Control of Road Snow and Ice by Salt and Electrical Road Heating

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The normal treatment for control and removal of snow and ice from roads in the United Kingdom is the application of sodium chloride, usually in the form of rock salt. The efficiency of this method depends on whether salting-lorry crews get into action at the correct moment; in addition, reliable ice warning devices are needed. This paper briefly reviews present salting practice and work being done to develop suitable ice warning equipment. It also gives an account of the development of an inhibitor to the corrosion of steel in automobile bodies caused by sodium chloride. The cost of this corrosion in the United Kingdom is many times greater than the cost of adding a corrosion inhibitor, if a suitable one can be found. A feasible, although expensive, alternative to using salt is to employ electrical road heating. This paper discusses work done at the Road Research Laboratory on the design and specification of these systems and gives some practical experience with their use in the United Kingdom.

Chemical treatment of roads and road heating for control and removal of snow and ice have become very widely used in the United Kingdom in the past 10 years. British winters are not so severe overall as those of, for example, Canada or the Scandinavian countries, and the winter of 1962-63, when land in the English lowlands was under snow for about 60 days, was the coldest in over 200 years. However, the rapid fluctuations in temperature and weather that can take place in the United Kingdom bring their own difficulties, and the organization and equipment required for winter maintenance are increasing rapidly in cost and complexity to keep the increasing traffic flowing satisfactorily. The considerable use of sodium chloride (normally in the form of rock salt) has also brought other problems due to its corrosive nature. This paper discusses the weather conditions in the United Kingdom that require treatment, and outlines the way that the problems are being tackled by research and development.

WEATHER CONDITIONS REQUIRING TREATMENT

The commonly occurring conditions requiring treatment are snow; ice films formed when a road surface, wet by rain or dew, cools below the freezing point; and hoarfrost, which consists of small crystals of ice deposited when the surface is cooled by radiation to a temperature below the frost point of the air. Less frequently, glare ice may be formed by rain on a surface at a temperature below 0 C.

Snow

The occurrence of snow is recorded by meteorological observers, and information on the amount of precipitation and the temperature at which it occurs is available from daily weather records of the Meteorological Office.

Data extracted from the records for the period from October 1962 to March 1965 for London Airport are given in Table 1. Quantity of precipitation is expressed as an equivalent depth of water so that, taking the density of snow to be about 100 kg/m^3, 10 mm of snow is equivalent to 1 mm of water. The air temperatures during snowfall were rarely below -1 C and on the majority of occasions were above freezing point.

TABLE 1

AMOUNT OF PRECIPITATION AND AIR TEMPERATURE RECORDED DURING SNOWFALL AT LONDON AIRPORT, OCTOBER 1962 TO MARCH 1965

Amount of Precipitation as an Equivalent Depth of Water (mm)	Number of Observations at Different Air Temperatures (deg C)										
	4	3	2	1	0	-1	-2	-3	-4	-5	-6
0.1		1	2	1	1						
0.2					2			1			
0.3				1		1					
0.4				1	1	2			1		
0.5											
0.6		1	1	1	1						
1.0			2	2	2	1					
2.0	1	1		2	3						
3.0				1			1				
4.0			1		3	1					
5.0	1		1								
6.0						1					

Coatings of Ice

There is a lack of recorded information on the temperatures of road surface during icy conditions, but an indication of the probable range is given in Table 2. The table gives the frequency with which minimum temperatures in various ranges were recorded and when icy roads had been forecast and salt was applied as a precautionary measure. Temperatures were usually above -2 C but were down to -4 C on 4 occasions.

Hoarfrost

Hoarfrost is not often seen on roads with substantial thicknesses of construction, which, because of their thermal characteristics, cool more slowly than their surroundings. The vapor content of the air is depleted mainly by deposition on the colder surfaces of vegetation, which develop thick coatings of frost. However, appreciable deposits sometimes form on roads of lighter construction and on bridge decks, which cool more quickly because of heat loss from their lower surfaces.

