Heating the 9th Street Interchange: Construction and Initial Operation

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MEMORANDUM TO:  G. F. Kemper  
State Highway Engineer  
Chairman, Research Committee 

SUBJECT:  Research Report 486; "Heating the 9th-Street Interchange: Construction and Initial Operation;" KYHPR-71-65; HPR-PL-1(13), Part II. 

The report enclosed comes belatedly with respect to the completion of the interchange and the performance of the deck-heating system during the past winter; it is premature from the standpoint of including performance through the current winter. The 4-inch snow of November 27, 1977, was melted satisfactorily even though a few circuits in the pavement (on embankment) drew too much current and had to be disconnected.  

Research observations and reporting are expected to continue through FY '82. At least, a final, summary report will be forthcoming. Operating costs and maintenance may be reported in the interim.

Respectfully submitted, 

[Signature]  
Jas. H. Havens  
Director of Research  

gd  
Enc.  
cc's: Research Committee  
Irvin S. Griffin
The 9th-Street interchange was designed and constructed with an automated, electrical heating system for snow and ice removal. This report describes the heating system, its construction, and initial operation. The heating system was capable of keeping the interchange free of ice and snow accumulation. The average daily slab temperature fell below $32^\circ$F ($0^\circ$C) on only one occasion. The average cost of electrical power for heating the interchange was $905 per day.
Research Report
486

HEATING THE 9th-STREET INTERCHANGE: CONSTRUCTION AND INITIAL OPERATION

KYHPR-71-65; HPR-PL-1(13), Part II

by

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Commonwealth of Kentucky

in cooperation with
Federal Highway Administration
U. S. DEPARTMENT OF TRANSPORTATION

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Kentucky Bureau of Highways. This report does not constitute a standard, specification, or regulation.

January 1978
INTRODUCTION

The presence of snow or ice on highways, especially at bridges and interchanges, often results in hazardous driving conditions. Conventional snow-and-ice removal may prove inadequate due to the time lag between ice and snow accumulation and plowing and/or salting operations. Also, deterioration of concrete in bridge decks is often attributed to the use of deicing chemicals. A number of non-chemical methods of preventing freezing have been investigated. One solution for the control of such conditions is a heating system for bridge decks and pavements. The system must be capable of melting any snow or ice that might accumulate on the roadway. Various systems of heating pavements such as embedded pipes, embedded electrical elements - have been tried in the United States, Canada, and Europe. Analyses of these systems have confirmed their ability to remove and prevent the accumulation of snow and ice on bridge decks and pavements (1). However, the installation and operation of these systems is very expensive as compared to the cost of conventional snow removal.

The 9th-Street interchange in Louisville, I64-2(87)3, is subject to extreme conditions of driving due to the use of maximum interstate grades and superelevations, the height of the ramps, and the interchange location near the Ohio River. The major portions of the ramps are elevated, exposing both the top and bottom surfaces of the ramps to wind currents. Conventional snow and ice removal would be undesirable due to potential traffic congestion. Therefore, an automated, heating system, with manual override switches, was deemed necessary for this location.

The 9th-Street interchange was first conceived in 1959 (2). Preliminary design began in the early 1960's, and design began in 1964. Hazelet and Erdal of Louisville were the principal consultants. They engaged Bosch and Latour of Cincinnati, Ohio, to design the electrical heating system, controls, and monitors. The design criteria established by the Department are summarized as follows:

1. three independent, parallel, 20-watt circuits, with variable controlled inputs, to provide a total heating capacity of 60 watts/foot² (645.8 watts/m²),
2. embedded, mineral-insulated (MI) cables, interrupted at joints and otherwise sectionalized,
3. prevent icing and clogging of deck drains and downpipes,
4. provide building to house controls and monitors,
5. provide TV monitoring throughout,
6. provide ice detectors at strategic points,
7. provide remote-reading temperature sensors and recorders,
8. provide meters and indicators of circuit operation, and
9. provide operating and maintenance manuals and operator training.

