Composite Conductor

795-kcmil

Derivation of Power-Law Creep Parameters

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<u>795-kcmil, 3M™ Composite Conductor: Derivation of Power-Law Creep Parameters</u>

Summary
Creep Testing was performed at room temperature on 795-kcmil, 3M™ Composite Conductor (also known as ACCR – Aluminum Conductor Composite Reinforced). The work was carried out by NEETRAC and is summarized in a report entitled, "795-kcmil, 3M™ Composite Conductor Room-temperature Creep", NEETRAC Project Number: 02-241, May 2005. The data from that study is used here to generate the creep equations governing the creep behavior of the conductor.

Creep Data:
The raw data was obtained from NEETRAC in the form of Microsoft Excel® Spreadsheets, and all the subsequent analysis was performed using Microsoft Excel® Software. The specification for the 795-kcmil, 3M™ Composite Conductor is provided in Appendix A. Data from each testing load was plotted in a graph of Creep Strain vs. Time (Figure 1-4), using creep strains that have been corrected for load and temperature drift (see original test report noted above). This data was selected from one hour onwards since the first hour of creep can often be influenced by a variety of effects (time to load, conductor sample preparation, etc.). The target time for the creep test was 1000 hours, although often this time was exceeded depending on the availability of the test equipment. Power-law curve fits are made to the data and the resulting equations are compiled in Table 1, which relate creep strain (y) to time (x) for each loading (%RBS) condition.

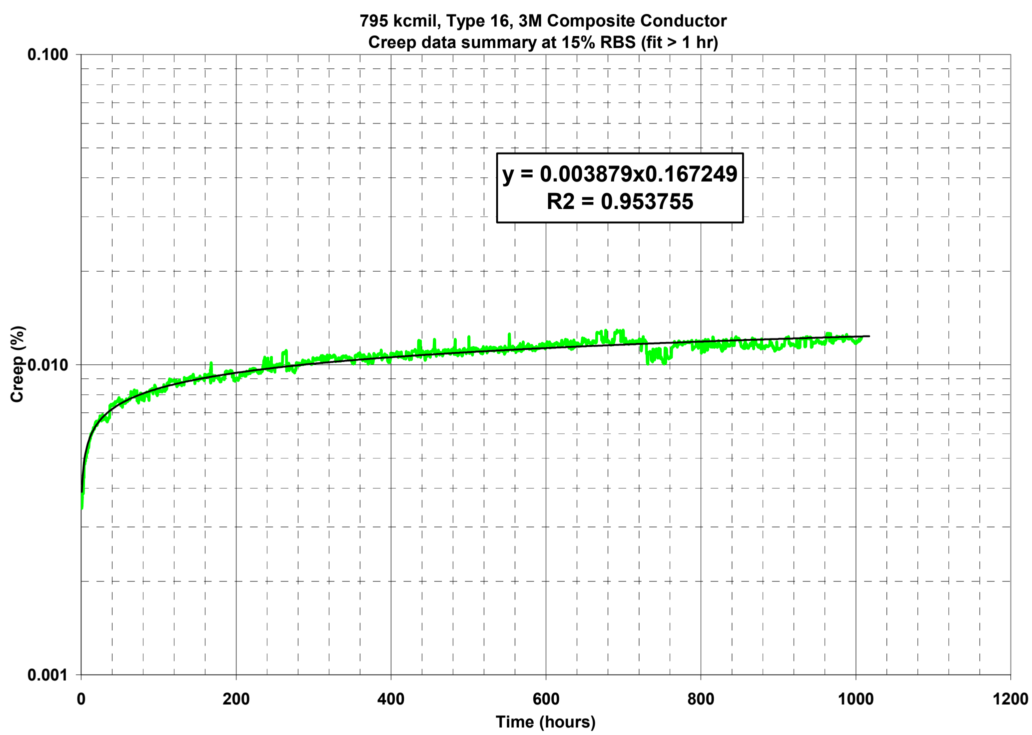

Figure 1. Creep strain vs. time for 795-kcmil, 3M™ Composite Conductor at 15% RBS

