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PAVEMENT HEATING, 1969-1975,

FINAL REPORT

Frank Winters

S. Robert Sasor

Division of Research and Development
New Jersey Department of Transportation

February 1977

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16. Abstract

In order to evaluate a roadway heating system which utilized the energy stored in the earth for snow melting, a 3200 square foot experimental heated pavement was constructed in Trenton, New Jersey. Heat was extracted from the earth by means of a grid of pipes buried 3 to 13 ft. below ground and transferred via an ethylene glycol-water solution to pipes embedded in a test pavement. For purposes of comparison, a section of pavement heated by electrical resistance wires was also included as part of the installation.

Results of operation have indicated that the best snow melting has taken place on sections of portland cement concrete containing 3/4" and 1-1/4" wrought iron pipe spaced on 6" centers and embedded at a depth of 2 inches. These sections produced an average heat dissipation rate of approximately 100 BTU's per square foot of surface area per hour when 2 linear feet of pipe buried in the earth were coupled to 1 linear foot of pipe embedded in the test pavement. Snow melting rates were usually between 1/4 inch and 1/2 inch per hour.

During the Summers of 1970 and 1971 the system was operated for the purpose of transferring heat from the warm pavement to the earth where it could be stored for use during the winters. Heat was successfully transferred; however, due to the loss of heat to the surrounding earth and the atmosphere during the fall, no significant storage of heat was achieved by the start of the snow season. The thermal insulation used with the pipes buried 3 to 13 feet in the earth was not effective in reducing heat loss during the fall.

(continued on next page)

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Heated Pavement, Snow Melting, Snow and Ice Control, Stored Earth Energy Embedded Wrought Iron Pipes, Heat Exchanger, Thermal Insulation, Electrical Heating Mats

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ABSTRACT (cont.)

Though this installation was shown to be more economical to operate than an electrically heated pavement, the total cost was higher when construction cost was considered.

Scope of the Report

This is a final report on this project and it covers the design and construction of the experimental installation as well as the results obtained for operation from 1969 to 1975.

Three previous reports have been issued on this project and they are dated March 1970, August 1971 and June 1972. These reports have introduced the pavement heating project and its objectives, described the design and construction of the test installation, and have covered the results of winter operation of the installation for 1969-70, 1970-71 and 1971-72 and summer operation from 1970 and 1971. This final report repeats and updates text material from these past reports and also covers new information on winter operation for 1973-74 and 1974-75.

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1. Introduction

1.1 Statement of the Problem

The presence of snow or ice on highways expecially at interchanges, ramps, and bridge decks often results in hazardous driving conditions, reduced traffic volumes, and traffic congestion. Conventional snow and ice control techniques may prove inadequate at these locations for several reasons. First, limited snow storage area often exists at these locations; second, there may be a time lag between ice and snow formation and plowing, salting, and sanding operations; and third, alternate freezing and thawing of plowed or unplowed snow on elevated ramps can occur.

An ideal solution for the control of snow and ice at these problem locations is the use of heated pavement, capable of melting any snow or ice forming on the roadway.

The major obstacle presently limiting the use of heated roads in New Jersey and elsewhere has been the high construction and operating cost of such an installation. The development of methods which would result in lower operating costs may justify the more widespread use of heated roadways.

1.2 Previous New Jersey Department of Transportation Pavement Heating Projects

Previous work by the NJDOT resulted in the construction of two electrically heated pavements utilizing copper jacketed, mineral insulated, resistance cables. Both installations were designed to have a heat dissipation rate of 30-35 watts per square foot of approach roadway and 40 watts per square foot of bridge pavement. Both were manually activated.

The first installation was completed in 1961 on the westerly approach to the Passaic River Bridge on U. S. Truck Route 1 and 9 in Newark. Cables were installed in conjunction with a bituminous concrete resurfacing of the bridge deck and approaches. The site was 840 feet in length and covered two 10 foot wide traffic lanes. Daily traffic was 40 percent heavy trucks. After several years of operation, this installation was abandoned when pavement failure lead to dislodgement of cables in the overlay and eventual failure of conductors. Pavement design was judged not suitable for traffic conditions.

From the experience gained on the first test site, a second installation was designed. Construction was completed in 1964 with newly constructed pavement on two bituminous concrete ramps, and a portland cement concrete bridge deck at the U. S. Routes 46 and 17 interchange in Teterboro. The entire portion of heated roadway (18,000 $ft.^2$) has a 5.95 percent grade. To date, this system has been operating satisfactorily in controlling snow and ice at the site. Total cost for installation of the heating system averaged approximately $\$4.00/ft^2$; and annual operating cost, $\$0.45/ft.^2$ of pavement surface.[1]

1.3 Pavement Heating Utilizing Earth Heat

To evaluate the use of the earth as a heat source, an experimental roadway heating system was designed and constructed in 1969 in Trenton, New Jersey. The basic method of heat recovery was to bury a heat exchanger, consisting of a network of pipes, in the earth below the test pavement. An anti-freeze solution was then circulated through the heat exchanger and also through coils of pipe (pipe panels) embedded in the test pavement. In the process, heat was transferred from the earth to the pavement surface where it could be utilized for snow melting.

[1]Pittman, J. M., Electrical Heating of Bridge Deck and Approaches for Snow and Ice Control, Electrical Bureau, NJDOT, 1969, page 7.

The goal of this project was to find a more economical source of energy for pavement heating - some source which could be used in place of conventional organic fuels or electricity. This led to establishing the following objectives;

1) To use the heat available in the earth immediately below the road surface as an energy source.
2) To use the earth immediately below the road surface as a reservoir for summer thermal energy to be utilized during the winter months.
3) To evaluate the use of insulation in terms of its effectiveness in reducing heat loss from the earth.
4) To determine what combination of pipe size, depth, spacing, pavement material, and operating method was most effective.
5) To observe any deterioration or structural failure of the system.
6) To evaluate the snow melting ability of the heated pavement.

2. Summary of Results and Conclusions

This project has shown that the earth is an economical source of heat for pavement heating in that the annual operating cost based on electrical energy usage for this type of installation is roughly 45 times less than that of an equivalent pavement heating system utilizing electrically heated embedded elements. However, the high cost of construction outweighs any reduction in operating cost and, for an assumed structural life of 20 years, a pavement heating system of this type appears to be, from the average yearly cost analysis presented, approximately 50% more expensive, in addition to being less capable of melting snow, than conventional pavement heating systems utilizing electrical heating cables.

The conclusions corresponding to the objectives are:

1) This experimental project has shown that the melting of snow and ice can be achieved by transferring the heat energy available in the earth to a surface pavement.

2) Thermal energy was successfully transferred from the warm pavement to the earth by operating this installation during the summer. However, due to the rapid rate of heat loss from the earth during system inactivity in the fall, the benefit to snow melting derived from summer operation was minimal.

3) The use of 6 and 8 inch thick, 1-1.5 pounds per cubic foot polystyrene insulation, either partially or completely enclosing the heat exchangers (reservoirs), did not significantly reduce the rate of loss of heat stored in the earth.

4) The most effective snow melting for embedded pipe panels, took place on sections of portland cement concrete panels containing

wrought iron pipes embedded at a depth of 2 inches and spaced on 6-inch centers. Generally, portland cement concrete panels were 50% more effective in snow melting than their corresponding bituminous panels. Panel sections of closer pipe spacing and larger pipe diameters were better snow melters.

5) No major structural failure of the pavement or wrought iron pipes was observed. No internal pipe corrosion was observed, and no deterioration of the heating fluid to a more acid state was measured. Because of two leaks which developed in the heating panel which contained rigid polyvinyl chloride (PVC) plastic pipe, it is questionable whether this type of plastic pipe possesses sufficient strength for use in an embedded pipe type of pavement heating system.

6) For most snowstorms in which an underground heat exchanger provided earth heat to two panels of pipe embedded at a 2" depth in the test pavement, the most effective melting sections (portland cement concrete panels, 6-inch pipe spacing) produced a heat dissipation rate of approximately 100 BTU per hour per square foot for a heating fluid temperature of 40-60°F and an air temperature of 20-35° F. The above conditions resulted in an average snow melting rate for most snowstorms of between 0.2 to 0.3 inches per hour. The melting which took place on these panel sections was judged better than that on the 20 watts* per square foot section of the electrically heated portland cement concrete reference panel but less than that measured for the 40 watts/ft^2 section.

For most snowstorms in which an underground heat exchanger provided earth heat to four panels of pipe embedded at a 2" depth in test pavement, the average snow melting rate on the most effective

*1 Watt = 3.4 BTUH (British Thermal Units per Hour) melting sections was reduced to between 0.1 and 0.2 inches per hour with a corresponding reduction in heat dissipation rates. Heating fluid temperature ranged from 35° to 55°F. The melting which took place on these sections was judged worst than that on the 20 watts per square foot sections of the electrically heated portland cement concrete reference panel.

When pavement pipe panels were supplied with a higher temperature heating fluid (average 90°F) by a 30 kilowatt hot water heater, the most effective melting panel sections were able to melt snow 3 to 4 times as rapidly as when supplied with earth heat. The average melting rate for these best melting sections supplied with (average 90°F) heating fluid was approximately 1 inch per hour. This melting rate is approximately 50% greater than the melting rates measured on the most effective 60 watts/ft^2 sections of the electrical resistance panels.

In almost all snowstorms, the 40 and 60 watts/ft^2 sections of the electrically heated reference panels produced better melting than pavement pipe panels supplied with earth heat.

Following are additional conclusions which though not in direct answer to the objectives have been reached from work done on this project.

7) For the Winter of 1969-70, the operating cost of the earth heated pavement pipe panels based on electrical energy cost was approximately 45 times less than that of the electrically heated reference panels for an equivalent amount of snow melting and based on electrical energy cost only.

For an equivalent amount of snow melting, the operating cost (electrical energy cost only) of the hot water heated pavement pipe panels was approximately equal to that of the electrically heated reference panels.

8) By the end of 1970's selective summer operation for the purpose of storing heat in the earth, the heat stored in Heat Exchangers #1 and #2 was increased by approximately 10%.

For the period from June 4 to October 6, 1971, continuous summer operation of the uninsulated Heat Exchanger #3 for 2,976 hours was approximately equal in heat storing ability but 4.2 times more costly (based on electrical energy cost) than selective summer operation for 715 hours during 1970.

9) With the uninsulated Heat Exchanger #3 servicing four heating panels, with at least three hours of system operation, and with the temperature of the heating fluid in the range of 35° to 46°F, heat was extracted from the earth during snowstorms at a rate of between 4-18 BTUH per linear foot of 1-1/4 inch heat exchanger pipe.

10) For this type of system, the placement of 2 inches of cellular glass thermal insulation below a portland cement concrete pavement of 9" thickness was not an effective means of improving the snow melting ability of 20-60 watts per square foot heating elements embedded at a depth of 2 inches below the pavement surface.

11) A considerable amount of data was lost due to failures of temperature sensors and temperature recording equipment. By the last year of operation more than 25% of the temperature sensors showed strong indications of being in error.

3. Recommendations

1) Though pavement heating systems have been considered justifiable for limited application in relatively small critical locations where traffic delays and hazards caused by snow or ice outweigh costs, the use of a pavement heating system utilizing earth heat is not, at this time, recommended for these locations, primarily because it does not compare favorably in terms of economics with conventional electrical pavement heating systems.

2) This type of pavement heating system should not be operated either continuously or selectively for purposes of storing heat from June 4 to October 6 unless some method of preventing heat loss from the earth during the fall can be devised.

3) When placed as in this installation, 6-8 inches of 1.0-1.5 pounds per cubic foot rigid, expanded polystyrene insulation should not be used with buried pipe heat exchangers for the purpose of reducing the loss of stored heat during system inactivity in the fall.

4) Polyvinyl chloride (PVC) plastic pipe should not be used in embedded pipe pavement heating systems designed for highway use pending the results of further research into the possibilities of breakage.

5) Unprotected vinyl tipped, general purpose thermistor probes of the type used for this project are not recommended for sub-soil readings at depths of 2.5 to 15 feet.

4. Discussion of Project

4.1 Design of Pavement Heating System

4.1.1 Location

The experimental heated pavement system is located in the parking lot adjacent to the Annex of the New Jersey Department of Transportation main headquarters at 1035 Parkway Avenue, Trenton, New Jersey. See Figure 1, page 10 . It was installed during the construction of the parking lot. This site was selected in order to control the traffic over the test area during snow conditions. Since one of the project objectives was to observe the snow melting rates on different sections of pavement, an attempt was made to prohibit traffic on the test area since it was felt the action of traffic would obscure observation.

4.1.2 Pavement and Base

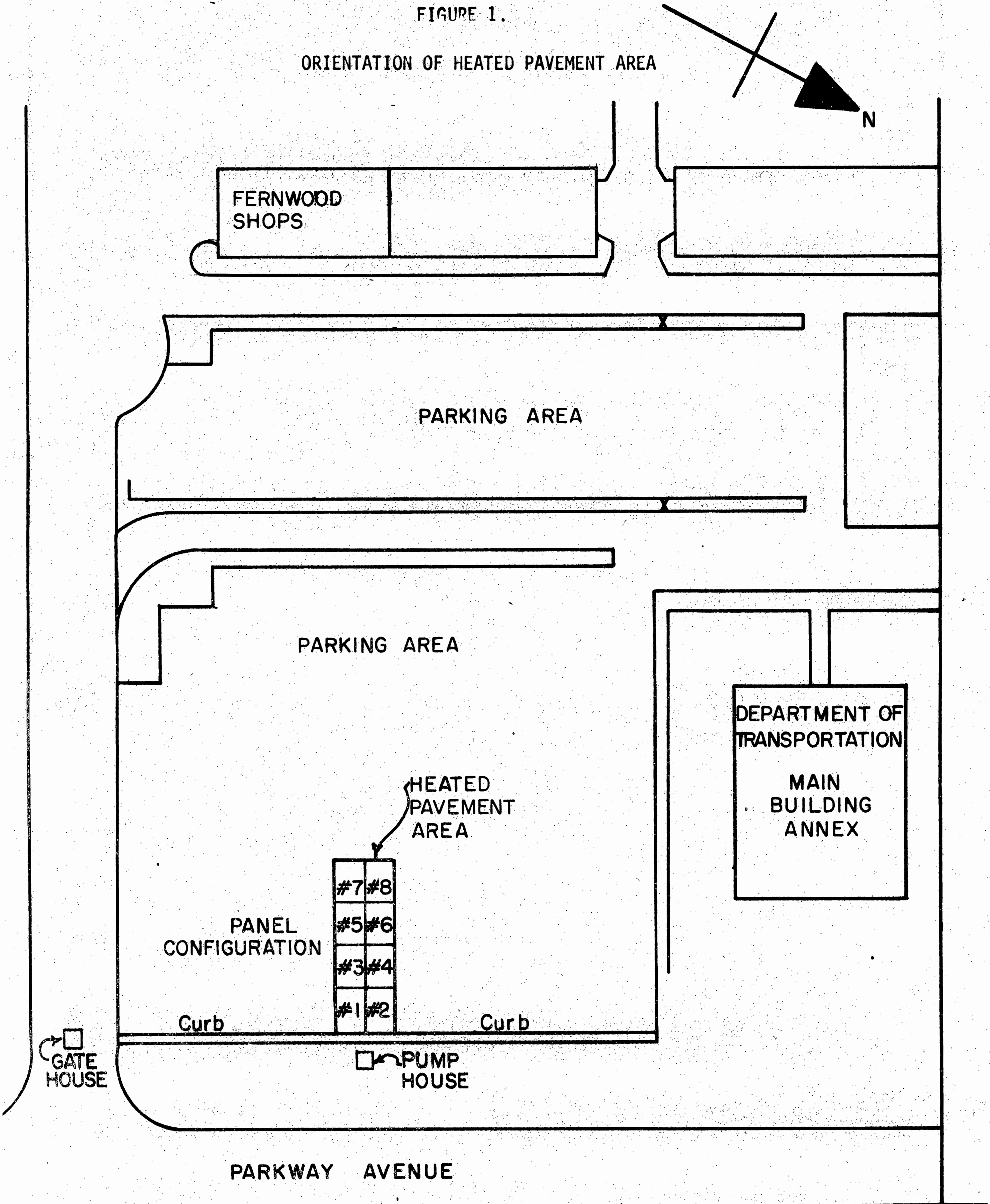
The test pavement consists of two parallel "lanes" each 13 feet wide and 123 feet long. One lane consists of 9-inch thick slabs of portland cement concrete on a subbase while the other lane consists of 7 inches of bituminous concrete on a 6-inch macadam base. The design of both lanes of pavement and subbase was typical of pavement construction current in New Jersey at the time of system installation (April-December 1969). Each lane is subdivided into four independent panels such that a malfunction on any one panel will not disable the entire system.

4.1.2.1 Pavement Pipes

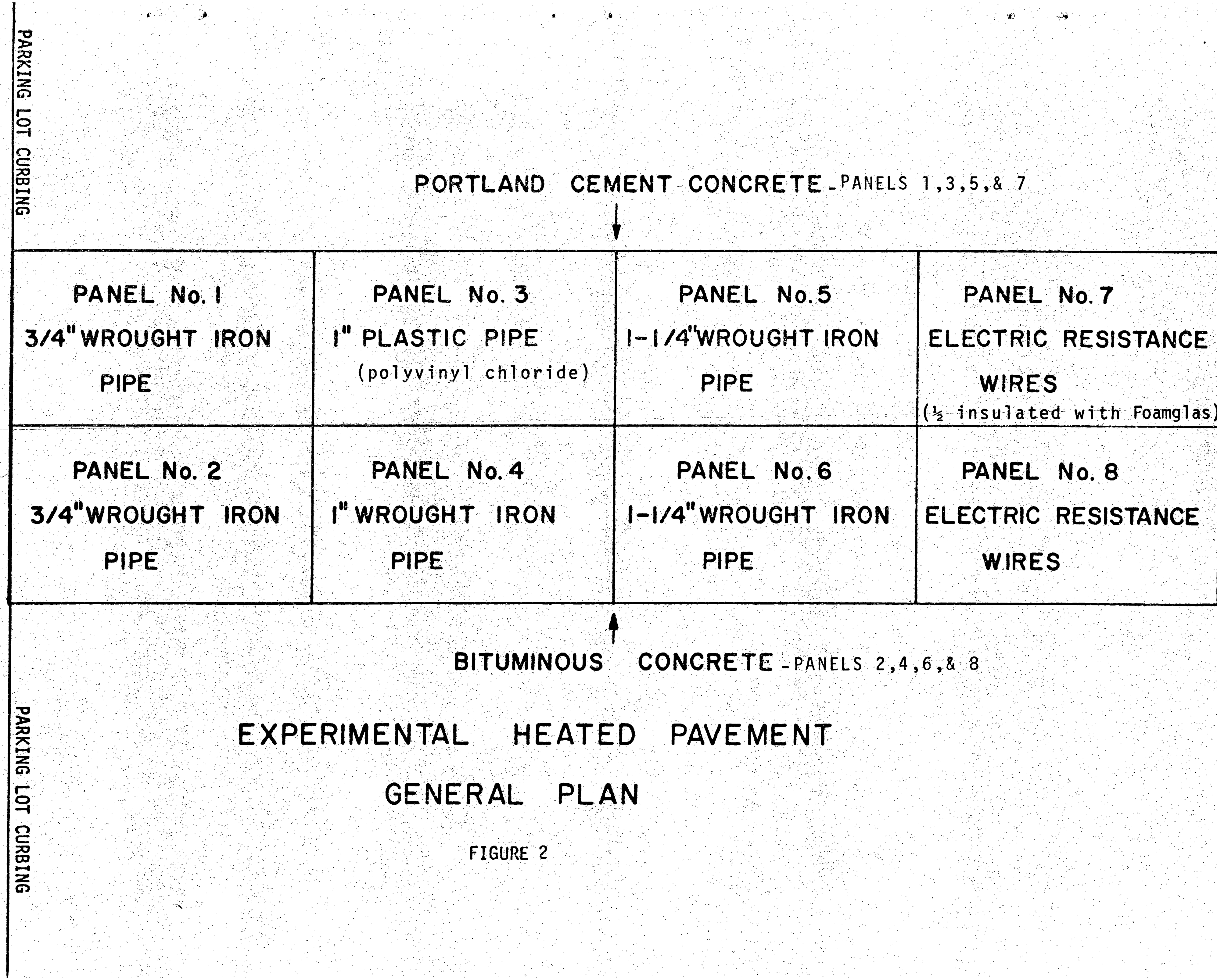
Pipes with nominal diameters of 3/4 inch, 1 inch and 1-1/4 inch are embedded in the pavement of Panels #1 and 2, 3 and 4, and 5 and 6, respectively, at depths of 2 and 4 inches. See Figure 2, page 11.

FIGURE 1.

ORIENTATION OF HEATED PAVEMENT AREA



SCALE: 1 1/4" = 100'



EXPERIMENTAL HEATED PAVEMENT

GENERAL PLAN

FIGURE 2

In each of these panels, the pipe spacing is varied from 6 to 12 to 18 inch centers, and the pipes embedded at 2 inch and 4 inch depths are staggered with respect to each other as shown in Figure 3, page 13. All pipes are standard weight wrought iron with the exception of Panel #3 where a rigid polyvinyl chloride plastic pipe is used. The plastic pipe, which is resistant to chemical corrosion, was chosen in order to test its structural properties.

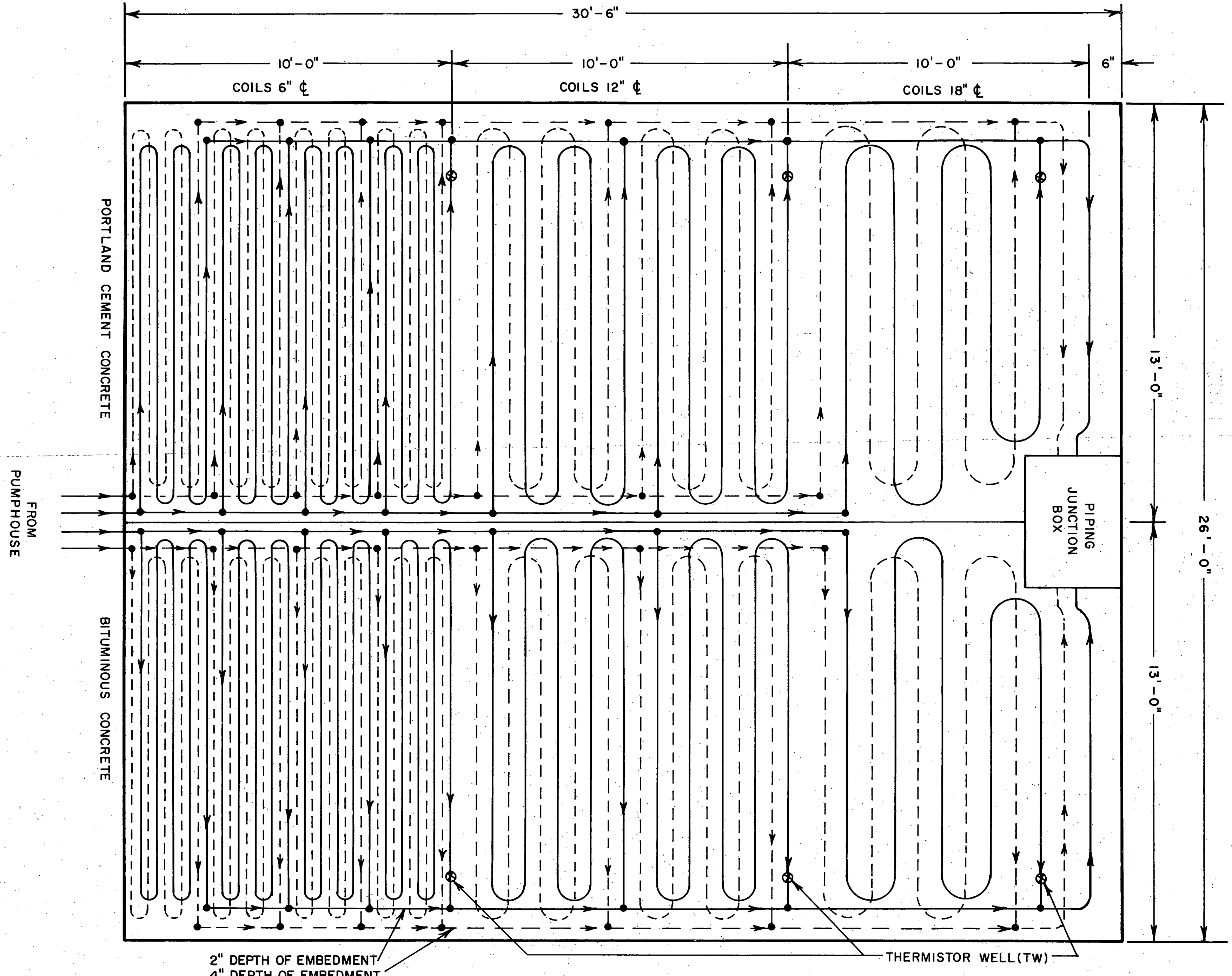
The preceding design was selected in order to evaluate the combination of pipe spacing, pipe diameter, depth of embedment, and pavement material which would produce the most effective snow melting.

4.1.2.2 Electrically Heated Pavement

To serve as a reference, Panels #7 and #8 contain vinyl insulated electric resistance wires embedded at a depth of two inches. Each of the panels is subdivided into three sections designed to dissipate a known amount of heat. The sections have heat dissipation rates of 20 watts (68 BTUH),* 40 watts (136 BTUH), and 60 watts (204 BTUH) per square foot of surface area. See Figure 4, page 14. It is generally accepted that 40 watts/foot^2 heat dissipation at this depth can keep pavements clear of snow and ice under most climatic conditions in New Jersey[2]. Thus, the heat dissipation rates of the embedded pipe panels can be roughly determined by a visual comparison of their melting effectiveness to that of the electrically heated reference panels. A two-inch layer of glass foam insulation was placed directly below one-half of the electrically heated portland cement concrete Panel #7. This insulation was included to test its effectiveness in reducing downward heat losses.

*BTUH - British Thermal Units per Hour

2. Ibid., page 5.



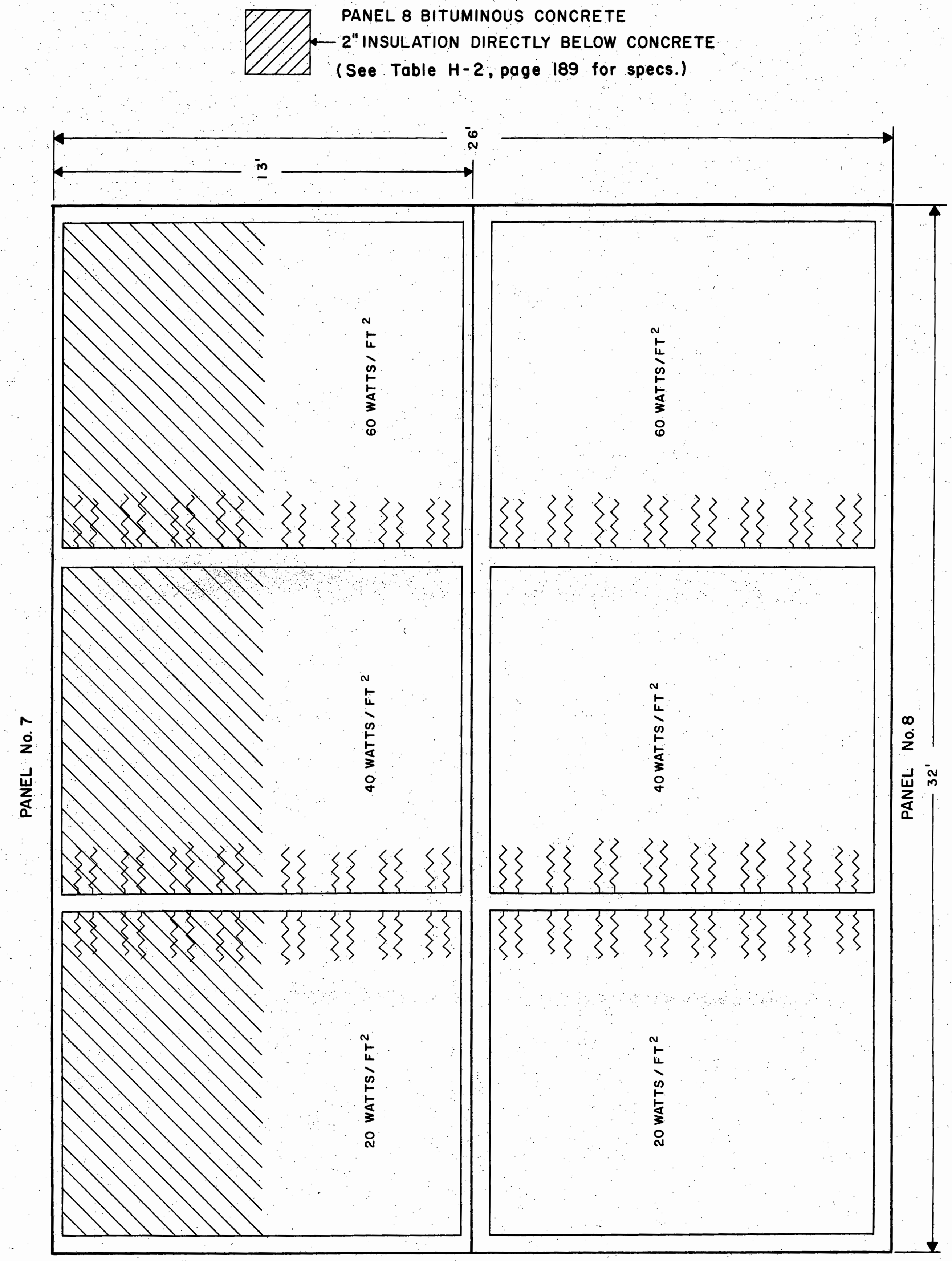
TWO TYPICAL EMBEDDED PIPE PANELS

FIGURE 3

FIGURE 4

ELECTRICALLY HEATED PANELS

PANEL 7 PORTLAND CEMENT CONCRETE
PANEL 8 BITUMINOUS CONCRETE



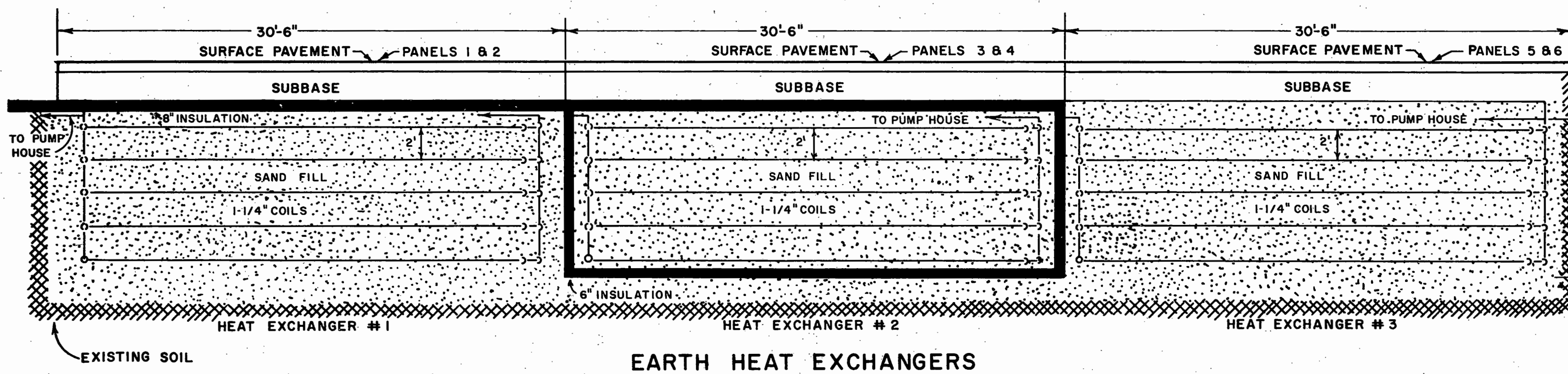
4.1.3 Heat Exchangers

Three independent heat exchangers are buried in the ground below the six embedded pipe panels. See Figure 5, page 16. Heat Exchanger #1 is buried beneath Panels #1 and 2; Heat Exchanger #2 beneath Panels #3 and 4; and Heat Exchanger #3 beneath Panels #5 and 6, respectively. Each exchanger consists of 2,000 linear feet of 1-1/4 inch wrought iron pipe arranged in a grid and buried at a depth of 3 to 13 feet in the earth. The grid, which measures 32' x 30.5' x 10', is made up of five layers of pipe installed with a horizontal and vertical spacing of two feet between pipes (Figure 5, page 16 and Figure 6, page 17). These pipes are immediately surrounded by sand fill which extends to the boundaries of the pipe grid. An eight-inch layer of expanded polystyrene foam insulation (1.5 lbs/ft^3) lies directly above Exchangers #1 and 2 and six-inch layers (1 lb/ft^3) enclose the remaining sides of Exchanger #2 (Figure 5, page 16 and Figure 6, page 17). No insulation was used with Exchanger #3. The sand fill heat exchangers are surrounded by the existing soil.

The horizontal layer of insulation used with Heat Exchangers #1 and 2 was employed to determine its ability to prevent heat stored in the earth during the summer months from dissipating to the atmosphere during the fall and winter. The additional insulation used with Heat Exchanger #2 was employed to determine its ability to prevent heat stored in the heat exchanger earth over the summer from dissipating to the surrounding earth in the fall and winter.

4.1.4 Heat Transfer Fluid, Flow and Pumping Equipment

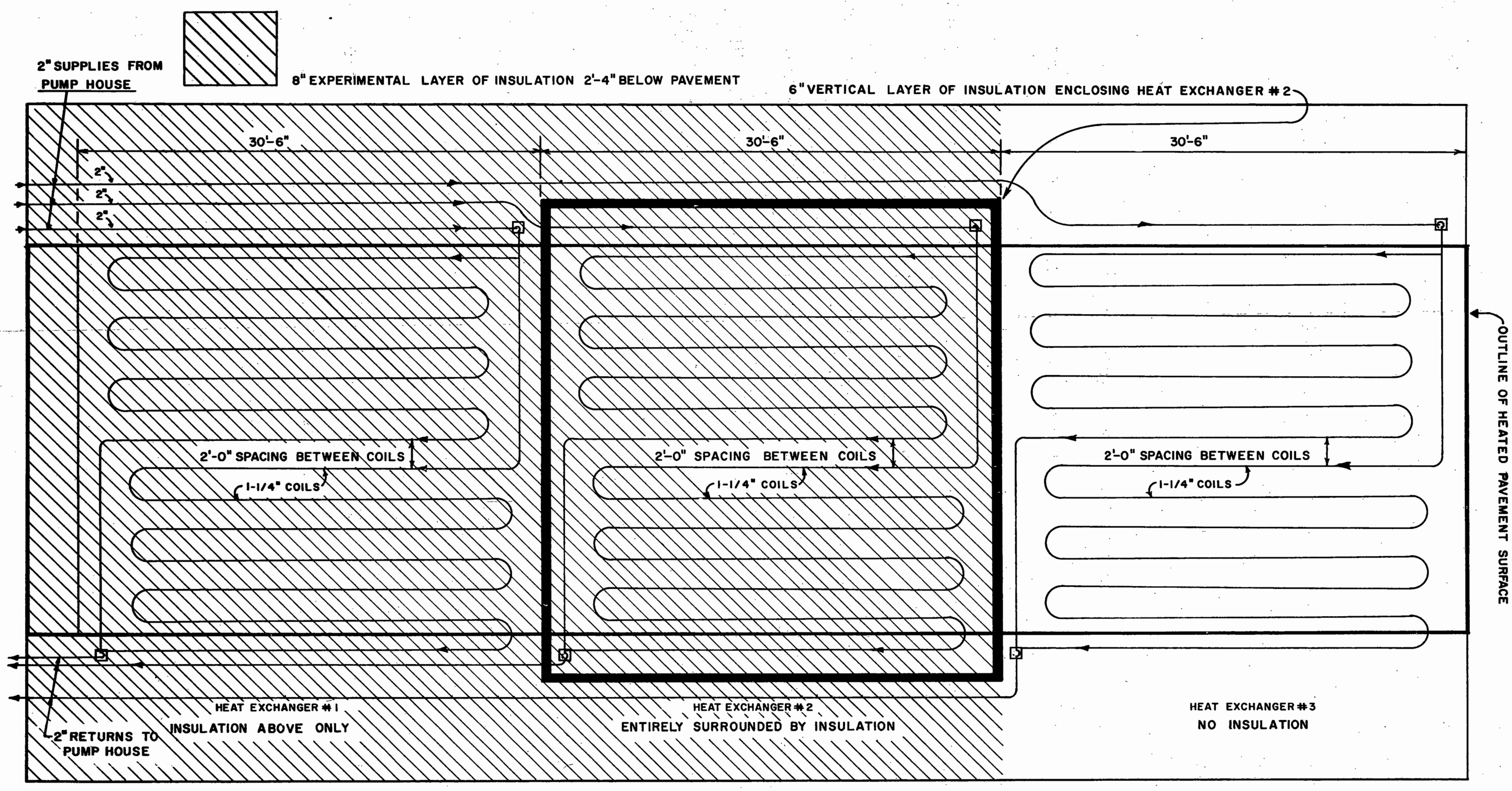
The heat transfer fluid is an antifreeze solution of approximately 60 percent water and 40 percent ethylene glycol by volume. This solution is obtained by mixing water and Prestone Antifreeze (manufactured by



EARTH HEAT EXCHANGERS

SECTION

FIGURE 5



EARTH HEAT EXCHANGERS

PLAN

FIGURE 6

Union Carbide Corporation) to a total of approximately 920 gallons. When the system is operated, the fluid is circulated in a closed piping loop from buried heat exchanger, to the pump house, to the test pavement, and back to the buried heat exchanger.

Proper fluid flow is maintained at the pump house (Figure 1, page 10 and Figure 7, page 19) by pumping and flow equipment. One set of equipment is shown in Figure 7 and consists of a 1/6 H.P. circulating pump, a flow meter, an air separator, a pressure gauge, an expansion tank, and control valves. There are three such sets in the pump house, one for every two embedded pipe heating panels. Rate of flow is controlled by the circulating pumps and regulating valves and is measured by Wallace and Tiernan, Inc.,glass tube, variable area flow meters which are accurate to ±0.5 gallons per minute. Fluid pressure is measured by 4-1/2" Bourdon tube gauges. The air separators remove air from the system thereby helping to provide unrestricted flow. The expansion tanks act as air reservoirs as well as allowing for the expansion of the ethylene glycol-water solution with temperature increases.

