Experimental Roadway Heating Project On a Bridge Approach

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During October 1961, electric heating cables for snow removal and ice control were installed in connection with a bituminous concrete resurfacing operation on the approach to a State Highway drawbridge in Newark, New Jersey. The cables were installed in an 840-ft length of two lanes of the bridge approach roadway. This approach ascends at a 3 percent grade and was the scene of major traffic delays during the heavy snowstorms of the previous winter. The installation was made under emergency conditions on a very heavily traveled highway and the work of laying the cable was designed so as to produce minimum delay or interference with resurfacing operations.

This paper describes methods and special equipment used for laying the heating cable and the various steps of the entire operation. Installation costs and complete design data are given including watts per square foot dissipation, total power required, conductor sizes, and electric circuitry. The winter of 1961-62 in the area was very mild with little snow accumulation. This condition precluded the gathering of firm data on performance. Conclusions are given concerning suitability of materials and methods of construction, together with a brief analysis of electric power costs as related to the rate structure of the utility company. Photographs of several steps in the construction are included.

• THE DISRUPTIONS of highway traffic caused by the heavy snows in New Jersey during the winter of 1960-61 focused attention on the necessity to study the possibility of improving methods of snow removal. The first result of these studies was the identification of critical locations where traffic had stalled on grades early in the storms, making it impossible to get plows into the area to clear the roadway.

One of these trouble spots was the westerly approach to the large movable bridge spanning the Passaic River on Routes US 1 and 9 in Newark. This approach was the scene of a major traffic tie-up during the storm of December 12, 1960. The 1,000-ft length of this approach rises at a grade of 3 percent. The average daily traffic volume is over 50,000, with heavy trucks constituting 40 percent of the total. The substantial grade, the presence of heavy and rapid traffic, and the storm tie-up combined to recommend this approach as a proper location for an experimental roadway heating project. Fortunately, a large supply of power was available, already installed, providing for the operation of the drawbridge.

Search for precedents for such an installation revealed that an apparently successful installation of electric heating cables has been made on the Mound in Edinburgh, Scotland. The heating units were installed in conjunction with an asphalt resurfacing project. In Aberdeen, S. D., electric heating cables covering only the 18-in.-wide wheel tracks, were installed in the concrete roadway of an overpass. Both these installations are apparently doing a satisfactory job, although neither is associated with a heavily traveled public highway. An electric heating installation in such a highway would be a pioneering effort on a purely experimental basis.

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It was early recognized that the major problem was one of installing the heating cable in a resurfacing operation without damaging the conductors and without serious delay or disturbance to the paving work. To obtain some information on the effect of a normal resurfacing operation on an insulated electrical conductor, test lengths of mineral-insulated cable were subjected to conditions that would prevail during such an operation, passage of heavy trucks and caterpillar treads of paving machines over them, and the compaction of bituminous material around them. After a series of these operations, the test lengths were removed, examined for sleeve damage, and tested for insulation resistance. Results indicated that this type of cable would withstand practically any amount of pressure from truck tires, caterpillar treads, or the compaction of bituminous material, provided a sharp stone did not press directly upon the cable sleeve.

With this background information, the installation was planned in four steps:

1. Laying a coarse-aggregate leveling course.
2. Laying the heating cables and securing them to the leveling course.
3. Spreading a ½-in. coat of sand-mix asphalt by hand to cover the cables; rolling with a 10-ton roller.
4. Laying the 1½-in. final course by paving machine in the usual manner.

The portion of this roadway selected for heating traverses both a land fill area and a bridge area. All available data, including that from the Edinburgh and South Dakota installations indicated that a heat dissipation of 30 watts per sq ft would be sufficient for the land fill area, and 40 watts per sq ft for the bridge area. There are no firm data to indicate how much heat would be lost by conduction downward, though there appears to be a consensus that the heating cables should not be installed more than 2 in. below the roadway surface. Using the accepted value of the heat of fusion of ice, and assuming that the installation will be required to perform satisfactorily when snow is accumulating at the rate of 1 in. per hr, a dissipation of 40 watts per sq ft gives nearly twice as much heat as is required to melt 1 in. of snow per hour at 32 F. If the extreme assumption is made that one-half the heat is conducted downward, then the remaining half is sufficient for the purpose on the bridge area when the benefit of the ef-

