Measurement and Prediction of Preferential Icing Potential of a Bridge Deck

C. Birnie, Jr., Pennsylvania State University, University Park

Preferential icing, the tendency of a bridge deck to freeze before the adjacent roadway, was studied by the Pennsylvania Transportation Institute, Pennsylvania State University, in cooperation with the Pennsylvania Department of Transportation from 1969 through 1973. A bridge deck on I-80 in Pennsylvania was instrumented, and complete data on the meteorological conditions and surface temperatures of both the bridge deck and the adjacent roadway were gathered during the winters of 1971-72 and 1972-73. This paper summarizes these experimental findings and suggests a method for determining an overall rating of the preferential icing potential of a bridge deck. A computer model was developed to determine the thermal response of both a bridge deck and adjacent roadway to ambient conditions. A method is described that, if one uses this model, can predict the possible formation of preferential icing on a bridge deck before it occurs and statistically determine an overall rating of the preferential icing potential of a bridge. A simple instrument package for surveying bridges for preferential icing is described.

Preferential icing, the tendency of a bridge deck to freeze before the adjacent roadway, was the subject of an investigation conducted by the Pennsylvania Traffic Institute, Pennsylvania State University. The project was sponsored by the Pennsylvania Department of Transportation and the Federal Highway Administration. It was initially funded in January of 1969 and was concluded in August 1973.

The project consisted of three major phases. Although each phase had particular goals, the overall objectives were to study the various factors that lead to the preferential icing of a bridge deck, to measure the phenomena at a selected test site, and to determine methods of predicting its occurrence. Summaries of the work done in the first two phases of the project are contained elsewhere (1, 2, 3).

In the final phase of the study, experimental data were gathered at the test site during the winters of 1971-72 and 1972-73 and were subjected to extensive analysis. A good portion of this paper will be devoted to reporting on these experimental data and on the results. A method for determining an overall rating of the preferential icing potential of a bridge deck based on measured data will be suggested.

In addition to the experimental portion of the study, considerable time was devoted during all phases to the development of a transient, heat-transfer simulation model of both the bridge deck and the adjacent roadway. The final version of the model was completed during the last phase and will be described. A suggested method for using the model to predict the possible formation of preferential icing on a bridge deck before it occurs and to statistically determine an overall rating of the preferential icing potential of bridges will be outlined in detail.

TEST SITE DESCRIPTION

The bridge on the eastbound lane of I-80 over Bald Eagle Creek in Centre County, Pennsylvania, was selected as the test site. The site is located some 25.7 km (16 miles) from State College, Pennsylvania, near the US-220 interchange of I-80. It is on the floor of Bald Eagle Valley just east of the foot of the Allegheny Mountains. The creek that flows under the bridge is relatively warm because of the presence of a steam power plant that discharges cooling water into it about 3.2 km (2 miles) upstream. The warm humid air rising from the creek in the winter thus provides additional moisture for condensation on the bridge surface. The bridge selected is relatively new; it was built in 1964. It is an all-concrete structure approximately 61 m (200 ft) long and 6.1 m (20 ft) high. The understructure is box-beam, poured-in-place, stripped-form concrete.

Instrumentation of the site was based on the variables and conditions that were deemed important enough to have the greatest influence on preferential icing, that is, meteorological conditions at the site and the thermal characteristics of the bridge deck and of the approachway. A plan view of the general location of the instrumentation is shown in Figure 1. The measured variables are

1. Temperatures,
2. Humidity,
3. Wind velocity and direction,
4. Precipitation,
5. Ice detection,

Publication of this paper sponsored by Committee on Winter Maintenance.

6. Solar radiation, and
7. Event recording.

The thermal gradient within the bridge deck and approachway and some subgrade temperatures were measured by using thermocouple probes. The probes were made from 0.05-cm (20-AWG) thermocouple grade copper-Constantan (type T) extension wire with polyvinyl chloride (PVC) covering over PVC insulation. The temperatures changed slowly enough that response was not a problem. To measure the thermal gradients, two 10-cm-diameter (4-in-diameter) class AA concrete cores were poured; each had 10 thermocouples located axially through a 19-cm (7.5-in) depth. One core was grouted into the roadway, and the other was grouted into the bridge deck at the midpoint between two beams. The cores were grouted in to form an integral part of the surfaces of the bridge deck and approachway. Air temperatures were monitored at the instrument shack, and at various points over and under the bridge. The output of all thermocouples was recorded on a 24-channel balance potentiometer. The potentiometer was connected to a timer that actuated it every hour for a period of approximately 6 min, which was long enough to record all temperatures once. Experience had shown that the values changed slowly enough that readings taken at 1-h intervals were satisfactory. There was enough chart to operate without servicing for 30 days.

