Insulation of Concrete Bridge Decks

W. A. Mossbarger Jr.
Kentucky Highway Materials Research Laboratory
MEMORANDUM

TO: W. B. Drake, Assistant State Highway Engineer
Chairman, Kentucky Highway Research Committee

SUBJECT: Research Report; "Insulation of Concrete Bridge Decks;" KYP-64-2

The attached report concludes a phase of study pertaining to the moderation of some insidious effects of freezing temperatures. In this study, we were especially concerned with the possibilities of preventing premature icing on bridges. Some rather marvelous insulating materials have been developed by industry during the past several years; perhaps the most familiar one is styrofoam which is usually a pre-molded product. The advantages of a sprayed-on, hardening foam are evident from the standpoint of coating structural shapes. A type of urethane resin having this unique method of application was developed recently and has been applied experimentally to bridges in several states to insulate underneath surfaces— that is, in an effort to hold indigenous heat and thus to delay freezing. The insulation, for our study, was contributed and applied by Dow Chemical Company in October of 1962.

Our temperature records indicate that the insulation delays freezing for a nominal period of time but that it also delays warming and thawing for about an equivalent time. There seems to be no possibility of preventing night-time icing by just insulating the underneath surfaces; this is due to the fact that the loss of heat through the upper surfaces becomes the controlling factor. Moreover, the deck structure is thermally isolated from a replenishing source or reservoir of heat; and, of course, there is no regenerative supply of heat to balance the losses. At this stage, it appears that a generative supply of heat would be an essential adjunct to insulation, and vice versa.
We are not planning any additional measurements on the bridge at this time; the insulation and wiring are being left intact since it does not appear to impair the bridge in any way. Although we are concluding the experiment with the submission of the report, we are not necessarily dismissing the problem from future consideration or study. The Division of Bridges is currently considering providing deck heating on some steep bridge ramps to be constructed on the Riverside Expressway in Louisville, I 64-2(20)3. Some thought was given to the use of box-girder-type construction and internal cavity heating, but evidently this approach was rejected in favor of more conventional types of designs. Heretofore, deck heating has been principally a surge input for melting snow and ice; heating cables have been installed near the top surface; the duration of the input may or may not be long enough to warm the underneath surface sufficiently to cause a significant loss or waste of heat in that direction. A significant waste of heat in that way could be thus counteracted by insulation.

Inasmuch as this is an informational type of report, it requires no specific action or response. Copies will be issued within the Department, and courtesy copies will be forwarded to the Bureau of Public Roads and to Dow Chemical Company. Comments and suggestions are invited.

Respectfully submitted,

Jas. H. Havens
Director of Research
Secretary, Kentucky Highway Research Committee

JHH:jsm

Attachment

cc: Research Committee
A. O. Neiser
R. O. Beauchamp
T. J. Hopgood
Russell Johnson
Guy F. Vansant, Jr.
Research Report

INSULATION OF CONCRETE BRIDGE DECKS
(KYP-64-2)

by

W. A. Mossbarger, Jr.
Research Engineer

Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

132 Graham Ave.
Lexington, Kentucky

July, 1965
INTRODUCTION

The complete elimination of snow and ice from principal highways would dispel the last real impediment from winter-time driving. It is not possible, of course, to prevent rain and snow from falling onto the roadway nor to heat endless miles of roads in order to keep them snow- and ice-free. Applications of de-icing salts during the onset or following icy weather has become a standard practice since 1948, and the quantity of salt used for this purpose has increased steadily each successive year. At the present time, salting provides the most expediently satisfactory treatment for icing conditions. Bridges sometimes pose a rather special problem inasmuch as they are more exposed and tend to ice prematurely—that is, before the condition prevails elsewhere or throughout the roadway. This poses a rather serious hazard for unwary motorists who are traveling confidently upon a wet, pavement and who suddenly find themselves confronted with a dangerous, icy, or frosty bridge. Warning signs and caution lights are sometimes installed at critical locations. Because bridges tend to respond more readily to changes in air temperature, they experience more severe temperatures than pavements resting directly on earth and appear to suffer commensurately greater damage from winter freezes.

In this study, an insulating material was applied experimentally to the underside of a bridge to retain or delay the escape of heat
from the deck structure whenever air temperatures fell below freezing. There was no real hope of preventing freezing and icing of the bridge except on rare occasions when the air temperature might drop very briefly below 32°F. The chief incentive was to delay icing and frosting of bridges sufficiently to coincide with or follow the development of icing elsewhere on the roadway. It was presumed, of course, that a driver who recognizes hazardous conditions on the roadway would be equally wary of bridges.