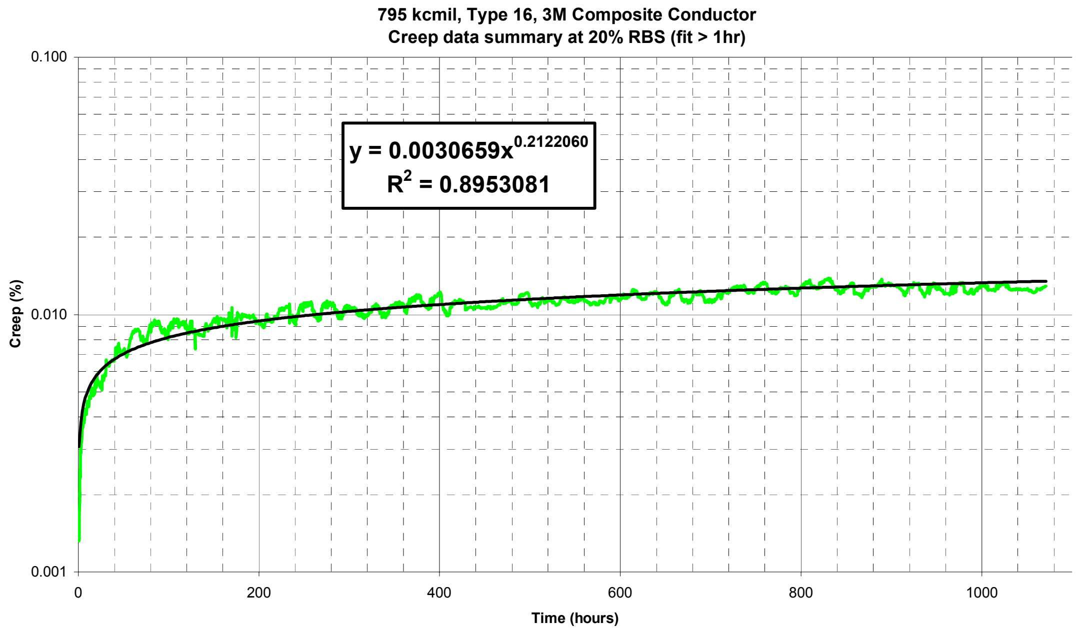

Figure 2. Creep strain vs. time for 795-kcmil, 3M™ Composite Conductor at 20% RBS

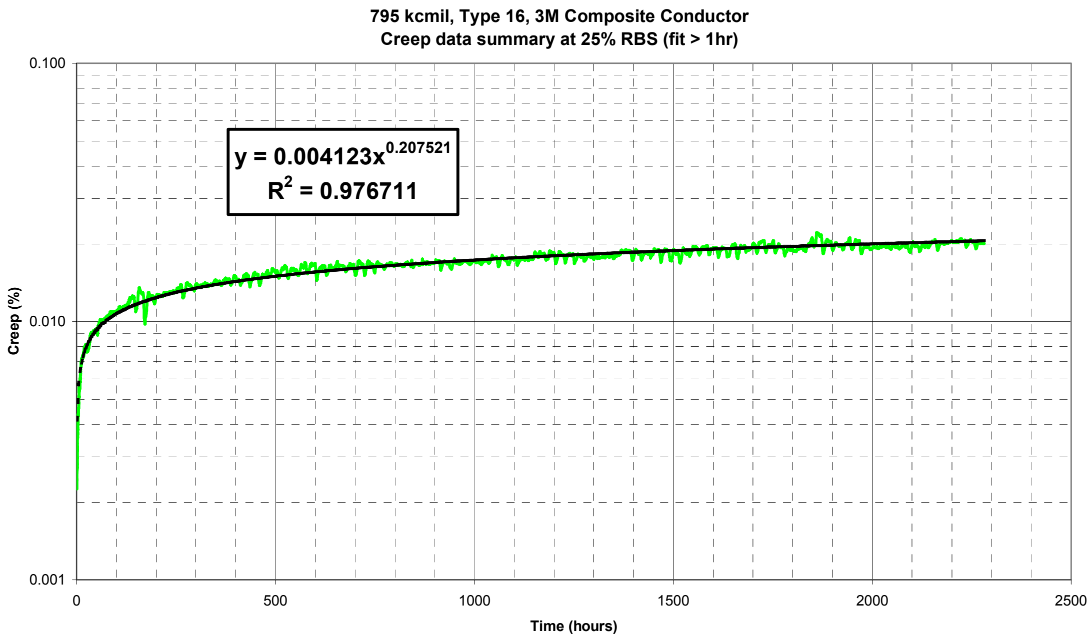

Figure 3. Creep strain vs. time for 795-kcmil, 3M™ Composite Conductor at 25% RBS

