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Elevated Temperature Creep of AAC, AAAC, ACAR, AACSR, & ACSR Conductors

The purpose of this technote is to explain elevated temperature creep (ETC), its impact on the sag of conductors, and how the calculations are performed in **PLS-CADD**. All ETC calculations in **PLS-CADD** are based on IEEE standard 1283.

ETC is a phenomenon that occurs in conductors, primarily with high percentages of aluminum, that after subjected to periods of high temperature operation which causes additional permanent elongation beyond that of typical creep elongation. The ETC feature in **PLS-CADD** allows you to select a wire and subject it to hypothetical high temperature events by specifying the temperature and duration of each event. **PLS-CADD** uses the predictor equations documented in the IEEE 1283 standard to derive an equivalent change in temperature to reflect the additional creep stretch your conductor will see from elevated temperature operation. Using the results of this calculation you can modify existing weather cases in the criteria file, or make new ones that account for the equivalent change in wire temperature. This modification of the existing wire temperature simulates the additional elevated creep stretch. Note that the IEEE 1283 standard is not intended to be used to calculate typical creep elongations, nor is it intended to be used for calculating time dependent creep.

In order to use ETC in **PLS-CADD**, your cable files must meet certain requirements. The IEEE 1283 standard only supplies predictor equations for the following conductor types: AAC, AAAC, ACAR, AACSR, & ACSR, and only for strandings listed in Table A.3.1.5. Using any other type of cable or stranding will not yield any results from the ETC calculation in **PLS-CADD**. Further, IEEE 1283 states that for any steel reinforced conductor the ratio of steel strand area needs to be less than 7.5% of the total area, otherwise the effects of ETC can be ignored. So in order for a **PLS-CADD** wire file to be eligible for use in the ETC function you must specify an appropriate cable type as shown below, and if using an AACSR or ACSR the ratio of steel strand area to total area must be less than 7.5%.

An example of an ACSR cable file that meets these criteria would be 636 Kcmil Kingbird with 18 strands of aluminum around 1 strand of steel. Both the aluminum and steel strands have individual diameters of 4.7752mm. This yields a total cross sectional area of 340.332mm^2.

$$Cable\ Area = Aluminum\ Strands * Aluminum\ Strand\ Area + Steel\ Strands * Steel\ Strand\ Area$$

$$Cable\ Area = 18 * \pi * \left(\frac{4.7752}{2}\right)^2 + 1 * \pi * \left(\frac{4.7752}{2}\right)^2 = 340.332mm^2$$