4.1.5 Temperature Measuring Instrumentation

The temperature of the earth, pavement, and ethylene glycol-water solution was monitored with 120, Model 401 Digitec general purpose thermistors. Air temperature was monitored with a Digitec Model No. 405 air temperature thermistor. For specifications, see page 185. These thermistors are electrical resistors which make use of a semiconductor whose resistance varies in a known manner with temperature. The locations of the thermistors in the heat exchangers, pavement, and pipes are shown in Figures 8, 9, and 10, pages 20, 21, and 22. Types A, B, and C thermistors are located in the test pavement at the depths shown in Figure 9. Type TW

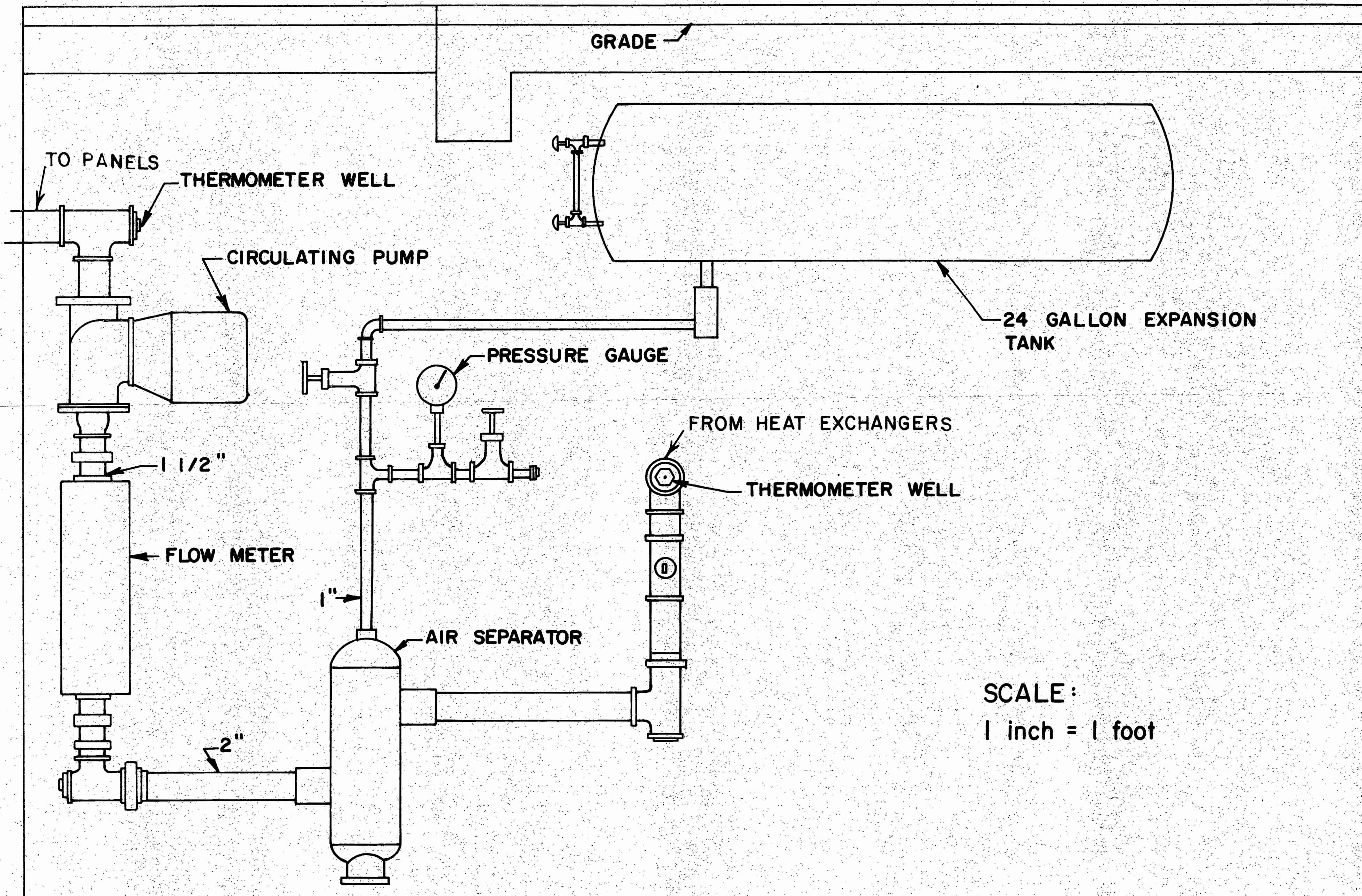


FIGURE 7

Basic Setup Of Pumping Equipment Located In The Pumphouse

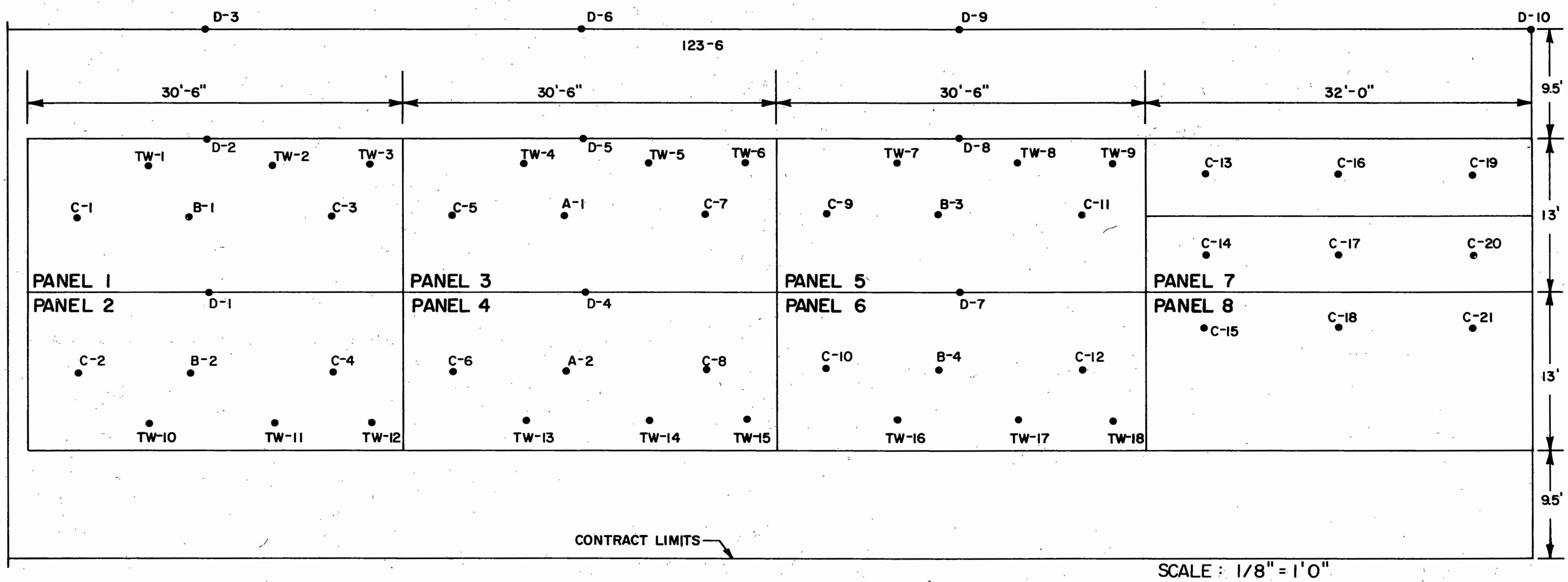


FIGURE 8.

LOCATION OF THERMISTORS

See Figure 9 and 10, next two pages for explanation of lettering code.

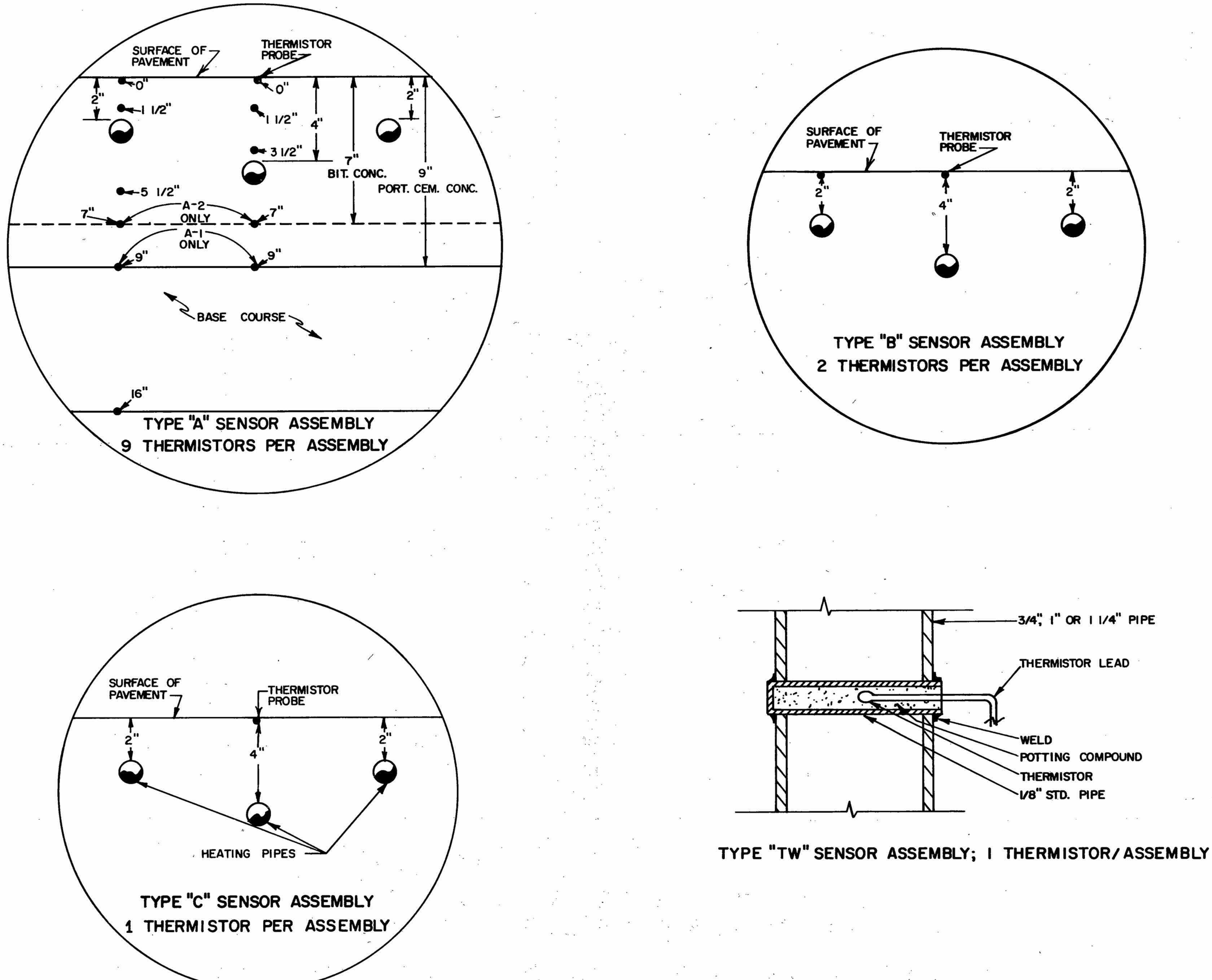
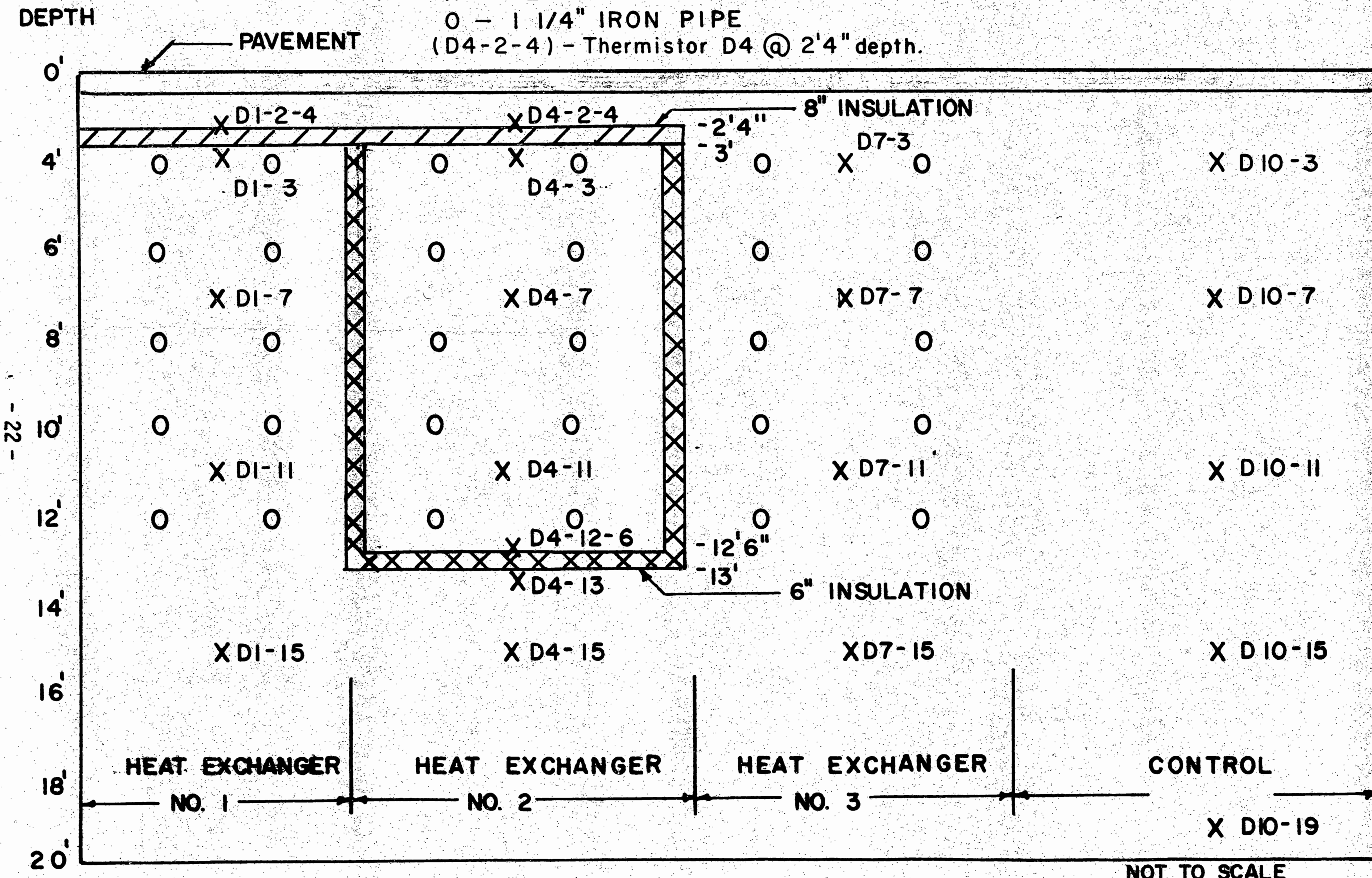


FIGURE 9.

SENSOR ASSEMBLIES – types A, B, C, & TW

FIGURE 10 - TYPE "D" SENSOR ASSEMBLIES

SECTIONED VIEW OF EXPERIMENTAL AREA
X - TEMPERATURE SENSOR (THERMISTOR)
O - 1 1/4" IRON PIPE
(D4-2-4) - Thermistor D4 @ 2'4" depth.



CONTROL THERMISTORS LOCATED OUTSIDE
OF HEAT EXCHANGERS

thermistors are located in the pipes embedded in the test pavement and are placed as shown in Figure 9. Thermistors types D1 to D9 are located within the earth of the heat exchangers. Type D10 thermistors are located in existing parking lot soil and serve as controls. See Figure 10. Leads from these thermistors are connected to a multi-conductor cable which runs from the heated pavement area to the gate house. See Figure 1, page 10. At the gate house, the cable is linked to a Digitec digital measuring and recording system (accuracy $\pm$0.3°F) composed of a digital thermistor thermometer, digital clock, multiplexer, scanner, and printer. See Figure G-4, page 185. The air temperature thermistor was mounted outside the gate house and its lead wire was connected directly to this Digitec system. The Digitec equipment could be set to sample and record from 1-100 temperature data points per scanning cycle. The time interval between scanning cycles could be set at 1, 5, 10, 30 or 60 minutes; and data point dwell could be varied from 0.1-10 seconds.

One hundred data points were read and recorded for one full scanning cycle. The time of the reading, and thermistor number and temperature were automatically recorded on paper tape by the printer. Because of the late arrival of some of the equipment, automatic operation of the Digitec system was not possible prior to the snow storm of March 3, 1971. Before this storm and after that of February 23-24, 1972, the reading registered by the digital thermometer was manually entered in a log book or on prepared forms. Digitec equipment failure led to the resumption of manual recording after the latter date.

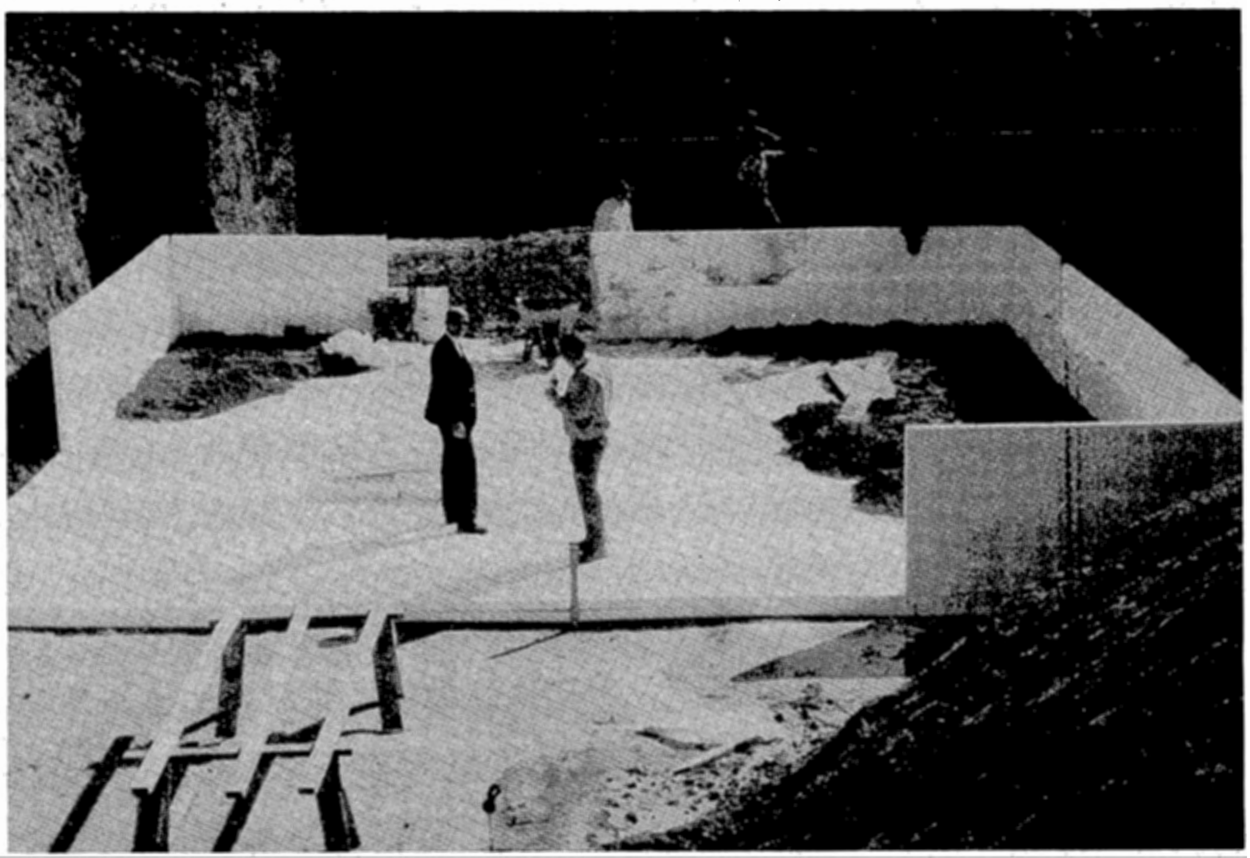
The panel input and output temperatures of the ethylene glycol-water solution were measured in the pump house by six Trerice alcohol thermometers and entered in a log book, prior to the date of February 17, 1971. On this day, the Trerice thermometers were replaced by six

Model 401 Digitec thermistors. These six thermistors were connected to the multiconductor cable running to the gate house so that they too could be automatically read. This was done since the Digitec thermistor and digital thermometer (accuracy ±0.3°F) provide a more exact measurement of these input and output temperatures than did the Trerice thermometers (accurate to ±1°F).

4.2 Construction of Pavement Heating System

4.2.1 Placement and Fabrication of Heat Exchangers

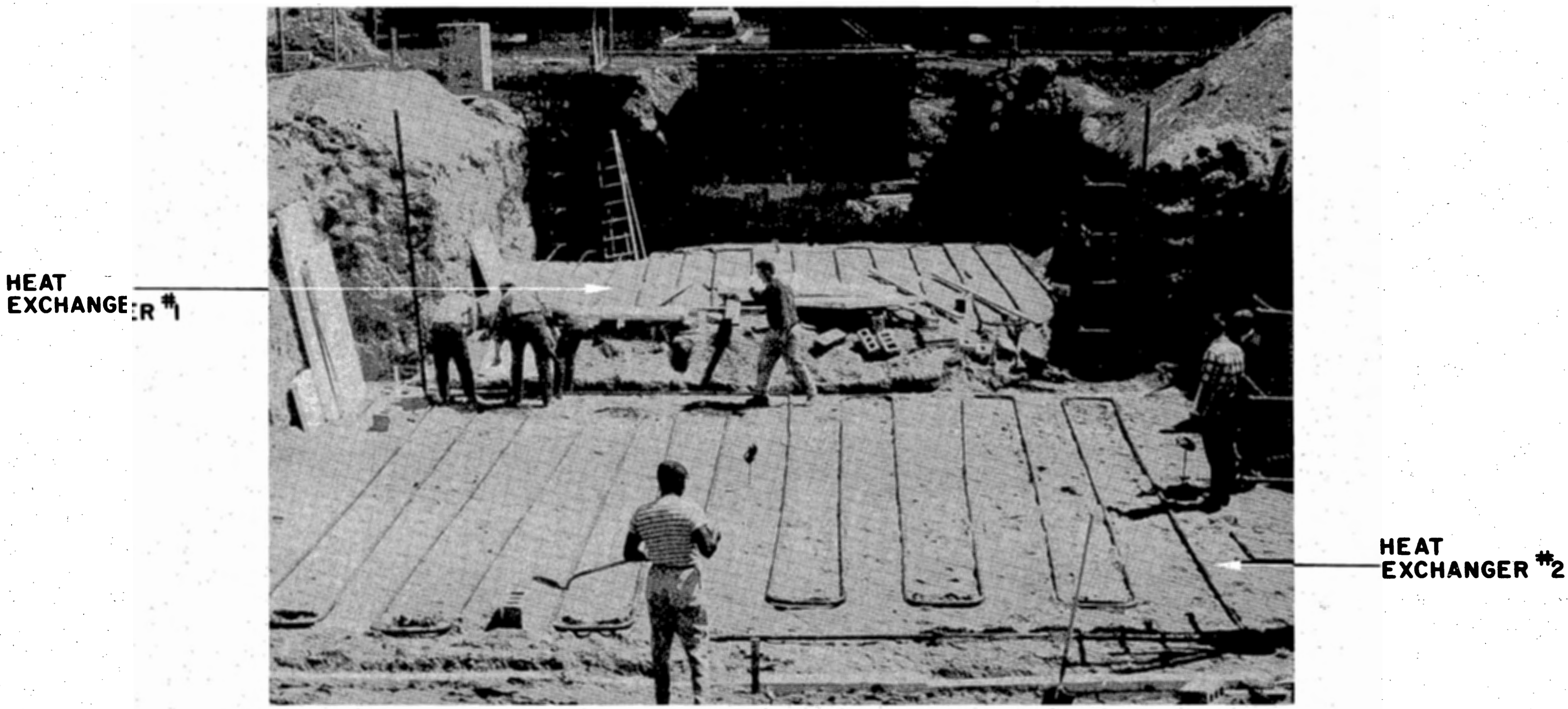
Construction began on April 7, 1969. A 100 feet x 40 feet area was first excavated by a bulldozer to a depth of 14 feet. All excavated material was trucked away as it was not considered suitable for backfill. The area was surveyed and the sites for the heat exchangers were layed out. Suitable sand backfill was dumped from trucks, and six inches were spread by hand over the entire area and compacted with a small hand operated compactor. For backfill gradation requirements, see Table H-1, page 188. In the area set aside for Heat Exchanger #2 a six inch horizontal layer of polystyrene insulation was placed on the sand base (Photograph 1, page 25). This layer was constructed from 4 feet x 8 feet x 3 inch blocks of insulation with all joints overlapped. Six inches of sand backfill was placed over this insulation and compacted. A layer of prefabricated 1-1/4 inch wrought iron pipe coils was then placed by hand on the compacted sand (Photograph 2, page 26). At this point a sequence of operations of placing and compacting sand backfill in 6 inch layers and the placement of 1-1/4 inch coils with a 2 feet separation between coil layers continued until all five layers of the heat exchanger were completed. See Figures 5 and 6, pages 16 and 17.



MAY 1969 PHOTOGRAPH 1

CONSTRUCTION OF HEAT EXCHANGER NO. 2

(6-INCHES OF INSULATION ENCLOSING HEAT EXCHANGER)



MAY 1969 PHOTOGRAPH 2

CONSTRUCTION OF HEAT EXCHANGERS NO.1 & NO.2

(1-1/4 INCH COILS ON 2 FOOT CENTERS)

As it was placed, a coil layer was connected to the preceding layer(s) and pipe joints were gas welded and tested for leaks by pressurizing the layers of coils to 150 pounds per square inch for 8 hours. After the construction of all the heat exchangers was completed, the entire system of heat exchangers was pressure tested at approximately 150 pounds per square inch for more than a week.

Some difficulty was encountered in compacting the sand above the insulation due to its resiliency, however, as successive layers of backfill were placed it was possible to achieve the specified compaction of at least 95% of maximum density.

The 6 inch thick vertical walls of insulation enclosing Heat Exchanger #2 were constructed of 4 feet x 8 feet x 3 inch blocks with all joints overlapped. See Photographs 1 and 3, pages 25 and 28. This insulation was put in place as the heat exchangers were being backfilled. Upon completion of backfill operations, an 8 inch horizontal layer of polystyrene insulation, constructed of 4 feet x 12 feet x 4 inch blocks, with all joints overlapped, was placed above Heat Exchanger #2.

Construction of the other two heat exchangers took place concurrently with that of Heat Exchanger #2 and in the same manner with these exceptions -- insulation was placed on top of Heat Exchanger #1 and no insulation was used with Heat Exchanger #3.

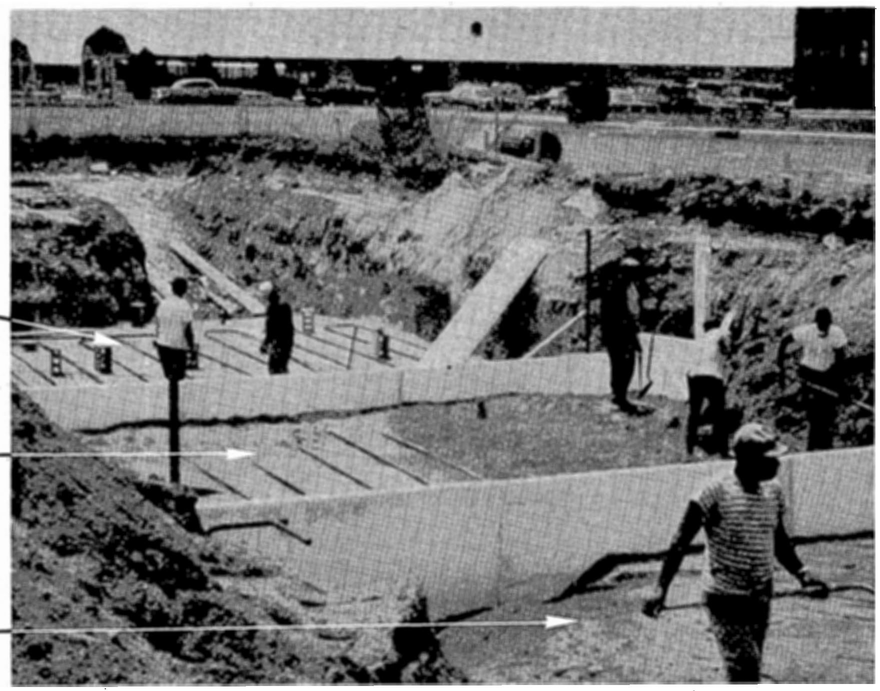
4.2.2 Pavement Subbase

Subsequent to placing the 8 inch layer of insulation, construction of the subbase and base courses for the surface pavement proceeded in a conventional manner. See Figure 11, page 29, for subbase and base course classi-

HEAT EXCHANGER NO. 3

HEAT EXCHANGER NO.2

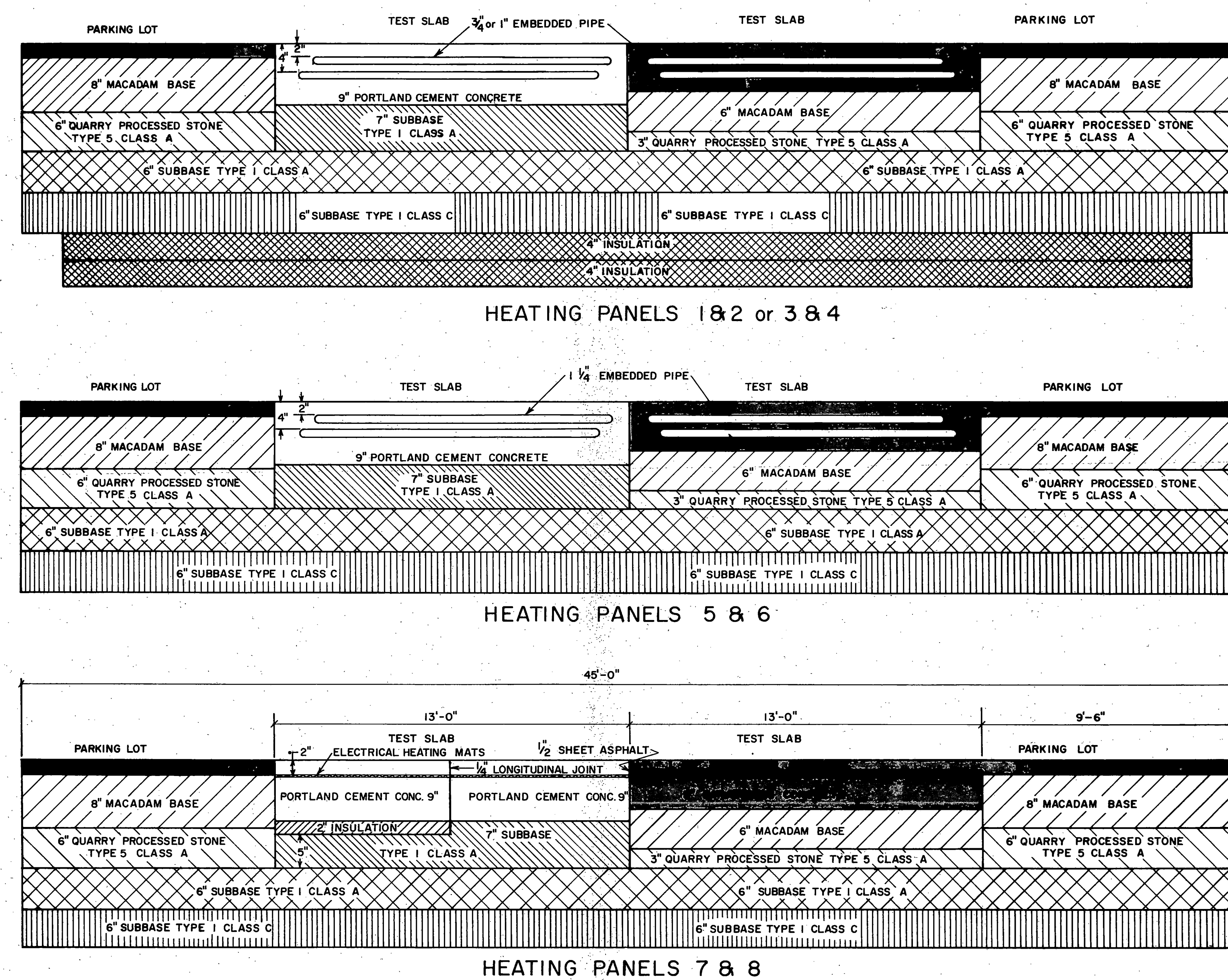
HEAT EXCHANGER NO.1



PHOTOGRAPH 3

CONSTRUCTION OF HEAT EXCHANGERS

(ONLY NO.2 AND NO.3 ARE SHOWN; NO.1 IN FOREGROUND)



TYPICAL SECTIONS — PAVEMENT & SUBBASE

FIGURE 11

fications and placement diagram.* Precaution was taken to maintain at least 6 inches of subbase material above the insulation during operation of heavy construction equipment, so that the insulation would not be damaged.

4.2.3 Portland Cement Concrete Pavement

Upon completion of the subbase and base courses, forms for the P.C.C. (Portland Cement Concrete) slabs were installed and the prefabricated wrought iron coils were placed within the forms at the specified heights by the use of "chairs" fabricated from 1/2 inch reinforcing rods. All pipe joints were gas welded and pressure tested at 150 pounds per square inch for eight hours. The coils for Panel #3 were fabricated at the site from standard weight polyvinyl chloride plastic pipe (Photograph 4, page 31). All joints were solvent welded and pressure tested at 150 pounds per square inch for eight hours.

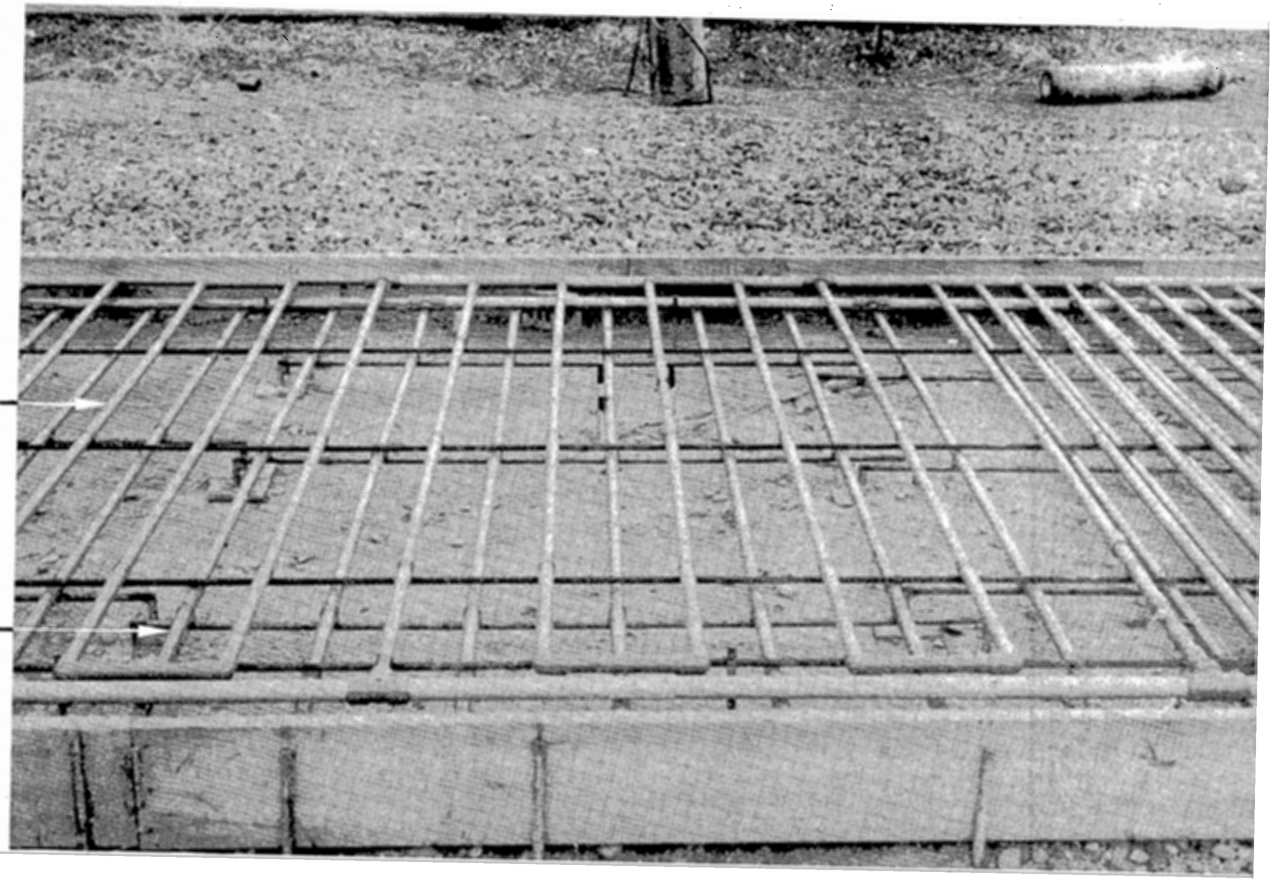
The 2" layer of glass foam insulation below Panel #7 was placed on the subbase as shown in Figure 11, page 29. Concrete was then poured to within 2" of finished grade level. Electrical heating mats were positioned and covered with the final two inches and the pavement was leveled off.

Portland Cement Concrete for this project was a standard pavement mix as used in a typical New Jersey state highway as of the time of construction. For gradation requirements, see Table H-1, page 188. Placement, finishing and curing of the concrete was accomplished according to standard specifications for highway construction in New Jersey.

4.2.4 Bituminous Concrete Pavement

The Bituminous Concrete was placed in four lifts on a 6 inch macadam base course. All four lifts were mix #5 as listed in Table H-1, page 188. After

*For further explanation of the requirements for the different subbase and base course classifications in effect at the time of construction, see the 1961 "Standard Specifications of the New Jersey Highway Department for Road and Bridge Construction" (Green Book) as amended.



OCTOBER 1969

PHOTOGRAPH 4

CONSTRUCTION OF PANEL NO. 3

(1 INCH PVC PIPES IN PORTLAND CEMENT CONCRETE)

placing and compacting the first lift, the prefabricated wrought iron coils to be embedded at a depth of 4 inches were placed on the hot surface and placing and compaction of the second lift began (Photograph 5, page 33). This operation was again repeated for the next layer of coils to be embedded at a depth of 2 inches. The bituminous concrete was placed mostly by hand although a spreader was used for the bottom and top courses. A 5 ton, 2 wheel roller was used to compact all four lifts. The only problem encountered was warping of the iron pipe due to heat from the hot mix. This may have resulted in the formation of voids either above or below some of the coils.

The electrical heating mats for Panel #8 were positioned after the compaction of the third lift had been completed. The mats were then covered with a 1/2" course of sand asphalt which was thereafter compacted. No tack coat was used since the third lift was still hot when the sand asphalt was placed. A 1-1/2" top course was then placed and compacted, see Figure 11, page 29.

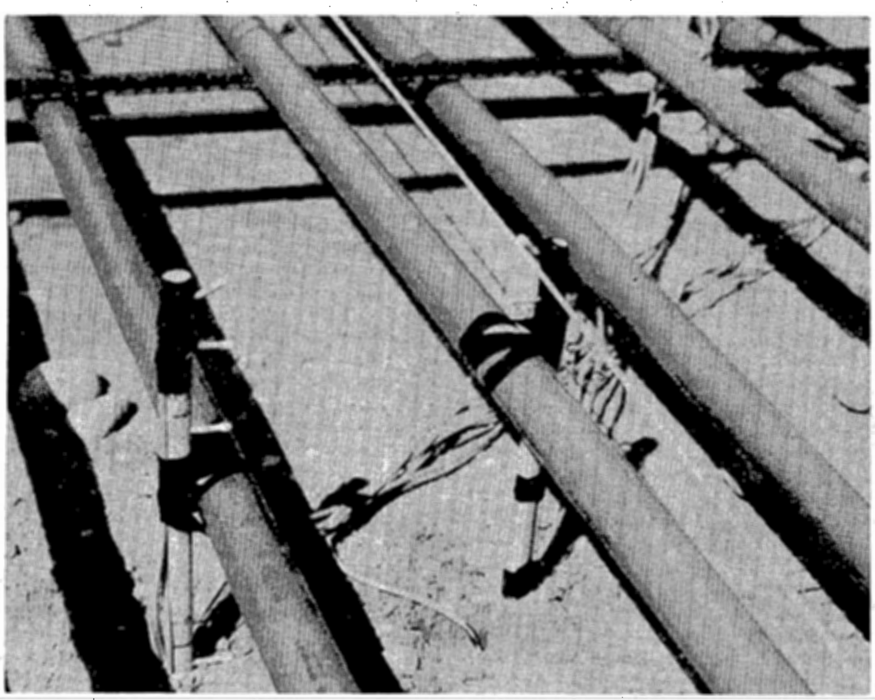
4.2.5 Placement of Thermistors

Thermistors within the heat exchangers were placed during the backfill operations. Thermistors in the earth adjacent to the heat exchangers were fastened to a wooden rod, at specified intervals, which was then inserted into a hole drilled to the proper depth. Positioning of the thermistors in both the P. C. C. and the B. C. (Bituminous Concrete) was by means of 1/2 inch wooden dowels driven into the base courses. The thermistors were inserted into holes drilled through the dowel and then secured with plastic tape (Photograph 6, page 34). Thermistor leads were run to junction boxes where they were connected to a multi-conductor cable which was run through conduit to the gate house. Here final connection to measuring instruments was made.

SEPTEMBER 1969 PHOTOGRAPH 5

CONSTRUCTION OF PANEL NO. 2

(3/4 INCH WROUGHT IRON PIPES EMBEDDED AT A 2-INCH DEPTH IN BITUMINOUS CONCRETE)



PHOTOGRAPH 6

POSITIONING OF THERMISTORS IN PAVEMENT

4.2.6 Temperature Recording Instrumentation

Temperature recording equipment was installed in the gate house in accordance with design Section 4.1.5, page 18. For equipment interconnection diagram and equipment specifications refer to Figure G-4, page 185.

4.2.7 Pumphouse

A 10 x 10 x 7.5 foot reinforced concrete pumphouse was constructed below grade. It is located adjacent to the heated pavement area and houses the flow controlling equipment mentioned in Section 4.1.4 page 15, as well as electrical power controls. Drainage is provided by a 1/3 H. P. submersible sump pump. The entrance to the pumphouse is a 1/4" aluminum diamond plate hatch cover.

4.2.8 Pipe Insulation

Piping in the pumphouse was insulated with 1/2" thick fiber glass low pressure pipe insulation. Two inch supply and return mains that extend from the pumphouse to the heating panels were insulated with 1/2-inch of O-C (Owens Corning) flexible insulation.

4.3 Method of Operation

The dates between which the pavement heating system was operated are listed in Table 1, page 36. The purpose and type of operation as well as a listing of the heat exchangers and heating panels in operation are also shown in the table.

4.3.1 Definitions

The words "selective" and "continuous" as used in Table 1 and elsewhere in this report when referring to types of operation are defined as follows:

TABLE 1

METHOD OF OPERATION

Dates	Purpose	Type of Operation	System in Operation	Hours
Winter 1969-70 (Dec. 25- Feb.14)	Snow Melting	On before or during snowstorms	HE 1 - P 1 & 2 * HE 2 - P 3 & 4 PANELS 7 & 8 HE 3 - P 5 & 6	210 Hrs. 210 Hrs. 210 Hrs. 130 Hrs.
Summer 1970 (June 4- Oct. 6)	Storing heat in earth	Selective	HE 1 - P1 & 2 HE 2 - P3 & 4 HE 3 - P5 & 6	715 Hrs. 715 Hrs. 715 Hrs.
Winter 1970-71 (Dec. 21 -April 7)	Snow Melting	On before or during snowstorms	HE 1 - P1 & 2 HE 2 - P4 HE 3 - P5 & 6 PANELS 7 & 8 HE 2 - P3	105 Hrs. 105 Hrs. 105 Hrs. 105 Hrs. 60 Hrs.
Summer 1971 (March 16- Oct.6)	Storing heat in earth	Continuous	HE 3 - P5 & 6	4880 Hrs.
Winter 1971-72 (Dec. 30-Feb.24)	Snow Melting	Continuous	HE 3-P1,2,5 & 6 PANELS 7 & 8	1440 Hrs. 85 Hrs.
Winter 1973-74 (Dec. 16- Feb.26)	Snow Melting	On during Snowstorms	HE 3 - P5 & 6 HE 3 - P5 HE 1 - P1 HWH** P1 & 2 HWH - P1 & 5	150 Hrs. 1 Hr. 1 Hr. 95 Hrs. 17 Hrs.
Fall 1974 (Oct. 23- Nov.13)	Heat Extraction rates	Continous	HE 3-P1,2,5 & 6	512 Hrs.
Winter 1974-75 (Jan. 20- Feb. 5)	Heat Extraction rates	On during snowstorms	HE 3-P1,2,5 & 6	13 Hrs.

* HE 1 - Heat Exchanger #1. * P 1 - Panel #1. **HWH - Hot Water Heater

Selective Operation -

Operation of the system only during those times when temperature data indicated that heat was being transferred to the earth.

