Linear Elastic Cable Model With Creep Proportional to Tension

This document illustrates differences in the way creep is handled in the "Linear elastic with permanent stretch due to creep proportional to creep weather case tension" cable model compared to cable models available in earlier versions. You may download a PLS-CADD/Lite project for the example used in this discussion from http://www.powline.com/technotes/creep_proportional_to_tension.bak should you want to experiment with this yourself. Our thanks to Mr. Greg Chapman of Ergon Energy for his contributions to the development of this cable model and this tech note.

There are three types of cable models that are available for modeling conductors in PLS-CADD. The first and most accurate is the non-linear cable model which uses separate polynomials for initial and creep behavior for inner and outer materials. The second is the improved linear cable model which models permanent stretch due to creep proportional to the creep weather case tension. The third is the linear cable model with permanent stretch due to creep specified as a user input temperature increase.

As shown below in Figure 1, the improved linear cable model more accurately reflects the sag of the non-linear cable model in the creep condition at various tensions. You can see how at 22 kN all three cables are very similar in their creep display since this is the tension selected when stringing the conductor. However when the cables are strung at 44 kN instead of 22 kN, you can see how the new improved linear cable model more accurately reflects the creep sag of the non-linear cable model.
Figure 1

Linear Cable Models vs. Non-Linear Cable Model
Figure 2 below illustrates the method of modeling long term creep by a temperature shift such that the plastic creep is modeled as thermal strain which is the model that was used originally in PLS-CADD for a linear cable.

![Diagram of linear cable model with variables α, E, t, and ε labeled.]

**Figure 2**

**Linear Cable Model**

**Long Term Creep Modeled as Thermal Strain**

The variables used in the figure are:

- \( \alpha \) = coefficient of linear thermal expansion per 100°C
- \( E \) = final modulus of elasticity/100 (MPa/100)
- \( t \) = temperature compensation for long term creep (°C)

The equation for the elastic stress-strain curve (number 1) is

\[
\sigma = a_0 + a_1 \varepsilon
\]

where \( a_0 = 0 \) and \( a_1 = E \)
while the equation for the creep curve number (2) is
\[ \sigma_c = b_0 + b_1 \varepsilon \]
where \( b_0 = -E \alpha t \) and \( b_1 = E \)

The primary disadvantage to this model is that a constant allowance is made for creep that is not related to the value of the stringing tension.

The other more accurate approach is to pro-rata the creep as shown in Figure 3 below.

![Figure 3](Image)

**Figure 3**

**Improved Linear Cable Model**
**Long Term Creep Modeled as Proportional to Tension**

From initial curve number (1)

\[ E = \frac{\sigma_1}{\varepsilon_1} \]
\[ E_c = \frac{\sigma_1}{\varepsilon_2} \]
\[ \varepsilon_2 = \varepsilon_1 + \alpha t \]
Solving for $E_c$ gives

$$E_c = 1/(\frac{1}{E} + \frac{at}{\sigma_1})$$

Therefore the equation for the final creep curve number (3) is

$$\sigma_c = c_0 + c_1 \varepsilon$$

where

$c_0 = 0$
$c_1 = E_c$

"$\sigma_1$" is the constant value of stress that produces a creep strain equivalent to $t^\circ C$. It would normally be the "full" tension value of stress where experimental values of creep strain have been evaluated.

It is important that "$t$" represents only the metallurgical value of creep strain; the elastic strain, thermal strain, and strand settling strain components having been accounted for in the test results.

The best method of cable modeling is to include the polynomial coefficients for the non-linear stress-strain curve and for the non-linear creep curve.

