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Parks/Chena Ridge Air Convection Embankment Performance Report October 1998 to September 1999

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Parks/Chena Ridge Air Convection Embankment Performance Report October 1998 to September 1999

by
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13. ABSTRACT (Maximum 200 words)

This report describes the thermal performance of an experimental Air Convection Embankment (ACE) that 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 October 1998 through September 1999. Additional reports by the same author (cited in this report) describe the design and construction of the ACE experimental feature, and data analyses that cover the period from November, 1996 through September, 1998.

ACE is composed of coarse, open-graded fill material that promotes circulation of air throughout the embankment mass during winter, thus cooling and preserving underlying permafrost foundation soils. Natural wintertime temperature gradients are established within the extremely porous ACE, and produce unstable conditions throughout the enclosed air mass. These instabilities initiate and sustain convective air cells that remove heat from underlying foundation soils, and eject heat at the cold embankment surface. The summertime temperature gradient within the embankment produces stable conditions, so air circulation ceases within the embankment. The overall effect is that the entire embankment becomes a passive, 1-way heat valve, i.e., a refrigeration system that helps protect ice-rich foundation materials from thaw and loss of strength.

Results to date indicate that the system is performing successfully.

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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 (AKDOT&PF). The contents of the report do not necessarily reflect the views or policies of AKDOT&PF or any local sponsor. This work does not constitute a standard, specification, or regulation.

ABSTRACT

This report details the thermal performance of the 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 October 1998 through September 1999. See Goering (1997) for details regarding the design and construction of the ACE experimental feature and Goering (1998) for data analysis which extends from November, 1996 through September, 1998.

ACKNOWLEDGMENT

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." Additional support has been provided by the Alaska Science and Technology Foundation under grant #92-2-1110, "Enhanced Convection for Roadway Stabilization."

1.0 BACKGROUND

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 (AKDOT&PF) and the Alaska Science and Technology Foundation (ASTF). Results from the initial AKDOT&PF study have been summarized in Goering and Kumar (1996) and 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 present 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 September, 2000. The Phase 1 final report (Goering, 1997), detailed the design and construction process. In addition, the first 23 months of monitoring (November, 1996 – September, 1998) were discussed in Goering, 1998. 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 October, 1998 – September, 1999 time period and associated remedial operations at the ACE test site.

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 8 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.

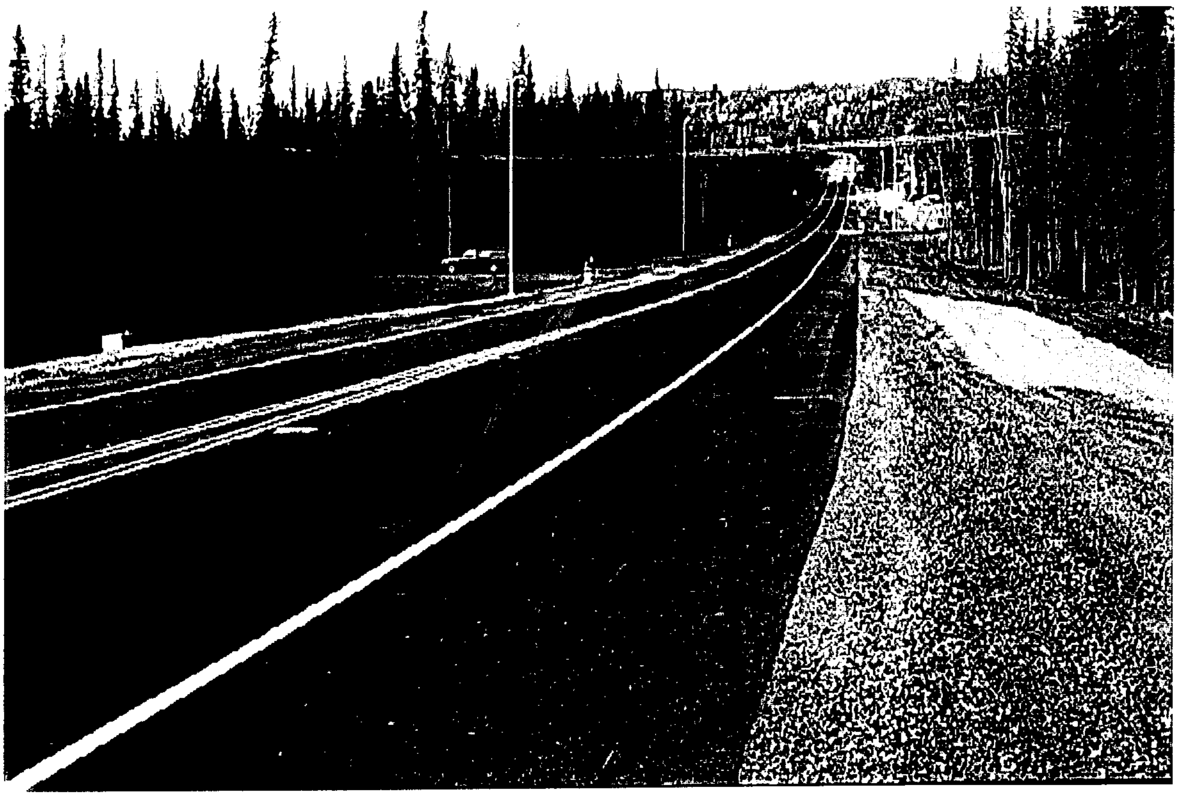


Figure 1. Finished ACE test section with control section in the background.

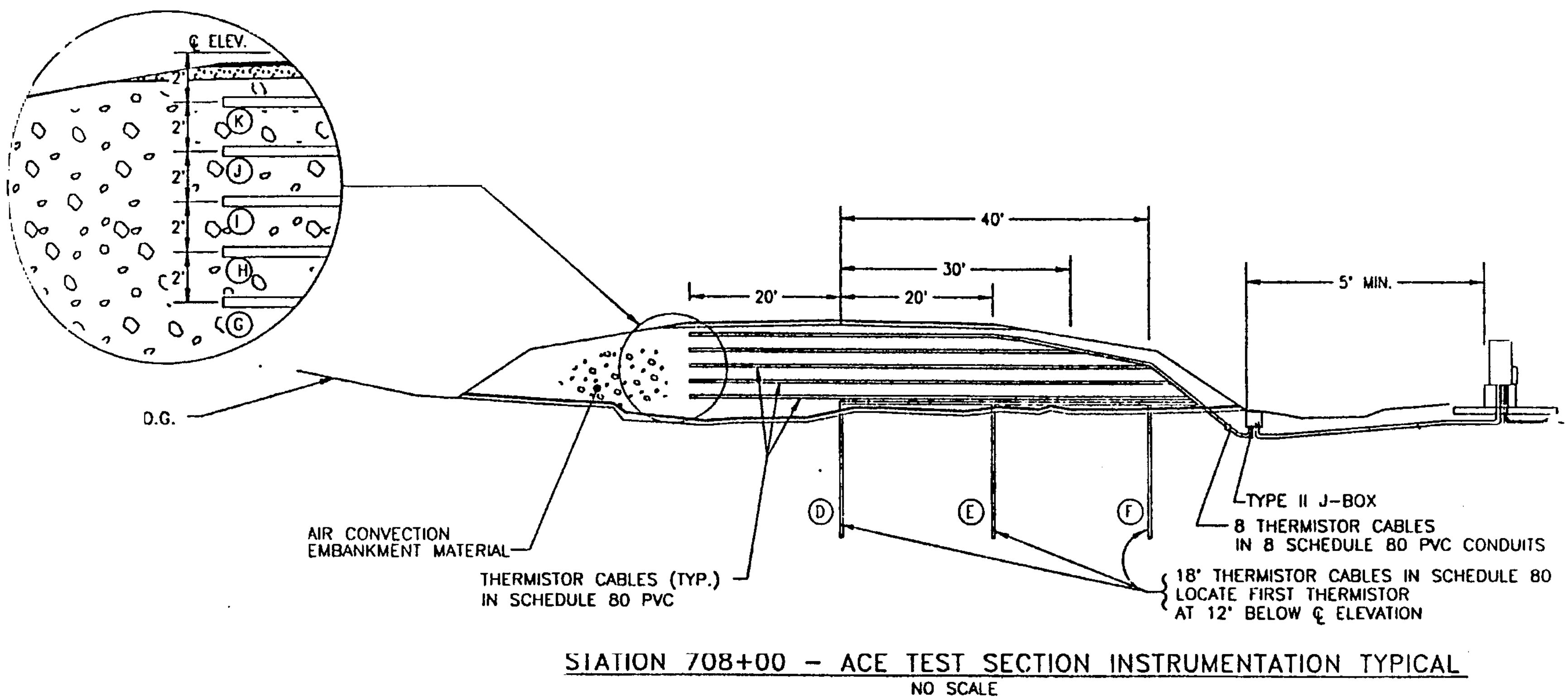


Figure 2. ACE test section configuration.