There is a short period after dawn when high thermal conductivity has an adverse effect, and conditions appear to favor frost formation on the road. At this time the temperature of the surrounding vegetation may be rising quickly, releasing water vapor that can condense on the cooler road. The period during which these conditions exist is brief but may account for the suddenly occurring phenomenon sometimes termed "flash icing."

Frost quantities on roads have not been measured, but measurements of deposits formed in a cold room and having a similar appearance to those on the road indicate that the range from slight to heavy corresponded to equivalent water depths from 0.01 to 0.15 mm. There is, however, no obvious relationship between the amount of deposit and the atmospheric conditions recorded.

TABLE 2

FREQUENCY AND LEVEL OF MINIMUM TEMPERATURE RECORDED ON MOTORWAYS WHEN THE ROAD WAS SALTED

Minimum Temperature Range (deg C)	Frequency Recorded	Minimum Temperature Range (deg C)	Frequency Recorded
3 to 4	2	-1 to 0	10
2 to 3	1	-2 to -1	9
1 to 2	9	-3 to -2	6
0 to 1	9	-4 to -3	4

Salt-treated roads are often wet when neighboring untreated roads are dry. This is because of condensation induced by the presence of salt. This condensation usually occurs at sunrise when temperatures are rising, but may sometimes begin soon after treatment early in the night. Again the quantity is limited by heat exchange processes, and in practice there does not appear to be any risk of brine becoming so diluted that it freezes when the temperature falls to a lower level.

Glare Ice

This form of ice occurs when rain falls on a surface with a temperature below freezing. The rain may be supercooled and partially freeze on striking the ground so that dangerous conditions develop very quickly. Meteorological conditions that cause extensive glare ice are rare over Britain, but they probably occur a number of times each year in limited areas. Instances were recorded in the vicinity of the Road Research Laboratory at Harmondsworth in 1964 and 1966. Both occurred between 7:00 and 8:00 a.m., and air temperatures recorded at the time were -3 C. On such occasions the ice may be quite thick, perhaps up to 30 mm.

CHEMICAL TREATMENT

Undoubtedly the major development in winter maintenance in the United Kingdom has been the rapid increase in recent years in the use of rock salt for the prevention of ice formation on roads and for facilitating the removal of snow.

Recommendations on the use of chemicals were issued by the Road Research Laboratory as long ago as 1941, but this method of treatment did not begin to be generally applied until the mid-1950's. Since that time there has been a sixfold increase in the amount of salt used, and recommended methods of treatment, taking into account the developments that have taken place in equipment, have been published as a Road Research Laboratory Road Note (1), from which the following paragraphs are summarized extracts.

Salt is most effective when applied early in the potential development of icy conditions. At this stage the quantity of ice to be prevented or cleared, and therefore the quantity of salt required, cannot be known. Furthermore, in certain circumstances, the rate of clearing has to be considered, and this may depend on factors not easily assessed beforehand. The treatments recommended are therefore based on the application of standard quantities that will be adequate in average conditions; more severe weather, or the need for more rapid clearing, will entail repeated applications. Modern equipment will effectively spread the quantities of salt recommended, without mixing the salt with abrasive.

When forecasts of icy conditions can be obtained from meteorological stations or from local observations, salt may be spread on heavily trafficked roads as a precautionary measure before any ice actually forms. Such forecasts will inevitably be incorrect on occasions, but the resulting wastage of salt may be partly offset by the smaller quantities required when icy conditions do develop later. The practice is justified on motorways by the virtual elimination of the occurrence of ice.

Thin films of ice formed by the freezing of water on the road surfaces are usually less than 0.25 mm thick, which is equivalent to approximately 0.25 kg/m^2 of ice. The temperature during periods of icing is usually above -3 C, so that an application of 15 g/m^2 of common salt is sufficient to effect complete melting. Application of this quantity before the onset of freezing will prevent the formation of ice.

When ice has formed, 15 g/m^2 of salt will not be sufficient to bring about the required increase in skidding resistance in a reasonable time and 50 g/m^2 should be applied.

