REMOTE FROST DEPTH MONITORING

FINAL REPORT

By

Billy Connor, P.E.
Senior Research Engineer

December 1984

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DIVISION OF PLANNING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AK-RD-85-13		

4. Title and Subtitle	5. Report Date
Remote Frost Depth Monitoring	January 1985
	6. Performing Organization Code
7. Author (s) Connor, Billy	8. Performing Organization Report No.
9. Performing Organization Name and Address Alaska Department of Transportation and Public Facilities 2301 Peger Road - Research Section Fairbanks, AK 99701	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Alaska Department of Transportation and Public Facilities Pouch Z Juneau, AK 99811	13. Type of Report and Period Covered FINAL REPORT 14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Three frost depth indicators were developed for use in establishing load restrictions. The first made use of ground resistivity. Since frozen and thawed ground have greatly differing resistivity, this property can easily be used to differentiate between the two.

The second system passed a light through a column of water to a detector. When the water froze, the detector can no longer "see" the light. This information can easily be passed through a computer.

The third system uses a thermistor in a balance bridge. Whenever the temperature of the thermistor deviates from a preset temperature, say 32°F, the bridge becomes unbalanced causing an electronic switch to be closed.

The last system appears most reliable but it has not been thoroughly tested. The first two systems have inherent problems which may or may not be overcome.

17. Key Words	18. Distribution Statement
frost depth, thaw weakening	Unrestricted

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

	PAGE
List of Figures	iv
List of Tables	iv
Introduction	1
Ground Resistivity Device	1
LED System	4
Thermocouple or Thermistor Strings	7
Summary and Conclusions	11
Acknowledgements	12
References	13

LIST OF FIGURES

		PAGE
Figure 1	Dye Frost Tube Detail	2
Figure 2	Conductivity Frost Tube	3
Figure 3	LED Frost Tube	5
Figure 4	Block Diagrams for LED System	6
Figure 5	Comparator Circuit	10

LIST OF TABLES

Table 1	Readings on the Copper Rings	4
Table 2	Materials and Cost for the Comparator Circuit	9

Introduction

The relationship between thaw depth of the embankment and roadway thaw weakening has been recognized for many years. The first formal investigations in Alaska to relate thaw depths with deflection, carried out in 1977, concluded that maximum deflections were generally obtained when thaw depths reached 3½ feet to 5 feet.(1) Further research completed in 1983 concluded that the maximum strain in the pavement layer generally occurs when the thaw depth reaches between 1 and 3 feet.(2) The maximum pavement damage therefore occurs at thaw depths between 1 and 5 feet. However, these relationships are site specific, and must be correlated with deflection data.

