Alaska Department of Transportation & Public Facilities

Research & Technology Transfer

Loftus Road Extension Project - Final Report

Part A:
Parks/Chena Ridge Air Convection Embankment Experimental Feature Performance Report, Jan. 2001 to Dec. 2003

Part B:
Loftus Road/Thompson Drive final instrumentation report

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Research and Technology Transfer
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This report consists of two parts.

Part A summarizes data collected as part of the project entitled 'Air Convection Embankment Experimental Feature Design' which was funded by the Alaska Department of Transportation and Public Facilities. The project involved the design and monitoring of an experimental Air Convection Embankment (ACE) which was included as an experimental feature in the Parks/Chena Ridge Interchange project (Federal Project No. I-0A4-5(7), State of Alaska Project No. 63538). Data is included for January 2001 through December 2003. See Goering (1997) for details regarding the design and construction of the ACE experimental feature, Goering (1998, 1999, & 2001(a)) for data analysis which extends from November 1996 through December 2000.

Part B provides a review and summary of the final instrumentation of the Loftus Road/Thompson Drive test sections. The original instrumentation plan, additions to that plan, and a review of the final installation are discussed. Initial data collection efforts and data verification are described but no formal data analysis is included. For a complete discussion of the original design report, including a summary of the recommended instrumentation plan, see Goering (2001(b)).

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DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the accuracy of the data presented herein. This research has been funded by the Alaska Department of Transportation and Public Facilities (ADOT&PF). The contents of the report do not necessarily reflect the views or policies of ADOT&PF or any local sponsor. This work does not constitute a standard, specification, or regulation.

ABSTRACT

Part A of this report summarizes data collected as a part of the project entitled “Air Convection Embankment Experimental Feature Design” which was funded by the Alaska Department of Transportation and Public Facilities. The project involved the design and monitoring of an experimental Air Convection Embankment (ACE) which was included as an experimental feature in the Parks/Chena Ridge Interchange project (Federal Project No. I-0A4-5(7), State of Alaska Project No. 63538). Data is included for January 2001 through December 2003. See Goering (1997) for details regarding the design and construction of the ACE experimental feature and Goering (1998, 1999 & 2001(a)) for data analysis, which extends from November 1996 through December 2000.

Part B of the report reviews the instrumentation plan that was utilized for the Loftus Road Extension/Thompson Drive project. The initial installation plan, additions to that plan, construction and installation details, and initial data collection/verification efforts are all described.

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Funding for this research was provided by the Alaska Department of Transportation and Public Facilities under project SPR-UAF-95-08, "Air Convection Embankment Experimental Feature Design," and under the project SPR-UAF-01-80, “Elimination of Longitudinal Cracking.” Additional support has been provided by the Alaska Science and Technology Foundation under grant #92-2-1110, "Enhanced Convection for Roadway Stabilization."

PART A: Parks/Chena Ridge Air Convection Embankment Experimental Feature Performance Report, Jan 2001 to Dec 2003.

1.0 PROJECT SUMMARY

The Air Convection Embankment (ACE) has been the focus of two previous studies conducted by the author and funded by the Alaska Department of Transportation and Public Facilities (ADOT&PF) and the Alaska Science and Technology Foundation (ASTF). Results from the initial ADOT&PF study summarized in Goering and Kumar (1996) showed that the ACE concept could be used to provide passive cooling for roadway embankments in permafrost zones. The present project began in 1995 with the intention of designing and installing an ACE roadway embankment in an actual road-building project via the Experimental Features in Construction Program. Design and construction of the experimental feature took place during 1995-97, with completion of the ACE test section in July of 1997. In 1996, the original project was extended into a second phase to allow for three years of monitoring. This monitoring period began in November of 1996 and was originally scheduled for completion at the end of September 1999. A no-cost extension of the project during 1999 extended the monitoring period through the end of December 2000. The Phase 1 final report (Goering, 1997), detailed the design and construction process. In addition, the first 5 years of monitoring (November 1996 – December 2000) were discussed in Goering, 1998, Goering, 1999, and Goering 2001(a). Please refer to these prior reports for additional background information, details concerning the construction process, and thermal data from the initial monitoring period. The present report focuses on data collected during the January 2001 – December 2003 time period.

2.0 ACE TEST SECTION AND CONTROL SECTION CONFIGURATIONS

During the spring of 1995, the Parks/Chena Ridge Interchange project was identified as a desirable site for inclusion of the ACE experimental feature. The project included a new segment of road with an ice-rich permafrost foundation that had not been disturbed due to previous road-building projects. Stations 706 to 709 were identified as appropriate for both test and control sections. Figure 1 shows a photo of the completed ACE test and control sections. The ACE section is identifiable by the moisture on the road surface and the control section is located further up the hill, approximately adjacent to where the blue pickup is parked in the photo.

2.1 ACE Test Section

The ACE test section stretches 200 ft. (61 m), from station 707 to 709. The shape of the embankment in this area is unaltered from the original plans; however, the 4" (10.2 cm) of insulation board was removed from the embankment in this area. Figure 2 (taken from the construction plans) shows the resulting ACE cross section. A total of eight instrumentation strings labeled D, E, F, G, H, I, J, and K are located in the center of the ACE test section at station 708, as shown in the figure. Strings G, H, I, J, and K have thermistor temperature sensors centered on 2 ft. (0.61 m) increments. This results in a total of 140 sensors within the embankment proper, located on a 2 ft. × 2 ft. (0.61 m × 0.61 m) grid. Strings D, E, and F were drilled into the foundation before embankment construction and contain 6 thermistors each. The exact location of these thermistors is indicated by the dots in Figure 3, which shows that these strings have sensors placed at depths ranging from 2 ft. (0.61 m) to 20 ft. (6.1 m) below approximate original grade.

2.2 Control Section

The control section also stretches 200 ft. (61 m), from station 705 to 707. The mechanical design of the embankment within this control section was unaltered from the original plans, with the exception of the inclusion of instrumentation at station 706. Figure 4 (also taken directly from the construction plans) shows the location of the insulation board and thermistor sensor strings (labeled A, B, and C) with respect to the surface of the embankment at station 706. Strings A and B contain 10 thermistor sensors each, the uppermost of which is located immediately above the insulation board. String C contains 8 sensors. Exact positioning of the sensors is indicated by the solid dots in Figure 5. In this case, several of the thermistors are located above the original grade within the embankment material.

Figure 1. Finished ACE test section with control section in the background.

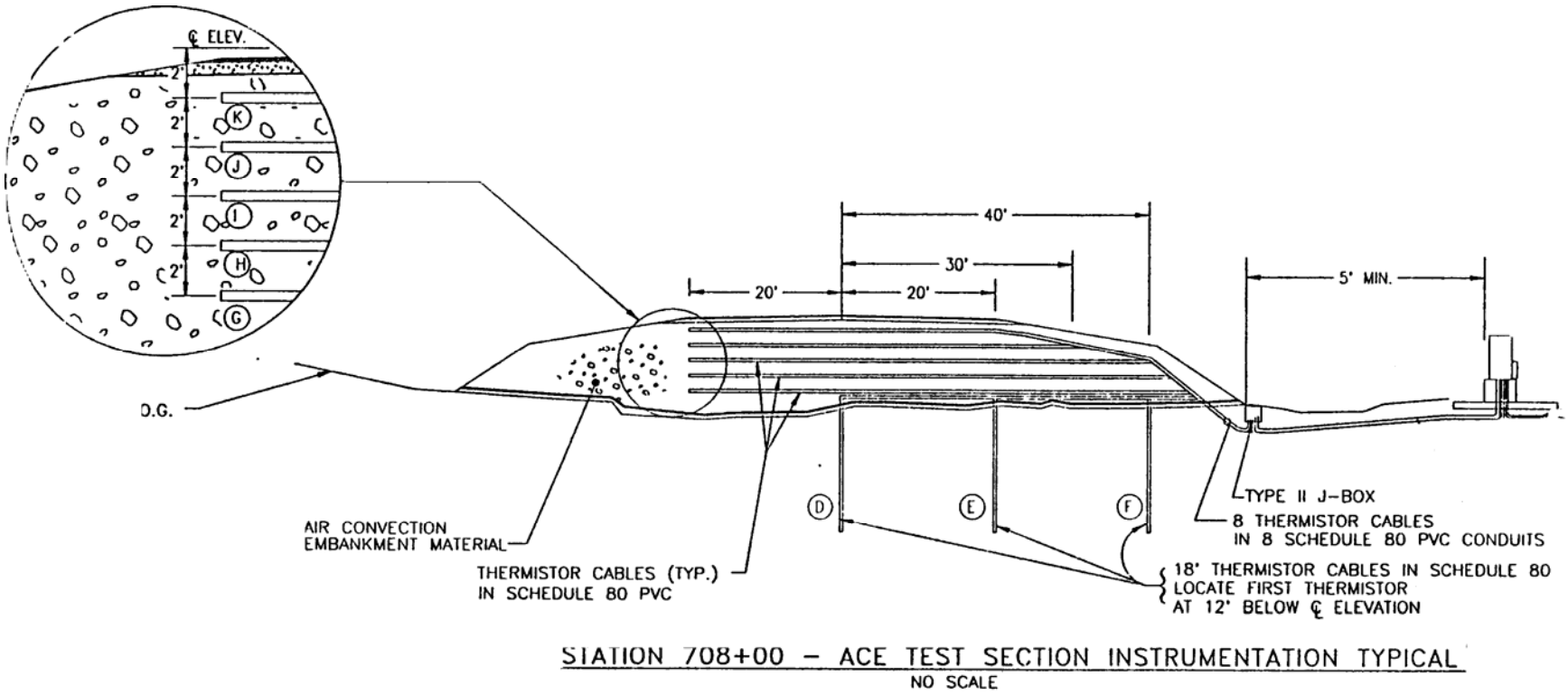


Figure 2. ACE test section configuration.

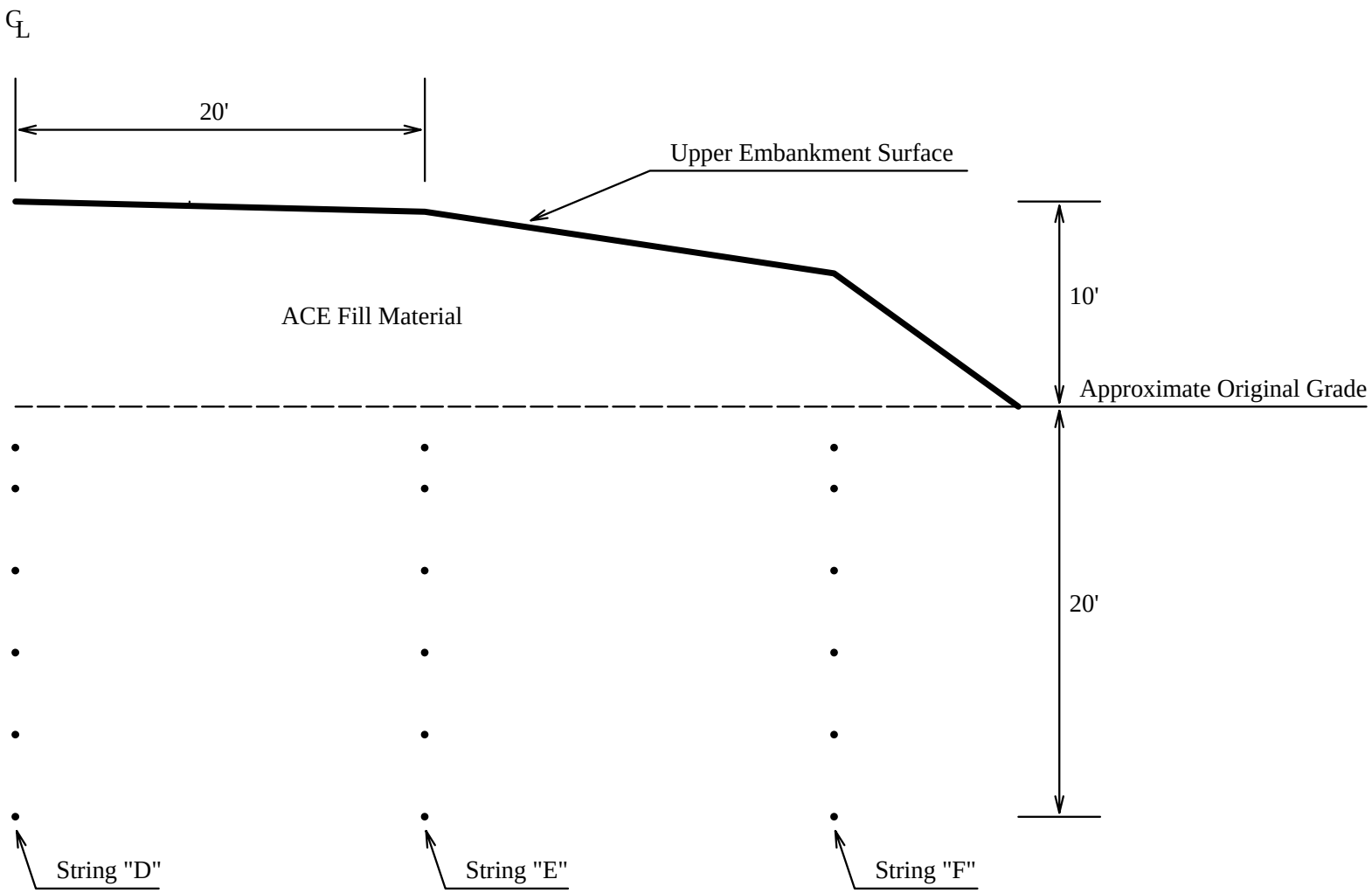


Figure 3. Thermistor positions for strings D, E, and F, located below the ACE test section.

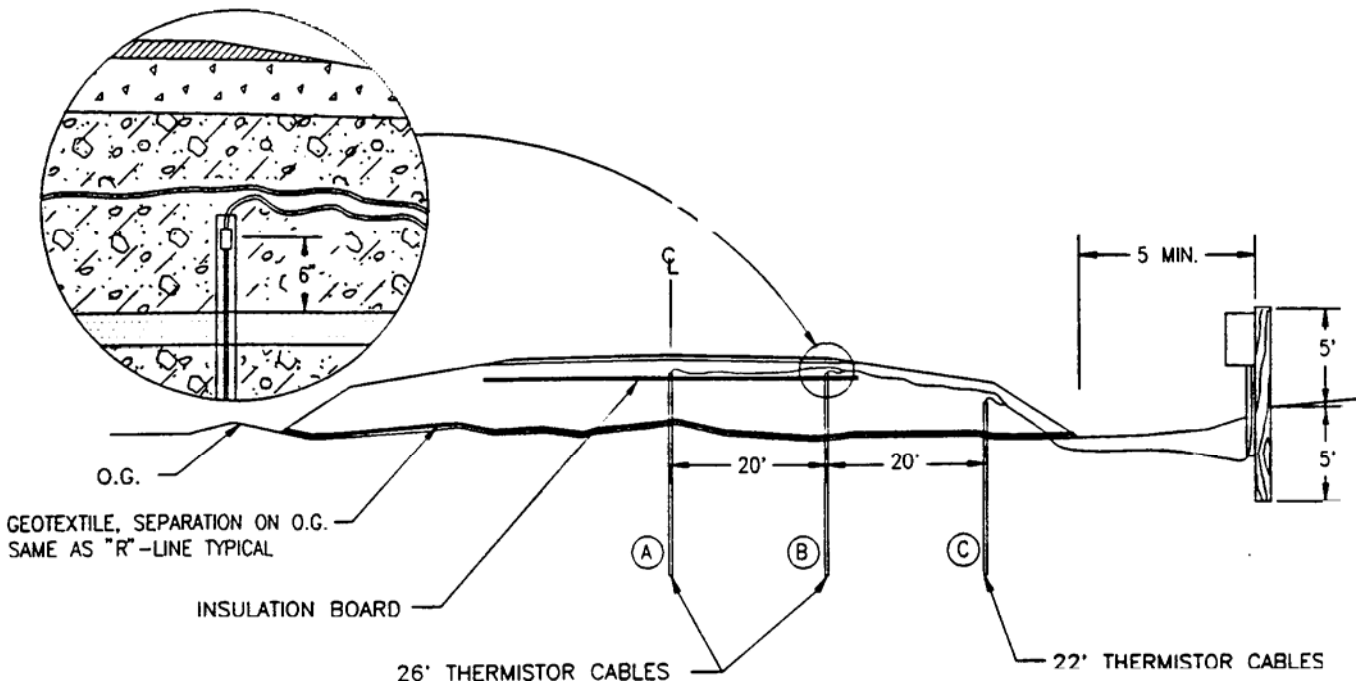


Figure 4. Control section configuration.

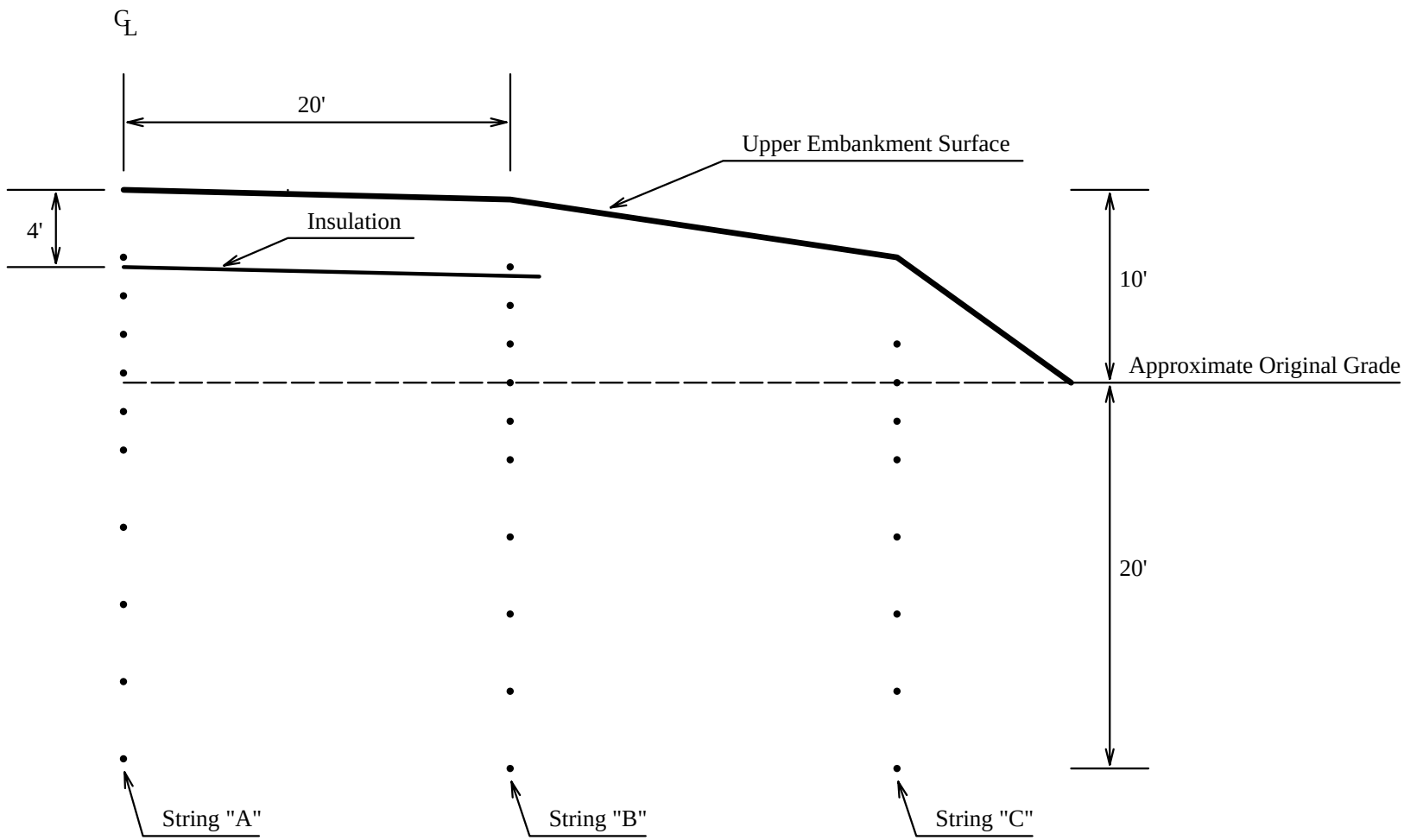


Figure 5. Thermistor positions for strings A, B, and C, located within and beneath the control section.