The density of fresh untrafficked snow is about one-tenth that of ice, that is, about 90 kg/m^3; a 1-cm depth of snow is therefore roughly equivalent to 1 kg/m^2 of ice.

In practice, it is found that one-half of the quantity of common salt required for complete melting will reduce the snow to a state in which it can be dispersed by traffic, and about 6 g/m^2 of salt is required per 1 cm of fresh snow for each degree centigrade that the air temperature is below the freezing point. When snowfalls of 1 cm or more occur, the temperature is usually higher than -3 C and 1 or 2 applications of salt at 50 g/m^2 will be sufficient to clear the average fall. The quantities of salt required for the treatment of 1 km of a 7.3-m wide roadway are about 100 kg at 15 g/m^2 and about 360 kg at 50 g/m^2.

Every effort should be made to ensure by the prompt application of adequate amounts of salt that thick layers of hard-packed snow and ice do not form on the roadway. If such layers do form and are no thicker than about 25 mm, their removal is possible at temperatures above about -5 C by applying salt at 5 times the rate required for the same depth of fresh snow. When the layer is considerably thicker than 25 mm or the temperature is low, application of salt is inadvisable, because the accumulation of salt solution in the depressions will produce a very uneven and slippery running surface.

In these circumstances abrasives may be spread to make the surface less slippery. The amount of abrasive required ranges from 100 to 400 g/m^2 of road surface. The addition to the abrasive of about $1/30$ of its weight of salt will prevent the abrasive particles from freezing together and will help them penetrate the surface of the hard snow or ice.

FORECASTING FOR PRECAUTIONARY TREATMENT

Forecasts of snow and icy roads are issued by the U.K. Meteorological Office to assist engineers responsible for maintenance in making arrangements for snow clearing and chemical treatment. These warnings are transmitted during normal working hours to enable maintenance crews to be alerted and equipment prepared. However, forecasts made perhaps many hours before icy conditions are expected to develop may not prove accurate, and they are revised periodically throughout the night so that, where a night shift is worked, action can be delayed until conditions become more certain.

Road temperatures are frequently only a degree or two below freezing point when ice forms, so that the margin of error in forecasting these temperatures is small. Moreover, whether ice forms often depends on the rate at which the road dries, and this is determined by factors, such as drainage and amount of traffic, that the forecaster cannot take into account.

As far as is known, no research is currently being undertaken on the forecasting of icy conditions on roads. During the past year, several papers have been published on the night minimum temperatures of roads or of concrete slabs. Three papers (2, 3, 4) were concerned with the relationship to night minimum air temperature and showed that the latter was about 1 C higher in the winter months. Thus techniques for forecasting night minimum air temperature can be extended to the forecasting of minimum road temperature. Another paper (5) on minimum road temperatures was based on the temperature of the surface at 1800 G.m.t. the previous evening and the mean cloud cover during the night. Further work is being based on the surface temperature at 1200 instead of 1800 G.m.t.

ICE WARNING DETECTORS

Local measurements of road conditions may provide a more reliable guide for maintenance staff than meteorological forecasts. Devices that measure road temperature and wetness are now available, and trial ice warning installations have been set up in Britain and elsewhere in Europe. These devices measure road temperature by means of an embedded probe and detect wetness by the decrease in electrical resistance between electrodes in the road surface. Signals from the detecting elements are combined to give an alarm signal when icing conditions develop. Advance warning for precautionary treatment can be obtained by setting the critical temperature a degree or more above freezing point, although, naturally, the higher the temperature is set the greater will be the likelihood of a false alarm. Table 3 gives the amount of warning and frequency of false alarms obtained with various temperature settings of a prototype warning device tested at the Road Research Laboratory.

The onset of snowfall may be detected by using a second pair of electrodes separated by a surface that is heated to melt the snow and give a moisture signal. Figure 1 shows a commercial arrangement of temperature, wetness, and snow sensors to be placed in the road surface. The left circular element is the snow sensor, the right one is the moisture sensor, and the block between them contains the temperature sensor.