Relative humidity and air temperatures over the bridge were measured on a hygrothermograph that was mounted at deck height outside the bridge parapet at midstream (Figure 1). The instrument was mounted so that it was exposed to the humidity flux off the stream. Values were recorded continuously on a 60-day folding strip chart.

Wind velocity and direction were measured 4.8 m (16 ft) above the bridge deck by a sky vane. Output from the sky vane was recorded continuously on a strip chart to measure gross wind speed and direction over the bridge.

The quantity and rate of all types of precipitation were measured by a heated precipitation gauge in 0.25-mm (0.01-in) increments. The gauge was located on the valley floor adjacent to the stream (Figure 1) and was mounted on a steel platform sufficiently high to protect it from flooding. Output from the instrument was recorded continuously on a 7-day drum chart.

The presence of surface moisture on the bridge deck was detected by using an ice detection system. The basic element of this system consists of two moisture sensors located in the bridge deck. In principle, these sensors are capable of determining whether the bridge deck is dry, wet, or frozen. The output signal from the system was recorded continuously on an event recorder.

During the work in the first winter (1969-70), it became evident that the diurnal variation of solar radiation had a major influence on the bridge and roadway surface temperatures. Therefore, a recording solar meter was added to the instrumentation at the test site beginning with the 1970-71 winter. The solar meter was installed on the roof of the instrumentation shack adjacent to the site (Figure 1). It recorded the instantaneous and total solar radiation. Data were collected once a week from a drum chart.

A 10-channel event recorder was used as an overall monitoring device on most of the other instrumentation. On it, periods of precipitation, output of the ice detection system, and periods during which the thermocouple output recorder was on were recorded. This gave a single time on which this information was recorded.

All the recorders for the various probes (with the exception of the hygrothermograph) were housed in a 1.5 by 2.4-m (5 by 8-ft) metal shack located on the berm at the western end of the approach to the bridge (Figure 1). The shack was insulated with styrofoam and was electrically heated. The recorders located in the shack measured temperature, wind, rain, and events.

TEST SITE DATA

A small amount of data was gathered from January 1970 to June 1970 primarily to test out the instrumentation. During the winter of 1970-71, complete temperature profiles for both the bridge deck and the roadway were taken. The bulk of the data taken and discussed here, however, was recorded during the winters of 1971-72 and 1972-73. During this period, the principal variables measured were bridge surface temperature, adjacent road surface temperature, ambient air temperature, hourly precipitation, and solar radiation. Data were recorded on an hourly basis. Because the amount of data was extensive, they were transcribed into an IBM card file. This final file consists of two sections. Section 1 is of 85 selected days of the 1971-72 season and represents those times when preferential freezing [bridge deck below 0°C (32°F) when adjoining roadway was not] most likely occurred. The second section consists of all the daily data taken in the 1972-73 season, a total of 165 days. Table 1 gives a summary of the days when data were taken. In Table 2, a similar summary of the days on which solar radiation data were taken is given.

Precipitation measurements were taken by using the recording rain gauge, and periods when the bridge surface was wet or icy were recorded by using the Econolite ice detection system. These were also incorporated into the data file on an event card.

The data file was used in a number of types of analyses. All these were carried out by using an IBM 370 computer at Pennsylvania State University. The format used on the data cards is such that they can be run on any large digital computer.

Initially, all of the data collected were processed and presented in the form of a series of daily temperature graphs. The principal graph is a plot of ambient air, bridge surface, and road surface temperatures versus time, starting at 1 a.m. and going to midnight of the date. A second plot on the same graph shows the solar radiation (1 kJ/m^2 = 0.024 langley). The daily graphs for the winters of 1971-72 and 1972-73, 250 in all, are available elsewhere (4).

Because periods of preferential icing require that the roadway surface temperature be above the bridge surface, this temperature difference (road-bridge) was determined at each hourly interval. An analysis of the data showed that, most of the time, road surface temperature was above that of the bridge. Figure 2 shows the three conditions under which preferential icing can occur. In this plot, the road and bridge surface temperatures are shown to follow closely parallel paths. This type of variation was frequently observed at the test site. Zones of preferential icing can occur during periods of decreasing temperature (I) and rising temperature (II) and under conditions when the temperatures are steady but around 0°C (32°F). In the case of rising and falling temperatures, the magnitudes of I and II will increase when the road-bridge temperature difference increases. For III, the greater the difference is, the more likely it is that preferential freezing will occur.