Continuous Operation -

Operation of the system 24 hours a day during all days of an operational period.

4.4 Evaluation of Operation

4.4.1 Snow Melting and Heat Dissipation Rates

This section presents the snow melting rates and heat dissipation rates determined for the eight pavement heating panels during the four years of winter operation.

The results of operation of the embedded pipe heating panels are covered for Winters 1969-70, 1970-71, 1971-72, and 1973-74. For the first three of these winters, the embedded pipe heating panels were supplied with heat from the earth. During Winter 1973-74, several embedded pipe panels were supplied with earth heat while others were supplied with heat by a 30 kw electric hot water heater which had been installed in the pumphouse during the Fall of 1972. Summer operation for the purpose of storing heat in the earth preceded Winters 1970-71 and 1971-72.

For the electrical resistance heating panels, the results of operation for Winters 1969-70, 1970-71, and 1971-72 are presented.

4.4.1.1 Embedded Pipe Heating Panels

The same pattern of snow melting was evident for the embedded pipe heating panels for all winters.* After system activation, snow first begins to melt

*Only the pipes embedded at a 2" depth were used during winter operation.

directly over the embedded pipes. As the concrete slab warms up more uniformly, snow melting gradually spreads out and away from the pipes until all snow between them has melted. This pattern of snow melting is illustrated in Photograph A-1, page 86. The flow of heat via the heat transfer fluid from the earth to the pavement and snow results in the melting.

For all winters, the best melting occurred on the sections of portland cement concrete pavement containing pipes embedded at a 2" depth with a 6" center to center pipe spacing. Generally, portland cement concrete panels were 50 percent more effective in snow melting than their corresponding bituminous concrete panels. Also, panel sections containing pipes of closer spacing and larger pipe diameters were usually more effective snow melters. Accordingly, P5 (6)* and P1 (6) were the panel sections that produced the fastest melting; and P6 (18), P4 (18) and P2 (18) the slowest melting. An exception to the rule was Panel #3 which contained plastic pipes of 1" diameter; it did not melt snow as effectively as Panel #1 (wrought iron pipes of 3/4" diameter.)

In the following sections of this report the snow melting rates of panel sections were determined by several different methods depending upon the quantity and quality of recorded observations. Snow accumulation and observation times were obtained from a log book which is kept for each snow storm. Since an observer was not usually present when a given section was clear of snow, it was not possible to accurately determine the melting rates for each storm. Melting rates calculated by both methods are considered conservative. Melting rates calculated by the more conservative method, represent the melting rates of the slowest melting portions of a heated panel section. By actual observation, the rate of melting observed directly above the embedded pipes was normally more than twice as rapid.

*Panel 5 (6 inch pipe spacing), for further explanation of this notation see Appendix A, Section A.1, Table A-1, page 81

Heat dissipation rates were calculated from the input and output temperatures of the heating fluid for each spacing of coils in the various panels and from the flow rate of the heating fluid. For a panel section, the input temperature of the heating fluid was measured by temperature sensors located in the pumphouse. The output fluid temperature for a panel section was measured by TW temperature sensors located at the exit of the pipe coils. See Figure 3, page 13, for the position of the TW thermistors. A sample calculation of heat dissipation rates is shown in Section F.4, page 178.

4.4.1.1.1 Winter Operation 1969-70*

The pavement heating system was put in operation shortly before or during snowstorms. Panels 1 and 2, 3 and 4, and 5 and 6, were connected to Heat Exchangers #1, 2, and 3 respectively. Panels #1, 2, 3 and 4 were in operation during all snowstorms of this winter. Panels #5 and 6 - Heat Exchanger #3 were in operation for the first three snowstorms, but they were thereafter not operated due to a minor leak at a valve in the pumphouse. Panels 1, 2, 3, and 4 were operated for approximately 210 hours; Panels 5 and 6, 130 hours. Glycol-water temperature was in the range of 40 to 52°F (see Table B-4, page 102). For Winter 1969-70, air temperature averaged 32.5°F and snowfall was measured at 26.6 inches.[3]

The best melting embedded pipe sections were P1 (6) and P5 (6). From observations made during and after snowstorms, these sections were judged better in melting ability than the 20 watts/foot^2 area of electrically

*For details of winter operation for all years, see Appendices B, C, D, and E. Operating procedure, storm observations, photographs, and data are included.

[3]Climatological Data, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. See Table H-4, pages 192-196.

heated panel #7--P7 (20W)*. During most storms, it is estimated that the melting rates of P1 (6) and P5 (6) were between 0.20 and 0.30 inches of snow per hour. The highest melting rate calculated for these two panel sections was 0.4 inches per hour for the storm of December 25-29, 1969. In reference to the other embedded pipe panel sections, as already mentioned, sections of portland cement concrete, closer pipe spacing, and larger pipe diameters were most effective in melting snow.

For this winter, heat dissipation rates and applicable pavement surface temperatures for the pavement pipe panels are presented in Table B-1, B-2, B-3, pages 96-101**. For the fifth snowstorm of this winter, only pavement surface temperatures are presented. Heat dissipation rates were not presented for the last snowstorm of this winter or for subsequent winters, because temperature data used in this calculation became questionable after the snowstorm of January 20-21, 1970***. Pavement temperatures listed in Table B-1 were measured at the surface midway between the pipes embedded at a two inch depth. Figure 9, page 21, illustrates the locations of these thermistors. As shown in Table B-1, heat dissipation rates for the embedded pipe panel sections varied from approximately 5 to 115 BTU per hour per square foot. As expected, the highest heat dissipation rates occurred for P1 (6) and P5 (6) and averaged nearly 100 BTU per hour per square foot.

4.4.1.1.2 Winter Operation 1970-71

The pavement heating system was put in operation shortly before or

*See Section A-1, pages 81-83 for explanation of this notation.

**See Appendix Section A.3 for table format and B.4, page 102 before proceeding into Tables B-1, B-2, B-3.

***Questionable temperature data yielded by the TW thermistors shown in Table H-3, page 190.

during snowstorms. Panels 1 and 2, 3 and 4, and 5 and 6 were connected to Heat Exchangers #1, 2, and 3, respectively. Panels 1, 2, 4, 5, and 6 were in operation during all snowstorms. Panels #3 was only operated during the first three snowstorms; thereafter it was not operated due to a leak which was traced to the plastic pipe embedded at a 2" depth. Panels 1, 2, 4, 5 and 6 were operated for approximately 100 hours; Panel 3, 60 hours. Glycol-water temperature ranged from 46.5° to 61°F (Table C-2, page 129). Air temperature averaged 34.9°F and snow fall was 22.7 inches.

The rate of snow melting of all embedded pipe panels was approximately the same as for the previous year. The most effective melting occurred on P1 (6) and P5 (6) and once again it is estimated that during most snowstorms the melting rates of P1 (6) and P5 (6) were betweed 0.2 and 0.3 inches of snow per hour. The highest melting rates determined for these two panel sections were roughly 0.7 inches per hour for P1 (6) - Storm #5; and 0.5 inches per hour for P5 (6) - Storm #8.

For snowstorms of this winter, pavement surface temperatures and corresponding surface conditions are presented in Table C-1, pages 121-128*. As mentioned, heat dissipation rates will not be presented for this winter; however, it is believed that they were nearly the same as those for the Winter 1969-70, since snow melting rates determined for both winters were approximately the same.

4.4.1.1.3 Winter 1971-72

On December 30, 1971, Heat Exchanger #3 which had previously serviced two panels (P5 and P6) was adapted to service four panels (Nos. 1, 2, 5 and 6). From this time forth the heat exchanger was operated continuously -

*See Appendix A, pages 80-87, for Notation and Terminology used in Table C-1.

i.e. 24 hours a day - for the duration of the winter. Heat Exchanger #1 and 2 and Panels 3 and 4 were inactive. Glycol-water temperature ranged from 35° to 55°F (Figure G-3,page 184). Air temperature averaged 37.4°F and snowfall was 14.9 inches.

A reduction in snow melting ability was apparent for this winter. The best melting panel sections were again P1 (6) and P5 (6), but their melting ability was reduced. The melting ability of these panel sections was judged worst than P7 (20W). It is estimated that during most snowstorms, P1 (6) and P5 (6) melted snow at a rate of between 0.15 and 0.20 inches per hour. Similar decreases in melting rates were found for all embedded pipe panel sections. Table C-1 pages 121-128 lists pavement surface temperatures and corresponding surface condition for the snowstorms.

4.4.1.1.4 Winter Operation 1973-74

During Winter 1973-74, a 30 kilowatt electric hot water heater was used to supply an average temperature (90°F) ethylene glycol-water solution to embedded pipe panels.* The hot water heater serviced Panels 1 and 2 (95 hours) and Panels 1 and 5 (17 hours). For most of this winter, Panels #5 and 6 were connected to Heat Exchanger #3; this hook-up was operated for 150 hours. Heat Exchanger #2 and Panels #3 and 4 were inactive during this winter. The hot water heat system and the earth heat system were usually operated simultaneously during snowstorms. The glycol-water temperature ranged from 42.5° - 54.5° for the Heat Exchanger #3 system. The glycol-water temperature for the hot water heat system averaged 90°F** and the

*See Section E.1.1, page 154, for additional information on water heater.

**The hot water heater required over 3 hours to warm the heating fluid from the starting temperature (roughly the pavement temperature) to the average operating temperature (90°F), when connected to Panels 1 and 2. When connected to Panels 1 and 5 the time is increased to over 6 hours.

highest supply temperature recorded was approximately 120°F. Air temperature averaged 37.3°F and 24.8 inches of snow fell.

When supplied with hot water heat, embedded pipe panels melted snow more effectively than when supplied with earth heat. For this winter, the most effective embedded pipe panel sections had melting rates which were usually 3 to 4 times higher than those calculated for Winters 1969-70 and 1970-71, when these same panel sections were supplied with earth heat. During Winter 1973-74, P5 (6) and P1 (6) had melting rates which averaged approximately 1 inch per hour. Similarly, increases in melting were observed for all embedded pipe panel sections supplied by the hot water heater.

As in previous winters, portland cement concrete panel sections of closer pipe spacings and larger pipe diameters were better snow melters.

Embedded pipe panels #5 and 6 when serviced by Heat Exchanger #3 melted snow at approximately the same rates as those observed in Winters 1969-70 and 1970-71. The greatest melting rate determined for these panels was 0.40 inches per hour for P5 (6) during the snowstorm of January 4th.

For several snowstorms of this winter, pavement surface temperatures and corresponding surface condition for both hot water heated and earth heated panels are listed in Table D-1, pages 147-152.

4.4.1.2 Electrical Resistance Heating Panels

The electrical panels were designed to dissipate a known amount of heat. The 60 watts/foot^2, 40 watts/foot^2, and 20 watts/foot^2 sections dissipated 204 BTU per hour, 136 BTU per hour, and 68 BTU per hour, respectively.

Electrical resistance Panels #7 and 8 were operated for approximately 210 hours, 105 hours, and 85 hours during the Winters of 1969-70, 1970-71 and 1971-72, respectively. Performance of these panels was essentially the same for all winters. As mentioned earlier, Panel #7 was constructed of Portland Cement concrete; Panel #3, of Bituminous concrete. Approximate average melting rates for these panels was P7 (60W)*- 0.65 in/hr; P8 (60W) - 0.45 in/hr; P7 (40W) - 0.30 in/hr; P8 (40W) - 0.25 in/hr; and P7 (20W) and P8 (20W) - 0.20 in/hr. In almost all snowstorms the 40 and 60 watts per square foot sections of panels 7 and 8 melted snow more effectively than any of the embedded pipe panels supplied with earth heat by the underground heat exchangers. During most storms, the rate of melting on the uninsulated portion of Panel #7 exceeded that on the insulated portion.

Though the electrical resistance panels and the hot water heated embedded pipe panels were never operated during the same snowstorm, a comparison of recorded observations for several winters indicates that the snow melting ability of the 60 watts per square foot section of Panel #7 exceeded all hot water heated panel sections except P1 (6) and P5 (6).

For observations of the snow melting performance of the electrical resistance panels, see "Storm Records", Appendix B, pages 90-93, Appendix C, pages 104-114, and Appendix D, pages 132-141, and "Photographs", Appendix C, pages 115-119, and Appendix D, bottom photographs on pages 143 and 145.

4.4.1.3 Summary of Snow Melting and Heat Dissipation Rates

For all winters, the most effective snow melting and highest heat dissipation rates for pavement panels supplied with earth heat occurred on sections of portland cement concrete panels containing wrought iron pipes embedded at a depth of 2 inches and spaced on 6 inch centers. Generally, portland cement concrete panels were 50% more effective in snow melting than their corresponding bituminous panels. Panel sections of the closest pipe

*Panel #7 (the 60 watts per square foot section). See Section A.1, page 81, for explanation of notation.

spacing and largest pipe diameters were the best snow melters.

When pavement pipe panels were supplied with a higher temperature heating fluid (100°F) by a 30 kilowatt hot water heater, the most effective melting panel sections were able to melt snow three to four times as rapidly as when supplied with earth heat.

In most snowstorms, the 40 and 60 watts/ft^2 sections of the electrically heated reference panels produced better melting than pavement pipe panels supplied with earth heat.

4.4.2 Evaluation of Summer Operation for Heat Storage

For the purpose of storing heat in the earth, two methods of summer operation - namely, selective and continuous - were investigated.

4.4.2.1 Selective Operation

From June 4 to October 6, 1970, the pavement heating system was selectively operated for 715 hours. Selective operation implies that heat exchangers and their associated pavement panels were kept in operation whenever temperature data (the temperature of the glycol-water solution entering and leaving the heat exchanger) indicated that heat was being transferred from the pavement to the earth. On a daily basis department personnel drove to the test site, monitored the before mentioned temperature data, and left the system in operation if heat storage was indicated. The temperature of the earth within the heat exchangers ("D" thermistor readings) was recorded on a weekly basis when possible.

During operation, the glycol-water solution circulated along a route through the pavement pipes (only those embedded at a 2" depth), down to the buried earth heat exchanger, and back again to the pavement, at a rate of from 5-20 gallons per minute. In the process, heat from the pavement was extracted by the fluid and transferred to the earth in the immediate vicinity of the underground heat exchanger. All three heat exchanger systems were operated for approximately the same number of hours, at approximately the same time. Parking on the pavement above all the panels was not restricted.

4.4.2.1.1 Heat Storage

The average temperature of the earth within a heat exchanger is an indication of the heat stored therein; therefore, the goal of a heat storage operation is to maximize this temperature.

The effects of 1970's selective summer operation on the temperature of the earth within the three heat exchangers is indicated in Figure G-1, page 182. The effect of 1970's selective operation on heat stored in the earth (millions of BTU's) is shown in Figure G-2, page 183. Figure G-1 indicates the average earth temperature within the heat exchangers from October 1, 1969 to May 1, 1972 as calculated according to the method outlined in Section F.2, page 177. The figure also indicates the control earth temperature which is the average temperature of the soil 32 feet from the nearest heat exchanger. The control earth temperature is calculated from the D-10 thermistor readings* according to the method outlined in Section F.2, page 177.

The degree to which 1970's selective summer operation increased the heat stored in Heat Exchangers #1 and 2 can be seen by examining Figure G-1, page 182, during the time periods June 4 to October 6, 1970 and June 4 to October 6, 1971.

*See Figure 8, page 20, and Figure 10, page 22 for location of D-10's.

Note that Heat Exchangers #1 and 2 were not operated during the summer of 1971. A numerical estimate of the increase in stored heat can be made by looking at October 6 of both years. On October 6, 1971, the average earth temperatures of Heat Exchangers #1 and #2 were 67.5°F and 70.0°F, respectively. On October 6, 1970, they were 76 °F and 79.5°F, respectively. This represents an increase of 8.5°F for Heat Exchanger #1 and 9.5°F for Heat Exchanger #2. Adjusting for the fact that the control earth temperature was 1.5°F higher on October 6, 1970, the real increases in temperature are reduced to 7.0°F and 8.0°F for Heat Exchangers #1 and #2, respectively. Thus, by October 6, selective summer operation increased the average earth temperatures and consequently the heat storage of Heat Exchangers #1 and #2 by approximately 10.4% and 11.4%, respectively. A similar numerical estimate could not be calculated for the increase in the heat storage of Heat Exchanger #3 due to selective summer operation because earth temperature data is not complete for summers when this heat exchanger was not operated.

The selective summer operation of 1970 had the effect of raising the average earth temperature of Heat Exchanger #2 higher than that of the other two heat exchangers. As shown in Figure G-1, page 182, the highest average temperatures of the earth within Heat Exchangers Nos. 1, 2 and 3 during the period of selective operation were 81.0°F (August 19), 84.5°F (September 2), and 80.5°F (August 19), respectively. These temperatures were 12°F, 13.5°F and 11.5°F, respectively, above the control earth temperature. By the end of the period of selective summer operation, more heat was stored in the earth within Heat Exchanger #2 than either of the other heat exchangers. This is indicated by the fact that on October 6, 1970 the average earth temperatures of Heat Exchangers Nos. 1, 2, and 3 were 76.0°F, 79.5°F and 74°F, respectively.

4.4.2.2 Continuous Operation

Heat Exchanger #3 (Panels 5 and 6) was operated continuously from June 4 to October 6 of 1971 for a total of 2,976 hours. Continuous operation implies that the system was active 24 hours a day during the test period whether or not heat transfer to the earth was assured.

The system was checked for proper operation and on a weekly basis. Earth temperature readings were also taken at this time. Flow rate of the glycol-water solution was set at 15 gallons per minute. Parking on the pavement above the panels was not restricted.

4.4.2.2.1 Heat Storage

The effects of continuous summer operation on the average temperature of the earth within Heat Exchanger #3 is indicated in Figure 12, page 49 and Figure G-1, page 182. The highest average temperature of the earth within Heat Exchanger #3 during the period of continuous operation was 80°F on August 18. This temperature was 11°F above the control earth temperature.

4.4.2.3 Comparison of Selective and Continuous Operation

A comparison of these types of operation could only be made for Heat Exchanger #3 since Heat Exchangers Nos. 1 and 2 were not operated over the summer of 1971.

4.4.2.3.1 Heat Storage

To compare two heat storage operations during two different years, however, normal variations in the temperature of the earth must be considered. These normal fluctuations are indicated by the control earth temperature--the temperature of the soil outside of the system (See Figure 13, page 50). Thus

FIGURE 12

AVERAGE EARTH TEMPERATURE WITHIN HEAT EXCHANGER NO. 3

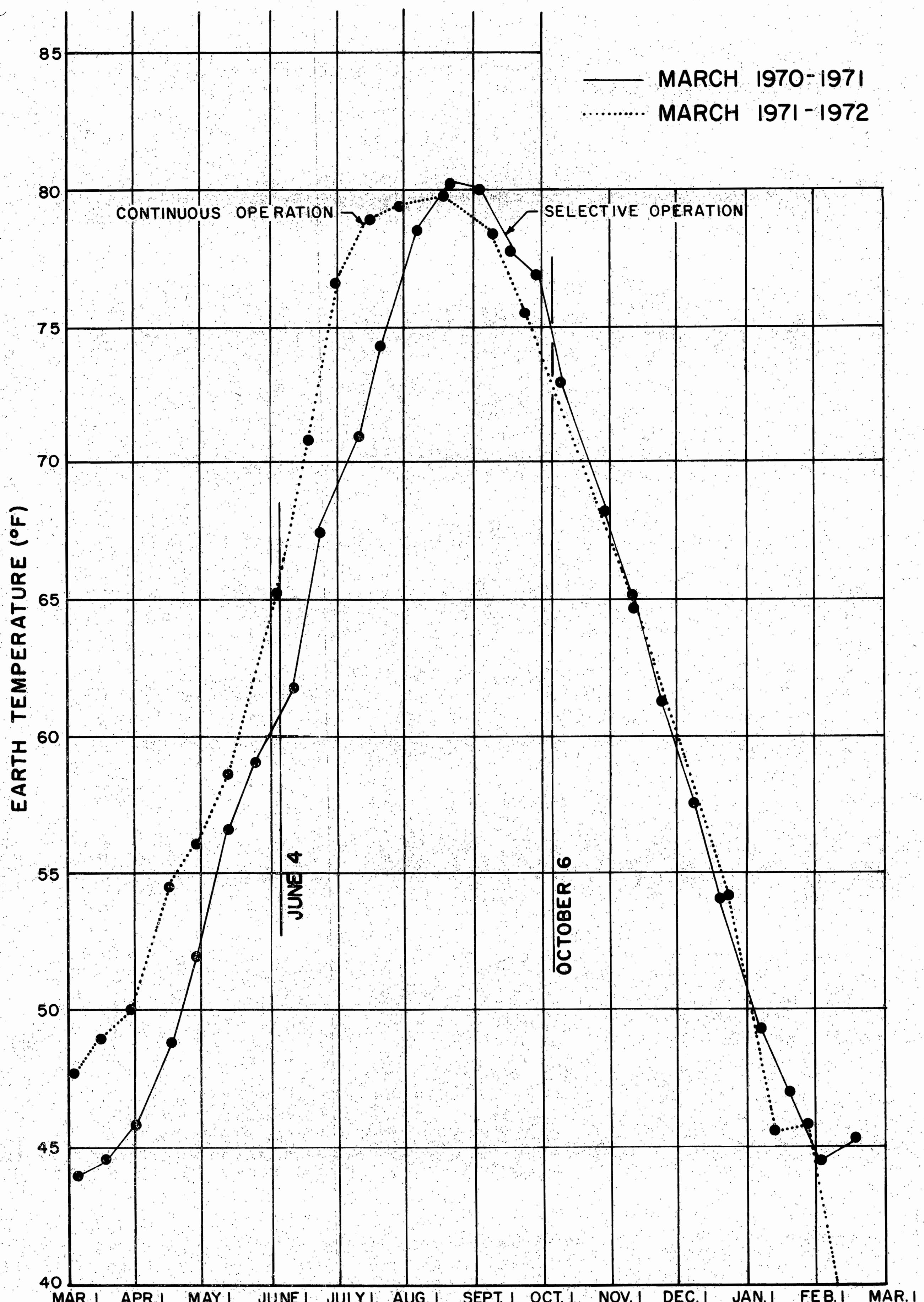
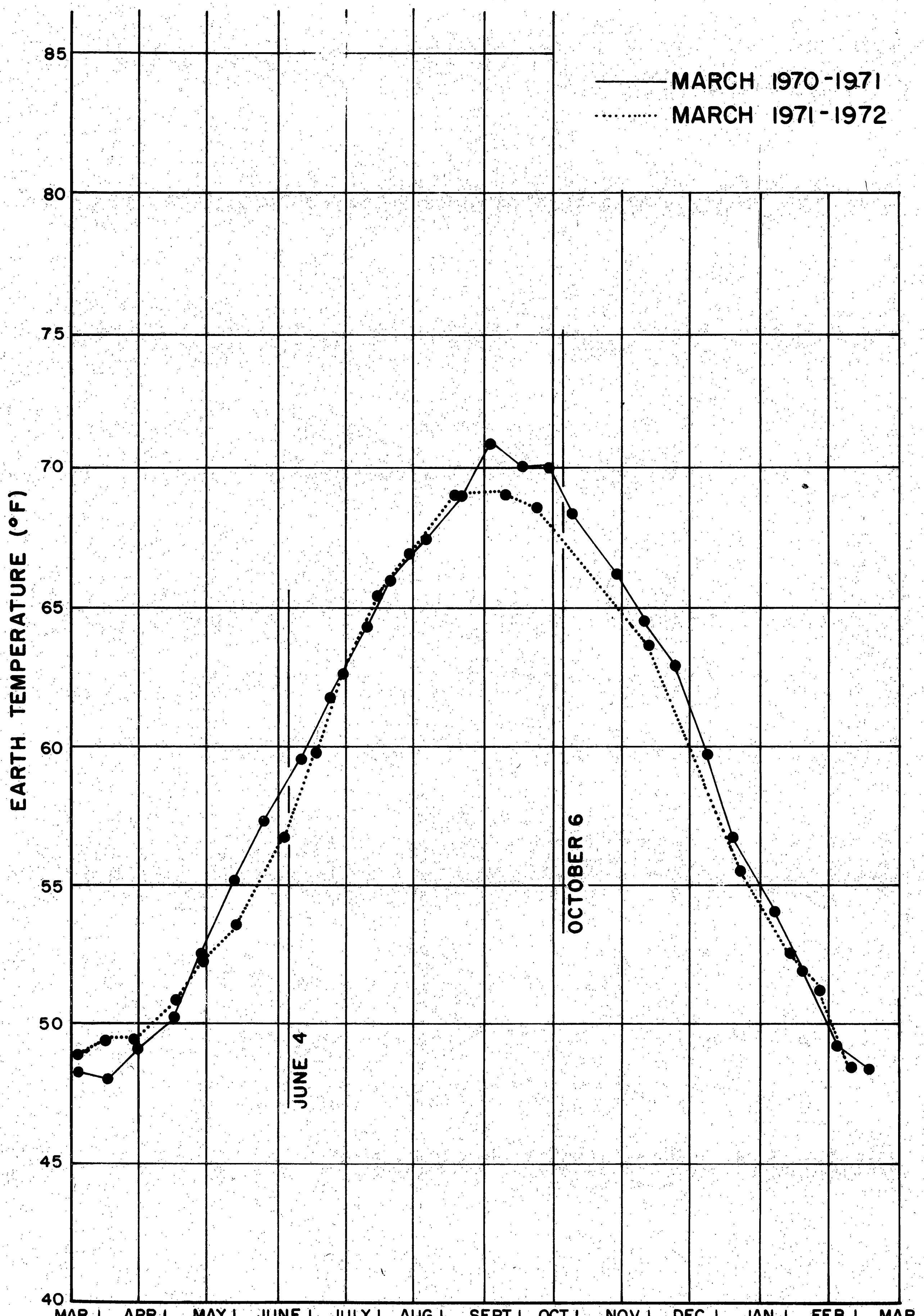


FIGURE 13

AVERAGE TEMPERATURE OF CONTROL EARTH



the temperature difference between heat exchanger earth and control earth at the end of the test period is an indication of the heat storing ability of a particular operating method.

Accordingly, the temperature of Heat Exchanger #3 and the control earth temperature were examined on October 6 of both 1970 and 1971. On October 6, 1971, the average temperature of the earth within Heat Exchanger #3 was 72.5°F, and control earth temperature was 67°F; while on October 6, 1970 the average temperature of the earth within Heat Exchanger #3 was 74°F and control earth temperature was 68°F (Figures 12 and 13 pages 49 and 50). Continuous operation for 2976 hours and selective operation for 715 hours both raised the earth temperature of Heat Exchanger #3 to approximately an equal number of degrees (5.5-6.0°F) above control earth temperature, thus they are approximately equal in heat storing ability for their respective operational hours.

4.4.2.3.2 Operation Cost

A. Electricity

A calculated electrical cost and energy usage for both types of operation are given in Table 2.

TABLE 2

Electrical Cost

Operation of Heat Exchanger #3

Operating Method	Period	Hours of Operation	Energy Usage	Total Cost
Continuous	June 4 - Oct. 6, 1971	2976	535 kw-hr	$21.40
Selective	June 4 - Oct. 6, 1970	715	128 kw-hr	5.13

The energy usage was calculated from the power requirement and hours of operation of the 1/6 HP circulating pump used with Heat Exchanger #3. The electrical cost was obtained by multiplying usage by an energy charge of $0.04/kw-hr. The cost of temperature monitoring equipment was not included in this comparison since it was, at least for this system, equal for both types of operation.

The cost presented in Table 2 is not the actual electricity cost billed to the State by Public Service Gas and Electric Co. (PSE&G). The actual bills were not presented because (1) a minimum service charge of $5.00 a month was levied regardless of energy usage, and (2) bill totals included the costs of electricity for items (lights, space heater, etc.) not essential to the particular type of operation being investigated. The energy charge of $0.04/kw-hr, however, was based on PSE&G bills for the summer of 1970, and included a demand charge (kilowatt charge). For purposes of comparison, this same energy charge was applied to 1971's summer operation.

B. Manpower and Maintenance

In terms of manpower, selective operation was more costly than continuous operation, since personnel had to present at the test site on a daily basis to compare temperature data and start or stop system operation as indicated. Maintenance cost of both types of operation was essentially the same.

4.4.2.4 Summary of Evaluation of Summer Operation

Heat was successfully transferred from the warm pavement to the earth by operating this installation during the summer. By the end of 1970's summer operation, the heat stored in Heat Exchanger #1 and 2 was increased by approximately 10 percent. However, due to the rapid rate of heat loss from the earth during system inactivity in the fall, the benefit to snow melting derived from summer operation was minimal.

For Heat Exchanger #3, the amount of heat stored by 2,976 hours of continuous operation in 1971 between June 4 and October 6, is equal to the amount of heat stored by 715 hours of selective operation in 1970 for the time period June 4 to October 6. Based on energy usage, the electrical operating cost of continuous operation was 4.2 times greater than that of selective operation. Conversely, manpower costs for continuous operation was less.

4.4.3 Evaluation of Insulation Used in Conjunction with Heat Exchangers #1 and 2

During the design phase, it seemed probable that heat stored in the earth of a heat exchanger during summer operation would be dissipated during the period of system inactivity during the fall. Therefore, thermal insulation was used with Heat Exchangers #1 and 2.

The purpose of the insulation was to prevent the conduction of heat from the earth within the heat exchangers upward to the air or outward to the surrounding earth.

Heat Exchanger #1 (HE1) was insulated with an 8-inch layer of 1.5 PCF*, rigid, expanded polystyrene insulation placed above the heat exchanger, as shown in Figure 5, page 16, and Figure 6, page 17. For insulation specifications, see Table H-2, page 189. This insulation was intended to prevent the conduction of heat to the air.

* PCF - Pounds per cubic foot.

Heat Exchanger #2 (HE2) was also covered with an 8-inch layer of the same type of insulation and in addition had a 6-inch layer of 1 PCF polystyrene insulation placed to completely enclose the earth within the heat exchanger as shown in Figures 5 and 6. This insulation was intended to prevent the conduction of heat to the air and to the surrounding earth.

Heat Exchanger #3 (HE3) was not insulated in order to serve as a control.

The effects of the insulation used with Heat Exchangers #1 and 2 were evaluated during the Summer and Fall of 1970 and Winter 1970-71. The objective for this period was to raise the temperature of the earth within all the heat exchangers to at least 20°F above the control earth temperature at the time of the first snowfall and to maintain this temperature difference throughout the winter. A 20°F higher heat exchanger earth temperature during the winter was desired because theoretically it would substantially improve the snow melting ability of the system. It was hoped this goal could be reached by a combination of the effects of summer operation and thermal insulation.

The effects of the insulation used with Heat Exchangers #1 and 2 on the heat that was stored during 1970s selective summer operation can be observed by referring to Figure G-1, page 182. As shown in this graph, the maximum earth temperatures reached during the period of summer operation were 84.5°F for Heat Exchanger #2 on September 2, 1970, and 81.0°F and 80.5°F for Heat Exchangers #1 and #3, respectively, on August 19, 1970. The greatest number of degrees that the temperature of the earth within the heat exchangers was raised above the control earth temperature occurred on August 19, 1970 and was 12°, 15°, and 11.5°F for Heat Exchangers #1, 2, and 3, respectively. Thus not only did the heat exchanger earth temperatures reached fall short of the desired 20°F rise, but the maximum earth temperatures which occurred within insulated Heat Exchangers #1 and 2 were not much greater than those measured for uninsulated Heat Exchanger #3. In addition, as shown in the figure, the average earth temperatures of Heat Exchangers #1, 2, and 3 were approximately 76.0°, 79.5° and 74°F, respectively, by October 6, the end of summer operation. Thus by the end of the period of summer operation, the average earth temperatures of the insulated heat exchangers exceeded that of the uninsulated Heat Exchanger (#3) by 2.0° and 5.5°F for Heat Exchangers #1 and 2, respectively. Consequently at this time the heat stored in insulated Heat Exchangers #1 and 2 was roughly 2.7% and 7.4% greater than that stored in Heat Exchanger #3. The average earth temperatures of Heat Exchangers #1, 2 and 3 were 7.5°, 11.0°, and 5.5°, respectively, above the control earth temperature on October 6, 1970.

By again referring to Figure G-1, page 182, the inability of the insulation to reduce the rate of heat loss from Heat Exchangers #1 and 2 during the period between the end of summer operation and the first snowstorm can be observed. From October 6, 1970 to December 21, 1970 the average earth temperatures of Heat Exchangers #1, 2 and 3 fell from 76.0°F to 57.0°F, 79.5° to 59.5°, and 74.0° to 53.5°F, respectively. For this 76 day period, the rate of earth temperature decrease was approximately 0.25 degrees per day for all heat exchangers. This indicates that the rate of loss of stored heat from insulated Heat Exchangers #1 and 2 was essentially the same as that from uninsulated Heat Exchanger #3. Thus by December 21, 1970 (date of the first snowfall), the average earth temperatures in Heat Exchangers #1 and 2 were 3.5° and 6.0°F above that of Heat Exchanger #3, and consequently the heat stored in Heat Exchangers

#1 and 2 was 6.5% and 11.2% greater than that stored in Heat Exchanger #3. On December 21, the average earth temperatures of Heat Exchangers #1 and 2 were 0.5° and 3.0°F above the control earth temperature, while the average earth temperature of Heat Exchanger #3 was 3.0°F below control temperature. The fact that Heat Exchanger #3 was below the control earth temperature could be due to the different type of soil in which the control temperature sensors were located or to thermistor error.

The effects of the insulation used with Heat Exchangers #1 and 2 was not clear for Winter 1970-71. As shown in Figure G-1, the average earth temperatures of Heat Exchangers #1 and 2 were several degrees higher than that of Heat Exchanger #3 for the first 6 weeks of winter operation. This result, however, is not an effect which can be attributed solely to the insulation, the different amounts of heat lost by the heat exchangers during snowstorm operation could account for some of the differences in average earth temperature indicated in the graph.

4.4.3.1 Summary of Insulation Used With Heat Exchangers

The use of thermal insulation with Heat Exchangers #1 and 2 did not significantly increase the heat stored in these heat exchangers during 1970s summer operation, nor did it significantly reduce, during system inactivity in the fall of 1970, the rate of loss of heat stored during summer operation. In addition, the combination of summer operation and thermal insulation did not result in an observed improvement in snow melting for Winter 1970-71.

4.4.4 Heat Extraction Rates for Heat Exchanger #3 - Panels #1, 2, 5, and 6

During Winter operation for 1971-72 and 1974-75, Panels #1, 2, 5, and 6 were served by Heat Exchanger #3. This heat exchanger could be connected to service four heating panels after additional piping was placed in the pumphouse on December 30, 1971. For the 4:1 panel to heat exchanger ratio in operation for Winters 71-72 and 74-75, heat extraction rate versus glycol-water temperature is shown in Figures 14 and 15, pages 57 and 58. Heat extraction rate represents the total heat supplied by a heat exchanger as a function of time. For this snow melting system, it is equal to the sum of the heat dissipation rates of the heating panels serviced by a heat exchanger plus the rate of heat loss in the pumphouse, supply and return mains, etc. Heat extraction rates were calculated according to the equation outlined in Appendix F, page 179, and are based on heat exchanger input and output temperature data supplied by thermistors located in the pumphouse. For all heat extraction rates shown, Panels #1, 2, 5 and 6 were more than 50% snow covered and the system had been in operation for more than 3 hours (essentially steady state conditions). The highest heat extraction rate indicated in the graphs is 35,470 BTU per hour (17.7 BTU per hour per linear foot of heat exchanger pipe) and occurred for a glycol-water temperature of 45.8°F, three hours after system activation.* During the first half hour after system activation, heat extraction rates as high as 47,500 BTU per hour (23.8 BTU per hour per linear foot) have been calculated. Glycol-water temperature is shown in Appendix Figure G-3, page 184.

In summary, during the snow storms of Winters 1971-72, and 1974-75, heat was extracted from Heat Exchangers #3 at a rate of between 8000 and 35,500 BTUH (4-18 BTUH/Linear foot of heat exchanger pipe) for heating fluid temperatures in the range of 35-46°F and for at least 3 hours of continuous operation.

* Each heat exchanger has 2000 linear feet of pipe.

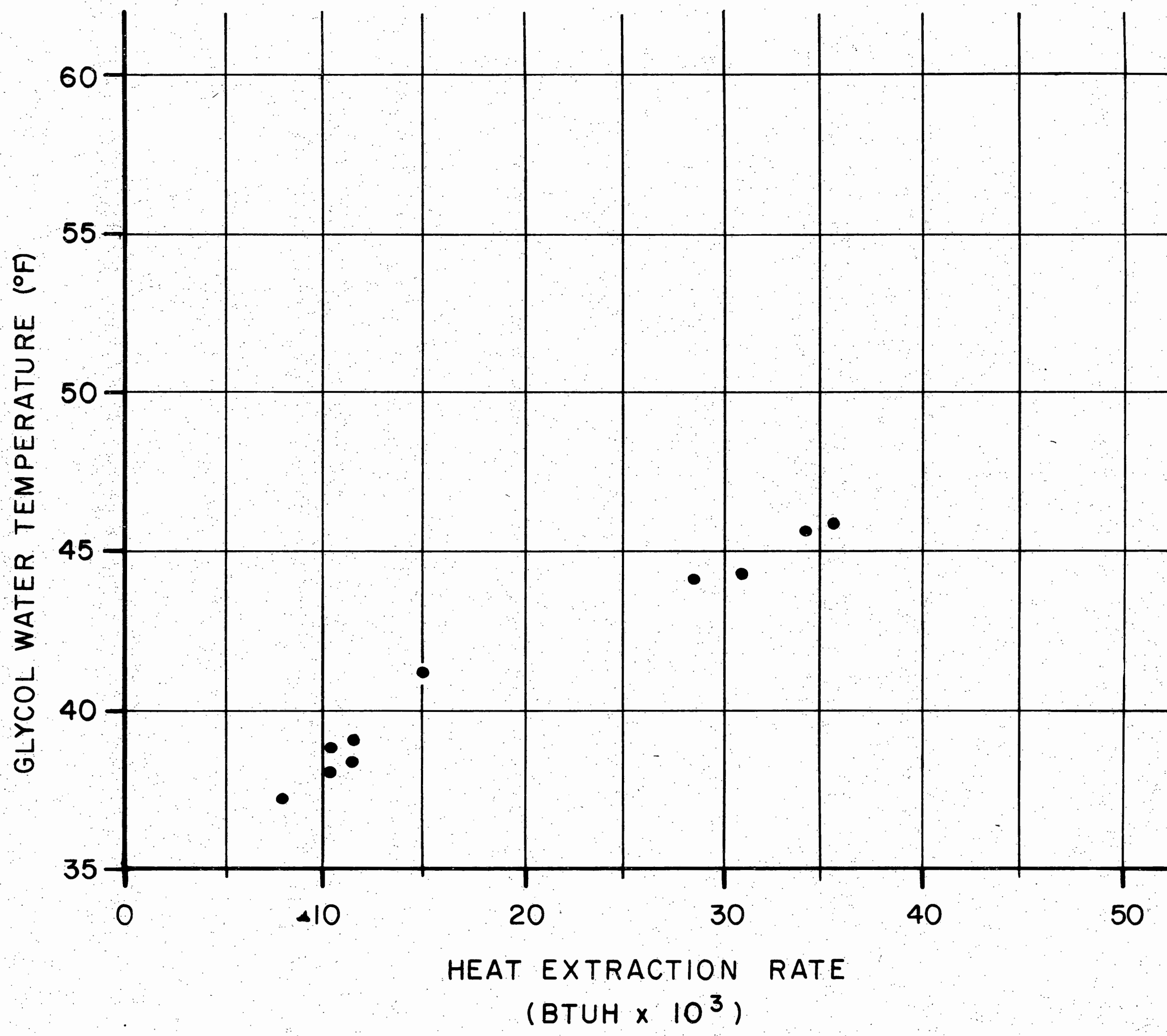


FIGURE 14 — HEAT EXTRACTION FOR HEAT EXCHANGER #3
PANELS 1, 2, 5, & 6
(WINTERS 1971–72 & 1974–75)

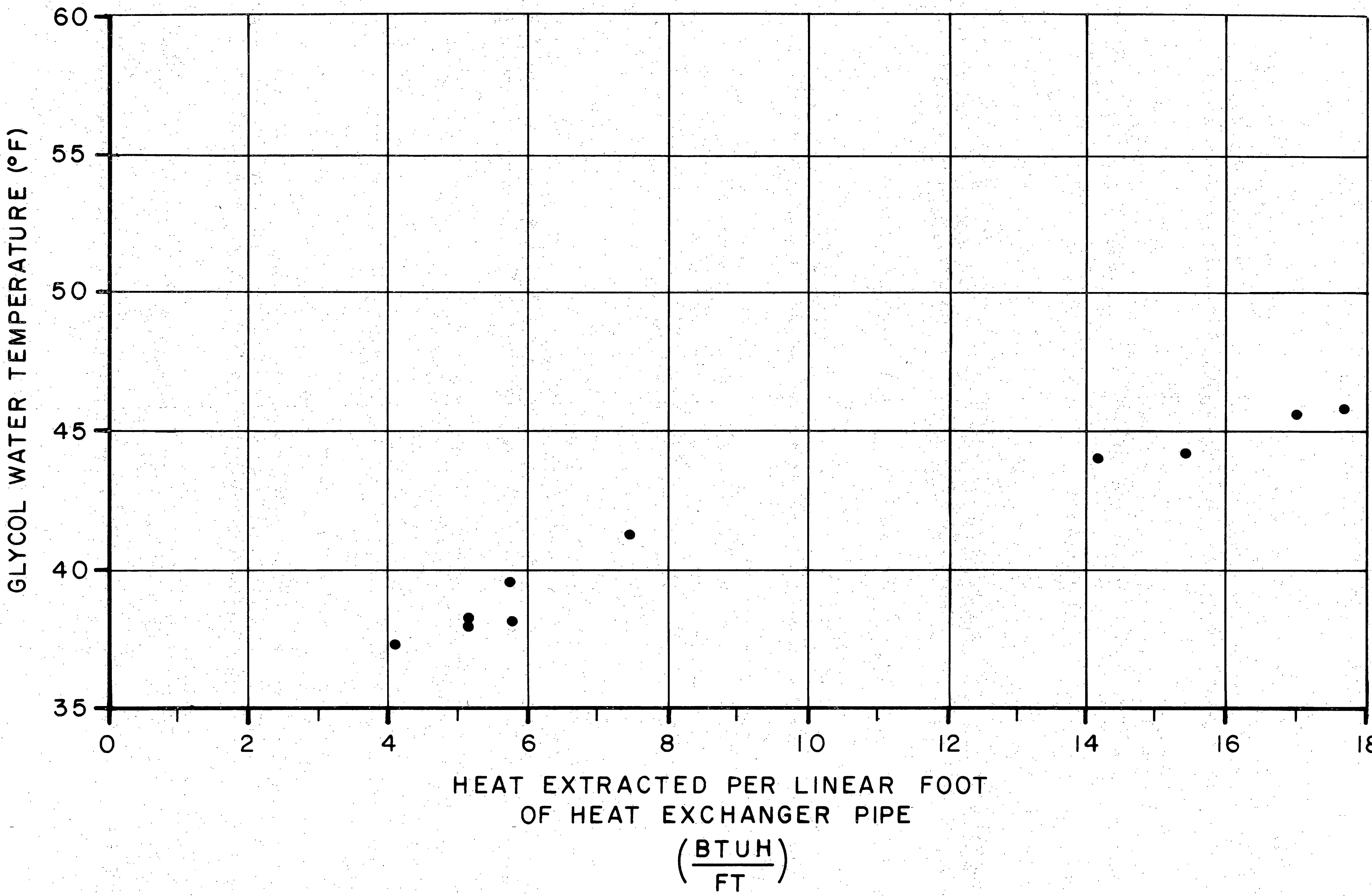


FIGURE 15- HEAT EXTRACTED PER LINEAR FOOT OF PIPE - HEAT EXCHANGER #3
PANELS 1, 2, 5, & 6
(WINTERS 1971-72 & 1974-75)

4.4.5 Structural Failure and Deterioration of Pavement and Piping

4.4.5.1 Pavement

No major structural failure of the Bituminous or Portland Cement Concrete was observed. Small cracks in the pavement have occurred. The trasverse crack in Panel #7, first noted in 1970, has increased to a width and depth of approximately 3/32" and 3/16", respectively. See Figure 16, page 63 and Photograph 7, page 61. A crack in Panel #6 runs completely across the panel and varies in width and depth from approximately 3/32" and 3/16", respectively, near Panel #5 to a hairline crack at the outer edge (Figure 16 and Photograph 8, page 61). A 3/32-inch wide crack is present in Panel #8, decreasing in size to a hairline crack, it extends for 2.7 feet across the panel. Hairline cracks are also present in Panels #3 and 5 as shown in Figure 16.

