Document for CIGRE TF 12-6 (B2), October 21, 2004

Variability of Conductor Temperature in a Two Span Test Line

Tapani O. Seppa, The Valley Group, Inc.
Robert Mohr, The Valley Group, Inc.
Herve Deve, 3M Company
John P. Stovall, Oak Ridge National Laboratory

Background

A large number of prior reports have indicated substantial temperature variability within a single span in test lines and significant variation of temperature between point measurements in adjacent spans. More anecdotal evidence, e.g. in the discussion records of the Proceedings of the IEEE Panel on Dynamic Line Ratings on July 20-21, 1982, indicate that, at high temperature, longitudinal temperature variation of 10-25^{o}C had been observed in a single span. Accurate documentation of such variation is generally not available.

It is also generally recognized that the tension and sags of a line section between two dead-ends should be a function of the average temperature of the conductor. Observations have generally shown a good correlation between measured temperatures and sags, but high quality data for comparisons has typically not been available.

Because the high temperature conductor tests at the Oak Ridge PCAT facility are extremely well instrumented, these tests can provide answers to the above questions.

Powerline Conductor Accelerated Testing Facility (PCAT)

Testing Facility Description:

The Powerline Conductor Accelerated Testing facility (PCAT) at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee is an outdoor facility for thermal stress and age characterization tests of power line conductors, [1,2]. The facility includes a 2MW DC power supply fed by a 13.8kV/4160V transformer which can vary the loading of the conductor under test up to 400 Vdc and 5000 Adc.

Figure 1: Aerial view of PCAT facility

The test line is instrumented to measure the conductor's tension, clearance, temperature and environmental conditions (e.g., wind, solar, ambient). Surface and core temperatures are measured by means of thermocouples at multiple locations along the test line. The facility consists of three 161kV-rated steel transmission structures, with two tubular steel poles at each of the two dead-end locations and one in the center with steel davit arms. The test line consists of two circuits, referred to as "road side" and "tree side", each is 366 m (1200 ft.) in length. Each circuit has two spans that are 183 m (600 ft.) in length. The line is configured in a loop by connecting the two circuits at one end, providing a total of 732 m (2400 ft.) of transmission conductor with which to perform tests.

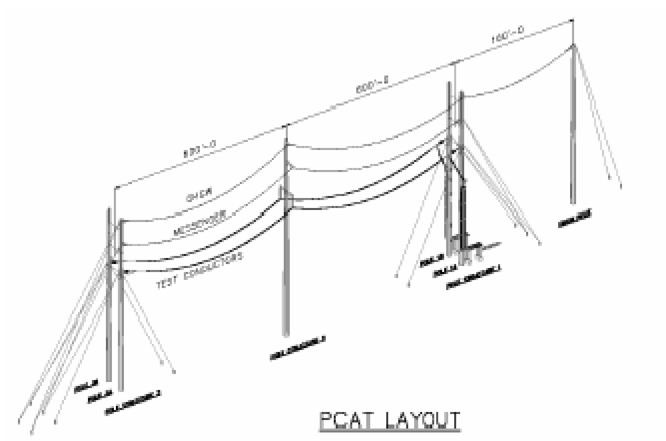

Figure 2. PCAT design layout showing the pole structures and supports.

A thermocouple instrumentation system was used to measure conductor temperatures along the length of the line. The conductor surface temperatures used in this analysis were measured at locations 7,6 m (25 ft.) from either dead-end, ¼ span, mid-span and ¾ span in each of the two span lengths. Core temperatures were taken at the mid-point of each span. A CAT-1 system operating in continuous sampling mode was used to collect tension, net radiation and ambient temperature, wind speed and direction. Data was collected from all sensors along the test line at 1-minute intervals during temperature cycling.

Data used for this analysis was collected on February 27th, 2004. The test line at that time was configured with a 675 kcmil trapezoidal ACCR (aluminum-conductor composite-reinforced) conductor which had undergone 99 hours and 16 cycles of high temperature testing.

High Temperature Test, February 27, 2004.

This test run was selected because the conductor had already undergone several test runs and its behavior had stabilized. The data from this 6,5 hour high temperature test does not differ substantially from any other tests runs made before or after the test. The dc current was modulated between 1215 and 1671 Adc with an average of 1470 Adc in order to maintain an approximate average conductor temperature rise of 180°C

During this test the ambient temperature averaged 6°C and the solar temperature 10°C. The record of the individual thermocouple temperatures is shown in Figures 3 and 4. The standard deviations of the individual simultaneous conductor temperatures were 23°C in Figure 3 and 27°C in Figure 4, which is +/- 15%. For each minute, the standard deviation of the conductor temperatures was calculated and then these were averaged over the test period. These standard deviations characterize the systematic variation.