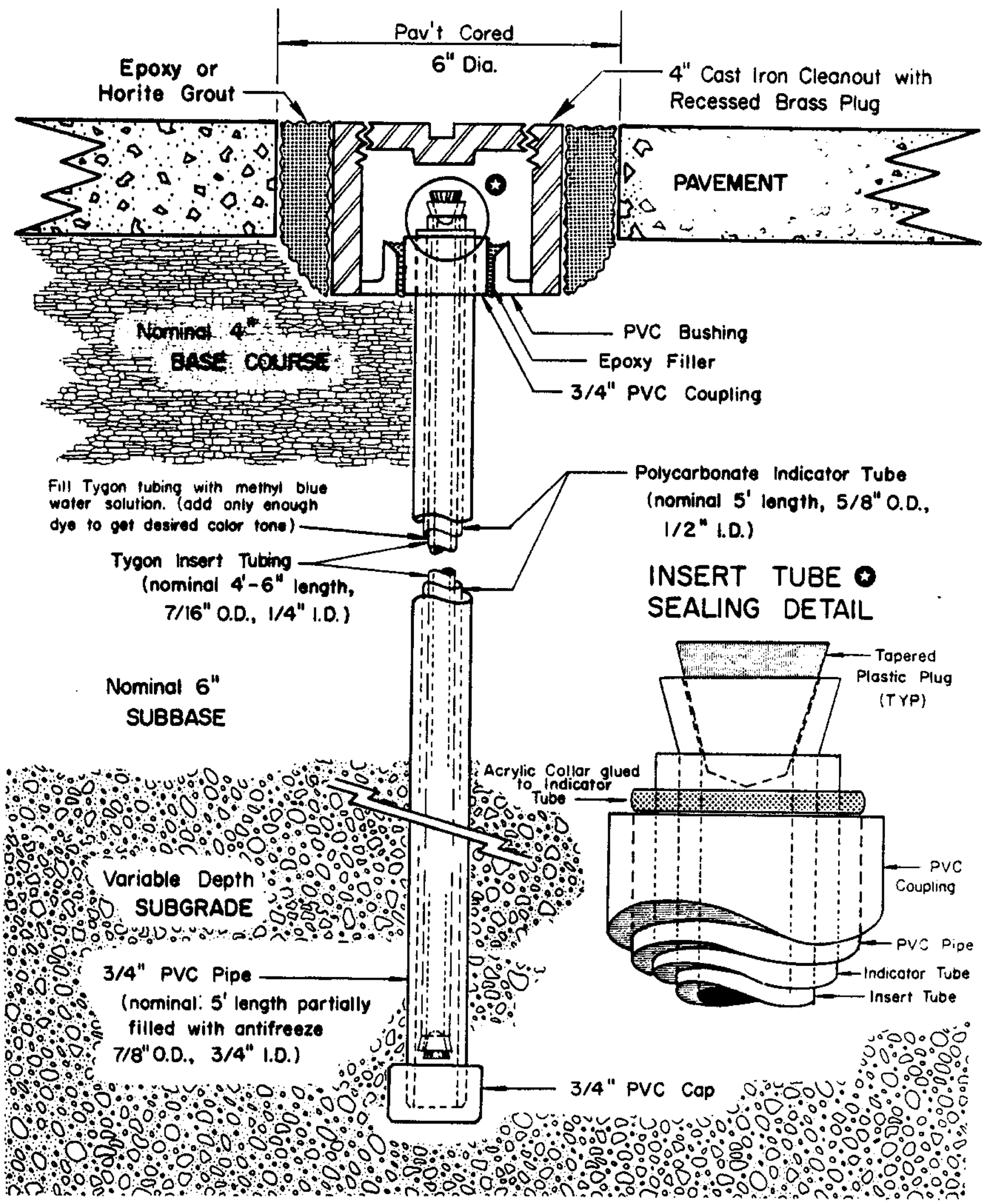
First attempts at monitoring thaw depths made use of a frost depth indicator originally developed by Gandahl.(3) A similar system shown in Figure 1 uses a dye solution such as methylene blue in a clear tube. This dye is forced from the ice during the freezing process leaving a visually apparent demarcation between the clear frozen zone and dye solution. The major problems with this system were that the cap providing access to the tube as well as the tube itself frequently froze into place, and the person reading the tubes was also required to be exposed to the hazards of traffic. Three systems allowing remote readings outside the roadway prism were therefore developed and evaluated in this study.

Ground Resistivity Device

The conductivity and its inverse, resistivity, of soil changes by an order of magnitude or more between the thawed and frozen states. This property has been successfully used to distinguish frozen and thawed soils in areas of discontinuous permafrost areas. The resistivity measurement system shown in Figure 2 was designed, constructed and installed in a roadway embankment in Fairbanks.

The system consists of copper rings spaced on 4 inch centers along a 3/4 inch pvc pipe. This is then placed in a 4 inch plastic pipe casing which is in turn filled with saturated Ottawa sand and sealed. Readings are periodically taken using an AC conductivity meter. The system worked very well until the outer casing developed a leak allowing the water to drain.