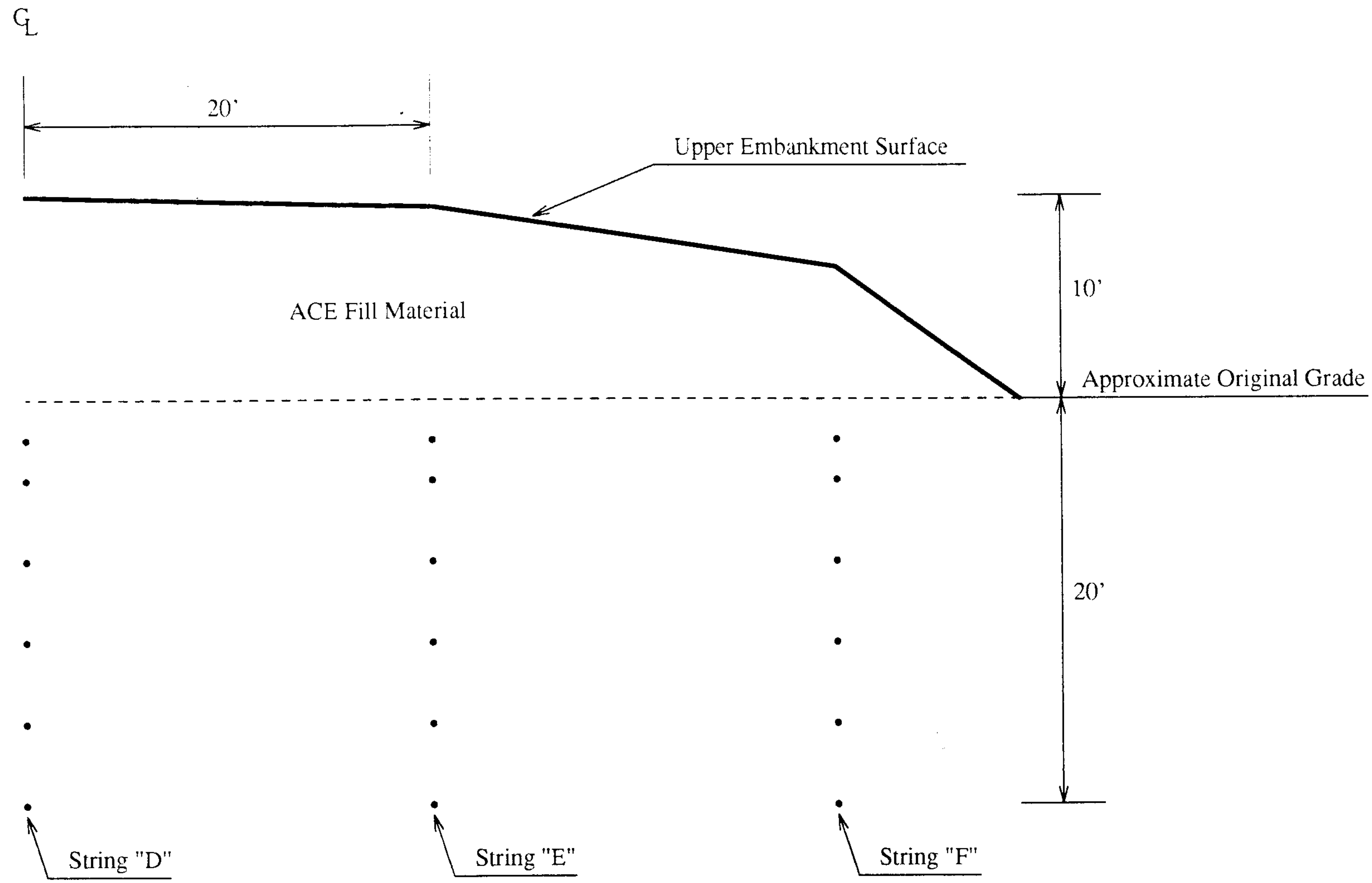


Figure 3. Thermistor positions for strings D, E, and F, located below the ACE test section.

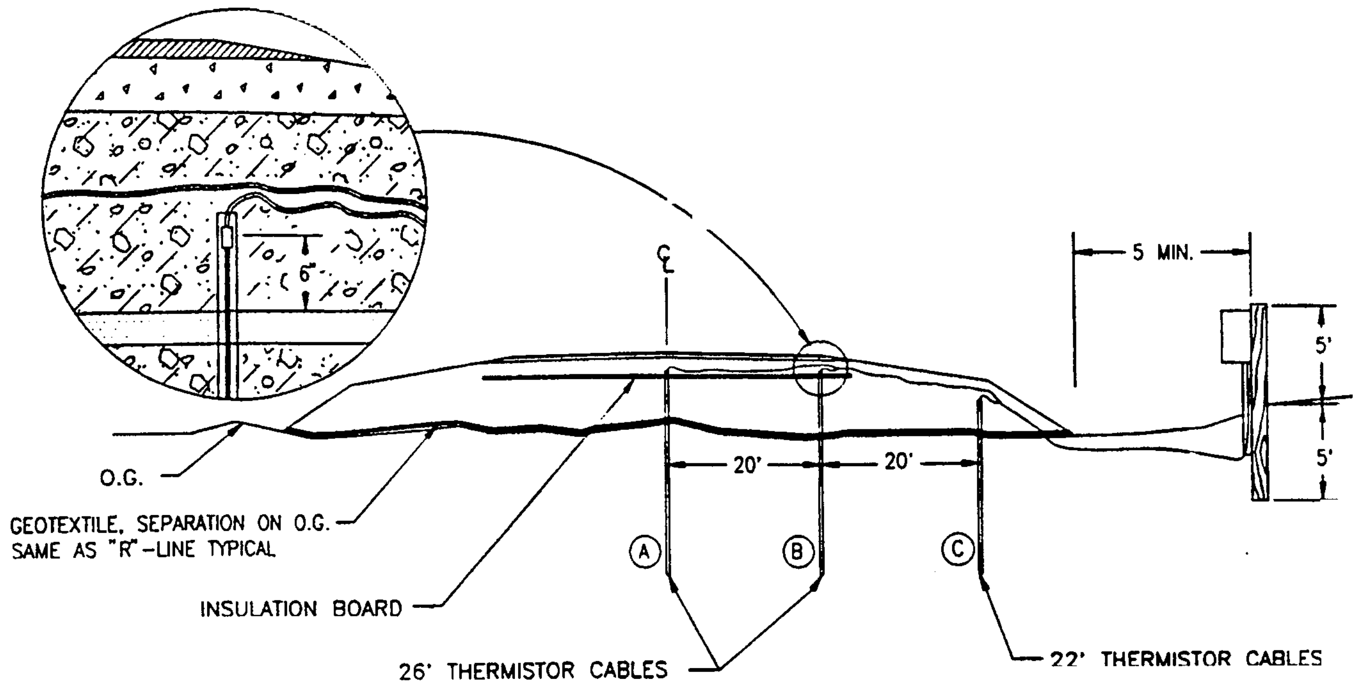


Figure 4. Control section configuration.