This report does not analyze the dependence of conductor temperature on the weather variables. Such analysis is presented in [3] which concluded that the measured conductor temperatures were relatively close to those predicted by IEEE 738 standard and the measured weather parameters and line current.

The temperature data shows that the conductor temperatures were generally higher at midspan. This could be anticipated because at maximum conductor temperatures the midspan clearance of the conductor was 7,0-7,3 m (23-24 ft.) from ground, compared to 12,5-12,8 m (41-42 ft.) from the ground at the thermocouples nearest to the ends of the span. Such a height difference can cause a substantial difference in the wind velocity. Because of the relatively small diameter of the compact conductor, the core temperatures were typically only 3-4^{o}C higher than surface temperatures.

The comparison between “treeside” and “roadside” circuits shows significant temperature differences from time to time. A comparison between average temperatures is shown Figure 5. The difference is most likely caused by the difference in wind speeds on different sides of the narrow line corridor. The conductor temperatures indicate that the average effective wind speed around noon was slightly below 0,6 m/s on the “treeside” and about 0,8 m/s on the “roadside” span. Comparison to the measured wind speed at 12:00 Noon (1,77 m/s (5.8 ft/sec) at 24 degrees angle) would imply a conductor temperature of 152^{o}C. This compares reasonably well with the measured average temperatures of 176^{o}C and 165^{o}C for tree and road side spans respectively. Earlier and later tests indicate similar relative variations (also in the opposite direction) between the two sides of the test line.

The conductor temperature showed a span wise trend of higher temperatures in the middle of the span than at the ends of the span, as shown in Figure 6.

The calibrated relationship between the conductor tension measurements and the average temperature are shown in the calibration curves of Figures 7 and 8. Note that the measured tension/temperature relationship shows a certain amount of hysteresis. This can be explained by a combination of two processes:

1. The knee point of a layered conductor is actually a range of temperatures. The knee point of the 675 kcmil ACCR conductor falls between 95-110^{o}C. Manufacturing tolerances make it impossible for all the wires in the outside layers to reach zero tensile stress simultaneously. When passing through the knee point range, each strand must settle in relationship to the others.
2. There is substantial longitudinal variability in the conductor temperature. This means that there are compressive and tensile stresses in the outside layers which will try to move the outside wires longitudinally. Such stresses are constrained by the friction between the core and the outside layers.

As a result, the tension-temperature equilibrium shown in Figures 6 and 7 will exhibit a clear, albeit minor, hysteretic behavior.

Figures 9 and 10 show the relationship between the measured average temperature of the two circuits and the conductor temperatures derived based on tension measurements. The close correlation between the measurements proves conclusively that the conductor tension is a function of the average temperature of the line section.

Conclusions:

1. During the test, the average temperature rise was about 180^{o}C as compared to solar temperature, and the longitudinal variation of individual temperature rises along the two spans was +/-40^{o}C, i.e. about 22%.

2. The 22% variation is approximately one half systematic variations (some locations show, on the average, higher temperatures than others) and approximately one half random variations.

3. Because the temperature rise tends to be highest at locations with the lowest clearance to ground, conductor rating measurements should be based on temperatures at such locations, unless other locations are more sheltered from wind.

4. Conductor tension follows quite accurately the average temperatures of the line sections.

5. When conductor temperature excursions exceed the kneepoint temperature, tension/temperature relationship indicates a moderate hysteresis.

Acknowledgement

This material is based upon work supported by the U.S. Department of Energy under Award No. DE-FC02-02CH11111. Any opinions, findings or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the U.S. Department of Energy.

The Power-line Conductor Accelerated Test Facility is operated by Oak Ridge National Laboratory for the U.S. Department of Energy, Office of Electric Transmission and Distribution. The Oak Ridge National Laboratory is managed by UT-Battelle, LLC for the U.S. Department of Energy under contract no. DE-AC05-00OR22725.

References

[1] ORNL Reporter, No 40, August 2002

[2] http://www.ornl.gov/sci/oetd/about.htm

[3] "Weather Observation and Thermal Ratings in a Short, High Temperature Test Line", Herve Deve, 3M. Presented at the IEEE TP&C Panel on Selection of Weather Parameters for Overhead Lines, Denver 2004.