TABLE 1

DESIGN DATA FOR INSTALLATION OF HEATING CABLE[a]

Design Factor	Land Fill Area	Bridge Area
Length (ft)	710	130
Width (2 lanes) (ft)	20	20
Area (sq ft)	14,200	2,600
Watts per sq ft dissipated	30	40
Total power required (kw)	426	140
Nominal voltage, 3 φ, 3 w (v)	450	450
Watts per ft of heater cable	11.2	15
Heater cable, total length (approx.) (ft)	38,000	8,400
Heater cable spacing (in.)	4-5/16	3-3/4
Approx. calc. length of unit (ft)	1,410	945
Actual length of unit to fit length of area (ft)	1,420	910
Conductor size, heater cable	No. 14 AWG	No. 16 AWG
Conductor size, cold lead	No. 6 AWG	No. 6 AWG
Type of cable	Mineral insulated	Mineral insulated
Depth in cover (in.)	± 2	± 2

[a]Portion of roadway heated, 2 right-hand lanes; total length heated, 840 ft; and total area heated, 16,800 ft.

fects of heavy traffic are taken into consideration. Conditions on the land fill area are not so critical and it was assumed that a somewhat lesser rate of heat dissipation would be sufficient.

With 1½- to 2-in. cover over the heating cables, it was felt that there might be a possibility of creating a plane of cleavage if the cables were spaced too closely. A minimum spacing of 3½ in. was fixed. Holding to this minimum spacing required that the conductors should dissipate 11 to 15 watts per linear foot, a rather high figure for plastic-insulated cable. This high heat dissipation, combined with the requirement for mechanical strength of cable sheath, determined the selection of mineral-insulated cable.

Three-phase, three-wire power at 450 volts was available from the bank of 600-KVA transformers feeding the bridge. This amount of available power fixed the minimum area of roadway that could be heated. For economy in power distribution, it was desired to keep the number of heating units as low as possible and this consideration ruled out the use of resistance alloy heating elements. All these controlling factors pointed to the use of a single copper conductor carrying current sufficient to raise the resistance loss to the desired wattage. Calculations on this basis indicated the use of No. 14 B&S gage copper on the land fill area and No. 16 on the bridge area. All units were star-connected in groups of three to the three-phase, 450-volt line. A grounded neutral was desirable, but the establishment of such a neutral was not practical.

Figure 1 shows the physical characteristics of the roadway area involved. Figure 2 shows the placement of the heating cables. The photographs, taken during the work of cable installation and paving, give a clear idea of the methods used.

For convenience, limitation of voltage drop and economy of distribution copper, the cold ends of the units on the land fill area were all brought out in a slot cut in the roadway directly over the bridge abutment. Each 1,420-ft unit was laid in a "U," 710 ft long, bringing both ends of the "U" into this slot. One cold end of each of the 910-ft bridge area units was laid in this slot and the other end taken down through a hole in the deck 130 ft away, at the end of the heating area on the bridge. This procedure was followed because it was necessary to make seven 130-ft passes for each unit and this odd number of passes made it impossible to bring both ends of the bridge units back to the slot.

On the land fill area, the conductors were laid in two groups: 14 units in the first pass and 13 in the second. As the conductors payed out from the reels on the cable-laying rig (Fig. 3), they were cemented to the roadway with asphalt joint sealer every 4 ft. On the bridge area, the single conductor was payed out from a hand-operated reel around templates at each end of the bridge area. These templates had semicurcular

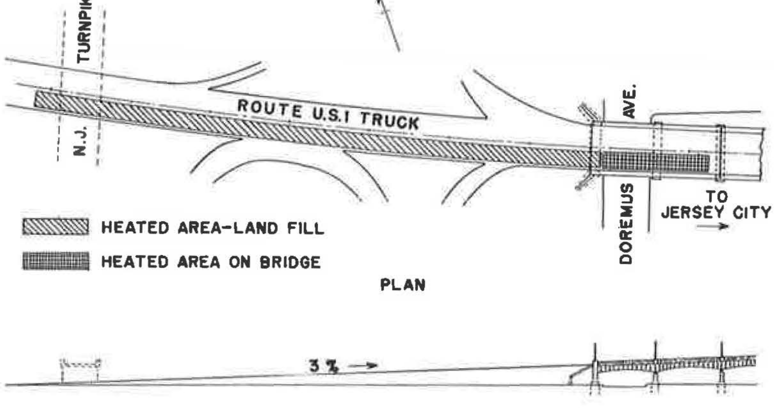

Figure 1. Test site.