Figure 1 DYE FROST TUBE DETAIL



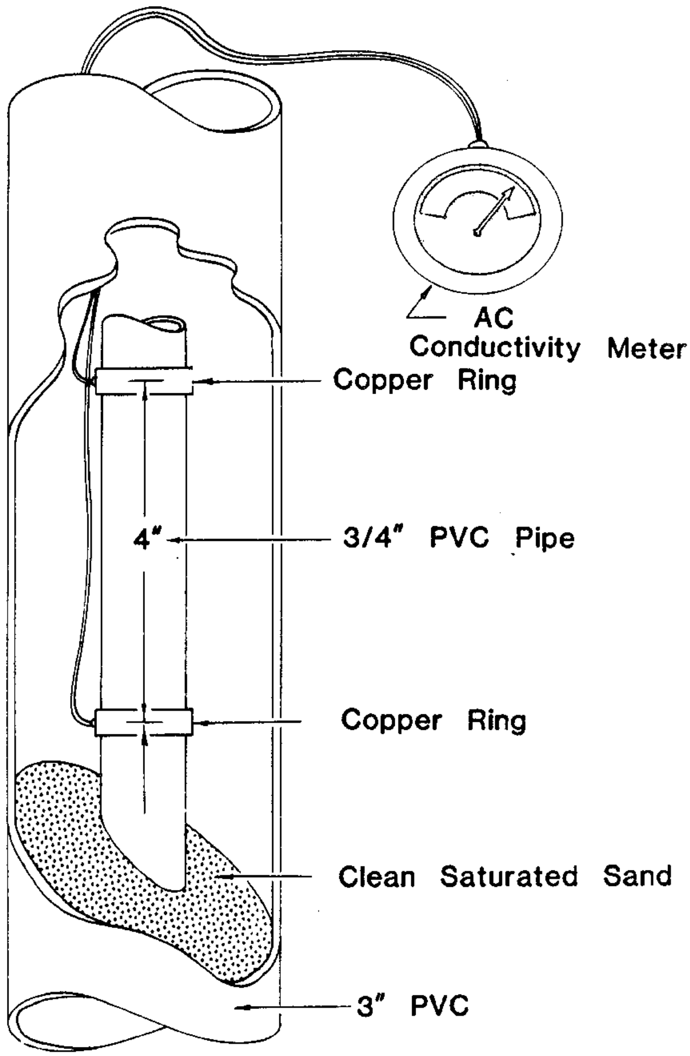


Figure 2 CONDUCTIVITY FROST TUBE

Table 1 shows readings taken during the freezing process. Notice the large difference in resistance on April 29 between rings 6-7 and 7-8. This is the demarcation of the thaw front. The difference is readily apparent. Looking across the table, it is easy to follow the progression of the thaw depth. A closer investigation of the values shows there is a transition zone. Part of the 4 inches of soil between the rings may be frozen causing a shift in resistance. At temperatures slightly below freezing, not all of the water is frozen. This unfrozen water also lowers the soil resistance.

This system requires an A.C. ohm meter which is readily available at a modest cost. If the leakage of water can be eliminated, this method of thaw remote depth monitoring would be excellent. Unfortunately, the rings cannot be placed directly in the embankment since high moisture content is required to allow a demarcation to be observed.

TABLE 1: READINGS ON THE COPPER RINGS

Ring Pair	Resistance (ohms)			
	4/29	4/30	5/3	5/6
1 - 2	5,180	5,140	5,710	5,900
2 - 3	2,240	2,250	2,310	2,190
3 - 4	2,620	2,580	2,540	2,360
4 - 5	2,750	2,740	2,750	2,530
5 - 6	2,550	2,580	2,620	2,450
6 - 7	2,310	2,270	2,300	2,170
7 - 8	12,700*	5,460	5,600	4,790
8 - 9	52,900*	33,200*	6,810	5,870
9 - 10	177,000	173,000	62,000*	5,720
10 - 11	185,000	171,000	109,000	10,800*
11 - 12	203,000	156,000	128,000	105,000

* Transition zone

LED System

The second system investigated was a system using infrared light emitting diodes (LED's) and photo-transistors depicted in Figure 3. The beam from the LED readily passes through water and is detected by the photo-transistor. In theory, when the water freezes, the beam of light can