Whereas pavements resting on the ground may draw heat from the earth—visualized here as a vast heat source when air temperatures are lower than ground temperatures and as a heat storage reservoir when the converse of these conditions exist—, bridges are almost completely isolated from a replenishing source of heat; and warming arises almost wholly from the radiant heat of the sun and warming of the surrounding air. Such logic further provides a foreboding thought; whereas pavements benefit from the warmth of the ground—tending to resist freezing and also to hasten recovery—, insulation on bridges might act to delay warming trends as well as cooling trends. Therefore, the icing hazard may persist on insulated bridges after it has disappeared elsewhere. Hence, any early benefits derived from the delay of icing might be completely nullified by this aftermath unless the bridge
and roadway were salted or otherwise de-iced in the meantime.

Temperatures of strategic locations in the insulated and un-insulated portions of the bridge and in the pavement near by were recorded during two winters and part of the intervening summer. The data were analyzed only to the extent of determining significant trends and not in classical, thermodynamic terms. The results indicate that the insulation produces a time-lag of one to two hours in the response of the deck to ambient temperatures of the surrounding air. In general, winter temperatures of the nearby pavement tended to be warmer than bridge temperatures. This is attributed largely to the flow of heat from the ground under the pavement.

It seems logical to assume that the major loss of heat from the pavement and the insulated portion of the bridge was through the top surfaces to the cold air above. There was no opportunity for the bridge to draw heat from any source when it was surrounded by frigid air; however, had there been an artificial means of generating heat in internally, the insulating might have proven to be effective in preventing costly and needless losses.

DESCRIPTION OF TEST INSTALLATION

The bridge selected for study was a three-span reinforced concrete overpass (M. P. No.: 37-905-HG8) located at Johnson Road, east-bound lane of Interstate Route 64, Franklin County, Kentucky. Figure 1 shows a side view of the bridge; Figure 2 shows a cross-section view and the locations of thermocouple junctions. The hatched area indicates the portion of the bridge which was coated with insulation.

The thermocouples were installed by drilling 3/4-inch diameter holes to the desired depths, attaching the thermocouples and filling the holes with a mixture of epoxy resin and sand. Thermocouples 1, 2, 3, and 4 were installed 1/2 inch below the top surface. Thermocouple 6 was installed 3 1/2 inches below the top surface; whereas thermocouples 8 and 9 were installed 7 inches below the top surface. Thermocouples 5 and 7 were installed 1/2 inch above the bottom surface. The ambient air temperature was recorded by thermocouple 12 which was located on a mast attached to the side of the bridge. The location of thermocouples 10, 11, 13, and 14 is noted in Figure 2. The thermocouple leads were attached to a 12-channel potentiometer recorder which was located in a heated compartment beneath the bridge (Figure 3). The temperature of each thermocouple was recorded at 12-minute intervals. Initially, the temperature of thermocouples 1 through 12 was monitored; however, later it was decided to discontinue recording from
Figure 1. Test Bridge. Eastbound Johnson Road Overpass, Interstate Route 64, Franklin County, Kentucky.
NOTE: THE FOLLOWING DESCRIPTIONS GIVE THE LOCATION OF THERMOCOUPLES NOT ON THE TEST BRIDGE

NO. 10 - APPROACH SLAB, TEST BRIDGE, UPPER SURFACE OF PAVEMENT.

NO. 11 - EXIT SLAB, TEST BRIDGE, UPPER SURFACE OF PAVEMENT.

NO. 13 - EXIT SLAB, TEST BRIDGE, 10 INCHES BELOW UPPER SURFACE OF PAVEMENT (TOP OF DENSE-GRADED AGGREGATE BASE).

NO. 14 - EXIT SLAB, TEST BRIDGE, 17 INCHES BELOW UPPER SURFACE OF PAVEMENT (TOP OF SUBGRADE).

Figure 2. Diagram Showing Locations of Thermocouple Junctions and Urethane Foam Insulation.
Figure 3. Heated Compartment Containing Potentiometer Recorder.
thermocouples 6 and 10 and to attach thermocouples 13 and 14 to the vacated channels.