Many false warnings can be given by this simple device when moisture condenses on the road only because of the presence of salt remaining from a previous treatment. By using a third pair of moisture electrodes in a concrete block near the road but free from salt, this ambiguity can be resolved.

TABLE 3

AMOUNT OF WARNING AND NUMBER OF FALSE ALARMS GIVEN BY VARIOUS TEMPERATURE SETTINGS OF AN ICE WARNING DEVICE

Alarm Temperature Setting (deg C)	Frequency Recorded (percent)						
	Amount of Warning (h)						False Alarms
	<½	½ to 1	1 to 1½	1½ to 2	2 to 5	>5	
1.5	0	10	9	17	27	6	31
1.0	4	23	17	10	18	2	26
0.5	25	41	13	4	6	0	11

If the moisture deposit on the road is not created merely by the hygroscopic nature of the salt but is due perhaps to slight drizzle, there may nevertheless be enough salt remaining from a previous treatment to prevent the formation of ice. A further pair of electrodes placed in the road with an associated trigger circuit set to operate at a sufficiently low resistance can be used to cancel the warning signal.

Hoarfrost cannot be predicted or detected by these sensors just described. A lithium chloride humidity sensor can give an indication of dewpoint or frostpoint, which when compared electrically with the road surface temperature could be used to detect or predict the formation of hoarfrost. A sensor of this type is being developed at the Road Research Laboratory.

Figure 2 shows a suitable interconnection of all the sensors mentioned to give a warning to spread salt. An instrument based on this circuit is now being evaluated at the Road Research Laboratory.

There seems at present to be no way of predicting glare ice by instruments placed in the road, but fortunately this condition is rare in the United Kingdom.

HARMFUL EFFECTS OF SALT TREATMENT

Damage to Roads

Although salt has long been known to accelerate the scaling of concrete by frost action, the factors affecting the resistance of concrete, such as the amount of entrained air, water-cement ratio, and age before treatment, are now also known and there is little evidence in Britain so far of damage to concrete pavements or structures made to modern specifications.

Bituminous surfacings, which are permeable by water, may be damaged by frost, but there is no evidence from the laboratory that the process is accelerated by the application of salt. The only controlled tests of salt treatment on roads appear to be those carried out by Nichols and Price (6) in Cheshire from 1952 to 1956. Comparing adjoining sections of bituminous macadam and surface-dressed roads, they found that salt treatment had no harmful effect and in fact the untreated section suffered greater damage over the period of observation. However, salt modifies road conditions by temporarily lowering the temperature when it is applied to snow or ice, and facilitates the entry of water into structures that would be impermeable when frozen. The possibility that this is sometimes a contributory factor in damage to roads cannot be entirely ruled out. A recent survey (7) of current opinion in 30 counties showed that there was little definite evidence of damage due to salt,

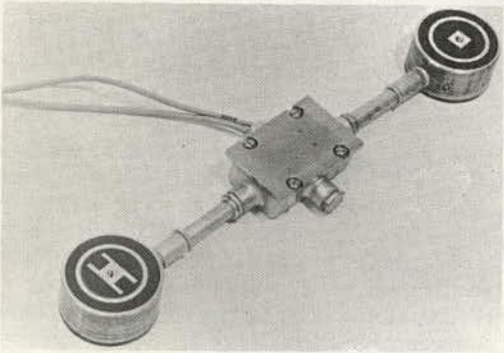

Figure 1. Sensors for detection of snow, low temperatures, and surface moisture.

