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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.

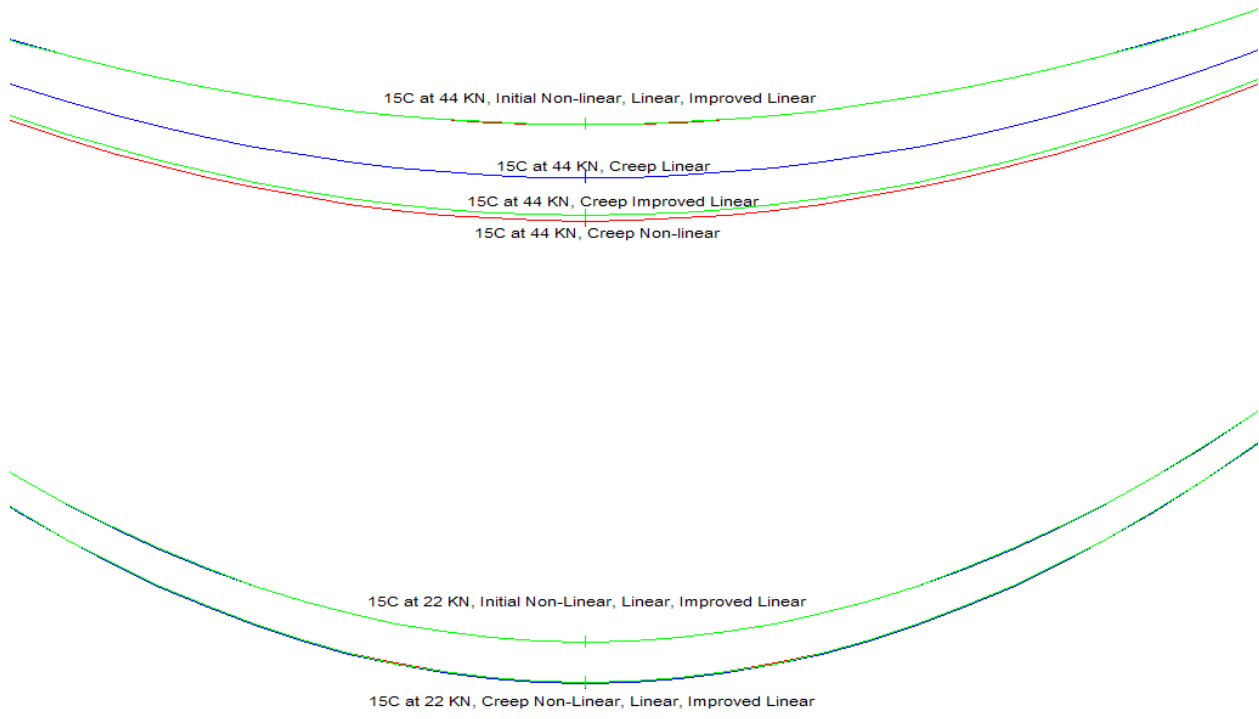


Figure 1

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.