$$Steel\ Area = 1 * \pi * \left(\frac{4.7752}{2}\right)^2 = 17.909mm^2$$

$$Percentage\ of\ Steel\ to\ Total = \frac{17.909}{340.332} * 100 = 5.26\%$$

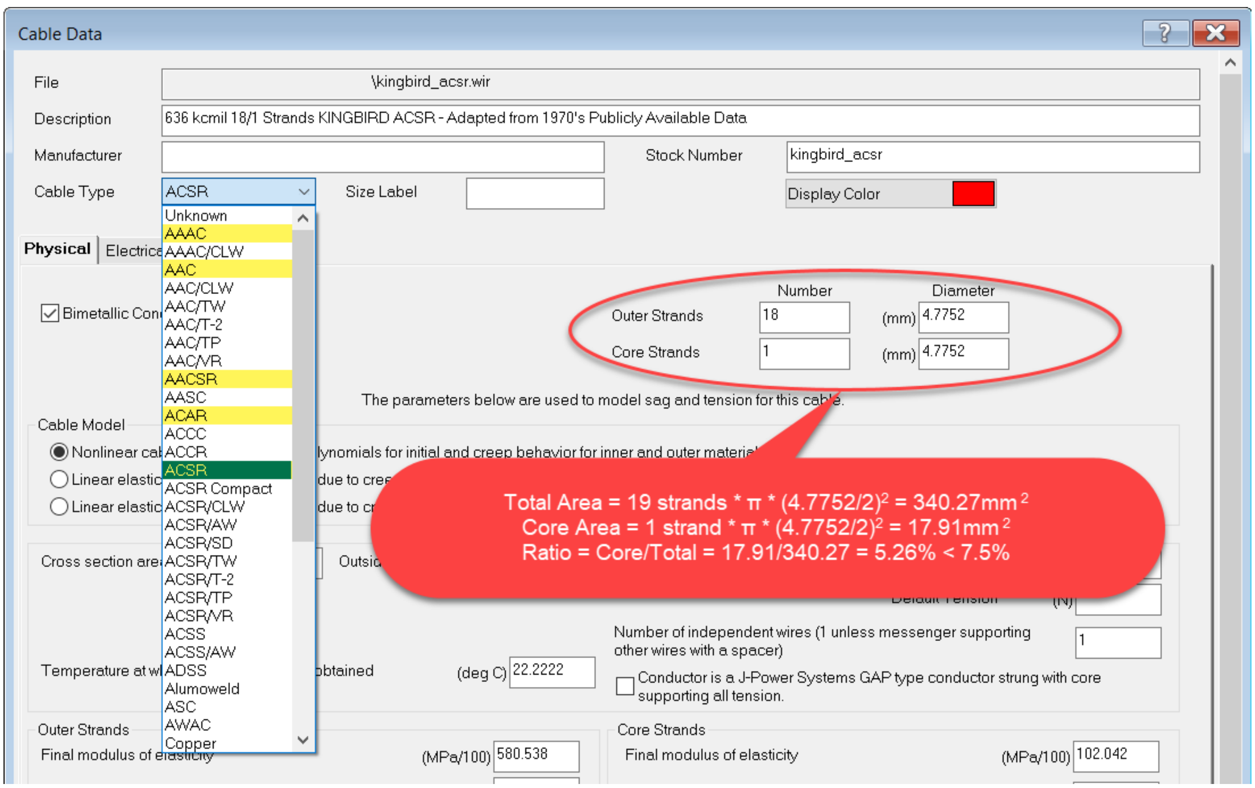
An example of an ACSR cable file that doesn't meet these criteria would be 636 Kcmil Grosbeak with 26 strands of aluminum around 7 strand of steel. The aluminum strands have individual diameters of 3.9726mm. The steel strands have individual diameters of 3.0886mm. This yields a total cross sectional area of 374.711mm^2.

$$Cable\ Area = Aluminum\ Strands * Aluminum\ Strand\ Area + Steel\ Strands * Steel\ Strand\ Area$$

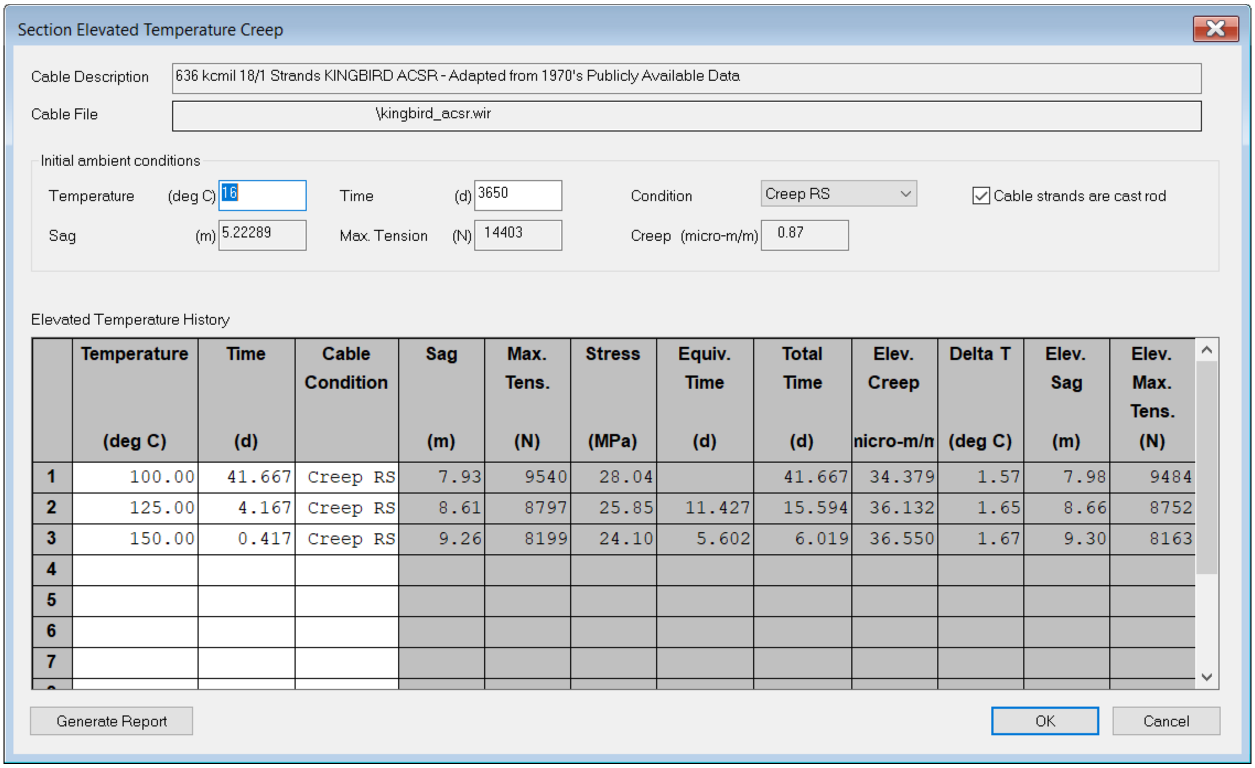
$$Cable\ Area = 26 * \pi * \left(\frac{3.9726}{2}\right)^2 + 7 * \pi * \left(\frac{3.0886}{2}\right)^2 = 374.711mm^2$$