Figure 3. Thermocouple Temperatures- Tree Side
February 27, 2004

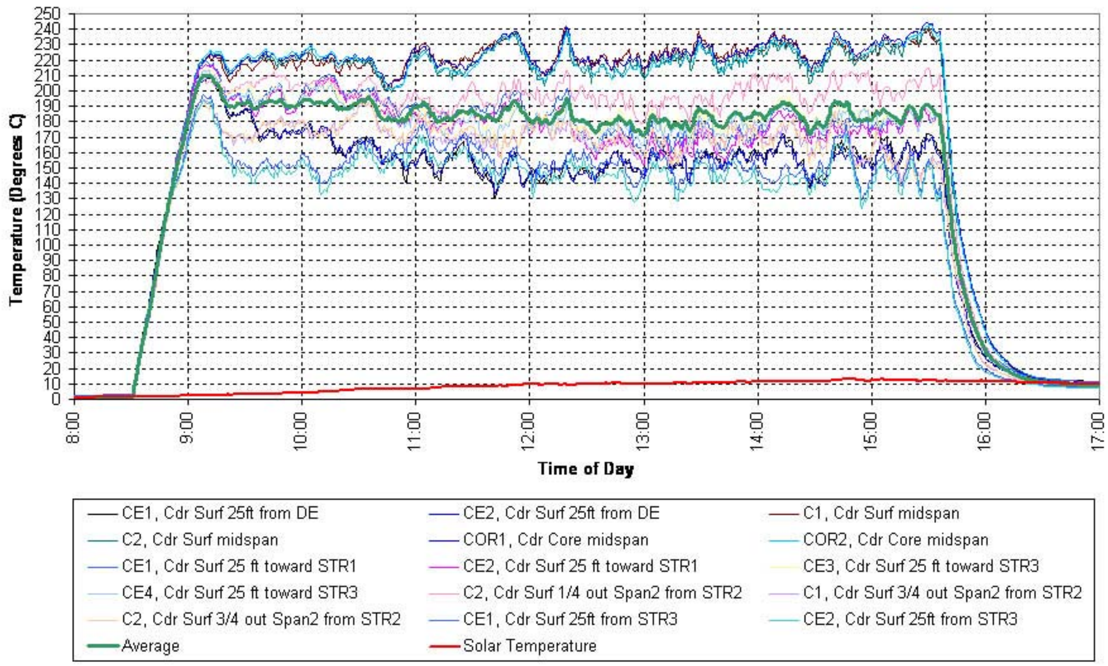

Figure 4. Thermocouple Temperatures- Road Side
February 27, 2004

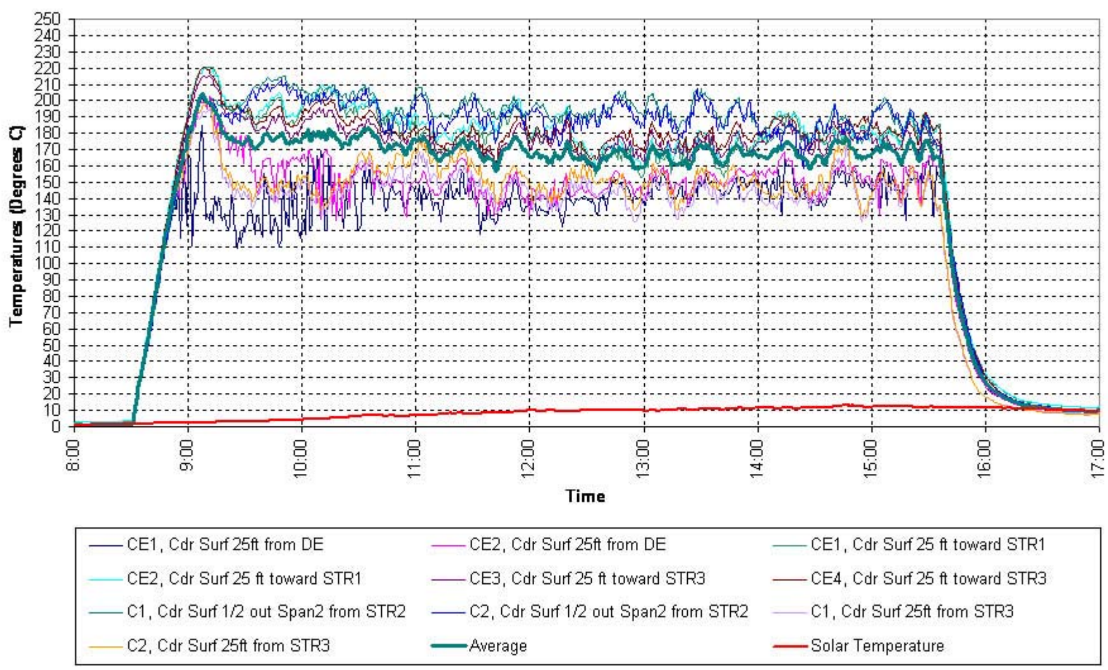