The urethane foam insulation was supplied and applied by the Dow Chemical Company and consisted of a two component liquid which was sprayed on the structure. After spraying, an exothermic reaction occurred between the two components; expansion of a gas formed a finished material consisting of a rigid, bloated, cellular structure. The material was sprayed in sufficient quantity to produce a final minimum thickness of one inch. Figure 4 shows the spraying operation and Figure 5 shows a view of the underside of the bridge after spraying was completed. Figures 6 and 7 give some idea of the finished texture of the foam. The light area in Figure 7 represents a layer of foam approximately one inch thick.
Figure 4. Application of Urethane Foam.

Figure 5. View of Bridge after Spraying.
Figure 6. Close-up View Indicating Finished Texture of Foam.

Figure 7. Close-up Showing Layer of Foam Approximately One Inch Thick.
RESULTS

Temperatures were recorded during two successive winter seasons; the first season extending from November 10, 1962 through March 22, 1963 and the second from November 10, 1963 through March 22, 1964. Due to equipment failure, temperatures were not recorded on the following days during these periods: 1962-63 season--Nov. 16, Dec. 6, 7, 17-29, Jan. 7-9, 11-18; 1963-64 season--Jan. 2, Feb. 12, March 4 and 5.

Although the temperature of each thermocouple was recorded at approximately 12-minute intervals, it was not feasible to analyse the data using all points recorded. Instead, hourly values were tabulated from the chart recordings, punched on computer data cards, and processed by using an IBM 7040 computer. All of the processed data are presented in Appendix A. It is to be noted there that the last nine columns of data for each day contain weather data from the U. S. Department of Commerce, Weather Bureau, Blue Grass Field, Lexington, Kentucky. This weather station was located approximately 20 miles from the test site. Table 1 contains a monthly weather summary from Blue Grass Field giving the precipitation, prevailing wind direction, and cloud cover for the months during which the study was conducted.

The temperature chosen to represent the point at which
## TABLE 1
MONTHLY WEATHER SUMMARY
LEXINGTON, KENTUCKY

<table>
<thead>
<tr>
<th>Month and Year</th>
<th>Total Inches (Water Equivalent)</th>
<th>Greatest in 24 hrs.</th>
<th>Date</th>
<th>Snow, Sleet</th>
<th>Precipitation</th>
<th>Prevailing Wind Direction</th>
<th>Cloud Cover (No. of Days)</th>
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<tr>
<td>Nov, 1962</td>
<td>3.92</td>
<td>1.95</td>
<td>9-10</td>
<td>T</td>
<td>T</td>
<td>18+</td>
<td>ENE</td>
</tr>
<tr>
<td>Dec, 1962</td>
<td>2.36</td>
<td>1.09</td>
<td>20-21</td>
<td>2.4</td>
<td>0.1</td>
<td>14+</td>
<td>WSW</td>
</tr>
<tr>
<td>Jan, 1963</td>
<td>1.47</td>
<td>0.68</td>
<td>10-11</td>
<td>6.8</td>
<td>4.4</td>
<td>23</td>
<td>SSW</td>
</tr>
<tr>
<td>Feb, 1963</td>
<td>1.81</td>
<td>0.56</td>
<td>10-11</td>
<td>8.2</td>
<td>2.2</td>
<td>19</td>
<td>S</td>
</tr>
<tr>
<td>Mar, 1963</td>
<td>6.82</td>
<td>1.87</td>
<td>4-5</td>
<td>T</td>
<td>T</td>
<td>21+</td>
<td>SSW</td>
</tr>
</tbody>
</table>

| Nov, 1963      | 1.81                            | 0.82                | 28-29| 1.0         | 1.0           | 29                       | SSW                      | 8 4 18                    |
| Dec, 1963      | 0.81                            | 0.28                | 8-9  | 8.2         | 5.4           | 22-23                    | WNW                      | 9 11 11                   |
| Jan, 1964      | 2.83                            | 0.76                | 1    | 10.8        | 6.4           | 31-1                     | 20                      | 14 6 11                   |
| Feb, 1964      | 2.52                            | 0.77                | 5-6  | 12.0        | 6.1           | 10                       | 30                      | 10 5 14                   |
| Mar, 1964      | 10.06                           | 3.54                | 4    | 0.3         | 0.3           | 29                       | 20                      | 5 9 17                    |

Note: + = Also on earlier date.
T = Trace, an amount too small to measure.
precipitation on the bridge deck would freeze was 32°F. If the
temperature was greater than 32°F., it was assumed that a thawing
condition existed; whereas, if the temperature was less than or equal
to 32°F., a freezing condition was assumed. Perhaps this does not
precisely represent actual conditions*; however, it suffices as a
criterion since the primary concern is a relative comparison of
results between thermocouples.