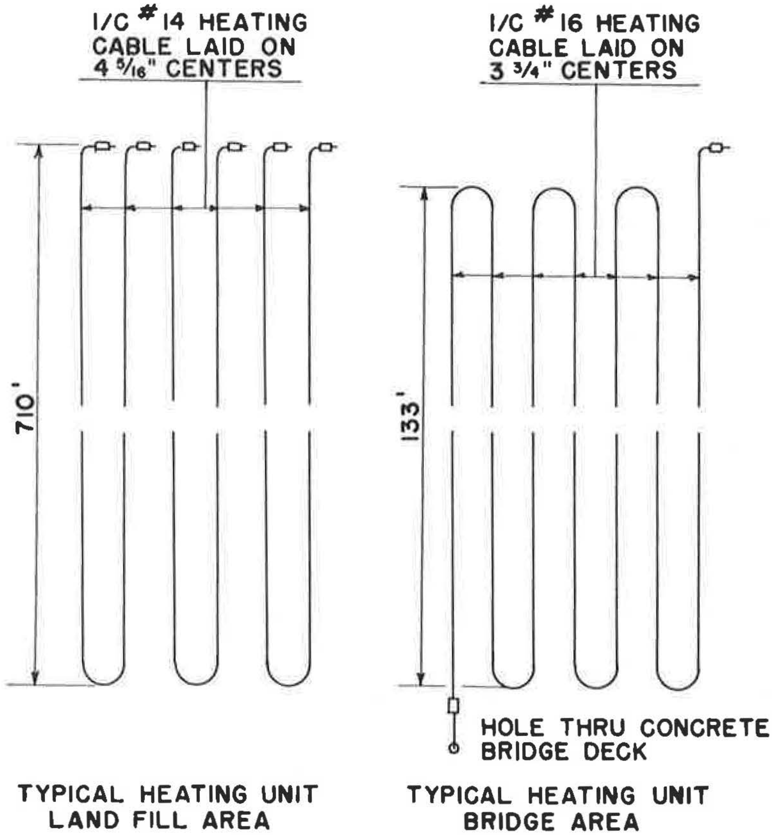

Figure 2. Layout of heating cables.

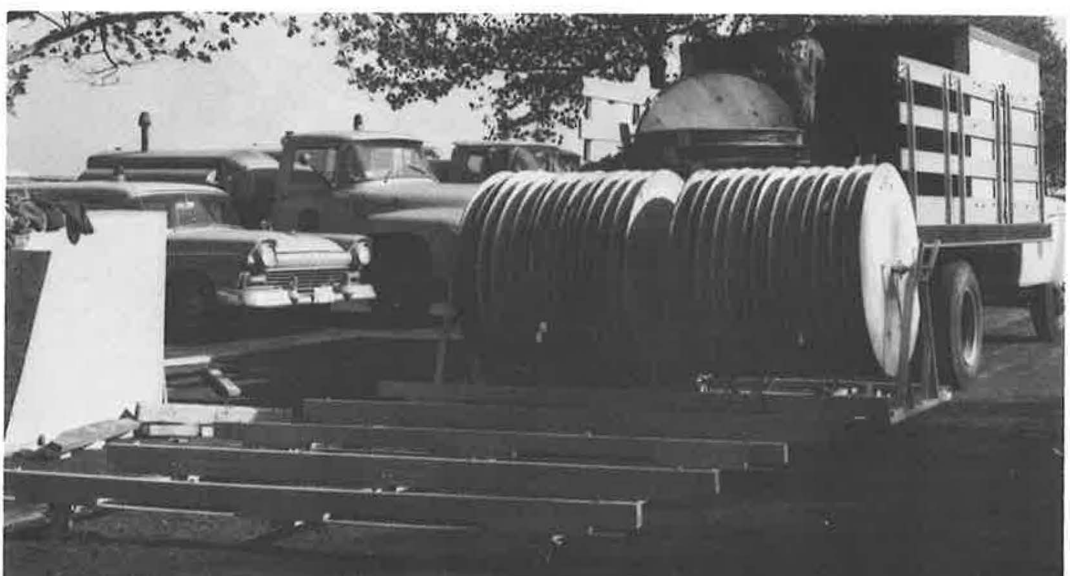

Figure 3. Cable-laying rig.