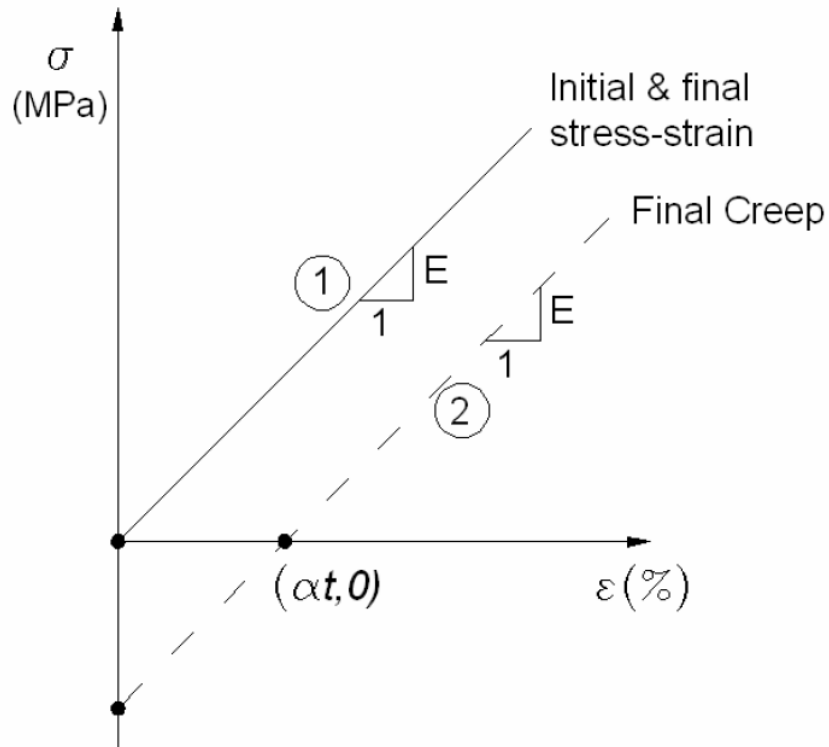


Figure 2

**Linear Cable Model
Long Term Creep Modeled as Thermal Strain**

The variables used in the figure are

α = 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.

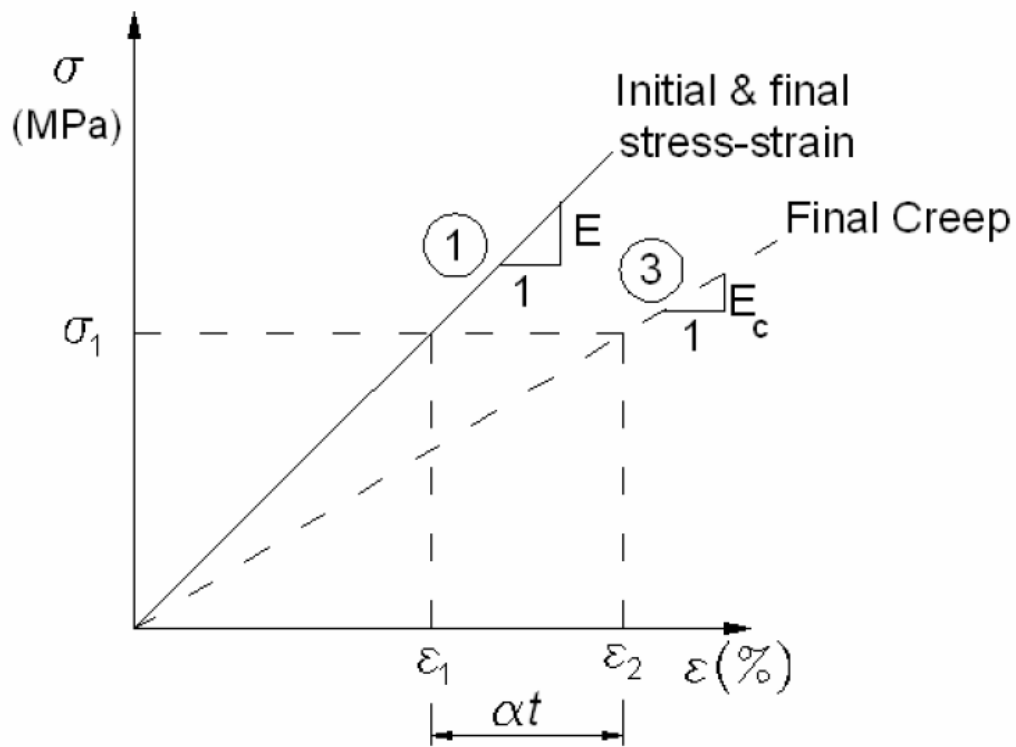


Figure 3

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

From initial curve number (1)

$$E = \sigma_1 / \varepsilon_1$$

$$E_c = \sigma_1 / \varepsilon_2$$

$$\varepsilon_2 = \varepsilon_1 + \alpha t$$

Solving for E_c gives

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

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

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

where

$$c_0 = 0$$

$$c_1 = E_c$$

" σ_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.

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 case tension
 Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: \\nas\projects\cable model\drake-nonlinear.wir

Description: DRAKE STANDARD ACSR 26/7 795.0 KCMILS

Stock Number:

Cross section area (mm²): 468.644 Unit weight (N/m): 15.9657 Number of independent wires (1 unless messenger supporting other wires with a spacer): 1
 Outside diameter (mm): 28.1432 Ultimate tension (N): 140119

Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension.