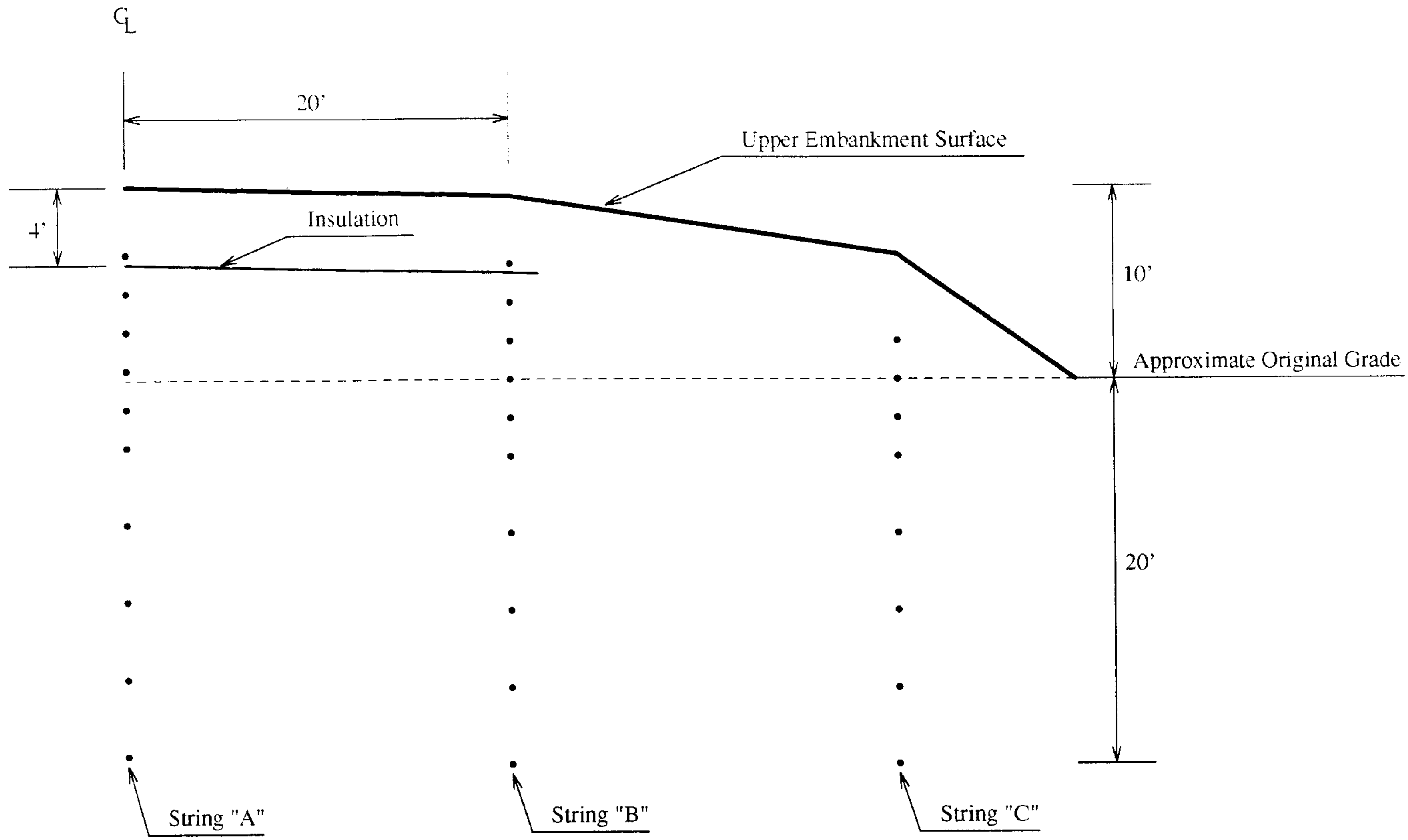


Figure 5. Thermistor positions for strings A, B, and C, located within and beneath the control section.

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.

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.

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 and unusable data. Unfortunately, the most trouble-prone strings are D, E, and F, which are located beneath the ACE test section. As of May, 1999, most of the 18 sensors located in these three strings were producing unusable data. Since these strings are oriented vertically beneath the ACE test section, it is likely that water ran down the instrumentation casings and inundated several of the sensors. It is also probable that this water would have frozen and may have caused damage due to the expansion during freezing.

Because of the problems with strings D, E, and F, noted above, 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 in 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 back filling 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 Figure 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 Figure 8 reveals a number of thin ice lenses. The amount of clear water present above the saturated silt shown in Figure 9, illustrates that this sample originally contained about 50% excess water (ice).

Data acquisition has been ongoing 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.

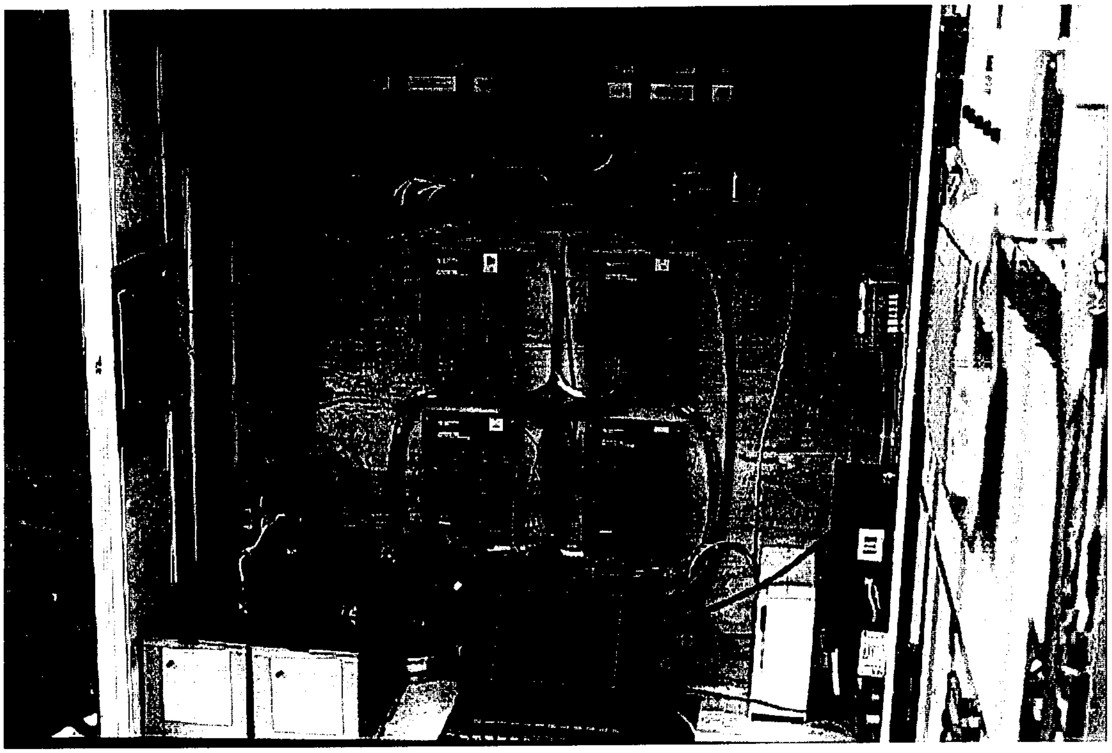


Figure 6. Campbell data acquisition system installed in highway traffic controller cabinet.

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

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

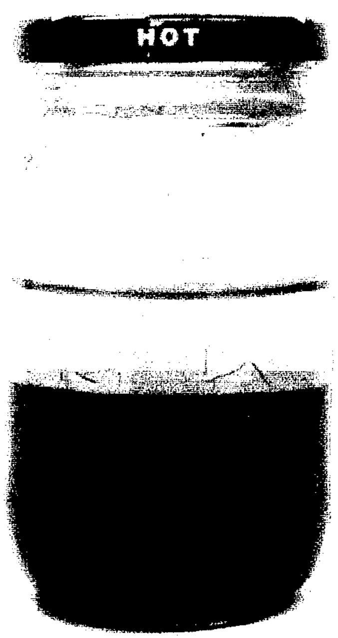


Figure 9. Core sample after thawing, indicating approximately 50% excess water content.

