DEVELOPMENT OF A FROST AND ICE DETECTION SYSTEM FOR HIGHWAY BRIDGES

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A frost and ice detection system for bridge decks based on the detection of the heat of fusion of ice is being used experimentally in Iowa. Observation of the operation of 5 installations during the 1971-72 winter revealed that 57 alarms were genuine and 9 were false and that on 7 occasions the units failed to detect frost, ice, or snow.

•SYSTEMS for the detection of frost or ice on bridge floors have been commercially available for at least 8 years. In 1965, the Iowa State Highway Commission obtained two such systems, which were used experimentally during the winters of 1965-66 and 1966-67.

The two systems purchased by the commission distinguished between liquid water and frost or ice by detecting a difference in the electrical conductivity of water in its frozen and liquid forms. Investigation confirmed that a difference in electrical conductivity does exist, provided the water is relatively low in salt content. When the water contains an appreciable salt content, it is difficult or impossible to detect any difference in conductance. An explanation of this is suggested by the observation that, as saline water freezes, the dissolved salt is displaced to the surface where a supersaturated film of microscopic thickness is formed. This film has the same conductance as the unfrozen saline water.

Investigation of several other ice detection systems revealed that some have operating characteristics apparently based on the assumption that water freezes at 32 F (0 C). This is not always true on highway bridge decks, since the presence of dissolved salts often makes the freezing point indeterminate. Investigation in Iowa revealed that, after the first application of salt to a bridge deck, frost seldom formed above 22 F (-5.5 C).

The investigation of commercially available frost and ice detection systems eventually led to consideration of the most desirable operating characteristics for a dependable system and to a study of the theory and design features necessary to produce such a system.

OPERATION OF IOWA SYSTEM

The operation of the Iowa system for detection of frost and ice on bridge decks is based on detection of the heat of fusion of ice. The sensing surfaces are heated periodically at a carefully controlled rate so that melting of any frost, ice, or snow on the surface can be obtained. If the sensing surface is dry or wet, the relationship between the rate of temperature change and time will follow characteristic patterns. Water in a frozen form produces a definite change in the rate of temperature rise in the sensor at that point in time when the heat of fusion occurs.

The sensing element is a thin, stainless steel plate $^{5}/_{16}$ in. (7.9 mm) wide and 2 in. (5 cm) long. A Chromel-Alumel thermocouple is attached to the underside of the plate. The element is mounted in a nonconducting holder that is cylindrical and that has a diameter of 4 in. (10.2 cm) and a thickness of 1 in. (2.5 cm). The element and holder are inserted in a hole drilled in the bridge deck between the wheel paths. The surface of the sensor is flush with the surface of the bridge. Each installation consists of three sensors that are placed about 8 in. (20.3 cm) apart.

When the presence of frost or ice or snow is tested for, one of the three detectors is activated each 30 min. During the sampling period, the stainless steel plate is heated at a definite rate. The resulting change in temperature is detached by the themocouple. Since there is a 90-min interval between successive heat applications to an individual sensor, there is adequate time for possible frost or ice formation.

The electronics package for each installation contains the necessary circuits to provide a programmed heating rate and detection of the resulting temperature change by the thermocouple. The temperature change with reference to time is electronically double differentiated. The signal then is fed to a detector circuit that is capable of distinguishing a signal that is indicative of frost, ice, or snow melting on the surface of the sensor.

TESTING OF IOWA SYSTEM

There are several methods whereby frost and ice detection equipment may be coupled with warning devices to alert motorists of dangerous bridge deck surfaces. Perhaps the most common method is use of an illuminated sign at some approach distance from the end of the bridge.

During the Iowa investigation, it was concluded that it would be impractical to equip many highway bridges with frost and ice detectors and that it would be preferable for the highway agency to take some positive action to alleviate the condition rather than to merely warn the motorist that the danger exists. When frost and ice form, the Iowa system is to be used to alter local maintenance personnel, who will immediately apply salt and abrasives as required.

Arrangements were made with maintenance department personnel to evaluate the operation of five detectors during the 1971-72 winter. Special forms were completed each time an alarm was received and each time maintenance personnel observed an icy condition that did not produce an alarm. All alarm conditions were verified by actual observations.

Each unit was tied into the radio system operated by the Iowa State Highway Commission. All alarms generated by the frost and ice detectors were relayed by the radio system as a distinctive beeping tone obtained by modulation of the transmitter. Receivers were installed in the homes of the maintenance foremen responsible for the test locations. During normal working hours, frost or ice alarms were monitored at the maintenance garages and in local maintenance vehicles equipped with two-way radios. Alarms were sounded by the unit in the maintenance foreman's home at all other times.

Data from the five installations for a 4-month period are as follows:

Condition	Genuine Alarms	Alarm Failures
Snow	30	3
Ice	19	3
Frost	8	1
Total	57	7

Nine false alarms were received during the 4-month period.

Attempts were made to immediately identify the causes of alarm failures and of false alarms. These investigations resulted in a few minor adjustments in the electronic systems. For example, the reliability of two of the units was improved by a slight modification of the heating circuit. The effect of these minor adjustments was evident during the testing.

An important purpose of the frost and ice detecting system is to provide a warning of frost or ice on a bridge deck at times when adjacent pavement may be free of frost or ice. Because of this, it was deemed necessary to achieve a high degree of sensitivity in the detecting system. Unfortunately, this sensitivity is such that the sensors may be overpowered by rapidly forming deposits of wet snow or freezing rain and sleet. It was determined that three of the seven alarm failures occurred under such conditions.

CONCLUSIONS

The Iowa frost and ice detection system will reliably report thin layers of frozen water; therefore, its reliability is best for frost, fresh snow, and light freezing rain. Packed snow and rain mixed with snow are not detected with the same degree of reliability. Frost is detected when it is barely discernible on the pavement surface.

The five units that were in operation during the winter of 1971-72 had a total reliability of 78 percent [(57×100)/(57+9+7)]. Analysis of the failures and false alarms of the individual units suggests that reliability is greatly influenced by the quality of the electronic components. The most dependable unit contains high-grade components throughout. These, alone, cost about $900. Modification had been made in the electronic design of the other four units to permit a cost reduction of about $500 per unit. Development efforts are currently being directed to obtaining both operational reliability and economical design.