The contract for the 9th-Street interchange was awarded April 27, 1973, to the E. Randle Company and the R. R. Dawson Bridge Company. The electrical subcontractor was the Marine Electric Company. The Nelson Electric Company was contracted to manufacture the heating cables. Work began on the project May 17, 1973. The interchange was opened to traffic and the heating system became operational December 3, 1976. The final acceptance of the project by the Department was March 29, 1977. The final costs of the heating system are listed in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1. HEATING SYSTEM: FINAL COSTS</th>
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<tr>
<td>Electrical Distribution System</td>
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<tr>
<td>Roadway Heating and Connectors</td>
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<tr>
<td>Control Building</td>
</tr>
<tr>
<td>Instrumentation System</td>
</tr>
<tr>
<td>TV System</td>
</tr>
<tr>
<td>Total</td>
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The total project cost was $14,130,645.45.
DESCRIPTION OF SYSTEM

The 9th-Street interchange (Figure 1) consists of 4,108.0 feet (1,252.12 m) of welded, steel plate girder (continuous, composite) bridge ramps and 1,161 feet (353.87 m) of grade ramps for a total length of 5,269.0 feet (1,605.99 m). The width of the ramps ranges from 22.0 feet (6.70 m) to 52.0 feet (15.85 m). The decks are 9 inches (229 mm) thick while the pavements are 10 inches (254 mm) thick. Class AA concrete (6.6 bags/yd³ (368.1 kg/m³)) was used in both bridge and ramp sections. The total area of heated pavement is 174,095 feet² (16,713.95 m²). The bridge ramps can be heated to a maximum of 60 watts/foot² (645.83 watts/m²) and the grade ramps can be heated to a maximum of 50 watts/foot² (538.20 watts/m²).

All power for the ramp heating system is supplied by a Louisville Gas and Electric (L.G. & E.) underground cable at 13,800 volts, three-phase, ungrounded. There is a 1,200-amp, 500-MVA, air-type, circuit breaker ahead of the L.G. & E. meter. The main switch-gear, located in the control building, is supplied with 13,200 volts; the remaining power is for auxiliary purposes. The power level is controlled by a motorized, tap-changing-under-load voltage regulator having 32 steps and a range of 2,200 to 13,200 volts. The voltage regulator (Figure 2), positioned behind the control building, may be controlled manually or by automatic response to various sensing devices.

Power from the voltage regulator is distributed through underground, electrical ducts to five substations where transformers reduce the adjusted high voltage to low voltage levels which can be utilized by the ramp-heating system. Each substation (Figure 3) supplies approximately 2,500 KVA. The maximum, secondary voltage at the substations is 480 volts, phase-to-phase, and 277 volts from neutral to ground. Each substation transformer is equipped with two, main buses to feed two sections of pavement. Each bus has three panels, each having 12, three-pole, 100-amp breakers. Each panel is protected by a ground-fault interrupter (GFI). The secondaries are three-phase, undergrounded, wye-type; each phase returns to neutral. The maximum input to any heater circuit is 270 volts.

Distribution cables (No.-4 wire (5.95-mm)) from the substations extend in conduit (Figure 4) to steel, wireway units, termed plinth boxes (Figure 5), on the bridge ramps or concrete hand-holes (Figure 6) on the grade ramps. It is here the distribution cables from the substation connect to the cold section of the embedded, roadway-heating cables.

Three types of plinth boxes are employed. The first is the plinth-feeder box, i.e., entrance box. The distribution cables connect to the cold sections of the heating cables in this unit. The second type is the plinth-expansion box. Connections are made in this type of box between cold leads of adjacent bridge sections so that a bypass may be made around the expansion joint (Figure 7). The third type is the plinth-termination box where the phase leads are joined together to complete the wye-neutral connection. The same type of arrangement is made in the concrete hand-holes for the grade ramps. Both the steel, plinth boxes and concrete hand-holes are designed so that the cover may be removed for periodic inspection or repair of the various cables.

Cold-section cables leave the plinth boxes through ports and are embedded in the lower plinth and curbing concrete. The connection of the hot and cold section of each cable is in the concrete below the curb and gutter. The entrance of the cable to the pavement and position of the cold joint prior to the placement of the concrete is shown in Figure 8. The hot sections of the cables extend various distances across the roadway from the entrance box, then turn to run longitudinally for the length of the ramp unit. At the end of the ramp, they turn and exit on the side opposite their entrance. This pattern continues through three or four ramp sections where the cables exit in the termination box and are joined to complete the neutral "wye" connection. At converging bridge or grade sections, the heating cable is joined to a cold section which passes through a sealed, construction joint box (Figures 9 and 10) to the adjoining pavement and is rejoined to the heating cables.

The cable spacing varies to accommodate the reinforcing rod pattern in the respective units. However, the cables are arranged so that each cable is essentially the same length and has the same current for a prevailing voltage, thus assuring uniform heating in the respective units. In addition, phase leads from the three-pole breakers are alternated so that, in the event of a three-pole-breaker tripout, three, separate, 6-inch (152-mm), unheated widths alternating with 12-inch (305-mm), heated widths would occur rather than one, 18-inch (457-mm), unheated area.