4.0 ACE CROSS SECTION THERMAL PROFILES

As mentioned above, 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. This data is then processed using Equation (1) and plotted using a contouring package. Figures 10-21 show the instantaneous temperature contours that were obtained at noon on the 15th of each month, starting in October of 1998 and ending in September of 1999. 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 the winter of 1998-99 in a state of fairly uniform temperature (ranging from 32-34°F at the base to about 28°F just beneath the asphalt). By November 15, there is already strong evidence of convective activity within the embankment and a series of rising and falling plumes are evident in Figure 11. Note that the entire ACE cross-section is already substantially below the freezing temperature. These convective plumes are similar to those which have been seen in previous years (Goering, 1998) and in modeling studies (Goering, 1997). They are the result of the unstable pore-air density stratification which exists in the winter time and causes internal circulation cells to develop within the ACE cross section.

As the winter progressed, convective activity continued. Figure 12 shows large temperature variations throughout the ACE cross section associated with the presence of the convective circulation cells. Temperatures ranging from about 16°F to 24°F are present at the embankment base. Temperatures at the base of the embankment continued to drop during January and February. Figure 14 indicates base temperatures ranging from –4 to about +10°F on February 15.

Starting in March, base temperatures begin to increase slightly and there is no longer strong evidence of organized convective activity within the embankment. In fact, Figure 15 shows that the temperature profiles have begun to moderate and reach a more uniform state as of March 15. By April 15 (Figure 16), the upper portions of the embankment have begun to warm to near the melting point, although the lower portions of the embankment remain at temperatures well below freezing.

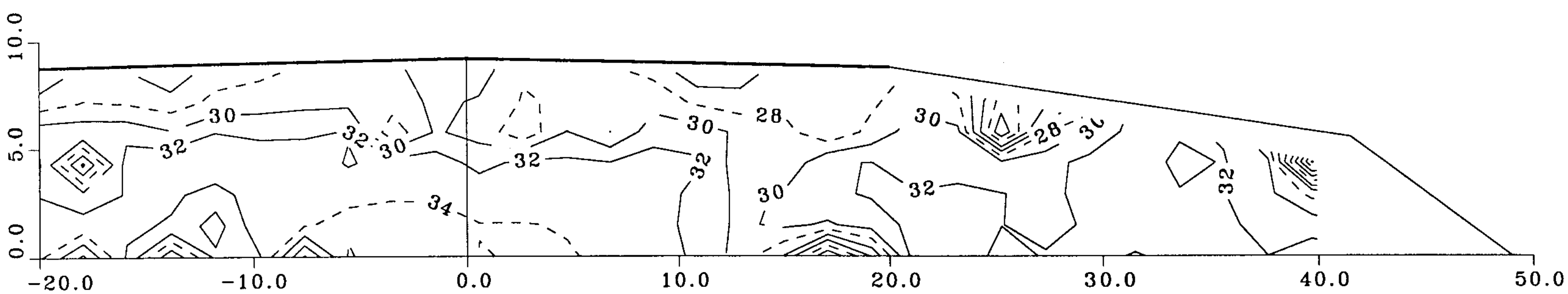
Figures 17 and 18 show that the upper portion of the embankment thaws during May and June. It should be noted, however, that data collection problems during June have resulted in a somewhat misleading contour plot. As mentioned previously, one of the multiplexer lines began having intermittent connection problems in early June. This resulted in problems with data collection from String G (see Figure 2), which is located at the base of the embankment. As a result, contour lines shown in Figure 18 for locations near the base of the embankment cannot be relied upon, and it is unlikely that the temperatures were as high as indicated there. In fact, Figure 19, which shows data for July 15, is much more reliable and indicates a series of tightly spaced isotherms with an actual base temperature ranging from about 30 – 36°F. This is consistent with observations made during the drilling operations described in Section 3, where we found that the foundation soils were frozen from the base of the ACE rock layer downward.

During August and September the embankment warms further, although, as shown in Figure 21, temperatures are only slightly above freezing at the embankment base on September 15 (ranging from about 32 – 40°F). The temperature profiles shown in

Figures 19 through 21 are generally flat and horizontal in nature, indicating a lack of air mixing or convective activity during the summer. During prior years rapid cooling of the embankment has occurred during October (see, for example, Figure 10) so it is likely that embankment temperatures did not substantially exceed those shown in Figure 21 during the 1999 calendar year.

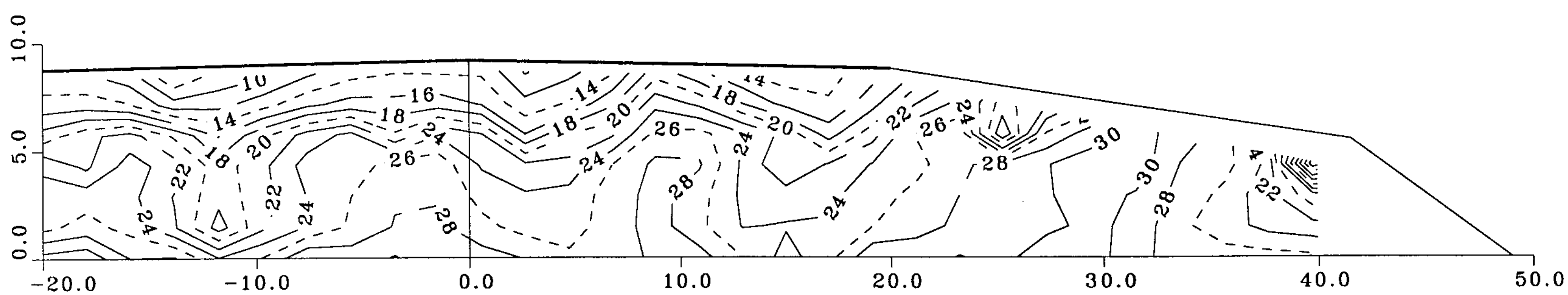
In order to attempt to quantify the cooling effectiveness of the ACE test section, mean annual temperatures were calculated for the period July 15, 1997 through July 15, 1998 and for the period July 15, 1998 through July 15, 1999. Figures 22 and 23 show contour plots of mean annual temperature within the embankment for these periods. Also noted on the figure is the mean ambient air temperature for each time period. Note that the second year of operation was significantly colder than the first year with a mean ambient temperature of 25.1°F compared to 29.0°F. Because of this, mean temperatures at the embankment base were somewhat colder during the July 1998-99 time period than they were a year earlier, with values ranging from approximately 26 to 29°F. Both of these figures clearly show a reduction in mean temperatures at the embankment base compared to those near the upper surfaces. This effect is due to the convective heat transfer which takes place within the embankment during winter months. The fact that mean temperatures are remaining significantly below freezing, indicates that permafrost beneath the embankment should remain thermally stable.

Figure 24 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. 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. Careful examination of the picture shown in Figure 24 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.



Julian Day = 288, Time = 1200, Ambient Air Temperature = 28.3 F.

Figure 10. Temperature contours in the Parks/Chena Ridge ACE embankment on October 15, 1998.



Julian Day = 319, Time = 1200, Ambient Air Temperature = -0.7 F.

Figure 11. Temperature contours in the Parks/Chena Ridge ACE embankment on November 15, 1998.

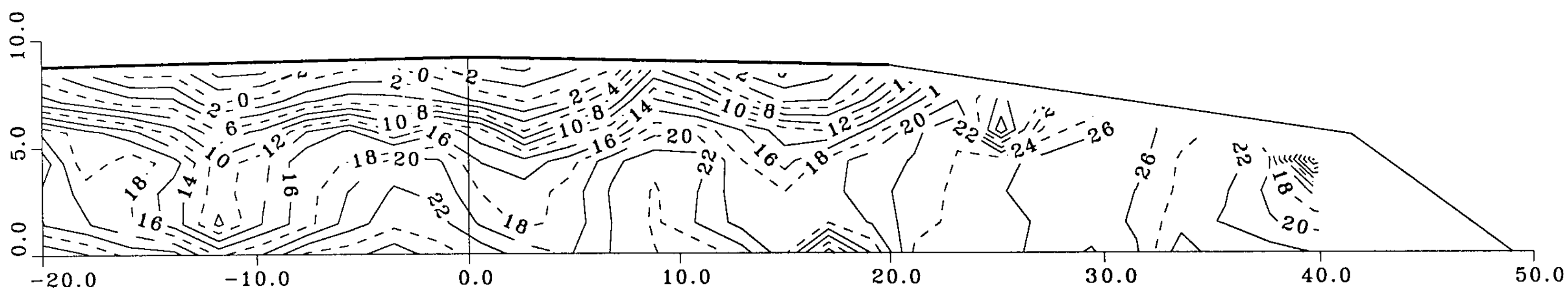


Figure 12. Temperature contours in the Parks/Chena Ridge ACE embankment on December 15, 1998.