lugs of the size and spacing required to maintain the $3\frac{3}{4}$-in. spacing of the cable (Fig. 4). Each unit was secured to the pavement with asphalt joint sealer before the templates were removed.

After the laying of the leveling course, the work of cable laying and paving was done on two consecutive weekends; the land fill area was completed on the first weekend and the bridge area on the second. In each case, the planned steps were followed and the entire operation went smoothly. There was no indication that the paving operations did any damage to the heating cable.

The mechanics of laying the cable on the land fill area with the cable-laying rig were relatively simple (Fig. 5). Each of the 27 reels carried one 1,420-ft unit wound double; that is, in an elongated "U." The unit had been wound on the reel starting with the closed end of the "U" and terminating with the cold conductors.

The function of the harrow-like assembly or drag on the cable-laying rig was to straighten the cables, take the curvature or kinks out of them, and align them in the proper spacing. This drag consisted of a series of split yokes mounted on a rigid frame. Each yoke consisted of a piece of 2- by 4-in. lumber with clearance holes for the cables at the proper spacing. The piece was split down the center line of the holes and the halves held together with wing bolts. These yokes were opened and the cables drawn out from the reels and laid in the grooves of the bottom halves of the yokes. The top halves were then closed and secured with the wing bolts.

To begin the actual laying process, a similar split yoke was anchored to the roadway at the edge of the roadway slot. When the cable-laying rig was in position for the start of the run, the yoke was opened and the ends of the conductors placed in the proper grooves in the bottom half of the yoke, with the splicing sleeves and cold conductors on the slot side of the yoke. The yoke was then closed, securing the cable ends in position by reason of the bearing of the splicing sleeves against the fixed yoke.

The rig was started and moved down the road at the rate of 5 to 10 ft a minute. The work of securing the cables to the binder course followed about 30 ft behind the laying rig at the point where the cables lay naturally on the roadway surface. At 4-ft intervals, a piece of 2- by 6-in. timber was laid across the cables, holding them firmly against the surface of the road while the asphalt joint sealer was poured (Figs. 6 and 7).

Figure 4. Laying cable, land fill area.

Costs of this installation were accumulated in such a manner as to segregate the cost of paving from the cost of laying the cable and installing electrical equipment. The cost of laying the cable and the installation of electrical distribution and control equipment was $25,777. This electrical equipment does not include any transformers or service facilities. These facilities were already installed to serve the drawbridge, and power for the roadway heating installation was taken from the bus bars of the bridge switchboard through suitable circuit breakers and interlocking mechanisms. The cost does include the construction of the cable-laying rig and the installation of temporary lighting required because most of the work was done at night. The figure represents a cost of $1.56 per sq ft for the 16,800-ft area. With the knowledge that this cost is burdened by factors that accompany any experimental installation, and further, with expenses incurred by the doing of the work under emergency conditions on a heavily traveled roadway, it is estimated that under normal conditions the same installation could be made at a maximum cost of $1.10 per sq ft.