3.0 DATA ACQUISITION SYSTEM

The data logging system consists of a Campbell Scientific CR10XT data acquisition module, which is connected to five AM416 multiplexers, and two SM716 memory modules. All equipment with the exception of one multiplexer is located in the traffic controller box adjacent to the ACE test section and is shown in Figure 6. One of the multiplexers is located in the multiplexer enclosure adjacent to the control section. The control section thermistor signals were routed from the multiplexer at the control section through a subsurface wiring harness to the CR10XT data logger located in the traffic controller cabinet. All of the data acquisition hardware was installed by early November of 1996, and actual data collection began on November 16, 1996. See Goering (1998) for a discussion of the data collected between November 1996 and September 1998, Goering (1999) for a discussion of the data collected between November 1998 and September 1999, and Goering (2001(a)) for a discussion of the data collected between October 1999 and December 2000.

The sensor arrays were constructed with 0.2°C interchangeable Betatherm thermistors with a resistance of 16K Ohms at 0°C. During data processing, the following equation is used for converting resistance values to temperatures:

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3 \qquad (1)$$

Where
A, B, C = known constants supplied by manufacturer,
T = temperature, °R (or K),
R = thermistor resistance, Ohms.

The thermistor strings were armored using schedule 80 PVC electrical conduit. In order to avoid loss of sensor accuracy due to the PVC casing, holes were drilled in the casing at the thermistor locations. The thermistors themselves were then moved outside the casing

and shielded with aluminum rings that were glued in place with electrically safe RTV sealant.

Data acquisition has been in operation continuously since November of 1996. The data logger is currently programmed to collect a complete set of temperature data once each hour. It then averages over six-hour periods and records the data four times per day. It also records ambient air temperature twice each hour and then reports mean daily air temperature, daily minimum temperature, and daily maximum temperature for each 24-hour period. Some loss of data occurred during the summer of 1999 due to a loose connection on one of the multiplexers; however, this only affected a small portion of the data.

Unfortunately, a number of thermistors have begun having problems since they were installed in 1996. Initially there were approximately five malfunctioning thermistors out of the total of 192. After installation, the instrumentation contractor attempted to remedy the problems with these channels but was unable to make significant improvements. Unfortunately, additional sensors have failed since 1996, and the difficulties have begun to reduce the quality of the thermal data obtainable from the ACE test section. Most of the problems are likely due to the infiltration of water into the sensor arrays, but it is also likely that some of the sensor leads are shorted to the aluminum shielding rings, resulting in ground loops that affect data quality.

Some of the most pronounced data quality problems occurred with strings D, E, and F, which are located in the foundation soil beneath the test section. Because of this, it was decided to replace at least two of these strings during the summer of 1999. Funding for replacement strings and installation was provided by AKDOT&PF. In order to minimize

traffic disturbance, it was decided to replace strings E and F, which are outside the normal driving lane (see Fig. 3). Replacement operations were completed on July 15, 1999 with the aid of an AKDOT&PF track mounted drill rig. The replacement strings were installed into vertical holes which were drilled through the embankment and into the underlying foundation soil. In order to avoid hitting existing instrumentation, the new bore holes were located approximately 5 feet to the west (up the hill and away from the camera position in Fig. 1) of the original strings. PVC conduit was lowered into the bore holes and locked in place by backfilling with dry mortar sand. The replacement thermistor cables were then lowered into the PVC conduit and the annulus was filled with silicone oil. The cables were run through PVC conduit to the instrumentation cabinet shown in Fig. 6 and connected in place of the original string E and F cables.

During the drilling operation for the replacement of string E, core samples were taken. Figure 7 shows the core sample which was recovered from the upper portion of the foundation soil, starting approximately at original grade (just below the organic mat) and extending downward about 5 feet. We found that all the original foundation soil was frozen right up to the base of the ACE embankment rock. Figures 8 and 9 show close-ups of a section of the core sample, in the original frozen state and then after thawing, respectively. Close examination of Fig. 8 reveals a number of thin ice lenses. The amount of clear water present above the saturated silt shown in Fig. 9 illustrates that this sample originally contained about 50% excess water (ice).

Replacement of strings E and F has solved all the data quality issues for those two strings; however problems continue to increase with some of the other thermistor strings. In an effort to improve the situation, we are currently planning on adding an additional multiplexer and changing the wiring configuration. The original wiring strategy made

use of common thermistor grounds (in groups of three) in order to increase the number of sensors which could be supported by each multiplexer. Unfortunately, this wiring arrangement makes the system very sensitive to ground loops or galvanic potentials, which can be caused by water infiltration into the thermistor strings. Rewiring the system to avoid common grounds will help alleviate these problems; however an additional multiplexer will be required to accomplish this.

Figure 6. Campbell data acquisition system installed in highway traffic controller cabinet.

Figure 7. Core sample taken from string E replacement hole, July 1999.

Figure 8. Close-up view of frozen core sample.

Figure 9. Core sample after thawing, indicating approximately 50% excess water content.

4.0 ACE CROSS SECTION THERMAL PROFILES

As mentioned in the previous section, thermal data has been collected for the ACE test section on an hourly basis since November of 1996. This data consists of temperature measurements for the entire array of 140 thermistor sensors made up of strings G, H, I, J, and K. The data is processed using Equation (1) and plotted using a contouring package. Figures 10-24 show the instantaneous temperature contours that were obtained at noon on the 15th of each month, starting in January of 2001 and ending in December of 2003. The horizontal and vertical scales shown in these figures are in feet and the temperature contours are labeled in °F. The zero for the horizontal scale is located at the embankment centerline, and the zero for the vertical scale is located at approximate original grade.

Figure 10 shows that the ACE cross-section began calendar year 2001 with some evidence of convection plumes existing in the embankment. Examination of the 16°F or 14°F temperature profiles indicates a likely circulation of pore air upward beneath the centerline of the embankment and downward beneath each driving lane. These convective plumes are similar to those which have been seen in previous years (Goering, 1998, 1999, and 2000) and in modeling studies (Goering, 1997). They are the result of the unstable pore-air density stratification which exists in the wintertime and causes internal circulation cells to develop within the ACE cross section.

Starting in March, Figure 12 shows that temperatures begin to increase slightly and there is no longer strong evidence of organized convective activity within the embankment. In fact, Figure 12 shows that the temperature profiles have begun to moderate and reach a more uniform state. Comparing the temperature profiles shown in Figure 12 with March profiles in previous years (given in the earlier reports) it is apparent that data quality has degraded significantly. In Figure 12, several “hot/cold” spots appear in the isotherms.

These are indicative of measurement errors, and the effect on the contour plot is exaggerated by the uniformity of the temperature field. By April 15 (Figure 13), the upper portions of the embankment have begun to warm and the thaw has begun to penetrate from the top, although the lower portions of the embankment remain at temperatures well below freezing.

Figures 14, 15, 16, and 17 show that the embankment thaws during May and June, and then continues to warm slowly over the summer. Vertical temperature gradients are large during June and July and show a temperature difference of about 30°F across the embankment from bottom to top. This comparatively large gradient is a consequence of the stable temperature profile and lack of convective mixing within the embankment. The lack of convective mixing is also indicated by the isotherms in figures 15 through 17 which are generally flat and horizontal in nature (with the exception of apparent temperature measurement errors), indicating an absence of air circulation during the summer.

During August and September the embankment warms further, although, as shown in Fig. 18, temperatures are only slightly above freezing at the embankment base on September 15 (ranging from about 34 – 38°F). These are the warmest temperatures that occur at the embankment base during the year. In late September and October the embankment begins to cool and refreeze.

Figures 19, 20, and 21 show the cooling and refreezing of the embankment that occurs in the fall and early winter of 2001. These figures can be compared to Figs. 31, 32, and 33, and Figs. 43, 44, and 45, for the years of 2002 and 2003. Trends are similar for all three periods, although differences in ambient temperature trends do yield variations in the

embankment cooling rates. Note that Figs. 43, 44, and 45 have very obvious plotting errors in the contours. This is a result of a complete lack of reasonable data for the upper thermistor strings, another indication that the overall data quality has decreased to the point where the accuracy of the contour plots is in serious doubt.

In order to attempt to quantify the cooling effectiveness of the ACE test section, mean annual temperatures were calculated for calendar years 2001 and 2002. It was not possible to carry out the same calculation for 2003 due to the data quality issues mentioned above. Figure 46 shows a contour plot of mean annual temperature within the embankment for the calendar year 2001. Also noted on the figure is the mean ambient air temperature for the year 2001 of 27.9°F based on air temperature measurements taken at the site. Figure 46 clearly shows a reduction in mean temperatures at the embankment base compared to those near the upper surfaces; however the contour shapes are irregular most likely because of measurement error. This cooling effect is due to the convective heat transfer which takes place within the embankment during winter months. The mean temperature ranges from about 28 – 31°F at the base of the embankment indicating that permafrost beneath the embankment should remain thermally stable. Figure 47 shows a similar behavior during the 2002 calendar year.

Figure 48 shows a time sequence of three temperature records beginning in January of 1997 and extending through the end of 2003. In each case, these temperatures represent monthly average values. The first sequence is simply the monthly averaged ambient air temperature as measured at the site. The other two are the mean upper embankment temperature and the mean lower embankment temperature. The mean upper temperature was obtained by averaging the temperatures along the upper thermistor string (string K in Figure 2.), while the lower temperature was obtained by averaging the temperatures along

string G. Examination of Fig. 48 reveals several interesting characteristics of the thermal behavior. First of all, note that the embankment upper temperature is consistently warmer than the ambient air temperature. This is true in summer and winter, and is a consequence of the energy balance at the surface of the asphalt. The mean base temperature has an attenuated annual variation due to the thermal mass of the embankment. Comparing the mean upper and mean base temperatures shows that there is a relatively larger difference between these two during the summer as compared to the winter. As a consequence, the mean annual temperature at the base is much lower than it is in the upper portion of the embankment, illustrating the cooling effect of the winter convection. It is also interesting to note the clear downward trend in the peak summer temperatures at the base of the embankment. Maximum temperatures at the base have declined each and every summer since construction of the embankment in 1996. Peak average base temperature during the summer of 2003 was 34.1°F, indicating that the permafrost table has gradually aggraded and is now nearly at the base of the embankment.

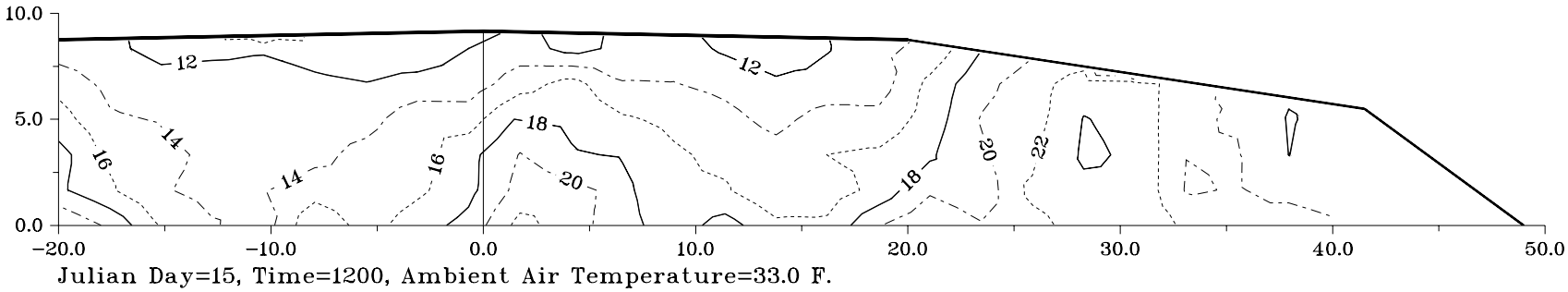


Figure 10. Temperature contours in the Parks/Chena Ridge ACE embankment on January 15, 2001.

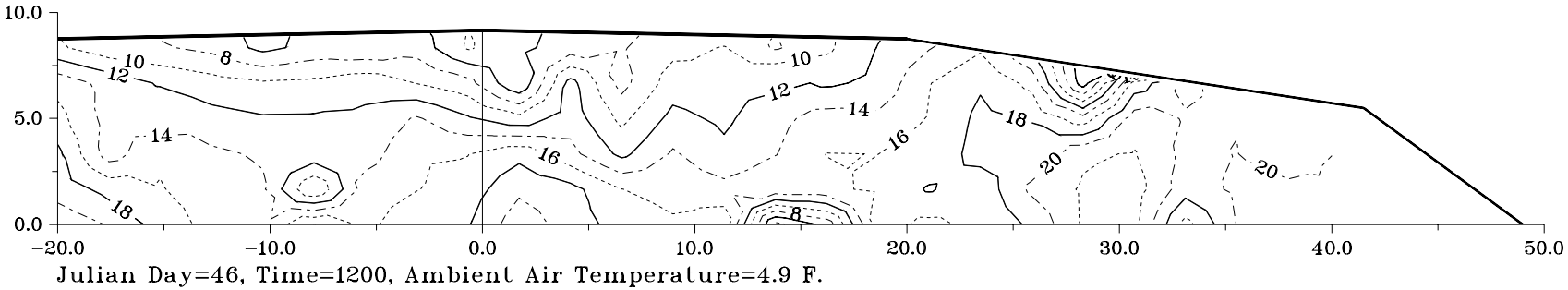


Figure 11. Temperature contours in the Parks/Chena Ridge ACE embankment on February 15, 2001.

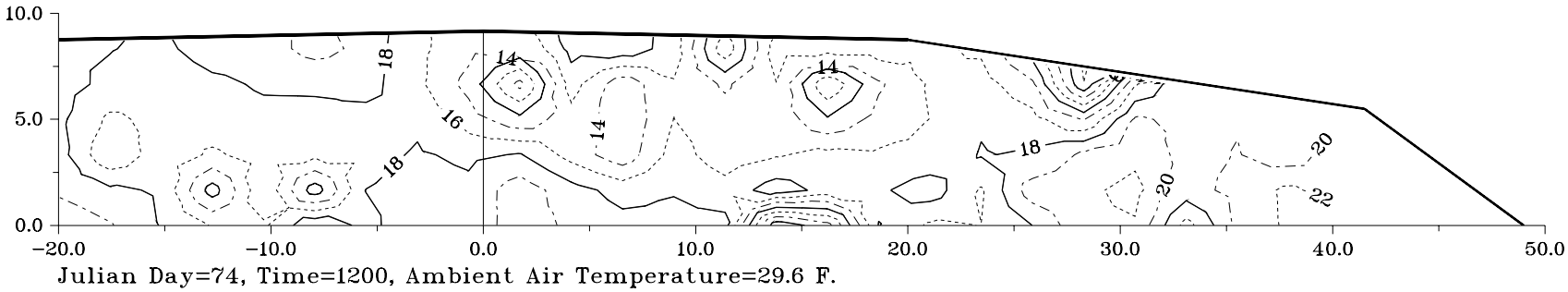


Figure 12. Temperature contours in the Parks/Chena Ridge ACE embankment on March 15, 2001.

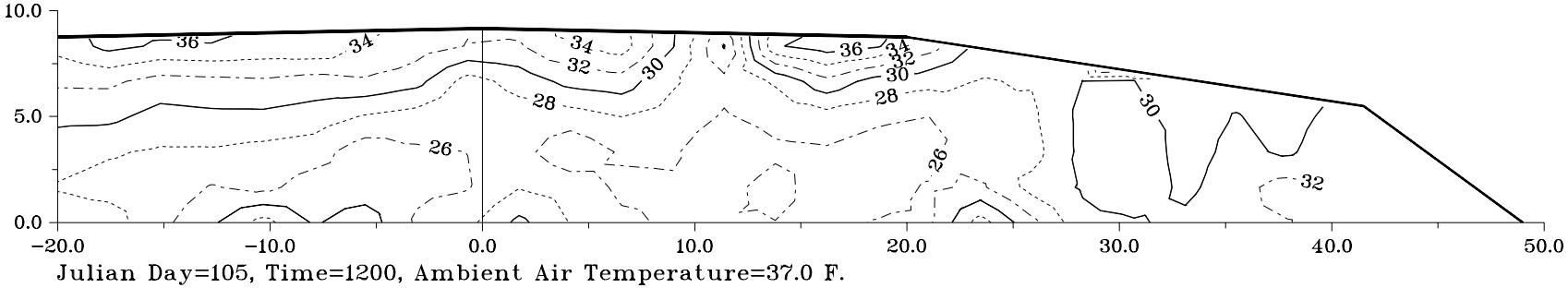


Figure 13. Temperature contours in the Parks/Chena Ridge ACE embankment on April 15, 2001.