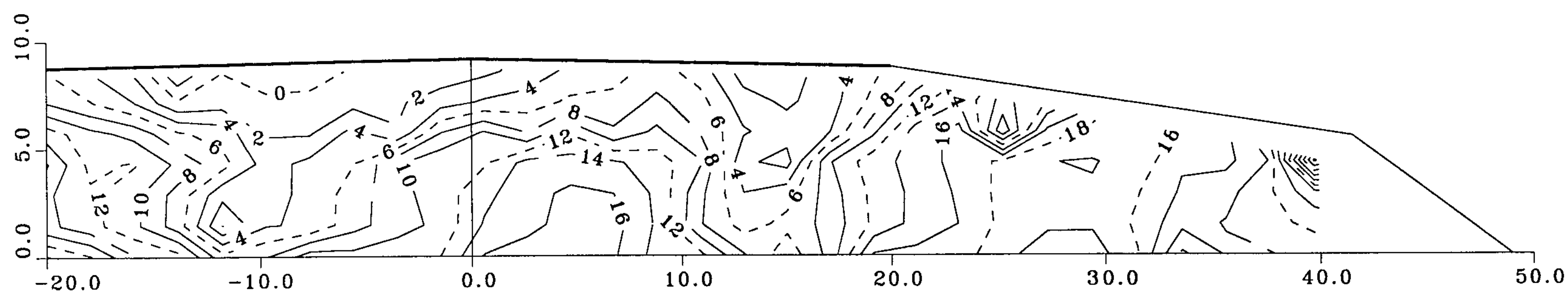


Figure 13. Temperature contours in the Parks/Chena Ridge ACE embankment on January 15, 1999.

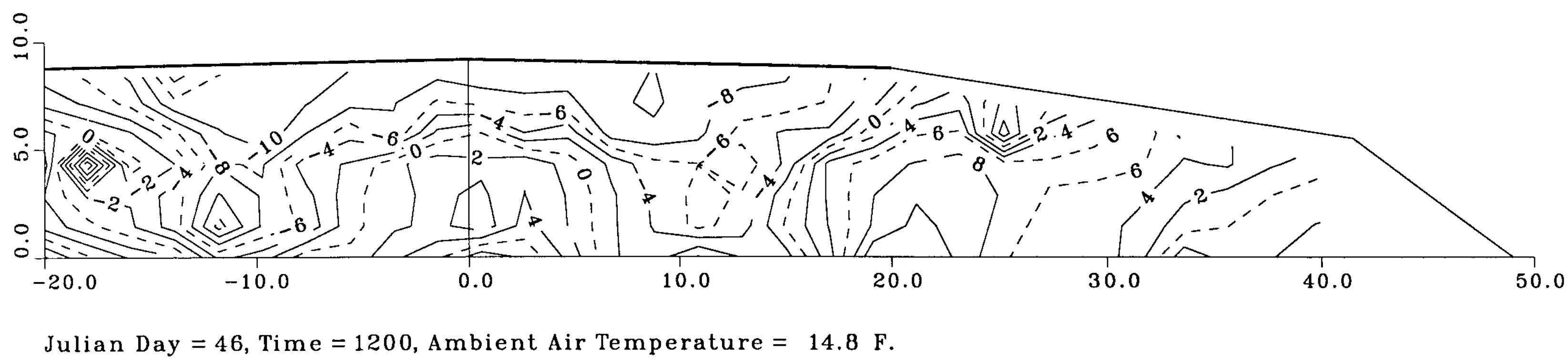


Figure 14. Temperature contours in the Parks/Chena Ridge ACE embankment on February 15, 1999.

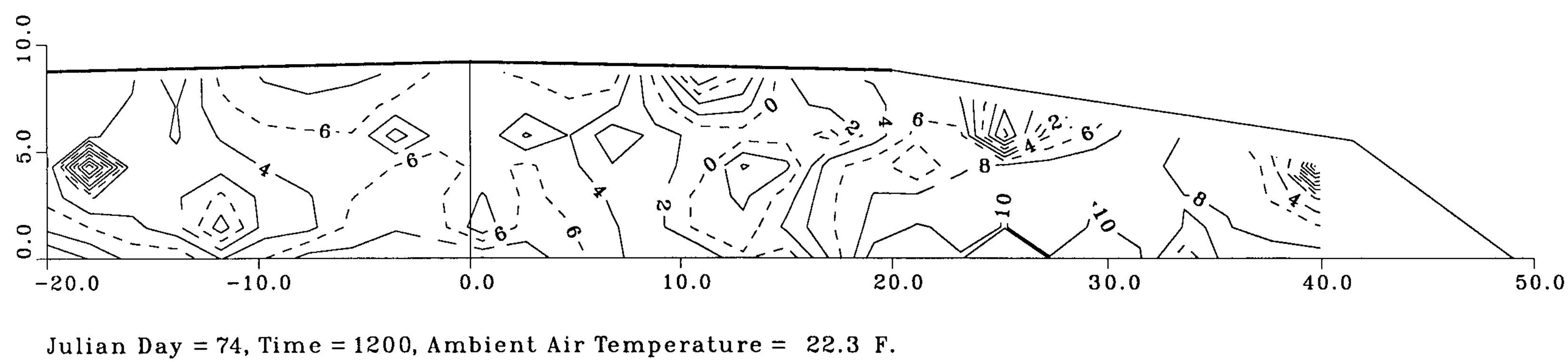
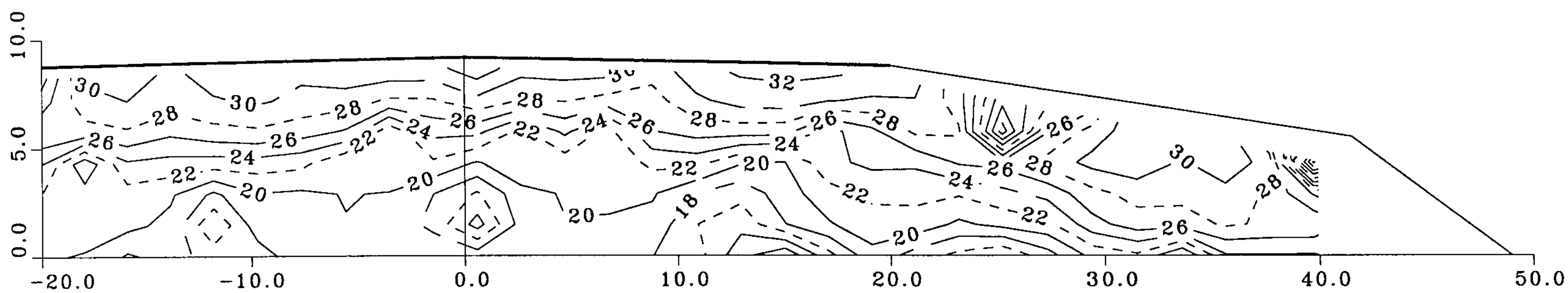
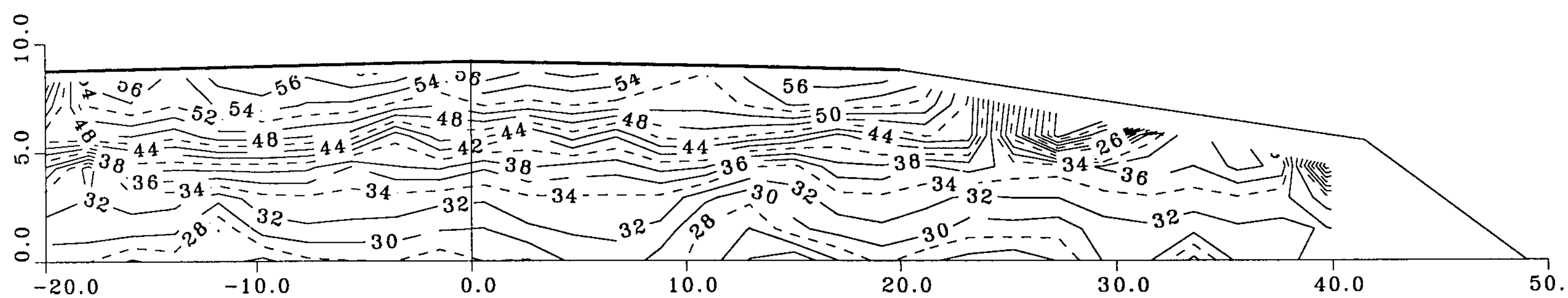


Figure 15. Temperature contours in the Parks/Chena Ridge ACE embankment on March 15, 1999.



