joint fabricated with high-strength bolts being able to resist reversals of stress, I used as the value for the maximum stress to which the bolt could be subjected, the product of the yield point of the steel and the section of the bolt at the root of the thread. On this basis, the computations indicated that the joint should be able to function properly when subjected to a reversed-load cycle.

If the tension to which a bolt can be subjected is based on an area equal to the average of the area of the section at the root of the thread and the area of a section through the body of the bolt, the ability of the joint to resist reversals of stress would be correspondingly greater.

In other words, my statement in the paper is quite conservative.

STUDIES ON THE HEATING OF BRIDGE DECKS AND CONCRETE PAVEMENTS

G. S. Paxson, *Bridge Engineer, Oregon State Highway Commission*

SYNOPSIS

In this paper are described a pavement heating project using heat from a well driven into a subsurface strata carrying hot water and the preliminary experiments and design of a project involving the heating of a concrete bridge deck by electricity.

Klamath Falls Pavement Project—At Klamath Falls, Oregon, a 400-ft. section of four-lane roadway including two spans of a bridge was built on an eight percent grade. To minimize the traffic hazard from frost and snow, the roadway was heated. The project is underlaid by a strata carrying natural hot water. A 12-in. well, 425 ft. deep, was drilled to this strata supplying hot water which rises to the ground surface. The water temperature at the bottom was approximately 180 deg. F. The water contains mineral salts in solution, and to guard against deposits in the pipes a heat exchanger was placed in the well and an unmineralized solution circulated through the pavement slabs. The circulating system consists of 0.75-in. wrought-iron pipes at 18-in. centers placed at mid-depth of the slabs.

The system was designed to melt 0.5-in. of snow or .26 lb. of ice per sq. ft. per hr. This required 37.4 BTU per sq. ft. per hr. The design was based on a flow of 116 gal. per hr. per 30-ft. length of pavement slab, entering at 160 F. and leaving at 70 F. In actual operation the fluid entered at 130 deg. and left at 65 deg. The change in initial temperature was compensated for by increasing the flow to 158 gal. per hr. The actual BTU per hr. per sq. ft. varied from 43 to 47.

The installation operated through the winter of 1949–50, which was the most severe on record. With snow falling at the rate of one-half inch per hr., the pavement surface was moist but clear, with a surface temperature of 37 deg. F. and air temperature of 32 deg. F. A storm with a snowfall of 6 in. in 5 hr. left 0.5 in. of soft slush on the pavement, which was cleared in 30 min. At no time did any ice form. Tests indicate that after the pavement and subsoil reach equilibrium temperature little if any heat is lost into the subsoil. In fact the heat stored in the subsoil helps to maintain the pavement heat during periods when the system is working to capacity.

Willamette River Bridge at Salem—Limited distance in which to rise from street level and overcross a railroad forced the use of a seven percent grade on the approach to a bridge over the Willamette River at Salem, Oregon. Heavy snowfall is infrequent in the Willamette Valley, but high humidity results in frequent frost. As a safety measure the concrete deck of the approach will be heated by electric heat.

The bridge deck will be a reinforced concrete slab supported by concrete gird-

ers. On top of this deck a 2- by 2-in., 14-gauge, galvanized iron wire mesh will be laid forming the heating elements. This will be covered with 1½ in. of plant-mix asphaltic concrete. The delivery of heat will be regulated by the voltage supplied to the grid. An experimental concrete slab 6 in. thick, 20 in. wide, and 6 ft. long, with wire-mesh heating element and asphaltic-concrete topping was prepared. This was tested in a cold room in which zero F. temperature could be maintained.

Tests were run to determine the temperature at bottom, center and top of the concrete slab, of the heating element itself, and at the top of the asphaltic surfacing at a range of air temperatures and varying power input. The placing of a 3⅝-in. rock-wool insulation on the lower surface was found to give a great increase in efficiency. Circulation of air simulating a wind greatly increased the power needed. Power at the rate of 15 watts per square foot of surface will be supplied with switching arrangements whereby the total normal power can be concentrated in the wheel tracks in each traffic lane during unusually cold weather. It is expected that pavement surface temperatures can be kept about 15 deg. F. above air temperatures under normal weather conditions.

KLAMATH FALLS PAVEMENT

Three years ago the Oregon State Highway Commission undertook the construction of a new north entrance to the City of Klamath Falls. This entrance is a part of Route US 97 and carries a considerable volume of through traffic, as well as a heavy local traffic. The most feasible route into the city is alongside the east bank of the Reclamation Service main canal leading from Klamath Lake to the irrigated area to the south. The completed route will by-pass the business district, keeping to the east of the canal with an entrance to the district at Esplanade Street. At present only the north entrance to Esplanade Street and the city connection on that street have been built.