SIMULATION OF THERMAL RESPONSE OF BRIDGE DECK AND ADJACENT ROADWAY

Ideally, one would like to have a mathematical model that would, given certain weather conditions, predict the potential of accidents occurring due to preferential icing on a given bridge. The output of such a model could be a statistical probability that a given number of icing accidents per year would occur. The basic approach to the problem is to divide it into two categories: (a) response of the bridge to local weather, which will determine the probability that preferential freezing occurs, and (b) given that ice is present on the bridge, the probability that a vehicle will skid and cause an accident. In this study, effort was directed toward determining the icing probability of a given bridge based solely on data gathered on the thermal characteristic of the bridge structure and adjacent roadway and the local weather most likely to occur. For this purpose a simulation model, SIMULATION III, was developed (5).

SIMULATION III is actually two separate digital computer programs that solve the heat transfer problem existing, first, between the bridge deck and the ambient weather conditions and, second, between adjacent roadway and ambient weather conditions. The bridge deck has been treated as a plane slab of uniform thermal properties. The adjacent roadway is also treated as a slab but is assumed to consist of three layers of different material. These are the concrete roadway proper, a subbase assumed to consist largely of gravel, and a subgrade of earth. The depths of both the bridge and the layers of the roadway, along with the thermal characteristics of each layer, can be varied. This is supplied as input data. Figure 3 shows the geometry and thermal characteristics required. In each case, the heat transfer is assumed to be one-dimensional and perpendicular to the surface. In the case of the bridge deck, ambient weather boundary conditions are applied to both the upper and lower surfaces, although they need not be the same on both. For the roadway, the temperature at the bottom of the subgrade is held constant at a value considered typical of that expected at that depth.

The output of the simulation can be complete temperature profiles for both bridge and roadway at fixed-time intervals. The program can be run for any overall desired time periods. Runs have been made covering periods from 1 day to 1 month. It is anticipated that, in rating bridges, a period corresponding to the winter season (October to March) would be used.

The accuracy of the surface temperatures generated by the model is dependent on the accuracy of the weather boundary conditions applied. The boundary conditions used are time dependent and take into account the three major factors that influence the surface heat transfer. These are ambient air temperature, wind speed, and solar radiation. The values of air temperature, solar radiation, and wind speed supplied must represent those expected to be encountered over a typical winter at the bridge site.

If the thermal response of a bridge over a typical winter season is to be determined by simulation, good statistical models for the ambient air temperature, wind velocity, solar radiation, and precipitation are necessary as boundary conditions. Weather bureau records for the primary weather stations in Pennsylvania were used for this. This represents the most comprehensive collection of data available and was considered to be an adequate basis for the formulation of the required models. Data were obtained from the National Climatic Center on magnetic tape. The data covered 1961 through 1972 for the following stations: Allentown, Philadelphia, Harrisburg, Wilkes-Barre, Williamsport, Erie, and Pittsburgh. Originally, these data were on a number of different tapes that used several formats. Therefore, the data had to be processed. The processing procedure allowed the information to be compacted and put in a uniform format.

As a result, two magnetic tapes containing all the weather information were produced. The first tape, entitled WEATH 1, is a single file containing 325 480 logical records; each record is 104 characters long and represents one set of observations. On this tape, the observations are grouped by stations in ascending, chronological order. The station order is the same as the listing previously given. On the second tape, entitled WEATH F, the data are arranged into seven separate files, one for each city. This is more convenient to use when only the observations of a single station are required. This work is contained in a separate publication (6).

The influence of solar radiation is taken into account by assuming that it varies sinusoidally from sunrise to sunset. Since the period from sunrise to sunset varies in terms of the latitude of the bridge and time of year, this was taken into account. Obviously, the actual solar radiation depends on the amount of existing cloud cover. Although the final version has not been done, it is anticipated that a cloud cover model similar to the temperature model can be developed by regression analysis.

Accurately establishing the effect of wind on the surface heat transfer involves two problems. First, a model giving at least wind magnitude similar to the temperature model is needed. Second, if wind magnitude is given, the actual value of the surface film coefficient of heat transfer has to be determined. Efforts have been put into the latter and reported (7). So far, no attempt has been made to develop a statistical wind magnitude model because the wind effect was not considered to be as important as temperature and solar radiation. Additional work is required in this area.