Julian Day = 105, Time = 1200, Ambient Air Temperature = 43.3 F.

Figure 16. Temperature contours in the Parks/Chena Ridge ACE embankment on April 15, 1999.



Julian Day = 135, Time = 1200, Ambient Air Temperature = 68.9 F.

Figure 17. Temperature contours in the Parks/Chena Ridge ACE embankment on May 15, 1999.

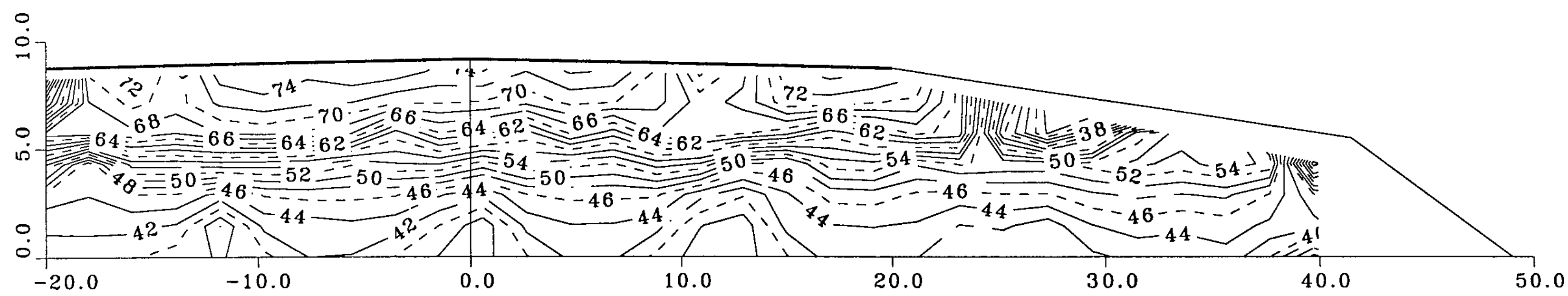


Figure 18. Temperature contours in the Parks/Chena Ridge ACE embankment on June 15, 1999.

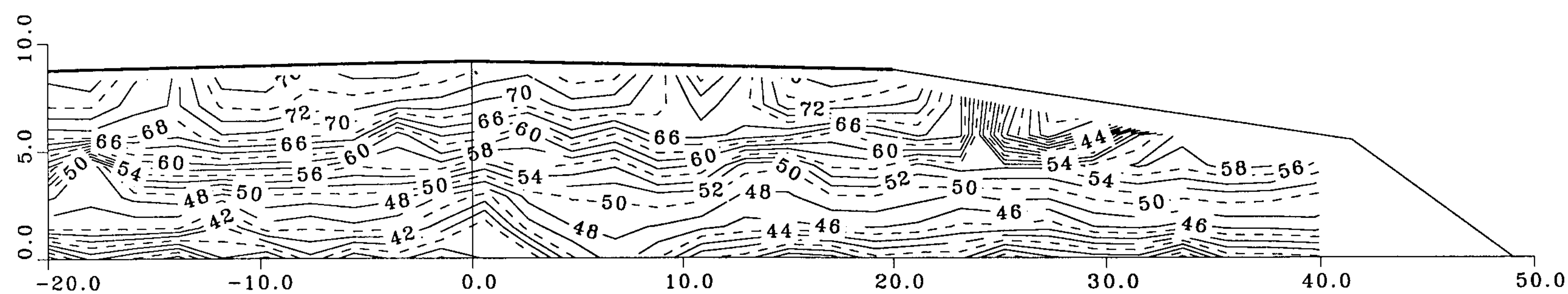


Figure 19. Temperature contours in the Parks/Chena Ridge ACE embankment on July 15, 1999.

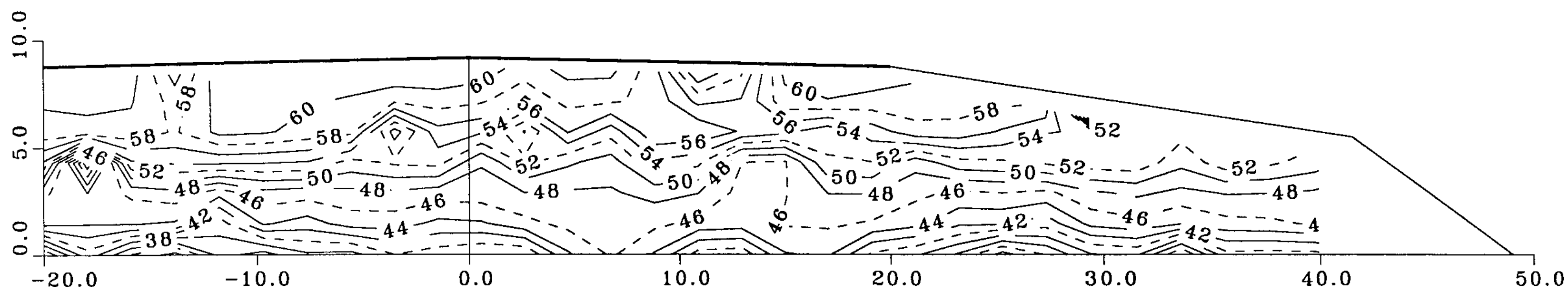


Figure 20. Temperature contours in the Parks/Chena Ridge ACE embankment on August 15, 1999.