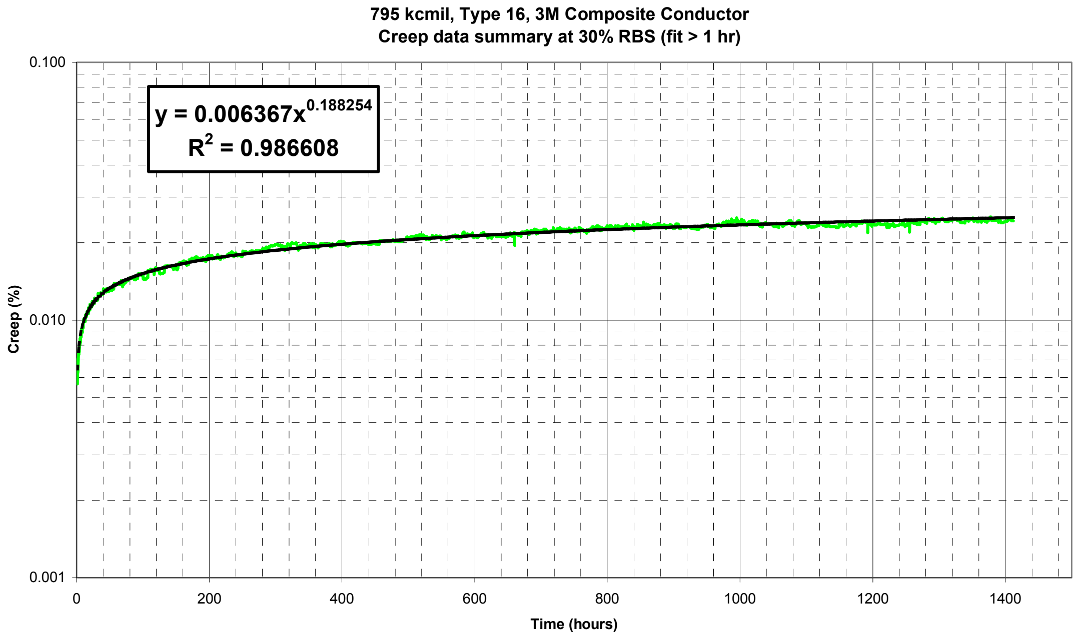

Figure 4. Creep strain vs. time for 795-kcmil, 3M™ Composite Conductor at 30% RBS

Load (%RBS)	Fitting Equation	Correlation Coefficient
15%	$y = 0.003879\ x^{0.167249}$	$R^2 = 0.953755$
20%	$y = 0.0030659\ x^{0.2122060}$	$R^2 = 0.8953081$
25%	$y = 0.0041237\ x^{0.207521}$	$R^2 = 0.976711$
30%	$y = 0.006367\ x^{0.188254}$	$R^2 = 0.986608$

Table 1. Summary of Fitting Equations (in the form y (%) = b*[(x in hrs)^c])

Examining the data in Table 1, the coefficients of the fitting equations seem reasonably well behaved for the 20-30% loads but the 15% load level parameters seem a little different. The power term varies from 0.167-0.222 with the term at 15% RBS perhaps lower than the others, since this term does not usually vary with stress. The first term before the abscissa usually increases with stress, and this progression is not well behaved either because the parameter is high for the 15% load (most likely) or is low for the 20% load level.

Self-Consistency of Creep Data:

Creep data is notoriously difficult to generate experimentally due to small variations in both samples and test procedure. Plotting the fitting equations on a single graph, yields Figures 5 and 6, which are extrapolated out to 100,000 hours to check for sensible behavior in the extrapolation. This data is used to predict the 10-year (87,600 hours) creep behavior of the conductor. In Figure 5, the curves are uniformly spaced suggesting the relative long-term creep behavior is well captured. However, in Figure 6 the short-term behavior is not as consistent. The line for 15% RBS load crosses the 20% RBS load data at about 200 hours, suggesting an over estimation of creep for the 15% RBS load for short times. At longer times (the more critical region), this discrepancy appears to reduce. The remaining curves for 20-30% RBS are parallel and evenly spaced suggesting they are consistent with each other. However, overall this data seems to be suitable for predicting the long-term creep.