The heating cables consist of a single, copper (No.-16 wire (1.6-mm)) conductor with magnesium oxide (MgO) insulation in a copper sheath. The cold section, 6 feet (1.83 m), at each end of the heating cable, is No.-6 (5.2-mm), copper wire in a copper sheath.

The system is equipped with closed-circuit television so that the effectiveness of the heated pavement can be monitored visually. Six, pan-and-tilt, zoom-lense TV cameras are mounted on standards above the plinth (Figure 11). The housings for the cameras are weatherproof and equipped with window wipers. Shielded, transmission cable extends from each camera to the control room where the six, TV monitors are located.
Figure 1. General Facilities and Location.
Figure 2.  Voltage Regulator.

Figure 3.  Typical Substation.
Figure 4. Distribution Cables in Conduit.
Figure 5. Typical Flinth Box.

Figure 6. Concrete Handholes, Pavement Section.
Figure 7. Expansion Loop, Expansion Joint.

Figure 8. Position of Cold-Section Junction.
Figure 9. Converging Pavement Sections; Junction Box at Construction Joint.

Figure 10. Junction Box at Construction Joint.
Two weather stations are also mounted on standards above the plinth (Figure 12). Each is capable of measuring wind speed and direction, outdoor temperature, and humidity; and each is equipped with sunshine, rain, and snow detectors.

The system has eleven, thermocouple stations. At each station there are either six or twelve thermocouples. Where six are employed, they are in the drain; where twelve are employed, six are in the gutter area and six are in the centerline of the deck (Figure 13). One of two surface temperature detectors (Figure 14) can be used for modulation of the voltage regulator.

All drainage troughs and drain pipes are insulated to prevent icing and clogging. The drain troughs are insulated with 5/8-inch (16-mm), foamed plastic and covered with 0.08-inch (2-mm), galvanized steel. The drain pipes (Figure 15) are insulated with 1-inch (25.4-mm) fiber glass and covered with a 0.01-inch (0.2-mm), stainless steel jacket.

The control building (Figure 16) is located on Main Street under the converging sections of Ramps I and II. It houses the main switchgear, TV monitors, power and weather meters, and the Master Controller.

The L. G. & E., 13.8-KV service enters in the switchgear room. The power is fed through the main circuit breaker, the main switchgear, and on to the voltage regulator and then runs underground to the various substations. The Uninterruptable Power Supply (Figure 17) is also located in the main switchgear room. This 20-unit, battery system provides storage of energy for resetting the voltage regulator and the main circuit breaker in the event of a power failure.

The control room houses the six, television monitors and various instruments for monitoring the weather and power levels and for adjusting the heating system. The individual meters are listed in APPENDIX A.

The TV monitors, power meters, weather indicators, and thermocouple monitors allow the operator to stay abreast of current road, weather, and power conditions at the interchange. The annunciator-display panel will immediately indicate the location of any problem in the electrical system. Two, failsafe systems protect the electrical heating system from overheating. One lowers the voltage regulator when the controlling slab temperature exceeds the set point. The other failsafe trips the main circuit breaker when the outdoor temperature is 18°F (-8°C) and the voltage regulator is on step 33, or when the outdoor temperature is 75°F (24°C) and the voltage regulator is on step 1.
Figure 12. Weather Station.

Figure 13. Typical Thermocouple Installation; Centerline of Deck.
Figure 14. Surface Sensor.
Figure 15. Insulated Drain Pipe.
Figure 16. Control Building.

Figure 17. Uninterruptable Power Supply.
The Master Controller is provided to obtain as full an automatic control as possible. The basic concept is to operate the heating system at a low level of heat when the slab temperature goes above a certain set point. As the temperature drops, slab temperature sensors cause the voltage regulator to increase the voltage into the system. As the temperature increases, the voltage level is reduced. However, various weather parameters, such as barometric pressure, rain, snow, humidity, and others, are programmed into the system so that the system actually operates on the probability of snow and ice rather than the detection of snow or ice. An illustration is given in Figure 18. The slab temperature establishes a base-line condition. As the temperature drops, more heat input goes into the slab. The basic, straight-line situation is then changed by the weather factor signal modifiers, represented by the cross-hatched areas between the curve. If weather conditions remain ideal, even though the temperature goes very low, a minimum of heating would be required, as shown by the lower portion of the cross-hatched area. If weather conditions are unfavorable, more heat would be required as shown by the upper portion of the cross-hatched area (3).

There are eleven, signal modifiers affecting the modified slab temperature. The conditions required by the signal modifiers are listed in APPENDIX B. The eight, digital timers on the weather instrumentation console are used by the Master Controller for timing weather condition changes and duration of heating at the various steps. The output of these timers is incorporated into the logic of the Master Controller to automatically establish the amount of power to be delivered to the heating system.