Finally, it should be noted that the ambient temperature, solar radiation, wind, and precipitation have been treated as essentially independent quantities. This certainly is an area that requires further investigation. As proposed, the combination of models may lead occasionally to the creation of improbable weather conditions such as days of high solar radiation with precipitation or low ambient air temperatures.

METHODS OF MEASURING PREFERENTIAL ICING POTENTIAL OF A BRIDGE

Even when the response of a bridge deck and adjacent roadway to given weather conditions as well as what weather conditions most commonly occur at the bridge can be accurately determined, the question of how to best present the data remains. There are always two factors to be considered: the frequency at which the event occurs without regard to its duration and the actual duration of the event. Often the periods of icing are quite short (15 min or less), and these may be periods when no traffic occurs. The problem is which of these—frequency or duration—is more significant. Because an overall rating is desired, the accumulative hours per year of preferential icing are proposed to be used as a method of rating the response of a bridge to weather. This is not a probability, but it does seem to be a logical parameter for comparing different bridges, perhaps within a state or a region of a state, to determine the worst performers.

To determine the accumulative hours per year of preferential icing requires not only knowledge of when the bridge is below and when the roadway is above 0°C (32°F) but also information on the periods and type of precipitation that falls. Obviously, these data can be obtained on a short-term basis if sufficient instrumentation is installed on a given bridge. However, this is not always practical. A less sophisticated measure of the potential of a bridge to ice would be to consider only surface temperatures and to determine periods of preferential freezing. Preferential freezing will be defined as those periods when the bridge is below 0°C (32°F) but the roadway is not, without regard for precipitation. Again this is a useful figure for comparisons.

Data on preferential icing and freezing can be arrived at in a number of ways: (a) direct measurement of temperature and weather at the site, (b) generation of data by simulation techniques, and (c) a combination of both simulation and direct measurement. All of these techniques have been explored in various degrees, and items

Figure 1. Location of instrumentation at bridge test site on I-80.

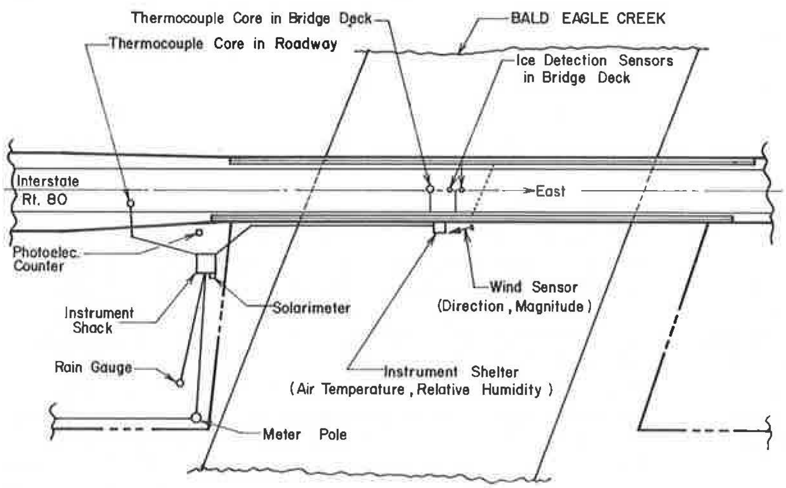


Figure 2. Zones of preferential icing.

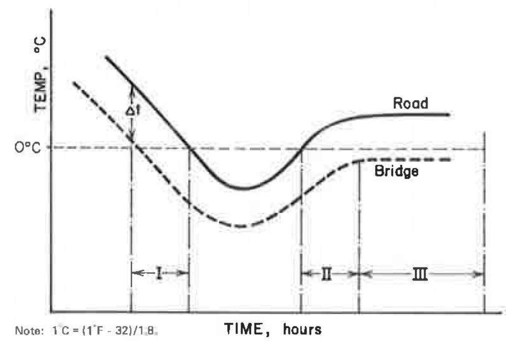


Table 1. When data from I-80 test site were taken.

Season	Month and Year	Date	Number of Days
1971-72	November 1971	9, 12, 24, 25	4
	December 1971	11 to 15, 17 to 23, 29 to 31	15
	January 1972	1 to 24	24
	February 1972	1, 7, 8, 14 to 23, 28, 29	15
	March 1972	1 to 27	27
	Total		85
1972-73	October 1972	6 to 31	26
	November 1972	1 to 30	30
	December 1972	1 to 31	31
	January 1973	1 to 31	31
	February 1973	1 to 28	28
	March 1973	1, 6 to 20, 27 to 29	19
	Total		165

Table 2. When solar radiation data from I-80 test site were taken.