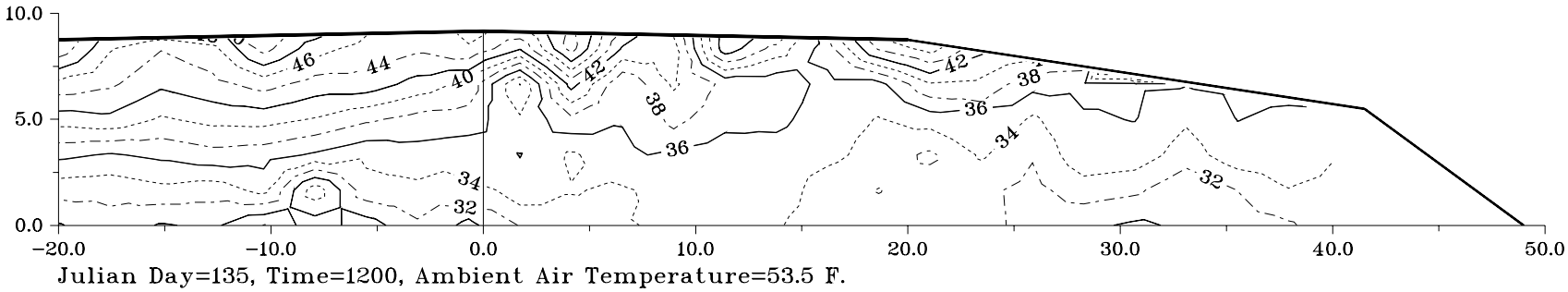


Figure 14. Temperature contours in the Parks/Chena Ridge ACE embankment on May 15, 2001.

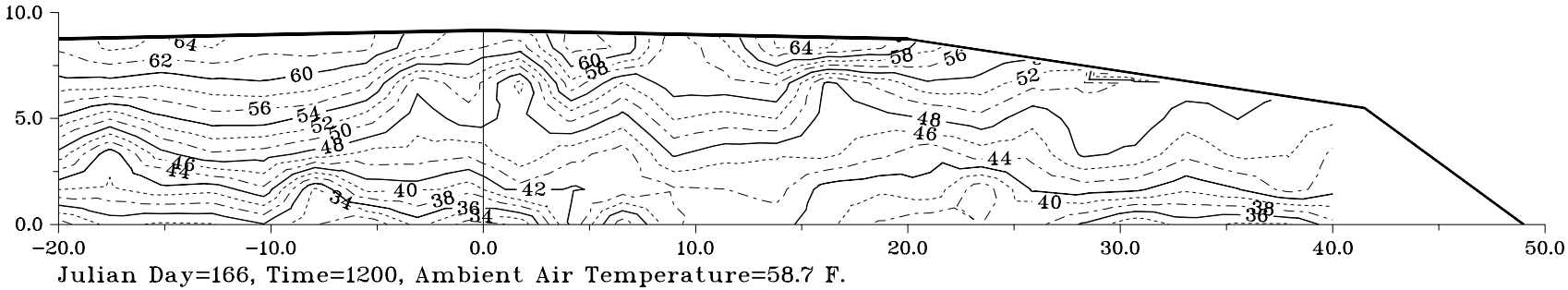


Figure 15. Temperature contours in the Parks/Chena Ridge ACE embankment on June 15, 2001.

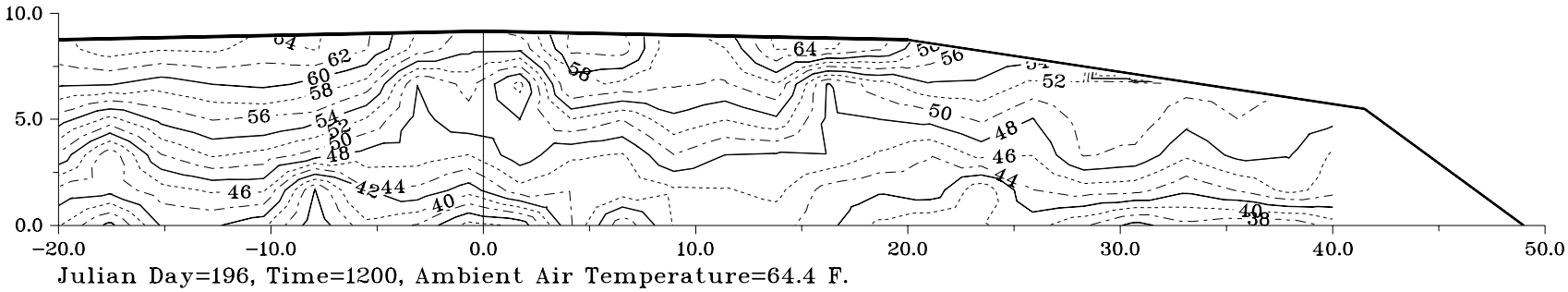


Figure 16. Temperature contours in the Parks/Chena Ridge ACE embankment on July 15, 2001.

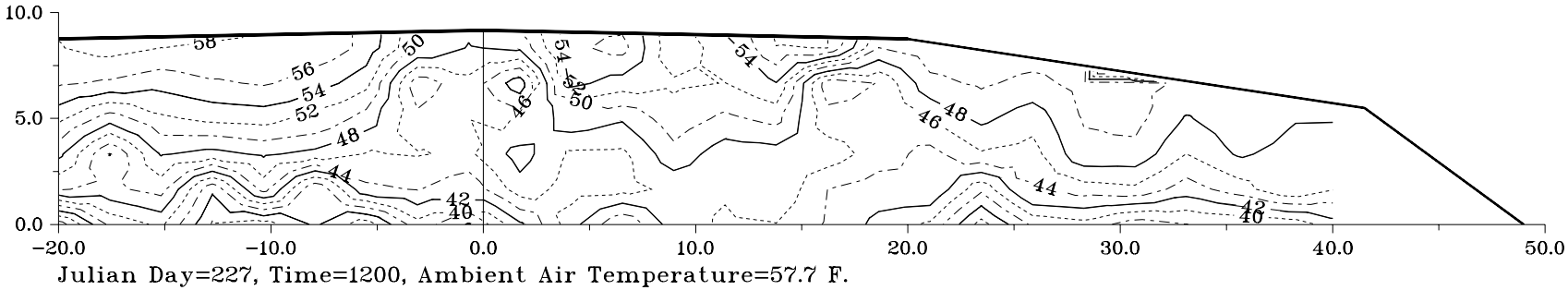


Figure 17. Temperature contours in the Parks/Chena Ridge ACE embankment on August 15, 2001.

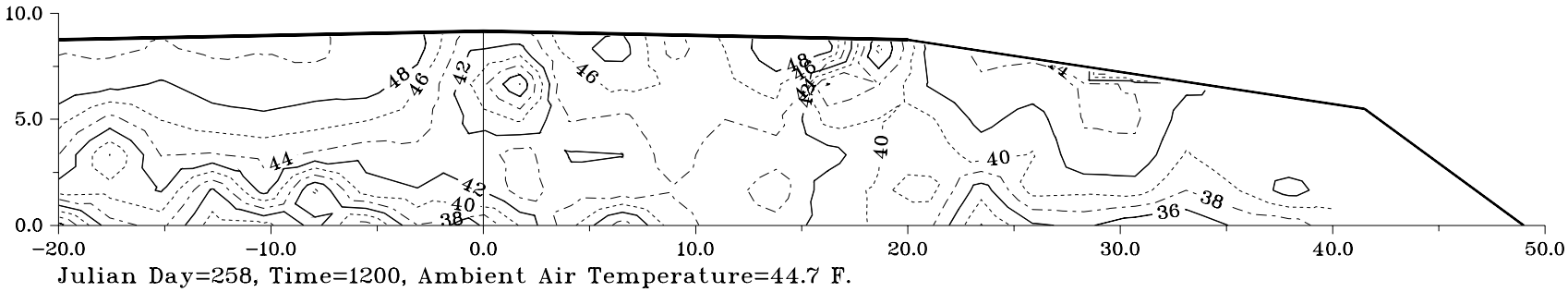


Figure 18. Temperature contours in the Parks/Chena Ridge ACE embankment on September 15, 2001.

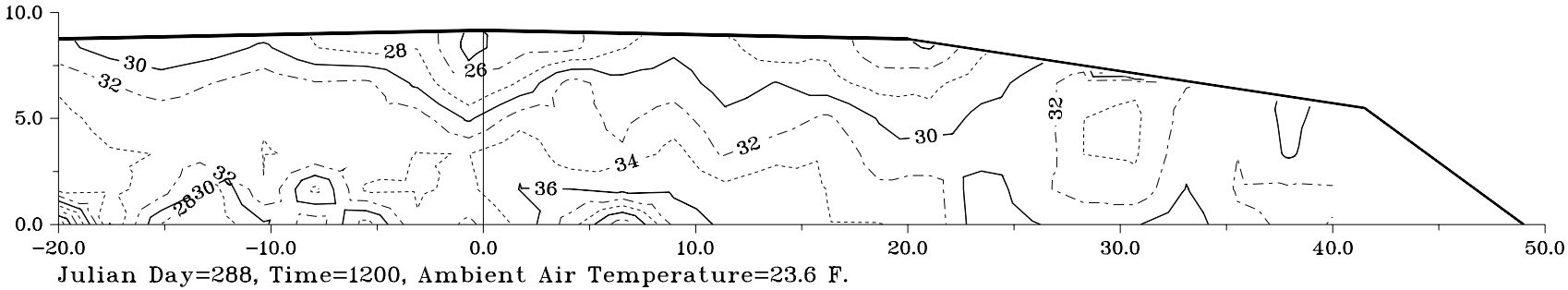


Figure 19. Temperature contours in the Parks/Chena Ridge ACE embankment on October 15, 2001.

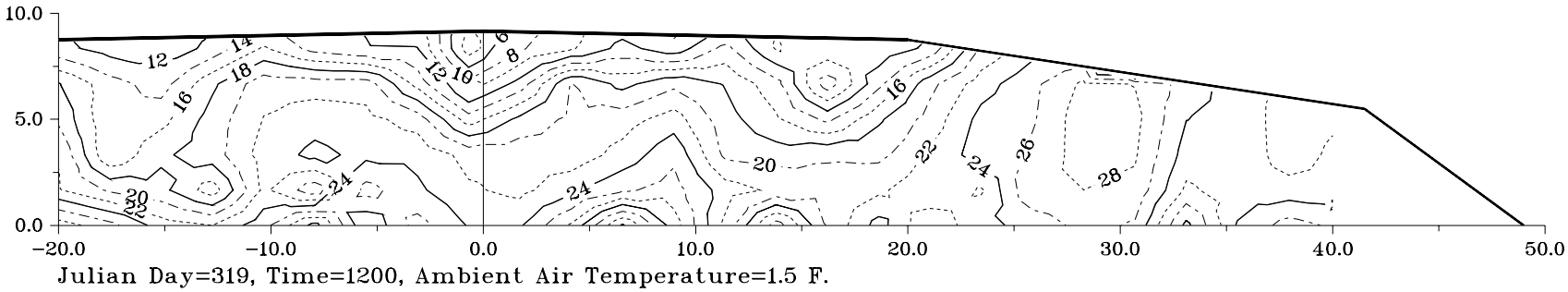


Figure 20. Temperature contours in the Parks/Chena Ridge ACE embankment on November 15, 2001.

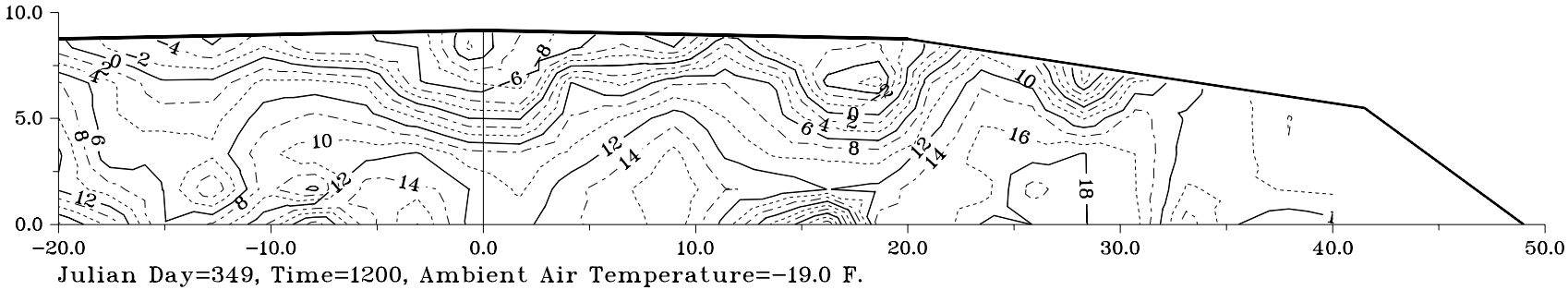


Figure 21. Temperature contours in the Parks/Chena Ridge ACE embankment on December 15, 2001.

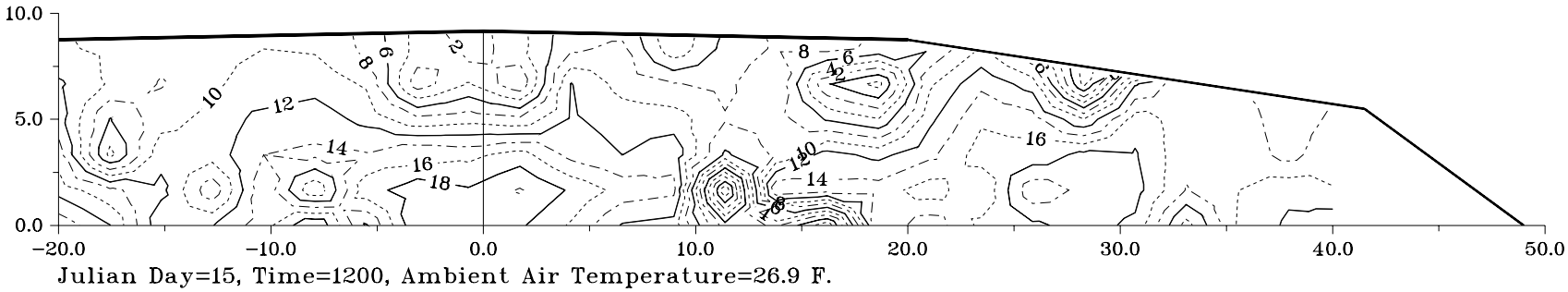


Figure 22. Temperature contours in the Parks/Chena Ridge ACE embankment on January 15, 2002.

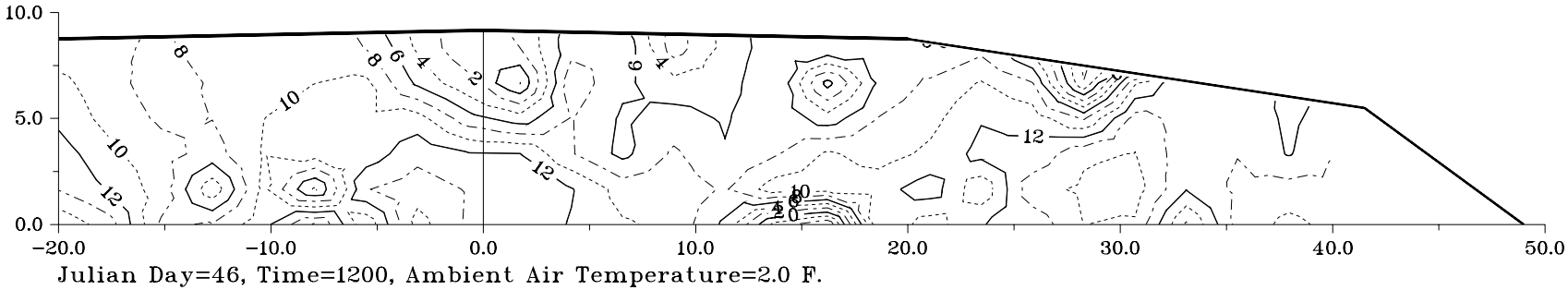


Figure 23. Temperature contours in the Parks/Chena Ridge ACE embankment on February 15, 2002.

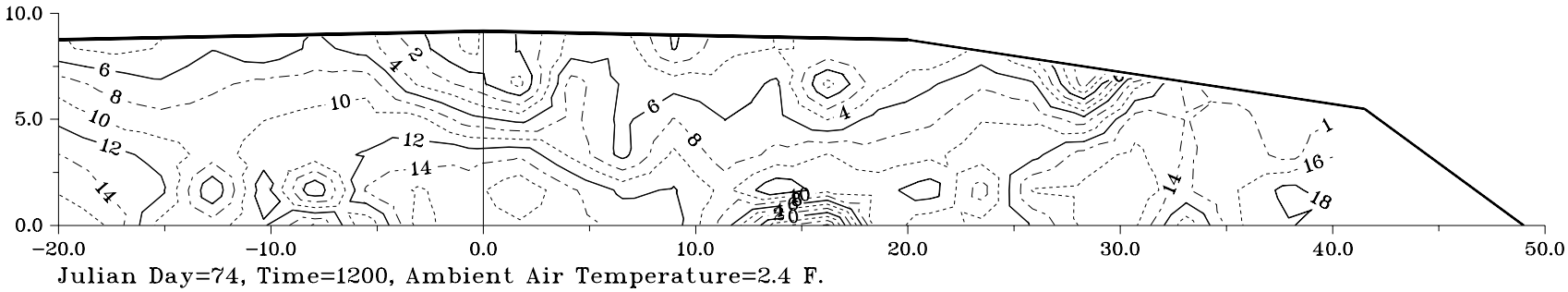


Figure 24. Temperature contours in the Parks/Chena Ridge ACE embankment on March 15, 2002.

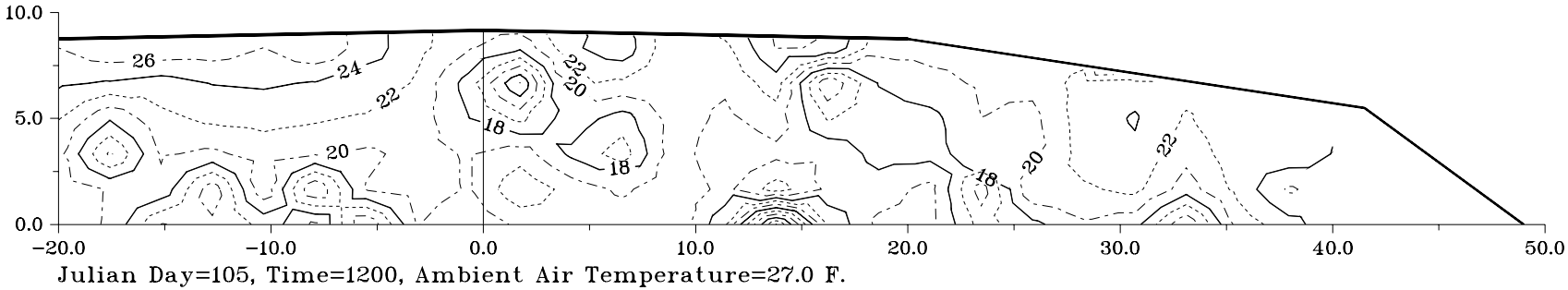


Figure 25. Temperature contours in the Parks/Chena Ridge ACE embankment on April 15, 2002.