The signal modifiers and slab set point can be set manually on the system control console. The slab set point is a predetermined, slab temperature used by the Master Controller. If the modified, slab temperature as computed by the Master Controller falls below this set point, the Master Controller calls for more heat; if the modified, slab temperature goes above the set point, the controller reduces the amount of heat to the slab. The console is also equipped with two recorders. The Weather Factor Signal Recorder indicates which signal modifiers have been activated by the prevailing weather conditions. The Slab Temperature for Control and Composite Weather Factor Signal Recorder indicates the actual, slab temperature used for control and the modified, slab temperature, as computed by the signal modifiers.

CONSTRUCTION

Original design of the heating cables called for the outer sheath to be stainless steel and of a thickness not less than 22 mils (0.56 mm). The cables in the decks were to be tied at 3-foot (0.91-m) intervals with No.-16 (1.6-mm), stainless steel wire. The cables in the pavements were to be clipped to stainless steel mounting strips which were 10 feet (3.05 m) by 1 inch (25 mm). The mounting strips were on 3-foot (0.91-m) intervals, and the clips on the strips were on 5 1/2-inch (140-mm) centers. However, due to difficulties in drawing the stainless steel covering, the decision was made to use copper-sheathed, mineral insulated (MI) cable with a minimum, sheath thickness of 24 mils (0.61 mm). This necessitated a means of relieving galvanic action between the copper sheath and the reinforcing steel. To insulate between the copper sheath and the reinforcing steel, the top mat of steel, including the truss bars, in the decks and the entire, reinforcing mats in the pavements were epoxy-coated. Copper, tie wire replaced the stainless steel, tie wire. The stainless steel, mounting strips were replaced by 1/4-inch (6.4-mm), solid, copper rods on 2-foot (0.61-m) intervals. All chair or bar supports were to be epoxy-coated or of a rustproof material.

Mineral-insulated cable is very rugged, and its use is widespread. It can be hammered almost flat without destroying its operating characteristics; however, it still must be handled and installed with great care. A small cut in the sheath would permit moisture to enter and destroy the electrical, insulating properties of the magnesium oxide (3).

The heating cables were delivered to the job site in pre-cut lengths and with the cold sections attached at the factory. The cables were coiled and packaged in individual, cardboard boxes.

All work, except the concreting, was completed on the decks before cable installation began. Prior to being positioned on the decks, the cables were lubricated with a Dow Corning silicone compound (Figure 19). The lubricant was used to prevent the adherence of the concrete to the surface of the cable. Individual cables were played out from reels and stretched the length of the deck for proper positioning (Figure 20). The heating cables were to be no closer than 1 1/2 inches (38 mm) horizontally to any, longitudinal, reinforcing bar or no closer than 4 inches (102 mm) to another heating cable or at a distance not greater than 6 inches (152 mm) apart. However, some deviations (Figure 21) in this spacing occurred due to variations in cable length as received from the manufacturer. After positioning the cables on the deck, the cables were tied with copper tie wire at 3-foot (0.91-m) intervals (Figures 22 and 23). All electrical connections were made according to conventional, wiring codes. Plywood walkways (Figure 20) were provided for construction workers, preventing damage to the cables prior to the placing of concrete.
Figure 18. Modified, Slab Temperature Conditions.
Figure 19. Lubricating Heating Cables prior to Installation.

Figure 20. Individually Packaged Cables, Reels Used for Installation of Cables and Plywood Walkways for Workers.
Figure 21. Variations in Cable Spacing due to Improper Lengths.

Figure 22. Workman Securing Heating Cable to Reinforcing Steel.
Concrete was placed with a crane and bucket. The finishing machine used was a self-propelled, rail-mounted, Bidwell finishing-machine with a rotating drum, front-mounted auger and a drag-type plate. Concrete was dumped ahead of the finishing machine from approximately 1 1/2 feet (0.46 m) above the heating cables (Figures 24 through 26). No apparent damage or displacement of the heating cables occurred as a result of dropping the concrete from this height (Figure 27). The concrete was partially leveled with specially modified shovels and rakes (Figure 28). Tubing was welded to the sharp edges of these tools to prevent damage to the cables. The concrete was vibrated by hand-held, portable vibrators (Figure 29). Workmen stood on plywood walkways (Figure 24) which were continually backed away as the concreting operation progressed. The concrete was cured in a normal manner.

Each cable assembly was tested for continuity and insulation resistance before, during, and after concreting operations (Figure 30). Each cable assembly was required to measure not less than 200 megohms. Of the 1,800 cables in the system, only one failed during concreting operations.