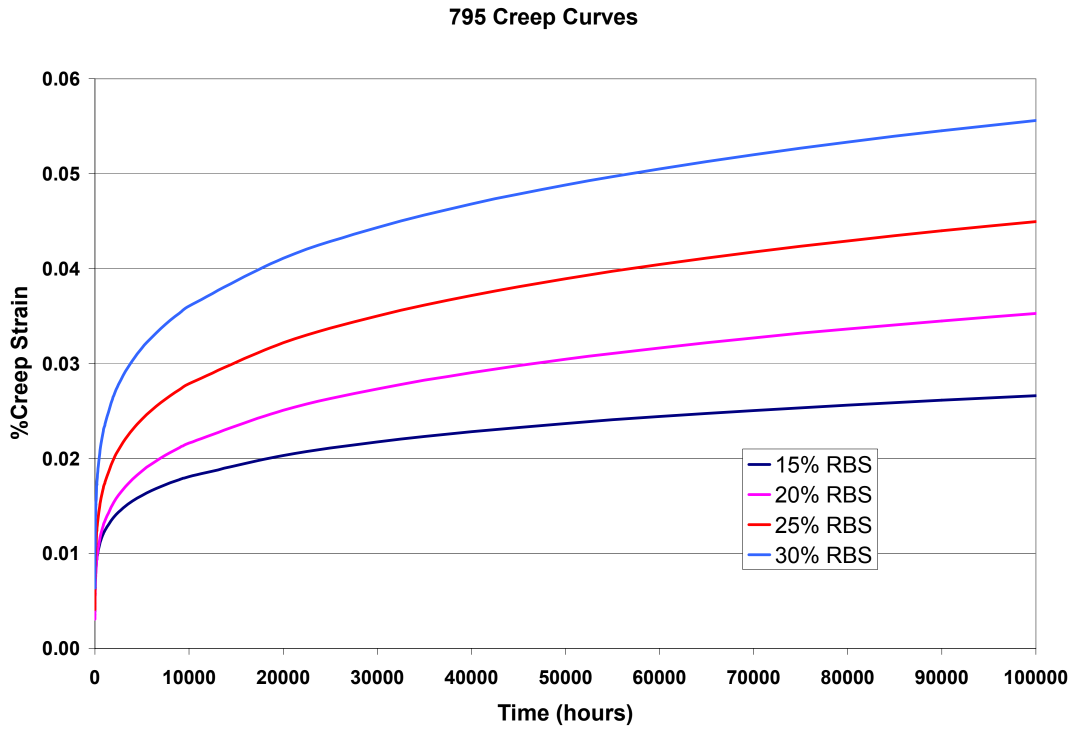

Figure 5. Creep strain vs. time for 795-kcmil, at all test loads.

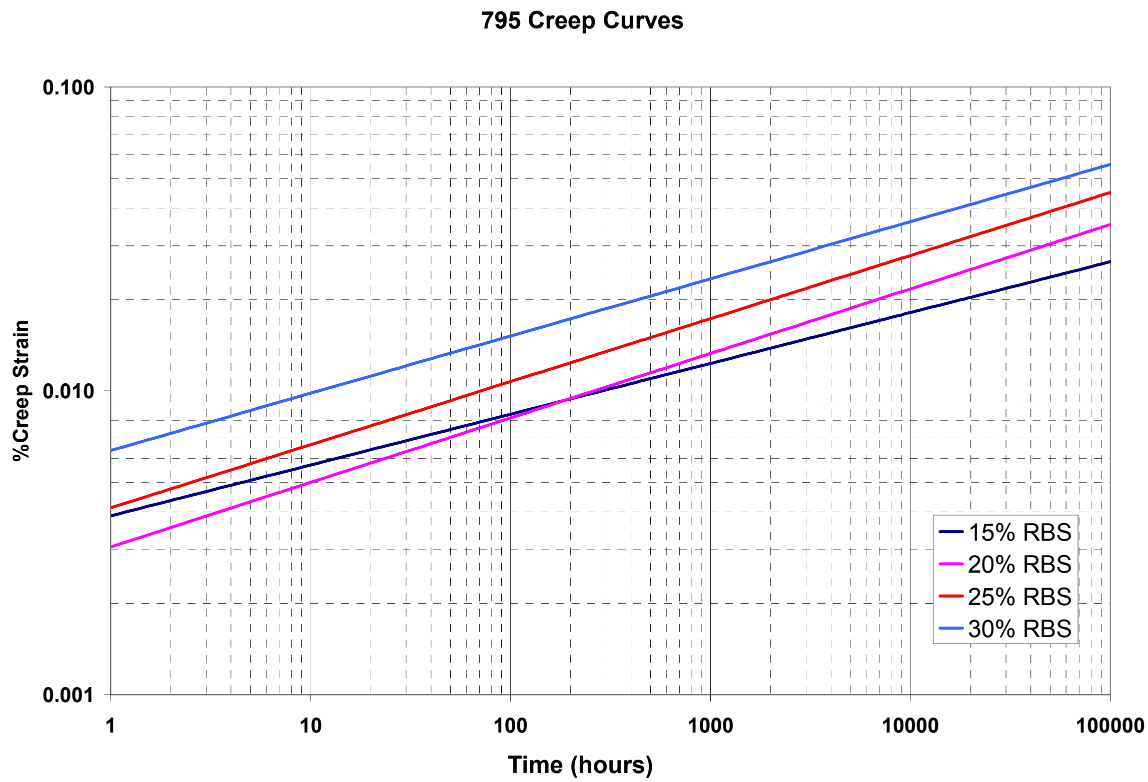

Figure 6. Log. Creep strain vs. Log. time for all test loads.

Initial Loading Condition:

One cause for discrepancies in creep data can be during the initial loading phase. Data from this phase is presented for each loading condition in Figures 7-10 for comparison.