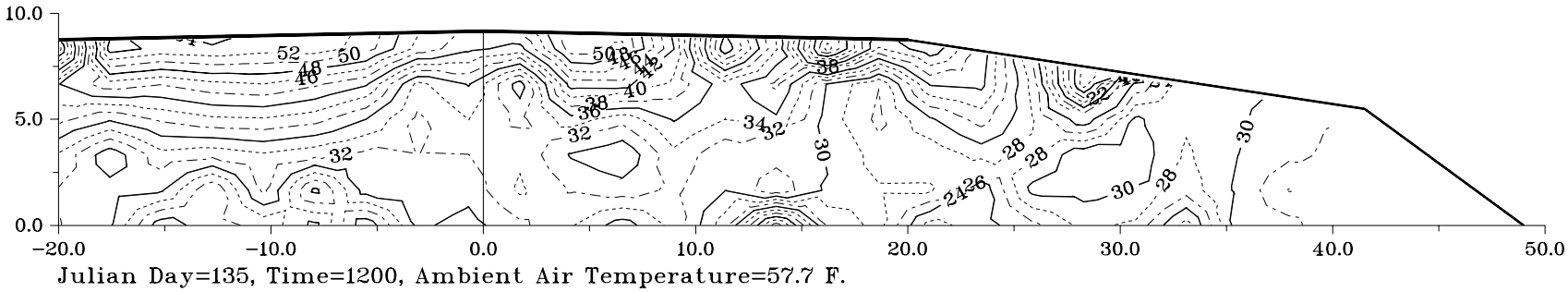


Figure 26. Temperature contours in the Parks/Chena Ridge ACE embankment on May 15, 2002.

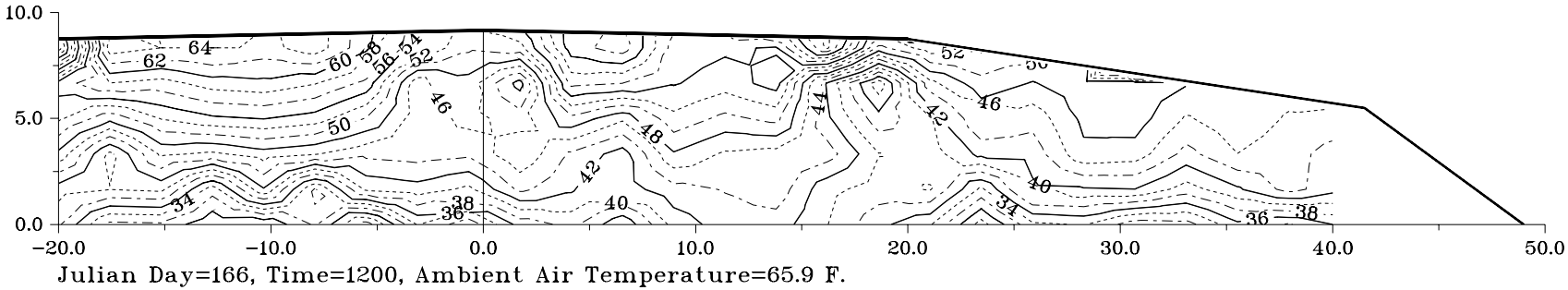


Figure 27. Temperature contours in the Parks/Chena Ridge ACE embankment on June 15, 2002.

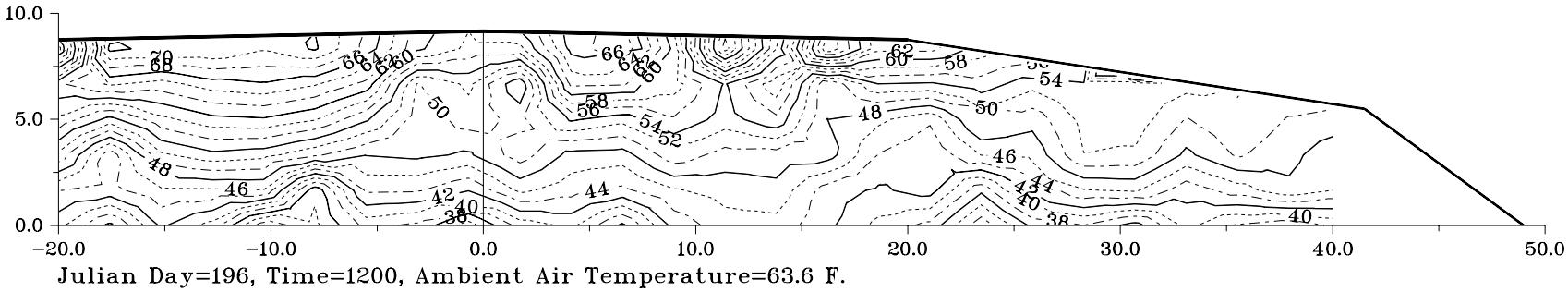


Figure 28. Temperature contours in the Parks/Chena Ridge ACE embankment on July 15, 2002.

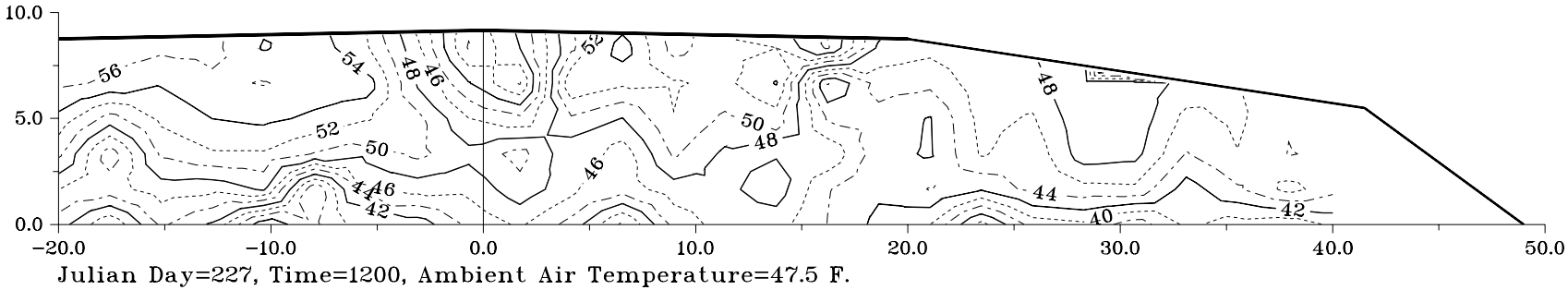


Figure 29. Temperature contours in the Parks/Chena Ridge ACE embankment on August 15, 2002.

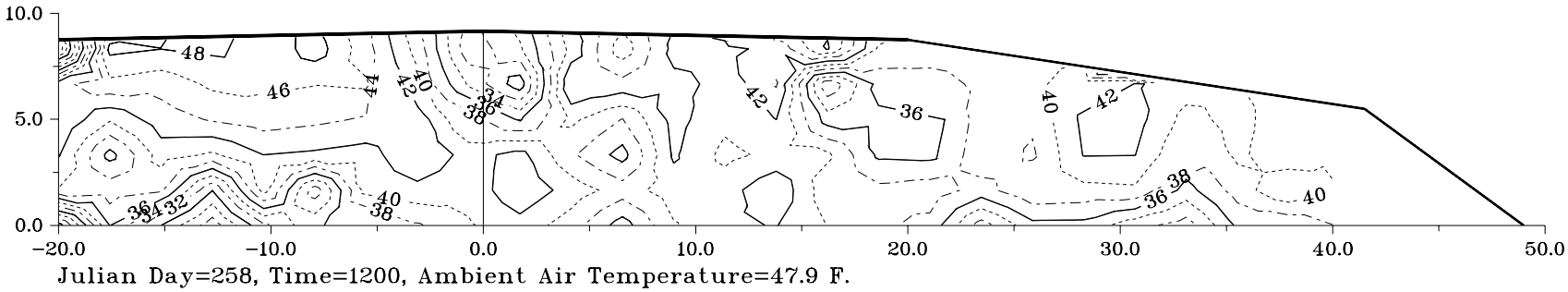


Figure 30. Temperature contours in the Parks/Chena Ridge ACE embankment on September 15, 2002.

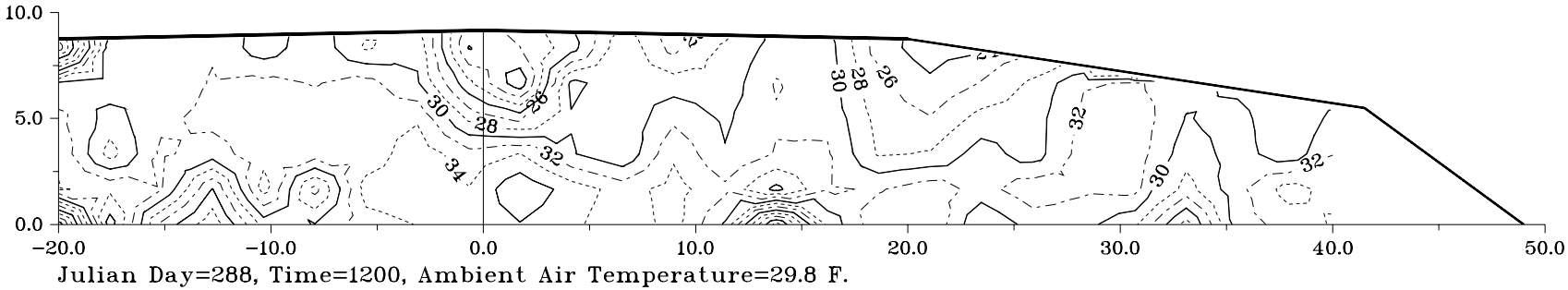


Figure 31. Temperature contours in the Parks/Chena Ridge ACE embankment on October 15, 2002.

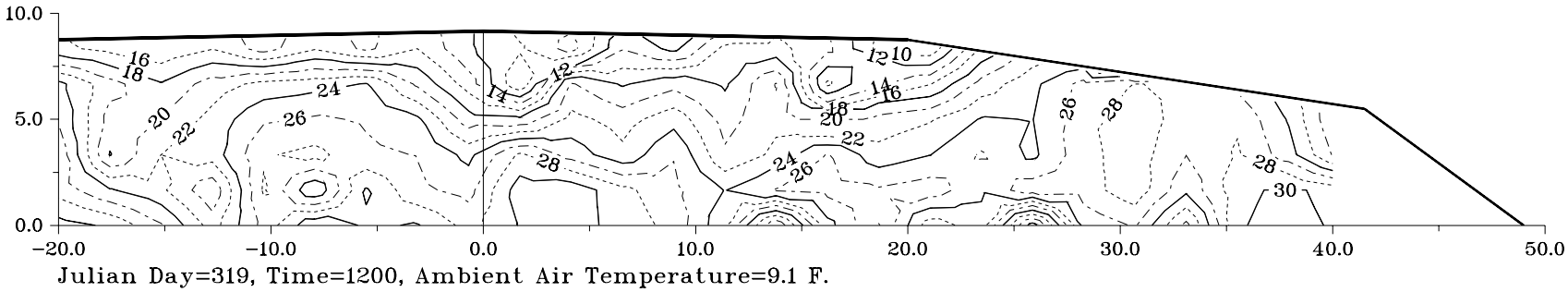


Figure 32. Temperature contours in the Parks/Chena Ridge ACE embankment on November 15, 2002.

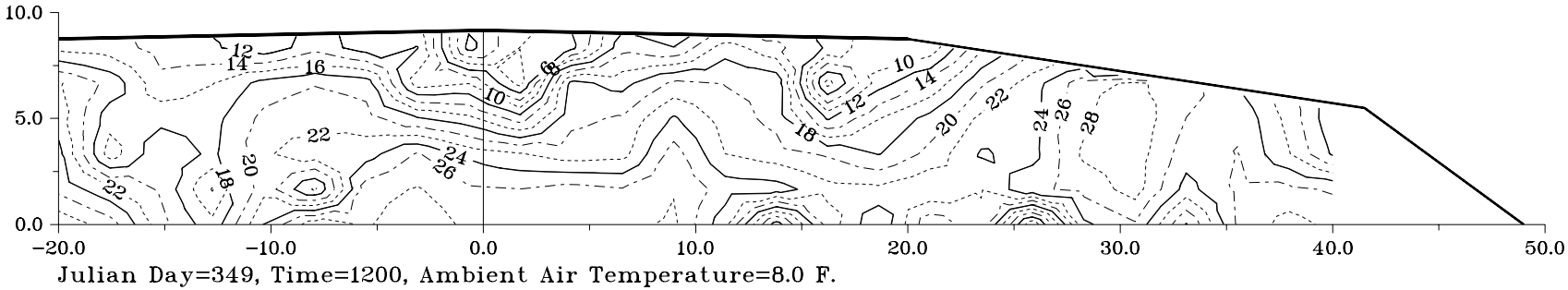


Figure 33. Temperature contours in the Parks/Chena Ridge ACE embankment on December 15, 2002.

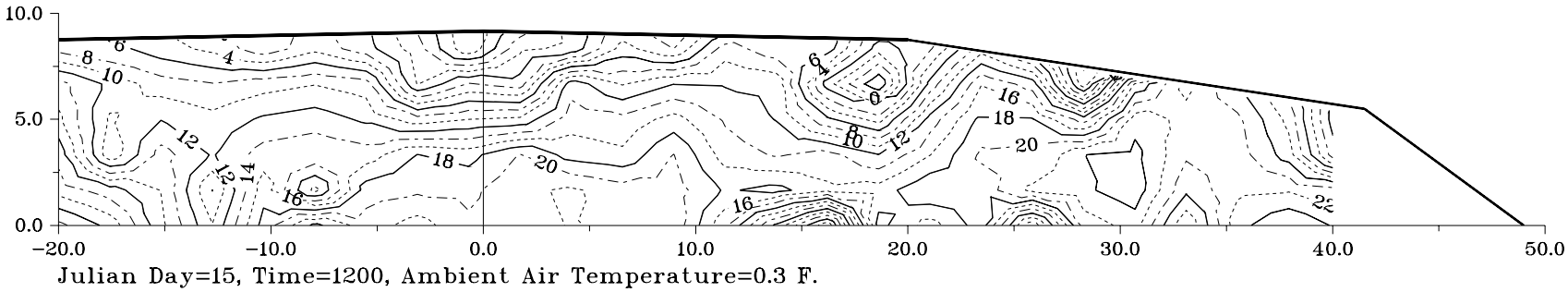


Figure 34. Temperature contours in the Parks/Chena Ridge ACE embankment on January 15, 2003.

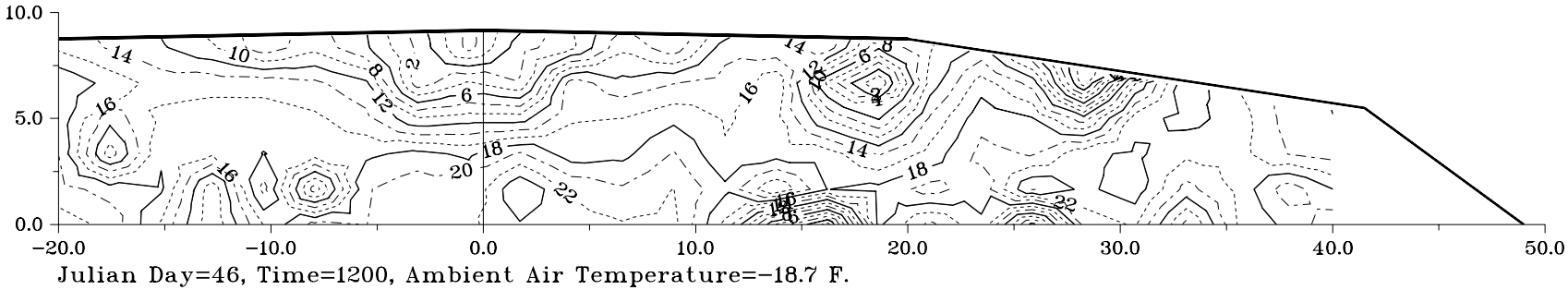


Figure 35. Temperature contours in the Parks/Chena Ridge ACE embankment on February 15, 2003.

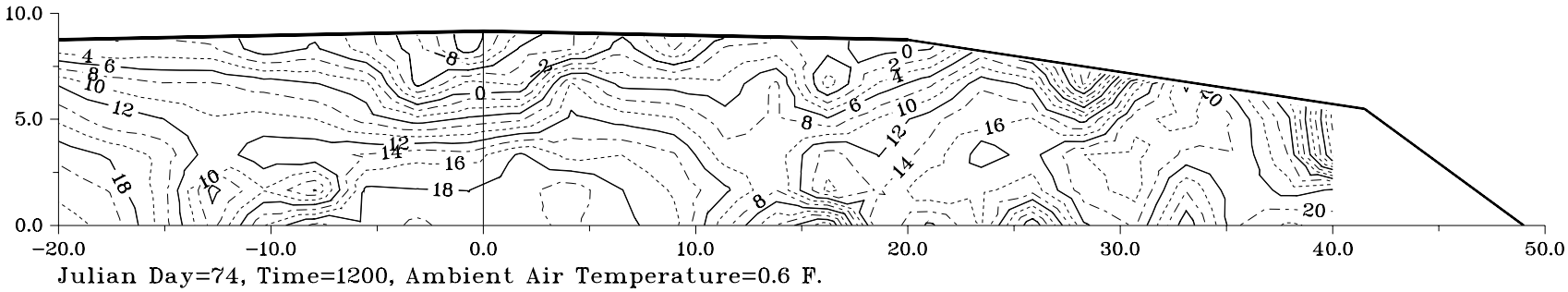


Figure 36. Temperature contours in the Parks/Chena Ridge ACE embankment on March 15, 2003.