As just stated, the cost of this installation does not include the cost of transformer and electric service equipment. The cost of such equipment for a load of this size would be in the neighborhood of $18,000. With this included, the unit cost of the entire installation, under normal conditions, would be $2.19 per sq ft, and it is apparent that one-half of this cost would be absorbed in transformer and power supply equipment. In other words, the cost of transformer and switching facilities ahead of the switchboard would be approximately equal to the cost of the installation of the heating cable and the electrical distribution facilities on the load side of the switchboard. There is every indication

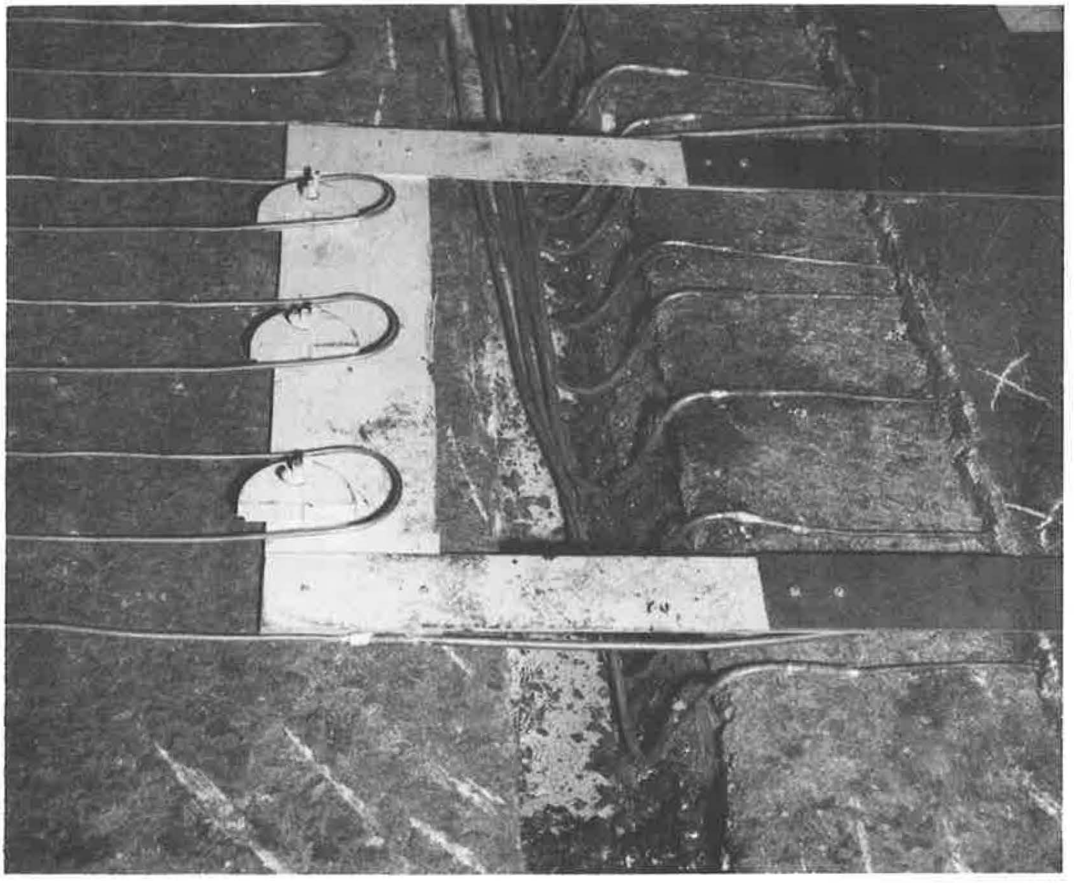

Figure 5. Cold conductors in roadway slot showing template for bridge area cable laying.

Figure 6. Spreading sand-mix asphalt.

Figure 7. Rolling sand-mix.

that this ratio will persist, generally, as the size of the project increases, up to the point where power requirements are too great to be served from the power company's 4,100-volt primary network.

Figures on the energy costs for heating this 16,800-sq ft area of roadway can be misleading, unless the utility rate structure is understood. The 600-KVA service for the bridge carries a monthly minimum charge of $400. On the condition that the roadway heating supply would be interlocked at the bridge switchboard in such a manner that the bridge operation and the heating operation could not be carried on simultaneously, the utility company agreed that there would be no charge in this monthly minimum. The remainder of the monthly bill is composed of the demand charge and the consumption charge. By the very nature of its use, a roadway heating load has a high demand, with relatively low consumption during any month of operation. It has been estimated that in the New York Metropolitan area a roadway heating system would be used only 125 hr in any one winter. If a heating system were used for 2 or 3 hr for only one storm in any one month, the demand charge for that month would be established, although the consumption charge would be relatively small. This unbalanced relationship between demand and consumption imposes the same economic penalty on roadway heating as on any large, intermittent load.