Season	Month and Year	Date	Number of Days
1971-72	November 1971	9, 12, 24, 25	4
	December 1971	11 to 15, 17 to 23	12
	January 1972	5 to 8	4
	February 1972	4, 7, 8, 15 to 23, 29	13
	March 1972	1 to 27	27
	Total		60
1972-73	October 1972	25 to 31	7
	November 1972	1, 3 to 8, 10 to 14, 16 to 26, 29, 30	25
	December 1972	1 to 3	3
	January 1973	12 to 16, 18 to 28	16
	February 1973	6 to 25, 27, 28	22
	March 1973	1, 7 to 11	6
	Total		79

Table 3. Monthly frequency and accumulative hours of preferential freezing for winter of 1972-73.

Month and Year	Days	Frequency	Duration (h)	Mean (h/event)
October 1972	26	5	17	3.4
November 1972	30	22	70	3.18
December 1972	31	21	56	2.67
January 1973	31	28	66	2.36
February 1973	28	25	53	2.12
March 1973	19	5	39	7.80
Total	165		301	

Figure 3. Geometric and thermal characteristic input data to SIMULATION III.

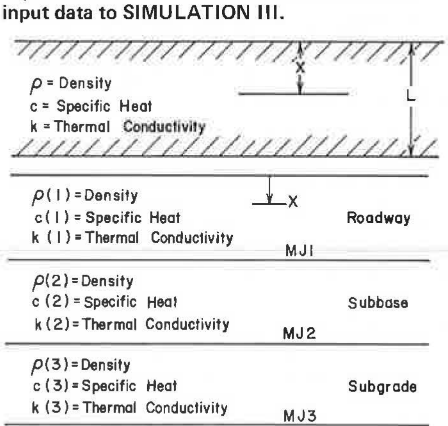


Table 4. Frequency and accumulative hours of preferential freezing at different times of day for winter of 1972-73.

Time Period	Frequency	Duration (h)	Mean (h/event)
Midnight to 4 a.m.	12	34	2.83
4 a.m. to 8 a.m.	15	45	3.0
8 a.m. to noon	33	74	2.42
Noon to 4 p.m.	16	41	2.56
4 p.m. to 8 p.m.	17	46	2.70
8 p.m. to midnight	13	61	4.69

a and b will be reported on. Each has its advantage and disadvantage.

Direct Measurement

A computer program was developed to analyze the data from the test bridge for periods of preferential freezing and icing. In Table 3, a monthly summary is given of the frequency and accumulative hours of preferential freezing for 1972-73 as an example of the program output. In the table, the mean represents the total accumulative hours divided by the frequency of preferential freezing.

Information about the time of day that preferential freezing most often occurs can also be obtained. In Table 4 such an analysis is given.

Tables 5 and 6 give preferential icing data, which were determined by comparing the periods of preferential freezing with the precipitation data. Preferential icing is a more reliable rating of a bridge, but it requires continuous measurement of precipitation.

Direct measurement of periods of preferential icing and freezing requires, at a minimum, the measurement on a common time base of three variables: bridge surface temperature, adjacent road surface temperature, and presence of precipitation. From this information, periods of preferential freezing can be measured. Periods of preferential icing can be reasonably deduced as occurring on the bridge when precipitation falls during periods of preferential freezing. The reliability of the method for determining preferential icing is limited by the instrumentation used to detect small amounts of precipitation. Also the presence of frost is very difficult to measure. In some cases, this could be a serious problem. (Preferential frost formation was never encountered at the test site.) The method also has the disadvantage of requiring the direct installation of instrumentation at the bridge and accompanying costs. Furthermore, even if data are gathered for an entire winter season at a bridge, it would be difficult to say that this was typical of its performance over an extended period. However, the simultaneous gathering and comparison of such data at a group of adjacent bridges in a given locale could possibly serve to initially identify the worst in the group.

Simulation

Data such as those taken at the test site and analyzed to obtain Tables 3 through 6 could also be obtained by determining the thermal response of a bridge deck by simulation. By knowing the thermal characteristics of a given bridge and subjecting the model to boundary conditions that represent a statistically typical winter at the bridge site, one can generate a data file similar to that obtained at the test site. Such an overall modeling procedure is shown in Figure 4.