Temperature at which strand data below obtained (deg C): 21.1111

Outer Strands

Final modulus of elasticity (see note below) (MPa/100): 441.264

Thermal expansion coeff. (/100 deg): 0.002304

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

	a0	a1	a2	a3	a4
Stress-strain	-8.3633E-01	305.493	-96.556E-01	-259.367	211.503
Creep	-3.7562E-01	147.732	-129.912	37.8866	

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

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (MPa/100): 255.106

Thermal expansion coeff. (/100 deg): 0.001152

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

	b0	b1	b2	b3	b4
Stress-strain	-0.4778E-01	266.337	27.5659	-315.17E-01	192.308
Creep	0.32474	249.668	84.1255	-499.124	319.489

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

Bimetallic 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 Criteria/Bimetallic Conductor Model
 Aluminum does not take compression at high temperature (Bird Cage)
 Aluminum can go into compression at high temperature

VirtualStress = ActualStress * Ao / At
 Ao = cross section area of outer strands
 At = total cross section area of entire conductor (outer + inner strands)

Maximum virtual compressive stress (MPa): 68947.4

Thermal Rating Properties

Resistance at two different temperatures

Resistance (Ohm/km): 0.0728247 at (deg C): 25

Resistance (Ohm/km): 0.0868677 at (deg C): 75

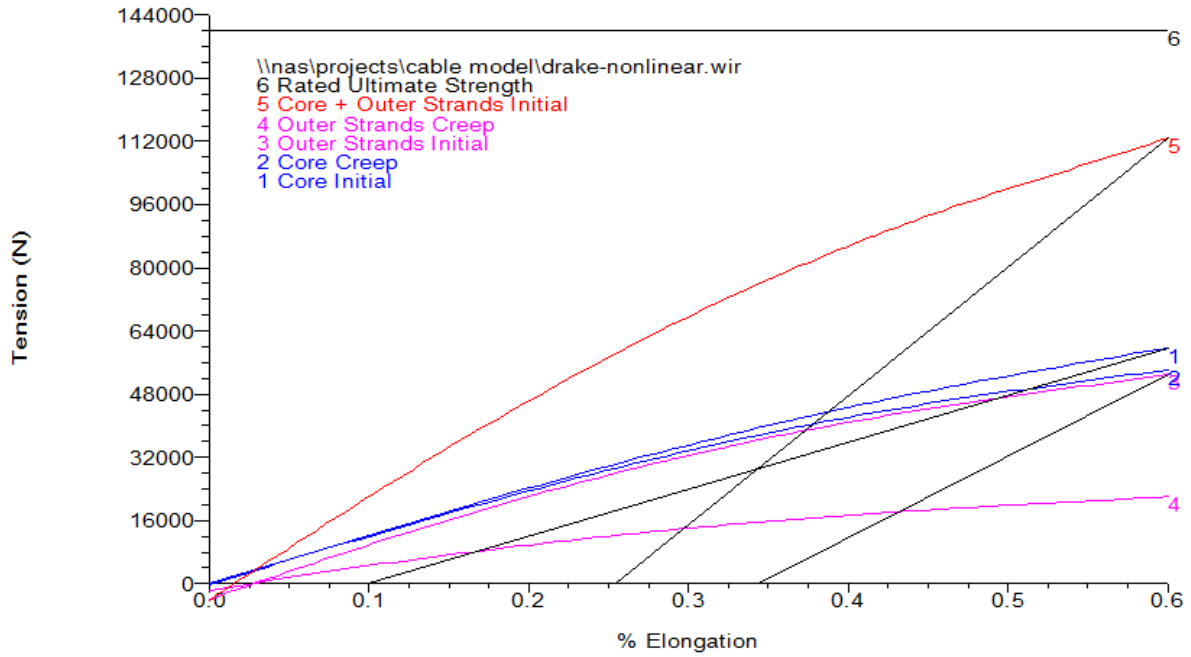
Emissivity coefficient: 0.5

Solar absorption coefficient: 0.5

Outer strands heat capacity (Watt-s/m-deg C): 1064.19

Core heat capacity (Watt-s/m-deg C): 243.992

**Nonlinear Cable Model
Long Term Creep Modeled with Polynomial**



Nonlinear Cable Model
Long Term Creep Modeled with Polynomial

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 case tension
 Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: \\nas\projects\cable model\drake-linear-creep-proportional-tension.wir

Description: DRAKE STANDARD ACSR 26/7 795.0 KCMILS

Stock Number:

Cross section area (mm²): 468.644 Unit weight (N/m): 15.9657
 Outside diameter (mm): 28.1432 Ultimate tension (N): 140119

Temperature shift used to model long term creep (deg C): 16.6667
 Tension at which temperature shift above applies (N): 22000

Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension.