The canal is located on the west slope of a hill ascending toward the east. Parallel to the canal and about 300 feet to the west is the main line of the Southern Pacific railroad. The railroad is built on an embankment a few feet below the water level of the canal. The highway on Esplanade Street must pass over the canal and under the railroad in this 300 feet. With an allowance for the necessary vertical curves this required an 8 percent grade.

Klamath Falls is situated on the high plateau east of the Cascade Mountains at an elevation of 4,100 ft., and the winters are rather severe. An ice- or snow-covered pavement on an 8 percent grade is a greater traffic hazard than should be embodied in the design of a major highway. It was not practicable to change the elevation of the railroad because of the adjacent station and yards. The canal could have been lowered by building a large inverted syphon with at least 300 sq. ft. of area. This would have been quite costly, and the lowering of the highway alongside the canal would have seriously damaged adjoining property.

It so happens that this area is underlaid, at a considerable depth, by a strata carrying a large volume of hot mineral water. This natural heat supply has been used for many years for the heating of residences and public buildings and by several industries. Rather than lower the canal it was decided to use this heat supply to keep the pavement free of ice and snow and to accept the necessary short section of 8 percent grade. The plan and profile of the heated section are shown in Figure 1.

The section to be heated was 411 ft. long, including an 81-ft. bridge over the canal and 330 ft. of four-lane pavement 52 ft. wide. The heating coils were to be embedded in the concrete, and to guard against breakage at cracks in the pavement a wire-mesh reinforcement, with No. 1 wire at 6-in. centers both ways, was used in the pavement slabs. Expansion joints were placed at 30-ft. intervals, dividing the pavement into 11 sections. While the bridge is a continuous structure, the heating was arranged in three 27-ft. sections, making 14 sections in all. The pavement slabs are 8 in. thick and are laid on a 7-in. crushed-rock base with a sand cushion between the base and the slab.

Weather records show that the usual winter storm seldom exceeds a rate of snowfall of ½ in. per hr. for any long period, although short periods of snowfall might occur at more than double this rate. The design of the heating system was based on melting snow at ½ in. per hr. Newly-fallen snow, depending on the temperature, may vary in weight from as low as 3 lb. per cu. ft. at +5° F. to as much as 7 lb. per cu. ft. at +32° F. Heavy snowfall with temperatures lower than +26° F. is unusual. At this temperature snow weighs about 6¼ lb. per cu. ft. The melting of ½ in. of snow per hour was assumed to be equal to the melting of 0.26 lb. of ice per hour, or 37.4 Btu per square foot of surface per hour. There is some loss of heat into the subbase and subgrade. of the heat into the base and subsoil was assumed. This increased the heat requirement to 41 Btu per sq. ft. of surface per hour. Each pavement panel is 52 ft. wide and 30 ft. long, with 1,560 sq. ft. of surface. The heat required for each panel is 64,000 Btu per hour.

The hot water supply comes from a stratum approximately 400 ft. below the ground surface. The well was located alongside the roadway at the lowest point of the heated section. The upper 308 ft. of well was cased with a 12-in. steel casing. Below this depth, the ma