The roadway heating system was used during the period from November 8, 1961 to February 7, 1962, for a total of 67.7 hr. This use covered three monthly billing periods for energy consumed. Each billing, of course, was for a total consumption of energy by bridge operation and roadway heating. For the purpose of identifying the approximate cost of energy for the roadway heating, it is sufficiently accurate to compare the billing for these periods with the billing for similar periods in the preceding year. The difference in these billings would represent the increase in cost due to the use of roadway heating.

Although Table 2 does not furnish a full picture of the cost of operation of this heating system during a severe winter, nor the cost of operation of this system if it were installed and fed independently of any other load, it does show very strikingly the overriding influence of the demand charge in the energy cost picture. For this reason, figures on costs per hour have little actual significance, except to show that, for any one billing period, the hourly cost will vary inversely with the period of use. Rate structures of utility companies may show wide variations in different parts of the country. With knowledge of the total load and the rate structure of the utility involved, the energy cost for any heating installation can be readily calculated.

The entire bridge approach was resurfaced, but heating cables were installed in only one-third of the area. Altogether, 1,127 tons of bituminous concrete were used, ex-

TABLE 2

OPERATIONAL COSTS

Billing Period	Total Bill ($)	Cost of Heating ($)	Hours Used	Cost per Hour ($)
11-8/12-8-61 11-8/12-8-60	1,231.98 490.90	741.08	4	$185.75
12-8-61/1-10-62 12-8-60-1- 9-61	1,627.51 481.62	1,145.89	28.75	39.85
1-10-62/2-7-62 1- 9-61/2-9-61	1,561.44 489.62	1,071.75	34.95	30.66
Total		2,958.72	67.7	
Avg.				43.70
Avg. per sq ft				0.0026

clusive of the material in the leveling course. Of this total, only 6 percent was spread by hand raking. There is no doubt that the hand-placing operation increased the unit cost of paving, but because of the very small quantity involved, it is impossible to determine this increase with any degree of accuracy. During the times when the hand-spreading operation was being performed in the cable area, paving crews were also engaged in paving operations elsewhere on the project, absorbing what would otherwise have been idle time. The paving crew was augmented to accomplish the hand-laying operation. A survey of this additional manpower indicates that hand raking added approximately \$0.50 per ton to the placement of the material. This cost increment applies only to the 68 tons of sand-mix. When the total cost of the entire resurfacing operation is considered, the added cost of placing the sand-mix is insignificant.

In the ten months since this installation was completed, there has been no evidence that the heating cables have tended to lift or separate the resurfacing from the leveling course. It is, of course, too early to assume that this will not happen, though the relatively wide spacing of the cables makes it highly improbable. It was anticipated that the cables might tend to rise out of the sand-mix ahead of the roller during compaction, but this operation did not appear to alter the position of the cables in any manner. Contrary to expectations, rising of the heating cable did occur at two places while the final course was being placed by the paving machine. When the machine stopped for a few minutes during change of trucks for reloading, the cable rose out of the loose material directly behind the paving machine. This was attributed to the fact that the stopping of the paving machine permitted a concentration of heat in the area underneath the machine hopper which produced excessive expansion of the cable at that point. This buckling of the cable did not occur at any time when the paver was in continuous operation, nor did it occur during the final compaction process.

Unfortunately for the success of this experiment, snowfall in the Newark area during the winter of 1961-62 was very light. There were no storms that were characterized either by low temperatures, heavy precipitation, or long duration. Only one storm began with air temperature as low as 26 F and road surface temperature 25 F. Atmospheric temperature during this storm rose rapidly. This rise in temperature, coupled with the action of traffic, made it impossible to evaluate the effect of the heating system. No storm was of sufficient duration to permit the roadway temperature to reach a steady state. It is therefore impossible to make a firm evaluation of the ultimate capabilities of this system from the necessarily fragmentary data accumulated. Visual observations tend to confirm expectations that the heat dissipations, 40 and 35 watts per sq ft for the bridge and land fill areas, respectively, are sufficient to melt 1 in. of snow per hour, but this could not even be tentatively documented by instrumentation during the brief, light snowfalls of the 1961-62 winter.