Number of independent wires (1 unless messenger supporting other wires with a spacer): 1

Temperature at which strand data below obtained (deg C):

Outer Strands

Final modulus of elasticity (see note below) (MPa/100): 696.369

Thermal expansion coeff. (/100 deg): 0.0018819

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

	a0	a1	a2	a3	a4
Stress-strain		696.369			
	c0	c1	c2	c3	c4
Creep		475.244			

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

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (MPa/100):

Thermal expansion coeff. (/100 deg):

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

	b0	b1	b2	b3	b4
Stress-strain					
	d0	d1	d2	d3	d4
Creep					

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

Bimetallic 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 Criteria/Bimetallic Conductor Model
 Aluminum does not take compression at high temperature (Bird Cage)
 Aluminum can go into compression at high temperature

$VirtualStress = ActualStress * Ao / At$
 $Ao =$ cross section area of outer strands
 $At =$ total cross section area of entire conductor (outer + inner strands)

Maximum virtual compressive stress (MPa): 68947.4

Thermal Rating Properties

Resistance at two different temperatures

Resistance (Ohm/km): 0.0728247 at (deg C): 25

Resistance (Ohm/km): 0.0868677 at (deg C): 75

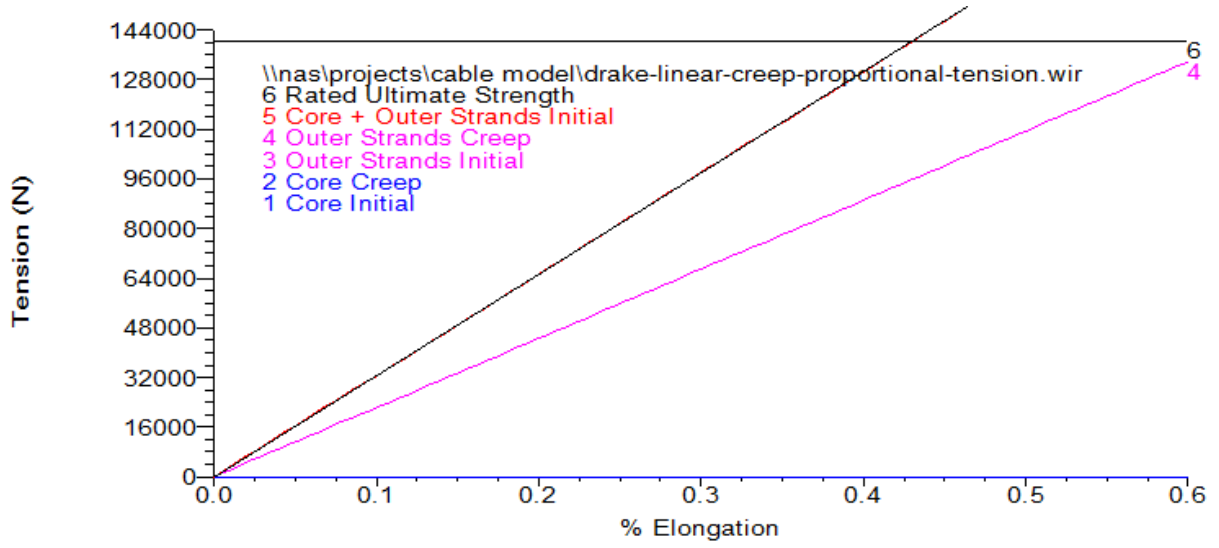
Emissivity coefficient: 0.5

Solar absorption coefficient: 0.5

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



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

Cable Data [?] [X]

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 case tension
 Linear elastic with permanent stretch due to creep specified as a user input temperature increase

Name: \\nas\projects\cable model\drake-linear-creep_temp_increase.wir

Description: DRAKE STANDARD ACSR 26/7 795.0 KCMILS

Stock Number: []

Cross section area (mm²): 468.644 Unit weight (N/m): 15.9657 Number of independent wires (1 unless messenger supporting other wires with a spacer): 1
 Outside diameter (mm): 28.1432 Ultimate tension (N): 140119

Temperature shift used to model long term creep (deg C): 16.6667 Conductor is a J-Power Systems GAP type conductor strung with core supporting all tension.