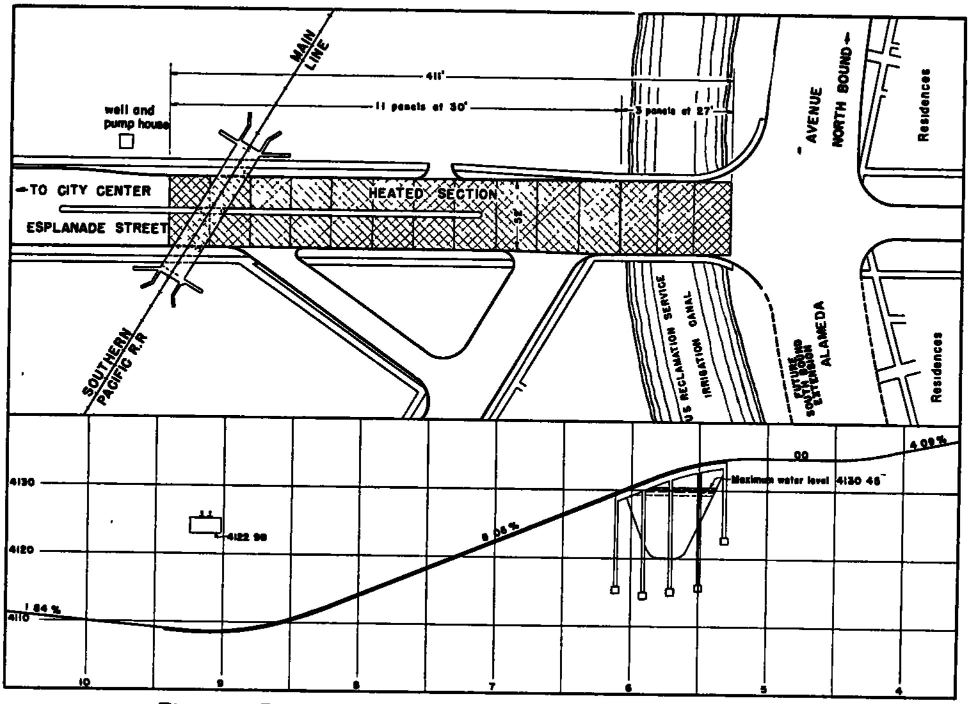

Figure 1. Plan and Profile, Klamath Falls Heating Installation

How much this amounts to is hard to estimate. It will vary over a rather wide range with the difference in temperature between the heat source and the air. Also, when the system is first started and the pavement, base and subsoil are cold, there will be a considerably larger movement of heat downward than will be the case after the system is warm. With the almost unlimited supply of natural heat available, the system would operate continuously during cold weather, and the larger loss during the warm-up period was not a factor. With these factors in mind a loss of 10 percent terial encountered was firm enough to stand without casing, and a 10-in. well was drilled to a total depth of 420 ft. When the hot-water stratum was reached, the water rose to the surface and overflowed at the rate of 20 gal. per min. This water carries considerable mineral in solution and is mildly corrosive when exposed to air. There is also a tendency to deposit a coating on the inside of pipes. Rather than circulate the natural hot water through the grids, a heat exchanger in the well was used. This heat exchanger consists of two 2-in. pipes, extending 310 ft. into the well, and a

2-in. return. The upper 125 ft. of the return pipe was encased in a 3-in. pipe jacket to prevent recooling of the heated fluid.

The circulating fluid is a closed system taking heat from the well, giving up its heat in the pavement and returning to the well for another cycle. As there is danger of power-supply failure or mechanical trouble that might stop the circulation and allow freezing of the grid pipes or headers, a commercial antifreeze was added to the circulating water to protect against freezing to +10° F.

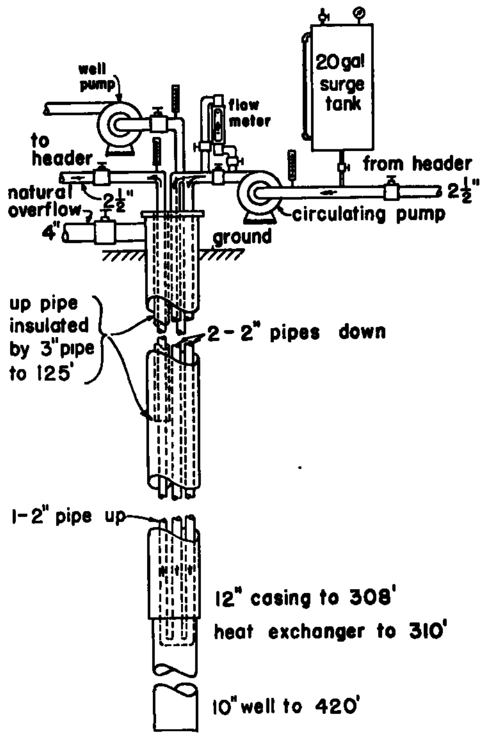

Figure 2. Well and Pumps, Klamath Falls Heating Installation

Figure 2 is a schematic diagram of the arrangement at the well. The second pump, marked "well pump," was added after a trial run. Cooling the column of water in the well by the heat exchanger decreased the natural overflow until not enough hot water was rising in the well to supply the needed heat. For test purposes a flow meter was installed in the line and thermometers placed in the incoming and outgoing header pipes and in the overflow pipe.

The depth below the pavement surface and the spacing of the pipes was a problem concerning which very little information was available. By closely spacing the pipes a more even distribution of heat could be had, but the cost would be materially increased. Uniformity of heat distribution is not as essential for pavement heating as for floor heating in buildings, and a grid of ¾-in. pipe at a relatively wide spacing of 18 in. was selected for this project. The pipes were placed with the top 3 in. below the pavement surface. A cross section of the pavement slab is shown in Figure 3.

The circulating solution enters the grid and cools as it passes through. In order to distribute the heat over the 30-ft. length of each panel, the pipe from its entrance at the lower end of the panel is placed in 36-in. loops and then returned to its point of entry in loops

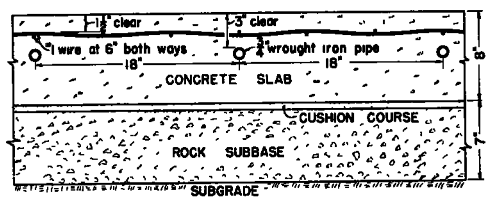

Figure 3. Cross Section of Heated Pavement Panel

half way between the first series. In this way the average temperature of each two adjacent pipes is fairly constant over the entire slab length. The arrangement is shown in Figure 4, and a photograph showing the grids just prior to placing the concrete is shown in Figure 5. The outlet line of each panel has a valve by which the flow through the panel can be regulated and the surface temperature of all the panels equalized. Flow meters to measure the volume of fluid circulating and temperature wells to determine the surface, mid-point and bottom temperatures of the panels were installed in three panels for test purposes.