After 30 feet (9.14 m) of concrete had been placed in Ramp 3 (R3-II-1B), resistance in a cable at the gutterline dropped below the required 200 megohms. As concreting continued, the damaged cable was removed from the fresh concrete and a replacement cable was installed in its place (Figures 31 through 33). The replacement cable was tied at irregular intervals with copper wire. The concrete was replaced around the new cable and floated by hand. No revibration of the concrete occurred. The completed interchange is shown in two, aerial photos taken December 2, 1977 (Figures 34 and 35).

Upon completion of the interchange, the electrical heating system underwent a full-load test to determine the integrity of the system. At a time when the outdoor temperature was predicted to be below 20°F (-7°C) for a period of 24 hours or longer, the system was advanced to full load (step 33) at regular intervals. The system was required to maintain a stabilized condition at this load with all heating cables, power, weather, and recording instruments functioning properly. The results of this test are listed in APPENDIX C.
Figure 24. Workers Placing Concrete.

Figure 25. Workers Placing Concrete.
Figure 26. Worker Leveling Concrete.

Figure 27. Heating Cables in Fresh Concrete.
Figure 28. Specially Modified Shovels and Rakes.

Figure 29. Workmen Vibrating Concrete.
Figure 30. Testing Cable Resistance during Concreting Operations.

Figure 31. Workmen Removing Damaged Cable from Fresh Concrete.
Figure 32. Damaged and Replacement Cable in Fresh Concrete.

Figure 33. Replacing Concrete around New Heating Cable.
Figure 35. 9th-Street Interchange, Looking Upstream.
DISCUSSION

The 9th-Street interchange was opened to traffic December 3, 1976. The initial operating season extended through April 16, 1977. The heating system was in operation at various levels throughout this period. Monthly weather summaries are listed in Table 2. Figures 36 through 39 compare the average, daily, slab temperature to the average, daily, air temperature as recorded at the 9th-Street interchange and the United States Weather Bureau. The position of the thermocouple used in determining the average slab temperature was at the surface of one of the bridge ramps. On only one occasion, January 10, 1977, during the period December 30, 1976, to April 16, 1977, did the average, slab temperature fall below 32°F (0°C). This was the date of the greatest snowfall (7.8 inches (198 mm)) of the winter season. Visual observations throughout this period indicated that both the deck and pavement sections were kept free of snow and ice accumulation. Figures 40 and 41 show the transition between heated and non-heated pavements during a period of snow accumulation. Both pictures were taken of the same snowfall. The official ground cover for this day was 5 inches (127 mm) of snow. In Figure 40, note the accumulation of snow on the plinth and curb and patches of snow directly above the roadway drains in the gutterline. These are non-heated areas. Figure 42 is an aerial view of the entire interchange taken on January 11, 1977. The photo clearly shows the difference between heated and non-heated sections during severe cold and snow accumulation.

On January 10, 1977, a short circuit in a plinth box caused a portion of one bridge ramp (R4-1-4A) to be without heat for four days (January 10 through January 13). The largest snowfall of the winter season occurred during this period. However, a combination of adjoining, heated pavement and traffic was able to keep this section of pavement clear of ice in the wheel tracks (Figure 43). Inspection of the plinth boxes on this bridge ramp revealed the cause of the short circuit. An apparent build up of heat within the plinth box had melted the insulation on the cables, thus allowing bare wires to come in contact. The damaged wires (No. 6 (5.2 mm)) were replaced with No.-4 (6.0-mm) wires, and heat was restored to the bridge section. An inspection of all plinth boxes followed and a decision was made to ventilate all plinth boxes and separate the cables within the boxes to prevent further damage to the cables from excessive heat (Figure 44). All plinth boxes were opened and have remained open since that date with no further damage occurring. The cost to the Department for repair of the cables was approximately $5,000.

Heating the 9th-Street interchange on the probability of snow appears to be an advantage over other roadway heating systems because it does not require "catch-up" time after a snowfall to clear a pavement but rather keeps the interchange clear as the snow falls.

Figures 45 through 48 show the actual slab temperature compared to the modified slab temperature as computed by the Master Controller for the period January 1, 1977, to April 16, 1977. The average, modified, slab temperature is slightly lower than the average, actual, slab temperature throughout this period, because the heating system is based on the probability rather than the actual occurrence of bad weather. In Figures 45 through 48, any average, modified, slab temperature above 50°F (10°C) is recorded as 55°F (13°C).