Temperature at which strand data below obtained (deg C): []

Outer Strands

Final modulus of elasticity (see note below) (MPa/100): 696.369
 Thermal expansion coeff. (/100 deg): 0.0018819
 Polynomial coefficients (all strains in %, stresses in MPa, see note):
 Stress-strain: a0 [] a1 696.369 a2 [] a3 [] a4 []
 Creep: c0 -21.842E c1 696.369 c2 [] c3 [] c4 []

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

Core Strands (if different from outer strands)

Final modulus of elasticity (see note below) (MPa/100): []
 Thermal expansion coeff. (/100 deg): []
 Polynomial coefficients (all strains in %, stresses in MPa, see note):
 Stress-strain: b0 [] b1 [] b2 [] b3 [] b4 []
 Creep: d0 [] d1 [] d2 [] d3 [] d4 []

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

Bimetallic Conductor Model..

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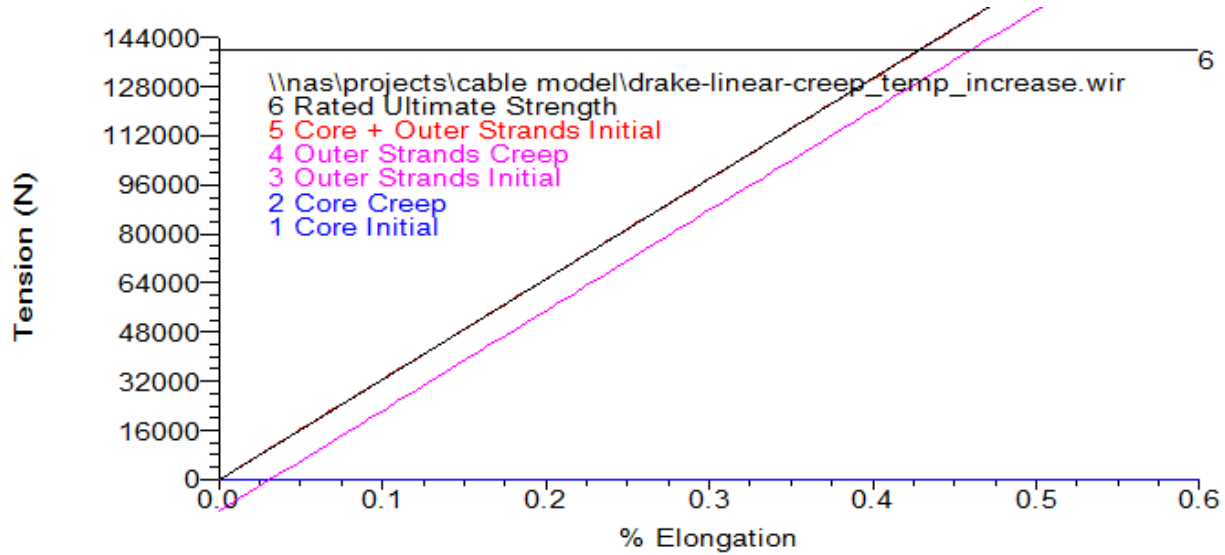
Maximum virtual compressive stress (MPa): 68947.4

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Resistance at two different temperatures
 Resistance (Ohm/km): 0.0728247 at (deg C): 25
 Resistance (Ohm/km): 0.0868677 at (deg C): 75

Emissivity coefficient: 0.5
 Solar absorption coefficient: 0.5
 Outer strands heat capacity (Watt-s/m-deg C): 1064.19
 Core heat capacity (Watt-s/m-deg C): 243.992

**Linear Cable Model
Long Term Creep Modeled as Temperature Shift**



Linear Cable Model
Long Term Creep Modeled as Temperature Shift