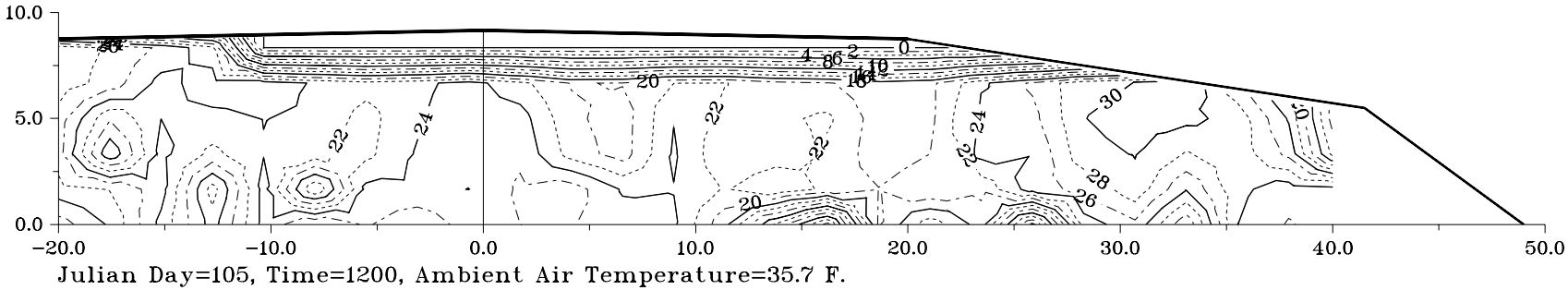


Figure 37. Temperature contours in the Parks/Chena Ridge ACE embankment on April 15, 2003.

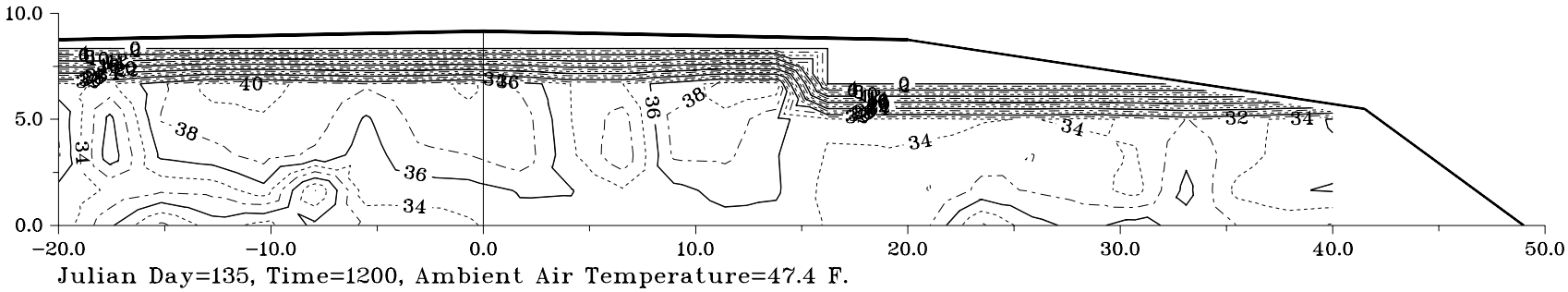


Figure 38. Temperature contours in the Parks/Chena Ridge ACE embankment on May 15, 2003.

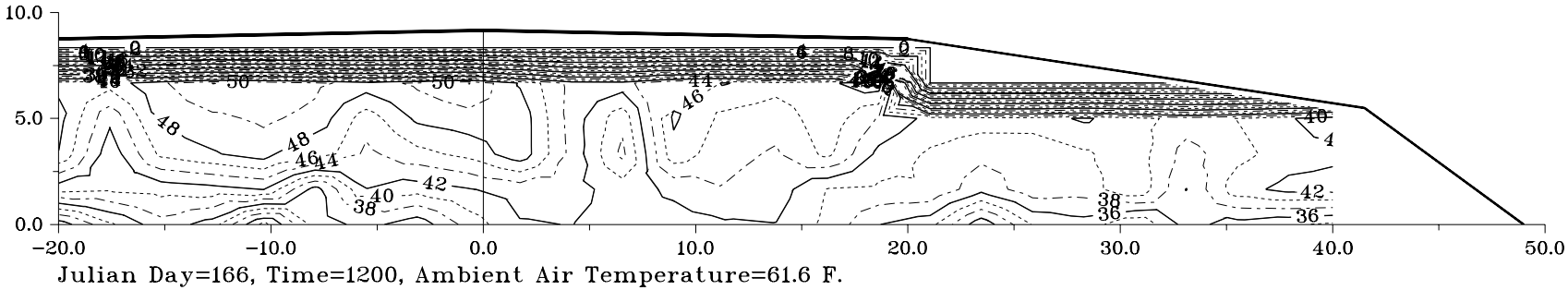


Figure 39. Temperature contours in the Parks/Chena Ridge ACE embankment on June 15, 2003.

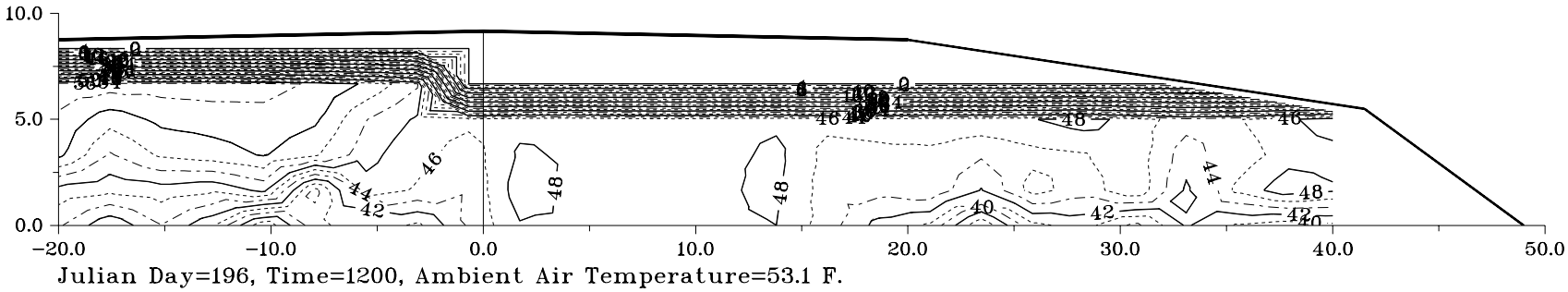


Figure 40. Temperature contours in the Parks/Chena Ridge ACE embankment on July 15, 2003.

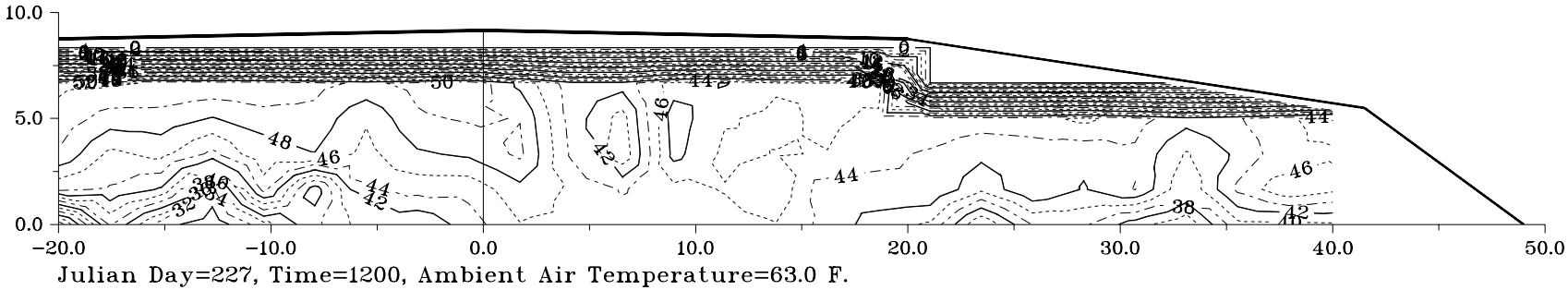


Figure 41. Temperature contours in the Parks/Chena Ridge ACE embankment on August 15, 2003.

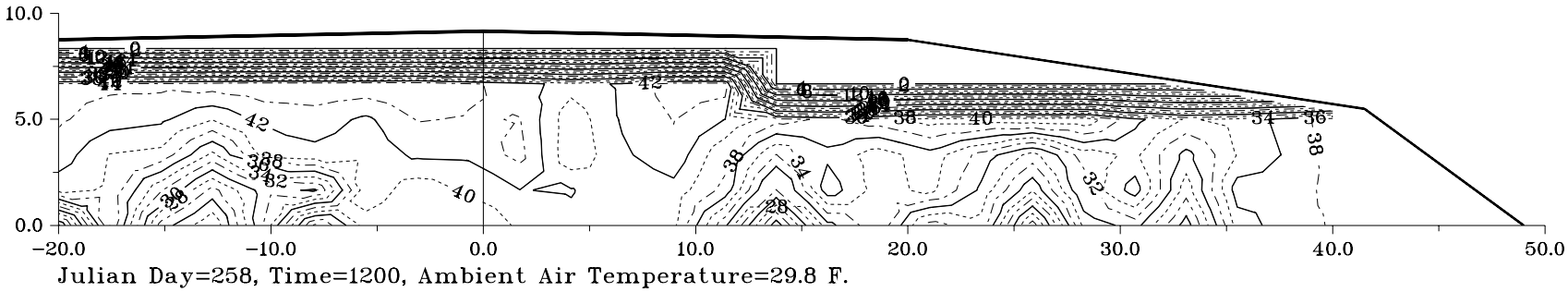


Figure 42. Temperature contours in the Parks/Chena Ridge ACE embankment on September 15, 2003.

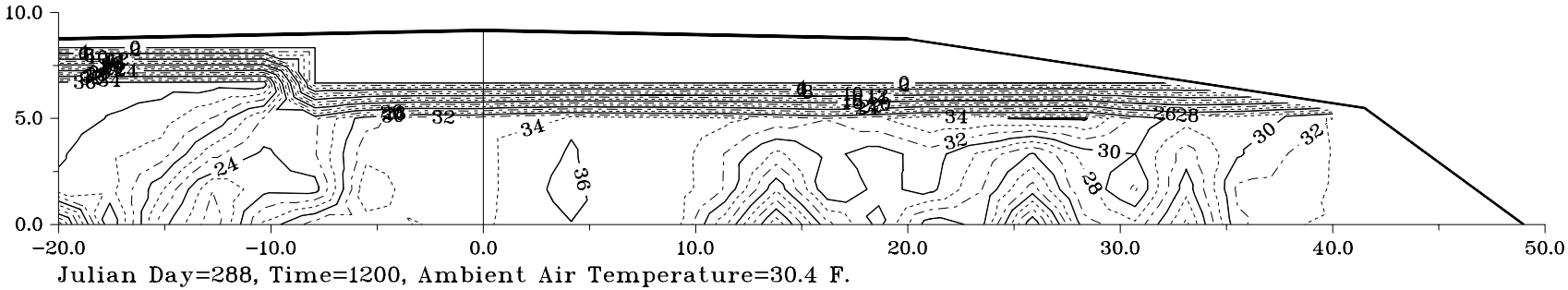


Figure 43. Temperature contours in the Parks/Chena Ridge ACE embankment on October 15, 2003.

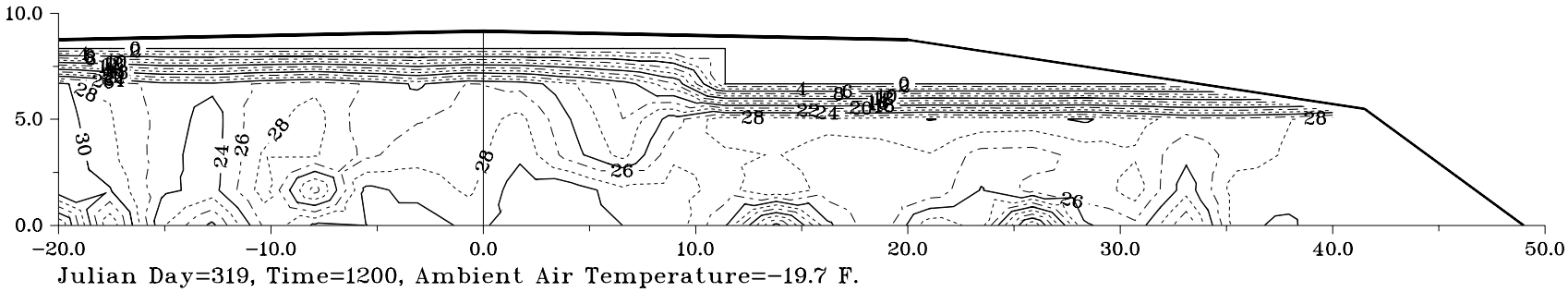


Figure 44. Temperature contours in the Parks/Chena Ridge ACE embankment on November 15, 2003.

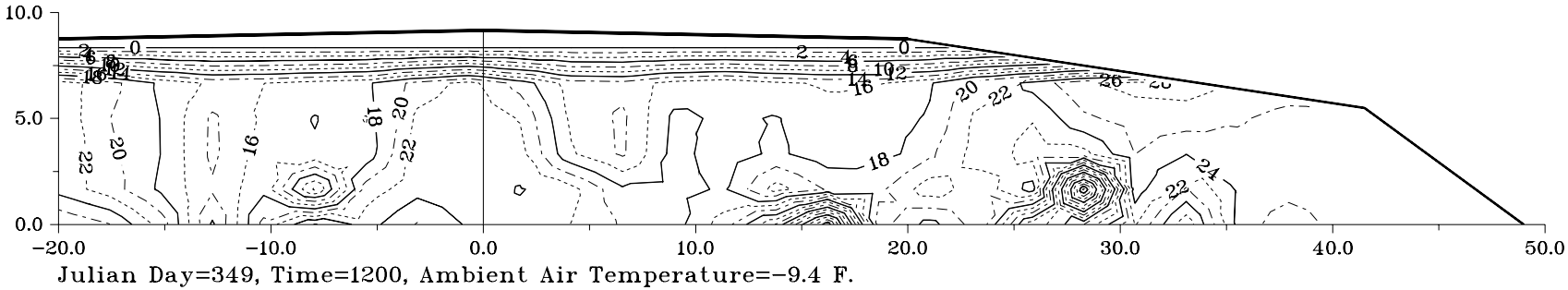


Figure 45. Temperature contours in the Parks/Chena Ridge ACE embankment on December 15, 2003.

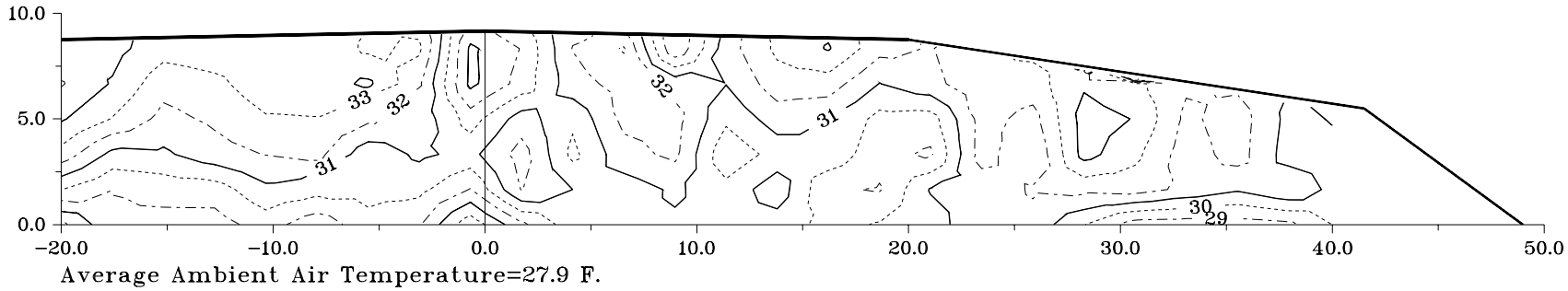


Figure 46. Mean annual temperature contours in the Parks/Chena Ridge ACE embankment (January to December 2001).

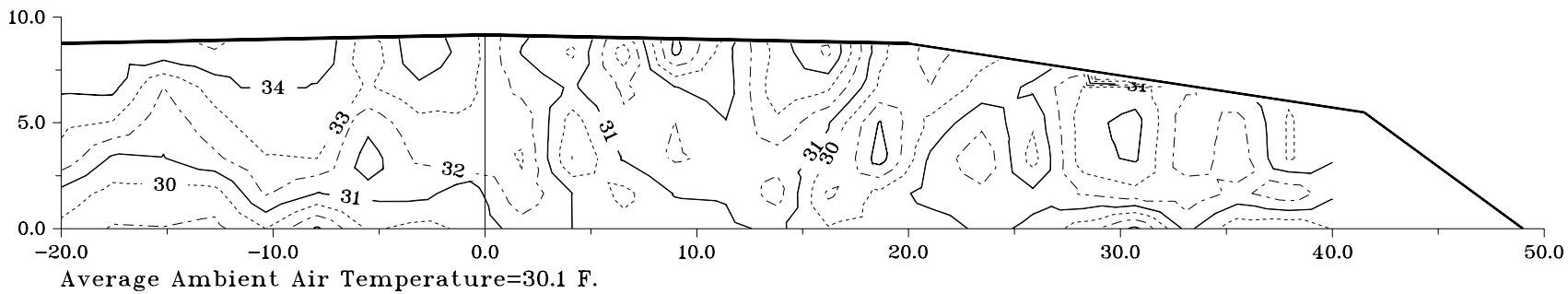


Figure 47. Mean annual temperature contours in the Parks/Chena Ridge ACE embankment (January to December 2002).

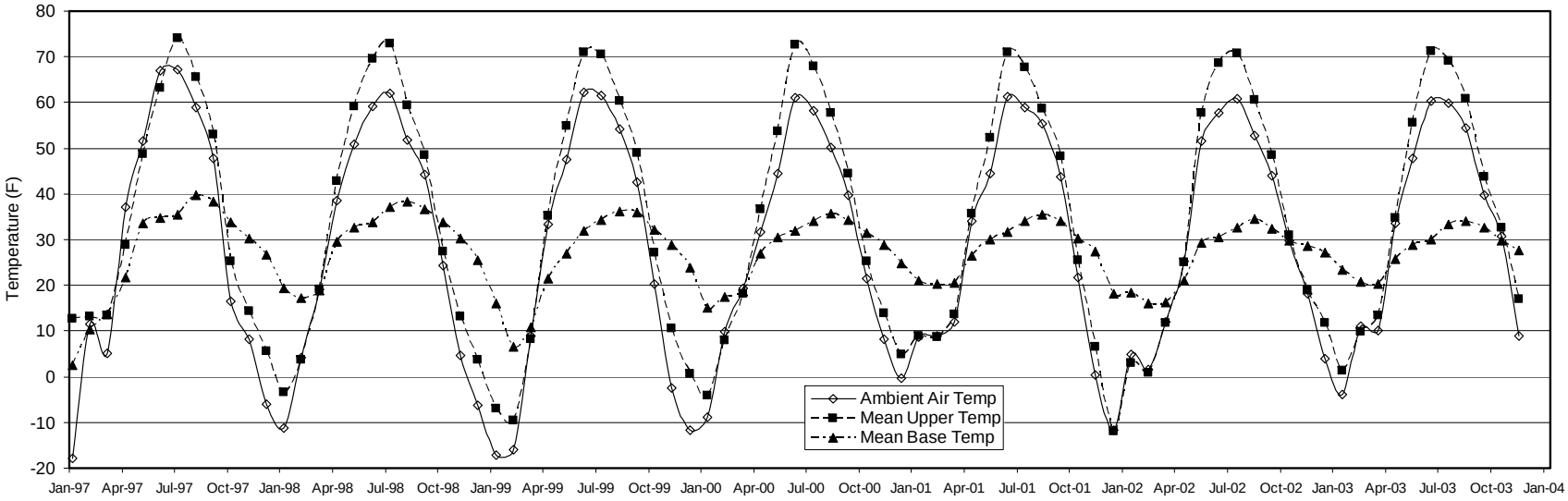


Figure 48. Mean monthly temperatures for the ambient air, upper embankment layer, and base embankment layer in the Parks/Chena Ridge ACE embankment (January 1997 to December 2003).