A slab set point of 38°F (3°C) was adjudged to be the temperature at which, under normal conditions, the Master Controller should call for more heat. This allows for a time lag in which the slab may begin to heat as snow and ice conditions approach. The set point was adjusted to as high as 41°F (5°C) by the operator when threatening conditions prevailed. Although compensation is made by the signal modifiers for rapidly changing weather conditions, the voltage-raise timer must also be adjusted as is the slab set point. The schedule listed in Table 3 was used as a guide for setting the voltage-raise timer. Care was exercised in adjusting both the slab set point and the voltage-raise timer as a sudden increase in the voltage could damage the cables or thermally shock the concrete.

It must be noted that the above conditions apply to "automatic operation". The operator may adjust the voltage regulator manually as he deems necessary.

The power usage and costs for the heating system are listed in Table 4. The cost for heating the interchange from December 9, 1976, through April 16, 1977, was $0.79/foot² ($8.50/m²). These costs do not include labor charges for operators who monitor the interchange 24 hours per day throughout the year. An agreement with the electrical subcontractor for maintenance of the system has been estimated to be $50,000 per year.

The cost of operating the heating system is dependent on several factors. The weather greatly determines the power required to heat the pavement. January of 1977 had the lowest, average temperature for any month dating back to 1872. The 19.6 inches (498 mm) of snow made it the snowiest January since 1918 for the Louisville area. Manual settings of the signal modifiers and the slab set point may also affect the amount of heat input to the slab. The voltage-raise-and-lower timers affect the power demand...
by controlling the time allowed the voltage regulator for increasing or decreasing the heat input to the slab. The opinion of the operator, in judging weather conditions and the probability of snow or ice, determines the settings for these instruments.

Some time after April 16, 1977, a longitudinal crack, approximately 310 feet (94 m) in length, was noted in Ramp 1 (R1-I-3B-5B) (Figure 49). Some transverse cracking in this ramp and in Ramp 3 (R3-III-1B) were noted in the fall of 1977 (Figure 50). The cracking appears to have had no effect on the integrity of the heating system at this time.

On November 25, 1977, Load Center 1-A was tripped by the ground-fault interrupter (GFI). To restore power, four breakers, in three panels of Load Center 1-A, had to be opened. Upon checking the resistance records, these circuits were found to have low resistances. The resistance measurements of these circuits from July 1976 and September 1977 are listed in Table 5. The cables in these circuits are in the pavement section of Ramp 1 (R1-I-3B-5B). Although the cables from these breakers are adjacent to each other in sections of the pavement, neighboring cables have kept the pavement clear of any snow or ice accumulation (4 inches (102 mm) recorded November 27, 1977) during the first snowstorms of the winter season.

The heating system at the 9th-Street interchange has proven functional; but no economic justification has been attempted. There are no data pertaining to conventional snow removal costs in the Louisville District or to actual maintenance costs of the heating system. Future research efforts will include the monitoring of deck temperatures at various depths and the establishment of definite operational settings for the logic system of Master Controller.

### TABLE 2. MONTHLY WEATHER SUMMARIES

<table>
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<tr>
<th></th>
<th>DECORBER</th>
<th>JANUARY</th>
<th>FEBRUARY</th>
<th>MARCH</th>
<th>APRIL</th>
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<td>High Temperature</td>
<td>65°F (18°C)</td>
<td>45°F (7°C)</td>
<td>77°F (25°C)</td>
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<td>2°F (28°C)</td>
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<td>16.6°F (-7°C)</td>
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<td>Total Snowfall</td>
<td>11.1 in. (281 mm)</td>
<td>19.6 in. (498 mm)</td>
<td>0.8 in. (20 mm)</td>
<td>0.1 in. (3 mm)</td>
<td>0.8 in. (20 mm)</td>
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Figure 36. Average Temperature Versus Time (January)
Figure 37. Average Temperature Versus Time (February).

Figure 38. Average Temperature Versus Time (March).
Figure 39. Average Temperature Versus Time (April).
Figure 40. Heated Pavement (January 14, 1977).

Figure 41. Non-Heated Pavement (January 14, 1977).
Figure 42. Aerial View of the 9th Street Interchange on January 11, 1977, showing the Distinct Difference between Heated and Non-Heated Sections (Courier-Journal; reprinted with permission).
Figure 43. January 14, 1977; R4-I-4A Heating System Inoperative.

Figure 44. Opened Plinth Boxes with Cable Separators.
Figure 45. Average Temperature Versus Time (January).

Figure 46. Average Temperature Versus Time (February).
Figure 47. Average Temperature Versus Time (March).