During the winter of 1949–50, the first winter of operation, the project was watched rather closely. At several times measurements of the heat delivered to the pavement and of the temperature on the surface and in the interior was determined. Table 1 shows the results from a selected group of observations covering a range of snowfall up to 1¼ in. per hour.

When no snow is falling, the surface temperature is about 47° F., even with an air temperature of 10° F. It is evident that the formation of frost is entirely prevented. Melting of snow requires more heat, and as the rate of snowfall increases, the surface temperature drops. At a rate of 1¼ in. of snow per hour, the capacity of the installation has been reached. During the storm when these data were taken, snow fell at a rate of 1¼ in. per hour for 5 hours. The pavement surface was kept clean for 2 hours and then it gradually accumulated a thin layer of slush which attained a depth of ½ in. at the end of the 5-hr. period. This melted off within ½ hr. after the snowfall ceased. At no time did any ice form. The slush was soft enough that traffic was not bothered. The amount of heat delivered was practically constant under all conditions, ranging from 43 Btu per sq. ft. per hour, when the surface temperature was highest, up to 47 Btu when the surface temperature was the lowest.

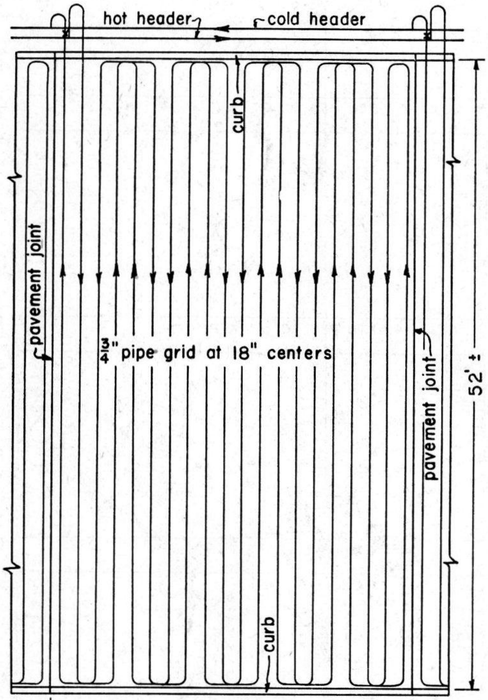

Figure 4. Pipe System in a Heated Pavement Panel

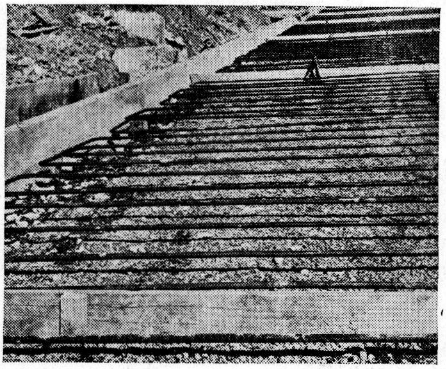
Figure 5. Pipe Grid in Place

Surface and interior temperatures and probable isothermal lines for four weather conditions are shown in Figure 6. The most notable thing shown by these graphs is the uniformity of the surface temperature. The maximum difference over the entire section was 2 deg. This would indicate that a wider spacing of the pipes would be practical. Figure 7 shows the project in operation immediately after a moderately severe storm.

TABLE 1
TEMPERATURES AND HEAT DELIVERY

Rate of Snowfall	Air Temp.	Surface Temp.	Heat Flow	Fluid In	Temp. Out	Well Overflow	Weather
in.	*deg. F.*	*deg. F.*	a	*deg. F.*	*deg. F*	*deg. F.*	
0	+10	46–48	45.7	131	64	100	Clear, No Wind
0	+28	49–51	43.0	131	68	102	Cloudy, Wind
⅛	+30	45–47	44.4	134	69	104	Snow, No Wind
¼	+30	42	44.4	133	68	104	Snow, No Wind
½	+30	37	45.0	132	66	102	Snow, No Wind
1¼	+23	32	47.1	131	62	99	Snow, No Wind

[a] BTU per sq. ft. per hr.

The installation was operated continuously from October to March of the winter of 1949–50. The total power cost, at a rate of $0.03 per KWH, was $237.75, or approximately $40 per month. The system has not operated long enough to indicate the yearly maintenance cost.

The construction cost of the system exclusive of the well and pump house was $10,700. The well and pump house cost $8,000, making the total cost of the system $18,700.