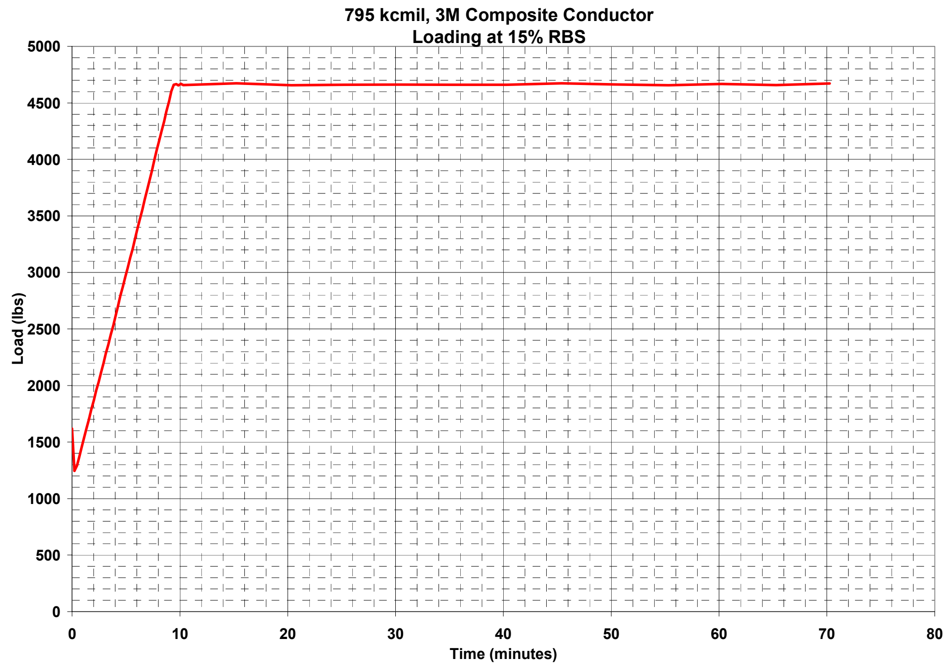

Figure 7. 15% RBS initial loading. Load was increased to target load in 9 minutes.

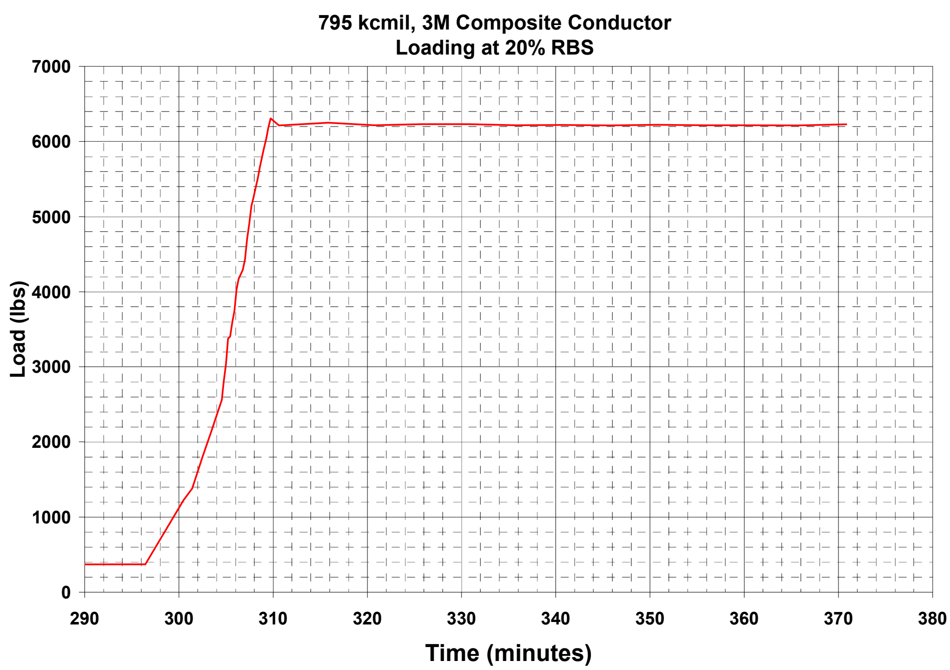

Figure 8. 20% RBS initial loading. Load was held at approx. 400 lbs for 5 hours and then increased to target load in 14 minutes.