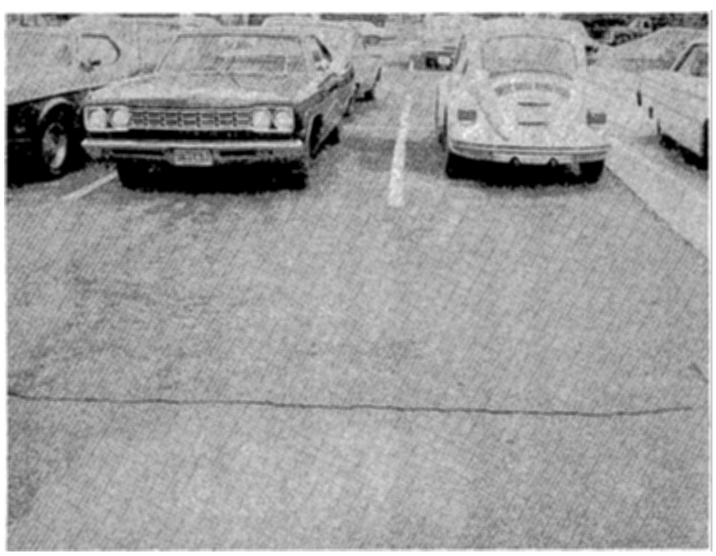
All cracks observed extend in the same general direction; i.e., transverse to the length of the panels.

Slight, regular depressions of the pavement surface were observed in Panels #2 and 4. These depressions are transverse to the length of the panel and appear to occur roughly between the heating pipes. The section of pavement where depressions are present is shown in Figure 16. This condition first became apparent in Spring, 1975.

As mentioned, the heated pavement is located in a parking lot. Cars are parked on some areas of the test panels for approximately 8 hours a day on weekdays. The other areas lie in the drives between the parking spaces, and traffic passing over them is estimated as having been less than 200 cars a week. Truck traffic on the test pavement was virtually non-existent.

PHOTOGRAPH 7

Pavement Crack in Panel #7 (P.C.C.)



PHOTOGRAPH 8

Pavement Crack in Panel #6 (B.C.)

4.4.5.2 Pipes

4.4.5.2.1 Fluid Loss from Embedded Pipes

A leak in Panel #3, presumably caused by a break in the 1 inch, standard weight, rigid polyvinyl chloride plastic pipe two inches below the concrete surface, required that this panel be disconnected from service after January 2, 1971.

The 2" deep level of pipes in Panel #3 was drained of fluid, but location and repair of the "break" were not effected since excavation of the concrete would have been required. From this time forth, Panel #3 was used as a control panel during snowstorms; i.e., no fluid was pumped through the 2" deep pipe level and the pavement was not heated.

During routine checking of the system in June 1971, another leak was discovered in Panel #3. In this instance, the leak was traced to the plastic pipe 4 inches below the concrete surface. No repair was made since excavation would have been required. Panel #3 continued to be used as a control panel.

4.4.5.2.2 Corrosion

No corrosion inside the wrought iron pipes was observed when piping alterations (those required to adapt Heat Exchanger #3 to service four heating panels) were made in the pump house on December 29-30, 1971.

4.4.5.2.3 Anti-Freeze Solution

The ethylene glycol-water solution has remained basic throughout the years of operation. Values of pH and specific gravity are listed in Table 3, page 64.

FIGURE 16

LOCATION OF CONCRETE FAILURES

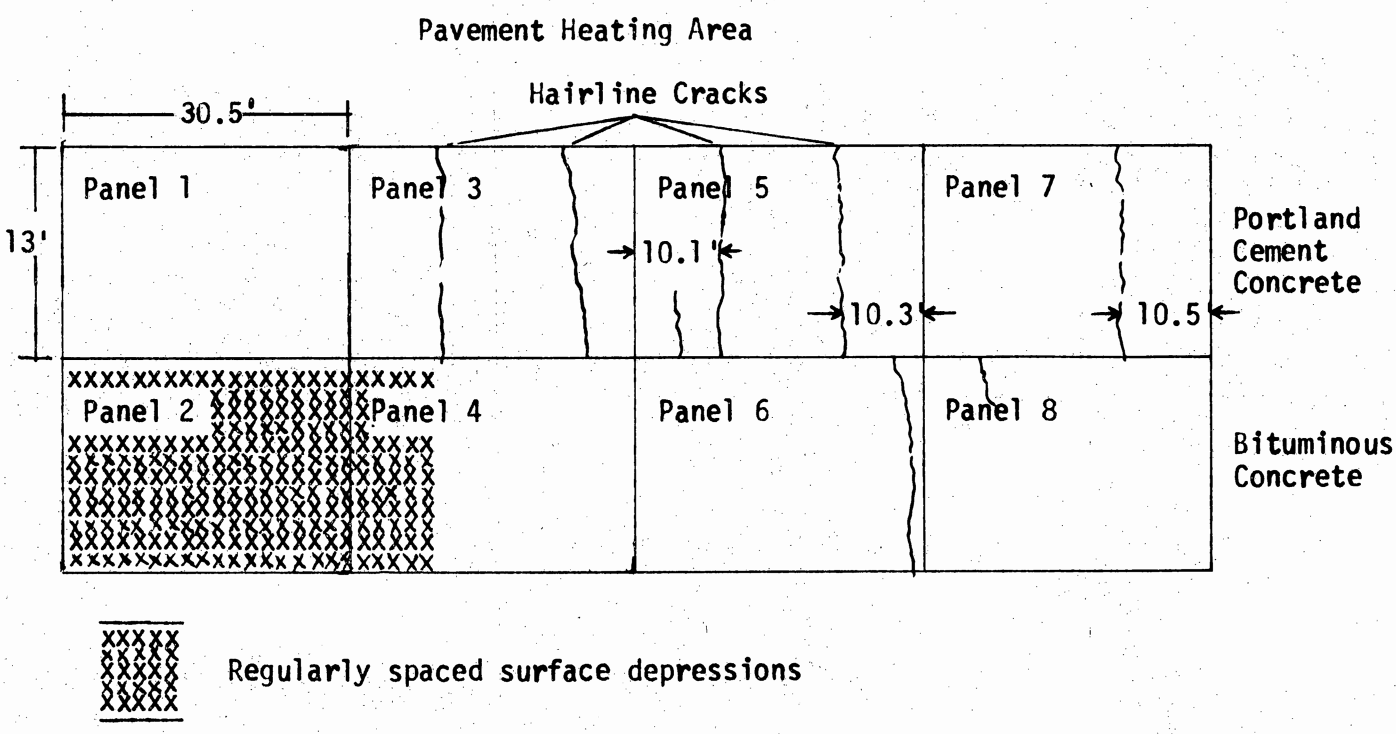


TABLE 3

Properties of Ethylene Glycol-Water Solution

Date	Heat Exchanger	Specific Gravity	pH
2-9-70	# 1	1.075	8.2
	# 2	1.080	8.2
	# 3	1.070	8.3
7-10-70	# 1	------	8.6
	# 2	------	8.5
	# 3	------	8.7
12-16-70	# 1	1.073	9.0
	# 2	1.076	8.8
	# 3	1.063	9.3
9-1-71	# 1	1.072	9.4
	# 2	1.054	9.2
	# 3	1.062	9.6
3-23-72	# 2	1.062	9.3
	# 3	1.067	9.6
10-8-74	# 1	1.067	9.7
	# 2	1.065	10.1
	# 3	1.072	9.8

4.4.5.3 Summary of Structural Failure and Deterioration

No major structural failure of the pavement or wrought iron pipes was observed.

Leaks have developed in the polyvinyl chloride pipes of Panel #3 at both the two inch and four inch deep levels. Thus, the use of this plastic pipe in an embedded type of pavement heating system seems unwise.

No internal pipe corrosion has been observed, and the glycol-water heating fluid has remained basic.

4.4.6 Effectiveness of Insulation Installed with Panel #7

Two inches of cellular glass insulation* was installed below the Portland Cement Concrete of electrically heated Panel #7 as shown in Figure 11, page 29. The effectiveness of this insulation in reducing downward heat losses was evaluated during the Winter of 1969-70.

Observations of melting for Panel #7 during the snowstorms of this winter indicated that during most storms the rate of snow melting on the uninsulated sections of electrically heated pavement was greater than that on the insulated sections of corresponding power output. In other words, the 60 watts/ft^2 section of the uninsulated area became clear of snow before the 60 watts/ft^2 section of the insulated area and so forth.

The most apparent difference in the melting ability of the insulated and uninsulated sections was observed during the first hour of system operation. During this period, the amount of melting which took place on the 20 and 40 watts/ft^2 sections of uninsulated area appeared equivalent to that on the 40 and 60 watts/ft^2 sections of the insulated area, respectively.

*Trade name - FOAMGLAS BOARD. See Table H-2, page 189 for specs.

In one instance, after 16 hours of operation, the amount of snow melted by the 20 watts/ft^2 uninsulated and insulated sections was judged equal by an observer at the test site.

In summary it was concluded that for a pavement heating system of this type ,the placement of 2 inches of this type of insulation below a Portland Cement Concrete pavement of 9 inch thickness was not an effective means of improving the snow melting ability of 20-60 watts/ft^2 heating elements embedded at a depth of 2 inches below the pavement surface. It is believed the insulation sufficiently restricted the natural flow of heat from the subbase up to the pavement such that the rate of snow melting on the insulated portion of the heated pavement was not as rapid as the melting on the uninsulated portion.

4.4.7 Problems

Following are problems encountered during system operation.

4.4.7.1 Unreliable Temperature Data

Deterioration of a number of thermistors (Digitec, Model 401)* resulted in erroneous temperature readings. This deterioration was marked by short and open circuits, in addition to increases in thermistor resistance. The most frequently occurring problem was increases in thermistor resistance which resulted in unreasonably low temperature readouts.

*See Appendix G, page 185 for specifications.

There are strong indications that at least 33 thermistors of a system total of 120, provided inaccurate data, which was not included in this report.*

The thermistors which are most inaccurate are those of the type "TW" and "D" sensor assemblies. See Figures 8, 9, and 10, pages 20-22, and Design Section 4.1.5, Page 18 for location and description. The "TW" thermistors are located in the pipes of the surface panels; and the "D" thermistors, in the earth within the heat exchangers (2'4" to 15'0" below ground). When last checked during March 1975, twelve out of the eighteen "TW" thermistors appeared to be unreliable as well as twelve out of the fifty D's. Though functioning properly at the beginning of this project, these thermistors subsequently became defective and were thereafter unable to provide worthwhile temperature data. During January of 1975, a comparison of heat dissipation calculations done by two different methods indicated that most of the TW thermistor readings have been inaccurate since the snowstorm of February 15, 1970. The reasons for thermistor deterioration are not known at this time.

4.4.7.2 <u>Failure of Temperature Measurement Equipment</u>

Digitec equipment was used from the beginning of this project to measure earth, air, pavement, and fluid temperatures. The measuring system consisted of a digital thermistor thermometer, digital clock, multiplexer, scanner, and printer.

*See Table H-3, pages 190 and 191 for a listing of defective thermistors.

Problems have occurred with three (3) pieces of Digitec equipment - scanner, printer controller, and digital clock.

Defective components in the scanner were replaced by Department personnel during December 1971, at a cost of under $7.00.

During the first half of 1973, the Digitec equipment was repaired and calibrated at a cost of $250.00 by Criterion Meteorology Incorporated, of Oakland, New Jersey.

The printer controller was not operational during Winters 1973-74, and 1974-75, thus automatic recording of temperature data was not possible.

The digital clock was also not operational during Winters 1973-74, and 1974-75. The trouble was diagnosed as mechanical malfunction of one of the pulse counters.

4.4.7.3 Circulating Pump Failure

On February 19, 1972 the bearing bracket assembly of the circulating pump for Panels 5 and 6 was replaced at a cost of $23.50. A faulty water seal and slinger were discovered.

4.4.7.4 Electrical Power Failures

Several times a year electrical power to the pump house was lost. This condition was generally due to a loss of service power at the utility pole. On some occasions, power loss in the pump house resulted from mechanical failure of circuit breakers.

Loss of power in the wintertime caused the interruption of snowstorm operation with accompanying loss of data. The majority of power losses resulted in minor flooding of the pump house. Once power was restored, the flooding was easily corrected by activating the submersible sump pump.

During February 1974, a 20-amp circuit breaker was replaced; the metal parts of other breakers were found to be heavily rusted. All circuit breakers were sprayed with contact cleaner and lubricant.

4.4.7.5 Summary of Problems

There were primarily four types of problems which resulted in a loss of data. These were (1) failure of about 1/4 of the temperature sensors used on this project, (2) malfunction of several pieces of temperature measuring equipment, (3) circulating pump failure, and (4) occasional power losses at the pump house.

4.4.8 Pavement Heating System Costs

4.4.8.1 Construction Cost

Construction of the pavement heating installation was completed under three contracts. Individual contract type and costs as well as the total contract cost of construction are listed below.

1) Electrical Contract	$ 21,463.36
2) Mechanical Contract	42,988.00
3) General Contract	54,138.10
	$118,584.46

The electrical contractor furnished and installed the temperature sensors, conduit, wire, and breaker panels and starters.

The mechanical contractor furnished and installed the pipes for the heat exchangers and the heating panels, the insulation for the supply and return mains, anti-freeze, circulating pumps, flow meters, expansion tanks, junction boxes, and drainage pipe. In addition, he provided any welding that was needed and tested the installation pipes for leaks.

The general contractor furnished the labor, materials and equipment necessary for the excavation of the soil at the test site to a 14' depth, the construction of the Portland Cement Concrete and Bituminous Concrete pavements, and the installation of the thermal insulation used with the heat exchangers and the electrical heating panels.

4.4.8.2 Instrumentation Costs

Following is a cost breakdown for the Digitec temperature monitoring and recording equipment.

Printer	$ 430.00
Printer Controller	395.00
Multiplexer	345.00
Digital Clock	390.00
Thermistor Thermometer	574.00
Scanner	695.00
Scanner Cards	950.00
Model No. 405 Thermistor Probe	32.50
Miscellaneous Cables and Items	150.00
	$3,961.50

The cost of the 120 Model 401 Digitec thermistor probes is included in the electrical contract.

For repair and calibration costs see Section 4.4.7, "Problems," page 66.

4.4.8.3 Operating Costs

Manpower costs will not be presented in this report because, due to the experimental nature of this installation, man-hours were spent in recording observations of snow melting and monitoring temperature data which would not normally be required for an operational system.

4.4.8.3.1 Electrical Operating Costs

The electrical operating costs presented in Table 4, pages 72-74, are calculated values and not the actual electricity cost billed to the State by PSE & G.* The energy usage for the embedded pipe systems was calculated from the power requirement of the 1/6 HP circulating pumps associated with the heat exchangers in operation. For Winter 1973-74, when a 30 kilowatt electric hot water heater was used to supply fluid at an average temperature of approximately 90°F to embedded pipe panels, the energy usage of the heater was added to that of the pumps. Energy usage for the electrical resistance panels was calculated from the rated power consumption of the resistance wires (60 watts/ft^2, 40 watts/ft^2, etc.). The electrical cost for each type of operation was then obtained by multiplying usage by the energy charge in cents per kilowatt-hour. The energy charge was calculated from PSE & G bills for each winter, and includes a demand charge (kilowatt charge). See Section F.1, page 175 for sample calculation.

*The reasons the bills were not used are those mentioned earlier in Section 4.4.2.3.2, page 51.

TABLE 4

Electrical Operating Costs

A. Winter Operation 1969-70

Energy Charge: $0.05/Kw/Hr

	Panel Type	Panels	Sections	Hours Operational	Cost	Cost ($/ft^2)*
I.	Embedded Pipe	1,2,3,4, 5 and 6	All	208.5	$ 5.63	$0.0024
II.	Electrical Resistance	7 and 8	20 $\frac{\text{watts}}{\text{ft}^2}$	208.5	50.04	0.19
			40 $\frac{\text{watts}}{\text{ft}^2}$	208.5	100.08	0.38
			60 $\frac{\text{watts}}{\text{ft}^2}$	208.5	150.12	0.57
				Total II	$300.24	
				Total (I & II)	$305.87	

B. Summer Operation, 1970

Heat Exchanger #1, Panels 1 and 2	$5.13
Heat Exchanger #2, Panels 3 and 4	5.13
Heat Exchanger #3, Panels 5 and 6	5.13

For details of cost calculation see Section 4.4.2.3.2, page 51

C. Winter Operation, 1970-71

Energy Charge: $0.06/Kw/Hr

*Dollars per square foot of pavement surface.

TABLE 4 - (continued)

	Panel Type	Panels	Sections	Hours Operational	Cost	Cost ($/ft^2)
I.	Embedded Pipe	1,2,4, 5 and 6	All	104.9	$ 3.40	$0.0015
II.	Electrical Resistance	7 and 8	20 $\frac{watts}{ft^2}$	104.9	30.21	0.12
			40 $\frac{watts}{ft^2}$	104.9	60.42	0.23
			60 $\frac{watts}{ft^2}$	104.9	90.66	0.35
				Total II	$181.29	
				Total (I & II)	$184.69	

D. Summer Operation, 1971

Heat Exchanger #3, Panels 5 and 6 $21.40

For details see Section 4.4.2.3.2, page 51

E. Winter Operation, 1971-72

Energy Charge: $0.06/Kw-Hr

	Panel Type	Panels	Sections	Hours Operational	Cost	Cost ($/ft^2)
I.	Embedded Pipe	1,2,5 and 6	All	1440	$31.10	$0.020
II.	Electrical Resistance	7 and 8	20 $\frac{watts}{ft^2}$	82.5	25.74	0.10
			40 $\frac{watts}{ft^2}$	82.5	51.48	0.20
			60 $\frac{watts}{ft^2}$	82.5	77.22	0.30
				Total II	$154.44	
				Total (I & II)	$185.54	

TABLE 4 - (continued)

F. Winter Operation, 1973-1974

Energy Charge: $0.06/Kw-Hr

	Panel Type	Panels	Sections	Hours Operational	Cost	Cost ($/ft^2)
I.	Embedded Pipe (Hot Water Heat)	1 and 2	All	95	$171.00	$0.22
II.	Embedded Pipe (Hot Water Heat)	1 and 5	All	17	30.60	0.04
III.	Embedded Pipe (Earth Heat)	5 and 6	All	150	1.62	0.0021
IV.	Embedded Pipe (Earth Heat)	1 and 5	All	1	0.02	------
				Total (I & II)	$201.60	
				Total (III & IV)	$ 1.64	

G. Fall 1974 and Winter 1974-1975 Operation*

Energy Charge: $0.06/Kw-Hr

Panel Type	Panels	Sections	Hours Operational	Cost	Cost ($/ft^2)
Embedded Pipe	1,2,5 and 6	All	525	$11.34	$0.0073

4.4.8.3.1.1 Operating Cost for Snow Melting

In comparing the operating costs presented in Section 4.4.8.3.1 for pavement heating by 1) earth heated embedded pipes, 2) hot water heated embedded pipes, and 3) electrical resistance mats, the operating cost determined for an equivalent amount of snow melting (from hereon referred to as adjusted operating cost) was used as the basis. To present the

*No operation for snow melting. Operated for heat extraction rate data. See Section 4.4.4, page 56.

costs most accurately, the "amount of snow melting" was expressed in both inches per hour and BTU per hour. In comparing the earth heated embedded pipe panels to the electrical resistance panels, the adjusted operating cost was expressed in dollars per BTU per hour ($/BTUH); and for the comparison of hot water heated embedded pipe panels and electrical resistance panels, dollars per square foot per inches an hour $\frac{\$/ft^2}{(in/hr)}$.

4.4.8.3.1.1.1 Earth Heat vs. Electrical Resistance Heat

The Winter of 1969-70 will be used for the comparison because during this winter, the six embedded pipe panels and the two electrical resistance panels were operated for the same number of hours (208.5).

The calculated operating cost for the earth heated panels was $0.0024 per square foot (Table 4, Part A, page 72), and the average heat dissipation rate for the six panels was roughly 40 BTUH per square foot (Table B-2, pages 98 and 99). By division, an adjusted operating cost of 0.006¢ per BTUH can be obtained.

The calculated operating cost for the 20 watts/ft^2 sections of the electrical resistance panels was $0.19 per square foot (Table 4, Part A, page 72), and the average heat dissipation rate was roughly 70 BTUH/ft^2. Thus, the adjusted operating cost was 0.27¢ per BTUH.

From a comparison of the adjusted operating cost, it can be seen that for an equivalent BTU output, the yearly operating cost of the earth heated embedded pipe panels is roughly 45 times less than that of the electrical resistance panels.

4.4.8.3.1.1.2 Hot Water Heat vs. Electrical Resistance Heat

Data for 1973-74 for the hot water heated panels (Table 4, Part F, page 74) indicates that for 112 hours of operation the calculated operating cost was $0.26 per square foot. An average melting rate of about 0.45 inches per hour for all operating panels and pipe spacings was calculated. An adjusted operating cost of $0.577/(ft^2-in/hr) was obtained.

Data for Winter 1970-71, indicates that for 105 hours of operation the calculated operating cost of the 60 watts/ft^2 sections of the electrical resistance panels was $0.35 per square foot (Table 4, Part C, page 72) and a melting rate of roughly 0.6 inches per hour was observed (Section 4.4.1.2, page 43). An adjusted operating cost was $0.583/(ft^2-in/hr). A comparison of these adjusted costs indicates that for an equivalent amount of snow melting, the yearly operating cost of the hot water heated embedded pipe panels was approximately the same as that of the electrical resistance panels.

4.4.8.4 Cost Comparison with NJDOT's Routes 17 and 46 Pavement Heating Installation

In the following analysis, cost data are presented in terms of operation and construction costs. Yearly costs are determined by dividing construction cost by the estimated system life-time and adding the annual operating costs. Original construction costs have not been adjusted for increased current material and labor costs. The annual operating costs presented are the most recent ones available.

As mentioned earlier, the total contract cost for construction of this installation in 1969 was $118,584.46. In order to arrive at a more realistic cost for an operational earth heat system of this type, the contract cost of many of the experimental features have been eliminated. Thus, the contract cost for the piping, pumps, excavation, and related items was approximately $50,000 for a heated area of 2340 square feet - $21.00/ft.^{2} Average annual operating costs from 1970 to 1974 are estimated at $0.002 per square foot of pavement (Section 4.4.8.3.1, page 71). A 20 year structural life is assumed for this system. Insufficient information exists to determine life expectancy more exactly.

The NJDOT installation at the intersection of Routes 46 and 17 has a pavement heated by electrical resistance cables. The heating system was installed during 1964 at a contract cost for construction of $71,200 for 18,000 square feet - $4.00/ft^2.[4] Average annual operating cost for 1971-1975 was roughly $0.50 per square foot of pavement.* Structural life of 20 years is estimated by NJDOT personnel involved with the installation.

Table 5, page 78, summarizes the cost data presented. As shown in the table, for the period of the system life, the average yearly cost for the earth heated embedded pipe system is 50% higher than that of the electrically heated installation at Routes 46 and 17.

[4]Pittman, J.M., loc. cit., page 2

*Metered Service Account Record, Public Service Electric and Gas Company

TABLE 5

System Costs

Pavement Heating System	Construction Cost ($/ft^2)	Estimated Life (Years)	Pro-rated Construction Cost ($/ft^2/yr)	Annual Operating Cost ($/ft^2/yr)	Average Yearly Cost ($/ft^2/yr)
1. Earth Heat, Embedded Pipe, Trenton (1969)	$21.00*	20	$1.05	$0.002	$1.052
2. Electrical Cables, Rts.46 and 17, (1964)	4.00	20	0.20	0.50	0.70

4.4.8.5 Summary of Pavement Heating System Costs

Construction cost for this pavement heating installation was $118,584.46.

Instrumentation cost was approximately $3,961.50.

The calculated annual electrical operating cost for earth heated pavement pipe panels averaged about $0.002/ft^2.

For an equivalent amount of snow melting, the calculated annual electrical operating cost was (1) for the earth heated pavement pipe panels; roughly 45 times less than that of the electrical resistance panels; and (2) for the hot water heated pavement pipe panels, approximately equal to that of the electrical resistance panels. Thus, in terms of operating cost, the earth is an economical source of heat for pavement heating.

With prorated construction cost considered, the average yearly cost of this earth heated pavement heating system is approximately 50 percent higher than that of the electrically heated installation at Routes 46 and 17.

*Experimental Features Eliminated

APPENDICES

Appendix | Page

Appendix A. Notation and Terminology

A.1 Notation

The notation presented in the following table is used throughout the body of this report as well as in the "Storm Records" presented in Appendices B, C, D and E. It is used to simplify the wording and to shorten the text. The various sections of the heating panels are designated as shown below.

TABLE A-1

Panel Notation

Embedded Pipe Panels

Notation	Panel Number	Type of Pipe	Type of Concrete	Pipe Diameter	Pipe Spacing	Pipe Depth
P1	1	Wrought Iron	P.C.C.*	3/4"	6", 12" and 18"	2"
P1 (6)	1	Wrought Iron	P.C.C.	3/4"	6"	2"
P1 (12)	1	Wrought Iron	P.C.C.	3/4"	12"	2"
P1 (18)	1	Wrought Iron	P.C.C.	3/4"	18"	2"
P2	2	Wrought Iron	B.C.**	3/4"	6", 12" and 18"	2"
P2 (6)	2	Wrought Iron	B.C.	3/4"	6"	2"
P2 (12)	2	Wrought Iron	B.C.	3/4"	12"	2"
P2 (18)	2	Wrought Iron	B.C.	3/4"	18"	2"
P3	3	Plastic-U.P.V.C.***	P.C.C.	1"	6", 12" and 18"	2"
P3 (6)	3	Plastic-U.P.V.C.	P.C.C.	1"	6"	2"

*P.C.C. - Portland Cement Concrete **B.C. - Bituminous Concrete
***U.P.V.C. - Unplasticized Polyvinyl Chloride

TABLE A-1 - (continued)

Embedded Pipe Panels

Notation	Panel Number	Type of Pipe	Type of Concrete	Pipe Diameter	Pipe Spacing	Pipe Depth
P3 (12)	3	Plastic- U.P.V.C.	P.C.C.	1"	12"	2"
P3 (18)	3	Plastic- U.P.V.C	P.C.C.	1"	18"	2"
P4	4	Wrought Iron	B.C.	1"	6", 12" and 18"	2"
P4 (6)	4	Wrought Iron	B.C.	1"	6"	2"
P4 (12)	4	Wrought Iron	B.C.	1"	12"	2"
P4 (18)	4	Wrought Iron	B.C.	1"	18"	2"
P5	5	Wrought Iron	P.C.C.	1-1/4"	6", 12" and 18"	2"
P5 (6)	5	Wrought Iron	P.C.C.	1-1/4"	6"	2"
P5 (12)	5	Wrought Iron	P.C.C.	1-1/4"	12"	2"
P5 (18)	5	Wrought Iron	P.C.C.	1-1/4"	18"	2"
P6	6	Wrought Iron	B.C.	1-1/4"	6", 12" and 18"	2"
P6 (6)	6	Wrought Iron	B.C.	1-1/4"	6"	2"
P6 (12)	6	Wrought Iron	B.C.	1-1/4"	12"	2"
P6 (18)	6	Wrought Iron	B.C.	1-1/4"	18"	2"

TABLE A-1 (continued)

Panel Notation

Electrically Heated Panels

Notation	Panel Number	Type of Concrete	Heat Output	Depth of Embedment
P7	7	P.C.C.	20, 40 & 60 watts/ft^2	2"
P7 (20W)	7	P.C.C.	20 watts/ft^2 (68 BTUH/ft^2)	2"
P7 (40W)	7	P.C.C.	40 watts/ft^2 (136 BTUH/ft^2)	2"
P7 (60W)	7	P.C.C.	60 watts/ft^2 (204 BTUH/ft^2)	2"
P8	8	B.C.	20, 40 & 60 watts/ft^2	2"
P8 (20W)	8	B.C.	20 watts/ft^2 (68 BTUH/ft^2)	2"
P8 (40W)	8	B.C.	40 watts/ft^2 (136 BTUH/ft^2)	2"
P8 (60W)	8	B.C.	60 watts/ft^2 (204 BTUH/ft^2)	2"

A.2 Terminology

The following terms are used in the "Storm Records" which appear in Appendices B, C, D and E.

Percentage Clear and Wet

When used in this report the expression "P1 (6) is x% clear and wet" means that x% of the pavement surface area of P1 (6) is wet and clear of snow, slush and ice. As a further example, "80% clear and wet" indicates that 20% of the pavement surface area of a panel is still covered by snow, slush or ice.

Photograph A-1, page 86 , provides an illustration of the above terminology. This photo shows Panels #1 and 2, with Panel #1 closest to the viewer. P1 (6) is "100% clear and wet", P1 (12) is "50% clear and wet," and P1 (18) is "20% clear and wet." P2 is snow covered.

Percentage Dry

The expression "P2 is x% clear and dry," means that P2 is clear of snow, slush, or ice, and x% of the pavement surface area of P2 is dry. In other words, if P2 is 5% clear and dry, then the other 95% of the surface area of P2 is clear and wet.

A.3 Data Table Guide

As an aid to interpreting the tables in Appendices B, C, D and E a guide to the basic form of the tables entitled "Storm Data-Embedded Pipe Panels" is presented on page 87 . This guide shows the columns in which storm data for each embedded pipe heating panel is entered. In the "Storm Data" tables, data for the embedded pipe panels is presented under three column headings--"Surface Temperature (°F)", "Heat Dissipation (BTUH/FT^2)", and "Pavement Surface Condition" - two of which are shown in the guide.

The surface temperatures presented in these tables are those measured by the thermistors placed just below the concrete surface at a position midway between the pipes embedded at a 2" depth. See Figure 9, page 21 for a pictorial view.

Heat dissipation was calculated from measurements of the input and output temperatures of the heating fluid for each spacing of coils in the various panels and from the flow rate of the heating fluid. See Appendix F.4, page 178 for sample calculation.

Under the heading "Pavement Surface Condition" are listed abbreviated descriptions of the observed state of melting on a particular embedded pipe panel section at the time indicated. The abbreviated notation is explained at the bottom of each table. The descriptions of melting were taken from a log book of snowstorm observations.

PHOTOGRAPH A-1

EXPLANATION OF PERCENT "CLEAR AND WET"

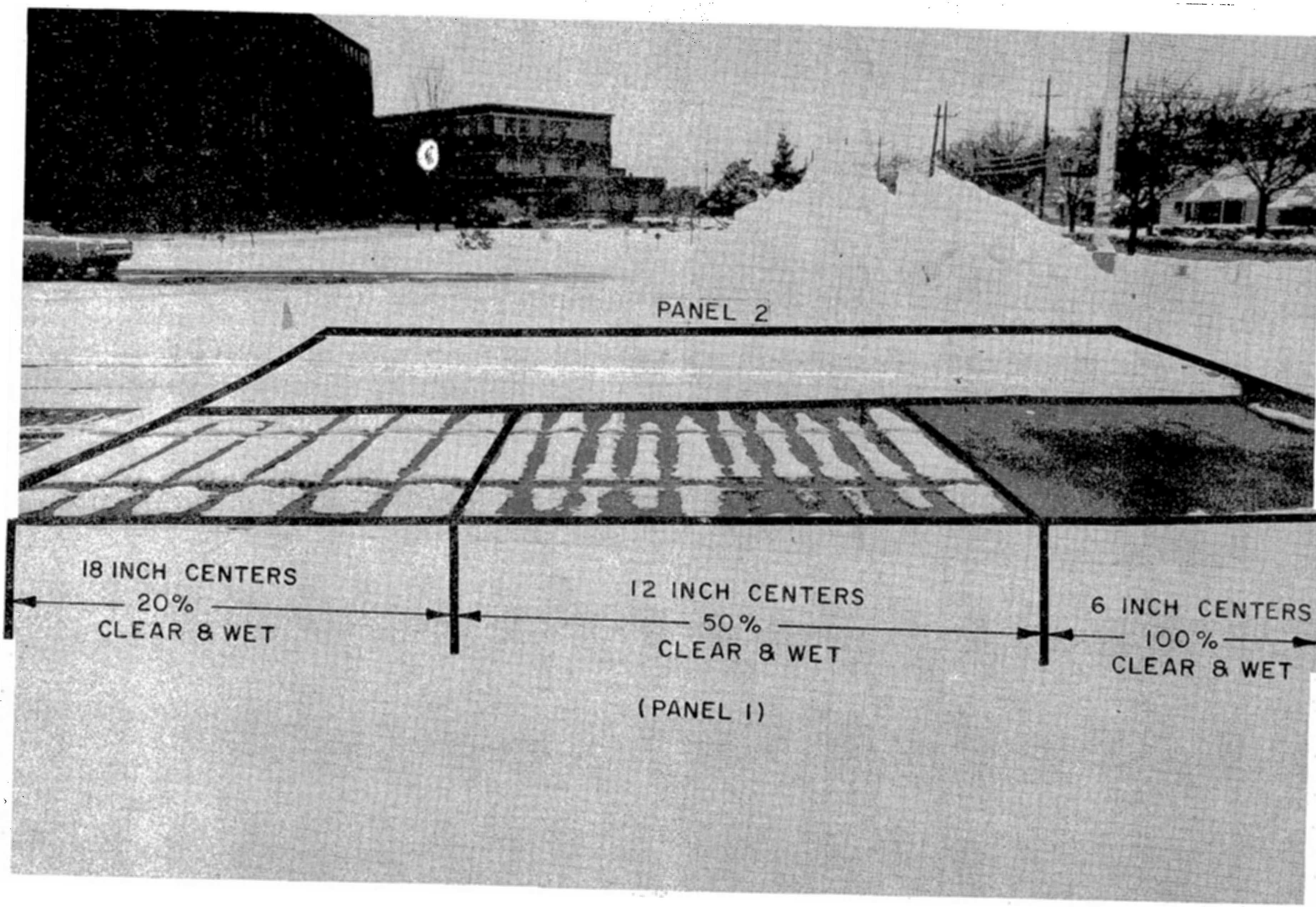


TABLE A-2

GUIDE TO STORM DATA TABLES

Type of Concrete	Pipe Spacing	Surface Temperature (°F) Pipe Diameter 3/4"	1"	1-1/4"	Heat Dissipation (BTUH/ft^2) Pipe Diameter 3/4"	1"	1-1/4"
Portland Cement	6"						
	12"	Panel 1	Panel 3	Panel 5	Panel 1	Panel 3	Panel 5
	18"						
Bituminous	6"						
	12"	Panel 2	Panel 4	Panel 6	Panel 2	Panel 4	Panel 6
	18"						

Pipe material in Panels #1, 2, 4, 5 and 6 is wrought iron.

Pipe material in Panel #3 is plastic pipe.

Appendix B. Winter Operation 1969-70

Appendix | Page

B.1 Snow Storm Operating Procedure

During the winter, daily weather forecasts were obtained from the Division of Maintenance. If snow was forecast, the system was activated in anticipation of snowfall. If non-forecast snow began to fall, the system was turned on as soon as assigned personnel arrived at the Fernwood test site.

To prevent the heated pavement area from being snow-plowed, and to restrict the travel of automobiles over the heated panels, traffic cones and snow alert signs were placed around the pavement heating area. The system was activated from the pump house. Only the pipes embedded in the pavement at a depth of two inches were put in operation.* Soon after activation occurred, the pressure of the glycol-water solution within the piping system was checked and the glycol-water flow rates were adjusted (if required), read, and recorded.

During the snowstorms, observations of the pavement surface condition and measurements of the depth of snow or slush accumulation on each panel section were entered in a log book. Also entered were measurements of snow accumulation in areas of the parking lot away from the test site. Depths of snow accumulation were measured with a ruler. To supplement this written material, photographs of all panels were taken when possible.

The calibration of the Digitec system was checked, and temperature data for the snowstorm was manually recorded in a log book.

*Pipes embedded at a four inch depth were not utilized during any winter. First observations indicated that they did not melt snow as effectively.

After snowfall had ended, the system was operated until one of the following three conditions existed. First, all the snow that fell on the panels was melted; second, it became evident that no more snow would be melted by the system; or third, automobile traffic over the panels had made meaningful data collection difficult.

During Winter 1969-70, Panels #1 & 2, 3 & 4, and 5 & 6 were connected to Heat Exchangers #1, 2, and 3, respectively. Panels 1, 2, 3, 4, 7 & 8 were in operation for all snowstorms. Each was operated for a total of 210 hours for this winter. Panels 5 & 6 were operated during the first three storms (130 hours); thereafter, they were not operated due to a leak at a valve in the pumphouse.

B. 2 Storm Records

Results presented here are for five snow storms which resulted in an accumulation of one inch or more.

Storm #1
(December 25-29, 1969)

Snowfall began at approximately 4:00 PM, December 25, and continued until the early morning hours of December 26, resulting in a total snow accumulation of 3-4 inches.* All panels were activated at 9:55 PM, December 25 at which time there was an accumulation of 2-1/2 inches of snow. Within one hour the snow above the wrought iron pipes spaced on 6 inch centers (P1 & P5) began to melt and turn to slush.

* Measured in an area of the parking lot outside of the test area.

Complete melting in these areas was accomplished by 4:15 PM, December 26, 1969. At this time there was localized melting directly above the pipes spaced on 12 inch and 18 inch centers in the same panels. Although there was some melting on P3 (PVC pipe in P.C.C.) and P2, P4, and P6 (wrought iron pipes in B.C.), the surface was still covered with 1-2 inches of snow.

Throughout the operation melting of snow on P1 (6) and P5 (6) was at least equivalent to the 20 watts per square foot area of P7 (electrically heated P.C.C.).

The system was kept in operation until 10:00 AM on December 29, 1969.

Storm #2

(January 6-7, 1970)

All panels were put in operation at 3:30 PM, January 6, in anticipation of snow. Snowfall began at 8:00 PM and continued throughout the night, producing a total accumulation of 3 inches. At 11:00 PM, all panels except P7 (40W), P7 (60W), P8 (40W) and P8 (60W) were snow covered. At 10:00 AM the next morning P1 (6) and P5 (6) were clear of snow (Photos B-1 and B-2). There was also localized clearing of snow directly above the pipes spaced on 12 inch and 18 inch centers. Panels #2, 3, 4 and 6 were covered with 1 inch to 2 inches of snow.

It was again observed that the rate of snow melting on P1 (6) and P5 (6) was at least equivalent to the electrically heated area dissipating 20 watts per square foot.

The system was turned off at 9:00 PM, January 7, 1970.

Storm #3

(January 12-13, 1970)

One inch of snow fell during the night and all panels were put in operation at 10:15 AM, January 13. Clearing of P1 (6) and P5 (6) was complete by 2:15 PM. At this time Panels #2, 3, 4 and 6 were still snow covered.

The system was turned off at 11:45 PM, January 13, 1970.

Storm #4

(January 20-21, 1970)

Snow flurries began at 5:00 PM, January 20, and continued until 12:00 PM, producing an accumulation of 2-1/2 inches. Panels #1, 2, 3, 4, 7 and 8 were activated at 11:45 PM, January 20 at which time the air temperature was 19.5°F. During the night melting had taken place on P1 (6), P1 (12), and the electrically heated Panels #7 and 8, however, P1 (6), P1 (12), P7 (20W), P8 (20W), and 10-20 percent of P7 (40W) and P8 (40W) refroze when the air temperature dropped below 15°F.* At 9:00 AM on January 21, P7 (60W) and P8 (60W) were 100% clear and wet, and P7 (40W) and P8 (40W) were 90% clear and wet - all other areas were either snow covered or ice covered. The system was kept in operation until 11:20 PM on January 21 at which time P1 (6) and P2 (6) were clear and dry.