5.0 SUBGRADE AND CONTROL SECTION THERMAL DATA

5.1 ACE Test Section Subgrade

As discussed in Section 2.1 and shown in Figures 2 and 3, the ACE test section includes thermistor arrays D, E, and F, which are located beneath the embankment in the foundation material. String D is located at the centerline, E is located beneath the edge of the asphalt, and F is located below the break point in the barn-roof side-slope. These three arrays were installed by drilling into the frozen foundation materials and placing the vertical strings before embankment construction took place.

Tables 1 through 36 contain temperature data taken from strings D, E, and F (as well as strings A, B, and C, which will be discussed later) on the 15th day of each month, beginning on January 15, 2001 and ending on December 15, 2003. The first column of the table lists the elevation in feet relative to the elevation of the original grade. These elevations correspond to those shown in Figures 3 and 5 for the ACE test section and control section, respectively. Temperatures are listed in °F in the tables, and bad data points are marked by # symbols. String D is no longer producing any usable data and, thus, all the data in column D has been marked bad. Since replacement of strings E and F in the summer of 1999, they have each been producing reliable data as shown in the tables.

Tables 1, 2, and 3, contain data for January, February, and March of 2001. The data for strings E and F show that the entire column of foundation soil has been chilled well below the freezing temperature with values of about 24°F just below the embankment base in March. Tables 3 through 11 then show a gradual warming of strings E and F during the summer and early part of the winter of 2001-2002. Table 11 shows that

November temperatures have reached 31.6°F at the upper end of strings E and F as of November 15th. After that, however, there is an abrupt and rapid decrease in the temperatures of strings E and F as winter convection begins in the embankment. Table 13 shows that, by January 15th, the upper temperatures for strings E and F have again decreased to values well below freezing.

Tables 13 through 24 and 25 through 36 indicate similar trends for strings E and F, a rapid cooling during the middle and late winter, followed by a gradual warming from the April through November time period. In general, the temperatures shown in Tables 1-36 for thermistor strings E and F tend to indicate that the foundation soils are remaining in a frozen state throughout the annual temperature cycle. This assertion is in agreement with the field observations made during the summer of 1999 while installing replacement thermistor strings for E and F which indicated frozen soil conditions during drilling.

5.2 Control Section Subgrade

In section 2 the details of the control section configuration were discussed. Figure 4 gives a detailed diagram that shows the position of thermistor strings A, B, and C within the control section. For strings A and B, the uppermost thermistor is located just above the insulation board, whereas the remaining sensors are located deeper in the embankment or in the foundation soils. Columns 2 through 4 of Tables 1 through 15 include data for strings A, B, and C.

Unfortunately, many of the data problems which have plagued thermistor strings D, E, and F, have also affected the reliability of the readings for strings A, B, and C. In particular, most of the thermistors on string A are no longer giving reasonable data and are marked with #'s in the tables. In addition, other values which have not been marked

bad are still suspect. Careful examination of some of the data for string B, for instance, reveals unrealistic behavior where one low temperature reading is continually bracketed by higher temperature readings above and below. Also, the data for string C indicates that the thermistor at 0 ft. is always warmer than the thermistors above and below, which cannot be the case year-round. It is likely that much of this unrealistic behavior is due to problems with the thermistor installation. Rewiring the thermistor sensors to eliminate the impact of ground loops and galvanic potentials should help reduce these data quality problems.

Given the data problems described above, it is probably wise to only depend on the data for strings A, B, and C to give a general indication of the temperature behavior beneath the control section, rather than exact temperature profiles. In general, the trends for strings A, B, and C mimic the behavior that would be expected based on the "whiplash curve." Trends in the tables indicate that string A is generally warmer in winter and colder in summer as compared to strings B and C. Although it is hard to say for sure given the questionable data, the tables seem to indicate that the foundation soils are thawing down about 4 ft. beneath the bottom of the embankment at the location of string B and somewhat more than this at the location of string C. These trends are in agreement with observations from previous years which indicated that the greatest depth of thaw occurred at the location of string C beneath the embankment side slope. Typically some thaw also occurs at the location of string B and a lesser amount at string A.

An overall comparison of the subgrade temperatures tends to indicate that there has been some cooling of the foundation soils beneath the ACE test section. The warmest foundation temperatures (on average) are occurring beneath the shoulder region of the control section.

Table 1. Subgrade Temperatures Beneath Control Section
and ACE Test Section on January 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	5.4	7.2				
4	29.6	32.1				
2	32.1	30.9	26.5			
0	####	31.5	28.9			
-2	32	29.5	26.5	####	23.2	28.1
-4	####	31.6	28.2	####	25.8	29.6
-8	####	30.2	29.5	####	28.8	30.6
-12	####	31.5	30.7	####	30.4	30.4
-16	####	31.2	30.3	####	30.1	30.5
-20	####	####	####	####	30.6	30.3

Table 2. Subgrade Temperatures Beneath Control Section
and ACE Test Section on February 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	11.6	13.2				
4	29.6	32				
2	32.5	30.8	26.1			
0	####	31.7	28.5			
-2	32.2	29.7	26.1	####	23.9	25.7
-4	####	31.4	27.7	####	25.6	27.5
-8	####	30	29.2	####	27.9	29.8
-12	####	31.3	30.6	####	29.8	30.2
-16	####	31.1	30.1	####	29.9	30.5
-20	####	####	####	####	30.6	30.4

Table 3. Subgrade Temperatures Beneath Control Section
and ACE Test Section on March 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	20.4	18.5				
4	29.6	31.9				
2	####	30.5	26.6			
0	####	31.3	27.2			
-2	32.1	29.4	####	####	24.2	24.2
-4	####	31	27.8	####	25.6	26.2
-8	####	29.9	29.6	####	27.4	28.7
-12	####	31.5	30.2	####	29.4	29.7
-16	####	31.2	29.7	####	29.7	30.4
-20	####	####	####	####	30.5	30.4

Table 4. Subgrade Temperatures Beneath Control Section
and ACE Test Section on April 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	30.1	31.7				
4	30.3	31.6				
2	33.2	28.5	26.2			
0	####	32.8	27.9			
-2	31.4	30.8	25	####	28.3	25.8
-4	####	31.5	28.7	####	27	25.8
-8	####	29.7	31	####	26.9	27.7
-12	####	32.1	29.3	####	28.9	29
-16	####	32.3	28.7	####	29.4	30
-20	####	####	####	####	30.3	30.2

Table 5. Subgrade Temperatures Beneath Control Section
and ACE Test Section on May 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	49.6	47.3				
4	31.7	####				
2	33.5	30.3	24.7			
0	####	31.5	29.3			
-2	30.5	29.5	26.9	####	30.5	29.8
-4	####	31.3	28	####	29.9	29.1
-8	####	30.2	29.6	####	28.5	28.6
-12	####	32.8	30.7	####	29.1	28.8
-16	####	32.2	30.6	####	29.2	29.7
-20	####	####	####	####	30.2	29.9

Table 6. Subgrade Temperatures Beneath Control Section
and ACE Test Section on June 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	66.4	64.4				
4	32.2	####				
2	32.8	30.9	25			
0	####	31.3	28.1			
-2	32.2	29.4	25.7	####	30.9	30
-4	####	31.4	27.5	####	30.5	29.8
-8	####	29.9	29.3	####	29.3	29.4
-12	####	31.6	30.7	####	29.6	29.2
-16	####	31.4	####	####	29.4	29.7
-20	####	####	####	####	30.2	29.9

Table 7. Subgrade Temperatures Beneath Control Section
and ACE Test Section on July 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	65.8	64				
4	34.2	####				
2	33.2	30.4	32.8			
0	####	31.5	31.9			
-2	32.4	29.4	27.2	####	31	30.6
-4	####	31.5	28.3	####	30.8	30.2
-8	####	30.1	29.6	####	29.7	29.9
-12	####	31.5	30.4	####	29.9	29.6
-16	####	31.3	29.9	####	29.6	29.9
-20	####	####	####	####	30.3	29.9

Table 8. Subgrade Temperatures Beneath Control Section
and ACE Test Section on August 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	59.8	58.6				
4	35.8	####				
2	34.7	31.1	39.4			
0	####	31.4	39.5			
-2	32.2	29.5	33.6	####	31.4	31
-4	####	31.3	31.8	####	31	30.4
-8	####	30	29.8	####	29.9	30.1
-12	####	31.6	30.6	####	30.2	29.9
-16	####	31.3	30.1	####	29.8	30.1
-20	####	####	####	####	30.4	30

Table 9. Subgrade Temperatures Beneath Control Section
and ACE Test Section on September 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	52.3	50.2				
4	35.9	####				
2	36.4	36.8	39			
0	####	35.1	41.6			
-2	33.3	31.5	36.4	####	31.7	30.8
-4	####	32.9	33.4	####	31.2	30.7
-8	####	30.6	30	####	30	30.4
-12	####	30.5	30.9	####	30.3	30
-16	####	30.3	30.4	####	29.9	30.2
-20	####	####	####	####	30.5	30.1

Table 10. Subgrade Temperatures Beneath Control Section
and ACE Test Section on October 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	32.6	33.3				
4	####	####				
2	38.2	36.3	33.7			
0	####	36.8	37.2			
-2	33.5	33.6	33.6	####	31.7	31
-4	####	33.2	33.8	####	31.4	30.8
-8	####	29.8	31	####	30.2	30.5
-12	####	31.6	30.3	####	30.5	30.2
-16	####	31.3	29.8	####	30	30.4
-20	####	####	####	####	30.5	30.2

Table 11. Subgrade Temperatures Beneath Control Section
and ACE Test Section on November 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	5.7	6.4				
4	####	####				
2	36.5	32.4	27.1			
0	####	34.2	32.1			
-2	33	32	29.8	####	31.6	31.6
-4	####	33	31.3	####	31.5	30.9
-8	####	30	30.7	####	30.4	30.7
-12	####	31.4	30.5	####	30.6	30.4
-16	####	31.1	30	####	30.2	30.5
-20	####	####	####	####	30.7	30.4

Table 12. Subgrade Temperatures Beneath Control Section
and ACE Test Section on December 15, 2001.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	-8.6	-7.1				
4	####	####				
2	36.4	30.6	24.5			
0	####	32.2	29.1			
-2	32.3	30.1	26.9	####	16.2	31.6
-4	####	31.9	29.3	####	23.1	31
-8	####	30	30.2	####	29.9	30.8
-12	####	31.6	30.4	####	30.7	30.4
-16	####	31.2	30	####	30.2	30.6
-20	####	####	####	####	30.8	30.5

Table 13. Subgrade Temperatures Beneath Control Section
and ACE Test Section on January 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	9.1	10.8				
4	####	####				
2	36.7	30.2	23.3			
0	####	31.7	27.8			
-2	32.6	29.7	25.5	####	20.7	23.3
-4	####	31.4	27.9	####	22.9	27.7
-8	####	29.8	29.5	####	26.7	30.4
-12	####	31.4	30.2	####	29.9	30.5
-16	####	31	29.8	####	30.1	30.6
-20	####	####	####	####	30.8	30.5

Table 14. Subgrade Temperatures Beneath Control Section
and ACE Test Section on February 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	6.8	7.3				
4	####	####				
2	36.5	29.8	22.7			
0	####	31.8	27.4			
-2	31.8	29.7	25	####	19.3	23.2
-4	####	31	27.8	####	21.9	25.4
-8	####	29.5	29.5	####	25.6	28.8
-12	####	32.1	30.1	####	28.9	30
-16	####	31.7	29.9	####	29.6	30.5
-20	####	####	####	####	30.7	30.5

Table 15. Subgrade Temperatures Beneath Control Section
and ACE Test Section on March 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	8.6	6.6				
4	####	####				
2	35.1	27.9	22			
0	####	31.7	27.5			
-2	32.5	29.5	24.9	####	20.1	20.4
-4	####	31.5	27.2	####	22	23.6
-8	####	29.9	29.2	####	24.7	27
-12	####	31.5	30.4	####	28	28.9
-16	####	31.3	29.9	####	29	30.1
-20	####	####	####	####	30.4	30.4

Table 16. Subgrade Temperatures Beneath Control Section
and ACE Test Section on April 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	29.1	24.8				
4	####	####				
2	34.4	####	21.3			
0	####	30.7	27.9			
-2	33.5	28.6	25.3	####	22.8	22.5
-4	####	32.1	26.4	####	23.4	23.2
-8	####	30.5	28.2	####	24.7	25.9
-12	####	30.6	31.1	####	27.3	27.8
-16	####	30.3	30.6	####	28.4	29.2
-20	####	####	####	####	29.9	30

Table 17. Subgrade Temperatures Beneath Control Section
and ACE Test Section on May 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	50.9	47.6				
4	####	####				
2	34.6	####	22.2			
0	####	31.4	27.4			
-2	32.8	29.4	25.1	####	29.7	28.7
-4	####	31.2	26.8	####	28.5	27.4
-8	####	30	28.7	####	26.6	26.8
-12	####	31.5	30.3	####	27.5	27.5
-16	####	31	30	####	28.1	28.8
-20	####	####	84.2	####	29.6	29.5

Table 18. Subgrade Temperatures Beneath Control Section
and ACE Test Section on June 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	63.7	60.9				
4	####	####				
2	35.2	30.6	23			
0	####	31.1	27.5			
-2	32.8	28.9	25	####	30.5	28.8
-4	####	31.3	26.8	####	29.9	29.1
-8	####	30.1	28.7	####	28.3	28.4
-12	####	31.3	30.4	####	28.5	28.3
-16	####	30.8	30.1	####	28.4	28.9
-20	####	####	####	####	29.5	29.3

Table 19. Subgrade Temperatures Beneath Control Section
and ACE Test Section on July 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	69.6	67.2				
4	####	####				
2	35.5	29.7	28.3			
0	####	31.6	27.3			
-2	32.4	29.6	24.6	####	30.9	30.2
-4	####	30.8	27.4	####	30.5	29.7
-8	####	29.5	29.2	####	29	29.2
-12	####	31.9	29.9	####	29.2	28.9
-16	####	31.5	29.7	####	28.9	29.2
-20	####	####	####	####	29.7	29.4

Table 20. Subgrade Temperatures Beneath Control Section
and ACE Test Section on August 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	59.5	57.3				
4	####	####				
2	35.1	30.6	35			
0	####	31.5	36			
-2	32.9	29.8	29.9	####	31.4	30.5
-4	####	31.1	28.5	####	30.8	30.2
-8	####	30.1	28.5	####	29.5	29.7
-12	####	31.2	30.3	####	29.6	29.3
-16	####	30.8	30	####	29.2	29.6
-20	####	####	####	####	29.9	29.6

Table 21. Subgrade Temperatures Beneath Control Section
and ACE Test Section on September 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	48.7	46.7				
4	####	####				
2	35.8	31.9	34.6			
0	####	31.3	38.1			
-2	33.1	29.6	33	####	31.7	31.1
-4	####	31.3	31.5	####	31.2	30.5
-8	####	30	29.8	####	29.8	30
-12	####	31.2	30.5	####	29.9	29.6
-16	####	30.7	30	####	29.5	29.9
-20	####	####	####	####7	30.1	29.8

Table 22. Subgrade Temperatures Beneath Control Section
and ACE Test Section on October 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	32.3	32				
4	####	####				
2	35.7	32.4	30.1			
0	####	33	35.4			
-2	32.8	30.7	31.9	####	31.7	31.5
-4	####	31.6	32	####	31.3	30.7
-8	####	29.7	30.6	####	30	30.2
-12	####	31.5	30.5	####	30.2	29.9
-16	####	31	30.1	####	29.7	30
-20	####	####	####	####	30.2	29.9

Table 23. Subgrade Temperatures Beneath Control Section
and ACE Test Section on November 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	15.4	18.8				
4	####	####				
2	35.4	31.1	25.9			
0	####	33.4	31.4			
-2	32.6	31.4	28.7	####	31.6	29.7
-4	####	31.6	30.3	####	31.4	30.9
-8	####	29.7	30.6	####	30.2	30.5
-12	####	31.7	29.8	####	30.4	30.1
-16	####	31.1	29.5	####	29.9	30.2
-20	####	####	####	####	30.4	30

Table 24. Subgrade Temperatures Beneath Control Section
and ACE Test Section on December 15, 2002.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	11	12.9				
4	####	####				
2	35.7	30.2	23.6			
0	####	32.3	29.1			
-2	32.6	30.9	26.5	####	31.6	31.5
-4	####	31.1	28.7	####	31.5	30.9
-8	####	29.5	29.8	####	30.3	30.6
-12	####	31.7	29.9	####	30.5	30.2
-16	####	31.1	29.6	####	30	30.4
-20	####	####	####	####	30.5	30.2

Table 25. Subgrade Temperatures Beneath Control Section
and ACE Test Section on January 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	1.5	4.4				
4	####	####				
2	35.2	####	22.5			
0	####	31.5	28.1			
-2	33.2	29.3	25.4	####	27.2	31.1
-4	####	31.3	27.2	####	30.1	31
-8	####	30	29	####	30.4	30.7
-12	####	31.1	30.4	####	30.6	30.4
-16	####	30.6	30	####	30.1	30.5
-20	####	####	####	####	30.6	30.3

Table 26. Subgrade Temperatures Beneath Control Section
and ACE Test Section on February 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	21.6	21.2				
4	####	####				
2	35	####	21.5			
0	####	31.2	28.1			
-2	32.7	28.9	25.4	####	25.5	15
-4	####	31.7	27	####	27.4	29.2
-8	####	30.3	28.8	####	29.4	30.7
-12	####	31.7	30.7	####	30.6	30.5
-16	####	31.2	30.2	####	30.2	30.6
-20	####	####	####	####	30.7	30.4