$$Steel\ Area = 7 * \pi * \left(\frac{3.0886}{2}\right)^2 = 52.446mm^2$$

$$Percentage\ of\ Steel\ to\ Total = \frac{52.446}{374.711} * 100 = 14.00\%$$



Once you configure the appropriate cable file with a compatible cable type and string it in your **PLS-CADD** model you can now run the ETC command by navigating to **Sections/Thermal Calculations (IEEE, CIGRE and TNSP)/Elevated Temperature Creep**... which results in the Section Elevated Temperature Creep table shown below.



In this table you'll enter the initial ambient conditions for the state of the wire before the high temperature operation. Typically the ambient temperature is assumed to be an average annual temperature like 60 Deg F or 15-16 Deg C. You'll also enter the amount of time the conductor was at normal ambient conditions to establish the approximate creep elongation until that point. A common choice is to enter a time period of 3650 days or 10 years, which is a typical industry accepted value for how long a wire takes to achieve its full natural creep elongation. You'll also select the cable condition which is commonly set to Creep RS. And the last input you'll need is to check the box for if the strands are cast rod. If you do not select this check box then PLS-CADD will use the IEEE 1283 equations for hot-rolled rod instead. After this the various periods of elevated temperature operation are input, such as the temperature of the cable, length of operation at that temperature, and cable condition (typically Creep RS).

Below are 2 detailed example calculations in which the results are interpreted based on the calculation from **PLS-CADD**. To start we are going to look at a 795 kcmil AAC 37/0 Strands Arbutus continuous cast wire that as a total cross sectional area of 402.8mm^2. It will be a 243.8 m (800 ft) ruling span and a maximum light loading tension of 25.1 kN (5644 pounds-force). The conductor will operate for 1000 hours at 100ºC (212°F), 100 hours at 125ºC (257°F) and 10 hours at 150ºC (302°F). Assuming that the conductor was installed at 16ºC and existed there for the majority of its lifetime, a simple **PLS-CADD/Lite** model was developed, and the following sag/tension table was generated for Creep RS.

Temperature	Sag	Tension
(°C)	(m)	(kN)
16	5.85	13.90892
100	8.57	9.55190
125	9.26	8.85760
150	9.91	8.29339

These values represent the typical baseline creep conditions before any sustained elevated temperature operation where ETC would occur. From here we look to equation A.1 of the IEEE 1283.

$$\varepsilon_c = K\sigma^{1.3}t^{0.16} \qquad \text{(A.1)}$$

K is the constant for calculating room temperature creep which varies depending on the stranding of our conductor per Table A.1 of the IEEE 1283 where K_1 is the constant for hot-rolled rods and K_2 is the constant for continuous cast rods.

Constant	7 Strands	19 Strands	37 Strands	61 Strands
K_1	1.36	1.29	1.23	1.16
K_2	0.84	0.77	0.77	0.71
M_1	0.0148	0.0142	0.0136	0.0129
M_2	0.0090	0.0090	0.0084	0.0077
G	0.71	0.65	0.77	0.61

So from this table we can see that our constant K is equal to 0.77 since our conductor is 37 strands and continuous cast rods.