WILLAMETTE RIVER BRIDGE

An urban project in the city of Salem, Oregon, presented a somewhat similar prob-

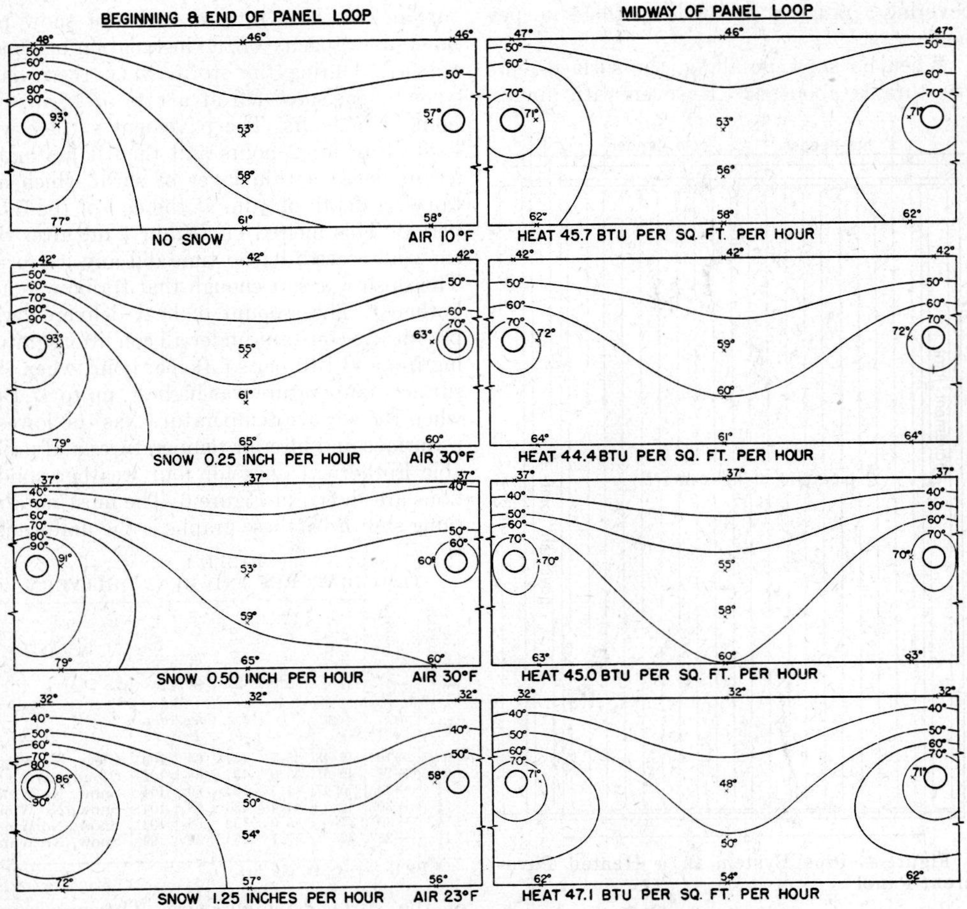

Figure 6. Temperatures and Isothermals in Heated Pavement

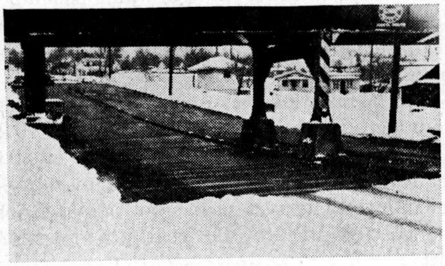

Figure 7. Klamath Falls Heating Installation in Operation

lem. This project included construction of a two-lane bridge and revision of an existing bridge across the Willamette River. In the completed project the new bridge will serve westbound travel, while the existing bridge will carry only eastbound traffic, fitting into a one-way-street grid for the city. Railroad tracks of the Southern Pacific Company and the Oregon Electric Railway Company are on a street one block from the river front and one block (450 ft.) farther east is a main north-south city street. The approaches to the bridge must meet the street grade at this main street and must overcross the street carrying the railroad tracks. This requires an ascending grade of 6.39 percent on the approach to the new bridge and a descending grade of 7.00 percent on the reconstructed approach of the existing bridge.

Snowfall is infrequent in the Willamette Valley and usually melts within a few days. The relative humidity is high, however, and there are several months each winter when heavy frosts can be expected. Considerable trouble has been experienced with skidding on similar grades under such conditions. To prevent the formation of frost and to melt the occasional snowfall, those portions of the bridge approaches with grades in excess of 5 per cent will be heated. Electric power is the only practical source of heat.

Heat is put into the pavement or bridge deck by metallic resistance elements. These elements can either be cast into a monolithic slab or attached to the top surface of the slab and covered with a wearing surface. Cracks from one cause or another are likely to occur even in the most carefully designed and constructed structure. These cracks might break the heating element, and if these elements were cast into the concrete slab itself, repairs would be costly and difficult. Primarily for that reason the heating elements will be placed on the surface of the concrete slabs and covered with a 1½-in. asphaltic concrete wearing surface.