Figure 3 LED FROST TUBE

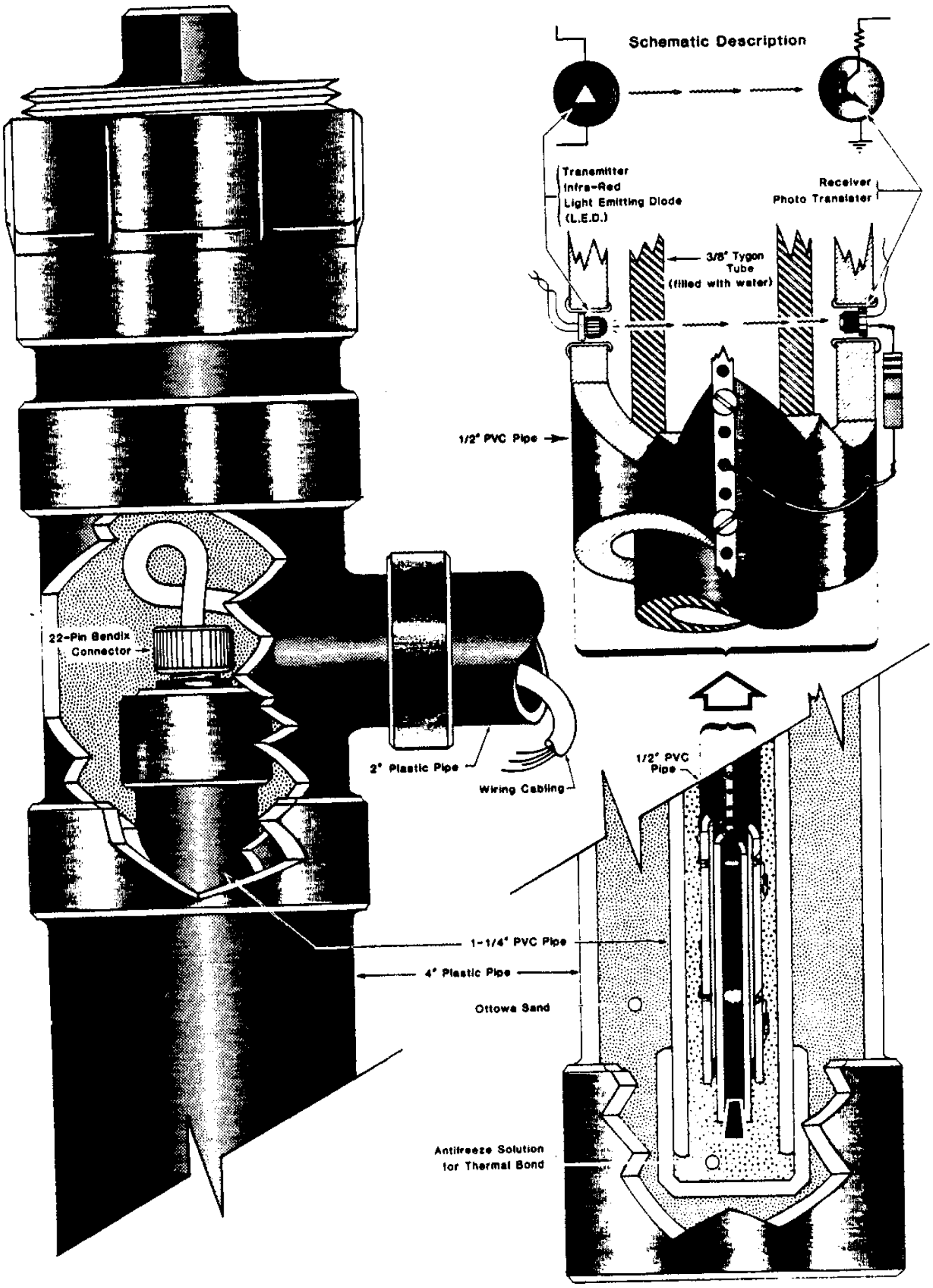
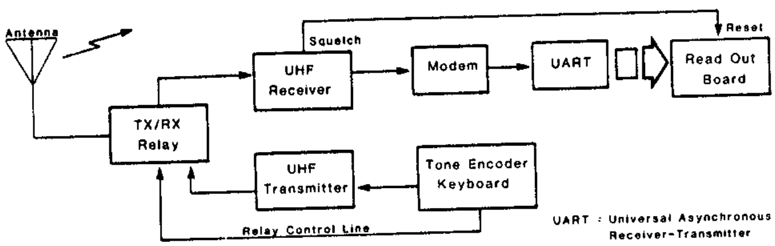
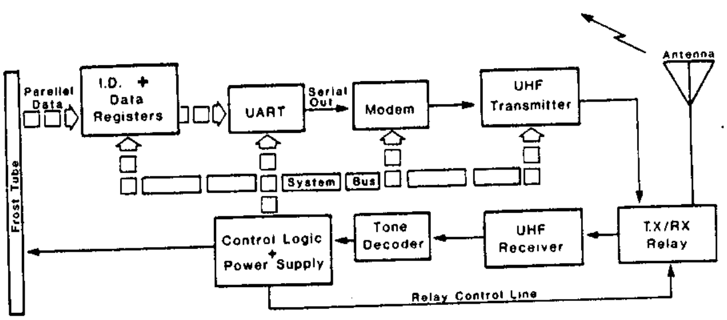


Figure 4   BLOCK DIAGRAMS FOR LED SYSTEM



BASE STATION BLOCK DIAGRAM



REMOTE SITE BLOCK DIAGRAM

no longer be detected. This yes/no information can be used as one bit of data which can readily be transmitted via radio to a central location.

A block diagram of the system is shown in Figure 4. The system is comprised of three major parts, the tube, the remote station which reads the tube and transmits the data, and the base station. All parts in the system are readily available and are relatively inexpensive.