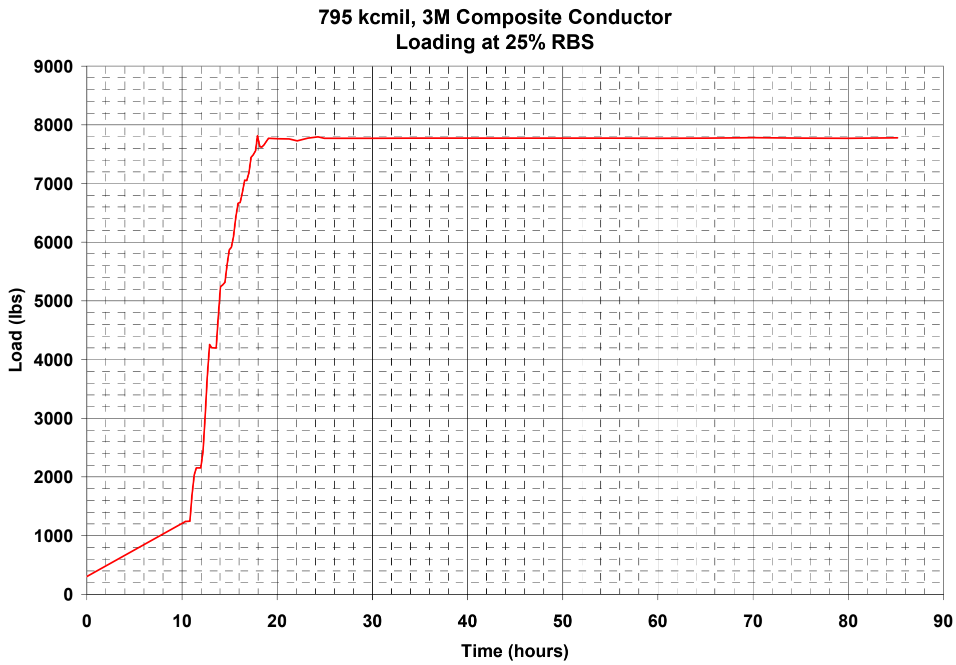

Figure 9. 25% RBS initial loading. Load was increased to 1200 lbs in11 minutes and then increased to target load in 7 more minutes.

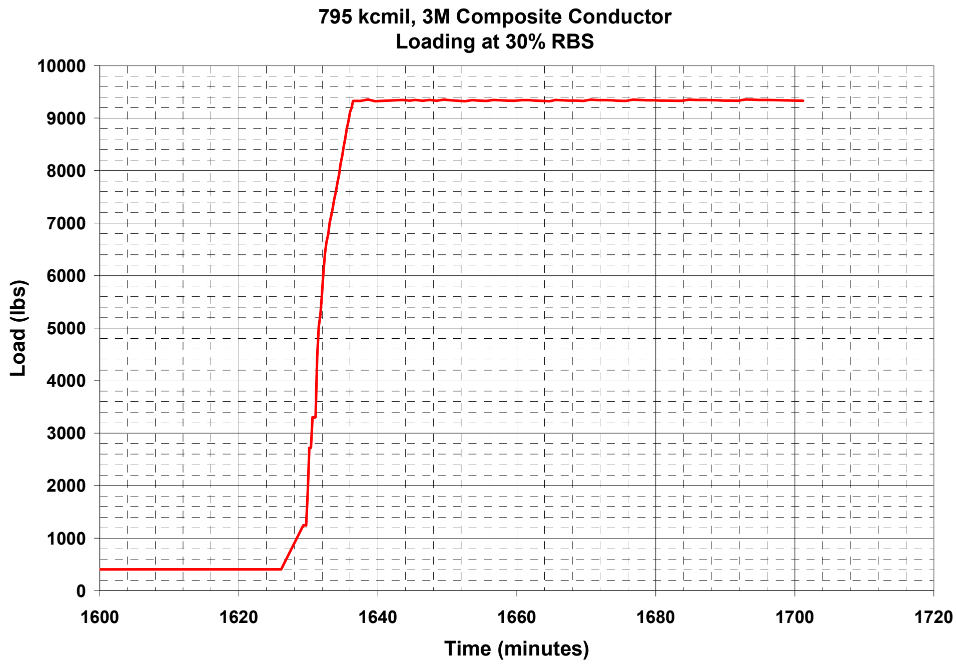

Figure 10. 30% RBS initial loading. After an initial load spike to 4800 lbs, the load was held at approx. 400 lbs for 27 hours and then increased to target load in 10 minutes.

Overall, while there are differences in pre-load holding time, target pre-load, and also in load ramp time, there is not sufficient difference or trend with condition to suggest any significant effects of the resulting creep data.

Creep Stress-Strain Curves

The creep behavior is used to generate stress-strain curves for the conductor after 6 months, 1-year and 10-years of creep. Using the creep equations in Table 1, the creep strain at each stress level is generated for each of the time intervals. These creep strains are then added to the strain from the inherent stress-strain behavior for each stress level. The latter strain is derived in a 3M Technical Report entitled, "795-kcmil 3M Brand Composite Conductor: Stress-Strain Polynomial Coefficients for Design Software", August 2005. The conductor stress-strain behavior is given by the following 4th order polynomial equation relating stress (y) in psi to % strain (x);

y = -6048.8x4 + 19663x3 - 59582x2 + 102023x

The creep strains and total conductor strains are given in Table 2.