The average daily temperature of each thermocouple was deter-
mined and the difference between the average and 32°F. calculated.
By accumulating this difference from day-to-day, an over-all trend
in temperature behavior was derived. Figures 8 through 15 show
a graphical representation of this result--the vertical axis being
the accumulated temperature difference and the horizontal axis being
days of the month. Each figure contains the results of different
groupings of six thermocouples. It is to be noted that all groups
contain the results from thermocouples 11 and 12 since these two
serve as more-or-less reference thermocouples. The days for
which data were missing were ignored in order to "bridge" the
time gap and provide a continuous plot. A rise in the accumulated
temperature difference curve indicates a warming trend whereas a

Physical Research Project No. 23, Bureau of Physical Research
New York State Department of Public Works, 1964.
Figure 8. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 1, 2, 3, 4, 11, and 12 for 1962-63 Season.
Figure 9. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 1, 2, 3, 4, 11, and 12 for 1963-64 Season.
Figure 10. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 5, 7, 8, 9, 11, and 12 for 1962-63 Season.
Figure 11. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 5, 7, 8, 9, 11, and 12 for 1963-64 Season.
Figure 12. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 3, 4, 8, 9, 11, and 12 for 1962-63 Season.
Figure 13. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 3, 4, 8, 9, 11, and 12 for 1963-64 Season.
Figure 14. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12 for 1962-63 Season.
Figure 15. Day-to-Day Accumulation of Difference between Average Daily Temperature and 32°F. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12 for 1963-64 Season.
drop indicates a cooling trend.

The maximum and minimum daily temperatures were also found for each thermocouple and plotted as shown in Figures 16 through 23. These curves give an indication of the temperature differential at each point and show the severity of daily temperatures.

Table 2 contains a summary of results for each season showing the per cent of time the temperature was greater than 32°F., per cent of time the temperature was less than or equal to 32°F., number of freeze-thaw cycles, and the average length of a freeze-thaw cycle. A freeze-thaw cycle was considered to occur when the temperature fell to 32°F. or below and then rose above 32°F. The average length of a freeze-thaw cycle was determined by dividing the number of freeze-thaw cycles occurring during a season by the amount of time the temperature was less than or equal to 32°F.

Results are not presented (except in Appendix A) for thermocouples 6, 10, 13, and 14 because only partial data are available for each season and therefore a comparison with the other thermocouples, using the techniques described above, would be meaningless.
Figure 16. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 1, 2, 3, 4, 11, and 12 for 1962-63 Season.
Figure 17. Maximum and minimum Daily Temperatures. Comparison of Thermocouples 1, 2, 3, 4, 11, and 12 for 1963-64 Season.
Figure 18. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 5, 7, 8, 9, 11, and 12 for 1962-63 Season.
Figure 19. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 5, 7, 8, 9, 11, and 12 for 1963-64 Season.
Figure 20. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 3, 4, 8, 9, 11, and 12 for 1962-63 Season.
Figure 21. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 3, 4, 8, 9, 11, and 12 for 1963-64 Season.
Figure 22. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12 for 1962-63 Season.
Figure 23. Maximum and Minimum Daily Temperatures. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12 for 1963-64 Season.
TABLE 2