When tested in the coldroom, the system worked very well. The ground cooling from the top down was simulated by insulating the sides of the tube allowing the top to be open to air. As the water in the tube froze, each corresponding light on the display panel went off to indicate the presence of ice.

Three of these devices were subsequently installed in local Fairbanks Roads in 1982. However, as the winter progressed, it became apparent that the tubes were not working properly. The photo transistors continued to "see" the LED's even though the ground was known to be frozen. Upon retrieving the tubes, the problem became immediately obvious. Because of the slow freezing rates in the ground, the water in the tubes formed a single clear crystal of ice. This crystal was so clear that light could pass through easily. Several attempts were made to cause the ice to cloud during slow freezing with no success. None of the methods tried worked.

From these field tests, it became apparent that the tubes must be frozen quickly and placed in the roadway after the embankment has frozen. Prefrozen tubes placed in the roadway tracked the thawing of the embankment well. However, the annual removal and prefreezing of the tube is not totally acceptable.

Thermocouple or Thermistor Strings

Thermocouple and thermistor strings have been used to measure ground temperatures for many years, and have proven to be very reliable for this purpose. They are relatively inexpensive and simple to use. However, during the phase change of water to ice, there can be a range of soil at 32°F, the temperature at which both ice and water can exist. Temperature alone does not allow the determination of thaw depth.

Until recently, reading of thermocouples and thermistors required trained personnel to insure proper measurement. Recent developments have allowed conversion of voltage or resistance to temperature and displayed digitally. Thermistors have proven to work better than thermocouples in this application.

Thermocouples are very inexpensive. However, they are difficult to read accurately. Typical accuracy can be expected to be 0.5°C with an ice bath reference. Failure rates are quite high.

Thermistors are considerably more expensive than thermocouples. The increase in initial cost can be offset by the ease of measurement, improved temperature sensitivity and greater reliability. No ice baths are required except for initial calibration in the laboratory. Measurements of 0.01°C are easily attainable with quality thermistors.

This advancement still does not allow transmission of data without expensive microprocessor hardware. Since only the thaw-depth is sought only one bit is necessary to determine if the temperature is above or below 32.0°F. This can be done using the comparitor circuit shown in Figure 5. When the thermistor resistance is greater than its resistance at 32.0°F, the bridge becomes unbalanced and the comparitor "turns on" the bit: i.e., the bit state becomes 1. In this manner, the status of 8 indicators can be sent using an 8 bit Byte. The electronics to do this are simple and inexpensive.

Table 2 provides a materials list and costs for the comparator circuit. Two options are available for the resulting comparator output. First and simplest is to turn an indicator light on as the ground thaws. This requires placing the comparator in series with the light, using the comparator as a switch.

The second option is to use the system shown in Figure 4 replacing the LED circuit with the comparitor circuit. This would allow telecommunications to be used to obtain data in the field allowing area-wide coverage from a single location.