*This air temperature was the lowest observed during the operation of the system for all years.

Storm #5

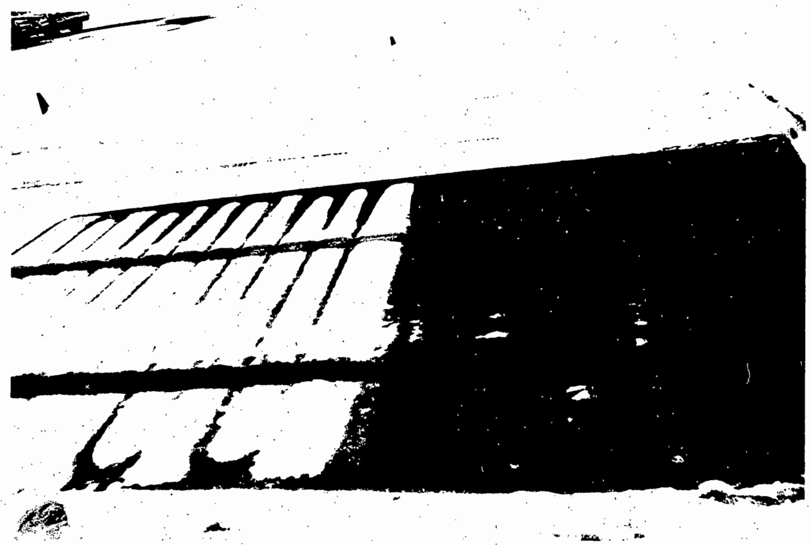
(February 14-17, 1970)

Panels #1,2,3,4,7 and 8 were put in operation at 12:45 PM, February 15. There was no snow falling at this time, there was an accumulation of approximately one inch, and the air temperature was in the low 30's. At 7:15 PM, Panels #7 and 8 were 75% clear and wet. At 1:30 AM, February 16, P1 (6) was 75% clear of snow, and P2, P3 and P4 were still snow covered. Air temperature was 33.4°F. At 10:10 PM, February 16, all areas of P1 and P2 were clear and dry.

The system was turned off at 10;00 AM, February 17, 1970 at which time P3 and P4 were completely clear of snow.

During all of these snow storms, the rate of snow melting on the uninsulated section of the electrically heated P.C.C. (Panel #7) was greater than the insulated area. The 20 watts per square foot section of the uninsulated area appeared equivalent to the 40 watt per square foot section of the insulated area.

B.3 STORM PHOTOGRAPHS

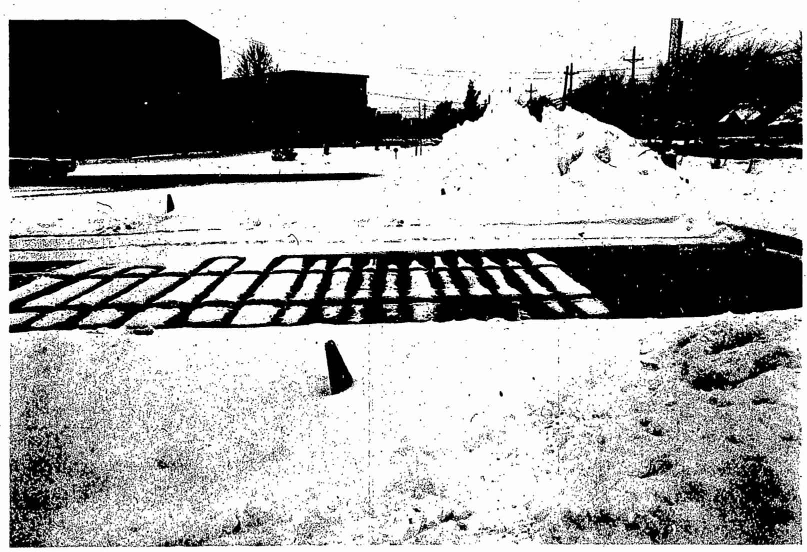


PHOTOGRAPH B-1 STORM #2

Panel #1. Portland Cement Concrete (Pipes on 6-inch centers in clear area)- P1 (6)

10:15 AM - January 7, 1970

(Operated 10.5 Hours) (Air Temp.- 25.4°F)



PHOTOGRAPH B-2 STORM #2

Panel #1. Portland Cement Concrete (Pipes spaced on 18 12 and 6 inch centers)

1:15 PM - January 7, 1970

(Operated 13.5 Hours)

B. 4 Storm Data

Table B-1, pages 96 and 97, shows heat dissipation per square foot of pavement surface and the corresponding surface temperature between the pipes for the snow storms reported for the Winter 1969-70. Heat dissipation rates calculated for Storm #5 are not presented since temperature data on which they were based became questionable as of this storm. For the data presented, hours of operation of the pavement heating system were in the range of 7 to 12 hours and the pavement surface was at least wet and in most instances covered with snow.

Table B-2 pages 98 and 99, shows heat dissipation rates and pavement surface temperatures for snow storm #1 (December 25-29). The large variations in the heat dissipated per square foot of surface pavement can be attributed to several factors including the air temperature, the amount of sunlight incident on the pavement surface, and whether the pavement surface was snow covered, wet or dry.

Table B-3, pages 100 and 101 , shows pavement surface temperatures measured during snow storm #5 (February 14-17).

Note: In Tables B-1, B-2, and B-3 unreliable temperature data is indicated by dashes (-----). Dashes are used in the "Surface Temperature" and "Heat Dissipation" columns. The statement "unreliable temperature data" in reference to heat dissipation rates indicates that input and output heating fluid temperatures are unreliable. The same statement used in reference to surface temperatures indicates that temperature data supplied by sensors located at the pavement surface is unreliable.

Table B-4, page 102, indicates the temperature of the heat exchanger fluid as measured at the output of a heat exchanger by an alcohol thermometer located in the pump house.

TABLE B-1. STORM DATA - EMBEDDED PIPE PANELS

NOTE: Pavement surface either snow covered or wet.

STORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACINGS	SURFACE TEMPERATURE(°F) PIPE DIAMETER 3/4"	1"	1-1/4"	HEAT DISSIPATION(BTUH/FT²) PIPE DIAMETER 3/4"	1"	1-1/4"
1. December 25-29,1969	12/26/69	10:05 AM (12 Hrs.)**	34.4	PORTLAND CEMENT	6"	34.6	33.2	33.7	105	72	115
					12"	33.9	32.3	32.5	60	42	51
					18"	32.3	32.1	----	26	13	19
				BITUMINOUS	6"	36.5	36.6	36.0	50	69	-----
					12"	33.1	33.3	33.5	----	46	19
					18"	32.6	32.7	33.6	18	35	5.8
2. January 6-7,1970	1/ 6/70	11:15 PM (7 Hrs.)	29.0	PORTLAND CEMENT	6"	33.9	32.8	33.2	75	51	80
					12"	32.6	32.3	32.4	42	26	38
					18"	32.2	32.1	----	20	11	15
				BITUMINOUS	6"	35.6	35.1	35.5	37	43	49
					12"	32.9	----	33.3	----	27	17
					18"	32.3	32.6	33.3	12	9	6
3. January 12-13,1970	1/12/70	8:00 PM (12 Hrs.)	27.5	PORTLAND CEMENT	6"	32.8	32.6	32.2	82	50	93
					12"	32.3	27.5	28.5	48	31	46
					18"	31.0	26.6	-----	22	10	18
				BITUMINOUS	6"	28.1	34.7	33.9	39	45	65
					12"	32.1	28.0	29.3	----	35	23
					18"	31.0	28.2	35.1	12	10	8

** Hours in operation ----- Temperature data unreliable

TABLE B-1. STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACINGS	SURFACE TEMPERATURE(°F) PIPE DIAMETER 3/4"	1"	1-1/4"	HEAT DISSIPATION(BTUH/FT^2) PIPE DIAMETER 3/4"	1"	1-1/4"
4. January 20-21,1970	1/21/70	9:05 AM (9 Hrs.)	16.0	PORTLAND CEMENT	6"	31.2	32.6	28.7*	98	47	*
					12"	32.2	28.2	28.1*	53	30	*
					18"	30.6	28.7	----	24	10	*
				BITUMINOUS	6"	35.0	34.7	29.0*	51	41	*
					12"	32.1	32.0	28.4*	---	29	*
					18"	30.6	30.5	28.4*	15	8	*
5. February 14-17,1970	2/16/70	1:30 AM (12.5 Hrs.)	33.4	PORTLAND CEMENT	6"	34.6	33.5	32.0*			
					12"	32.9	32.3	32.1*			
					18"	32.7	32.3	----			
				BITUMINOUS	6"	35.5	34.6	32.5*			
					12"	33.8	33.1	32.4*			
					18"	33.8	33.3	32.7*			

* Panel not in operation

---- Temperature data unreliable

TABLE B-2. STORM DATA - EMBEDDED PIPE PANELS

TORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	SURFACE TEMPERATURE(°F) PIPE DIAMETER 3/4"	1"	1-1/4"	HEAT DISSIPATION($BTUH/FT^2$) PIPE DIAMETER 3/4"	1"	1-1/4"
. December 25-29,1969	12/25/69	11:15 PM (1 Hrs.)	27.4	PORTLAND CEMENT	6"	33.7	32.4	33.3	132	87	144
					12"	30.3	29.5	31.6	76	49	63
					18"	29.4	29.0	----	31	18	24
					6"	33.6	34.2	34.0	81	96	101
				BITUMINOUS	12"	30.6	30.5	-----	---	62	30
					18"	30.4	29.3	29.9	21	20	10
. December 25-29,1969	12/26/69	10:05 AM (12 Hrs.)	34.4	PORTLAND CEMENT	6"	34.6	33.2	33.7	105	72	115
					12"	32.6	32.3	32.5	60	42	51
					18"	32.3	32.1	----	26	13	19
					6"	36.5	36.6	36.0	50	69	---
				BITUMINOUS	12"	32.1	33.3	33.5	---	46	19
					18"	32.6	32.7	33.6	15	35	6
. December 25-29,1969	12/28/69	11:00 AM (61 Hrs.)	34.8	PORTLAND CEMENT	6"	47.2	39.0	47.0	46	43	17
					12"	33.2	34.0	33.6	42	31	24
					18"	34.5	32.2	----	17	11	7
					6"	38.4	37.1	36.8	33	46	34
				BITUMINOUS	12"	35.6	34.8	34.1	---	30	9
					18"	33.1	32.9	33.0	11	10	2

----- Temperature data unreliable

TABLE B-2. STORM DATA - EMBEDDED PIPE PANELS

TORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	SURFACE TEMPERATURE(°F) PIPE DIAMETER 3/4"	1"	1-1/4"	HEAT DISSIPATION(BTUH/FT^2) PIPE DIAMETER 3/4"	1"	1-1/4"
. December 25-29,1969	12/29/69	9:30 AM (83.5 Hrs.)	37.2	PORTLAND CEMENT	6"	43.8	40.8	43.8	33	34	36
					12"	38.0	31.7	39.8	30	26	30
					18"	31.8	30.6	----	15	9	11
					6"	36.5	44.2	42.4	12	21	48
				BITUMINOUS	12"	32.9	-----	34.2	---	22	18
					18"	31.4	31.4	31.5	7	6	6

------ Temperature data unreliable

TABLE B-3. STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (° F)	TYPE OF CONCRETE	PIPE SPACING	SURFACE TEMPERATURE (° F) PIPE DIAMETER 3/4"	1"	1-1/4"
5. February 14-17, 1970	2/15/70	3:30 PM (2.5 Hrs.)	36.0	PORTLAND CEMENT	6"	33.7	32.5	32.0*
					12"	32.6	32.2	32.0*
					18"	32.5	32.2	-----
				BITUMINOUS	6"	34.6	34.2	32.4*
					12"	33.1	32.6	32.3*
					18"	32.9	33.0	32.6*
5. February 14-17, 1970	2/16/70	1:30 AM (12.5 Hrs.)	33.4	PORTLAND CEMENT	6"	32.6	33.5	32.0*
					12"	32.9	32.3	32.1*
					18"	32.7	32.3	-----
				BITUMINOUS	6"	35.5	34.6	32.5*
					12"	33.8	33.1	32.4*
					18"	33.8	33.3	32.7*
5. February 14-17, 1970	2/16/70	1:15 PM (24 Hrs.)	36.5	PORTLAND CEMENT	6"	49.5	46.4	32.1*
					12"	45.0	33.0	34.3*
					18"	43.9	32.8	-----
				BITUMINOUS	6"	37.0	40.2	32.6*
					12"	35.2	35.2	33.2*
					18"	35.6	34.5	32.9*

* Panel not in operation
--- Temperature data unreliable

TABLE B-3. STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND DATE	DATE OF OBSERVATION	TIME	AIR TEMP (° F)	TYPE OF CONCRETE	PIPE SPACING	SURFACE TEMPERATURE (° F) PIPE DIAMETER 3/4"	1"	1-1/4"
5. February 14-17, 1970	2/16/70	10:15 PM (33 Hrs.)	29.9	PORTLAND CEMENT	6"	36.0*	31.5	28.6*
					12"	32.9*	28.8	28.8*
					18"	31.0*	28.2	-----
				BITUMINOUS	6"	32.8*	32.0	29.2 *
					12"	30.2*	28.5	26.0*
					18"	30.1*	29.1	28.0*
5. February 14-17, 1970	2/17/70	10:45 AM (45.5 Hrs.)	37.1	PORTLAND CEMENT	6"	36.1*	45.1	31.4*
					12"	36.4*	38.1	33.3*
					18"	34.5*	32.7	-----
				BITUMINOUS	6"	36.0*	38.0	31.1*
					12"	38.0*	40.3	31.9*
					18"	32.7*	35.8	32.0*

* Panel not in operation
--- Temperature data unreliable

TABLE B-4

Output Temperature of Heat Exchanger Fluid, (°F)

Date	Total Accumulated Hours of Operation	Heat Exchanger #1	#2	#3
12-25-69	2	52.0	52.0	49.0
12-29-69	71	46.0	48.0	46.0
1-06-70	80	47.0	47.0	46.0
1-07-70	102	45.0	45.0	44.0
1-13-70	130	43.0	43.0	42.0
1-21-70	140	44.0	43.0	*
1-23-70	160	42.5	42.0	*
2-15-70	170	42.0	41.0	*
2-16-70	200	42.0	40.0	*

*Heat Exchanger #3 not operational after 1-13-70 due to minor leak at a valve located in the pump house. Repair was made but the Heat Exchanger #3 system could not be repressurized due to the cold weather.

Appendix C. Winter Operation, 1970-71

Appendix | Page

C.1 Snow Storm Operating Procedure

The operating procedure for this winter was the same as that outlined in Section B-1, except for the following changes.

1) Beginning with the storm of 2/17/71, the temperature data that had been manually recorded in a log book was thereafter automatically printed on paper tape by the Digitec system which had been programmed to print data on an hourly basis.

2) During Winter 1970-71, Panels #1 and 2, 3 and 4, 5 and 6 were connected to Heat Exchangers #1, 2 and 3, respectively. Panels #1, 2, 4, 5, 6, 7 and 8 were operated during all snow storms; Panel #3, only during the first three snow storms because of leakage. For the winter, Panels 1, 2, 4, 5, 6, 7 and 8 were each operated for a total of approximately 100 hours; Panel #3, for 60 hours.

C.2 Storm Records

Storm	Date	Page
(1)	December 21	105
(2)	December 22	105
(3)	December 31-January 2	106
(4)	January 13-14	107
(5)	January 24-25	108
(6)	February 17	110
(7)	March 3	110
(8)	March 4	111
(9)	April 6-7	113

Storm #1

(December 21, 1970)

A light snow, melting on contact with the pavement, began to fall at 4:20 PM. The entire system was activated at 4:55 PM. Snow continued to fall for the next five hours and finally ceased at approximately 10:00 PM. During this period the air temperature dropped several degrees from 34°F (4:35 PM) to 32°F (8:00 PM), and slush began to form on several panels, notably P2 (18) and P4 (18), while the snow melted on contact with the other panels.

At 10:00 PM, Panels #1, 3, 4, 6, 7 and 8 were wet and clear of all snow and slush, and P7 (60W) and P8 (60W) were 98% dry.* At this same time, slush still remained on P2 (18) and P4 (18), while P2 (6, 12) and P4 (6, 12) were clear and wet.

The best melting had occurred on P7 (60W) and P8 (60W). The slowest melting took place on P2 and P4 - both constructed of bituminous concrete. All other panels were equal in melting ability.

Storm #2

(December 22, 1970)

About 6:00 AM, light hail and snow began to fall and continued throughout the morning.

On arrival at the test site at 8:45 AM, all panels except P7 (40, 60W) were covered with 1/4 inch of snow. All systems were turned on at 8:50 AM.

*For explanation of percentage dry and percentage clear and wet refer to Appendix, Section A.2 page 82

By 10:07 AM, P7 (60W) and P8 (60W) were clear and wet, and P1 and P5 had produced sufficient melting to change the snow covering them to slush. P5 had produced better melting than P7 (20W) which was still snow covered. Snow covered all other panels to a depth of 1/2 inch.

The snowfall ended at about 11:15 AM, and was followed by light rain. Total accumulation of snow was measured as approximately one inch.

At 1:05 PM, Panels #1, 3, 5, 7 and 8 were for the most part clear and wet with only slight instances of slush, while P2, P4, and P6 were snow covered with localized melting occurring only directly above the buried pipes.

The system was deactivated at 1:40 PM.

Air temperature for the storm was measured as 33°F at 9:00 AM, 32.5°F at 11:00 AM, and 32.9°F at 1:00 PM.

The best snow melting had occurred on P7 and P8, both of which melted snow at an approximate rate of 1/2 inch per hour per square foot. P5 (6) and P1 (6) performed the best of the embedded pipe panels. P5 (6) melted snow at a rate of 1/2 inch per hour and P1 (6) at a rate of greater than 1/4 inch per hour.

Storm #3

(December 31, 1970 - January 2, 1971)

The system was turned on at 1:30 PM, with no snow falling at the time. Snow began falling sometime between 11:00 PM (12/31/70) and 1:00 AM (1/1/71).

By 11:45 AM (1/1/71), there was a snow accumulation of 4inches with heavy snowfall still continuing. P7 (40W, 60W) and P8 (60W) were partially clear, but all other sections and panels showed no signs of melting. The air temperature was 28°F.

Snow stopped falling at approximately 3:00 PM, the afternoon of January 1, 1971.

At 7:30 AM (1/2/71), P7, P1 (6) and P8 (40W, 60W) were clear. All other areas and panels were snow covered with melting directly above the buried pipes (Photo C-1, page 115). Air temperature was 21.6°F.

At 12:00 noon (1/2/71) P3 and P4 were turned off due to a sharp pressure drop in that particular system. P7 and P8, P5 (6) and P1 (6) were totally clear and dry, whereas all other pavement surfaces were clear and wet directly above the buried pipes with slush covering the pavement between pipe centers. Air temperature was 32.9°F.

By 4:00 PM (1/2/71), P1 (12), P5 (12), P2 (6) and P6 (6) were now clear. P3 and P4 showed little if any additional melting. Air temperature was 32.9°F. (Photo C-2, page 115).

The system was deactivated at 4:35 PM (1/2/71).

P7 (40W, 60W) and P8 (40W, 60W), P1 (6), and P5 (6) were observed to have the most satisfactory melting. P7 (60W) and P8 (60W) melted 4 inches of snow in 12 hours. P5 (6) and P1 (6) melted 4 inches of snow in less than 30 hours.

NOTE: This was the last time Panel #3 was operated this winter. From this time on Panel #3 served as a control panel; i.e., fluid was no longer pumped through the pipes and the panel was no longer heated. A leak developed in this panel possibly from a break occurring in the plastic pipe. This leak was discovered as a result of a pressure drop in the system servicing Panels #3 and #4. It was traced to the layer of plastic pipe in Panel #3 that lies two inches below the concrete surface. A more exact location of this leak could only be determined by excavation of the panel.

Storm #4

(January 13-14, 1971)

Light snow mixed with sleet started falling between 7:30 PM and 9:00 PM (1/13/71). The system was activated at 12:15 AM (1/14/71), with outside air temperature being 27°F.

By 1:05 AM, there had been no significant melting and all panels were covered with a hard crust of snow and sleet.

At 10:30 AM, the next morning, snowfall (total accumulation 1") had stopped and a light rain was falling. Outside air temperature was 33.5°F. P7, P8, P1 (6), P4 (6), and P5 (6) were wet and 100% clear of snow and ice. All other areas and panels were either snow or snow and ice covered. P7 and P8 were turned off at 10:50 AM and the other panels turned off at 2:23 PM.

At 2:30 PM, all panels except P2 (12, 18), P3, and P4 (18) were clear of snow and slush. P2 (12), P2 (18), and P4 (18) were slush covered, and the control P3 was still mostly snow covered.

Electrical panels #7 and #8 showed the best melting and were both clear and 65% dry by this time. Of the embedded pipe panels P1 (6), P4 (6), and P5 (6) melted snow most effectively.

Storm #5

(January 24-25, 1971)

Snowfall was intermittent on the 24th of January. Snowfall lasted from 4:00 PM to 6:00 PM, stopped for a period of two hours, then resumed from 8:00 PM to 11:30 PM for a total accumulation of two inches. At 11:30 PM, Panels 4, 5, 6, 7 and 8 were turned on.

At 9:55 AM (1/25/71), Panels #1 and #2 were activated while Panels #4, 5, 6, 7 and 8 were turned off. At this time, P7 (40W, 60W) and P8 (40W, 60W) were clear but still wet. P5 (6, 12), P4 (6), and P6 (6) were 90% clear and wet. P5 (18) ,P4 (12, 18), and P6 (12, 18) were partially snow covered.

P1, P2 and P3 were completely covered with 2 inches of snow. Air temperature was 35.6°F.

By 1:00 PM that afternoon, P4, P5,P6 and P1 (6) were 100% clear and wet. P1 (12, 18) was clear directly above pipe centers with slush existing between pipe centers.

P2, though mostly snow covered, was clear and wet above the 18" pipe spacing where cars had driven over it. P3 (control) was snow covered. Air temperature was 39°F. The system was completely deactivated at 1:05 PM (1/25/71). The best melting occurred on P7 and P8. The best performing pipe section was P5 (6). This buried pipe panel melted snow at better than 0.2 inches per hour.

P1 (6) which was activated 10-1/2 hours after the other panels melted snow at a rate of 0.7 inches per hour, however, the air temperature was above 35°F.

Storm #6

(February 17, 1971)

The system was activated at 4:35 PM (2/17/71), with a very light snow falling at the time. Air temperature was 36.2°F. Snow was melting on contact with the pavement surface and all panels were wet.

The snow gradually changed to rain which ceased at 7:20 PM (2/17/71). At 7:20 PM, all panels were clear and wet. Air temperature was measured at 36.7°F.

All systems were turned off at 7:20 PM (2/17/71).

There was no accumulation of snow on any panels or on the adjoining parking lot.

Storm #7

(March 3, 1971)

A light snow was falling at the test site at 10:00 AM. Air temperature was 32.5°F. P1 and P5 were slush covered, P3 was slush and snow covered, and P2, P4 and P6 were snow covered (Photo C-3, page116). The total snow accumulation was 1.5 inches. The system was activated at 10:15 AM.

By 1:45 PM, the air temperature had risen to 33.1°F and the snow had changed to rain. At this time, P1 and P5 were wet and clear of snow and slush. P3 (control), P4 and P6 were partially covered with slush and P2 was completely covered by slush (Photo C-4, page116).

The system was deactivated at 1:45 PM after 3-1/2 hours of operation.

P1 and P5 melted snow at a rate greater than 1/3 inch per hour, and once again these two panels produced better snow melting than any of the other pipe panels.

NOTE: P7 and P8 were covered by parked automobiles throughout this entire storm so no conclusive visual observations of P7 and P8 could be made.

Storm #8

(March 4, 1971)

Snowfall began between 4:00 AM and 5:00 AM (3/4/71). The snowfall was accompanied by high winds which caused drifting.

The system was activated at 9:00 AM, at which time all panels were snow covered to a depth of 2 inches. Air temperature was 28.8°F. The snowfall ceased sometime between 10:00 AM and 11:00 AM, and with drifting the final accumulation approached 3 inches.

At 11:00 AM, all panels were fully snow covered except P7 (60W) and P8 (60W) which were 80% clear and wet, and P7 (40W) and P8 (40W), which were 60% clear and wet (Photo C-7, page 118). Melting was observed on P1 (6), P5 (6) & P5 (18) (Photo C-5, page 117). Air temperature was 29.7°F.

An hour later, at 12:00 noon, P2, P3 and P4 were still snow covered though the depth of snow had been reduced to 1/2 - 3/4 inch on P2 and P4, and 1 - 1-1/2 inches on P3. P1 (6) was 50% clear and wet, while P1 (12, 18) was concealed by 1/2 inch of snow (Photo C-6, page 117). All sections of P6 were 50% clear and wet. P5 (6), P5 (12) and P5 (18) were 70%, 30% and 40% clear and wet, respectively. P7 (40W, 60W) and P8 (40W, 60W) were almost 100% clear and wet; P7 (20W) and P8 (20W) were 50% clear and wet (Photo C-8, page 118). Air temperature was 29.1°F.

At 2:00 PM, all sections of Panels #1, 2, 5 and 6 were at least 90% clear and wet. P7 (40W, 60W) and P8 (40W, 60W) were clear and dry. P7 (20W) and P8 (20W) were 100% clear and wet. P4 (12, 18) were 100% clear and wet, whereas P4 (6) was mostly slush covered. P3 was completely covered by slush. Air temperature was 29.9°F.

The system was deactivated after 6 hours of operation, at 3:00 PM, at which time these final qualitative observations were made. Panels #1, 2, 5 and 6 were wet and 100% clear of snow and slush. P7 and P8 were 100% clear and dry. P3 and P4 (6) were covered with slush. P4 (12, 18) were wet and 100% clear. Air temperature was 29.4°F.

P7 (60W) and P8 (60W) once again surpassed all of the other panel areas in snow melting ability. The 60 watts/ft^2 electrical areas of these panels melted 3 inches of snow in four hours for a melting rate of 3/4 inch per hour. Of the embedded pipe panels, P5 (6, 12) and P1 (6) melted snow at the fastest rate. P5 (6, 12) and P1 (6) melted 3 inches of snow in six hours for a snow melting rate of 1/2 inch per hour.

In order to obtain a more accurate estimate of snow melting rates, more frequent visual observations were made during this snow storm. The snow melting rates presented here are therefore considered to be the most accurate ones determined for this winter.

NOTE 1: Automobile traffic passed over Panels #3, 4, 5, 6, 7 and 8 sometime between 11:00 AM and 12:00 noon.

NOTE 2: Before this storm it was discovered that the thermistor used to measure outside air temperature had been placed close to an opened window of the gate house. Heat escaping from the window may have influenced outside air temperature readings taken previous to this storm. If the thermistor had been affected, it would have indicated readings higher than actual outside air temperature. This misplacement of thermistor was corrected, so that outside air temperatures, for this storm and the ones following it, are accurate.

Storm #9

(April 6-7, 1971)

Heavy wet snow began falling about 8:00 PM the evening of April 6, 1971.

At 10:05 PM, that same evening, Panels #1, 2, 4, 7 and 8 were turned on. P5 and P6 had been operated continuously since March 16, 1971, so these panels were already operational when the rest of the system was activated. All of the panels were covered with snow to a depth of three inches except P5 which was covered by 1.5 inches of snow. Air temperature was 32.3°F.

Overnight the snowfall ceased.

At 8:30 AM (4/7/71) the next morning, P7 (40W, 60W) and P8 (40W, 60W) and P5 (6) were 100% clear and wet. P7 (20W) and P8 (20W) were 90% clear and wet. P5 (12) was 50% clear and wet, and P5 (18) was 25% clear and wet (Photo C-9, page 119). P1 and P6 were completely covered with 1/4 - 1/2 inch slush and 1-1/2 - 2 inches of slush, respectively. P3 (control) and P4 were covered by two inches of wet snow, and P2 was covered by one inch of wet snow.

By 10:05 AM the wet snow covering P2, P3 and P4 had been reduced to slush. Slush still covered P6. P1 (6) and P5 (6) were 100% clear and wet, whereas, P1 (12, 18) and P5 (12, 18) were 80% clear and wet. P7 (40W, 60W) and P8 (40W, 60W) were clear and 10% dry, P7 (20W) and P8 (20W) were 100% clear and wet. Air temperature was 45.9°F.

At 11:45 AM, the system was deactivated. The air temperature was 49.3°F. By this time, all panels except P3 and P4 were 100% free of slush and snow. P3 and P4 were still 25% covered with wet snow. P7, P8, P1 (6) and P5 (6, 12) were completely dry (Photo C-10, Page 119). All other areas and panels were clear and wet.

P7, P8 and P5 (6) showed the best melting. P5 (6) melted snow at a rate greater than 0.3 inches per hour, and P1 (6) melted snow at a rate greater than 1/4 inch per hour. As in all other storms P5 (6) and P1 (6) exceeded all other buried pipe panels in effectiveness of snow melting.

NOTE: Considerable automobile traffic traversed P3 and P4 during this storm.

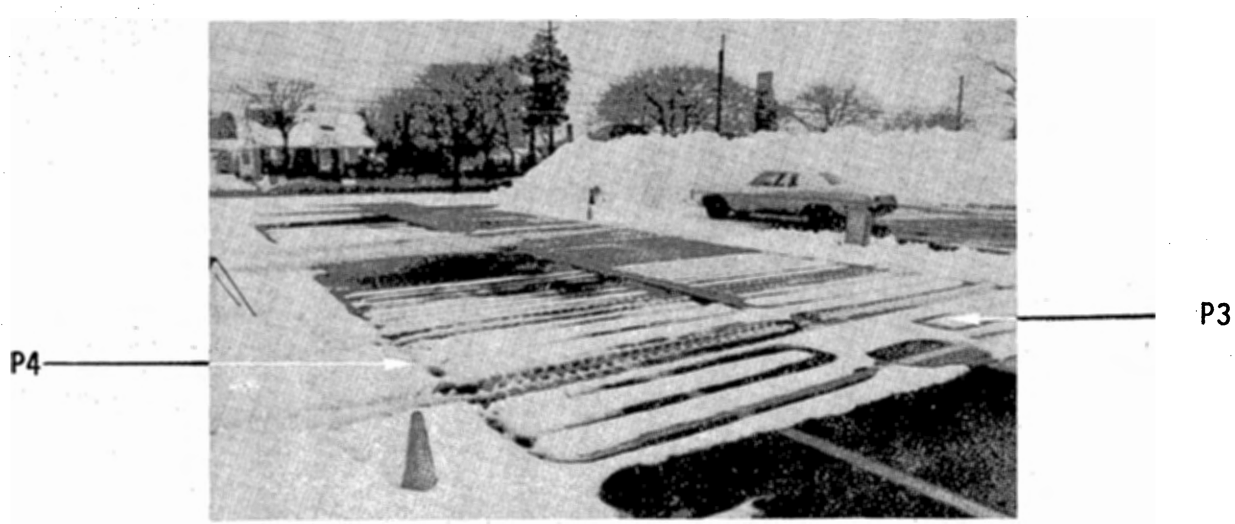
C. 3 STORM PHOTOGRAPHS

PHOTOGRAPH **C-1** STORM #3

Panel #3 (Portland Cement Concrete) & Panel #4 (Bituminous Concrete)
7:30 AM - January 2, 1971
(Operated 42 hours) (Air Temp. 21.6 °F)

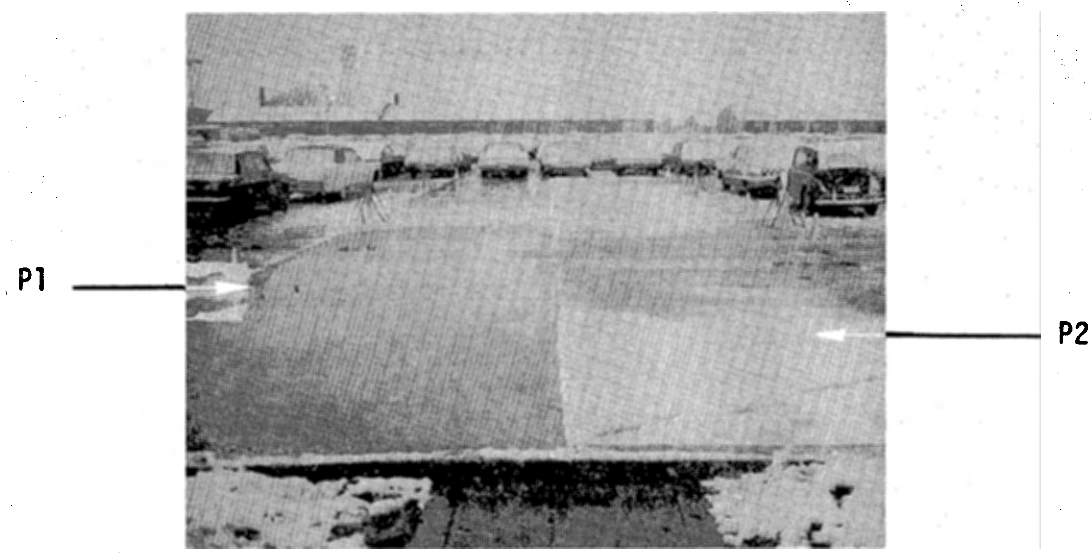
PHOTOGRAPH **C-2** STORM #3

Panel #3 (Portland Cement Concrete) & Panel #4 (Bituminous Concrete)
4:15 PM - January 2, 1971
(Operated 50 hours) (Air Temp. 35.0°F)



PHOTOGRAPH C-3 STORM # 7

Overall View --- Panels #1 & #2 nearest the observer
10:15 AM - March 3, 1971
(Just Activated) (Air Temp. 32.5°F)

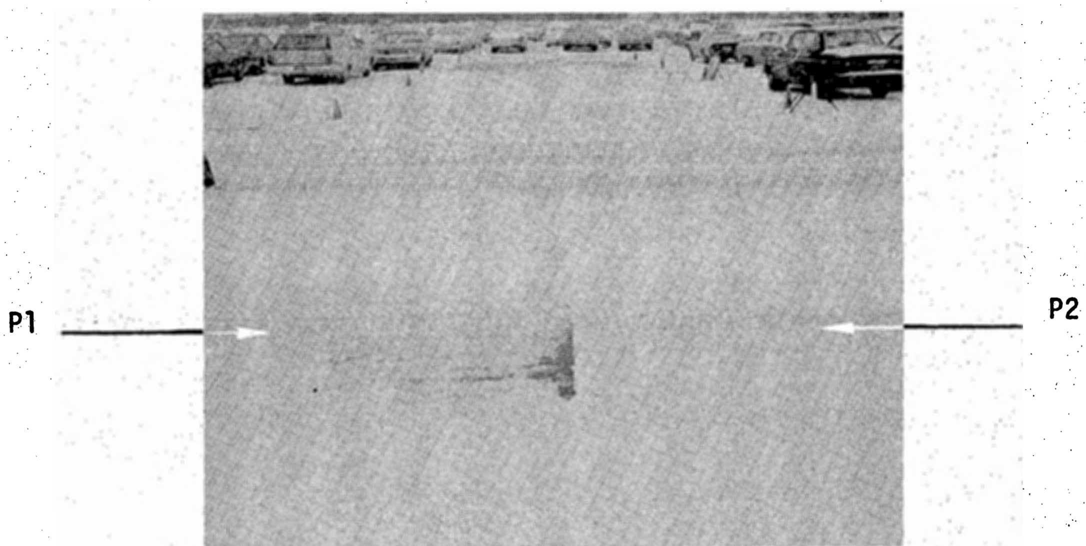


PHOTOGRAPH C-4. STORM # 7

Overall View --- Panels #1 & #2 nearest the observer
1:45 PM - March 3, 1971
(Operated 3.5 hours) (Air Temp. 33.1°F)

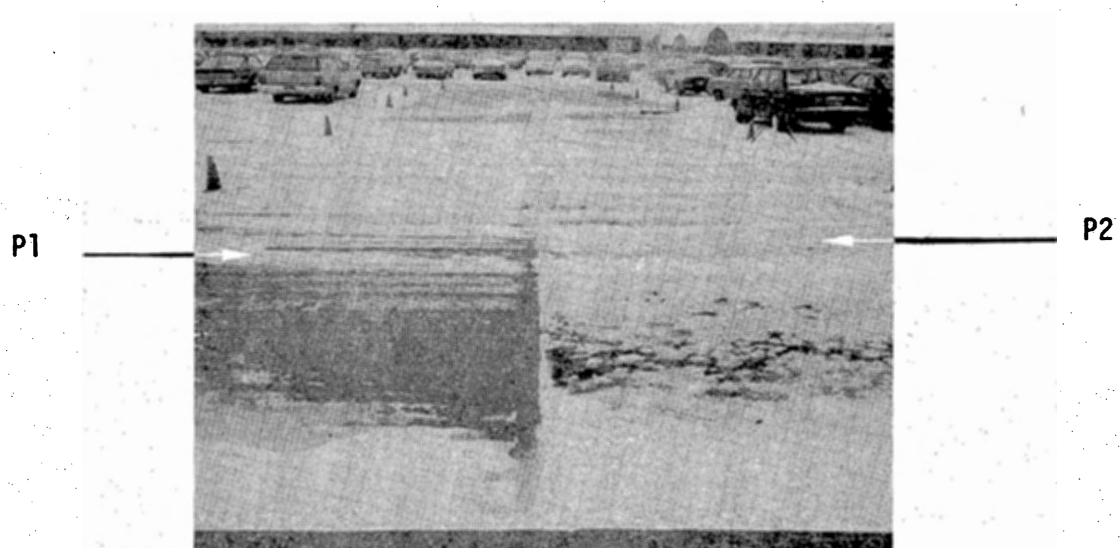
PHOTOGRAPH C-5 STORM # 8

Panel #1 (Portland Cement Concrete) & Panel #2 (Bituminous Concrete)
11:00 AM - March 4, 1971
(Operated 2 hours) (Air Temp. 29.7°F)



PHOTOGRAPH C-6 STORM # 8

Panel #1 (Portland Cement Concrete) & Panel #2 (Bituminous Concrete)
12:00 Noon - March 4, 1971
(Operated 3 hours) (Air Temp. 29.1°F)



PHOTOGRAPH C-7 STORM # 8

Panel #7 (Portland Cement Concrete) & Panel #8 (Bituminous Concrete)
11:00 AM - March 4, 1971
(Operated 2 hours) (Air Temp. 29.7°F)

P8  P7

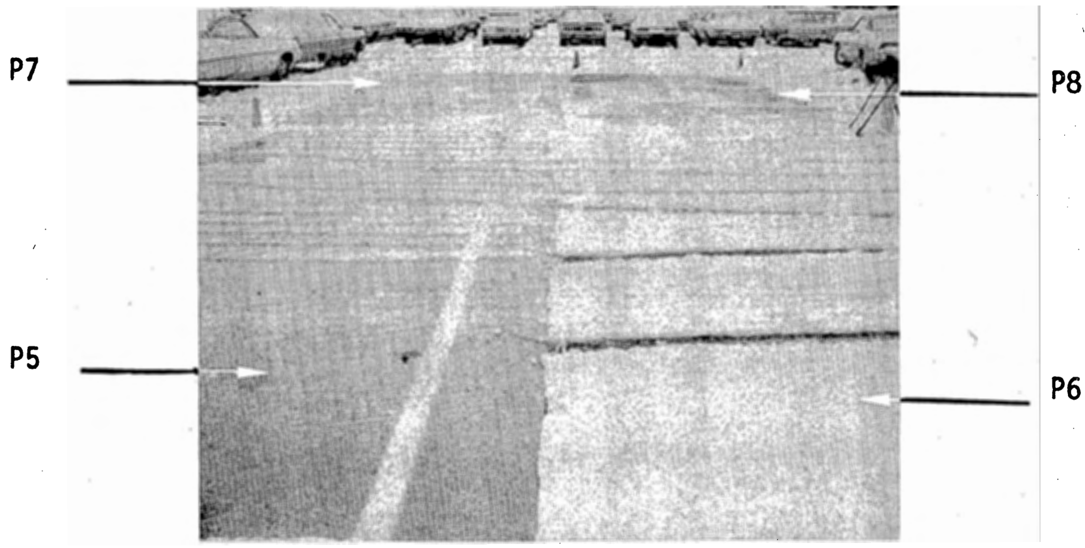
PHOTOGRAPH C-8 STORM #8

Panel #7 (Portland Cement Concrete) & Panel #8 (Bituminous Concrete)
12:00 Noon - March 4, 1971
(Operated 3 hours) (Air Temp. 29.1°F)

P8  P7

PHOTOGRAPH C-9 STORM #9

Panels #5, #6, #7, and #8
8:30 AM - April 7, 1971
(Operated 10.5 hours) (Air Temp. 37.0°F)



PHOTOGRAPH C-10 STORM # 9

Panels #5, #6, #7, and #8
11:45 AM - April 7, 1971
(Operated 13.5 hours) (Air Temp. 49.3°F)

C.4 Storm Data

Table C-1, pages 121-128, lists pavement surface temperatures and related surface conditions for snowstorms #1-9. Data is presented for surface conditions varying from snow, slush, and ice covered to clear and dry; operating times, from 1-51 hours; and air temperature, from 21.6-45.9°F. The most complete data presented is for snowstorm #8; here, surface temperatures are presented on an hourly basis. Table C-2 indicates that except for readings of 31.8°F for P2 (18) on 1/2/71 (7:45 AM) and 31.7°F for P1 (18) on 1/25/71 (1:05 PM), pavement surface temperature were maintained above 32°F at all of the times listed. Surface temperatures for panels in operation fell within the 32-50°F range with the exception of the 53.4°for P1 (6) on 1/2/71 (12:37 PM). The lowest temperature measured for a panel not in operation, was 30.4°F for P3 (18) on 1/14/71 (10:15 AM).