Stress (psi)	Initial Strain (%)	6-mo creep strain	1-yr creep strain	10-yr creep strain	Total 6-mo strain	Total 1-yr strain	Total 10-yr strain
6450	0.06569	0.0158	0.0177	0.0260	0.0815	0.0834	0.0917
8601	0.08878	0.0182	0.0210	0.0343	0.1069	0.1098	0.1231
10751	0.1125	0.0235	0.0271	0.0437	0.1360	0.1396	0.1562
12901	0.13693	0.0309	0.0352	0.0542	0.1678	0.1721	0.1912

Table 2. Creep strains with time and total strains for stresses used in creep tests

For each creep time, the total strain is plotted and then curve-fit using a 2nd-order polynomial equation with a zero intercept. An example for the 6-month creep is given in Figure 11.

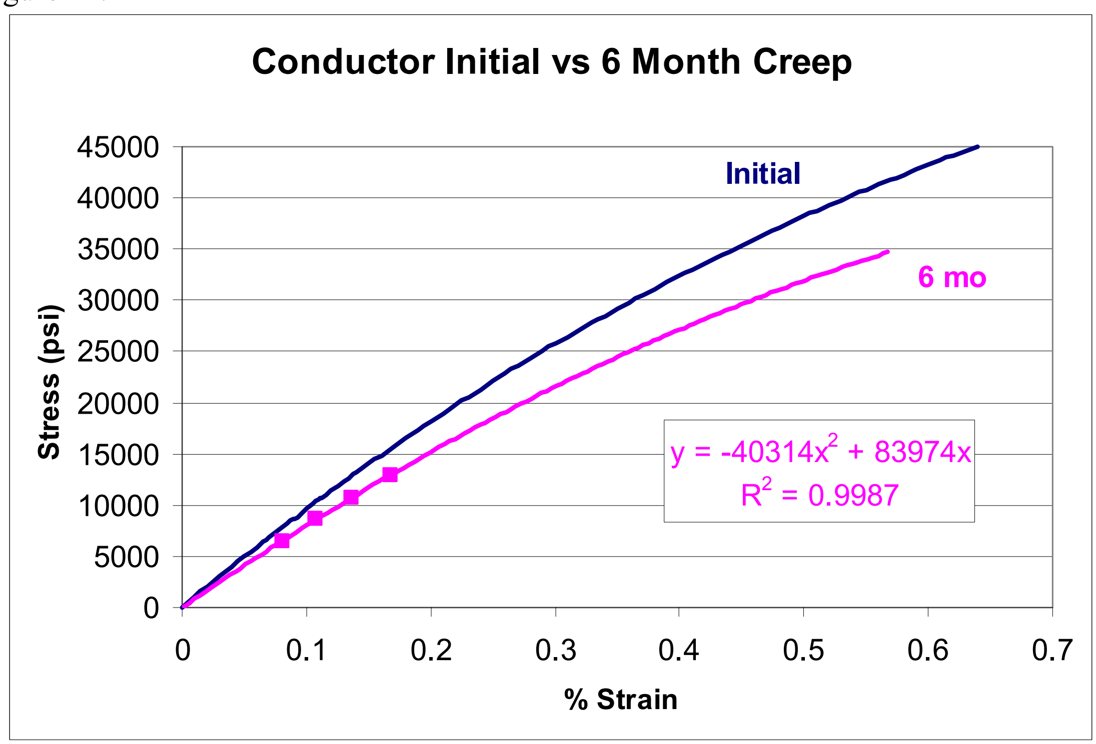

Figure 11. Six-month creep curve for 795-kcmil, 3M™ Composite Conductor

The stress-strain equations for different creep times are summarized in Table 3.

Creep Time	Creep Stress-Strain Equation
0	y = -6048.8x4 + 19663x3 - 59582x2 + 102023x
6 months	y = -40314x2 + 83974x
1 year	y = -38521x2 + 81880x
10-years	y = -31431x2 + 73575x

Table 3. Creep Stress-strain curves for 795-kcmil, 3M™ Composite Conductor

These equations are plotted in a summary form in Figure 12.