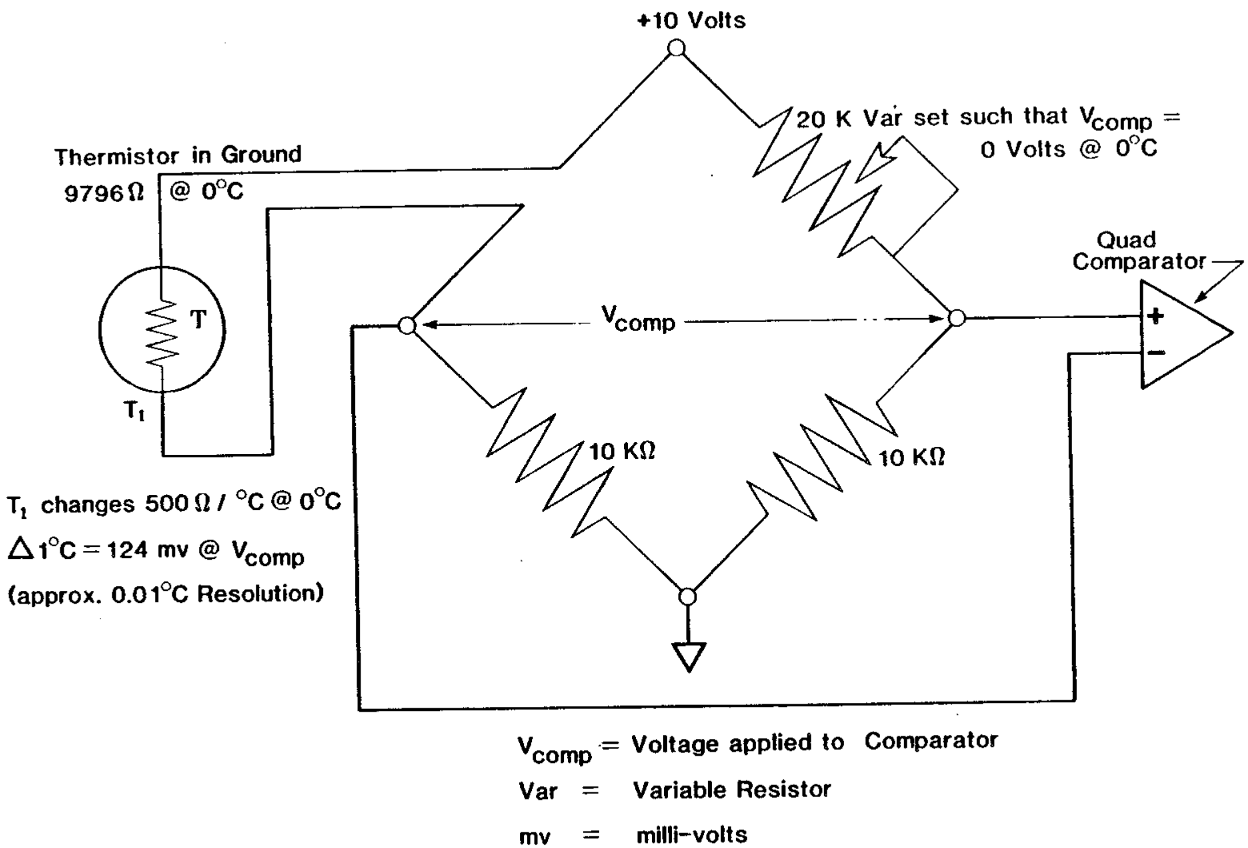
To date, this system has not been tested. It will be installed in the field during the spring of 1986. If the system performs as expected, thaw depth monitoring should be greatly enhanced.

TABLE 2

MATERIALS AND COSTS OF A COMPARATOR CIRCUIT

Quantity/Station	Description	Cost
1	Thermistors ±½% YSI 44033	$15.15
1	20K WW Pot ± 50 ppm/°C	4.26
2	10K metal film resistors ±50 ppm/°C	0.42
1	Quad comparator #54C909	5.20
	Total/Station	$25.03

Figure 5 COMPARATOR CIRCUIT



Summary and Conclusions

Three new thaw measurement systems were investigated under this study. They first used the change in soil conductivity between frozen and thawed states. This system did not prove satisfactory because of the difficulty in maintaining a saturated sand medium. Installation of the rings directly in the embankment was considered, but the system requires high moisture content.

The second system used an opto-electric sensor. The sensor could see a light through water. When the water was frozen in the laboratory, the ice precluded the light from the sensor. However, in the field, the slow freezing resulted in clear ice which allowed the sensor to "see" the light source. The tube could be frozen quickly and placed in the embankment during late winter. This is not felt acceptable.

The third system was designed at the end of the project and consequently was not tested. A comparitor circuit is used to determine if the soil is above or below 32°F. This allows the use of the same readout system developed in the opto-electric system. It has the additional advantage of allowing actual ground temperature measurement if desired.

In conclusion, the comparitor circuit appears to be the best alternative. Until further testing is performed, the system is not recommended for implementation.

Acknowledgements

The Alaska Department of Transportation and Public Facilities fully acknowledges the technical suggestions and funding assistance provided by the Federal Highway Administration under the Highway Planning and Research Program.

Special thanks goes to John Benevento and his staff at the University of Alaska Geophysical Institute for development work on the LED System.

Richard Briggs, electronic technician, is to be commended for his assistance in maintaining the systems under adverse climatic conditons. He also provided considerable technical expertise to the project.

References

[1] Esch, D., 1977. "Seasonal Roadway Deflection Correlations with Climate," Alaska Department of Highways.

[2] Stubstad, R. and Connor, D., August 1982. "Prediction of Damage Potential on Alaskan Highways During Spring Thaw using the Falling Weight Deflectometer," Alaska Department of Transportation and Public Facilities, Report Number AK-RD-83-11.

[3] Gandahl, Rune, 1963. "Determination of the Ground Frost Line by Means of a Simple Type of Frost Depth Indicator," Report 30A, The National Swedish Road Research Institute.