Below are the cable data input dialog from PLS-CADD including a graph of the % Elongation vs. Tension for the three different cable types as used in the example file that can be downloaded above.
Nonlinear Cable Model
Long Term Creep Modeled with Polynomial
Nonlinear Cable Model
Long Term Creep Modeled with Polynomial
**Improved Linear Cable Model**

*Long Term Creep Modeled as Proportional to Tension*

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**Thermal Properties**

- **Resistance at two different temperatures**
  - Resistance (Ohms/km) at (deg C) 25: 0.0752547
  - Resistance (Ohms/km) at (deg C) 75: 0.0993672

- **Entirety coefficient**: 0.5
- **Solar absorption coefficient**: 0.5
- **Outer strands heat capacity**: 1064.19
- **Core heat capacity**: 243.992

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**Bi-metallic Conductor Model**

- Aluminum has a larger thermal expansion coefficient than steel. If aluminum is used as the outer material over a steel core there is a temperature transition point at which the aluminum is no longer under tension.
  - Select the behavior you want for temperatures above the transition point
  - Use behavior from Bi-metallic Conductor Model
  - Aluminum does not take compression at high temperature (Bird Cage)
  - Aluminum can go into compression at high temperature

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**Composite cable properties**

- Generate Coefficients from points on stress-strain curve
- Composite cable properties
  - OK
  - Cancel

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Improved Linear Cable Model
Long Term Creep Modeled as Proportional to Tension
**Linear Cable Model**

**Long Term Creep Modeled as Temperature Shift**

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### Cable Data

- **Cable Model**
  - Nonlinear cable model (separate polynomials for initial and creep behavior for inner and outer materials)
  - Linear elastic with permanent stretch due to creep proportional to creep weather creep tension
  - Linear elastic with permanent stretch due to creep specified as a user input temperature increase

- **Name**: [Path to project/cable model/dake_linear_tension_temp_increase.m]
- **Description**: DRAKE STANDARD ACSR 28/7 795.0 KOHLS
- **Stock Number**: [Path to project/cable model/dake_linear_tension_temp_increase.m]

#### Cross Section Area
- **(m²)**: 488.864

#### Outside Diameter
- **(mm)**: 28.1432

#### Ultimate Tension
- **(N)**: 140119

#### Temperature Shift Used to Model Long Term Creep
- **(°C)**: 15.6867

- **Number of independent wires (%) unless messenger supporting other wires with a spacer:** 1
- **Conductor is a J-Power Systems SAP type conductor string with core supporting all tension.**

#### Temperature at which strain data below obtained
- **(°C)**: [Path to project/cable model/dake_linear_tension_temp_increase.m]

### Outer Strands

#### Final Modulus of Elasticity (see note below)
- **(MPa)**: 686.368

#### Thermal Expansion Coefficient
- **(1/100 deg)**: 0.0018819

#### Polynomial Coefficients (all strains in %, stresses in MPa, see note)

<table>
<thead>
<tr>
<th>Stress strain</th>
<th>c0</th>
<th>c1</th>
<th>c2</th>
<th>c3</th>
<th>c4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress strain</td>
<td>686.368</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creep</td>
<td>-21.8425</td>
<td>686.368</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Final modulus, stress-strain, and creep are actual material values multiplied by ratio of outer strand area to total area.

### Binestral Conductor Model

Aluminum has a larger thermal expansion coefficient than steel. If aluminum is used as the outer material over a steel core there is a temperature transition point at which the aluminum is no longer under tension.

- **Select the behavior you want for temperatures above the transition point**
  - Use behavior from Citek/Binestral Conductor Model
  - Aluminum does not take compression at high temperature (Bird Cage)
  - Aluminum can go into compression at high temperature

#### Thermal Expansion

- **Stress**: [Path to project/cable model/dake_linear_tension_temp_increase.m]
- **Thermal Expansion Coefficient**: [Path to project/cable model/dake_linear_tension_temp_increase.m]

#### Polynomial Coefficients (all strains in %, stresses in MPa, see note)

<table>
<thead>
<tr>
<th>Stress-strain</th>
<th>c0</th>
<th>c1</th>
<th>c2</th>
<th>c3</th>
<th>c4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress-strain</td>
<td>[Path to project/cable model/dake_linear_tension_temp_increase.m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creep</td>
<td>[Path to project/cable model/dake_linear_tension_temp_increase.m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Final modulus, stress-strain, and creep are actual material values multiplied by ratio of core strand area to total area.

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**Composite Cable Properties**

- **Elasticity Coefficient**: 0.5
- **Solar Absorption Coefficient**: 0.5
- **Outer Strands Heat Capacity**: 1064.19 [Watt-deg/C]
- **Core Heat Capacity**: 243.992 [Watt-deg/C]

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Linear Cable Model
Long Term Creep Modeled as Temperature Shift