σ is the stress in the cable, tension / cross sectional area. So for our cable stress at room temperature is:

$$\sigma = \frac{13.90892kN}{402.8mm^2} = 34.5305859\frac{N}{mm^2}$$

t is the time in hours which, if we assume the wire has fully crept before elevated temperature operation, will equal 10 years:

$$t = 24hrs * 365days * 10yrs = 87{,}600hrs$$

So now we have all the terms calculated and we can substitute them into equation (A.1)

$$\varepsilon_c = 0.77 * \ 34.5305859^{1.3} * 87600^{0.16} = 475.29\ \frac{micro - meter}{meter}$$

Now that we know the creep strain at full general creep before any elevated temperature operation, we can start looking at elevated temperature operations. This is done using equation (A.7) from IEEE 1283.

$$\varepsilon_c = MT^{1.4}\sigma^{1.3}t^{0.16} \qquad \text{A.7}$$

M is our elevated creep temperature constant obtained from table A.1 above, which since we have continuous cast rods we use M_2, which for 37 stranded conductor is 0.0084.

T is the temperature the conductor operated at for the elevated temperature event and we have 3 different events.

T_1 = 100°C $\quad$ T_2 = 125°C $\quad$ T_3 = 150°C

σ again is the stress in the cable, tension / cross sectional area. So for our cable the stress at the 3 temperatures is:

$\sigma_1 = \frac{9.55190kN}{402.8mm^2} = 23.71375372\frac{N}{mm^2}$

$\sigma_2 = \frac{8.85760kN}{402.8mm^2} = 21.99006951\frac{N}{mm^2}$

$\sigma_3 = \frac{8.29339N}{402.8mm^2} = 20.58934955\frac{N}{mm^2}$

And the t for the various time periods is: t_1 = 1000 hrs t_2 = 100 hrs t_3 = 10 hrs

Now we can calculate the elevated creep strain for all 3 events.

$$\varepsilon_c\ (event\ 1) = 0.0084 * 100^{1.4} * 23.71375372^{1.3}1000^{0.16} = 981.25\ \frac{micro-meter}{meter}$$

Now because these high temperature events aggregate we need to be able to add the creep strain of each event sequentially together. So before we can calculate the creep strain after event 2 we need to figure out what the equivalent time under event 2's conditions to get the 981.25 micro-meters/meter strain we just calculated. To do this we utilize equation A.7 again but we substitute the creep strain we just solved at event 1 and change the temperature to condition 2 and solve for the time equivalent.

$$\varepsilon_c\ (event\ 1) = 981.25\ \frac{micro-meter}{meter} = 0.0084 * 125^{1.4} * 21.99006951^{1.3} * t^{0.16}$$

Solving for t we get: t = 262.0135 hours

Now we can solve for the creep strain at event 2 while adding in the 262.0135 hours of equivalent time from event 1.

$$\varepsilon_c\ (event\ 2) = 0.0084 * 125^{1.4} * 21.99006951^{1.3}(100 + 262.0135)^{0.16} = 1033.34\ \frac{micro-meter}{meter}$$

Now we'll figure out the equivalent time at event 3's conditions to get the 1033.34micro-meters/meter strain so that we can add that in when calculating the strain after event 3.

$$\varepsilon_c\ (event\ 2) = 1033.34\ \frac{micro-meter}{meter} = 0.0084 * 150^{1.4} * t^{0.16}$$

Solving for t we get: t = 125.3516 hours

And now we can take the final step of calculating the creep strain after event 3.

$$\varepsilon_c\ (event\ 3) = 0.0084 * 150^{1.4} * 20.58934955^{1.3}(10 + 125.3516)^{0.16} = 1046.11\ \frac{micro-meter}{meter}$$

We have the creep strain calculated for the base line prior to elevated temperature operation and the creep strains for all elevated temperature events so we can now calculate the equivalent change in temperature to simulate the additional sag in the span attributed to elevated temperature operation using equation A.16.

$$\Delta T = \frac{(\varepsilon_{high} - \varepsilon_{ambient})}{\alpha} \qquad \text{A.16}$$

The α term is the coefficient of thermal expansion. Although the IEEE 1283 has a table of values for α, **PLS-CADD** uses the input thermal expansion coefficient in the cable file. *Note that for steel reinforced wires **PLS-CADD** will use the composite thermal expansion coefficient. The value of α for the cable in this example is $23.0*10^{-6}$. Substituting this we get the corresponding ΔT values for the various high temperature events.

$$\Delta T_1 = \frac{(981.25-475.29)}{23} = 22.00°C \quad \Delta T_2 = \frac{(1033.34-475.29)}{23} = 24.26°C \quad \Delta T_3 = \frac{(1046.11-475.29)}{23} = 24.82°C$$