Table 27. Subgrade Temperatures Beneath Control Section
and ACE Test Section on March 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	6.8	8.3				
4	####	####				
2	35	####	21.7			
0	####	31.3	27.6			
-2	33	29	24.9	####	25	27
-4	####	31.7	26.6	####	26.9	28
-8	####	30.5	28.5	####	28.6	30
-12	####	31.3	30.6	####	30.3	30.4
-16	####	30.7	30.1	####	30.2	30.6
-20	####	####	####	####	30.7	30.4

Table 28. Subgrade Temperatures Beneath Control Section
and ACE Test Section on April 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	31.4	29.9				
4	####	####				
2	35	####	21.3			
0	####	31.3	27.9			
-2	33.2	28.8	25	####	28.3	27.2
-4	####	31.2	26	####	27.3	27.1
-8	####	30.1	28.2	####	27.8	29.1
-12	####	31.2	30.4	####	29.8	29.9
-16	####	30.6	29.9	####	30	30.5
-20	####	####	####	####	30.7	30.4

Table 29. Subgrade Temperatures Beneath Control Section
and ACE Test Section on May 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	53.6	51.2				
4	####	####				
2	36.4	####	21.6			
0	####	####	27.5			
-2	33	29.3	24.5	####	30.6	30.3
-4	####	31.1	26.2	####	30.2	29.6
-8	####	30	28.5	####	29	29.5
-12	####	31.5	30.2	####	29.7	29.6
-16	####	30.9	29.6	####	29.7	30.2
-20	####	####	####	####	30.5	30.3

Table 30. Subgrade Temperatures Beneath Control Section
and ACE Test Section on June 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	69.8	67.2				
4	####	####				
2	35.2	####	22.1			
0	####	####	26.8			
-2	32.9	30.2	23.9	####	31	30.6
-4	####	30.4	26.6	####	30.7	30
-8	####	29.6	29	####	29.6	29.9
-12	####	31.5	29.8	####	30	29.8
-16	####	30.9	29.5	####	29.8	30.2
-20	####	####	####	####	30.5	30.2

Table 31. Subgrade Temperatures Beneath Control Section
and ACE Test Section on July 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	70.2	67.1				
4	####	####				
2	34.8	####	33.5			
0	####	####	35.5			
-2	33.6	29.8	29.2	####	31.2	31
-4	####	31.3	27.9	####	31	30.4
-8	####	30.2	28.6	####	29.9	30.2
-12	####	30.9	30.2	####	30.2	30
-16	####	30.4	29.6	####	29.9	30.2
-20	####	####	####	####9	30.5	30.2

Table 32. Subgrade Temperatures Beneath Control Section
and ACE Test Section on August 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	63.7	60.6				
4	####	####				
2	35.7	####	37.6			
0	####	####	41.6			
-2	33.1	30.6	35.3	####	31.7	31.1
-4	####	31.6	31.6	####	31.2	30.5
-8	####	30.1	29.9	####	30	30.4
-12	####	31.5	30.5	####	30.4	30.1
-16	####	30.9	30.1	####	30	30.4
-20	####	####	####	####	30.6	30.3

Table 33. Subgrade Temperatures Beneath Control Section
and ACE Test Section on September 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	46.2	45.9				
4	####	####				
2	38.8	####	36.9			
0	####	####	41.7			
-2	33.9	34.1	36.2	####	32.1	31.5
-4	####	32.7	34	####	31.4	30.8
-8	####	29.7	31.6	####	30.2	30.5
-12	####	31.4	30.1	####	30.5	30.3
-16	####	30.8	29.7	####	30.1	30.5
-20	####	####	####	####	30.7	30.4

Table 34. Subgrade Temperatures Beneath Control Section
and ACE Test Section on October 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	36.2	36.2				
4	####	####				
2	39.3	####	31.1			
0	####	####	37.2			
-2	34.5	34.2	33.3	####	31.9	31.7
-4	####	32.8	33.7	####	31.5	30.9
-8	####	29.1	32.4	####	30.3	30.7
-12	####	31.9	30.1	####	30.6	30.4
-16	####	31.4	29.7	####	30.2	30.5
-20	####	####	####	####	30.7	30.4

Table 35. Subgrade Temperatures Beneath Control Section
and ACE Test Section on November 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	19	23.7				
4	####	39.2				
2	37.6	####	25			
0	####	####	32.6			
-2	34.2	33	29.9	####	31.7	31.7
-4	####	32.7	31.3	####	31.6	31
-8	####	29.5	31.6	####	30.5	30.8
-12	####	31.8	29.8	####	30.7	30.5
-16	####	31.2	29.5	####	30.3	30.7
-20	####	####	####	####	30.8	30.5

Table 36. Subgrade Temperatures Beneath Control Section
and ACE Test Section on December 15, 2003.
(Elevation in ft. above or below original grade, temperatures in °F.)

Elevation	A String	B String	C String	D String	E String	F String
6	3.7	7				
4	####	34.5				
2	36	####	22			
0	####	####	30.2			
-2	32.5	29.9	27.6	####	31.6	31.5
-4	####	32.5	28.7	####	31.6	31
-8	####	30.3	30.2	####	30.5	30.9
-12	####	32	30.9	####	30.8	30.6
-16	####	31	30.2	####	30.4	30.7
-20	####	####	####	####	30.9	30.6

PART B: Loftus Road/Thompson Drive final instrumentation report.

6.0 INSTRUMENTATION INSTALLATION

Figure 49 shows an overview of the project area with the existing Geist Road on the left and the existing Tanana Loop and Tanana Drive on the right side of the figure. The Loftus Road extension (Thompson Drive) begins at Geist Road and crosses through a previously wooded area to the north. The embankment has a relatively small height near Geist Road and gradually increases in height as it heads north toward the railroad tracks. The embankment height reaches approximately 10 m at the location of the railroad tracks in order to join the overpass. Thus the project encompasses embankments with heights ranging from less than a meter to approximately 10 m.

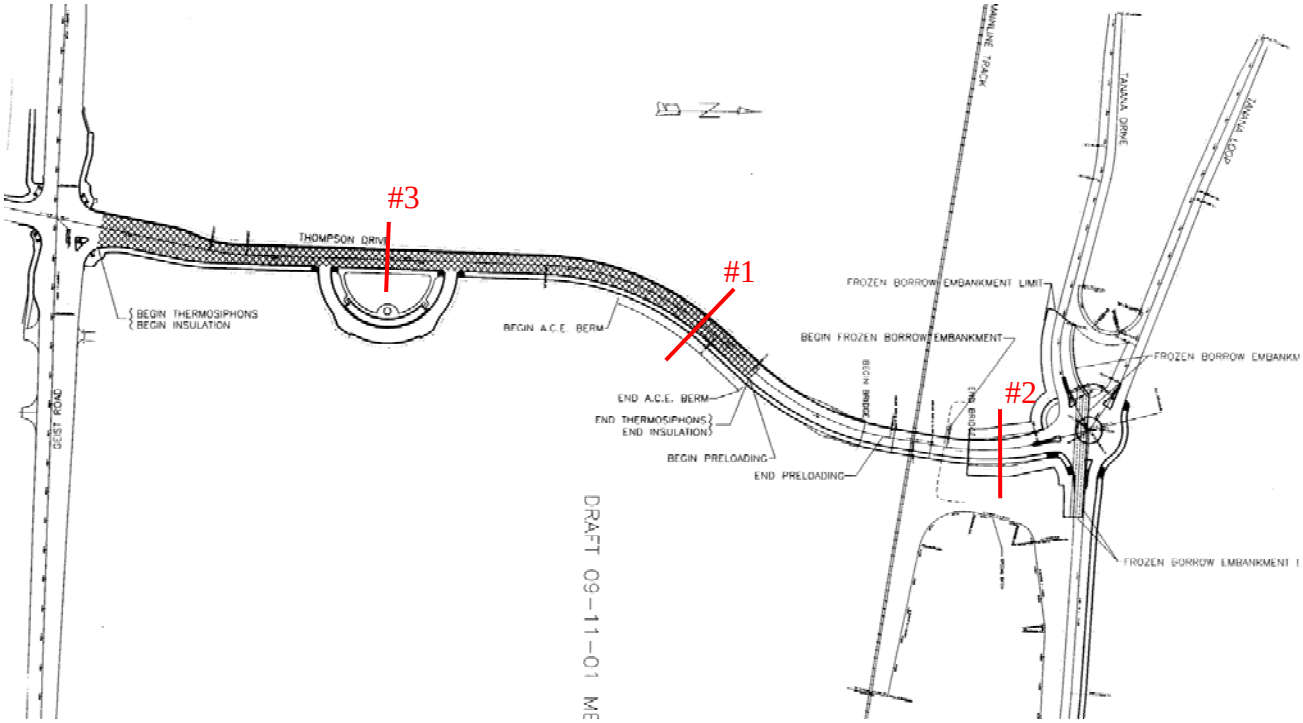


Figure 49. Lofus Road/Thompson Drive test section locations.

Due to the varying embankment height in different areas of the project, three types of passive cooling systems were proposed. See Goering (2001(b)) for a complete discussion and analysis of the proposed cooling systems. The first of the three consisted of an insulated roadway with an ACE side slope on the eastern side of the embankment and

hairpin thermosyphons beneath the roadway. This system was utilized in the wooded area just south of the railroad tracks. The location corresponds to the area near test section #1 shown in Fig. 49. In this area, the embankment height is approximately 4 m. The second system consists of an ACE core combined with ACE side slopes and is being utilized in the area north of the tracks (near test section #2 shown in Fig. 49) where the embankment height is about 10 m. Finally, the third system consisted of hairpin thermosyphons alone. This system was used near Geist Road (near test section #3 shown in Fig. 49) where the embankment height is very small. In this case, thermosyphons were utilized because the limited embankment height did not provide enough 'chimney' for an ACE configuration to operate properly.

In order to acquire accurate information regarding the thermal performance of the three test section configurations, it was proposed that each cross section be instrumented with temperature sensors connected to data logging equipment. The original instrumentation plan can be reviewed in Goering (2001(b)). The recommendations given there were incorporated into the design specifications, AKDOT (2002). Many of the detailed specifications for the instrumentation systems were very similar to those used for the ACE test section installed in the Parks Interchange Project, See AKDOT (1996) for additional details. In particular, it was recommended that the temperature sensors consist of encapsulated/armored thermistors with a resistance of 16K Ohms at 0°C. For the thermistor strings that are located in ACE material, the thermistor cables were shielded in schedule 80 PVC electrical conduit for protection against the ACE rock. Thermistor points were originally to be brought outside the PVC conduit and armored using aluminum rings (See AKDOT (2002) for details). After consultation with the instrumentation sub-contractor, an alteration to the original plan was allowed and instead of using aluminum rings, the thermistor cable was completely enclosed in the PVC conduit and sealed. Then vent holes were drilled in the PVC to allow communication with the pore air in the ACE rock. Finally, the PVC conduit was filled with silicone rubber blockages between the vented thermistors to avoid air transmission directly through the PVC shielding conduit. Figure 50 shows one of the finished thermistor

cables lying next to a prepared PVC shield pipe. During installation, the cables were laid out in position and then the conduit was drilled as shown in the figure. After drilling, the cable was pulled into the proper position within the shielding tube and silicone was injected at the intermediate points to hold the cable in place and block air motion. For the thermistor strings run vertically into the foundation soil, unshielded cables were used inside a sealed PVC casing with the annulus filled with silicon oil. When run along the thermosyphon evaporator and condenser pipes, the cables were fastened directly to the pipes and held in place with PVC pipe segments as shown in Figure 51.

Data acquisition equipment consists of Campbell CR10XT data loggers connected to AM416 multiplexers. Because of the distance separating the three test sections, three separate data logging stations were utilized. Each station will be connected to AC power with 12 VDC backup, and contains one CR10XT data logger, and the appropriate number of multiplexers (see paragraphs below for details). AC power was unavailable for the first year of the project, so deep cycle 12 VDC batteries are being used. Each of the three data acquisition stations are housed in permanent traffic controller electrical boxes. The following paragraphs give a brief description of the instrumentation strings included at each test section.

The thermistor sensor layout for test section #1 is shown in Fig. 54. A total of nine separate thermistor strings (strings A1-I1) are included in the diagram. Strings D1 and E1 are located within the ACE side slope layer and, thus, are shielded using vented PVC conduit. Strings H1 and I1 are fastened directly to the evaporator and condenser pipes of the thermosyphon. The remaining strings are of conventional construction and are installed vertically in sealed PVC wells with silicone oil. All instrumentation strings are run to the side of the embankment for connection to the data logging system. For this cross section, the nine thermistor strings contain a total of 62 thermistor sensors. Since each AM416 multiplexer is capable of switching up to 32 sensor lines, two multiplexers were installed at this test section. The table below lists the characteristics of each individual string.

Table 37. Thermistor String Characteristics for Test Section #1

String	Number of Sensors	Sensor Spacing	Construction
A1	8	2 m	Conventional
B1	8	2 m	Conventional
C1	8	2 m	Conventional
D1	6	2 m	Conventional
E1	6	2 m	Conventional
F1	5	2 m	Shielded
G1	5	2 m	Shielded
H1	4	3 m	Fasten to TS pipe
I1	4	3 m	Fasten to TS pipe

The suggested thermistor sensor layout for test section #2 is shown in Fig. 55. A total of nine separate thermistor strings (strings A2-I2) are included in the diagram. Strings E2, F2, G2, H2, and I2 are located within the ACE layers and, thus, are shielded using vented PVC conduit. The remaining strings are of conventional construction and are installed vertically in sealed PVC wells with silicone oil. All instrumentation strings are run to the side of the embankment for connection to the data logging system. For this cross section, the nine thermistor strings contain a total of 95 thermistor sensors requiring a total of 3 AM416 multiplexers. The table below lists the characteristics of each individual string.

Table 38. Thermistor String Characteristics for Test Section #2

String	Number of Sensors	Sensor Spacing	Construction
A2	8	2 m	Conventional
B2	8	2 m	Conventional
C2	7	2 m	Conventional
D2	4	2 m	Conventional
E2	15	1 m	Shielded
F2	16	1 m	Shielded
G2	17	1 m	Shielded
H2	12	2 m	Shielded
I2	8	2 m	Shielded

The thermistor sensor layout for test section #3 is shown in Fig. 56. A total of five separate thermistor strings (strings A3-E3) are included in the diagram. For this test section there is no ACE material so none of the strings require shielding. Strings D3 and E3 are fastened directly to the evaporator and condenser pipes of the thermosyphon. The remaining strings are of conventional construction and are installed vertically in sealed PVC wells with silicone oil. All instrumentation strings are run to the side of the embankment for connection to the data logging system. For this cross section, the five thermistor strings contain a total of 31 thermistor sensors. However, during the formulation of the design plans, AKDOT personnel decided to add thermistor strings adjacent to section #3 in the turnout area of the project, thus increasing the number of required AM416 multiplexers to two. The table below lists the characteristics of each individual thermistor string that was used beneath the roadway test section; see AKDOT (2002) for additional information regarding the thermistor strings beneath the turnout area.

In addition to thermistor sensors, it was also decided to add heat flux sensors to the thermosyphon evaporator and condenser pipes in section #3. Six Omega HFS-4 heat flux sensors were glued directly to the evaporator and condenser pipes at the positions shown by the blue dots in Fig. 56. These sensors produce a nominal output voltage of 2 $\mu V/(W/m^2)$. The addition of these sensors required six additional data channels which were available already available on the second AM416 included in section #3. Figure 52 shows a photograph of one of the heat flux sensors being attached to the evaporator tube using quick set epoxy. After attachment of the heat flux sensors, an additional layer of an epoxy/carbon powder mix was placed over the top of the sensors to shield them from impact. Also, a thick layer of silicone rubber was placed over the lead wires to help avoid damage due to compaction around the thermosyphons (see Fig. 53). The carbon powder was added in an attempt to better match the thermal conductivity of the epoxy sensor coating with that of the surrounding bedding material. In addition, the heat flux sensors were fastened to the side of the thermosyphon tubes (as opposed to the top or the bottom) in an effort to average out any peripheral heat flux variation.

Table 39. Thermistor String Characteristics for Test Section #3

String	Number of Sensors	Sensor Spacing	Construction
A3	7	2 m	Conventional
B3	7	2 m	Conventional
C3	7	2 m	Conventional
D3	5	3 m	Fasten to TS pipe
E3	5	3 m	Fasten to TS pipe

Figure 50. Thermistor sensor wire and vented PVC armoring tube as used in ACE areas.

Figure 51. Thermistor sensor and cover placed along thermosyphon tube.

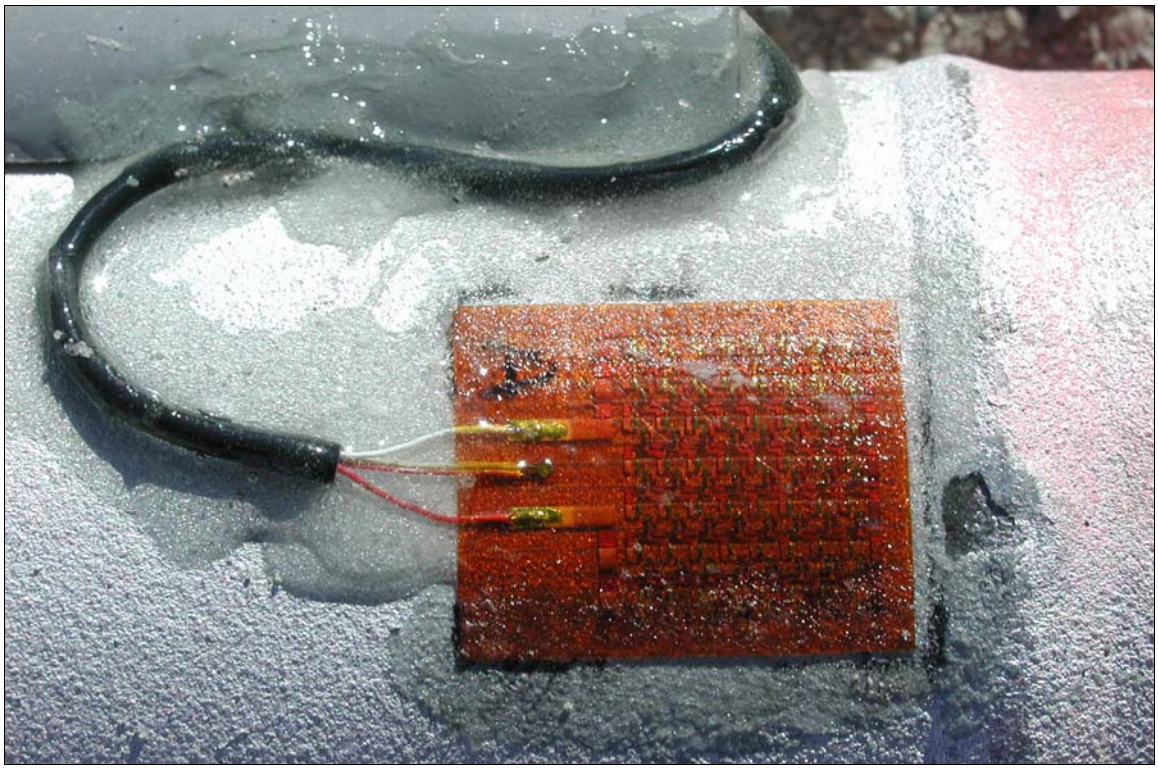


Figure 52. Installation of heat flux sensor on condenser tube.