Simulation of the periods of preferential freezing and icing has the advantage of requiring no installation of instrumentation at the bridge site. Data on the geometrical and thermal characteristics of the bridge can be obtained from the bridge specifications and perhaps one or two on-site inspections for purely local characteristics. Presumably, with the required input specifications, a large number of bridges in a given geographical region could be simulated and rated in terms of accumulative hours of preferential freezing and icing.

METHODS OF PREDICTING PREFERENTIAL ICING

The simulation model provides a possible method of forecasting preferential icing before it occurs. If, instead of a statistical weather model as input to the simulation, the actual weather forecasted for the bridge site were employed, the model should predict future bridge and road surface temperatures. In brief, throughout a winter season, the simulation model would be run essentially on a continuous basis, always receiving as input forecasted weather data and evaluating the response of the bridge to these data to predict road and bridge surface temperatures. By continually analyzing the output of the model, one could predict future periods of preferential freezing. If precipitation was forecasted for the preferential freezing periods, suitable countermeasures could be taken.

Although the method requires the use of a computer, it does have a number of advantages. First, it predicts bridge and road surface temperatures without any actual instrumentation at the bridge itself. Second, the time required for the computer to solve the response problem is very small in terms of the time scale associated with weather changes. The simulation solution could therefore be continually updated on the basis of newly received weather forecasts. Third, although the simulation as now proposed solves the heat transfer equations by numerical integration, a much simpler analog computer solution is possible. By using an analog computer, one could develop a very small unit for solving the simulation problem at reasonable cost. Last, the potential for using a single large computer to handle a number of bridges in a given locale is possible. In Figure 5, a flow diagram outlining this method is shown.

INSTRUMENT PACKAGE FOR MEASURING PREFERENTIAL FREEZING (ICING)

Observations at the test site plus the work on the simulation model indicated a clear need for some method for directly measuring periods of preferential freezing and icing on a bridge deck. This requires a continuous time record of a minimum of three variables: bridge surface temperature, adjacent road temperature, and presence of precipitation. Accumulative periods of preferential freezing and, with reasonable reliability, periods of icing can then be determined. Such an instrument to be practical should have the following characteristics: moderate cost, portability, ability to run unattended for at least a week, and ease of installation. Because no such instrument existed, a prototype was developed and subjected to limited tests as part of the project.

Figure 6a shows a schematic of the system developed. The principal element in the system is a portable strip recorder with a regulated motor drive. The recorder carries enough paper for 30 days of operation and requires a 12-Vdc source. Three channels are on the recorder; two are for temperature and one is used for event recording (in this case, for precipitation). The temperature probes are thermistors located at the end of 30.5-m (100-ft) cables. To detect precipitation, a heated moisture sensor is employed. This consists of a unit that can be pole mounted, either on the bridge or nearby, and that measures precipitation electrically. It consists of two wire grids spaced horizontally and exposed to the sky. The upper grid is heated and controlled by a thermostat that comes on at about 4.5°C (40°F). When snow or sleet falls, it melts on the upper, heated grid. When it comes in contact with the lower grid, an electrical signal is sent to the event channel of the recorder. Power for the heater grid is 12 Vdc.

The output of the unit as finally developed consists of a continuous strip chart of 30-day duration. A section of the chart produced is depicted in Figure 6b. Periods of preferential freezing (PF) and preferential icing

Table 5. Monthly frequency and accumulative hours of preferential icing for winter of 1972-73.

Month and Year	Days	Frequency	Duration (h)	Mean (h/event)
October 1972	26	5	15	3.00
November 1972	30	5	7	1.40
December 1972	31	6	13	2.17
January 1973	31	3	3	1.00
February 1973	28	2	4	2.00
March 1973	19	0	0	—
Total	165		42	

Table 6. Frequency and accumulative hours of preferential icing at different times of day for winter of 1972-73.

Time Period	Frequency	Duration (h)	Mean (h/event)
Midnight to 4 a.m.	2	2	1.0
4 a.m. to 8 a.m.	3	4	1.33
8 a.m. to noon	5	8	1.6
Noon to 4 p.m.	4	6	1.5
4 p.m. to 8 p.m.	5	11	2.2
8 p.m. to midnight	2	11	5.5

Figure 4. Simulation program for generating periods of preferential freezing and icing.