The most extensive experimental pavement heating project now installed is a test section near Detroit, Michigan. Through the courtesy of Mr. H. C. Coons, Chief Engineer of the Michigan Highway Department, and his staff, opportunity was had to inspect the project and to confer with its designers and operators. In this project the heating elements are strips of bare steel wire mesh, which is readily available and results in an economical installation. In this test section only the wheel tracks for two lanes are heated, while in the Salem installation it is proposed to heat the entire deck surface. For the Salem project a steel wire mesh of 14-gauge wire at 2-in. spacing both ways will be used.

So little is known about installations of this kind that considerable experimentation in the laboratory seemed advisable. A cold room 6 by 10 ft. in size, that could hold a temperature of zero deg. F., was available. A sample deck slab 6 ft. long, 1 ft. 8 in. wide and 6 in. thick was cast. A strip of mesh nine wires wide was welded to bus bars at each end and laid on the slab surface. An asphaltic concrete wearing surface 1½ in. thick covered the mesh. The ends and sides of the test specimen were covered with a 3⅝-in. rock-wool blanket to simulate the effect of adjoining concrete in a full-sized slab. Some of the tests were made without insulation on the bottom surface, and for other tests a rock-wool blanket was used.

Very few data are available on the electrical properties of steel wire mesh used as a heating element. There was some question as to the power factor and phase angle when using alternating current in an element made up of many parallel wires. Tests showed the power factor to be unity and the phase angle zero. Tests also gave resistance value of 0.0108 ohms per foot of single wire at 68° F. with a thermal coefficient of resistance of 0.0023 per deg. F. These values were determined by tests on the strip of grid nine wires wide. The current flowing in the several wires of the grid was found to be approximately equal. It can be assumed that the same values can be applied to grids the full width of the deck.

Figure 8 shows the test slab. Copper-constantan thermocouples were placed to measure temperatures on the top and bottom surfaces, on the longitudinal and transverse wires, between wires of the heating element, and at mid-depth of the concrete slab. A series of tests was made with different current inputs. In this series a constant air temperature and constant current was maintained until a steady state temperature was attained. The thermocouples were then read. Table 2 gives the results. The first three tests were made without bottom insulation. The last six tests were made with the rock-wool blanket on the lower surface. Column 8 is interesting as it shows that even with current input of 66.7 watts per sq. ft. the wire temperature will not be hot enough to damage the asphaltic concrete.

Some of the data from this table are shown in Figure 9, where the difference between air temperature and surface temperature is plotted against watts per square foot both with and without bottom insulation. The saving in power by the bottom insulation is sufficient to make insulation a paying investment.

Figure 9 also gives a good approximation of the power requirement. In this particular project it is proposed that the entire deck be kept free from frost to a temperature of +15° F. and free from snow during moderately heavy snowfall. For extreme conditions of either cold or snowfall the entire capacity is to be put into the four wheel tracks, which constitutes about one fourth of the deck area. Figure 9 shows that, for protection to +15° F., 17 deg. below freezing, less than 10 watts per sq. ft. is needed with an insulated deck and no wind blowing. Experience at the Klamath Falls installation, however, indicates that at least 45 Btu per hr. per sq. ft. should be provided. This will require 13.2 watts per sq. ft. There are also other factors to be considered, such as the effect of wind and the rate of heating.

A number of tests to determine the effect of wind were made by directing a current of air from an electrically-driven fan across the slab surface. The fan used gave an air speed of 8 m.p.h. The data from one of these tests are shown in Figure 10. In this test the slab was brought to a steady state temperature at 32° F. with the fan on, the air at 25° F. and 12.5 watts per sq. ft. power input. The fan was shut off for ½ hr. and then turned on for ½ hr. This cycle was repeated three times. The surface temperatures are shown plotted against time. With the wind blowing, the surface remains at 32° F. With no wind the surface temperature rises to 35° F. When the wind is again applied, the surface temperature drops again to 32° F. in about 10 min. and then remains constant.

In the case of heavy snowfall beyond the capacity of the installation to keep the entire deck area clear, all of the power input will be