Although documentation on performance of this installation must await the winter of 1962-63, some conclusions concerning materials, methods, and other details of this experimental installation can be reached.

1. An electric heating cable installation can be made in conjunction with a bituminous concrete resurfacing operation without undue delay or interference with the resurfacing work.
2. The hand placing and rolling of the intermediate sand-mix course does not make a significant increase in the cost of resurfacing if the work operations are properly staged.
3. No change in design of the cable-laying rig is indicated. A slight alteration in the bridle attachment to the truck is indicated to accommodate small changes in direction where cables pass around manholes or catch basins.
4. The method of securing the cables to the tack coat immediately after laying can be improved to eliminate the possibility of disturbance of the alignment of the cables by workmen during hand spreading of the sand-mix. A covering of cheesecloth saturated with asphalt joint sealer is being considered.

These conclusions necessarily relate only to the mechanical aspects of this installation. Optimum electrical design could not be attained because of the limitations imposed by the type and characteristics of the existing electrical service. Mineral-insulated cable appears to be well suited for this use, but there is no reason to assume that this is the only type of insulated cable that should be considered. The main virtue of this experiment lies in its proof of the ease with which heating cable can be included in a resurfacing operation on a major highway.

This leaves only the problem of economic justification. Heavy power costs, by reason of high demand and infrequent use, appear to limit these installations to relatively small critical areas where traffic delays and hazards caused by snow or ice justify such costs. Ease of installation and low maintenance cost of a system of electric cable heating recommend its use, but a wide area of investigation remains to determine the most effective and economical use of electric power. One area for study is the feasibility of continual heating of the roadway at a low dissipation rate throughout the winter season and stepping up this rate when required by storm conditions. This procedure might operate to level demand charges and make the load more desirable to utility companies, particularly if it is combined with some other load such as highway lighting.

Economic losses resulting from traffic delays and accidents in snowstorms on heavily traveled highways demand that research in roadway heating be uregently pursued. This experimental project helps to remove one of the problems from the area of speculation.

Discussion

J. D. GEORGE and IAN DYKE, Metropolitan Toronto Roads Department—The author's report was interesting and easy to follow. This was probably due to the fact that in the snow-melting experiment for the F.G. Gardiner Expressway in Toronto, Canada, the Metropolitan Toronto Roads Department is meeting similar problems.

The reasons for the conception of the project, which the author has clearly indicated in the first part of his report (i.e., important traffic routes, long, steep grades, and a location difficult to keep free of snow by conventional means) are all basic requirements for such a project. If these conditions were not present it would not be possible to justify using electricity to melt snow and ice. If any one of these three conditions were lacking, it would be difficult to justify such an expensive means of roadway heating.

The design of the author's project differs in many respects from the F.G. Gardiner Expressway project and a few others with which the writers are familiar. The Passaic River project uses mineral insulated cable for heating element, long panel stretches, and high voltages. Ordinary steel wire mesh (without insulation), short panel stretches, and low voltages (maximum 30 v) for safety have been used in experiments.

In one case, expensive heating element is combined with low-cost switch gear and transformers; in the other case, a low-cost heating element is combined with high-cost switch gear and transformers. No doubt each system has its merits and should be used to suit local conditions and reduce over-all capital costs.

The author's report does not indicate the means by which the power supply is controlled in his project, nor does he give any indication of the time required from when the power is turned on to when the pavement surface is warm enough to melt snow. Because the scheme does not use a base load to keep the pavement warm throughout the winter, this time element is quite important and could become critical during operation.

Construction aspects of the author's project seem to follow the usual trend as far as we know. Heating element is generally placed in the asphaltic surfacing of the roadway approximately 2 in. below the driving surface. Spacing of the heating elements seems to be generally between 2 and 4 in. However, the Metropolitan Toronto Roads Department is considering using, in a future experiment, a special layer of 2-in. fine-aggregate portland cement concrete in which to embed the heating element and then top it with waterproofing and the usual 1½-in. asphaltic concrete wearing course.

As for the economics of the method, the writers fully agree with the author's conclusions that this type of heating can be justified only under the extreme conditions mentioned.