Table C-2, page 129 lists the output temperatures of the heat exchanger fluid during this winter. Note that the general trend was for the output temperature to decrease as the winter progressed.

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND STORM DATE		DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
1.	Dec. 21, 1970	12/21/70	8:10 PM (3 hrs.)	32.0	PORTLAND CEMENT	6"	CW	CW	CW	44.1	37.6	41.9
						12"	CW	CW	CW	35.2	32.5	35.8
						18"	CW	CW	CW	37.9	32.5	34.3
					BITUMINOUS	6"	CW	CW	CW	39.6	34.1	43.6
						12"	CW	CW	CW	37.6	35.0	38.0
						18"	CW	CW	CW	35.3	32.8	36.2
		12/21/70	10:08 PM (5 hrs.)	32.0	PORTLAND CEMENT	6"	2%CD	CW	CW	46.0	40.3	43.6
						12"	2%CD	CW	CW	37.6	35.0	38.0
						18"	2%CD	CW	CW	35.3	32.8	36.2
					BITUMINOUS	6"	CW	CW	CW	42.0	42.5	41.3
						12"	CW	CW	CW	34.5	35.0	35.7
						18"	SL	SL	CW	34.0	34.1	34.5
2.	Dec. 22, 1970	12/22/70	11:00 AM (2 hrs.)	32.5	PORTLAND CEMENT	6"	50%SL,CW	SC,M	80%CW,SL	38.5	33.4	34.3
						12"	SC,M	SC,M	SC,M	32.9	32.4	32.8
						18"	SC,M	SC,M	SC,M	32.5	32.4	32.5
					BITUMINOUS	6"	SC	SC	SC	37.8	37.0	36.8
						12"	SC	SC	SC	33.7	33.8	33.7
						18"	SC	SC	SC	33.3	33.6	33.8

CW - Clear and wet
CD - Clear and dry
SL - Slush
SC - Snow Covered
M - Melting above pipes
I - Ice

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
2. Dec. 22, 1970 (Cont.)	12/22/70	1:00 PM (4 hrs.)	32.9	PORTLAND CEMENT	6"	CW	CW	CW	44.6	38.2	42.7
					12"	SL	SL	80%CW	33.1	32.5	33.0
					18"	SL	SL	30%CW	32.6	32.5	33.8
					6"	SC,M	SC,M	SC,M	38.6	37.9	37.3
				BITUMINOUS	12"	SC,M	SC,M	SC,M	34.1	34.2	33.8
					18"	SC,M	SC,M	SC,M	33.6	33.8	34.0
3. Dec. 31, 1970 TO Jan. 2, 1971	1/1/71	12:10 PM (23 hrs.)	28.0	PORTLAND CEMENT	6"	SC	SC	SC	37.5	33.1	33.8
					12"	SC	SC	SC	33.0	32.3	32.7
					18"	SC	SC	SC	32.5	32.9	32.4
					6"	SC	SC	SC	37.7	37.4	36.6
				BITUMINOUS	12"	SC	SC	SC	33.8	33.6	33.4
					18"	SC	SC	SC	32.9	32.8	33.9
	1/2/71	7:45 AM. (42.5 hrs.)	21.6	PORTLAND CEMENT	6"	100%CD	SC,I,M	SL	39.8	34.9	34.6
					12"	SL	SC,I,M	SC,M	34.8	33.8	35.5
					18"	SC,I	SC,I,M	SC,M	35.2	32.7	34.4
					6"	SC,M	SC,I,M	SC,I,M	40.7	34.1	38.1
				BITUMINOUS	12"	SC,M	SC,I,M	SC,I,M	34.1	33.7	34.5
					18"	SC	SC,I,M	SC,I,M	31.8	33.1	34.9

CW - Clear and wet
CD - Clear and dry
SL - Slush
SC - Snow covered
M - Melting above pipes
I - Ice

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
3. Dec. 31, 1970 to Jan. 2, 1971 (Cont.)	1/2/71	12:37 PM (47 hrs.)	32.9	PORTLAND CEMENT	6"	100%CD	SL	CD	53.4	34.7	48.6
					12"	SL	SL	SL	33.5	32.7	33.3
					18"	I,SL	SC,M	SL	34.2	32.5	33.1
					6"	CW	SL	CD	43.1	44.8	39.1
				BITUMINOUS	12"	SC,M	SL	SL	34.4	37.0	34.9
					18"	SC	SC,M	SL	33.5	33.4	34.3
	1/2/71	4:20 PM (51 hrs.)	35.0	PORTLAND CEMENT	6"	CD	SL	CD	48.5	*35.2	43.1
					12"	70%CW	SL	CD	36.9	*32.2	36.3
					18"	75%CW,I	SC,M	SL	32.3	*32.6	32.7
					6"	90%CW	SL	100%CW	41.7	*40.1	40.8
				BITUMINOUS	12"	SL	SL	SL	34.5	*34.8	35.0
					18"	I	SC,M	SL	34.0	*34.5	34.3
4. Jan. 13-14, 1971	1/14/71	10:15 AM (10 hrs.)	33.5°F	PORTLAND CEMENT	6"	100%CW	SC	100%CW	44.3	*31.3	40.7
					12"	SL	SC	SL	32.6	*30.7	32.4
					18"	SL	SC	SL	32.1	*30.4	33.6
					6"	SC,M	100%CW	SC,I	36.4	36.6	36.6
				BITUMINOUS	12"	SC	SC	SC,I	33.0	33.2	33.1
					18"	SC	SC	SC,I	32.8	32.6	34.2

CW - Clear and wet
CD - Clear and dry
SL - Slush
SC - Snow covered
M - Melting above pipes
I - Ice
* Panel Not in Operation

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

	STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
4.	Jan. 13-14, 1971 (Cont.)	1/14/71	1:30 PM (13.5 hrs.)	33.5	PORTLAND CEMENT	6"	100%CW	SL	95%CW	48.8	*31.8	44.3
						12"	100%CW	SL	95%CW	39.8	*31.8	40.3
						18"	100%CW	SL	95%CW	32.5	*32.1	40.0
					BITUMINOUS	6"	CW	CW	95%CW	42.7	46.3	44.2
						12"	SL	CW	95%CW	33.3	34.3	34.7
						18"	SL	SL	95%CW	33.0	33.1	42.8
5.	Jan. 24-25, 1971	1/25/71	10:00 AM (10.5 hrs.)	35.6	PORTLAND CEMENT	6"	SC	SC	90%CW	*37.5	*31.0	43.4
						12"	SC	SC	90%CW	*31.8	*30.8	38.3
						18"	SC	SC	SL	*31.8	*30.7	36.5
					BITUMINOUS	6"	SC	90%CW	90%CW	*31.9	42.8	40.2
						12"	SC	SL	SL	*31.9	33.2	36.1
						18"	SC	SL	SL	*31.8	32.6	33.8
		1/25/71	1:05 PM (13.5 hrs.)	39.0	PORTLAND CEMENT	6"	CW	SC	CW	43.9	*35.7	*44.9
						12"	SL	SC	CW	32.5	*31.8	*43.9
						18"	SL	SC	CW	31.7	*32.1	*43.5
					BITUMINOUS	6"	SC	CW	CW	34.8	*48.1	*46.4
						12"	SC	CW	CW	32.0	*45.4	*46.2
						18"	SC	CW	CW	33.9	*42.1	*46.6

CW - Clear and wet SL - Slush M - Melting above pipes
CD - Clear and dry SC - Snow covered I - Ice
* Panel not in operation

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

	STORM NUMBER AND STORM DATES	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
6.	Feb. 17-18, 1971	2/17/71	7:00 PM (3 hrs.)	36.4°F	PORTLAND CEMENT	6"	CW	CW	CW	43.9	*32.9	39.6
						12"	CW	CW	CW	35.3	*32.0	36.0
						18"	CW	CW	CW	34.2	*32.1	42.7
					BITUMINOUS	6"	CW	CW	CW	35.9	38.7	43.9
						12"	CW	CW	CW	32.3	35.7	35.5
						18"	CW	CW	CW	34.5	46.0	36.7
7.	March 3, 1971	3/3/71	11:00 AM (1 hour)	33.1°F	PORTLAND CEMENT	6"	SL	SL	SL	40.5	*34.2	35.8
						12"	SL	SL	SL	32.9	*32.3	34.6
						18"	SL	SC	SL	37.0	*32.5	40.3
					BITUMINOUS	6"	SC	SC	SC	35.2	35.2	40.9
						12"	SC	SC	SC	34.0	33.6	33.6
						18"	SC	SC	SC	34.8	39.9	34.5
		3/3/71	12 noon (2 hrs.)	33.1°F	PORTLAND CEMENT	6"	SL	SL	SL	44.2	*35.1	39.3
						12"	SL	SL	SL	35.6	*32.6	37.5
						18"	SL	SC	SL	36.9	*32.5	40.9
					BITUMINOUS	6"	SC	SC	SC	36.2	36.7	41.5
						12"	SC	SC	SC	34.1	33.7	33.8
						18"	SC	SC	SC	36.5	39.8	34.6

CW - Clear and wet   SL - Slush   M - Melting above pipes
CD - Clear and dry   SC - Snow covered   I - Ice
* Panel not in operation

TABLE C-1 STORM DATA – EMBEDDED PIPE PANELS

	STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
7.	March 3, 1971 (Cont.)	3/3/71	1:00 PM (3 hours)	33.1°F	PORTLAND CEMENT	6"	CW	50%CW,SL	CW	45.5	*36.5	40.3
						12"	CW	50%CW,SL	CW	37.3	*33.5	38.3
						18"	CW	50%CW,SL	CW	37.9	*32.6	41.1
					BITUMINOUS	6"	SL	50%CW,SL	SL	36.6	38.5	41.9
						12"	SL	50%CW,SL	SL	34.3	33.9	34.1
						18"	SL	50%CW,SL	SL	36.8	39.8	36.3
8.	March 4, 1971	3/4/71	10:00 AM (1 hour)	29.1	PORTLAND CEMENT	6"	SC	SC	SC	40.3	*32.4	33.9
						12"	SC	SC	SC	32.8	*32.3	33.1
						18"	SC	SC	SC	32.7	*32.4	40.7
					BITUMINOUS	6"	SC	SC	SC	35.1	34.5	41.5
						12"	SC	SC	SC	33.5	33.2	33.2
						18"	SC	SC	SC	33.4	39.8	33.8
		3/4/71	11:00 AM (2 hours)	29.7	PORTLAND CEMENT	6"	SC,M	SC	SC,M	40.6	*32.5	34.2
						12"	SC	SC	SC	32.9	*32.3	33.2
						18"	SC	SC	SC,M	32.8	*32.4	41.1
					BITUMINOUS	6"	SC	SC	SC	35.8	35.2	42.0
						12"	SC	SC	SC	33.7	33.4	33.4
						18"	SC	SC	SC	33.6	39.7	33.8

CW - Clear and wet SL - Slush M - Melting above pipes
CD - Clear and dry SC - Snow Covered I - Ice
* Panel Not in Operation

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURES (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
8. March 4, 1971 (Cont.)	3/4/71	12 noon (3 hours)	29.1	PORTLAND CEMENT	6"	50%CW,SL	SC	70%CW,SL	40.7	*32.6	34.5
					12"	SC	SC	30%CW,SL	33.2	*32.4	33.2
					18"	SC	SC	40%CW,SL	32.8	*32.4	41.3
					6"	SC	SC	50%CW,SL	36.2	35.5	42.4
				BITUMINOUS	12"	SC	SC	50%CW,SL	34.0	33.6	34.4
					18"	SC	SC	50%CW,SL	33.6	39.8	34.1
	3/4/71	1:00 PM (4 hours)	30.6	PORTLAND CEMENT	6"	50%CW,SL	SL	80%CW,SL	43.3	*32.5	36.8
					12"	90%CW,SL	SL	70%CW,SL	34.2	*33.3	33.2
					18"	SL	SL	70%CW,SL	33.2	*32.6	42.9
					6"	CW	CW	90%CW,SL	36.4	35.8	43.7
				BITUMINOUS	12"	80%CW,SL	90%CW,SL	90%CW,SL	34.0	35.1	34.4
					18"	80%CW,SL	90%CW,SL	90%CW,SL	34.1	41.1	37.2
	3/4/71	2:00 PM (5 hours)	29.9	PORTLAND CEMENT	6"	90%CW,SL	SL	90%CW,SL	48.0	*32.9	43.6
					12"	90%CW,SL	SL	90%CW,SL	40.2	*38.7	35.6
					18"	90%CW,SL	SL	90%CW,SL	34.8	*32.9	48.0
					6"	90%CW,SL	CW	95%CW,SL	36.6	36.1	48.8
				BITUMINOUS	12"	90%CW,SL	CW	95%CW,SL	39.5	41.5	42.8
					18"	90%CW,SL	CW	95%CW,SL	36.3	45.9	42.0

CW - Clear and wet
CD - Clear and dry
SL - Slush
SC - Snow Covered
M - Melting above pipes
I - Ice
* Panel Not in Operation

TABLE C-1 STORM DATA - EMBEDDED PIPE PANELS

	STORM NUMBER AND STORM DATE	DATE OF OBSERVATION	TIME (HOURS IN OPERATION)	AIR TEMPERATURE (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITIONS PIPE DIAMETER			SURFACE TEMPERATURE (°F) PIPE DIAMETER		
							3/4"	1"	1-1/4"	3/4"	1"	1-1/4"
8.	March 4, 1971 (Cont.)	3/4/71	3:00 PM (6 hours)	29.4	PORTLAND CEMENT	6"	CW	40%CW,SL	98%CW,SL	48.3	*34.8	42.2
						12"	CW	30%CW,SL	98%CW,SL	39.8	*38.2	39.7
						18"	CW	30%CW,SL	98%CW,SL	36.1	*35.4	47.8
						6"	CW	CW	CW	41.0	38.1	38.6
					BITUMINOUS	12"	CW	CW	CW	41.2	41.8	41.6
						18"	CW	CW	CW	38.7	46.1	40.4
9.	April 6-7, 1971	4/6/71	11:00 PM (1 hour)	33.5	PORTLAND CEMENT	6"	SC	SC	SC	41.1	*33.1	34.1
						12"	SC	SC	SC	33.6	*32.9	-----
						18"	SC	SC	SC	33.5	*33.2	40.2
						6"	SC	SC	SC	36.4	36.2	40.8
					BITUMINOUS	12"	SC	SC	SC	35.1	35.0	-----
						18"	SC	SC	SC	35.5	43.1	35.4
		4/7/71	10:39 AM (12.5 hrs.)	45.9	PORTLAND CEMENT	6"	CW	SL	CW	46.3	*39.0	58.6
						12"	80%CW,SL	SL	90%CW,SL	39.4	*32.8	52.7
						18"	80%CW,SL	SL	80%CW,SL	37.0	*37.5	49.8
						6"	SL	SL	SL	37.0	42.5	50.2
					BITUMINOUS	12"	SL	SL	SL	36.4	36.3	55.8
						18"	SL	SL	SL	37.0	47.0	49.8

CW - Clear and wet
CD - Clear and dry
* Panel Not in Operation
SL - Slush
SC - Snow Covered
-----Temperature Data Unreliable
M - Melting above pipes
I - Ice

TABLE C-2

OUTPUT TEMPERATURE OF HEAT EXCHANGER FLUID

Date	Heat Exchanger #1 Temperature °F	Heat Exchanger #1 Operational Hours	Heat Exchanger #2 Temperature °F	Heat Exchanger #2 Operational Hours	Heat Exchanger #3 Temperature °F	Heat Exchanger #3 Operational Hours
12/21/70	58	5.5	61	5.5	55	5.5
12/22/70	58	10.5	61	10.5	55	10.5
01/01/71	54	47	56	47	51	47
01/02/71	52	61.5	54	61.5	49	61.5
01/14/71	51	75.5	51.5	75.5	47	75.5
02/17/71	51	81.5	49.5	89	46.5	89
03/03/71	49	85	47	92	46	92
04/06/71	47	98.5	48	106	46.5	106

Appendix D. Winter Operation, 1971-72

Page

D.1 Snow Storm Operating Procedure

Operating procedure for this winter was the same as that outlined in Section B-1, except for the following changes:

1) If snow was forecast, electrical resistance Panels #7 and 8 were activated in anticipation of snowfall. If non-forecast snow began to fall, Panels #7 and 8 were turned on as soon as assigned personnel arrived at the test site. Panels #1, 2, 5 and 6, which were operated continuously throughout the winter, were already in operation at the start of snowfall.

2) The Digitec system was programmed to sample and print temperature data on an hourly basis.

3) Data collection and the recording of observations continued until all the snow that fell on Panels #1, 2, 5, 6, 7 and 8 had melted or it became evident that the panels would not melt more snow.

4) During this winter, Panels #1, 2, 5 and 6 were connected to Heat Exchanger #3. These panels were operated continuously (24 hours a day) throughout this winter from December 30, 1971 to February 24, 1972. Panels #1, 2, 5 and 6 were each operated for approximately 1,440 hours. Electrical resistance Panels #7 and 8 were operated only during snow storms, each for a total of 85 hours. Panels #3 and 4 and Heat Exchanger #1 and #2 were not operated this winter.

D.2 Storm Records

Storm #1

(January 28, 1972)

General Account

Snow was falling on arrival at the test site at 1:05 AM, January 28. Snowfall ended by 11:00 AM, January 28. An accumulation of 3 inches was recorded at the latter time. Sky conditions varied from cloudy to hazy and wind was slight to non-existent for the duration of the test period. Air temperature was 26.4°F at 1:05 AM, January 28. For a short time, between 2:00 and 4:30 PM, it rose to 33.0°F. Thereafter, air temperature averaged 26.0°F and dipped as low as 23.8°F.

Panels 3 and 4 (Control)

Maximum snow cover on the panels - 3 inches - was observed at 11:00 AM, January 28. Very little melting was apparent; thus, by 8:42 AM, January 29, a 3 inch accumulation was still present.

Panels 1, 2, 5 and 6 (Test)

In order of decreasing melting capability, the eight best melting embedded pipe panel sections were P5 (6), P1 (6), P5 (12), P5 (18), P1 (18), P6 (6) and P2 (6). P1 (6) and P5 (6) were the first to be clear and wet at about 1:00 PM, January 28, 12 hours after the start of snowfall. (See Photographs D-1 and D-2, page 142). P1 (6), which was 95% dry* at 4:35 PM, January 28, was the only panel section on which ice did not form between the pipes, when the air temperature fell to 29°F at 8:10 PM, January 28. By the end of the data collection period - 3:08 PM, January 29 - the only panel sections free of ice were P1 (6, 12) and P5 (6, 12, 18). Melting rates were: 0.28 in/hr - P1 (6) and P5 (6), 0.20 in/hr - P6 (6), P2 (6), P1 (12) & P5(12); and 0.18 in/hr - P5 (18) and P1 (18). The worst melting section was P2 (18) - 0.12 in/hr.

Panels 7 and 8 (Reference)

At 12:30 AM, January 28, the panels were turned on. By 11:00 AM of the same day, P7 (60W) and P8 (60W) were clear and 95% dry, and P7 (40W) and P8 (40W) were clear and wet. By 4:35 PM, the 60 and 40 watts/ft^2 sections were 100% and 95% clear and dry, respectively; whereas the 20 watts/ft^2 sections were clear and 50% wet. When the air temperature fell below 32°F during the late afternoon and evening, ice formed only on the 20 watts/ft^2 sections of the panels. This ice was still present when the electrical resistance panels were deactivated at 11:00 PM, January 28. Melting rates were: P7 (60W) and P8 (60W) - greater than 0.35 in/hr, P7 (40W) and P8 (40W) - 0.28 in/hr, P7 (20W) and P8 (20W) - 0.24 in/hr.

*See Appendix A, Section A.2, page 83

NOTE: For this storm P1 (6) equaled the melting produced by P7 (40W) and P8 (40W).

Storm #2

(February 2, 1972)

General Account

Light snow was falling at 8:30 AM and ceased at 12:40 PM on February 2. The wind was easterly at 15-25 mph. Air temperature readings were above 32.0°F, with the exception of those readings recorded at 8:30 AM (31.8°F) and 2:00 PM (31.9°F). Accumulation was 1/2 inch.

Panels 3 and 4 (Control)

The greatest accumulation of snow on the panels was 1/2 inch, and this was still remaining at 4:15 PM, February 2.

Panels 1, 2, 5 and 6 (Test)

All sections of P1 and P5 were clear and wet for the storm, with snow melting on contact with the pavement. (Photograph D-3, page 143). After some initial snow cover, P6 was 100% clear and wet at 10:10 AM and P2 was 100% clear and wet by 11:15 AM. By 4:15 PM, February 2, P2 and P6 remained clear and wet, although P1 (6), P1 (12), and P1 (18) were 60% dry, 5% dry, and 100% clear and wet, respectively, and P5 (6), P5 (12), and P5 (18) were 25% dry, 25% dry, and 100% clear and wet, respectively. In order of decreasing melting capability, the eight best melting panel sections were P1 (6), P5 (6), P5 (12), P1 (18), P5 (18), P6 (6) and P2 (6). The panels exhibiting the least melting were P2 (18), P2 (12), and P6 (18). For this storm, the melting rates of embedded pipe panels were approximately 0.2 in/hr.

Panels 7 and 8 (Reference)

At 8:30 AM, the electrical resistance panels were under a slight snow cover. They were activated ten minutes later (Photograph D-4, page 143). By 9:00 AM, the 60, 40 and 20 watts/ft^2 sections of P7 produced more rapid melting than their corresponding sections of P8. By 10:10 AM, both P7 and P8 were 100% clear and wet. Six hours later (4:15 PM), P7 and P8 (40W, 60W) were 100% dry, P8 (20W) was 80% dry, and P7 (20W) was 50% dry. Melting rates were better than 0.2 in/hr.

Storm #3

(February 6-7, 1972)

General Account

Very light snow was falling at the test site at 3:40 PM, February 6. This snowfall became heavier at about 8:35 PM and ceased at 11:23 PM with a maximum accumulation of 2-1/4 inches. Wind direction varied between NW and SW, and wind velocity was 10-15 mph until 11:00 AM, February 7. The wind was mild from this time forth. At 11:00 AM, February 7 the sky condition became clear and sunny and remained this way for the duration of data collection. Air temperature was almost always below 32°F, becoming colder as the storm progressed and dropping to 28.2°F by 1:40 PM, February 7.

Panels 3 and 4 (Control)

The control panels were under maximum snow cover (2-3/16 inches) at 11:23 PM, February 6. By the end of data collection (1:40 PM, February 7), 1-1/2 inches of snow still lay on the panels. The snow had melted at a rate of 0.05 in/hr.

Panels 1, 2, 5 and 6 (Test)

Of the embedded pipe panels P1 and P5 produced the fastest melting. The greatest accumulations on these panels - 11:23 PM, February 6 - were P1 (6) - 7/8 inch, P1 (12) - 1-1/4 inch, P1 (18) - 1-9/16 inch, P5 (6) - 9/16 inch, and P5 (12, 18) - 1-1/8 inch. At this time, P6 and P2 were covered with as much as 1-11/16 inches of snow. By 3:30 AM, February 7, P1 (6) and P5 (6) were 50% clear and wet with slush; by 8:45 AM, they were 90% clear and wet, 10% dry. P6 (6) and P2 (6) were not clear and wet until 11:00 AM. At the end of data collection (1:40 PM, February 7), these surface conditions existed: P1 (6, 12) - 100% dry, P1 (18) - 40% clear and dry, P2 (6) - 80% clear and dry, P2 (12) - 100% clear and wet, P2 (18) - 98% clear and wet (2% snow), P5 (6, 12, 18) - 100% dry, P6 (6) - 50% clear and dry, and P6 (12, 18) - 40% clear and dry. As usual, the closer pipe spacings provided more rapid melting, i.e., the pipes spaced on 6" centers yielded more effective snow melting than those spaced on 12" centers, and so on. Approximate melting rates obtained were P1 (6) and P5 (6) 0.15 in/hr, P6 (6) and P2 (6) - 0.12 in/hr (see Photographs D-5,6,7, and 8, pages 144 and 145).

Panels 7 and 8 (Reference)

The panels were activated at 4:40 PM, February 6. During the entire storm, there was no snow accumulation on the 60 watts/ft^2 sections of P7 and P8. The 20 and 40 watts/ft^2 sections of the panels had a slight slush buildup; however, P7 (40W) and P8 (40W) were clear and wet by 8:35 PM, February 6, and P7 (20W) and P8 (20W) were clear and wet at 11:23 PM. Melting rates were: greater than 0.37 in/hr for P7 (60W) and P8 (60W); 0.3 in/hr for P7 (40W) and P8 (40W), and 0.2 in/hr for P7 (20W) and P8 (20W).

Storm #4

(February 17-18, 1972)

General Account

At 6:15 PM, February 17, snow was falling at the test site. Snowfall became lighter around 9:00 PM and ceased at approximately 11:15 PM. The accumulation was read as 1-3/8 inches. Wind was from the north at a velocity of 10-15 mph. Air temperature was initially 29.7°F and stayed below 32.0°F until 3:08 AM, February 18. Henceforth, it remained above 32.0°F, and the highest reading (34.2°F) was measured at 10:30 AM.

Panels 3 and 4 (Control)

P3 and P4 were snow covered throughout the storm. Maximum snow cover was 1-3/8 inches at 11:15 PM, February 17. By the end of the storm (10:30 AM, February 18), 1 inch of snow cover remained. Melting rate for the panels was 0.03 in/hr.

Panels 1, 2, 5 and 6 (Test)

The first embedded pipe panel sections to become clear and wet were P1 (6) and P5 (6) (6:04 AM, February 18). They had the most rapid melting rate - 0.13 in/hr. The following surface conditions existed at 10:30 AM (16 hours after the beginning of the storm): P1 (6) - 50% wet, 50% dry; P1 (12) - 98% wet, 2% dry; P1 (18) - 100% wet; P2 (6) - 100% wet; P2 (12) - 80% wet, 20% slush; P2 (18) - 98% wet, 2% slush;

P5 (6) - 95% wet, 5% dry; P5 (12, 18) - 98% wet, 2% dry; P6 (6) - 100% wet; P6 (12) - 50% wet, 50% slush, and P6 (18) - 80% wet, 20% slush. The worst melting took place on P6 (18) - less than 0.09 in/hr.

Panels 7 and 8 (Reference)

The electrical resistance panels were activated at 5:00 PM, February 17. By 9:45 PM, P7 was clear and wet, and P8 was clear and wet with some slush present. They remained clear and wet throughout the period of snowfall, snow melting on contact with the panels. The panel sections were 100% dry at the following times: P7 (60W) and P8 (60W) - 11:15 PM, February 17; P7 (40W) - 1:15 AM, February 18; P8 (40W) - 3:15 AM; and P7 (20W) and P8 (20W) - 6:04 AM. Snow melting rates for all panel sections were better than 1/4 in/hr.

Storm #5

(February 19-22, 1972)

General Account

Snowfall began at 1:00 AM on February 19, 1972 and stopped at 11:00 PM of the same day; it was most intense shortly after 2:00 PM. The accumulation was 2 inches. The wind direction changed quite often and wind velocity was generally moderate (20-25 mph). At the outset of the storm, air temperature was 34.0°F. It remained above 32.0°F until 8:00 PM, February 19, when a reading of 31.6°F was recorded. During the rest of the storm, air temperature was below freezing with the coldest reading (16.8°F) occurring at 7:30 PM, February 20. The sky was overcast from the beginning of the data collection period until 12:00 noon, February 20, after which it was mostly clear.

Panels 3 and 4 (Control)

The greatest snow accumulation on these panels occurred at 5:00 PM, February 19. At this time, the panels were covered by 1-3/4 inches of wet snow. At 8:30 AM, February 22 (end of storm) the panels were covered by 3/4 inches of snow. The melting rate of the panels was approximately 0.02 in/hr.

Panels 1, 2, 5 and 6 (Test)

P1 (6) and P5 (6) were the first of the embedded pipe panels sections to be clear and wet (12 noon of February 19). After this time, snowfall became more intense and P1 (6) and P5 (6) became snow covered once more. These two panel sections were again clear and wet at 2:00 PM, February 20 - 15 hours after snowfall had ceased. At this time, P1 (6, 12) was ice covered to a 1/2 inch depth. P2 (6, 12, 18) was covered by 1 inch of crusted snow, P5 (12) was 40% clear and wet with 60% ice, P5 (18) was covered by 1/2 inch crusted snow, and P6 (6, 12, 18) were snow covered to depths of 3/8, 1/2, & 3/4 inch, respectively. Best melting took place on P1 (6) - 0.15 in/hr. Worst melting occurred on P2 (18) - 0.05 in/hr.

Panels 7 and 8 (Reference)

Turned on at 6:00 AM, February 19, these panels were clear and wet by 12 noon of the same day. Although snowfall became more intense after 2:00 PM, at 5:00 PM the 60 watts/ft^2 sections were 50% clear and wet with slush, and the 20 watts/ft^2 sections were covered by a 1/2 inch of slush. P7 (60W) and P8 (60W) were 100% dry by 8:00 PM, February

19 and remained dry for the duration of the storm. P7 (40W) and P8 (40W) were 100% dry by 11:00 PM, February 19 and stayed dry throughout the storm. P7 (20W) and P8 (20W) became 100% dry at 2:00 PM February 20 and remained dry. The melting rates for the 60, 40 and 20 watts/ft^2 sections were better than 0.4 in/hr, 0.3 in/hr, and 0.2 in/hr, respectively.

Storm #6

(February 23-24, 1972)

General Account

At 6:45 PM on February 23, snow was falling at the test site. The snow changed to sleet by 10:20 PM; the accumulation was 3 inches. All precipitation had ceased by 12:47 AM, February 24. Air temperature was 24.9°F at 6:45 PM on February 23 and did not go above freezing until 11:30 AM February 24. From this time on until the end of data collection (4:25 PM, February 24) air temperature ranged from 36.0°F to 42.6°F. A light wind blew throughout the entire storm.

Panel 3 and 4 (Control)

At 6:45 PM, February 23, P3 and P4 were covered with 3/4 inch of loosely packed snow. By 10:20 PM the snow cover was 3 inches. The maximum accumulation was 3-1/16 inches at 12:47 AM. At 4:25 PM, February 24, 2 inches of hard crusted snow still remained on these control panels. One inch had melted in 22 hours (0.05 in/hr.)

Panels 1, 2, 5 and 6 (Test)

The maximum snow accumulation on these panels was recorded at 10:20 PM, February 23. At this time the snow cover on P2, P6, P1, and P5 was 3, 2-3/4, 2-3/4, and 2-1/2 inches, respectively. For all panels, the pipes spaced on 6 inch centers exhibited better melting than pipes spaced on 12 inch and 18 inch centers. In most cases (60%) pipes spaced on 12 inch centers produced better melting than those spaced on 18 inch centers. In order of decreasing melting ability, the nine best melting panel sections were: P5 (6), P5 (12), P1 (6), P5 (18), P1 (12), P1 (18), P2 (6), P2 (18), and P2 (12).*

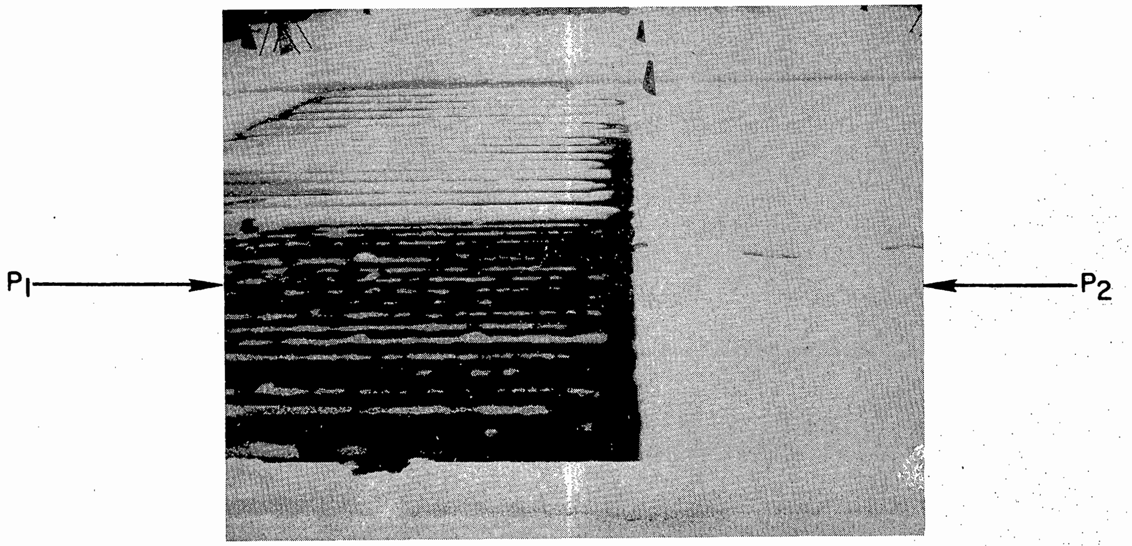
The best melting rate - P5 (6) - was 0.16 inches of snow per hour. The slowest melting rate - P2 (12) - was 0.14 in/hr.

Panels 7 and 8 (Reference)

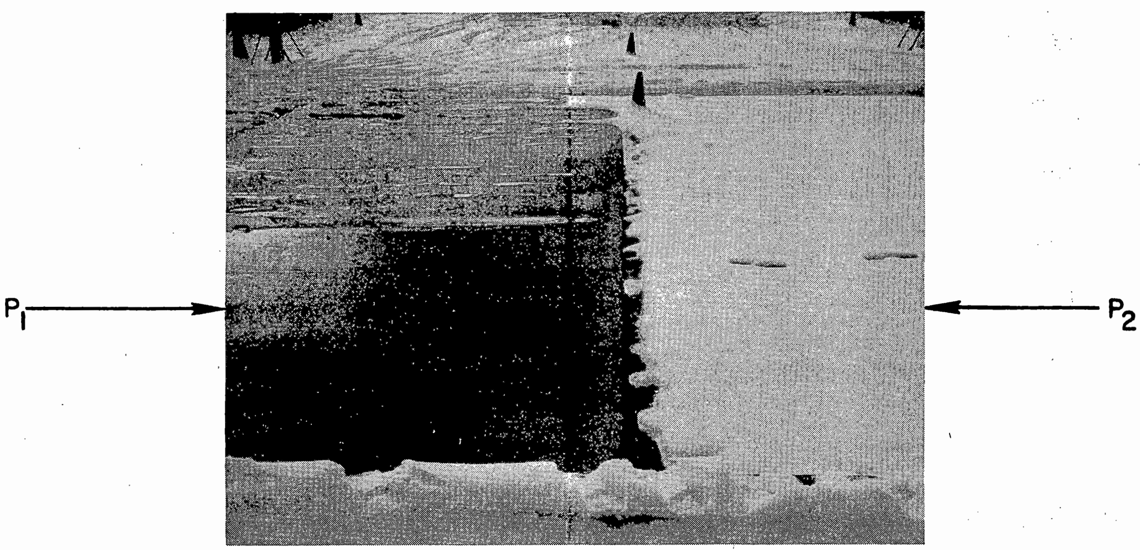
Panels #7 and #8 were activated at 6:50 PM, February 23. The 60 watts/ft^2 sections of these panels provided the fastest melting of any panel section. These sections were clear and wet by 10:20 PM. They had melted snow at a rate of 0.84 in/hr. The 40 watts/ft^2 sections had melted all snow by 12:47 AM, February 24 - melting rate (0.5 in/hr). The 20 watts/ft^2 sections produced a melting rate of 0.23 in/hr and were clear and wet by 4:30 AM, February 24.

*Visual observations of Panel #6 could not be compared with the others because heavy automobile traffic had transversed it.

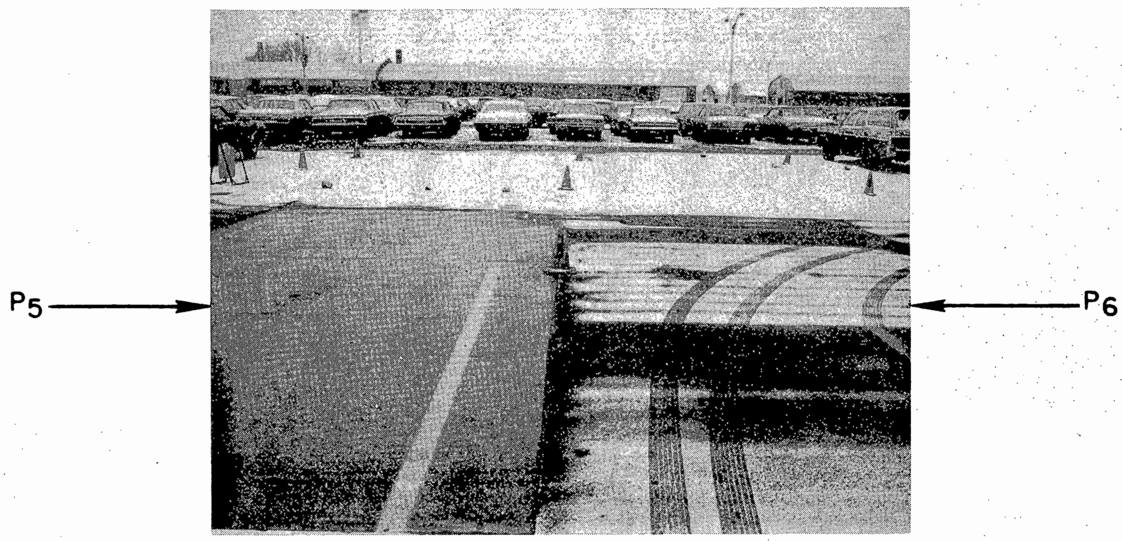
D.3 STORM PHOTOGRAPHS



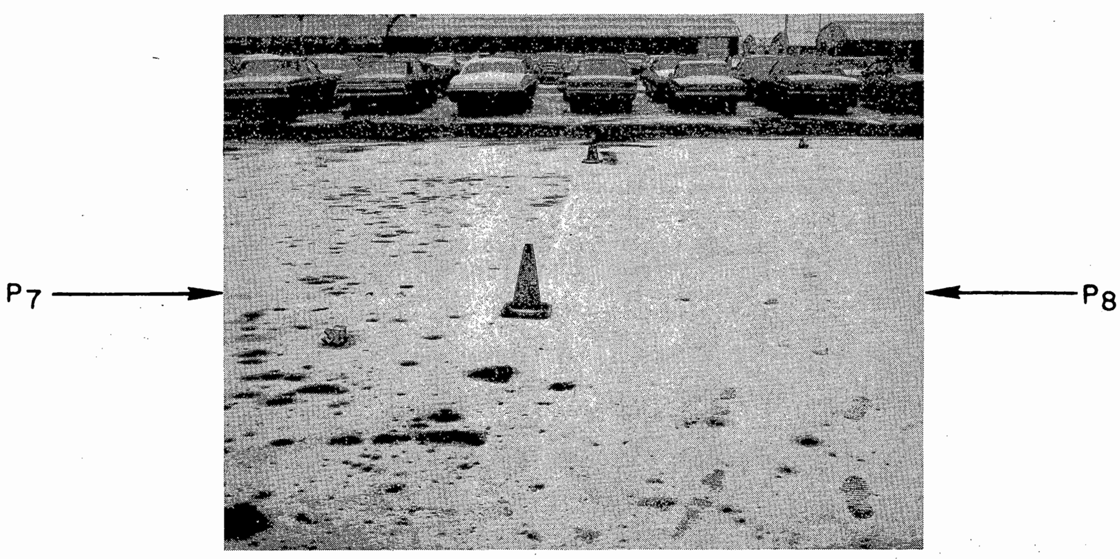
PHOTOGRAPH D-1 STORM #1
Panel #1 (Portland Cement Concrete) and Panel #2 (Bituminous Concrete)
11:00 AM - January 28, 1972
(13 hours from start of snowfall)(Air Temp. 28.0°F)



PHOTOGRAPH D-2 STORM #1
Panel #1 (Portland Cement Concrete) and Panel #2 (Bituminous Concrete)
2:00 PM - January 28, 1972
(16 hours from start of snowfall)(Air Temp. 33.9°F)

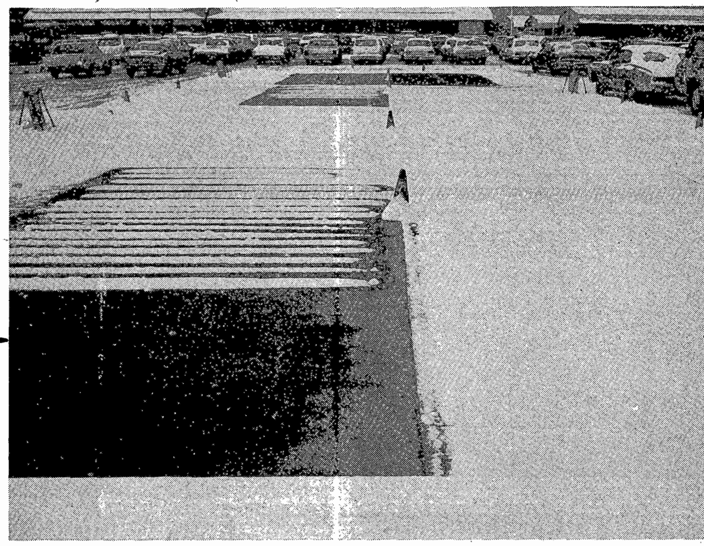


PHOTOGRAPH D-3 STORM # 2
Panel #5 (Portland Cement Concrete) and Panel #6 (Bituminous Concrete)
8:45 AM - February 2, 1972
(45 mins. from start of snowfall)(Air Temp. 32.1°F)

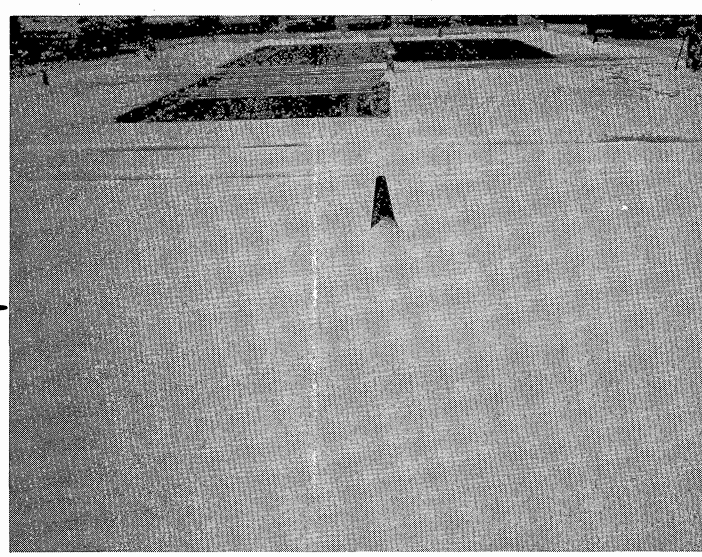


PHOTOGRAPH D-4 STORM #2
Panel #7 (Portland Cement Concrete) and Panel #8 (Bituminous Concrete)
8:45 AM - February 2, 1972
(45 mins. from start of snowfall)(Air Temp. 32.1°F)

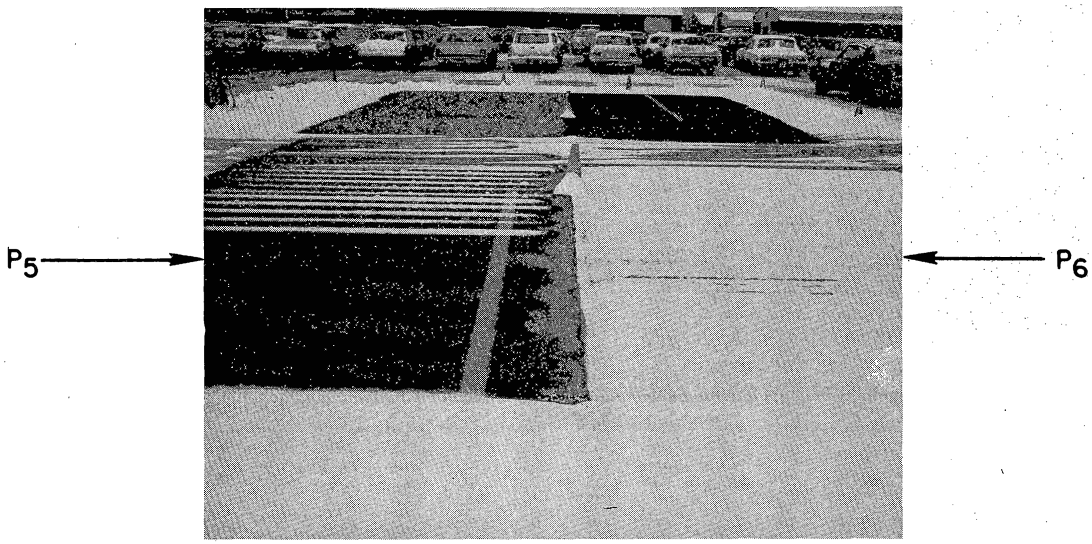
Note Salted Areas



PHOTOGRAPH D-5 STORM #3
Panel #1 (Portland Concrete Cement) and Panel #2 (Bituminous Cement)
9:00 AM - February 7, 1972
(18 hours from start of snowfall)(Air Temp. 29.3°F)



PHOTOGRAPH D-6 STORM #3
Panel #3 (Portland Cement Concrete) and Panel #4 (Bituminous Concrete)
9:00 AM - February 7, 1972
(18 hours from start of snowfall)(Air Temp. 29.3°F)



PHOTOGRAPH D-7 STORM #3
Panel #5 (Portland Cement Concrete) and Panel #6 (Bituminous Concrete)
9:00 AM - February 7, 1972
(18 hours from start of snowfall)(Air Temp. 29.3°F)

PHOTOGRAPH D-8 STORM #3
Panel #7 (Portland Cement Concrete) and Panel #8 (Bituminous Concrete)
9:00 AM - February 7, 1972
(16 hours from turn-on)(Air Temp. 29.3°F)

D.4 Storm Data

Table D-1, pages 147-152, lists pavement surface temperatures and corresponding pavement surface conditions for the embedded pipe panels during snowstorms #1, 2, 3, 4, 5 and 6. Temperature data is presented for surface conditions varying from snow, slush, and ice covered to clear and dry; air temperatures, between 18.7° - 42.7°F; and times from start of snowfall, between 0.5 - 42 hours. Surface temperature readings for panels in operation were generally above 32°F - a notable exception is Storm #5 at 7:00 PM. Surface temperature readings for panels in operation exceeded 40°F on only one occasion - Storm #6 at 4:00 PM.