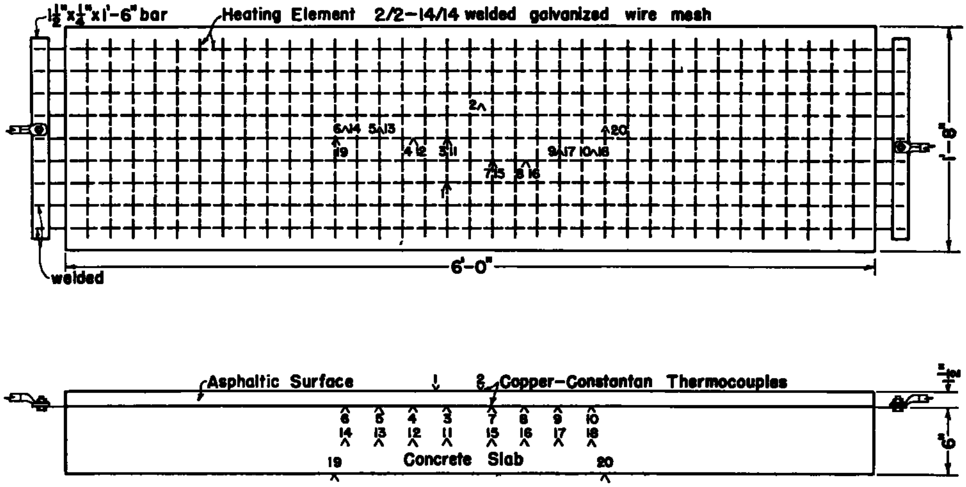

Figure 8. Electric Heat Test Slab

TABLE 2
TESTS AT STEADY STATE TEMPERATURE

1	2	3	4	5	6	7	8	9
Surface Temp.	Air Temp.	Dif.	Volts per ft.	Amp. Per Wire	Watts Per Wire per ft.	Watts per sq. ft.	Ave. Wire Temp.	Bottom Temp.
Without Bottom Insulation								
deg. F.	*deg. F.*	*deg. F.*					*deg. F.*	*deg. F*
+17	−2	19	.148	15.0	2.22	13.3	24.6	15
+32	+2	30	.217	20.7	4.49	26.9	52.2	31
+59	+8	51	.318	27.2	8.65	51.9	99.2	58
With Bottom Insulation								
24	0	24	.150	15.0	2.25	13.5	39.4	36
51	+30	21	.157	14.6	2.29	13.7	64.5	60
45	+2	43	.218	20.3	4.43	26.6	74.6	68
76	+7	69	.327	26.3	8.60	51.6	130.0	117
100	+33	67	.332	25.6	8.48	50.9	150.0	134
89	+12	77	.382	29.1	11.12	66.7	155.6	134

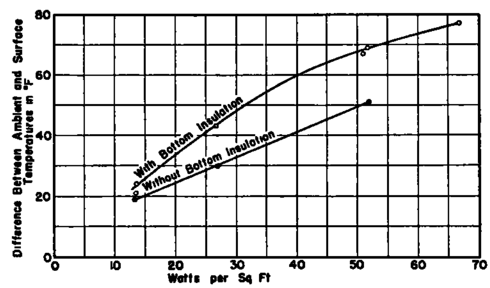

Figure 9. Relation of Watts per Sq. Ft. to Difference between Surface and Ambient Temperatures

applied to the wheel tracks. With heavy snowfall it is improbable that the air temperature will be below 20° F. A test was run starting with the slab and air at 37° F. The air temperature was lowered to 20° F. in 45 minutes with power applied at 50 watts per sq. ft. and an 8-mile wind blowing. The results are shown in Figure 11. The surface temperature dropped slowly to 32.5° F. in the first hour and then rose slowly reaching 35° F. at the end of 3 hr.

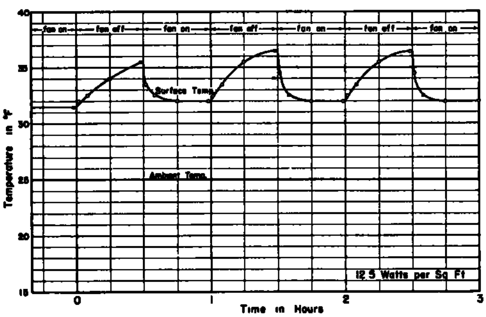

Figure 10. Effect of Intermittent Wind on Surface Temperature

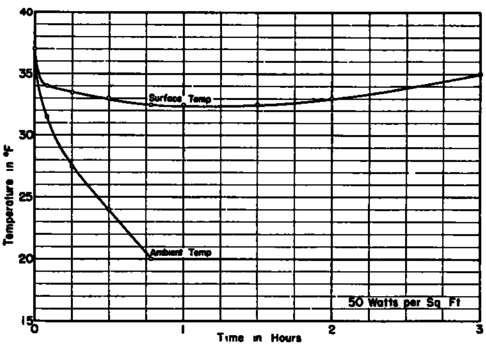

Figure 11. Surface and Ambient Temperatures, Constant Operation

From these tests it is apparent that the prevention of frost will not be the control in design. The Klamath Falls project indicated that approximately 45 Btu per sq. ft. per hr. would handle any ordinary snowfall for pavement laid on the ground. The bridge approach is more exposed to wind than a pavement slab, and some margin of safety should be provided. With this in mind, a heat input of 15 watts per sq. ft., which is equivalent to 51.2 Btu per sq. ft. per hr., was adopted as the basis for the design. Assuming that, with insulation on the lower slab surface, 95 per cent of the heat will reach the top surface, this should melt about $\frac{5}{8}$ in. of snow per hour. With the same power concentrated in the wheel tracks, a snowfall of about $2\frac{1}{2}$ in. per hr. could be handled. The record snowfall for the Salem area occurred in 1937, when 26 in. of snow fell in 18 hr.