SUMMARY OF RESULTS

<table>
<thead>
<tr>
<th>Thermo-Couple No.</th>
<th>Per Cent of Time Temp. &gt; 32°F</th>
<th>Per Cent of Time Temp. &lt; 32°F</th>
<th>No. of F-T Cycles</th>
<th>Avg. Length of F-T Cycles (hrs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>64 68</td>
<td>36 32</td>
<td>48 68</td>
<td>19 14</td>
</tr>
<tr>
<td>T2</td>
<td>66 72</td>
<td>34 28</td>
<td>46 66</td>
<td>19 13</td>
</tr>
<tr>
<td>T3</td>
<td>67 75</td>
<td>33 25</td>
<td>44 58</td>
<td>19 13</td>
</tr>
<tr>
<td>T4</td>
<td>66 73</td>
<td>34 27</td>
<td>44 58</td>
<td>20 15</td>
</tr>
<tr>
<td>T5</td>
<td>66 74</td>
<td>34 26</td>
<td>27 44</td>
<td>32 19</td>
</tr>
<tr>
<td>T7</td>
<td>69 76</td>
<td>31 24</td>
<td>28 44</td>
<td>28 17</td>
</tr>
<tr>
<td>T8</td>
<td>70 81</td>
<td>30 19</td>
<td>22 22</td>
<td>34 27</td>
</tr>
<tr>
<td>T9</td>
<td>70 80</td>
<td>30 20</td>
<td>22 24</td>
<td>35 27</td>
</tr>
<tr>
<td>T11</td>
<td>71 81</td>
<td>29 19</td>
<td>40 54</td>
<td>19 11</td>
</tr>
<tr>
<td>T12</td>
<td>62 70</td>
<td>38 30</td>
<td>46 69</td>
<td>21 14</td>
</tr>
</tbody>
</table>
DISCUSSION OF RESULTS

Due to the large amount of data gathered and presented, the grouping of thermocouples, as shown in Figures 8 through 23, was done in an effort to provide some form of organization and thereby avoid unnecessary confusion and repetition in the discussion and comparison of results. With this in mind, the discussion to follow will be confined to a comparison of results obtained from the thermocouples within each of the four groups.

Comparison of Thermocouples 1, 2, 3, 4, 11, and 12

Referring to Figure 2, it is seen that this grouping consists of surface thermocouples—thermocouple 1 being located over un-insulated deck, thermocouple 2 over insulated deck, thermocouple 3 over an un-insulated girder, and thermocouple 4 over an insulated girder. It is evident from Figures 8 and 9 that the temperature of the approach slab was consistently higher than the surface temperature of the bridge at all four locations. During the 1962-63 season, thermocouples 2, 3, and 4 exhibited similar accumulated temperature trends which were somewhat higher than that exhibited by thermocouple 1. During the 1963-64 season, the two thermocouples located over insulated portions showed slightly lower trends than the one located over the un-insulated girder. It is interesting to note that during this season thermocouples 1 and 12 portrayed accumulated temperature differences which were almost identical until the latter...
portion of the season.

Figures 16 and 17 indicate that the lowest minimum temperatures were generally recorded by thermocouples 1, 2, and, of course, 12. As a rule, the highest maximum and minimum temperatures were recorded in the approach slab, however occasionally thermocouples 1 and 2 showed higher maximum temperatures. Thermocouples 3 and 4 exhibited essentially the same maximum and minimum temperatures with the values lying between the extremes mentioned above.

The results in Table 2 indicate very little difference in the thermal behavior of the surface located over insulated and uninsulated portions of the bridge deck. Comparing thermocouples 1 and 2, it is seen that the per cent of time the temperature was less than or equal to $32^\circ F$. differed by a maximum of 4% in 1963-64, the number of freeze-thaw cycles differed by two cycles during both seasons, and the average length of freeze-thaw cycles were identical during the 1962-63 season and differed by one hour during the 1963-64 season. Similar results may be observed in comparing thermocouples 3 and 4. In comparing all four thermocouples, it is seen that T3 and T4, located over the girders, were subjected to a fewer number of freeze-thaw cycles, however the average length of a freeze-thaw cycle was approximately the same as for T1 and T2 during the 1962-63 season--with a maximum difference of two hours being observed during the 1963-64 season. The approach
slab was in a frozen condition a smaller per cent of the time and was subjected to a fewer number of freeze-thaw cycles during each season. The average length of a freeze-thaw cycle in the approach slab was the same in 1962-63 as it was for the other surface thermocouples, whereas it was appreciably lower in 1963-64. The results for thermocouple 12 are practically identical with thermocouple 1 except that the average length of a freeze-thaw cycle was two hours longer during the 1962-63 season.