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER: 1

STORM DURATION

	DATE	TIME
FROM:	January 27, 1972	10:00 PM
TO:	January 28, 1972	11:00 AM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
1/28/72	1:00 AM	3 hrs.	26.4	PORTLAND CEMENT	6"	SC	SC	SC	34.8	31.3*	33.5
					12"	SC	SC	SC	32.9	28.4*	33.4
					18"	SC	SC	SC	32.7	29.7*	----
				BITUMINOUS	6"	SC	SC	SC	34.8	31.7*	----
					12"	SC	SC	SC	33.3	28.6*	33.5
					18"	SC	SC	SC	33.4	30.1*	33.2
1/28/72	11:00 AM	13 hrs.	28.0	PORTLAND CEMENT	6"	SC,I	SC	95%CW,I	36.0	32.0*	34.2
					12"	SC,M	SC	50%CW,I	33.2	30.0*	33.7
					18"	SC,M	SC	50%CW,SC	32.5	32.3*	----
				BITUMINOUS	6"	SC	SC	SC	34.8	31.9*	----
					12"	SC	SC	SC	33.3	30.1*	33.5
					18"	SC	SC	SC	33.3	31.3*	33.2
1/28/72	5:00 PM	16 hrs.	32.0	PORTLAND CEMENT	6"	95%CD,W	SC	75%CW,D	37.6	32.0*	35.6
					12"	75%CW,D	SC	80%CW,D	33.4	29.7*	33.7
					18"	90%CW,SC	SC	95%CW,D	32.8	33.0*	----
				BITUMINOUS	6"	SC,M	SC	98%CW,SC	37.0	32.6*	----
					12"	SC,M	SC	75%CW,SC	33.3	29.1*	33.4
					18"	SC,M	SC	65%CW,I	33.2	33.0*	33.7

CW - Clear and wet D - Dry Sl - Slush M - Melting above pipes
CD - Clear and dry W - Wet SC - Snow Covered I - Ice
----Temperature Data Unreliable *Control Panel - Not in Operation

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER

2

STORM DURATION

	DATE	TIME
FROM:	February 2, 1972	8:30 AM
TO:	February 2, 1972	12:30 PM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
2/2/72	9:00 AM	0.5 hr.	32.1	PORTLAND CEMENT	6"	CW	SC	CW	35.5	30.5*	34.9
					12"	CW	SC	CW	33.8	30.2*	34.5
					18"	CW	SC	CW	32.7	31.2*	----
				BITUMINOUS	6"	SC	SC	50%CW,SC	34.3	30.8*	----
					12"	SC	SC	SC,M	33.0	30.2*	33.2
					18"	SC	SC	80%CW,SC	32.8	31.0*	32.5
2/2/72	10:00 AM	1.5 hrs.	32.5	PORTLAND CEMENT	6"	CW	SC	CW	35.9	30.9*	35.4
					12"	CW	SC	CW	34.3	30.7*	35.3
					18"	CW	SC	CW	33.3	31.6*	----
				BITUMINOUS	6"	CW	SC	CW	34.2	31.3*	----
					12"	60%CW,SC	SC	CW	33.0	30.8*	33.4
					18"	50%CW,SC	SC	CW	32.8	31.6*	32.8
2/2/72	11:00 AM	2.5 hrs.	32.4	PORTLAND CEMENT	6"	CW	SC	CW	36.5	31.3*	36.0
					12"	CW	SC	CW	35.1	31.0*	35.9
					18"	CW	SC	CW	34.1	32.0*	----
				BITUMINOUS	6"	CW	SC	CW	35.0	31.5*	----
					12"	CW	SC	CW	33.1	31.1*	34.6
					18"	CW	SC	CW	33.0	32.1*	33.8

CW - Clear and wet D - Dry Sl - Slush M - Melting above pipes
CD - Clear and dry W - Wet SC - Snow Covered I - Ice
----Temperature Data Unreliable *Control Panel - Not in Operation

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER: 3

STORM DURATION

	DATE	TIME
FROM:	February 6, 1972	3:40 PM
TO:	February 6, 1972	11:30 PM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
2/6/72	9:00 PM	5 hrs.	32.9	PORTLAND CEMENT	6"	SC	SC	SC,M	34.0	31.8*	32.9
					12"	SC	SC	SC,M	32.5	31.7*	33.1
					18"	SC,M	SC	SC,M	32.3	32.9*	----
				BITUMINOUS	6"	SC	SC	SC	33.9	31.9*	----
					12"	SC	SC	SC	33.0	31.9*	33.0
					18"	SC,M	SC	SC	32.7	33.0*	33.0
2/7/72	3:00 AM	11 hrs.	30.3	PORTLAND CEMENT	6"	SC,M	SC	50%CW,SL	33.9	31.3*	33.0
					12"	SC,M	SC	SC,M	32.5	31.4*	33.1
					18"	SC,M	SC	SC,M	32.2	32.9*	----
				BITUMINOUS	6"	SC,M	SC	SC,M	33.7	31.6*	----
					12"	SC,M	SC	SC,M	32.8	31.5*	32.9
					18"	SC,M	SC	SC,M	32.6	32.6*	32.7
2/7/72	9:00 AM	17 hrs.	29.3	PORTLAND CEMENT	6"	90%CW,CD	SC	95%CW,CD	35.0	31.1*	34.6
					12"	50%CW,SC	SC	70%CW,SC	33.0	31.4*	34.0
					18"	25%CW,SC	SC	SC	32.2	32.9*	----
				BITUMINOUS	6"	SC,M	SC	SC,M	33.7	31.3*	----
					12"	SC,M	SC	SC,M	32.8	31.3*	33.1
					18"	SC,M	SC	SC,M	32.6	32.9*	32.7

CW - Clear and wet D - Dry Sl - Slush M - Melting above pipes
CD - Clear and dry W - Wet SC - Snow Covered I - Ice
----Temperature Data Unreliable *Control Panel - Not in Operation

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER: 4

STORM DURATION

	DATE	TIME
FROM:	February 17, 1972	6:00 PM
TO:	February 17, 1972	9:15 PM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
2/17/72	9:00 PM	3 hrs.	30.3	PORTLAND CEMENT	6"	SC,M	SC	SC,M	34.0	31.9*	32.9
					12"	SC,M	SC	SC,M	32.6	31.6*	33.1
					18"	SC,M	SC	SC,M	32.6	32.6*	----
				BITUMINOUS	6"	SC	SC	SC	33.8	33.4*	----
					12"	SC	SC	SC	32.8	32.6*	32.9
					18"	SC	SC	SC	33.5	32.8*	33.3
2/18/72	1:00 AM	7 hrs.	32.0	PORTLAND CEMENT	6"	15%SL,SC	SC	SC,M	34.1	31.9*	33.0
					12"	SC,M	SC	SC,M	32.7	31.4*	33.2
					18"	SC,M	SC	SC,M	32.6	32.5*	----
				BITUMINOUS	6"	SC,M	SC	SC,M	33.8	33.0*	----
					12"	SC,M	SC	SC,M	32.8	32.4*	33.0
					18"	SC,M	SC	SC,M	33.2	32.6*	33.0
2/18/72	6:00 AM	12 hrs.	32.1	PORTLAND CEMENT	6"	CW	SC	CW	34.8	31.9*	34.5
					12"	50%CW,SL	SC	50%CW,SL	32.9	31.4*	33.5
					18"	50%CW,SL	SC	50%CW,SL	32.5	32.8*	----
				BITUMINOUS	6"	SC	SC	SL	33.9	32.8*	----
					12"	SC	SC	SL	32.9	32.3*	33.0
					18"	SC	SC	I	33.1	32.5*	33.0

CW - Clear and wet　D - Dry　Sl - Slush　M - Melting above pipes
CD - Clear and dry　W - Wet　SC - Snow Covered　I - Ice
----Temperature Data Unreliable　*Control Panel - Not in Operation

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER

5

STORM DURATION

	DATE	TIME
FROM:	February 19, 1972	1:00 AM
TO:	February 19, 1972	8:00 PM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION, PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F), PIPE DIAMETER 3/4"	1"	1-1/4"
2/19/72	5:00 PM	16 hrs.	31.9	PORTLAND CEMENT	6"	SC	SC	SC	34.1	31.9*	32.9
					12"	SC	SC	SC	32.6	32.1*	33.0
					18"	SC	SC	SC	32.4	33.0*	----
				BITUMINOUS	6"	SC	SC	SC	33.8	32.7*	----
					12"	SC	SC	SC	32.9	32.4*	32.9
					18"	SC	SC	SC	32.9	33.4*	32.8
2/20/72	5:00 AM	28 hrs.	23.9	PORTLAND CEMENT	6"	SC	SC	SC	33.4	31.9*	33.0
					12"	SC	SC	SC	30.3	32.0*	30.9
					18"	SC	SC	SC	28.8	32.1*	----
				BITUMINOUS	6"	SC	SC	SC	33.5	32.5*	----
					12"	SC	SC	SC	32.3	32.2*	32.3
					18"	SC	SC	SC	32.8	33.3*	32.3
2/20/72	7:00 PM	42 hrs.	18.7	PORTLAND CEMENT	6"	CD	SC	CD	28.5	23.6*	27.2
					12"	CW	SC	50%CD,I	23.0	24.1*	25.6
					18"	I	SC	SC,I	26.2	28.0*	----
				BITUMINOUS	6"	SC,I	SC	10%CW,I	29.1	25.4 *	----
					12"	SC,I	SC	I	25.9	24.0 *	23.9
					18"	SC,I	SC	I	26.3	26.8*	24.9

CW - Clear and wet D - Dry Sl - Slush M - Melting above pipes
CD - Clear and dry W - Wet SC - Snow Covered I - Ice
----Temperature Data Unreliable *Control Panel - Not in Operation

TABLE D-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER

6

STORM DURATION

	DATE	TIME
FROM:	February 23, 1972	7:00 PM
TO:	February 24, 1972	12:47 PM

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
2/23/72	10:00 PM	3 hrs.	24.9	PORTLAND CEMENT	6"	SC	SC	SC	33.8	30.3*	32.8
					12"	SC	SC	SC	32.4	29.0*	32.9
					18"	SC	SC	SC	32.3	27.9*	----
				BITUMINOUS	6"	SC	SC	SC	33.4	31.1*	----
					12"	SC	SC	SC	31.3	27.4*	32.6
					18"	SC	SC	SC	32.7	29.8*	32.9
2/24/72	8:00 AM	13 hrs.	30.9	PORTLAND CEMENT	6"	SC,M	SC	SC,M	34.0	30.6*	33.0
					12"	SC,M	SC	SC,M	33.0	30.0*	33.6
					18"	SC,M	SC	SC,M	32.2	30.1*	----
				BITUMINOUS	6"	SC	SC	SC	33.4	31.4*	----
					12"	SC	SC	SC	32.1	29.6*	32.7
					18"	SC	SC	SC,M	32.5	31.3*	32.6
2/24/72	4:00 PM	18 hrs.	42.7	PORTLAND CEMENT	6"	CW	SC	CW	42.1	31.7*	42.3
					12"	CW	SC	CW	38.8	31.8*	39.9
					18"	CW	SC	CW	32.7	32.8*	----
				BITUMINOUS	6"	SC,M	SC	CW	33.5	31.9*	----
					12"	SC,M	SC	CW	32.6	31.7*	41.3
					18"	SC,M	SC	CW	32.5	32.9*	42.5

CW - Clear and wet D - Dry Sl - Slush M - Melting above pipes
CD - Clear and dry W - Wet SC - Snow Covered I - Ice
----Temperature Data Unreliable *Control Panel - Not in Operation

Appendix E. Winter Operation, 1973-74

Page

E.1 Snow Storm Operating Procedure

Operating procedure was the same as that outlined in Section B-1 except for the following changes.

1) If snow began to fall, the system was activated when assigned personnel arrived at the test site.

2) Temperature data was manually recorded on data sheets.

3) The systems put in operation were those listed in Table 1, page 36.

As shown, Panels #1, #5 and #6 were supplied with earth heat - Heat Exchanger #3 (Panel #5 and #6) was operated for 150 hours; Heat Exchanger #3 (Panel #5), 1 hour; Heat Exchanger #1 (Panel #1), 1 hour. Panels #1, #2 and #5 were supplied with fluid heated by an electric heater - Panels #1 and #2 were in operation (supplied with electrically heated fluid) for 95 hours; Panels #1 and #5, for 17 hours. Panels #3, #4, #7 and #8 were not operated during this winter.

E.1.1 System Modification

A 30 kilowatt electric hot water heater (5-8 gallon capacity) was installed in the pump house during 1972. It was put in operation for this winter. There was no operation during Winter '72-'73 due to the lack of snowfall. The heater supplied a 85 - 110°F glycol-water solution to two heating panels formerly supplied with earth heated fluid (40 - 55°F). Accordingly, panels supplied with electrically heated fluid had been disconnected from their respective earth heat exchangers and coupled to the hot water heater.

E.2 Storm Records

Storm #1

(December 16-20, 1973)

General Account

This test was interrupted by several power failures. Panels 1 and 2 (hot water) lost all power due to a main circuit breaker malfunction at 8:15 PM (12/16/73). Power was restored and these panels were again operational by 9:15 PM (12/16/73). However, power was again lost sometime between 2:30 PM and 3:30 PM (12/17/73) due once again to circuit breaker problems. Power could not be restored to Panels 1 and 2, until 9:20 AM on December 20. Panels 5 and 6 (earth heat) were completely operational until deactivation at 11:45 PM (12/18/73). The test panels (and in particular P5 and P6) were mistakenly salted during the morning hours of the 16th.

Light sleet was falling at the test site when the system was activated at 7:15 PM on December 16 and it continued to fall until the morning of December 17. The only additional precipitation recorded was an occasional light snow on the afternoon of December 17. This, along with drifting, added 0.5 inch of snow to the previous 1 inch of ice crust. The skies remained overcast until the sun broke through on the morning of December 18, henceforth the skies remained clear until clouding up again on December 20. The air temperatures stayed in the twenties from December 16-18 with the exception of 18.0°F readings at 11:30 PM on December 17 and 18. On 12/20/73 the air temperature was 45°F at 1:40 PM and 48°F at the conclusion of the test at 4:15 PM. The only wind which was noted during the test period was a mild breeze between 10:30 AM (12/17/73) and 11:30 PM (12/18/73).

Panels 3 and 4 (Control)

Approximately 1 inch of snow covered the control panels at 7:15 PM (12/16/73). By 9:27 PM (12/16/73) this snow had changed into 1/8 inch of wet slush on P3 and 1/4 inch of crusty slush on P4. At 10:30 AM (12/17/73) both panels had about 1 inch of ice crust. At 9:15 AM (12/18/73) they were covered with 1 inch of ice crust and 1/2 inch of light snow. By 4:15 PM on December 20, 1 inch of ice remained; melting was still taking place.

Panels 1 and 2 (Hot Water Heater)

At 2:00 PM (12/17/73) P1 (6) was 90% wet, 2% dry, and 8% ice along the outer edge. The other sections of P1 and P2 were covered by an ice crust varying from 1/4 inch to 1 inch in depth. At the completion of the test at 4:15 PM (12/20/73), P1 (6) was 100% dry, P1 (12, 18) and P2 (6) were 100% clear and wet, and P2 (12, 18) were covered by 1/2 inch of ice.

Panels 5 and 6 (Earth Heat)

At 11:30 PM (12/18/73), just prior to deactivation of the system, P5 (6, 12) were 100% dry, P5 (18) was dry above the pipes with 1/4 inch of ice between the pipes, and P6 was still ice covered with no melting evident. On 12/20/73, with the system deactivated, P5 (6, 12) were 100% dry, P5 (18) and P6 (6) were 100% clear and wet, and P6 (12, 18) still had 1/4 inch of ice covering them. The best melting took place on P5 (6) - approximately 0.05 inches per hour, for the period of time the system was on.

Summary

It is difficult to draw a comparison between the hot water and earth heated panels due to the power failures which interrupted hot water system operation. From the limited amount of data available, however, P1 (6) appears to have the best melting ability.

Storm #2

(January 4, 1974)

General Account

The system was activated at 8:30 AM (1/4/74) with a total accumulation of 0.75 inch to 1 inch of wet snow having already fallen on the test site. The air temperature ranged from 33.0°F at 8:30 AM to 37.0°F at 11:00 AM when the system was deactivated. There was no precipitation during the test period. There was a mild wind and the skies were overcast throughout the duration of the test.

Panels 3 and 4 (Control)

The maximum cover on these panels was 0.75 inch to 1 inch of wet snow, at 8:30 AM (1/4/74). This cover turned into 0.5 to 0.75 inches of wet snow and slush at 10:45 AM on the same day.

Panels 1 and 2 (Hot Water Heat)

The melting rates for these embedded panel sections were all approximately 0.4 in/hr.* But in comparision, the sections in order of decreasing melting capability are as follows: P1 (6), P1 (12), P1 (18), P2 (6), P2 (12) and P2 (18). P1 (6) and P1 (12) were the only sections to be completely clear of snow, ice, or slush at 10:45 AM, 2.25 hours after the activation of the system. By 10:45 AM, P1 (6) was 95% clear and wet and 5% dry, while P1 (12) was 100% clear and wet. The remaining sections were covered by 10 to 50 percent of slush and/or wet snow.

Panels 5 and 6 (Earth Heat)

The melting rates for these embedded pipe sections were also approximately 0.4 in/hr. The melting capabilities of the sections decreased in order as follows: P5 (6), P5 (12), P5 (18), P6 (6), P6 (12), and P6 (18). Only P5 (6), P5 (12) and P5 (18) were 100% clear and wet at the conclusion of the test - the sections of P6, were 75% clear and wet, and 25% slush.

*The hot water heater requires over three hours to warm the heating fluid from the starting temperature (roughly the pavement temperature) to the average operating temperature (90°F), when connected to Panels 1 and 2. When connected to Panels 1 and 5 the time is increased to over six hours.

Summary*

P1 (6) had the best melting ability of all of the sections. P1 (12), P5 (6), P5 (12) and P5 (18) had melting abilities very close to that of P1 (6). The remainder of the sections were considerably less efficient in clearing of snow.

Storm #3

(January 9-11, 1974)

General Account

The snowfall began at approximately 1:00 AM (1/9/74) and the maximum accumulation of 4 inches had already fallen on the test site upon activation of the system at 8:50 AM (1/9/74). At 8:50 AM a light snow mixed with hail was falling. This changed into a light rain at 10:00 AM and all precipitation stopped by 11:00 AM on (1/9/74). It began sleeting and hailing again at 8:30 AM on (1/10/74) and 0.5 inch was added to the previous accumulation. The sleet and hail turned to rain which continued throughout the remainder of the test. There was no wind during the test period. The air temperature ranged from 27.7°F at 10:00 AM (1/9/74), to a low of 22.6°F at 10:00 AM (1/10/74), to 33.7°F by the end of the test. The hot water system was deactivated at 2:00 PM on (1/10/74) and the earth heat system was turned off at 8:45 AM on (1/11/74).

*It should be noted that in the "Summary" section of the storm records presented in this Appendix, hot water heated panels of 3/4" diameter are being compared with earth heated panels of 1-1/4" diameter.

Panels 3 and 4 (Control)

Four inches of snow were lying on the control panels at 8:50 AM (1/9/74). By 8:45 AM (1/11/74) this snow cover had changed into 2 to 3 inches of slush and snow with approximately 1 inch of ice in the tire tracks.*

Panels 1 and 2 (Hot Water Heat)

By 3:00 PM (1/9/74), P1 (6) was 60% dry and 40% wet while P1 (12), P1 (18) and P2 (6) showed considerable melting although they still had 0.75 to 1.0 inch of ice between the pipes. P2 (12) and P2 (18) at this time still had approximately 1.5 inches of hard crusted snow covering them. At midnight (1/10/74), P1 (6) and P1 (12) were 100% dry while P2 (6) was 100% clear and wet. P1 (18) was 40% dry with 0.25 inch of ice between the pipes, but P2 (12) and P2 (18) were still covered with approximately 0.75 inch of ice. At 8:45 AM (1/11/74), after additional rain, sleet, and hail, P1 (6, 12, 18) and P2 (6) were 100% clear and wet, and P2 (12) was 80% wet with ice still between the pipes. P2 (18) still had 0.5 inch of ice with some wet spots directly above the pipes.

The approximate melting rates for the best melting panel sections were: P1 (6) - 0.65 in/hr, P1 (12) - 0.35 in/hr, and P2 (6) - 0.25 in/hr.

Panels 5 and 6 (Earth Heat)

The melting abilities, in decreasing order, of the panel sections were as follows: P5 (6), P5 (12), P5 (18), P6 (6), P6 (12) and P6 (18). P5 (6) had an approximate melting rate of 0.15 in/hr. P5 (6) was the first section to be completely clear of ice

* NOTE: Parking lot traffic accidently passed over these test panels at approximately 3:00 PM (1/9/74)

and snow (100% wet). This occurred at 11:00 PM on (1/10/74). At the conclusion of the test, 8:45 AM (1/11/74), P5 (12) was 100% clear and wet, P5 (18) was 75% wet and 25% ice, P6 (6) was covered with 1 to 1.5 inches of ice and slush (the tire tracks on P6 (6) were wet); and P6 (12, 18), approximately 2.5 inches of snow and slush and 1 inch of ice.

Summary

P1 (6) displayed the best melting ability of all the test sections. With the exception of P2 (18), the melting rates of the hot water system (P1 and P2) were higher than or equal to those of the earth heat system (P5 and P6).

Storm #4

(February 6-7 , 1974)

General Account

Activation of the system took place at 9:10 PM (2/6/74) - freezing rain was falling. At this time, 0.5 inch of snow had already fallen on the test site - this was the maximum accumulation of snow. The freezing rain changed into a light rain around 1:20 AM (2/7/74), and by the conclusion of the test at 8:30 AM (2/7/74) all precipitation had ceased. The skies were overcast during the test and the wind slowly decreased in intensity from a mild breeze at 9:10 PM (2/6/74) into a calm at 8:30 AM on (2/7/74). The air temperature was 28.5°F at 9:10 PM and increased to 32.2°F at 1:20 AM where it remained throughout the rest of the test. Salt was inadvertantly spread on all of the panels during the parking lot salting.

Panels 3 and 4 (Control)

At 9:10 PM (2/6/74) there was 0.5 inch of snow on P3 and P4. By 1:20 AM (2/7/74) this snow had changed into 0.25 inch of ice with a layer of water lying on top.* At the conclusion of the test, at 8:30 AM, there was approximately 0.25 inch of ice on the control panels.

Panels 1 and 2 (Hot Water Heat)

The melting abilities of these panel sections in decreasing order were P1 (6), P1 (12), P1 (18), P2 (6), P2 (12) = P2 (18). Panel 1 was 100% clear and wet by 1:20 AM (2/7/74) while Panel 2 was 50% wet and 50% ice. By 8:30 AM (2/7/74), after the system was in operation 11.2 hours, P1 (6) was 100% dry, P1 (12) was 90% dry and 10% wet, P1 (18) was 50% dry and 50% wet, P2 (6) was 90% wet and 10% dry, and both P2 (12) and P2 (18) were 100% clear and wet.

Panels 5 and 6 (Earth Heat)

The melting abilities of these panel sections in decreasing order were: P5 (6), P6 (6), P5 (12) = P6 (18), P5(18) = P6 (12). At 1:20 AM (2/7/74), P5 (6) and P6 (6) were 90% clear and wet, while P5 (12), P5 (18), P6 (12),and P6 (18) were clear and wet above the pipes but had a thin layer of ice between the pipes. At the end of the test at 8:30 AM (2/7/74), P5 (6) and P6 (6) were 100% clear and wet, P5 (12) and P6 (18) were 90% clear and wet with 10% thin ice between pipes, and P5 (18) and P6 (12) were 75% clear and wet with 25% thin ice between pipes.

*Test panels had been salted.

Summary

P1 (6) had the greatest melting ability while P1 (12) was a close second. The remaining sections cleared the panel of snow or ice with the exception of P5 (12), P5 (18), P6 (12) and P6 (18). These sections were still covered with ice at the conclusion of the test.

Storm #5

(February 8-9, 1974)

General Account

The snow began falling at 11:00 AM (2/8/74), and 0.5 inch had accumulated when the system was activated at 1:05 PM on 2/8/74. The snowfall ceased at approximately 12:30 AM (2/9/74) and a total of 5 inches was accumulated during the storm. The hot water system (P1 and P2) was deactivated at 1:00 PM (2/9/74) while the earth heat system (P5 and P6) was deactivated at 11:15 PM (2/9/74). The air temperature readings were between 22.0°F and 24.3°F for the duration of the test with the exceptions of readings on 2/9/74 at 1:00 PM (30.7°F) and 4:45 PM (31.2°F). The winds were light and the skies remained overcast until 9:40 AM (2/9/74) when they became clear and sunny.

Panels 3 and 4 (Control)

The maximum accumulation on the control panels was 5 inches at 8:30 PM (2/8/74). At approximately 12:30 AM (2/9/74) the snow began to melt. Between 1:00 and 4:45 PM (2/9/74) the panels were accidently plowed. The snow cover at 4:45 PM was measured at 2.5 to 3.0 inches on the parking lot.

Panels 1 and 2 (Hot Water Heat)

P1 (6) was the first section to be 100% clear and wet at 5:00 PM (2/8/74). By 8:30 PM (2/8/74), P2 (6) was also 100% clear and wet while P1 (12) was 95% wet. (See Photograph E-1, page 167.) All of the sections of P1 and P2 were 100% dry by 4:45 PM (2/9/74).

Panels 5 and 6 (Earth Heat)

By 9:40 AM (2/9/74), considerable melting had taken place over the pipes but snow and ice still remained between the pipes. (See Photograph E-2, page 167.) By 1:00 PM (2/9/74), P5 (6) was 100% clear and wet, and P5 (12) and P6 (6) were 90-95% wet with snow between the pipes. By 11:10 PM (2/9/74), P5 (6, 12, 18) and P6 (6, 12) were completely dry while P6 (18) was 75% dry and 25% snow covered.

P5 (6) had a melting rate of approximately 0.2 in/hr, while P5 (12) and P6 (6) had rates slightly less than that.

Summary

Once again P1 (6) displayed the greatest melting ability. The hot water heated panels (P1 and P2) also showed much greater melting efficiency than the earth heated panels. The hot water system's slowest melting section was equal to the earth heat system's fastest melting section.

Storm #6

(February 15, 1974)

General Account

A light dusting, beginning at approximately 7:00 AM (2/15/74), left approximately an eighth of an inch of snow on the test site. The system was activated at 10:00 AM (2/15/74) with the skies overcast, a light breeze, and the air temperature at 21.5°F. An hour later at the end of the test, a light breeze was still blowing but the sun had broken through the overcast and the air temperature had increased to 25.0°F.

Panels 3 and 4 (Control)

The maximum accumulation of an 1/8 inch occurred at 10:00 AM on 2/15/74. By 11:00 AM (2/15/74), the conclusion of the test, P3 was 50% dry, 10% wet, and 40% light dusty snow. At the same time P4 was 100% clear and wet.

Panels 1 and 5 (Earth Heat)

By 11:00 AM, an hour after activation of the system, all of the sections of P1 and P5 were clear of snow. P1 (6) and P1 (12) were 100% dry, while P1 (18), P5 (6), P5 (12) and P5 (18) were 100% clear and wet.

Storm #7

(February 25-26, 1974)

General Account

The snowfall which began at approximately 6:00 AM (2/25/74) resulted in accumulation of 1 inch of snow when the system was activated at 8:50 AM (2/25/74). The snow stopped at 2:00 PM but started to fall again at 4:00 PM (2/25/74). It continued to fall until 1:55 AM (2/26/74) when a maximum accumulation of 3 to 3.5 inches was measured. The system was deactivated at this time (all snow on the test panels had melted). There was a light breeze throughout the test period. The air temperature, which was 31.0°F at 8:50 AM, slowly but steadily increased until reaching 35.8°F at 2:30 AM (2/25/74). The air temperature then decreased until reaching 26.5°F at 1:55 AM on 2/26/74.

Panels 3 and 4 (Control)

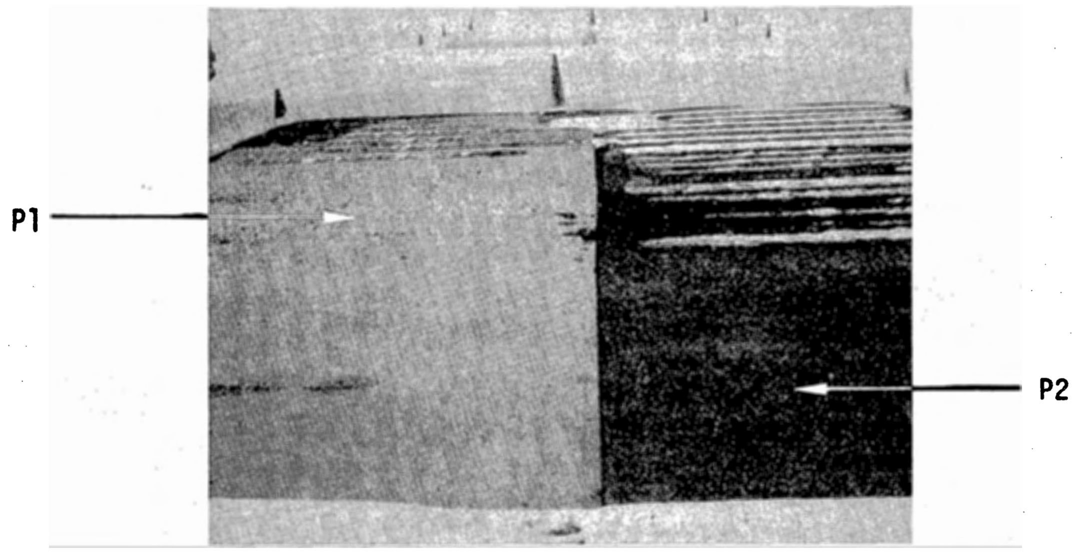
The snow accumulation on P3 and P4 was 1 inch at 8:50 AM and it continued to accumulate until reaching 3 inches at 12:45 PM (2/25/74). By 2:30 PM (2/25/74), the level had decreased to 2.5 inches. The snow started to fall again and the snow reached its maximum accumulation of 3 to 3.5 inches at 1:55 AM (2/26/74).

Panels 1 and 5 (Hot Water Heat)

At 12:45 PM (2/25/74), P5 (6) and P1 (6) were 100% clear and wet while P5 (12) was 98% wet and 2% slush. By 2:30 PM, P1 (18), P1 (12) and P5 (18) were 100% clear and wet. At the end of the test, at 1:55 AM (2/26/74), P1 (6), P1 (12), P5 (6) and P5 (12) were 100% dry while P1 (18) and P5 (18) were 90% dry and 10% wet. See Photographs E-3, E-4, E-5 and E-6, pages 168 and 169.

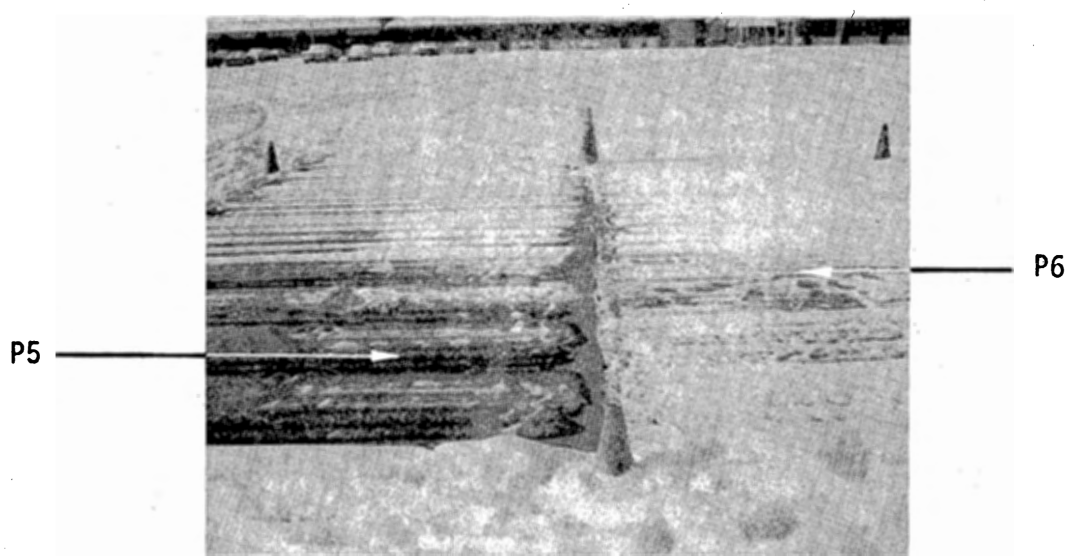
The melting abilities of the sections of embedded pipe in decreasing order were as follows: P5 (6), P1 (6), P5 (12), P1 (12), P1 (18) = P5 (18). P5 (6) had a melting rate of approximately 1.35 in/hr; P5 (12) and P1 (6), 0.80 in/hr; and P1 (12), P1 (18) and P5 (18), 0.55 in/hr.

E.3 STORM PHOTOGRAPHS



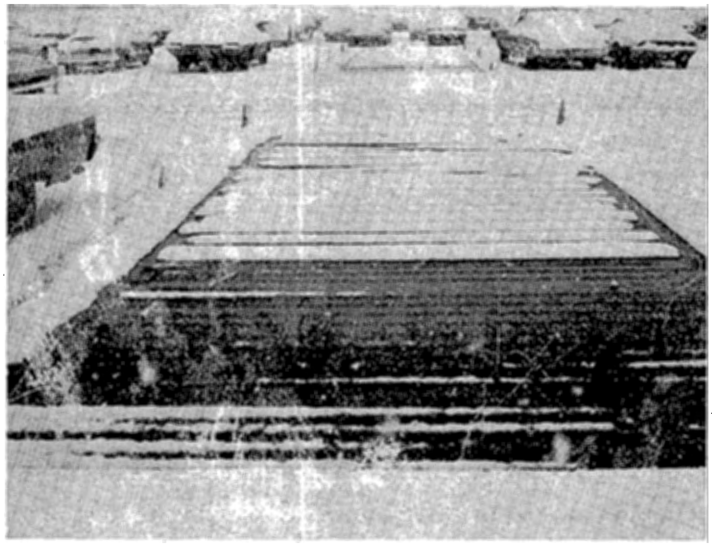
PHOTOGRAPH E-1 STORM #5

Panel #1 (Portland Cement Concrete) & Panel #2 (Bituminous Concrete)
HOT WATER OPERATION
10:00 AM - February 9, 1974
(Operated 21 Hours) (Air Temp. 22.3°F)



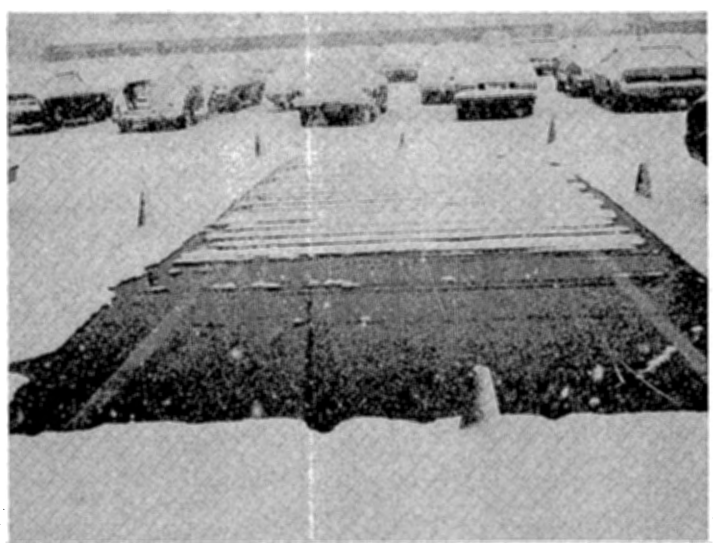
PHOTOGRAPH E-2 STORM #5

Panel #5 (Portland Cement Concrete) & Panel #6 (Bituminous Concrete)
EARTH HEAT
10:00 AM - February 9, 1974
(Operated 21 Hours) (Air Temp. 22.3°F)



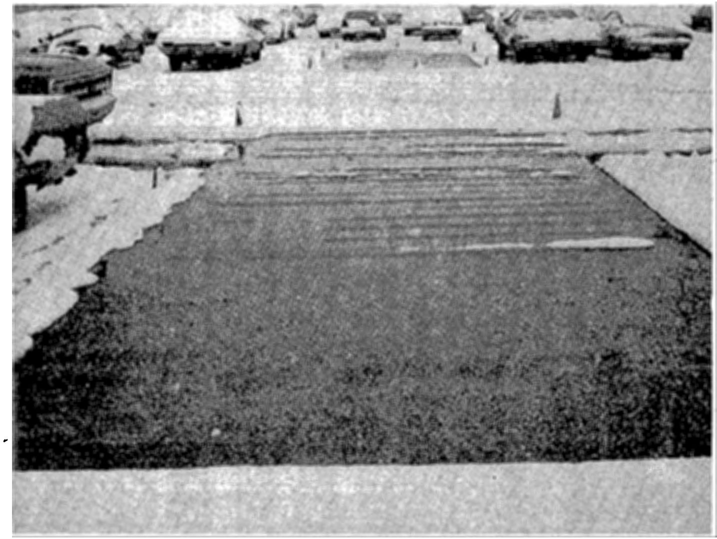
PHOTOGRAPH E-3 STORM #7

Panel #1 (Portland Cement Concrete)
HOT WATER OPERATION
11:10 AM - February 25, 1974
(Operated 2 Hours)(Air Temp. 32.2°F)



PHOTOGRAPH E-4 STORM #7

Panel #5 (Portland Cement Concrete)
HOT WATER OPERATION
11:10 AM - February 25, 1974
(Operated 2 Hours)(Air Temp. 32.2°F)



PHOTOGRAPH E-5 STORM #7

Panel #1 (Portland Cement Concrete)
HOT WATER OPERATION
12:45 PM - February 25, 1974
(Operated 3.5 Hours)(Air Temp. 33.0°F)

PHOTOGRAPH E-6 STORM #7

Panel #5 (Portland Cement Concrete)
HOT WATER OPERATION
12:45 PM - February 25, 1974
(Operated 3.5 Hours)(Air Temp. 33.0°F)

E.4 Storm Data

Table E.1 indicates pavement surface temperatures and corresponding surface conditions for the embedded pipe panels for storms #3 and #7. For storm #3 surface temperatures are shown for earth heated panels (P5 and P6) and hot water heated panels (P1 and P2); for storm #7, hot water heated panels (P1 and P5). Surface temperatures on pipe panels not in operation are also shown in Table E.1. Heating fluid temperature for the hot water heated panels ranged from approximately 70-105 degrees F; for the earth heated panels, from 47-48°F. Temperature data is presented for surface conditions varying from snow, ice, and slush covered to clear and dry; operating times, from 2-38 hours;and air temperatures, from 22.6-35.8°F. Note that surface temperature readings in the 50 to 70°F range were measured for the hot water heated pipe panels.