The heating elements in the slab are divided into 12 separate longitudinal strips which vary in width from 18 to 30 in. Each longitudinal strip is divided into three 240-ft. sections, making up the 720 lin. ft. of deck to be heated. A voltage drop of 0.165 volts per ft. is required

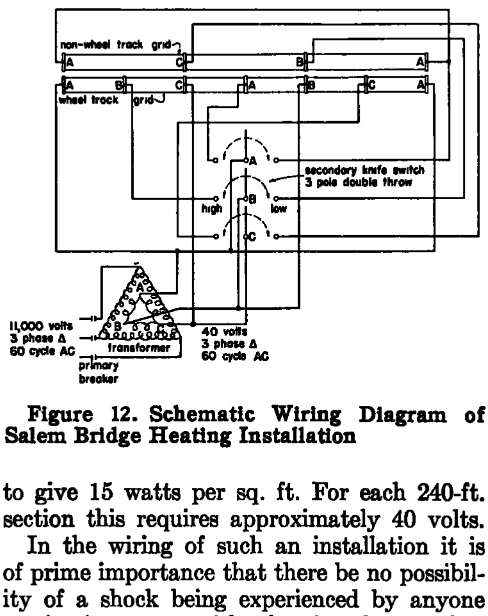

Figure 12. Schematic Wiring Diagram of Salem Bridge Heating Installation

to give 15 watts per sq. ft. For each 240-ft. section this requires approximately 40 volts.

In the wiring of such an installation it is of prime importance that there be no possibility of a shock being experienced by anyone coming in contact with a heating element that might be exposed by failure of the wearing surface. It is also important that the load on each phase of the three-phase power supply be in approximate balance at all times. These requirements are best met by using a "delta" system as shown in Figure 12.

The primary supply in this case is three phase at 11,000 volts. This is stepped down to 40 volts with taps on the secondary to vary the voltage plus or minus 5 volts in two steps each way. When heating the entire deck surface, each longitudinal grid strip is fed at the one-third point, 240 ft. apart, from each phase in order. The maximum difference in potential is thus 0.165 volts per ft. of distance. The grids in the wheel tracks are connected through a double-throw switch at the mid-point of each 240-ft. section, dividing these grids into 120 lengths. This doubles the voltage drop per foot and would supply four times the heat except for the increase in resistance due to the higher temperature of the wire. Actually the grids will supply about 55 watts per sq. ft. when heating the wheel tracks alone. Because of the heavy current in the secondary, the double-throw switch will be mechanically connected to the circuit breakers on the primary, so that it can only be operated when the circuit breakers are open and no current is flowing in the system.

With the system in operation the surface temperature will be controlled by thermostats set into the pavement surface. The master switch will be operated manually. Consideration is being given to operating the master switch by remote control from the local airport, as there are numerous occasions when the humidity is too low to form frost even with temperature below freezing.

The total power requirement for the 720 lin. ft. of bridge deck is 260 kw. Weather records show that the number of hours per year with temperature below freezing ranges from 200 to 750, with an average over the last 12 years of 350. Should the deck be heated for all subfreezing periods, the average yearly power consumption will be 91,000 K.W.H. The local rate for this kind of a load is approximately $0.01 per K.W.H. The estimated yearly power cost is $910.

The Willamette River Bridge at Salem is now under construction. The final contract, which includes the heating system, was placed under contract Dec. 20, 1950. Shortage of material, especially copper, has forced us to eliminate from the contract the heavy conductors feeding the grids from the transformer and also the control equipment. These will be installed later as they become available. The heating grids, conduits, and other items that would be difficult to install after the structure is built, are included in the present construction. It may be that it will be several years before we have an opportunity to observe the heating system in operation. In the meantime we propose to handle the situation by sanding the surface during freezing weather.

Pavement heating is an expensive operation. It can never come into general use. Even at the Klamath Falls installation, where nature furnishes the heat free, the power cost for circulating the fluid through 400 linear feet of pavement is about $40 per month. Using electric power the estimated cost per year for 700 feet of bridge deck, including maintenance, will be at least $1,000 in a region having the lowest power rate in the nation. There are instances, however, such as the two described above, where physical conditions controlling the project are such that consideration can well be given to heating rather than incur large construction cost for other treatment.

Acknowledgment should be made of the work of several engineers of the Oregon State Highway Department who have participated in the project. Mr. R. H. Baldock is the State Highway Engineer and it is through his help and encouragement that the work was initiated and carried on. Mr. W. E. Chandler is Division Engineer, and Mr. O. R. Kennen resident engineer in charge of the Klamath Falls project. Mr. P. M. Stephenson is Assistant Bridge Engineer in general charge of construction. Mr. Roy C. Edgerton, Research Engineer for the Bridge Division, designed the installation and conducted the tests.