - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \]

Where \( a = \frac{w_{\text{perCable}}}{\sum w_{\text{allCables}}} = \frac{1}{2} \)

**Three-Point Contact**

\[ \sum F_y = 0 = N_1 - awg - 2P \sin \beta \]
\[ \sum F_x = 0 = P \cos \beta - P \cos \beta \]

\[ P = N_2 \frac{\cos \alpha}{\cos \beta} \]
\[ N_2 \sin \alpha + P \sin \beta = awg \]
\[ N_2 \left( \sin \alpha + \frac{\cos \alpha}{\cos \beta} \sin \beta \right) = awg \]

\[ N_1 = awg + 2P \sin \beta \]
\[ = awg + 2N_2 \frac{\sin \beta \cos \alpha}{\cos \beta} \]
\[ = awg + 2awg \cos \alpha \cos \beta \]

\[ \mu(W_{awg}) = \mu N_1 + \mu(2N_2) \rightarrow W_c = a \left( 1 + 4 \left( \frac{d}{D-d} \right)^2 \right) + 2a \]

\[ W_c = a \left( 3 + 4 \left( \frac{d}{D-d} \right)^2 \right) \]

Where \( a = \frac{w_{\text{perCable}}}{\sum w_{\text{allCables}}} = \frac{1}{3} \)
Four-Point Contact

\[
\begin{align*}
\uparrow \sum F_y &= 0 = N_1 \sin \theta - a_0 w_g - P_2 \sin \delta \\
\rightarrow \sum F_x &= 0 = N_1 \cos \theta + P_2 \cos \delta - P_1 \\
\sum F_y &= 0 = N_2 \sin \phi - a_1 w_g + P_2 \sin \delta \\
\rightarrow \sum F_x &= 0 = N_2 \cos \phi - P_2 \cos \delta
\end{align*}
\]

\[
N_2 = \frac{\cos \delta}{\cos \phi} P_2 \left( \frac{\cos \delta \sin \phi}{\cos \phi} + \sin \delta \right) P_2 = a_1 w_g
\]

\[
N_2 = \frac{a_1 w_g \cos \phi \cos \delta}{\cos \phi (\cos \delta \sin \phi + \cos \phi \sin \delta)} = \frac{a_1 w_g \cos \delta}{\cos \delta \sin \phi + \cos \phi \sin \delta}
\]

\[
N_2 = \frac{a_1 w_g \left( 1 - 2 \left( \frac{d}{D - d} \right)^2 \right)}{4 \left( 1 - 2 \left( \frac{d}{D - d} \right)^2 \right)^2 \left( \frac{1}{4} - \left( \frac{d}{D - d} \right)^2 \right) + 6 \left( \frac{d}{D - d} \right)^2 \left( 1 - \frac{4}{3} \left( \frac{d}{D - d} \right)^2 \right) \left( 1 - \left( \frac{d}{D - d} \right)^2 \right)^{\frac{1}{2}}}
\]

\[
W_c = \frac{2 a_1 w_g \left( 1 - 2 \left( \frac{d}{D - d} \right)^2 \right)}{\left( 1 - \left( \frac{d}{D - d} \right)^2 \right)^{\frac{1}{3}}}
\]

\[
N_1 = a_0 w_g + P_3 \sin \delta = \frac{w_g \left( a_0 + \frac{a_1 \cos \phi \sin \delta}{\cos \delta \sin \phi + \cos \phi \sin \delta} \right)}{\sin \theta}
\]

\[
N_1 = \frac{w_g \left( a_0 + \frac{a_1 \cos \phi \sin \delta}{\cos \delta \sin \phi + \cos \phi \sin \delta} \right)}{\sin \theta} \left( \frac{3}{D - d} - \frac{4}{(D - d)^2} \right)
\]

\[
\mu(W_c w_g) = \mu(2N_1) + \mu(2N_2)
\]
A.4 Side Wall Bearing Pressure Formulae

**Two-Point Contact**

\[ W_c (\mu N_{\text{single}}) = 2(\mu N_1) \]

Where \( N_1 \) will experience maximum SWBP.

\[ W_c N_{\text{single}} = 2N_1 \]

\[ SWBP \propto N \Rightarrow W_c SWBP_{\text{single}} = 2SWBP_{\text{twoPoint}} \]

\[ SWBP_{\text{twoPoint}} = \frac{W_c T}{2r} \]

**Three-Point Contact**

\[ W_c (\mu N_{\text{single}}) = \mu N_1 + 2(\mu N_2) \]

\[ W_c N_{\text{single}} = N_1 + 2awg = N_1 + 2aN_{\text{single}} \]

Where \( N_1 \) will experience maximum SWBP.

\[ (W_c - 2a)N_{\text{single}} = N_1 \]

\[ SWBP \propto N \Rightarrow (W_c - 2a)SWBP_{\text{single}} = SWBP_{\text{threePoint}} \]

\[ SWBP_{\text{threePoint}} = \frac{(W_c - 2a)T}{r} \]

Where \( a = \frac{W_{\text{perCable}}}{\sum w_{\text{allCables}}} = \frac{1}{3} \).

**Four-Point Contact**

\[ W_c (\mu N_{\text{single}}) = 2(\mu N_1) + 2(\mu N_2) \]

Where \( N_1 \) will experience maximum SWBP.
\[ N_1 \sin \theta - awg = awg - N_2 \sin \phi \]
\[ W_c N_{\text{sin gle}} = 2N_1 + 2 \left( \frac{2awg - N_1 \sin \theta}{\sin \phi} \right) \]
\[ W_c = \frac{4a}{4 \left( 1 - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right)} \]
\[ N_{\text{sin gle}} = 2N_1 \left( 1 - \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \right) \]
\[ N_1 = 4 \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right) - 1 \]
\[ SWBP \propto N \Rightarrow SWBP_{\text{fourPoint}} = \frac{2 \left[ W_c \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right) - a \left( 1 - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \right]}{4 \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} - 1} \]
\[ SWBP_{\text{fourPoint}} = \frac{2 \left[ W_c \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right) - a \left( 1 - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} \right]}{4 \left( \frac{1}{4} - \left( \frac{d}{D-d} \right)^2 \right)^{\frac{1}{2}} - 1} \]

Where \( a = \frac{W_{\text{per Cable}}}{\sum \text{allCables}} = \frac{1}{4} \).