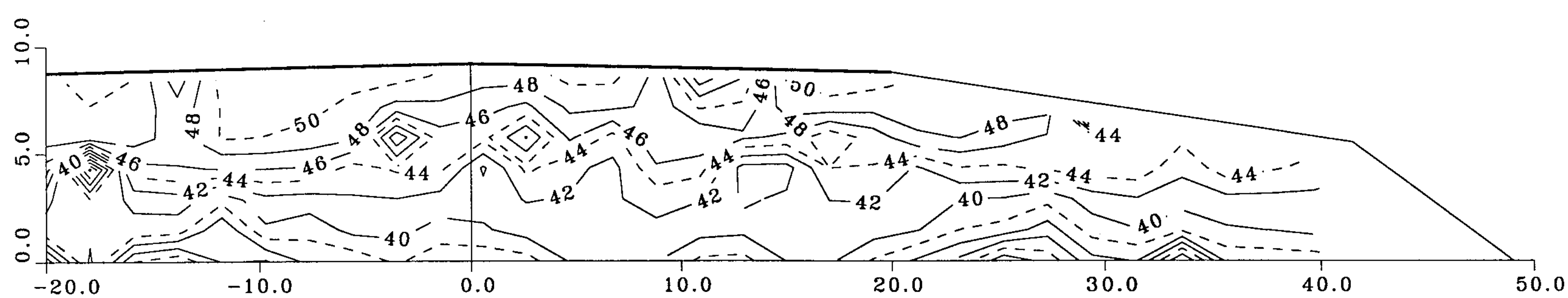
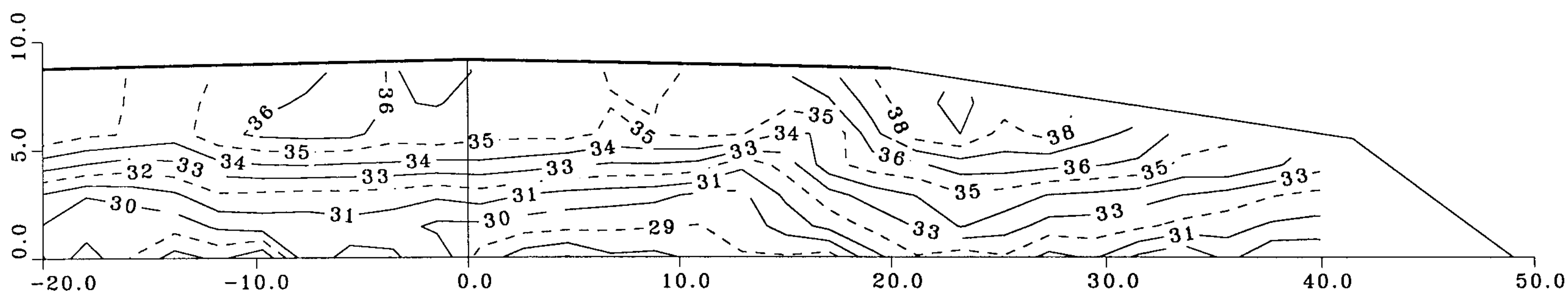
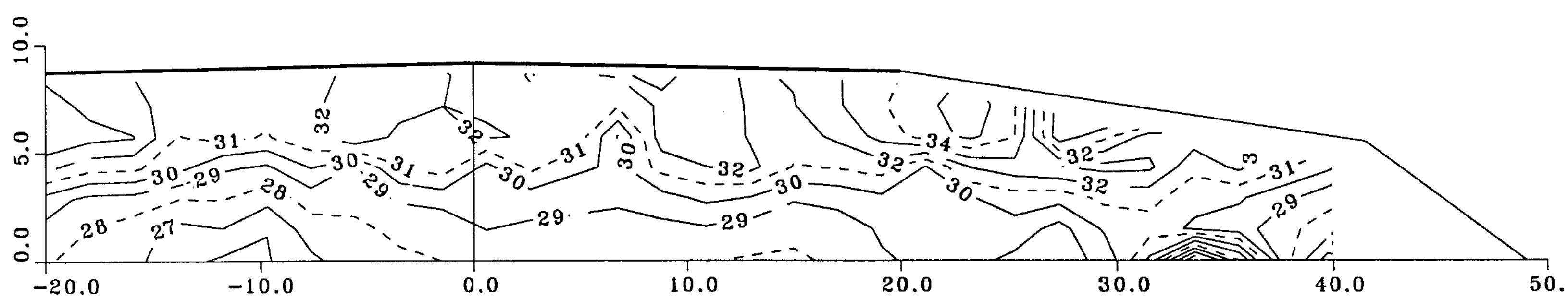


Figure 21. Temperature contours in the Parks/Chena Ridge ACE embankment on September 15, 1999.



Average Ambient Air Temperature = 29.0 F.

Figure 22. Mean annual temperature contours in the Parks/Chena Ridge ACE embankment (July 15, 1997 to July 15, 1998).



Average Ambient Air Temperature = 25.1 F.

Figure 23. Mean annual temperature contours in the Parks/Chena Ridge ACE embankment (July 15, 1998 to July 15, 1999).

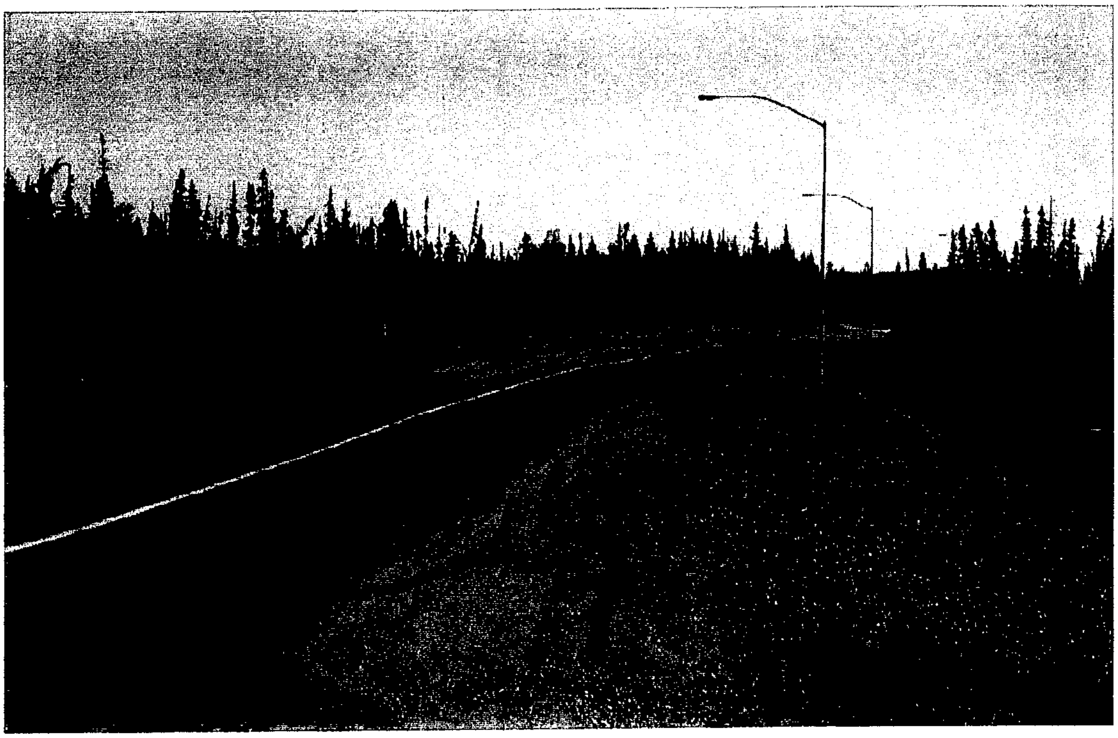


Figure 24. ACE test section on August 4, 1999.

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 included thermistor arrays D, E, and F, which were 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. As described in Section 3, most of the thermistors in stings D, E, and F had become non-functional by the fall of 1998 and, as a consequence, strings E and F were replaced in July of 1999.

Columns 5, 6, and 7 of Tables 1 through 12 contain temperature data taken from strings D, E, and F on the 15th day of each month, beginning on October 15, 1998 and ending on September 15, 1999. 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. Note that most of the data for strings D, E, and F is marked with # symbols in Tables 1 through 10. During August and September of 1999, after the replacement of strings E and F, good data was collected for these strings, as shown in Tables 11 and 12. As indicated in the tables, only a few of the points on strings A, B, and C have failed, so data is still relatively complete for the control section.

Tables 1 through 10 contain very limited data for the ACE test section subgrade due to the data problems mentioned above. Only three sensors remained in operation for the winter months stretching from October of 1998 to May of 1999. These were the lowermost sensors on strings E and F and generally indicate temperatures of about 29 to 30°F in the fall of 1998. The data then indicates a slow cooling trend to temperatures of 28 to 29°F by April of 1999. In May the remaining sensors stopped functioning, likely due to water infiltration associated with spring snowmelt.

After replacement of strings E and F in late July, data is once again available for these two strings, as shown in Tables 11 and 12. The data in Table 11 indicates subgrade temperatures ranging from approximately 31°F at 2 feet below original grade to about 29°F at a depth of 20 feet below original grade. A slight warming occurred between August 15 and September 15, but temperatures remain below freezing at all points in strings E and F, with values of about 31.5°F just below the original grade. These measurements are confirmed by the field observations made during drilling in late July. As discussed in Section 3, we found that the foundation soil was frozen at all locations beneath the base of the ACE rock layer.

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, 3, and 4 of Tables 1 through 12 include data for strings A, B, and C.

In general, the trends for strings A, B, and C mimic the behavior that would be expected based on the "whiplash curve." Also it appears that string A, which is located at the embankment centerline, is generally the coldest. This is exemplified by the fact that the deep soil temperatures are generally the coldest beneath the centerline location. Table 1 shows that maximum thaw depths for the control section in the late summer of 1998 were approximately 3 ft. below the original grade for string A and 7 to 8 ft. for strings B and C. These thaw depth trends are similar to those observed in previous years and are much larger than for the ACE test section which has not exhibited any thawing of subgrade soils.