Comparison of Thermocouples 5, 7, 8, 9, 11, and 12

This group consists of thermocouples located on the underside of the bridge (see Figure 2). In Figure 10, it is seen that the trend in the accumulated temperature difference is very similar for thermocouples 5, 7, 8, 9, and 12 up to January 19; then a rapid drop in the ambient air curve occurs along with a separation of the T8 and T9 curves. However, the T5 and T7 curves remain together until approximately February 6 where a distinct separation occurs. Thereafter, the T7, T8, and T9 curves tend to merge and do completely merge toward the end of the season. Figure 11 indicates a similarity in thermocouples 5, 7, and 9 for approximately half of the season, however the curves tend to diverge toward the end of the season. Of the thermocouples located on the bridge, T5 generally exhibited the coldest trend during both seasons. The warmest trend was exhibited by T9 during the 1962-63 season and
The maximum-minimum temperature curves (Figures 18 and 19) show similarity in thermocouples 5 and 7 and thermocouples 8 and 9. The temperature differential, indicated by the difference between the maximum temperature and the minimum temperature, is definitely much smaller for T8 and T9 than it is for any of the other thermocouples in the group.

Comparing the results in Table 2, one sees that T5 and T7 experienced the greatest number of freeze-thaw cycles, whereas the average length of each cycle was shorter. However, the average length of cycle for all four thermocouples was longer than that experienced by thermocouples 11 and 12.

Comparison of Thermocouples 3, 4, 8, 9, 11, and 12

This grouping is included for the purpose of focusing attention on a comparison of thermocouple 3 with 8 and 4 with 9 since each of these pairs are at identical locations--over girders--however at different depths.

Figure 12 shows practically identical results for all four thermocouples. The largest deviation appears to occur near mid-season at a transition point from a downward trend to an upward trend. Figure 13 indicates similarity between the thermocouples in each pair--with the surface thermocouples exhibiting slightly lower values throughout the season. It is to be noted that the pair located
over the un-insulated girder showed higher values for the majority of the season.

The fluctuation between the maximum and minimum temperature (Figures 20 and 21) was much greater for the two surface thermocouples than it was for the two located at the greater depth. It is interesting to note also that the temperature differential at the location of thermocouples 8 and 9 was much smaller than that experienced in the surface of the approach slab.

A comparison of the results in Table 2 shows that each of the surface thermocouples (T3 and T4) were subjected to a larger number of freeze-thaw cycles than T8 or T9, however the average length of a cycle was much shorter.

Comparison of Thermocouples 1, 2, 5, 7, 11, and 12

Referring to Figure 2, this group is included for the purpose of comparing the pair consisting of T1 and T5 with the pair consisting of T2 and T7.

Figures 14 and 15 indicate a general trend of slightly lower accumulated temperature differences in the un-insulated portion of the deck. During the early part of each season, the accumulated temperature difference is higher for the two thermocouples located on the underside of the deck, however toward the latter part of each season, the accumulated temperature difference for both thermocouples (T2 and T7) located in insulated portions exceeded that
indicated by the two located in un-insulated portions (T1 and T5).

Figures 22 and 23 show very similar maximum and minimum temperature curves for all the thermocouples in this group. Of course the two surface thermocouples (and T12) generally showed the lowest minimum temperature values.

Table 2 shows, as before, that the surface thermocouples were subjected to more freeze-thaw cycles, (however of shorter duration) than those located on the underside of the bridge.

Hourly temperatures are plotted in Figures 24 and 25 to show the hourly variation for a typical 24-hour winter period and a winter day when the temperature hovered near 32°F. Both of these plots indicate surface temperatures in the deck over both insulated and un-insulated sections which were generally as low as the ambient air temperature and in some instances even lower.* Focusing attention on the line indicating 32°F, it is seen that a time lag for both freezing and thawing exists for thermocouples located over insulated sections. This appears to be a paradox since delays in thawing can produce hazardous conditions as well as premature freezing.


Figure 24. Hourly Temperatures Recorded During a Typical 24-Hour Winter Period. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12.
Figure 25. Hourly Temperatures Recorded During a Winter Day for Which the Temperature Remained Near 32°F. Comparison of Thermocouples 1, 2, 5, 7, 11, and 12.
Figure 26 shows hourly temperatures recorded by thermocouples 1, 2, 5, and 7 during a typical summer day. (Temperatures were recorded for one week during the month of August, 1963.) This is included as a result of some concern being expressed about the possibility of increased thermal stresses occurring during the summer season as a result of the insulation causing higher temperature differentials between the top and bottom of the deck. However, Figure 26 indicates that the insulated portion of the deck did experience somewhat higher temperatures, but the maximum temperature differential between the top and the bottom was approximately the same for both the insulated and un-insulated portions.
Figure 26. Hourly Temperatures Recorded During a Typical Summer Day. Comparison of Thermocouples 1, 2, 5, and 7.
CONCLUSIONS

In general, the temperature trend, as indicated by the accumulated temperature difference, was slightly higher for the thermocouples located over the insulated portions of the bridge deck between girders. However, the converse was found to be true of the thermocouples located over girders. This indicates that the greater concrete mass, by serving as a partial heat reservoir, perhaps has as much, or even more, influence on the temperature than the urethane insulation.