Figure 48. Average Temperature Versus Time (April).
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<tr>
<td>11 - 17</td>
<td>003.0 Minute</td>
<td></td>
</tr>
<tr>
<td>18 - 22</td>
<td>007.0 Minute</td>
<td></td>
</tr>
<tr>
<td>23 - 27</td>
<td>020.0 Minute</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambient Temperature 21° - 38°F (-6° - 3°C)</th>
<th>Voltage Regulator Step</th>
<th>Voltage Timer Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>002.0 Minute</td>
<td></td>
</tr>
<tr>
<td>11 - 15</td>
<td>005.0 Minute</td>
<td></td>
</tr>
<tr>
<td>16 - 20</td>
<td>015.0 Minute</td>
<td></td>
</tr>
<tr>
<td>21 - 24</td>
<td>020.0 Minute</td>
<td></td>
</tr>
<tr>
<td>25 - 27</td>
<td>030.0 Minute</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambient Temperature Greater Than 38°F (3°C)</th>
<th>Voltage Regulator Step</th>
<th>Voltage Timer Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5</td>
<td>005.0 Minute</td>
<td></td>
</tr>
<tr>
<td>6 - 10</td>
<td>010.0 Minute</td>
<td></td>
</tr>
<tr>
<td>11 and Above</td>
<td>020.0 Minute</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fastest Possible Settings During Snowing Conditions</th>
<th>Voltage Regulator Step</th>
<th>Voltage Timer Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 10</td>
<td>Immediate</td>
<td></td>
</tr>
<tr>
<td>11 - 15</td>
<td>002.0 Minute</td>
<td></td>
</tr>
<tr>
<td>16 - 20</td>
<td>004.0 Minute</td>
<td></td>
</tr>
<tr>
<td>21 - 25</td>
<td>008.0 Minute</td>
<td></td>
</tr>
<tr>
<td>26 and Above</td>
<td>020.0 Minute</td>
<td></td>
</tr>
</tbody>
</table>
### Table 4. Power Usage and Costs

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of Days</th>
<th>KWh</th>
<th>Average KWh/Day</th>
<th>Cost</th>
<th>Average Cost/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-9-76 - 1-10-77</td>
<td>32</td>
<td>2,011,200</td>
<td>62,850</td>
<td>$50,765.62</td>
<td>$1,586.43</td>
</tr>
<tr>
<td>1-11-77 - 2-8-77</td>
<td>29</td>
<td>2,505,600</td>
<td>86,400</td>
<td>$63,484.30</td>
<td>2,189.11</td>
</tr>
<tr>
<td>2-9-77 - 3-10-77</td>
<td>30</td>
<td>648,000</td>
<td>21,600</td>
<td>$16,618.09</td>
<td>553.94</td>
</tr>
<tr>
<td>3-11-77 - 4-8-77</td>
<td>29</td>
<td>230,400</td>
<td>7,945</td>
<td>$5,952.84</td>
<td>205.27</td>
</tr>
<tr>
<td>4-9-77 - 5-10-77*</td>
<td>32</td>
<td>28,800</td>
<td>900</td>
<td>$797.36</td>
<td>24.92</td>
</tr>
<tr>
<td>12-9-76 - 5-10-77</td>
<td>152</td>
<td>5,424,000</td>
<td>35,684</td>
<td>$137,618.21</td>
<td>905.38</td>
</tr>
</tbody>
</table>

*Heating system turned off 4-16-77; billing cycle through 5-10-77.

Figure 49. Crack Found in Ramp 1 after April 16, 1977; Photo Taken December 1, 1977.
### Table 5. Resistance Measurements

<table>
<thead>
<tr>
<th>LOAD CENTER</th>
<th>PANEL</th>
<th>BREAKER</th>
<th>JULY 1976</th>
<th>SEPTEMBER 1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A</td>
<td>1</td>
<td>7</td>
<td>100 Ω</td>
<td>2,500 Ω</td>
</tr>
<tr>
<td>1-A</td>
<td>2</td>
<td>7</td>
<td>8 MΩ</td>
<td>700 Ω</td>
</tr>
<tr>
<td>1-A</td>
<td>3</td>
<td>3</td>
<td>125,000 Ω</td>
<td>2,400 Ω</td>
</tr>
</tbody>
</table>

**Figure 50.** Crack Found in Ramp 3 in Fall of 1977; Photo Taken December 1, 1977.

**References**


APPENDIX A

CONTROL ROOM INSTRUMENTATION
APPENDIX A

CONTROL ROOM INSTRUMENTATION

Power Metering Console
Total Load: 0-15000 kw
The kilowatts being used by the entire system
L. G. & E Voltage: 0-15kv
The voltage available from L. G. & E.
Regulated Voltage: 0-15kv
The voltage being used by the entire system
Load Center Voltage: 0-300V
The voltage being sent to each substation
Load Center Current: 0-2500 Amps
The amperage being sent to each substation