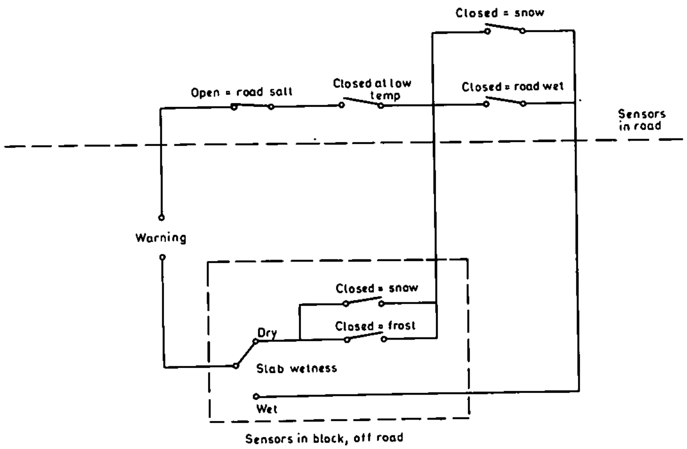

Figure 2. Suitable interconnection of sensors to give warning to spread salt.

although in 9 counties it was suspected of having accelerated the failure of some macadams and surface dressings.

Damage to Vehicles

It is now generally accepted that there is an increase in the corrosion of motor vehicles due to salt. A survey carried out by the Road Research Laboratory (8) has shown that corrosion rates of vehicles are appreciably higher in Derbyshire, where the average amount of salt used annually is about 4,400 kg/km, than it is in Pembrokeshire, where the amount of salt used is negligible. It is estimated for instance that the average life of mufflers in the unsalted area is about 4 years, about double that in the heavily salted area. It we assume that replacement costs £6 and that the general use of salt will be at the higher rates in the main centers of population, increased expenditure due to salting for this component alone amounts to about £1 per vehicle per year, or a total of £14 million per year for the estimated vehicle population in 1970.

The potential benefits of reducing corrosion are therefore considerable, and this fact has stimulated investigations into the use of corrosion-inhibiting agents in several countries.

Motor vehicles come into contact with de-icing salt solutions by splashing and by spray. A range of laboratory tests has been used by different investigators in their evaluations of inhibitors. Unfortunately, in the majority of cases, the conditions existing in the field have not been approximated in the laboratory. The 2 factors most ignored have been temperature and brine concentration.

The temperature is important because it governs the rate of the corrosion reaction and can have an effect on the protective action of the inhibitor. This is especially true in the case of film-forming inhibitors. It is surprising that a number of investigators have conducted their experiments at room temperature in the range 20 to 25 C.

Brine concentration also affects the rate of corrosion. It has been shown that brine is most corrosive in the 3 to 6 percent concentration range; above and below this range, the amount of corrosion caused decrease rapidly.

The most commonly applied test for the evaluation of corrosion inhibitors is an intermittent immersion test carried out on bare mild steel panels. Continuous immersion tests are not normally favored because it is considered unrealistic to have inhibitors continuously applied to a metal surface, a condition that would certainly not apply in practice.

At the Road Research Laboratory we have used an intermittent spray test of 4 hours duration followed by 20 hours at rest, at temperatures of both 5 and 25 C. It has been shown that inhibitors generally appear to be much more effective in reducing corrosion of mild steel when tested under intermittent immersion conditions compared with intermittent spray. It has also been shown that the effect of inhibitors on the corrosion rate of bare mild steel cannot be directly related to the effect on rust creep on phosphated and painted steel that has been damaged with a cross scratch. The addition of 1 percent sodium polymetaphosphate to salt reduces the rate of rust creep from scratch damage to a marked extent for both primers and for complete vehicle paint systems on phosphated steel panels. Under similar intermittent spray conditions the inhibition of bare steel corrosion by sodium polymetaphosphate is extremely small (Fig. 3).