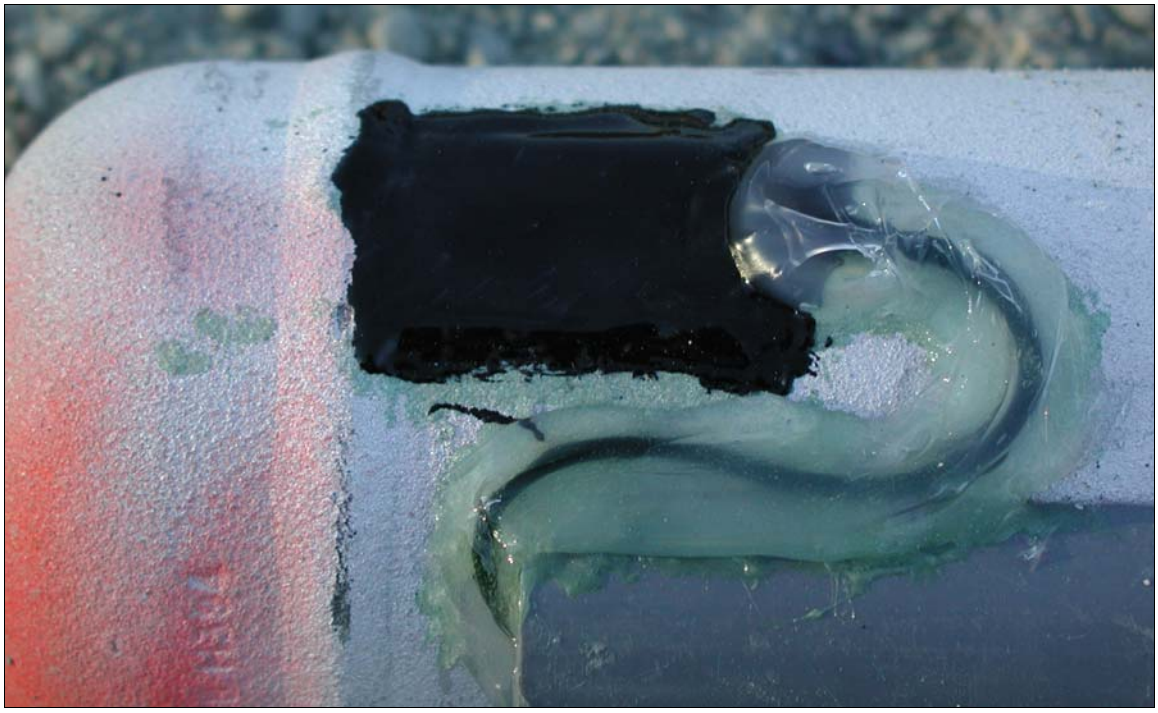
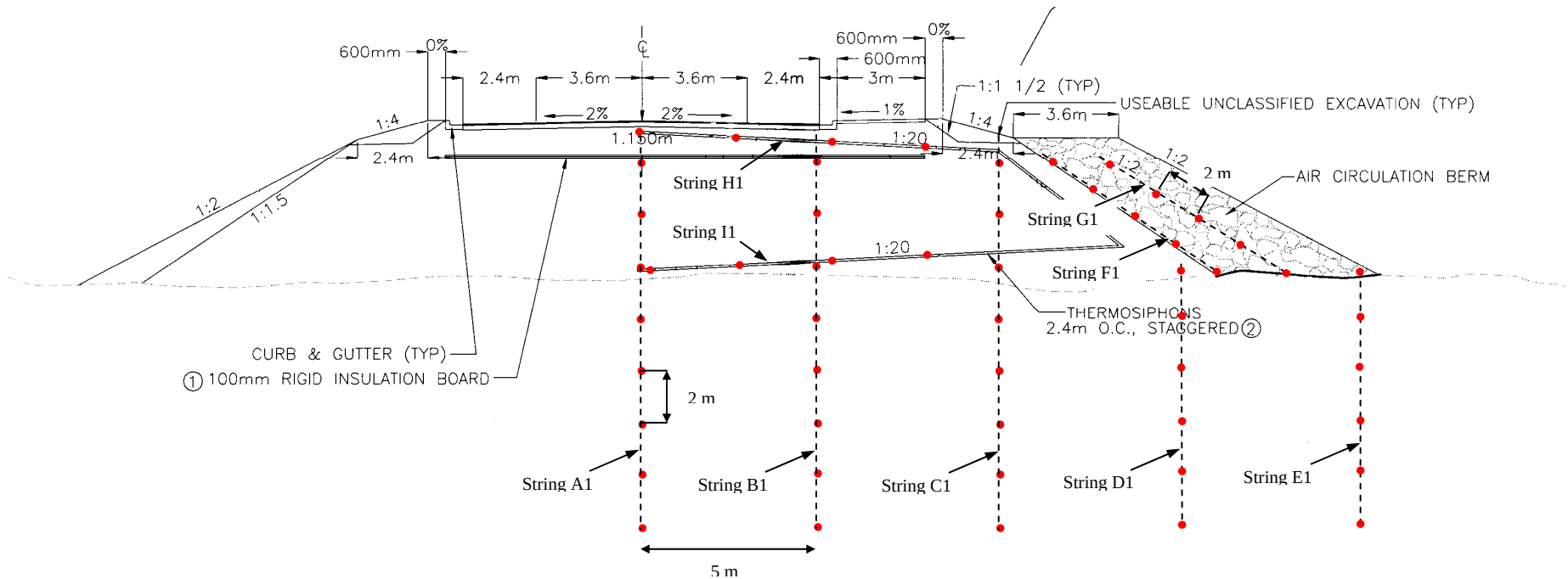


Figure 53. Carbon Powder/Epoxy coating and Silicone rubber protecting heat flux sensor.



Note: Strings H1 and I1 consist of 4 sensors each on 3 m centers, fastened directly to the condenser and evaporator pipes.

Figure 54. Instrumentation for test section #1 consisting of 9 thermistor strings with a total of 62 thermistor temperature sensors.

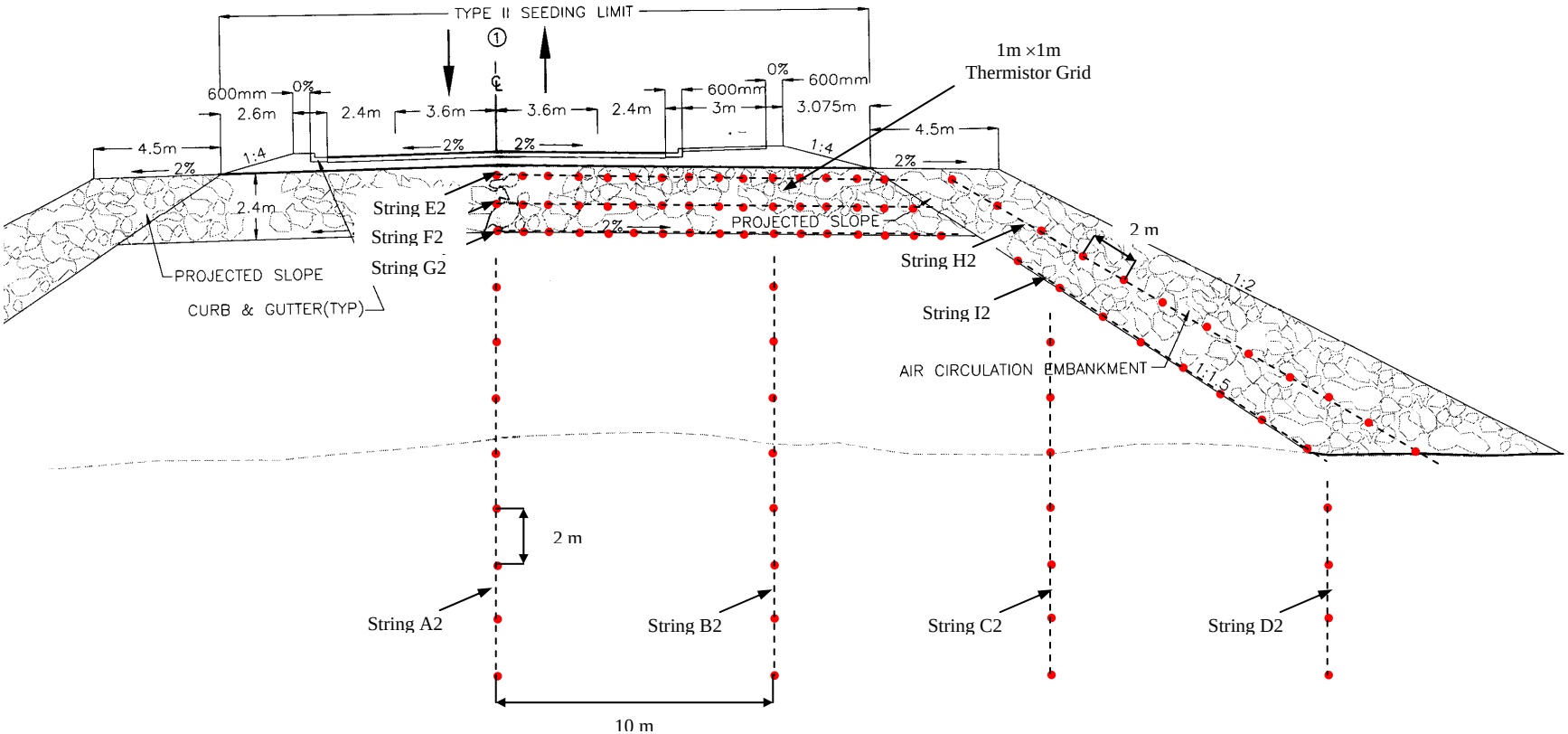
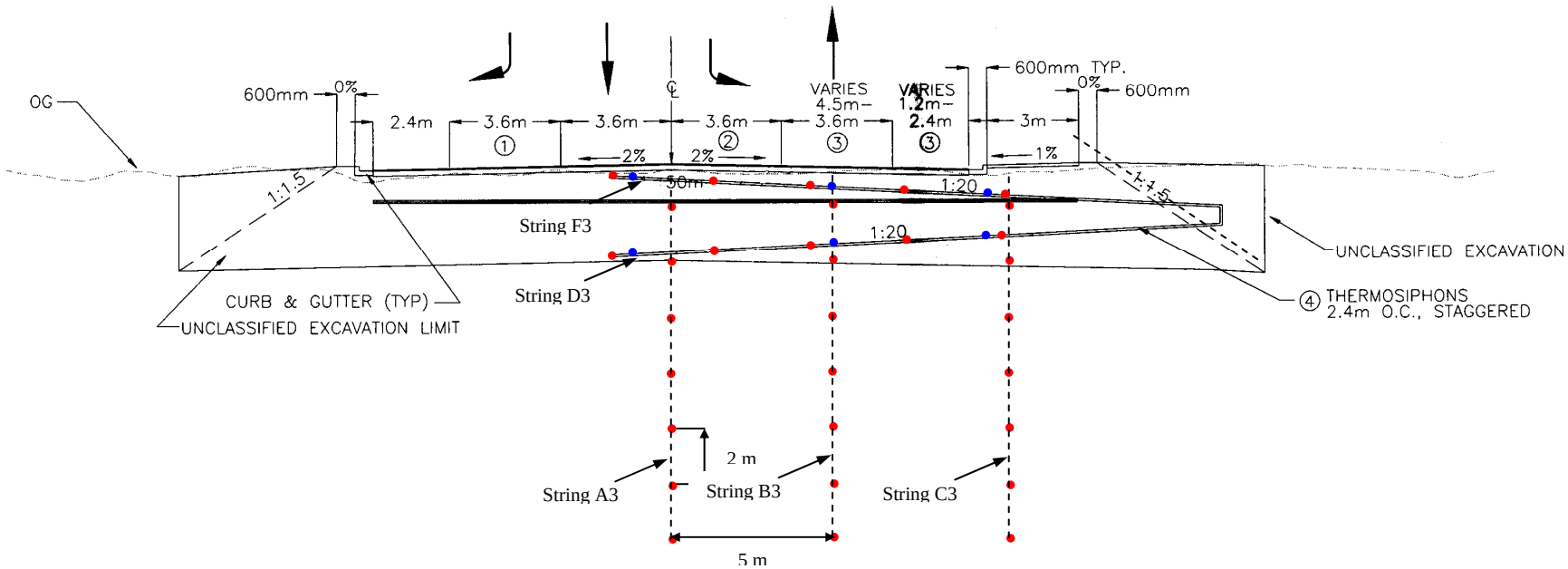


Figure 55. Instrumentation for test section #2 consisting of 9 thermistor strings with a total of 95 thermistor temperature sensors.



Note: Strings D3 and F3 consist of 5 sensors each on 3 m centers, fastened directly to the condenser and evaporator pipes.

Figure 56. Instrumentation for test section #3 consisting of 5 thermistor strings with a total of 31 thermistor temperature sensors.

7.0 CONCLUSIONS

7.1 Part A

The data collected from the Parks/Chena Ridge ACE test embankment between December 1996 and December 2003 indicates that convective cooling is taking place within the test embankment during winter months. During the first winter of operation, the lack of an asphalt covering allowed convection to occur from the toe toward the embankment centerline and then exit out the upper surface of the embankment. During the second and subsequent winters, internal convection occurred beneath the asphalt in a circular fashion, producing upward and downward plumes in the temperature contours. Mean annual temperatures were calculated for the ACE test section and used to generate contour plots for the 2001 and 2002 calendar years. Data problems prevented the calculation of accurate mean annual temperatures for 2003. The plots indicate that mean annual temperatures ranged from 32 to 36°F in the upper portion of the embankment cross-section, and 27 to 30°F in the lower portion.

After 7 years of operation, temperatures beneath the ACE test section are generally colder than those beneath the control section, and Fig. 48 tends to indicate a sustained trend of temperature reductions at the base of the ACE test section. The control section is colder at the embankment centerline and warmer in the side slope region. Data shows that the insulation layer included in the control section is effective at limiting the annual temperature extremes experienced by the foundation soil beneath the embankment centerline. In the side slope region, however, data shows that significant annual thaw is occurring into the native foundation soils beneath the control section.

Maintenance operations included replacement of thermistor strings E and F during July of 1999. The original strings had become completely non-functional due to infiltrating water. We are still hoping to make additional instrumentation changes which may help improve data quality in the future. These changes will include addition of another multiplexer and re-wiring of the instrumentation system to allow for double-ended measurement of all thermistor sensors.

Figure 57 shows a view of the ACE test section which was taken on August 4, 1999. The figure shows that the test section has remained level throughout the center portion and shows signs of settlement only at each end. Most of the settlement occurred within a year after construction, and much of the settled portion was located beyond each end of the test section in the conventional embankment. As noted in Goering (1998), problems during construction resulted in the inclusion of a large amount of fines at both ends of the ACE test section. These fines have likely resulted in blockage of the convection and a reduction in the cooling effectiveness. They may have also led to problems with proper compaction. Careful examination of the picture shown in Figure 57 reveals some distortion of the embankment near the end of the test section. Also apparent is significant settlement and distortion beyond the end of the test section in the conventional embankment. This is demonstrated in the figure by undulation of the white paint line at the asphalt edge. The conventional embankment is beginning to have problems with shoulder rotation in the area of the bend at the far end of the picture shown in Figure 57, although the ACE test section has shown no indication of settlement at either shoulder.

Figure 58 is a similar view of the ACE test section which was taken in late August of 2001. Patching operations were carried out by DOT during the summer of 2001 in order to level the settlement which had occurred at each end of the test section as described

above. As shown in the figure, a significant amount of patching material was applied to each end of the test section although the embankment appears to be maintaining its original grade in the center of the test section. The patch zones extend well beyond the end of the test section and into the conventional embankment on either end.

Figures 59 and 60 were taken during July of 2002 after further patching operations were carried out by DOT maintenance. Figure 59 shows that extensive patching has been required in the curved section on the far side of the ACE test section. Much of this area is experiencing severe shoulder rotation problems. Figure 60 is a view from the other end of the curved zone, looking back to the west with the ACE test section in the background. This figure clearly illustrates the large patch that was required to repair shoulder rotation problems. The curved zone is settling rapidly with shoulder rotation, even though 10 cm of insulation was included in the embankment in this zone. Looking back at Fig. 59, it is apparent that the center of the ACE test section has not experienced any settlement (the original markings are still visible in this area), nor does it show any signs of shoulder rotation.

7.2 Part B

The three data logging stations began operation in late September of 2004 when they were connected to 12 VDC deep cycle batteries. The loggers had been pre-programmed and began taking data automatically once the power connection was made. Initial checkout of the loggers took place in late October when each of the sites was visited by James Dryden (the instrumentation sub-contractor) and UAF researchers. Upon inspection we found that the data logger connected to test section #2 was defective and not operating. At that time we swapped the defective data logger with one that UAF had available and at that point all three stations were logging data correctly. Initial data was

collected and examined to ensure that reasonable values were being obtained from all sensors. A single sensor in test section #2 was found to be defective, but all others (including the heat flux sensors) were found to be operating properly. The defective data logger was returned to Campbell Scientific and repaired. In December 2004 this data logger was placed back into service at test section #2 and the UAF logger was returned.

As of the date of this report, data has been collected twice from the three test sections, once during initial field checks in October 2004 and a second time in December 2004. Although no formal data analysis has been carried out to date, the data has been examined to ensure that reasonable values are being obtained from all sensors. With the exception of a single thermistor point in test section #2, all sensors appear to be indicating reasonable temperature values.

Figure 57. ACE test section on, August 1999.

Figure 58. ACE test section, September 2001.

Figure 59. ACE test section, July 2002.

Figure 60. Curve to the east of the ACE test section, July 2002. ACE test section can be seen in the background.

8.0 REFERENCES

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