Figure 5. Average Temperatures of Road and Tree Sides
February 27, 2004

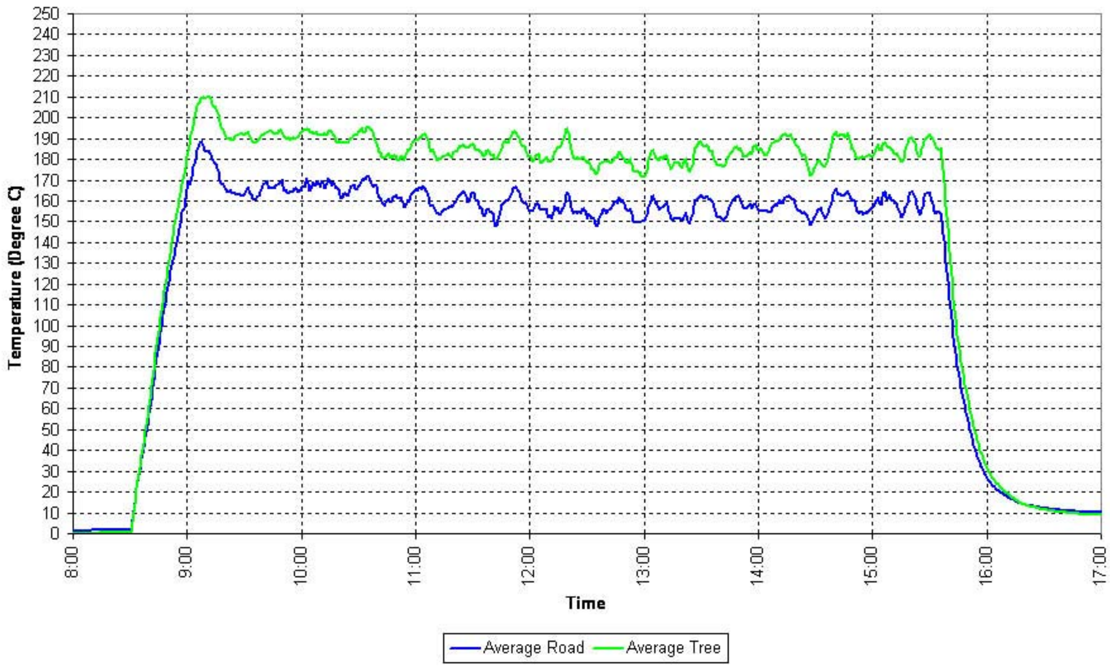

Figure 6. Variation of average temperature rise along the line