With the equivalent changes in temperature, the wire temperatures in the criteria weather cases can be modified so the impacts in sag/tension can be evaluated. By running the ETC report in **PLS-CADD** we can see the same values.

```
Span and Cable Input

Line No.             =          1
Section No.          =          1
Ruling Span Length =     243.80 (m)
Cast Rod Cable       =        Yes
Cable File           = C:\ETC\arbutus_aac.wir
Cable Description    = 795 kcmil 37/0 Strands ARBUTUS AAC - Adapted from 1970's Publicly Available Data


Initial Ambient Conditions

Temperature                 =       16.0 (deg C)
Time                        =     3650.0 (d)
Cable Condition             =    Creep RS
Creep                       =     475.29 (micro-m/m)
Sag                         =       5.85 (m)
Max. Tension                =   13908.92 (N)
Horiz. Tension              =   13845.19 (N)
Sag (elevated)              =       6.73 (m)
Max. Tension (elevated)     =   12110.21 (N)
Horiz. Tension (elevated) =     12036.89 (N)


Elevated Temperature Results

   Temp.      Time      Cable       Sag    Max.  Stress    Equiv.     Total Delta T | ------------Elevated----------- |
                     Condition             Tens.              Time      Time        |      Creep      Sag  Hori.    Max. |
                                                                                    |                      Tens.   Tens. |
  (deg C)      (d)                   (m)      (N)   (MPa)      (d)        (d)  (deg C) | (micro-m/m)     (m)    (N)     (N) |
--------------------------------------------------------------------------------------------------------------------------
   100.00     41.67   Creep RS    8.57    9552  23.71               41.67    22.00    981.2522    9.25   8762    8863
   125.00      4.17   Creep RS    9.26    8858  21.99     10.92     15.08    24.26   1033.3469    9.90   8191    8299
   150.00      0.42   Creep RS    9.91    8293  20.59      5.22      5.64    24.82   1046.1246   10.52   7714    7828
```

For the second example use a 636 kcmil ACSR 18/1 Strands Kingbird continuous cast wire with a total cross sectional area of 340.332mm^2. It will be a 243.8 m (800 ft) ruling span and a horizontal install tension of 16000.9N (3597.1 pounds-force). The conductor will operate at the same conditions as the previous example; 1000 hours at 100ºC (212°F), 100 hours at 125ºC (257°F) and 10 hours at 150ºC (302°F). Assuming that the conductor was installed at 16ºC and existed there for the majority of its lifetime a simple **PLS-CADD/Lite** model was developed and the following sag/tension table was generated for Creep RS.

Temperature	Sag	Tension
(°C)	(m)	(kN)
16	5.55	13.56109
100	8.18	9.25034
125	8.85	8.56546
150	9.48	8.01078

These values represent the typical baseline creep conditions before any sustained elevated temperature operation where elevated temperature creep would occur. From here we look to equation A.14 of IEEE 1283.

*Note the equation A.15 shown in this tech note does not match the currently published version of IEEE 1283. We discovered a typo in the document during implementation into PLS-CADD.

$\varepsilon_c = 1.1 * (\%RS)^{1.3} * t^{0.16}$ (A.14)

The 1.1 constant for calculating room temperature creep is for continuous cast rods. If this example was using hot-rolled rods then a constant of 2.4 would be used as per equation A.13. The %RS term is the ratio of conductor tension at the given conditions relative to the rated conductor strength. In this example the 636 Kcmil Kingbird ACSR conductor has a rated breaking strength of 69837.1N. So with this we can now calculate the general creep prior to elevated temperature elevation.

$$\varepsilon_c = 1.1 * \left(\frac{13561.09}{69837.1} * 100\right)^{1.3} * 87600^{0.16} = 321.2656285 \frac{micro - meter}{meter}$$

Now that we know the creep strain at full general creep before any elevated temperature operation we can now start looking at elevated temperature operations. This is done using equation (A.15) from IEEE 1283.

$\varepsilon_c = 0.24 * (\%RS) * T * t^{0.16}$ A.15

Now we can calculate the elevated creep strain for all 3 events.

$$\varepsilon_c\ (event\ 1) = 0.24 * \left(\frac{9250.34}{69837.1} * 100\right) * 100 * 1000^{0.16} = 960.0254374 \frac{micro-meter}{meter}$$

Again because these high temperature events aggregate we need to be able to add the creep strain of each event sequentially together. So before we can calculate the creep strain after event 2 we need to figure out what the equivalent time under event 2's conditions to get the 960.0254374 micro-meters/meter of strain we just calculated. To do this we utilize equation A.15 again but we substitute the creep strain we just solved at event 1 and change the temperature to condition 2 and solve for the time equivalent.