Two inhibitors are being tested in a full scale test track using 7 new small sedan vehicles that were obtained from the British Leyland Motor Corporation. These were standard production vehicles but produced under carefully controlled conditions on the production line in the same batch and were metal pretreated and painted under uniform conditions so that all are equivalent. During the winter of 1969-70 these 7 vehicles were run through 4 separate splash areas containing rainwater, brine, and brine plus

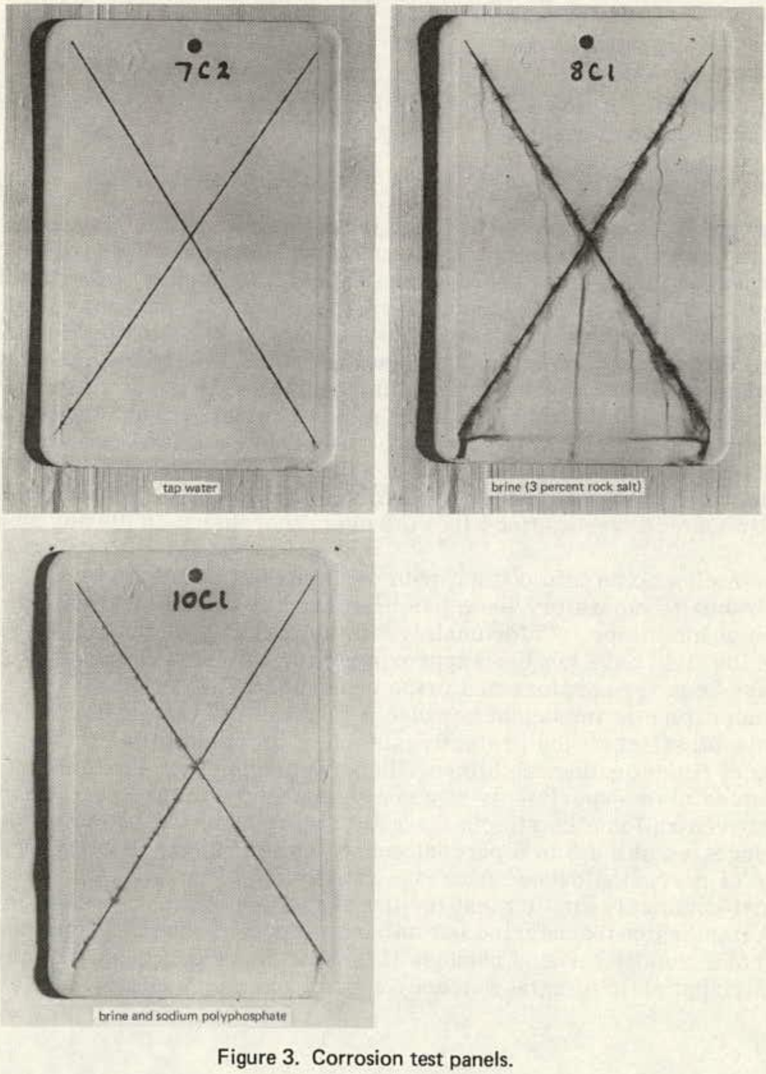

Figure 3. Corrosion test panels.

2 different inhibitors. Motoring at a speed of about 65 km/hr will simulate normal motoring conditions and ensure that corrosive liquids are driven into crevices. The track run is followed by garage storage, which prevents rapid drying out of the vehicles. When a sufficient level of corrosion damage has been developed, the vehicles will be cut open and examined in detail.

ROAD HEATING

In comparison with chemical treatment, road heating is an expensive method of snow and ice control, but its application can be justified in certain limited areas where failure to treat the road quickly can result in a disproportionate degree of traffic dislocation and create jams that make treatment by conventional methods impossible. Such areas are gradients approaching intersections, elevated roads and underpasses, and sharp bends and roundabouts.

Heating overcomes the problem of snow disposal on elevated roads where space limitations do not permit the storage of snow at the roadside. The fact that the question of damage to reinforced concrete by de-icing salts is as yet unresolved is an additional reason for protecting elevated structures by this method.

The Road Research Laboratory began experiments in 1956 with a small installation at Harmondsworth, Middlesex, in which 2 types of heating element were used: (a) PVC-insulated resistive wire elements operating at medium voltage (240 V) and (b) uninsulated expanded steel mesh carrying comparatively high currents at extra low voltage (55 V). Many installations of both types are now in operation, ranging in size from the 8-MW scheme on the elevated Chiswick-Boston Manor section of the M4 motorway, to installations of a few kilowatts on service ramps.