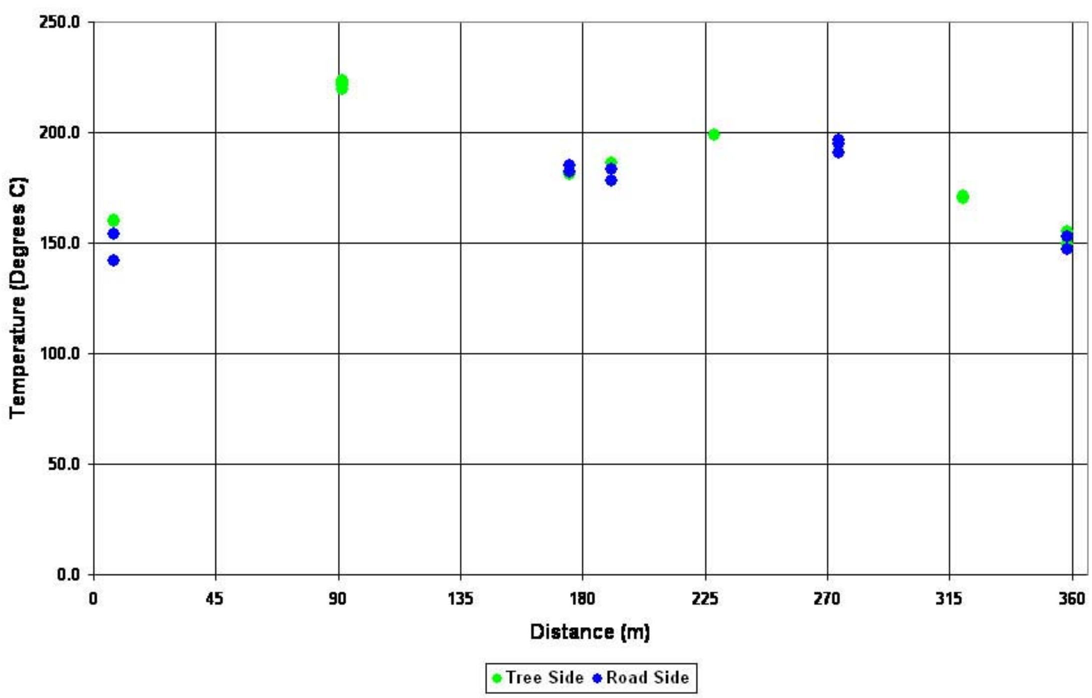

Figure 7. Tree Side Conductor Temperature Calibration Curve

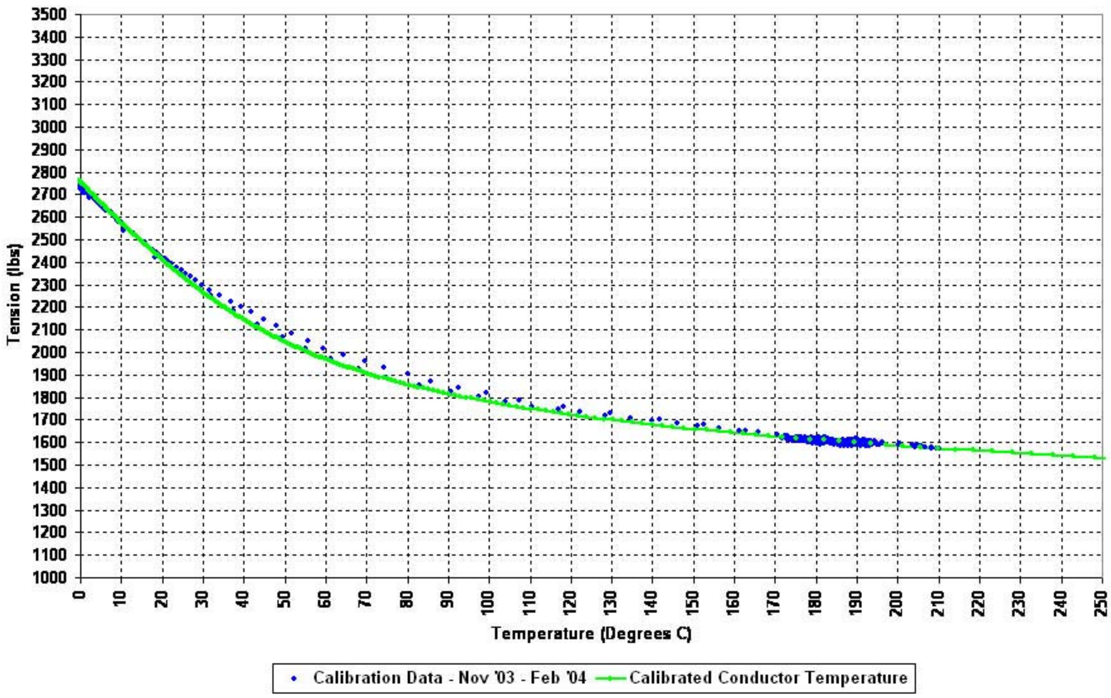

Figure 8. Road Side Conductor Temperature Calibration Curve