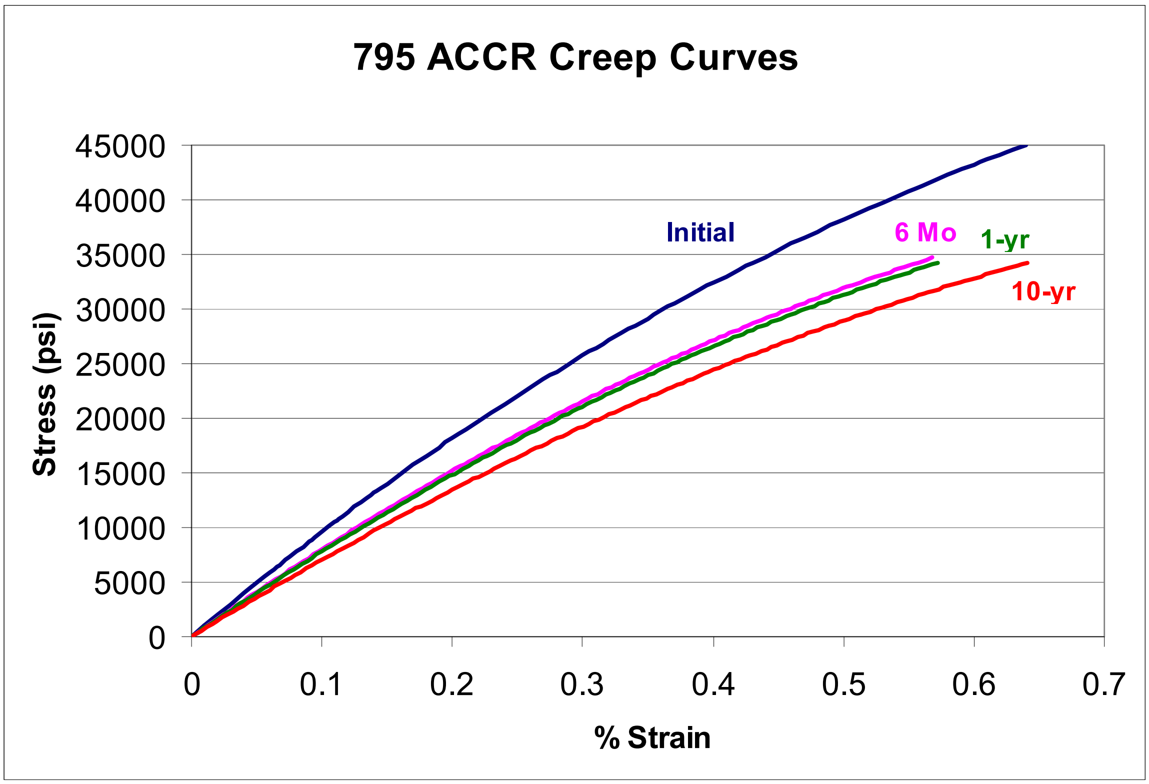

Figure 12. Creep Stress-Strain Curves for 795-kcmil, 3M™ Composite Conductor

Conclusion:

Creep data from 795-kcmil, 3M™ Composite Conductor reported was re-analyzed using a standard methodology and checked for consistency. The resulting power-law creep equations fit a form of:

a (%) = b*[(hrs)^c] where b and c are constants and a is the creep strain

The creep parameters are summarized in Table 4.

Load (%RBS)	Stress (psi)	b	c
15	6450	0.003879	0.167249
20	8601	0.003066	0.212206
25	10751	0.004123	0.207521
30	12901	0.006367	0.188254

Table 4. Summary of Creep Parameters for 795-kcmil, 3M^{TM} Composite Conductor

Acknowledgement:

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Disclaimer:

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

Appendix A: 795-kcmil, 3M™ Composite Conductor Specification

Conductor Physical Properties		
Designation		795-T16
Stranding		26/19
kcmils	kcmil	795
Diameter		
indiv Core	in	0.082
indiv Al	in	0.175
Core	in	0.41
Total Diameter	in	1.11
Area		
Al	in^2	0.624
Total Area	in^2	0.724
Weight	lbs/linear ft	0.896
Breaking Load		
Core	lbs	18,556
Aluminum	lbs	12,578
Complete Cable	lbs	31,134
Modulus		
Core	Msi	31.4
Aluminum	Msi	7.4
Complete Cable	Msi	10.7
Thermal Elongation		
Core	10^-6/F	3.5
Aluminum	10^-6/F	12.8
Complete Cable	10^-6/F	9.2
Heat Capacity		
Core	W-sec/ft-C	22
Aluminum	W-sec/ft-C	324

Conductor Electrical Properties		
Resistance		
DC @ 20C	ohms/mile	0.1100
AC @ 25C	ohms/mile	0.1126
AC @ 50C	ohms/mile	0.1237
AC @ 75C	ohms/mile	0.1349
Geometric Mean Radius	ft	0.0375
Reactance (1 ft Spacing, 60hz)		
Inductive Xa	ohms/mile	0.3986
Capacitive X'a	ohms/mile	0.0912