Weather Instrument Console
Aerovane Indicator:
Wind Speed - 0-100 mph (0-160.93 km/hr)
Wind Direction - 0-360° from North
Outdoor Temperature
Slab Temperature
Relative Humidity
Barometric Pressure
Rain Indicator
Snow Indicator
Falling Outdoor Temperature Timer
Raising Barometric Pressure Timer
Sunshine Duration and Load Cutback Timer
Voltage Regulator Raise Delay Timer
Regulator Return Position Timer
Voltage Regulator Raise Delay Snowing Override Timer
Voltage Regulator Snowing Override Reset Timer
Voltage Regulator Lower Delay Timer
Previous Outdoor Temperature
Previous Barometric Pressure
Rate of Temperature Drop
Rate of Barometric Pressure Drop

Annunciator and Recorder
Display Panel:
Indicates location of a problem in the electrical system
12 Point System Recorder:
1. L. G. & E. Voltage - actual voltage available 0-15000 volts
2. Regulated Voltage - actual voltage being used 0-15000 volts
3. Total Load Kilowatts - actual wattage being used 0-15000 kw
4. Outdoor Temperature - range -20°F to 120°F (-28.9°C to 48.9°C)
5. Slab Temperature Selected for Control - range 20°F to 50°F (-6.7°C to 10°C)
6. Controller Set Point Deviation
    % > 50 the system is raising the slab temperature
    % < 50 the system is allowing the slab temperature to drop
7. Wind Director - range 0° to 360° from North
8. Relative Humidity
9. Barometric Pressure - range 38 to 32 inches of hg (95 kPa to 108 kPa)
10. Wind Speed - range 0-100 mph (0-161 km/hr)
11. Rain - indicates rain condition
12. Snow - indicates snow condition

Thermocouple Selector
Two Slab Temperature Monitors
Control Selector Switch
Thermocouple Patchboard
Twelve Point Thermocouple Temperature Recorder

System Control
Manual Loading Stations for Weather Conditions
Event Recorder of Preset Weather Conditions
Weather Factor Signal Recorder - Indicates the activation of a particular signal modifier
Slab and Modified Slab Temperature Recorder
Voltage Regulator Position Indicator
Automatic/Manual Override Switch
Summer Lockout Switch
APPENDIX B

MANUAL LOADING STATIONS (MLS)
PRESET WEATHER CONDITIONS
APPENDIX B

MANUAL LOADING STATIONS (MLS)
PRESET WEATHER CONDITIONS

MLS-1
Slab temperature less than 38°F (11°C) and outdoor temperature less than 28°F (-2°C)
also
Outdoor temperature less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes
also
Not raining and not snowing

MLS-2
Raining
also
Outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes

MLS-3
Snowing
or
Humidity greater than 70%
and
Slab less than 38°F (11°C)
and
Outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes
and
Outdoor less than 34°F (4°C) or snowing and wind from 40° to 120° or 135 to 225° from the North

MLS-4
Snowing
or
Humidity greater than 80%
and
Slab temperature less than 38°F (11°C)
and
Outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes
and
Outdoor less than 34°F (4°C) or snowing and wind from 40° to 120° or 135 to 225° from the North

MLS-5
Barometric pressure is less than 29.8 inches of Hg (101 kPa)
and
Pressure not rising greater than 1 inch of Hg (3.4 kPa) per hour
and
Outdoor less than 34°F (4°C) or outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes

MLS-6
Barometric pressure greater than 29.5 inches of Hg (100 kPa)
also
Not raining and not snowing
and
Slab less than 38°F (11°C) and outdoor less than 28°F (-2°C)
and
Outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes
and
Barometric pressure not rising greater than 1 inch of Hg (3.4 kPa) per hour

MLS-7
Same as Number 6 only barometric pressure must be less than 29.0 inches of Hg (98 kPa)

MLS-8
Snowing

MLS-9
Wind greater than 6 mph (2.7 m/s)
and
Slab less than 38°F (11°C) and barometric pressure not rising greater than 1 inch of Hg (3.4 kPa) per 1 hour
and
Outdoor temperature less than 34°F (4°C) or outdoor less than 37°F (9°C) and falling greater than 1°F (0.6°C) in 45 minutes

MLS-10
Same as MLS-9 only wind must be greater than 12 mph (5.4 m/s)

MLS-11
Same as MLS-9 only wind must be greater than 18 mph (8.1 m/s)
APPENDIX C

FULL-LOAD TEST RESULTS