An overall comparison of the subgrade temperatures indicates that there was a general cooling trend during the winter of 1998-99, most likely due to the relatively low mean ambient temperature of 25.1°F that prevailed at the test site during this period. Additionally, comparison of data collected since 1996 indicates a substantial cooling of the foundation soils beneath the ACE test section and some cooling beneath the centerline of the control section. Cooling at the control section centerline may be aided to a certain extent by shading of the area due to a large stand of spruce trees just to the south of the control section. These trees are shown in Figure 1, just behind the blue pickup truck. As in prior years, the warmest foundation soil temperatures are generally found beneath the side-slope region of the control section.

Table 1. Subgrade Temperatures Beneath Control Section and ACE Test Section on October 15, 1998.
(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	31.7	32.2				
4	35.3	37.8				
2	35.6	37.7	37.1			
0	33.4	37.6	38.3			
-2	33.9	35.9	38.5	####	####	####
-4	31.2	34.1	36	####	####	####
-8	29.2	31.5	30.6	####	####	####
-12	28.6	31.4	31.2	####	####	####
-16	28.8	31.5	31	####	30.5	29.9
-20	29.7	####	31.7	####	28.9	####

Table 2. Subgrade Temperatures Beneath Control Section and ACE Test Section on November 15, 1998.
(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	6.5	8.6				
4	31.8	32.9				
2	33	33.9	31.9			
0	31.2	34.8	33			
-2	33	34.1	33.4	####	####	####
-4	30.7	33.4	33.5	####	####	####
-8	29	31.3	30.6	####	####	####
-12	28.4	31.4	31.2	####	####	####
-16	29.2	31.4	30.9	####	30.5	29.9
-20	29.5	####	31.8	####	29	####

Table 3. Subgrade Temperatures Beneath Control Section and ACE Test Section on December 15, 1998.
(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	-4	1.5				
4	31	31.6				
2	31.8	31.9	29.9			
0	30.3	32.6	30.8			
-2	32.1	32.1	30.8	####	####	####
-4	30.3	32.5	31.8	####	####	####
-8	29	31.2	30.4	####	####	####
-12	28.5	31.4	31.2	####	####	####
-16	29.6	31.5	30.9	####	29.9	29.9
-20	29.3	####	31.7	####	29.3	####

Table 4. Subgrade Temperatures Beneath Control Section and ACE Test Section on January 15, 1999.
(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	-6.5	-4.9				
4	29	30.1				
2	31.6	31.4	29.3			
0	30.2	31.9	29.7			
-2	31.9	31.4	29.4	####	####	####
-4	30	32	30.9	####	####	####
-8	28.8	31	30.3	####	####	####
-12	28.3	31.4	31.1	####	####	####
-16	####	31.4	30.8	####	29.5	29.8
-20	29.2	####	31.8	####	29	####

Table 5. Subgrade Temperatures Beneath Control Section and ACE Test Section on February 15, 1999.
(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	-20.2	-15.6				
4	24.9	26.3				
2	30.6	30.9	26.4			
0	30.1	31.7	29.3			
-2	31.6	31	28.7	####	####	####
-4	29.9	31.7	30.4	####	####	####
-8	28.8	30.8	30.1	####	####	####
-12	28.1	31.5	31.1	####	####	####
-16	####	31.5	30.7	####	29.7	29.4
-20	29.1	####	31.9	####	29.1	####

Table 6. Subgrade Temperatures Beneath Control Section and ACE Test Section on March 15, 1999.
(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	6.1	2.1				
4	25.8	25.9				
2	29.1	29.2	24.4			
0	29.9	31.7	28.2			
-2	31.6	30.8	28.4	####	####	####
-4	29.7	31.8	30.3	####	####	####
-8	28.6	30.8	30.1	####	####	####
-12	28.1	31.5	31.1	####	####	####
-16	####	31.4	30.8	####	28.8	28
-20	29	####	31.8	####	28.9	####

Table 7. Subgrade Temperatures Beneath Control Section and ACE Test Section on April 15, 1999.
(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	31.1	30.7				
4	29.6	29.2				
2	30.2	29.7	28.4			
0	####	31.4	27.9			
-2	31.6	30.7	28.2	####	####	####
-4	29.4	31.8	30.1	####	####	####
-8	28.5	30.8	30	####	####	####
-12	28.1	31.4	31.1	####	####	####
-16	####	31.4	30.7	####	28	####
-20	28.8	####	31.7	####	27.8	####

Table 8. Subgrade Temperatures Beneath Control Section and ACE Test Section on May 15, 1999.
(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	56.8	54.6				
4	31.2	31.1				
2	30.9	30.6	31.2			
0	####	31.4	28.5			
-2	31.5	30.6	28	####	####	####
-4	29.3	31.7	30	####	####	####
-8	28.4	30.7	29.9	####	####	####
-12	28	31.4	31.1	####	####	####
-16	####	31.3	30.6	####	####	####
-20	28.6	####	31.7	####	####	####

Table 9. Subgrade Temperatures Beneath Control Section and ACE Test Section on June 15, 1999.
(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	78.9	75.9				
4	32.5	31.8				
2	31.2	30.9	31.9			
0	####	31.4	28.7			
-2	31.6	30.5	27.8	####	####	####
-4	29.1	31.7	29.9	####	####	####
-8	28.3	30.7	29.9	####	####	####
-12	27.9	31.4	31.1	####	####	####
-16	####	31.3	30.5	####	####	####
-20	28.5	####	31.7	####	####	####

Table 10. Subgrade Temperatures Beneath Control Section and ACE Test Section on July 15, 1999.
(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	77.5	75				
4	36.1	35.4				
2	31.4	31.1	39.3			
0	####	31.5	29			
-2	31.5	30.6	27.7	####	####	####
-4	29	31.7	29.8	####	####	29.8
-8	28.2	30.6	29.9	####	####	####
-12	27.8	31.4	31	####	####	####
-16	####	31.3	30.4	####	####	####
-20	28.3	####	31.7	####	####	####

Table 11. Subgrade Temperatures Beneath Control Section and ACE Test Section on August 15, 1999.
(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	64.7	63.3				
4	37	37.2				
2	32.6	32.4	42.4			
0	####	31.5	33.6			
-2	31.4	30.7	27.8	####	31.1	31
-4	28.9	31.7	29.6	####	30.7	30
-8	28.1	30.6	29.8	####	29.4	29.4
-12	27.8	31.4	31	####	29.4	29
-16	####	31.3	30.4	####	29	29.4
-20	28.2	####	31.7	####	29.7	29.4

Table 12. Subgrade Temperatures Beneath Control Section and ACE Test Section on September 15, 1999.
(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	52.7	51.4				
4	36.6	37.2				
2	33.9	34.1	41.3			
0	####	31.6	37.3			
-2	31.4	30.9	33.4	####	31.5	31.4
-4	28.7	31.7	32.2	####	31	30.4
-8	28.1	30.5	29.9	####	29.8	29.9
-12	27.7	31.4	31	####	29.7	29.4
-16	####	31.3	30.4	####	29.3	29.7
-20	28.2	####	31.7	####	30	29.7

6.0 CONCLUSIONS

The data collected from the Parks/Chena Ridge ACE test embankment between October 1998 and September 1999 indicates that convective cooling is continuing to be effective at maintaining low foundation soil temperatures beneath the embankment. Drilling operations performed in July of 1999 in order to replace thermistor strings E and F confirmed that the foundation soil has remained in the frozen condition. Mean annual temperatures were calculated for the ACE test section and used to generate contour plots for the periods extending from July, 1997 to July, 1998 and from July, 1998 to July, 1999. The plots indicate that mean annual temperatures ranged from 36 to 38°F (2.2 to 3.3°C) in the upper portion of the embankment cross section, and 28 to 30°F (-2.2 to -1.1°C) in the lower portion during the July, 1997-98 period. During the July, 1998-99 period, temperatures were colder, ranging from 32 to 34°F (0 to 1.1°C) in the upper portion and 26 to 29°F (-3.3 to -1.7°C) in the lower portion of the embankment. Thus it appears that the thermal performance of the ACE test section continues to be good, and permafrost soils should continue to be maintained beneath the test site.

After 3 years of operation, temperatures beneath the ACE test section are generally colder than those beneath the control 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. Plans are currently underway for 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. These changes are being planned for implementation during the summer of 2000.

7.0 REFERENCES

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