$$\varepsilon_c\ (event\ 1) = 960.0254374 \frac{micro-meter}{meter} = 0.24 * \left(\frac{8565.46}{69837.1} * 100\right) * 125 * t^{0.16}$$

Solving for t we get: t = 400.9648 hours

Now we can solve for the creep strain at event 2 while adding in the 400.9648 hours of equivalent time from event 1.

$$\varepsilon_c\ (event\ 2) = 0.24 * \left(\frac{8565.46}{69837.1} * 100\right) * 125 * (100 + 400.9648)^{0.16} = 994.8437967 \frac{micro-meter}{meter}$$

Now we'll figure out the equivalent time at event 3's conditions to get the 994.8437967 micro-meter/meter strain so that we can add that in when calculating the strain after event 3.

$$\varepsilon_c\ (event\ 2) = 994.8437967 \frac{micro-meter}{meter} = 0.24 * \left(\frac{8010.78}{69837.1} * 100\right) * 150 * t^{0.16}$$

Solving for t we get: t = 243.584 hours

And now we can take the final step of calculating the creep strain after event 3.

$$\varepsilon_c\ (event\ 3) = 0.24 * \left(\frac{8010.78}{69837.1} * 100\right) * (10 + 243.584)^{0.16} = 1001.268578 \frac{micro-meter}{meter}$$

We have the creep strain calculated for the base line prior to elevated temperature operation and the creep strains for all elevated temperature events we can now calculate the equivalent change in temperature to simulate the additional sag in the span attributed to elevated temperature operation using equation A.16.

$$\Delta T = \frac{(\varepsilon_{high} - \varepsilon_{ambient})}{\alpha} \qquad \text{A.16}$$

The α term is the coefficient of thermal expansion. Although the IEEE 1283 has a table of values for α, **PLS-CADD** uses the input thermal expansion coefficient in the cable file. *Note that for steel reinforced wires **PLS-CADD** will use the composite thermal expansion coefficient. The value of α for the cable in this example is 21.3178×10^{-6} which can be obtained from **PLS-CADD** by editing the cable file and selecting the composite cable properties button at the bottom of the dialog. Substituting this we get the corresponding ΔT values for the various high temperature events.

$$\Delta T_1 = \frac{(960.0254374 - 321.2656285)}{21.3178} = 29.96°C$$

$$\Delta T_2 = \frac{(994.8437967 - 321.2656285)}{21.3178} = 31.60°C$$

$$\Delta T_3 = \frac{(1001.268587 - 321.2656285)}{21.3178} = 31.90°C$$

With the equivalent changes in temperature, the wire temperatures in our criteria weather cases can be modified so the impacts in sag/tension can be evaluated. By running the ETC report in **PLS-CADD** we can see the same values.

Span and Cable Input

```
Line No.           =         1
Section No.        =         1
Ruling Span Length =    243.80  (m)
Cast Rod Cable     =       Yes
Cable File         = C:\Users\jkohler\Desktop\ETC\kingbird_acsr.wir
Cable Description  = 636 kcmil 18/1 Strands KINGBIRD ACSR - Adapted from 1970's Publicly Available Data
```

Initial Ambient Conditions

```
Temperature                =      16.0  (deg C)
Time                       =    3650.0  (d)
Cable Condition            =  Creep RS
Creep                      =    321.27  (micro-m/m)
Sag                        =      5.55  (m)
Max. Tension               =  13561.09  (N)
Horiz. Tension             =  13505.14  (N)
Sag (elevated)             =      6.63  (m)
Max. Tension (elevated)    =  11376.19  (N)
Horiz. Tension (elevated)  =  11309.35  (N)
```

Elevated Temperature Results

Temp. (deg C)	Time (d)	Cable Condition	Sag (m)	Max. Tens. (N)	Stress (MPa)	Equiv. Time (d)	Total Time (d)	Delta T (deg C)	Elevated Creep (micro-m/m)	Elevated Sag (m)	Elevated Hori. Tens. (N)	Elevated Max. Tens. (N)
100.00	41.67	Creep RS	8.18	9250	27.19		41.67	29.96	960.03	9.03	8311	8402
125.00	4.17	Creep RS	8.85	8565	25.17	16.71	20.87	31.60	994.85	9.63	7797	7894
150.00	0.42	Creep RS	9.48	8011	23.54	10.15	10.57	31.90	1001.28	9.89	7593	7692