Operation of the Harmondsworth experimental installation at various levels of output and measurements of heat transfer made on this and other installations provided the basis of a method of relating the heat requirements to weather conditions (9).

Roads at Ground Level

Two weather conditions were considered: (a) clear nights, with strong radiation leading to ice formation, and (b) overcast skies and high winds, in which the installation might be called on to melt snow. Under clear skies it was found that the maximum heat transfer, Q (in W/m^2), from the surface could be expressed by the equation

$$Q = 90 + (11.9 + 1.69u)(T_s - T_a) \quad (1)$$

where T_s is the temperature of the surface in deg C, T_a is the temperature of the air in deg C, and u is the wind speed in mph. In overcast conditions when the heat transfer is mainly due to convection and evaporation the equation becomes

$$Q = (11.9 + 1.69u)(T_s - T_a) \quad (2)$$

In which of these 2 conditions the greater heat loss occurs depends on the nature of the site. On an urban installation sheltered from high winds, maximum heat loss probably occurs with clear skies, while on an exposed site it may be greater in the higher wind speeds and lower air temperatures associated with snow.

Elevated Roads

Measurements on British installations have shown that, when the road is in contact with the ground, heat flow downward from the elements is negligible after it has been in operation for a few hours, and no allowance is made for it in calculating heat requirement. For installations on elevated roads, an allowance is necessary to compensate for the heat lost by convection and radiation at the lower surface, which must be added to the values given by Eq. 1 or 2 for the upper surface.

The equation relating this heat loss to weather conditions, derived from measurements on elevated structures, is

$$Q_1 = (3.8 + 1.69u)(T_1 - T_a)$$

where T_1 is the temperature of the surface in deg C.

Practical Experience

The following conclusions have been drawn from an examination of the performance of heating schemes (10):

1. The power required is 100 to 130 W/m^2 (9 to 12 W/ft^2) for sheltered sites rising to 150 to 200 W/m^2 (14 to 19 W/ft^2) for exposed sites;
2. Installations using uninsulated steel mesh as the embedded conductor at extra low voltage have been found in general to be more reliable than installations using cable at a higher voltage;
3. The estimated capital cost in 1968 was about £4.6/m^2 and the average annual operating cost was about £0.15/m^2 for both types of installation; and
4. The costs of electrical road heating are about 30 times the cost of using rock salt, and local circumstances must be unusual and critical to justify this high cost.

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Informal Discussion

Glenn G. Balmer

You said that the cost of heating was about thirty times that of salt. Are you referring to electric heating, or are you considering heating by methods other than electric heating?

Watkins

I am considering electric heating only. There are few road installations with other forms of heating in the United Kingdom. Frankly, I am not particularly familiar with them, and I do not think there are likely to be very many.

John Pendleton

I very much appreciate your approach of anticipating storms and getting out on the highway ahead of time with chemicals. We would like to do that, but we generally cannot because the weather is continuously so poor. We do call crews out ahead of time. I am also interested in your early warning system. Do you have problems with keeping the salt on the highway before the precipitation starts, or does traffic tend to whip it off?

Watkins

This is one of the reasons why we use a fairly coarse material. We have experimented with different gradings. Somebody said earlier that in parts of Europe they used a very finely ground salt; we do not. We find that with the amount of warning we can get and the grading of the salt that we use, we do not have much trouble with this. At some places—the Severn Bridge for example—urea is used because of the corrosivity of salt and this is put down in a fine powder form. Owing to the high winds at this site, it blew off the bridge into the Bristol Channel and they had to combine it with a quantity of grit to give it some weight. Of course, it is more difficult for us to achieve our ideal of preventing ice formation in an urban area. The salting vehicles become snarled up with traffic and so on. It is much easier to achieve the ideal under the motorway conditions I have talked about.

John P. Wilmot

Have you used any plastic blades in place of rubber? In Europe, they call it Vulkollan.

Watkins

I do not know of any.