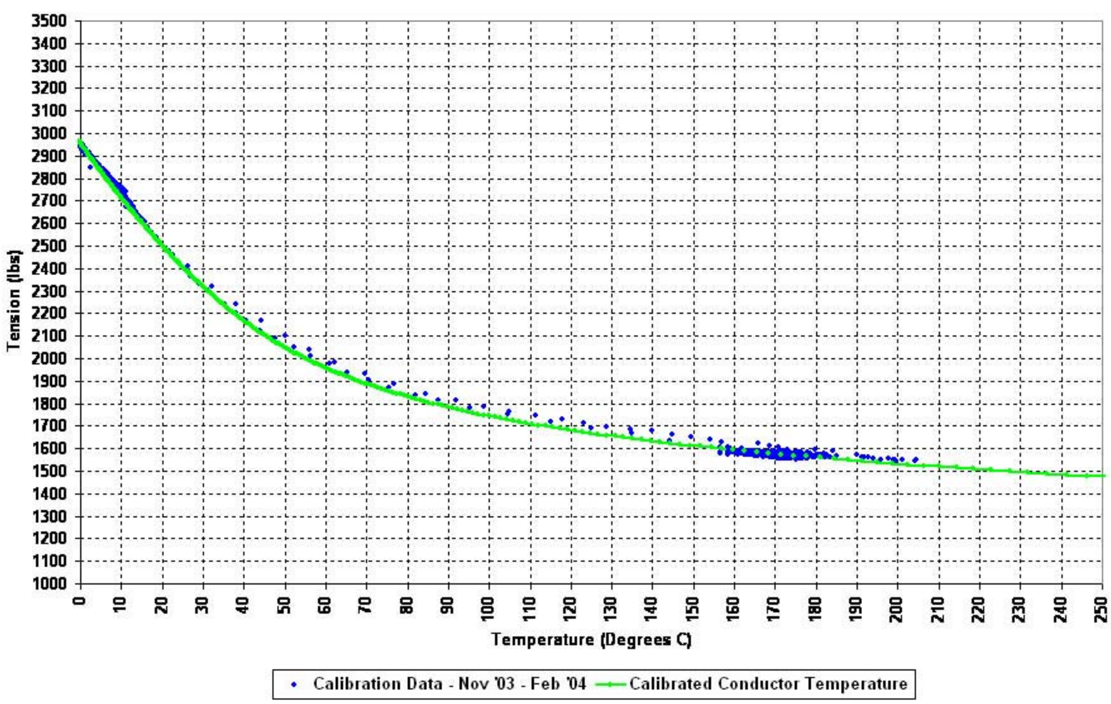

Figure 9. Conductor Temperature Comparison
Tree Side (Port 1) - 2/27/04

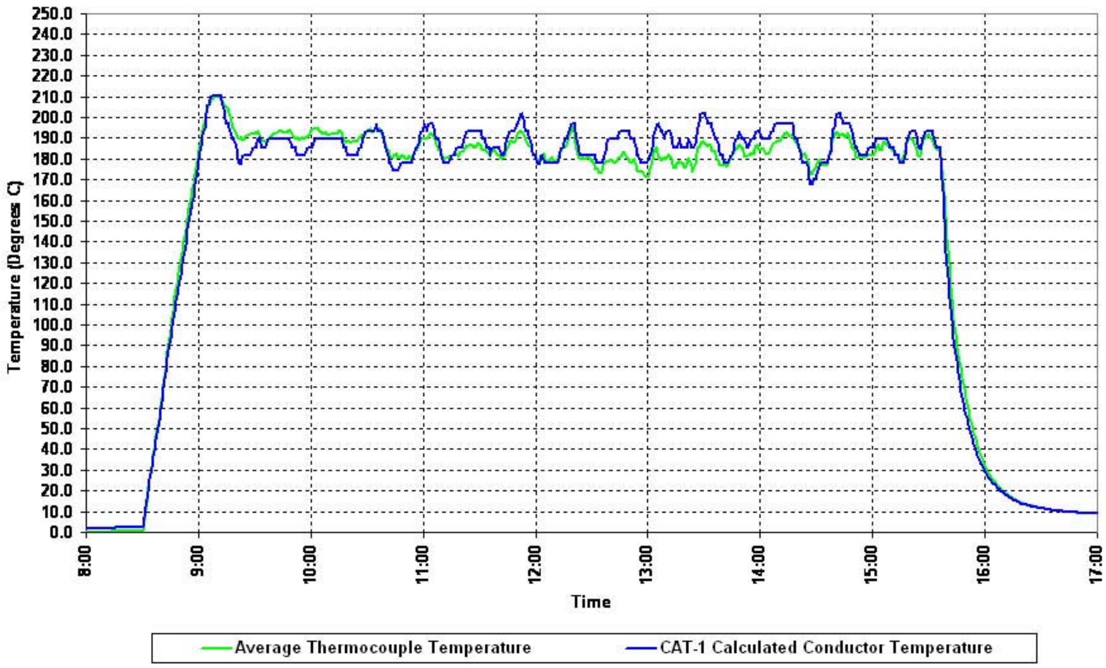

Figure 10. Conductor Temperature Comparison
Road Side (Port 2)- 2/27/04