TABLE E-1 STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER #3

STORM DURATION

	DATE	TIME
FROM:	JANUARY 9, 1974	9:00 AM
TO:	JANUARY 10, 1974	11:00 PM

ACCUMULATION 3.75"

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDITION PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
1/9/74	11:00 AM	2 Hrs.	27.4	PORTLAND CEMENT	6"	SC	SC*	SC	38.7	28.6*	33.2
	FLUID TEMPERATURE: **				12"	SC	SC*	SC	40.3	29.4*	33.0
	PANELS 1 & 2 - 79.9°F PANELS 5 & 6 - 47.1°F				18"	SC	SC*	SC	32.4	29.3*	-----
				BITUMINOUS	6"	SC	SC*	SC	40.0	31.9*	-----
					12"	SC	SC*	SC	31.5	31.2*	34.3
					18"	SC	SC*	SC	30.9	31.2*	32.6
1/9/74	1:00 PM	4 Hrs.	28.0	PORTLAND CEMENT	6"	I,M	SC*	SC	42.8	28.1*	33.3
	FLUID TEMPERATURE: **				12"	SC,M	SC*	SC	46.3	29.9*	36.2
					18"	SC,M	SC*	SC	33.0	28.4*	-----
	PANELS 1 & 2 - 86.6°F PANELS 5 & 6 - 47.4°F			BITUMINOUS	6"	SC	SC*	SC	44.0	31.9*	-----
					12"	SC	SC*	SC	33.9	31.5*	36.2
					18"	SC	SC*	SC	32.4	31.5*	32.9
1/9/74	3:00 PM	6 Hrs.	29.0	PORTLAND CEMENT	6"	60%CD,CW	SC*	I	61.1	28.2*	33.8
					12"	I,M	SC*	SC	54.9	30.8*	36.9
					18"	I,M	SC*	SC	33.7	28.3*	-----
	FLUID TEMPERATURE: **			BITUMINOUS	6"	I,M	SC*	SC	47.9	31.6*	-------
	PANELS 1 & 2 - 93.4°F PANELS 5 & 6 - 47.8°F				12"	SC	SC*	SC	36.0	31.7*	34.5
					18"	SC	SC*	SC	33.9	32.4*	33.3

** Average of input-output fluid temperature

CW- Clear and Wet
CD- Clear and Dry
Sl - Slush
SC- Snow Covered
M- Melting above pipes
I- Ice

--------- Temperature Data Unreliable
* Control Panel- Not in Operation

TABLE E-1. STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER		STORM DURATION DATE	STORM DURATION TIME	ACCUMULATION
3.	FROM:	JANUARY 9,1974	9:00 AM	3.75"
	TO:	JANUARY 10,1974	11:00 PM	

OBSERVATION DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE CONDTN. PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
1/9/74	5:00 PM	8 Hrs.	29.2	PORTLAND CEMENT	6"	CD	SC*	50%CW,I	69.2	28.2*	34.8
					12"	60%CW,I	SC*	I	57.3	30.8*	37.3
FLUID TEMPERATURE:**					18"	I	SC*	I	34.6	28.5*	----
				BITUMINOUS	6"	10%CW,I	SC*	SC	50.6	31.4*	----
PANELS 1 & 2 - 98.6 °F					12"	I	SC*	SC	37.8	31.6*	34.4
PANELS 5 & 6 - 47.5 °F					18"	I	SC*	SC	35.6	33.0*	33.6
1/9/74	12:00 MID.	15 Hrs.	22.6	PORTLAND CEMENT	6"	CD	SC*	50%CW,I	74.7	22.8*	35.8
					12"	CD	SC*	I	62.1	25.9*	37.0
FLUID TEMPERATURE:**					18"	40%CD,I	SC*	I	35.7	24.1*	----
				BITUMINOUS	6"	CW	SC*	SC	61.0	25.4*	----
PANELS 1 & 2 - 106.9 °F					12"	I	SC*	SC	40.4	26.6*	31.6
PANELS 5 & 6 - 47.5 °F					18"	I	SC*	SC	39.6	31.4*	33.2
1/10/74	11:00 PM	38 Hrs.	33.8	PORTLAND CEMENT	6"	Not Operated	SC*	CW	52.0*	30.0*	41.4
					12"		SC*	50%CW,I	44.1*	31.5*	33.6
FLUID TEMPERATURE:**					18"		SC*	I	42.0*	29.5*	----
				BITUMINOUS	6"	Not Operated	SC*	SC	48.7*	32.1*	-----
PANELS 1 & 2 - 60.0 °F					12"		SC*	SC	44.2*	31.2*	35.0
PANELS 5 & 6 - 46.9 °F					18"		SC*	SC	38.4*	33.2*	34.7

CW - Clear and Wet
CD - Clear and Dry
Sl - Slush
SC - Snow Covered

M - Melting above pipes
I - Ice
* - Panel Not in Operation
---- - Temperature Data Unreliable

** Average input-output fluid temperature.

TABLE E-1. STORM DATA - EMBEDDED PIPE PANELS

STORM NUMBER		STORM DURATION DATE	TIME	ACCUMULATION
7.				3.0"
	FROM:	FEBRUARY 25,1974	8:50 AM	
	TO:	FEBRUARY 26,1974	1:55 AM	

DATE	OBSERVATION TIME	TIME FROM START	AIR TEMP (°F)	TYPE OF CONCRETE	PIPE SPACING	PAVEMENT SURFACE COND. PIPE DIAMETER 3/4"	1"	1-1/4"	SURFACE TEMPERATURE (°F) PIPE DIAMETER 3/4"	1"	1-1/4"
/25/74	11:15 AM	2.5 Hrs.	32.2	PORTLAND CEMENT	6"	80%CW,SL	SC*	98%CW,SL	39.1	30.6*	43.1
					12"	SC,WP	SC*	SC,WP	38.7	32.3*	37.9
FLUID TEMPERATURE: **					18"	SC,WP	SC*	SC,WP	33.9	30.7*	----
PANEL 1 - 69.6 °F					6"				34.5*	34.7*	----
PANEL 5 - 67.7 °F				BITUMINOUS	12"	Not Operated			33.8*	33.9*	33.1*
					18"				33.5*	36.2*	33.8*
/25/74	12:45 PM	4 Hrs.	33.0	PORTLAND CEMENT	6"	CW	SC*	C W	52.1	30.6*	54.3
					12"	80%CW,SL	SC*	98%CW,SL	47.6	32.9*	42.1
FLUID TEMPERATURE: **					18"	75%CW,SL	SC*	75%CW,SL	33.9	30.7*	----
PANEL 1 - 74.0 °F					6"				34.5*	34.5*	----
PANEL 5 - 72.3 °F				BITUMINOUS	12"	Not Operated			33.7*	33.7*	35.0*
					18"				33.3*	36.0*	33.7*
1/25/74	2:30 PM	5.5 Hrs.	35.8	PORTLAND CEMENT	6"	75%CD,CW	SC*	25%CD,CW	59.2	30.7*	59.9
					12"	CW	SC*	CW	53.5	32.9*	55.7
FLUID TEMPERATURE: **					18"	CW	SC*	CW	38.5	30.6*	----
PANEL 1 - 79.7 °F					6"				34.2*	34.3*	----
PANEL 5 - 77.8 °F				BITUMINOUS	12"	Not Operated			33.6*	33.7*	36.1*
					18"				-----	35.9*	33.8*

** Average input-output fluid temperature.

CW - Clear and Wet
CD - Clear and Dry
---- - Temperature Date Unreliable
SL - Slush
SC - Snow Covered
M - Melting above pipes
I - Ice
* - Panel not in operation
WP - Wet above pipes

Appendix F. Methods of Calculation

Page

F.1 Calculation of Electrical Operating Cost

Since the actual monthly billing slips included (1) the cost of items (heaters and lights) not necessary for a particular type of operation, and (2) a minimum service charge of $5.00 per month, they could not be used to determine operating costs. Operating cost was calculated from the electrical power required only by items essential to a certain type of operation.

Cost of Embedded Pipe Panel Operation

The 1/6 H. P. pump that circulates glycol-water solution through these panels is the only consumer of electrical power. Thus the cost was calculated according to the following equation:

Equation 1.

Cost = Power Requirement x Hours Operated x Electrical Power Rate

($ = Kilowatts x Hours x $/ Kilowatt-hours)

Example 1:

Statement of the Operating Procedure: Heat Exchanger #3 (Panels 5 & 6) was operated continuously from June 4 to October 6.

Calculation:

Power Requirement (1/6 H. P. pump - 1.5 Amps @ 120 Volts) = 0.18 Kw

Hours Operated (124 days)(24 hours/day) = 2976 hours

Electrical Power Rate (billing cst./billing Kw-hrs.) = $0.04/Kw-Hr

Cost = (0.18 Kw.) (2976 hrs.) ($0.04/Kw-Hr.) = $21.43

Cost of Electrical Resistance Panel Operation

Similarly, the cost of operating the electrical resistance panels was calculated according to the same equation (Equation 1).

Example 2.

Statement of Operating Procedure: The 40 watts/ft^2 sections of Panels #7 and #8 were operated for 82.5 hours during the winter season.

Power Requirement = (40 watts/ft^2) (260 ft^2) = 10.4 Kw.

Hours Operated = 82.5 hrs.

Electrical Power Rate (cost/Kw-Hr.) =$ 0.06/Kw-Hr.

Cost = (10.4 Kw.) (82.5 Hrs.) ($0.06/Kw-Hr) =$51.48

F.2 Calculation of Average Temperatures of Heat Exchangers and Control Earth

1. Heat Exchangers:

   Average temperatures of the two readings at each level, i.e., 3 ft., 7 ft., and 11 ft.

   a. For Heat Exchanger #1 use:

$$\left[\frac{D1\text{-}3 + D2\text{-}3}{2} + \frac{D1\text{-}7 + D2\text{-}7}{2} + \frac{D1\text{-}11^{*} + D2\text{-}11}{2}\right] \Big/ 3$$

D1-3 is sensor D1 placed at a 3 foot depth. See Figure 10, page 21 for illustration of other "D" thermistor locations.

   b. For Heat Exchanger #2 use:

$$\left[\frac{D4\text{-}3 + D5\text{-}3}{2} + \frac{D4\text{-}7 + D5\text{-}7}{2} + \frac{D4\text{-}11^{*} + D5\text{-}11}{2}\right] \Big/ 3$$

   C. For Heat Exchanger #3 use:

$$\left[\frac{D7\text{-}3 + D8\text{-}3}{2} + \frac{D7\text{-}7 + D8\text{-}7}{2} + \frac{D7\text{-}11 + D8\text{-}11}{2}\right] \Big/ 3$$

2. Control Earth:

   Average the readings at 3 ft., 7 ft., and 11 ft..

   i.e. (D10-3 + D10-7 + D10-11)/3

F.3 Calculation of Heat Stored in Heat Exchangers

1. Average two readings at 3 ft., 7 ft., and 11 ft. in Heat Exchanger.

   Ex. $\frac{D1\text{-}3 + D2\text{-}3}{2}$ = Average

2. Subtract the control reading (D10) at 3 ft., 7ft., and 11 ft. from the average temperature at each depth, respectively.

   Ex. $\frac{D1\text{-}3 + D2\text{-}3}{2} - D10\text{-}3 = \Delta\overline{T}_3$

*Some of these readings were discarded because of obvious error.

3. Divide each Heat Exchanger into layers using an average $\Delta\bar{\bar{T}}$ For each layer

Thus: 3' to 5'	use	$\Delta\bar{\bar{T}}_3$	at 3'
5' to 9'	use	$\Delta\bar{\bar{T}}_7$	at 7'
9' to 12.5'	use	$\Delta\bar{\bar{T}}_{11}$	at 11'

4. Calculate the heat stored —— Q —— for each layer and sum Q for all three layers.

Ex. $Q_{total} = Q_{3-5} + Q_{5-9} + Q_{9-12.5}$

where $Q_{3-5} = \rho c\ \Delta\bar{\bar{T}}_3 \left[(5'-3') \times 32' \times 30'\right]$

$Q_{5-9} = \rho c\ \Delta\bar{\bar{T}}_7 \left[(9' - 5') \times 32' \times 30'\right]$

$Q_{9-12.5} = \rho c\ \Delta\bar{\bar{T}}_{11} \left[(12.5' - 9') \times 32' \times 30'\right]$

where ρ = earth density = 110 lb./ft^3 (known)

c = earth specific heat = 0.5 (assumed)

F.4 Calculation of Heat Dissipation Rates

$\dot{Q} = \dot{V}\ (60 \times \rho \times C_g \times C_h \times \Delta T)/A$

where $\dot{Q}$ = heat dissipation rate (BTUH)/ft^2

$\dot{V}$ = volumetric flow rate (gal./min.)

ρ = density of water = (8.3 lbs/gal.)

C_g = specific gravity of circulating fluid

C_h = specific heat of circulating fluid

ΔT = temperature drop (°F) heating fluid [input-output temperature drop panel section]*

A = surface area of panel section (ft.^{2})

and 60 = minutes/hour is the time conversion

*See top of page 39 for explanation.

F.5 Calculation of Heat Extraction Rates

$$\dot{Q}_{ex} = \dot{V}\,(60 \times \rho \times C_g \times C_h \times \Delta T)/L$$

where $\dot{Q}_{ex}$ = rate of heat extraction

$\dot{V}$ = volumetric flow rate (gal /min.)

ρ = density of water = 8.3 lbs./gal.

C_g = specific gravity of circulating fluid

C_h = specific heat of circulating fluid

ΔT = temperature of the fluid exiting from the heat exchanger - temperature of the fluid entering the heat exchanger

L = linear feet of heat exchanger pipe = 2000 and (60 = minutes/hour) is the time conversion

F.6 Calculation of Rates of Heat Storage

$$\dot{Q}_s = \frac{Q_2 - Q_1}{T}$$

where $\dot{Q}_s$ = rate of heat storage (BTUH)

Q_2, Q_1 = heat stored at times 2 and 1, respectively

T = time interval [between times 2 and 1]

F.7 Sample Calculation

Heat dissipation rates for storm of March 3, 1971, Panel #1 (6" pipe spacing).

$$\dot{Q} = 4\dot{V}\,(60 \times \rho \times C_g \times C_h \times \Delta T)/A$$

where $\dot{Q}$ = heat dissipation rate (BTUH/ft.^{2})

$\dot{V}$ = 1.07 ± 0.04 gallons per minute

ρ = 8.3 lbs//gal.

C_g = 1.073

C_h = 0.840

ΔT = 6.5 ± 0.4 °F

A = 124.50 ft.^{2}

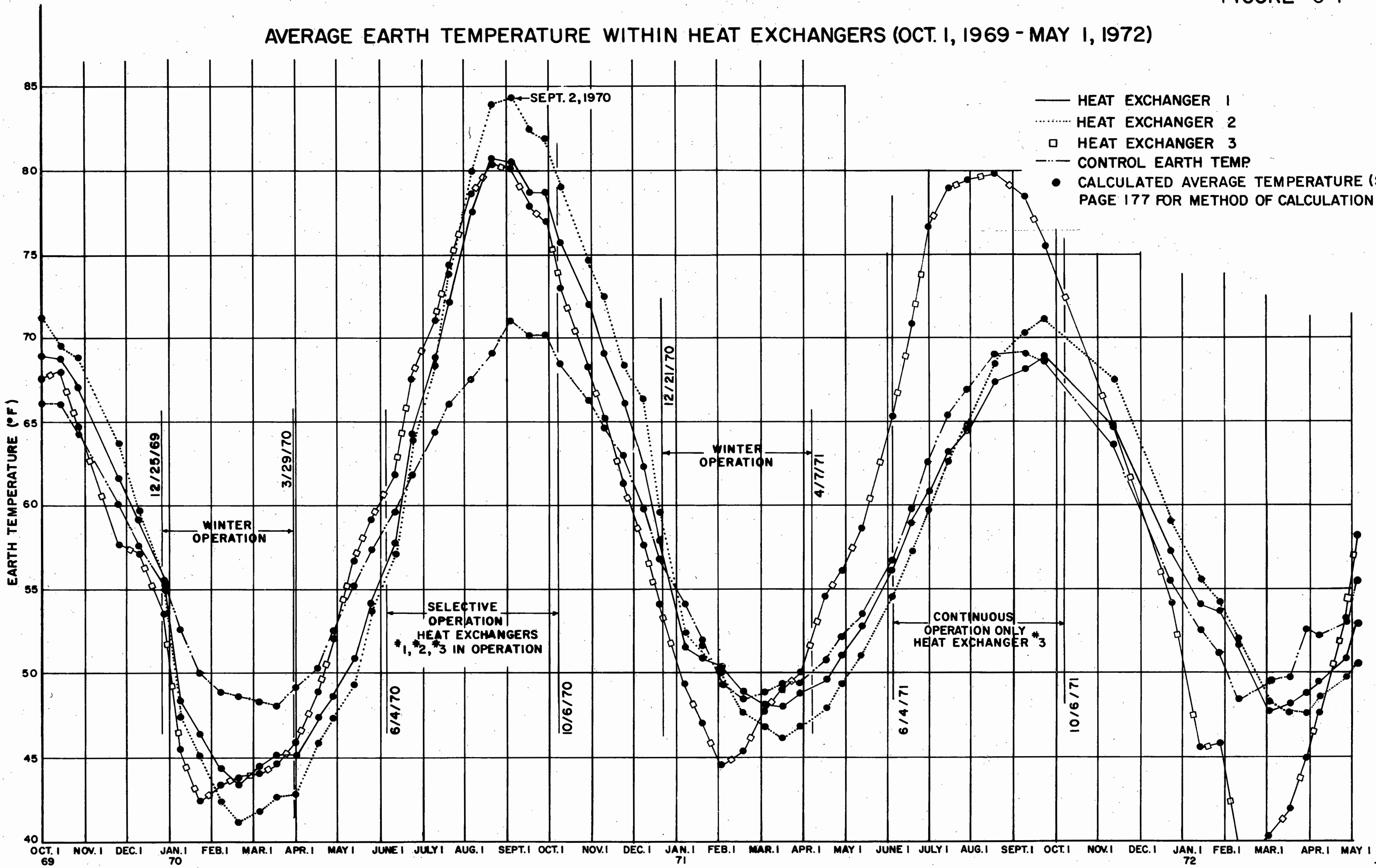
4 - is required since the flow through the 6 inch section is divided 4 ways (See Figure 3, page 13)

Q = 4(1.07 ± 0.04) (60 x 8.3 x 1.073 x 0.840) (6.5 ± 0.4)/(124.50)

Q = 100. 3± 10.5 BUTH/ft^2.

Appendix G. Figures

FIGURE G-1



AVERAGE EARTH TEMPERATURE WITHIN HEAT EXCHANGERS (OCT. 1, 1969 - MAY 1, 1972)
HEAT EXCHANGER 1
HEAT EXCHANGER 2
HEAT EXCHANGER 3
CONTROL EARTH TEMP.
CALCULATED AVERAGE TEMPERATURE (SEE PAGE 177 FOR METHOD OF CALCULATION)
EARTH TEMPERATURE (°F)
85
80
75
70
65
60
55
50
45
40
SEPT. 2, 1970
12/25/69
3/29/70
WINTER OPERATION
6/4/70
SELECTIVE OPERATION HEAT EXCHANGERS #1, #2, #3 IN OPERATION
10/6/70
12/21/70
WINTER OPERATION
4/7/71
6/4/71
CONTINUOUS OPERATION ONLY HEAT EXCHANGER #3
10/6/71
OCT. 1 69
NOV. 1
DEC. 1
JAN. 1 70
FEB. 1
MAR. 1
APR. 1
MAY 1
JUNE 1
JULY 1
AUG. 1
SEPT. 1
OCT. 1
NOV. 1
DEC. 1
JAN. 1 71
FEB. 1
MAR. 1
APR. 1
MAY 1
JUNE 1
JULY 1
AUG. 1
SEPT. 1
OCT. 1
NOV. 1
DEC. 1
JAN. 1 72
FEB. 1
MAR. 1
APR. 1
MAY 1

FIGURE G-2

HEAT STORED IN THE EARTH WITHIN HEAT EXCHANGERS
(OCT. 1, 1969 - MAR. 12, 1971)

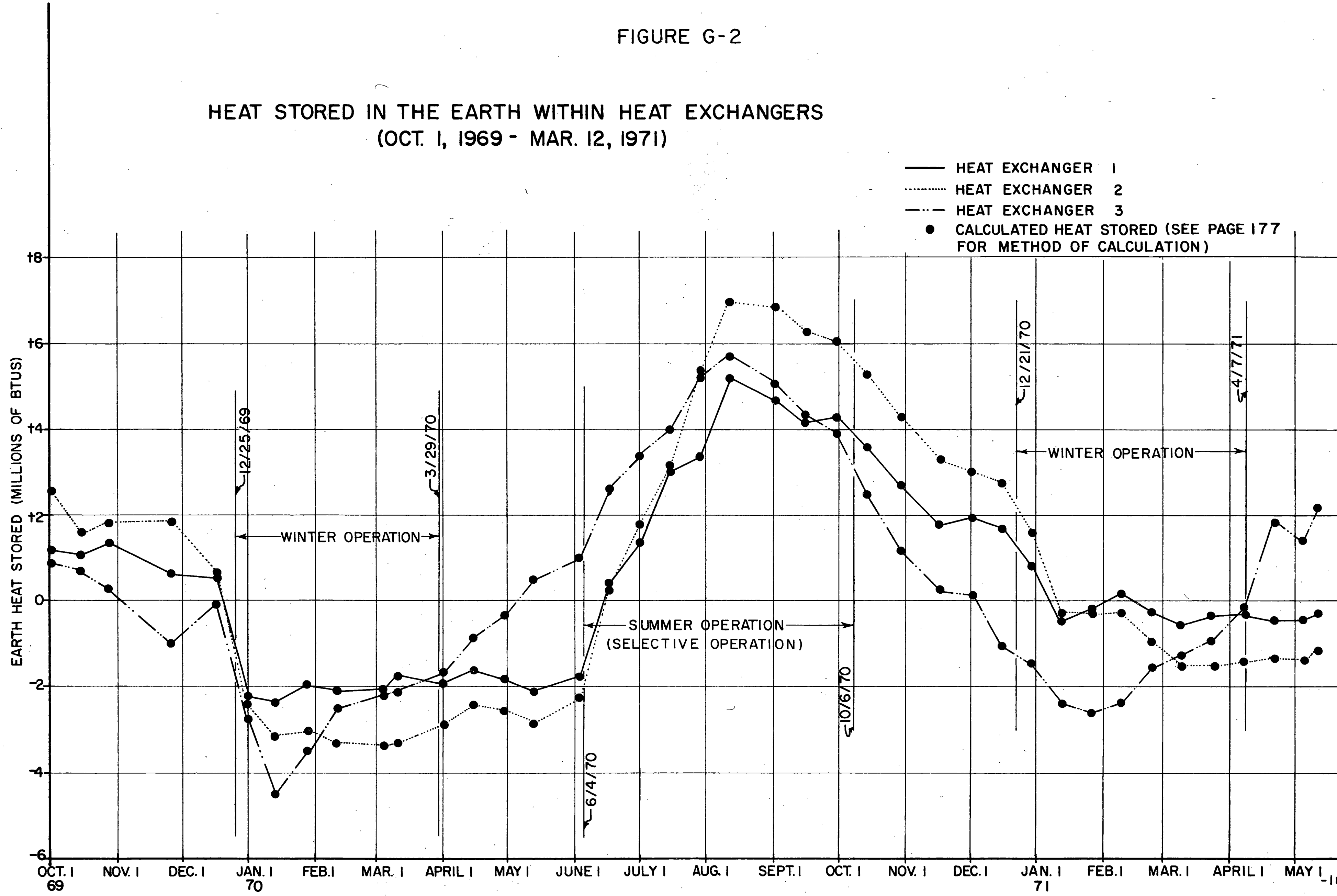
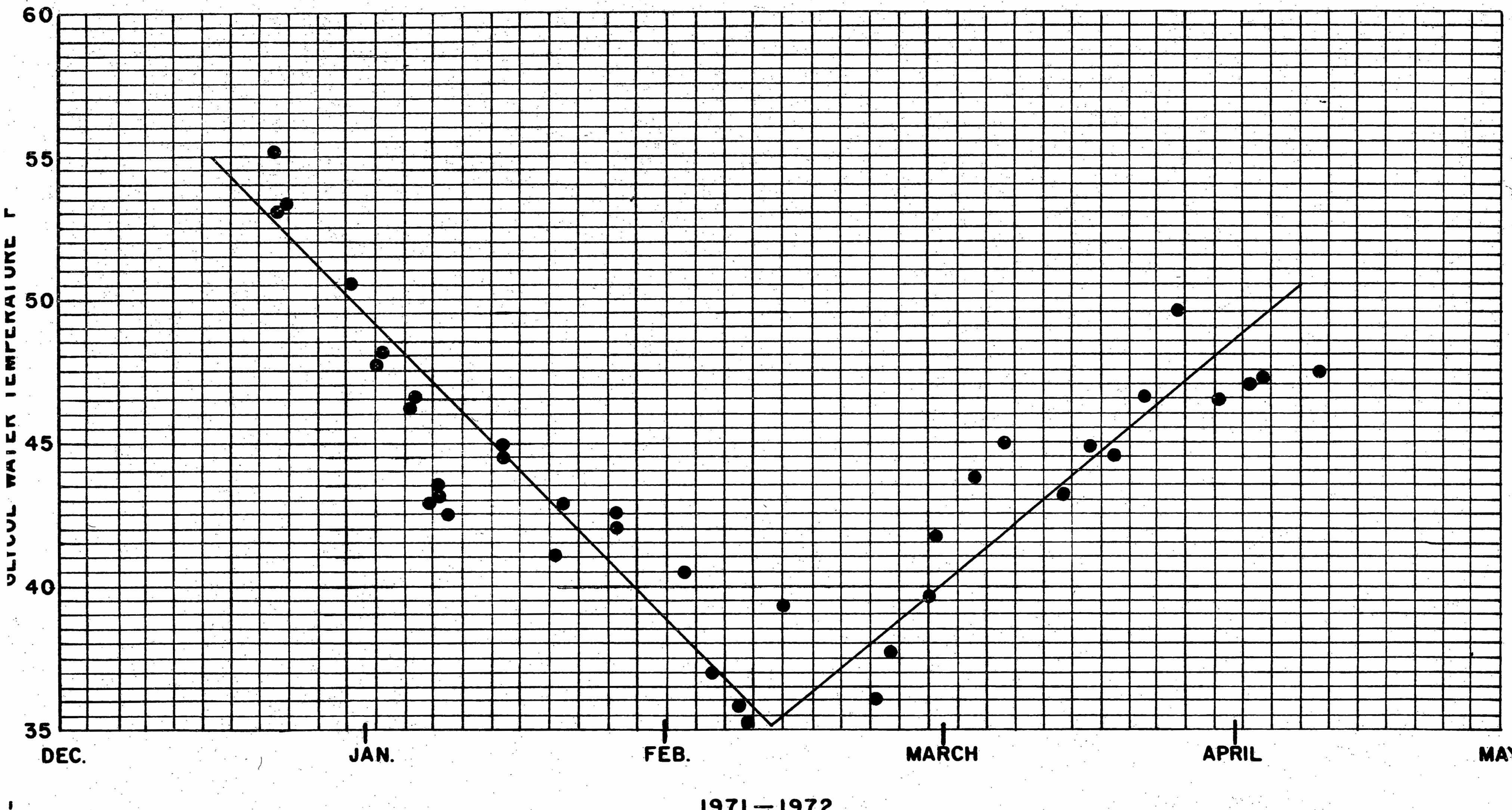
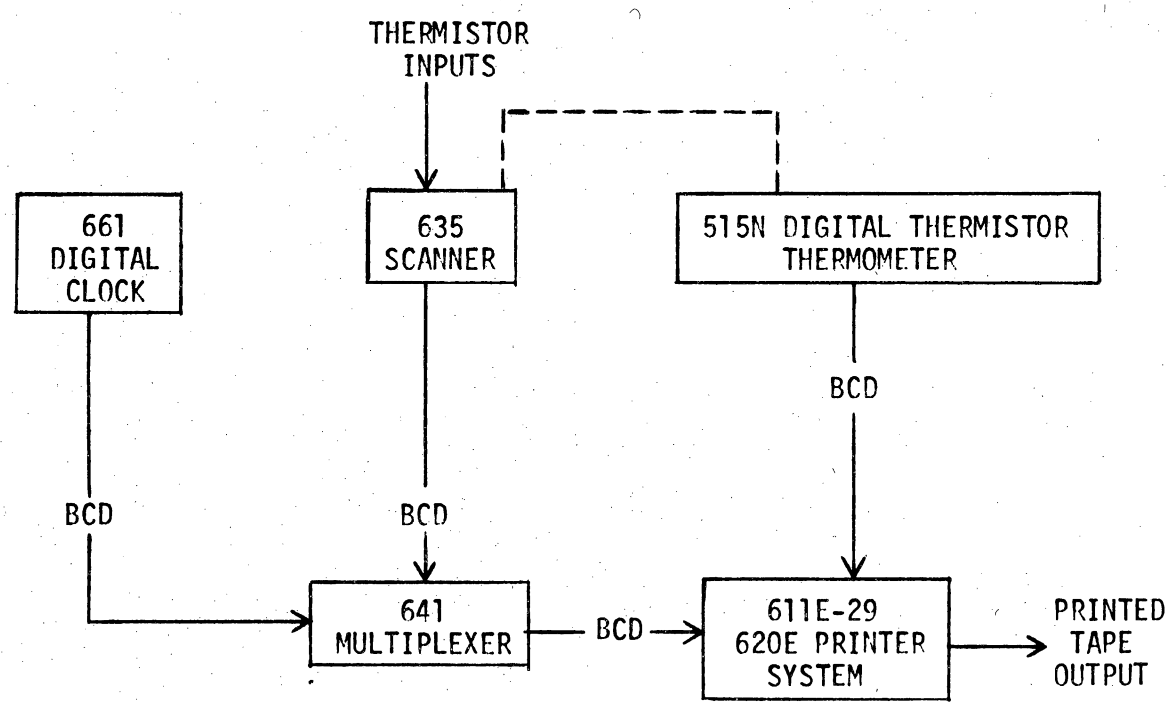


FIGURE G-3

GLYCOL-WATER TEMPERATURE (DECEMBER '71- MAY '72)

Temperate of Fluid Exiting From Heat Exchanger No.3 and Entering Panels No.1, 2, 5 and 6.





DIGITEC INSTRUMENTATION DIAGRAM

Figure G-4

Instrument Specifications

Note: ALL DIGITEC INSTRUMENTS PURCHASED FROM:

UNITED SYSTEMS CORPORATION
DAYTON, OHIO

1. Thermistor Probes	Model 401
Material	Vinyl tip
Lead	Standard - Lead is 10 foot, vinyl covered, shielded wire with phone plug.
Max. Temperature	212 °F
Time Constant	7 Seconds

2. <u>Thermistor Probe</u>	Model 405
Material	Stainless Steel
Lead	Standard
Max. Temperature	300°F
Time Constant	2 Minutes
3. <u>Digital Thermistor Thermometer</u>	Model 515N
Range	0° to 150°F
Accuracy	± 0.2°F
4. <u>Scanner</u>	Model 635
Capacity	100 Points
Dwell Time	0.1 to 10 Seconds
5. <u>Digital Clock</u>	Model 661
Readout	4 Column visual display
Program Interval	1, 5, 10, 30 and 60
6. <u>Printer and Controller</u>	Model 611E-29 and 620E
Readout	2 Channel, 10 Column
7. <u>Multiplexer</u>	Model 641

Appendix H. Tables

Page

TABLE H-1

Gradation Requirements

Type - 4E - Sandfill for Heat Exchangers

Square Sieve Size:	1/2"	#4	#30	#50	#200
% Passing	100	95-100	20-55	5-25	0-5

Type SPR 57 - Portland Cement Concrete Aggregate

Square Sieve Size	1-1/2"	1"	1/2"	#4	#8
% Passing	100	95-100	25-60	0-10	0-5

Type - Mix #5 Bituminous Concrete Aggregate

Square Sieve Size:	1/2"	3/8"	#4	#8	#50	#200
% Passing	100	90-100	60-80	41-51	14-22	4.3-8.3

TABLE H-2

Insulation Specifications

Manufacturer	Regular grade, expanded, polystyrene board insulation (used with Heat Exchangers #1 and 2) Johns-Manville		Foamglas Board, Cellular glass insulation (used with Panel #7 electrical heating) Pittsburgh Corning
Characteristics			
A. Density (Nominal)	1 lb/ft^3	1.5 lb/ft^3	8.5 lb/ft^3
B. Compressive Strength	10 psi	20 psi	100 psi
C. Flexural Strength	20 psi	44 psi	80 psi
D. Shear Strength	33 psi	----	50 psi
E. Absorption of Moisture	less than 2% by volume	less than 0.6% by volume	0.2% by volume
F. Moisture Permiability	2.5 Perm.-inch	1.5 perm.-inch	0.00 perm.-inch
G. Capillarity	None	None	None
H. Thermal Conductivity	0.25*	0.25*	$\frac{0.36 \text{ Btu-in}}{\text{Hr.-Ft}^2 - °F}$ @ 50°F
I. Coefficient of Expansion (in./in.-°F)	0.000025	0.000025	0.0000046

*$\frac{\text{Btu-in.}}{\text{Hr.-Ft}^2 - °F}$ @ 60 degrees F

TABLE H-3

List of Defective Thermistors*

Probe Number**		Designation	Symptom
7		C-7	low readings
10		C-10	shorted
11		C-11	shorted
13		C-13	shorted
15		C-15	shorted
17		C-17	shorted
19		C-20	open
32	Thermistor A-2, 7 in. below surface, directly under the pipe at 4 inch level. →	A-2-7-4	low readings
46		TW-1	low readings
47		TW-2	low readings
50		TW-5	open
51		TW-6	low readings
52		TW-7	open
53		TW-8	shorted
55		TW-10	open
56		TW-11	open
57		TW-12	low readings
58		TW-13	low readings
59		TW-14	low readings
60		TW-15	low readings

*See Section 4.15, pages 17 to 23 , for an explanation of the thermistor notation used here.
**Probe Number - Thermistors were numbered from 1 to 120

TABLE H-3 (continued)

List of Defective Thermistors

Probe Number	Designation	Symptom
76	D-2-7'0"	low readings
82	D-3-15'0"	open
86	D-4-11'0"	low readings
87	D-4-12'6 "	low readings
90	D-5-2'4"	low readings
96	D-5-15'0"	low readings
104	D-8-3'0"	low readings
106	D-8-11'0"	low readings
109	D-9-7'0"	low readings
111	D-9-15'0"	low readings
114	D-10-11'0"	low readings
115	D-10-15'0"	shorted
116	D-10-16'0"	low readings

TABLE H-4

TRENTON AREA CLIMATOLOGICAL DATA

U.S. DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ENVIRONMENTAL DATA SERVICE

Month	Year	Average Temp.	Departure From Normal	Number of Days: Max. Temperature 90° or Above	Number of Days: Max. Temperature Below 32°	Number of Days: Min. Temperature Below 32°	Number of Days: Min. Temperature 0° or Below	Amount of Snow (Inches)
12	68	----	----	0	8	24	0	----
1	69	31.3	-1.8	0	10	23	0	2.4
2	69	32.7	-0.7	0	4	22	0	14.5
3	69	39.4	-1.3	0	1	19	0	9.5
4	69	55.3	3.6	0	0	1	0	0
5	69	64.1	1.8	1	0	0	0	0
6	60	72.4	1.4	2	0	0	0	0
7	69	73.9	-2.1	3	0	0	0	0
8	69	75.8	1.9	3	0	0	0	0
9	69	67.4	0.3	1	0	0	0	0
10	69	56.0	-0.8	0	0	2	0	0
11	69	45.4	-0.4	0	0	10	0	0.2
12	69	33.5	-1.7	0	5	24	0	10.8

TABLE H-4 (continued)

Month	Year	Average Temp.	Departure From Normal	Number of Days: Max. Temperature 90° or Above	Number of Days: Max. Temperature Below 32°	Number of Days: Min. Temperature Below 32°	Number of Days: Min. Temperature 0° or Below	Amount of Snow (Inches)
1	70	25.5	-7.6	0	18	30	0	8.8
2	70	33.0	-0.4	0	7	22	0	4.4
3	70	37.8	-2.9	0	0	14	0	2.4
4	70	51.1	-0.6	0	0	3	0	Trace
5	70	63.6	1.3	1	0	0	0	0
6	70	70.3	-0.7	1	0	0	0	0
7	70	76.4	0.4	4	0	0	0	0
8	70	76.3	2.4	6	0	0	0	0
9	70	70.4	3.3	6	0	0	0	0
10	70	58.7	1.9	0	0	0	0	0
11	70	48.1	2.3	0	0	4	0	0
12	70	35.5	0.3	0	6	19	0	2.7
1	71	28.1	-5.0	0	13	28	0	11.0
2	71	35.7	2.3	0	5	13	0	1.2
3	71	40.3	-0.4	0	0	15	0	3.4
4	71	50.4	-1.3	0	0	0	0	4.4

TABLE H-4 (continued)

				Number of Days				Amount of
				Max. Temperature		Min. Temperature		Snow
Month	Year	Average Temp.	Departure From Normal	90° or Above	Below 32°	Below 32°	0° or Below	(Inches)
5	71	59.5	-2.8	0	0	0	0	0
6	71	72.3	1.3	3	0	0	0	0
7	71	75.3	-0.7	4	0	0	0	0
8	71	73.6	-0.3	2	0	0	0	0
9	71	69.9	2.8	1	0	0	0	0
10	71	62.2	5.4	0	0	0	0	0
11	71	45.1	-0.7	0	0	0	0	T
12	71	42.1	6.9	0	0	11	0	0.5
1	72	35.6	2.5	0	8	18	0	3.5
2	72	31.7	-1.7	0	7	24	0	9.8
3	72	40.0	-0.7	0	1	16	0	0.8
4	72	49.7	-2.0	0	0	3	0	0.3
5	72	61.7	-0.6	0	0	0	0	0
6	72	67.6	-3.4	0	0	0	0	0
7	72	76.3	0.3	11	0	0	0	0
8	72	74.9	1.0	3	0	0	0	0
9	72	68.3	1.2	0	0	0	0	0
10	72	52.1	-4.7	0	0	2	0	2.5

TABLE H-4 (continued)

Month	Year	Average Temp.	Departure From Normal	Number of Days: Max. Temperature 90° or Above	Number of Days: Max. Temperature Below 32°	Number of Days: Min. Temperature Below 32°	Number of Days: Min. Temperature 0° or Below	Amount of Snow (Inches)
11	72	44.0	-1.8	0	0	9	0	0.2
12	72	39.9	4.7	0	1	7	0	0.1
1	73	34.9	1.8	0	7	18	0	0.2
2	73	32.9	-0.5	0	5	19	0	0.3
3	73	46.6	5.9	0	0	3	0	T
4	73	53.0	1.3	0	0	1	0	T
5	73	59.1	-3.2	0	0	0	0	0
6	73	73.9	2.7	4	0	0	0	0
7	73	76.9	0.9	5	0	0	0	0
8	73	77.2	3.3	10	0	0	0	0
9	73	69.0	1.9	5	0	0	0	0
10	73	58.8	----	0	0	0	0	0
11	73	47.7	1.9	0	0	5	0	T
12	73	38.9	3.7	0	3	17	0	4.3
1	74	35.6	3.5	0	6	18	0	5.6
2	74	32.1	-1.3	0	7	26	0	13.3
3	74	42.4	1.2	0	0	11	0	1.3

TABLE II-4 (continued)

				Number of Days				Amount of Snow
				Max. Temperature		Min. Temperature		
Month	Year	Average Temp.	Departure From Normal	90° or Above	Below 32°	Below 32°	0° or Below	(Inches)
4	74	55.3	3.1	0	0	1	0	0.3
5	74	61.0	-1.1	1	0	0	0	0
6	74	68.8	-2.5	1	0	0	0	0
7	74	75.5	-0.4	9	0	0	0	0
8	74	74.8	0.9	1	0	0	0	0
9	74	66.2	-1.0	0	0	0	0	0
10	74	53.8	-3.4	0	0	3	0	0
11	74	47.6	1.3	0	0	8	0	0
12	74	39.4	4.5	0	0	15	0	1.1
1	75	37.2	5.1	0	4	18	0	4.5
2	75	35.6	2.2	0	3	16	0	9.1