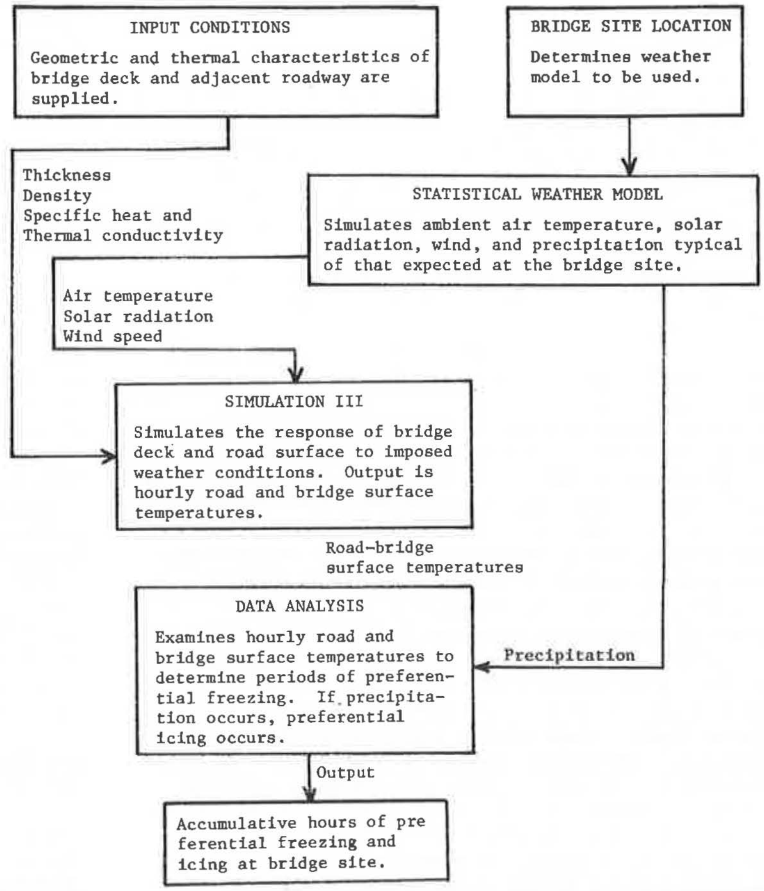


Figure 5. Use of simulation to predict periods of preferential icing.

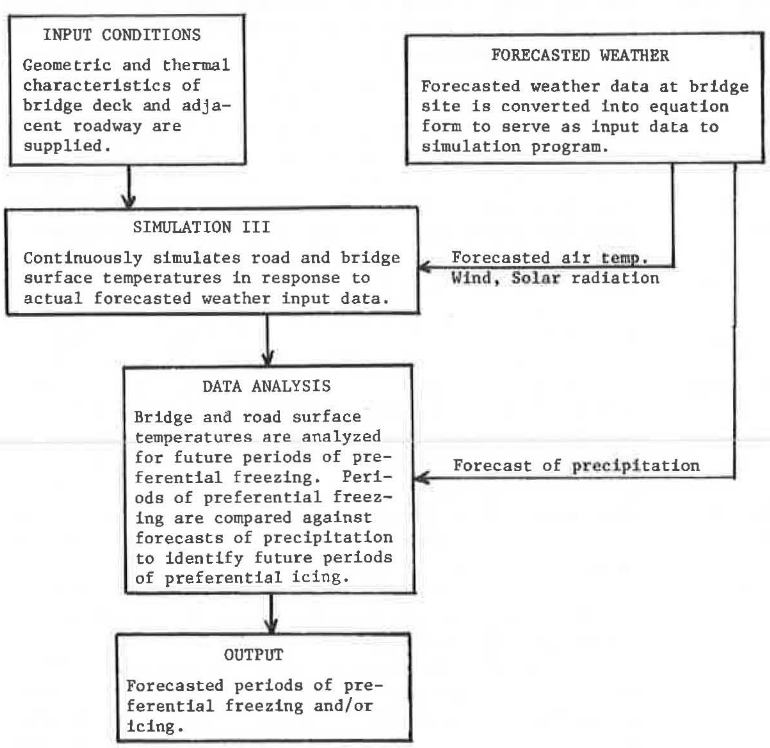
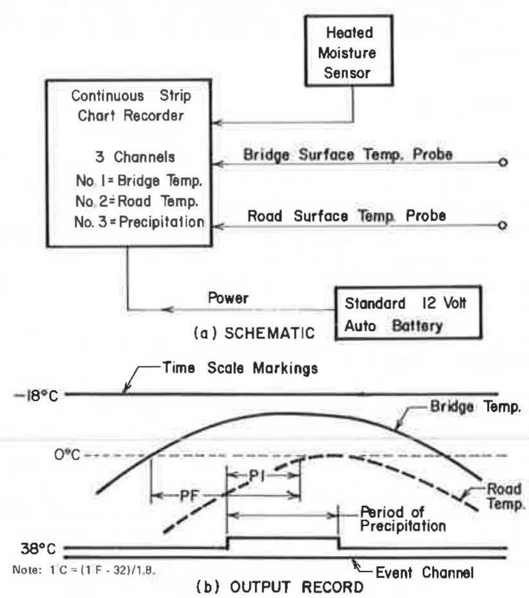


Figure 6. Instrument for measuring preferential freezing (icing).



(PI) are indicated. The completed instrument package consisted of three units: the recorder in a metal, waterproof case; the pole-mounted moisture sensor; and the 12-V battery pack. The units are of moderate weight; the battery (standard automotive) is by far the heaviest item. The cost of the unit and temperature sensors was $553. Additional costs were incurred in the purchase of the moisture sensor, battery, and necessary modifications. It is estimated that additional units could be built for approximately $1200.

SUMMARY OF RESULTS

Data File and Data Analysis

Data were collected at the test site for the winters of 1971-72 and 1972-73. These data were tabulated on IBM cards to form a permanent data file. The compilation of a data file makes possible convenient computer analysis of this information in a variety of ways. The data were analyzed to determine accumulative periods of preferential freezing and icing principally to illustrate the possible use of these parameters as a bridge rating factor.

Simulation Model

SIMULATION III, a digital computer program for determining the bridge and road surface temperatures in response to various input weather boundary conditions, was completed. A method for rating bridge decks for preferential freezing (icing) was proposed that employed the simulation model. This method consisted of applying as input boundary conditions to the simulation model (a) the geometrical and thermal characteristics of the bridge to be rated, and (b) a statistical weather pattern that represents a typical winter at the bridge site. The model will then determine the accumulative hours of preferential freezing (icing), which have been suggested as a bridge rating factor. A statistical winter temperature model for Pennsylvania was developed for use with the simulation program. Methods of developing models for wind and solar radiation were also discussed.

The potential use of the simulation model that uses actual forecast weather as a boundary condition for predicting periods of preferential freezing (icing) was discussed.

Instrument Package

A simple, inexpensive instrument package that can be installed on a bridge to measure periods of preferential freezing (icing) was developed. A prototype was tried in a field test and was found to substantially meet all the original objectives set for such an instrument.

ACKNOWLEDGMENT

This work was performed in cooperation with the Pennsylvania Department of Transportation and the Federal Highway Administration.

The opinions, findings, and conclusions expressed in this publication are mine and are not necessarily those of the Pennsylvania Department of Transportation or the Federal Highway Administration.

REFERENCES

1. T. Kuo and C. Birnie, Jr. Digital Computer Simulation of the Thermal Characteristics of a Bridge Deck (SIMULATION I). Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State Univ., University Park, TTSC Rept. 6915, Dec. 1969.
2. W. E. Meyer, C. Birnie, Jr., and D. Biss. Bridge Deck Deicing Study—Summary of Phase A. Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State Univ., University Park, TTSC Rept. 7014, Aug. 1970.
3. D. J. Biss. Bridge Deck Deicing Study—Phase B, Summary of Experimental Work at Test Site on Interstate 80. Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State Univ., University Park, TTSC Rept. 7107, Sept. 1971.
4. J. R. Hackney and C. Birnie, Jr. Bridge Deck Deicing Study—Summary of Bridge Deck and Roadway Temperatures. Automotive Research Program, Pennsylvania State Univ., University Park, Technical Memorandum 92, Jan. 1974.
5. C. Birnie, Jr., and G. Gamble. Digital Computer Simulation of the Thermal Characteristics of a Bridge Deck and Adjoining Roadway (SIMULATION III). Pennsylvania Transportation and Traffic Safety Center, Pennsylvania State Univ., University Park, TTSC Rept. 7321, Dec. 1973.
6. J. Tung. Statistical Temperature Model for Pennsylvania. Automotive Research Program, Pennsylvania State Univ., University Park, Rept. S60, Jan. 1974.
7. G. Gamble. Prediction of Preferential Bridge Icing From Statistical Weather Patterns and Thermal Simulation of Bridge Deck-Road System. Automotive Safety Research Program, Pennsylvania State Univ., University Park, Rept. S59, Dec. 1973.