The accumulated temperature difference of the approach slab was always appreciably higher than that indicated by any of the thermocouples located on the bridge. In fact, the difference was large enough in most cases to indicate that the relative benefit from the urethane insulation was negligible in this respect.

The maximum and minimum temperatures appeared to be dependent upon the location of the thermocouples rather than the insulating qualities of the urethane foam. For example, the surface thermocouples generally exhibited both the highest maximum and lowest minimum temperatures; and the thermocouples located over girders showed lower maximum and higher minimum temperatures than those located between girders. Also, the thermocouples located over girders indicated smaller temperature differentials than the others. This, again, indicates the influence of the greater mass of
concrete.

The per cent of time the temperature was less than or equal to $32^\circ F$. indicating the potential for icing was the same in some instances and differed only slightly in others when comparing insulated with un-insulated portions of the deck. The surface temperature of the approach slab, during both seasons, was less than or equal to $32^\circ F$. a smaller per cent of the time than any of the surface temperatures measured on the bridge deck.

There appeared to be no difference in the number of freeze-thaw cycles experienced as a result of the insulation. Comparable locations over insulated and un-insulated portions showed essentially the same number of cycles and the same average length of cycle. All locations in the surface of the deck experienced a larger number of freeze-thaw cycles which were either of the same or longer average duration than the approach slab.

Time delays in freezing as a result of the insulation were of insufficient duration and appeared to be offset by delays of equal duration in thawing.

The foregoing indicates that little, if any, benefit was received as a result of the urethane foam insulation. The bridge deck still exhibited a greater potential for freezing temperatures than the approach slab, and the decrease in the number of freeze-thaw cycles as a result of the insulation was negligible.
APPENDIX A
TEMPERATURE DATA

Legend

HR = Hour of day (1st hour corresponds to 1 A.M.)
MO = Month of year
DA = Day of month
Y = Year (2 indicates 1962, 3 indicates 1963, and 4 indicates 1964)
T1, T2, T3, etc. = Temperature of each thermocouple (°F)
CV = Sky cover (tenths)
SCON = Sky condition (See Note 2)
CEL = Ceiling (hnds. of ft.)
WEATHR = See code table for weather below
TDB = Dry bulb temperature (°F)
TWB = Wet bulb temperature (°F)
HUM = Relative humidity (%)
WDI = Wind direction
WS = Wind speed (Knots)
SUM TEMP = Sum of hourly temperatures
AVG TEMP = Average temperature = SUM TEMP/24
AVG TEMP = 32 = Difference between average temperature and 32°F
MAX TEMP = Maximum temperature
MIN TEMP = Minimum temperature
FREEZING = Number of hours temperature is less than or equal to 32°F
THAWING = Number of hours temperature is greater than 32°F
F-T CYCLE = Number of times temperature crosses 32°F level.
Number of freeze-thaw cycles = F-T CYCLE/2
ACC TEMP = Day-to-day accumulation of "AVG TEMP"
ACC FREZ = Day-to-day accumulation of "FREEZING"
ACC THAW = Day-to-day accumulation of "THAWING"
ACC F-T = Day-to-day accumulation of "F-T CYCLE"

Note 1: The quantity, -0, indicates a temperature value was not available; a blank was encountered on input data card.

Note 2: Numbers under sky condition represent covering of cloud layers in ascending order according to the following code:
1 = Thin scattered
2 = Scattered
4 = Thin broken
5 = Broken
7 = Thin overcast
8 = Overcast
x = Obscuration
- = Partial obscuration

A-1
## Code Table for Weather

<table>
<thead>
<tr>
<th>CODE NO.</th>
<th>COLUMN HEADED BY:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
</tr>
<tr>
<td>1</td>
<td>Thunder</td>
</tr>
<tr>
<td>2</td>
<td>Heavy Thunder</td>
</tr>
<tr>
<td>3</td>
<td>Tornado</td>
</tr>
<tr>
<td>4</td>
<td>Light Rain</td>
</tr>
<tr>
<td>5</td>
<td>Squall</td>
</tr>
<tr>
<td>6</td>
<td>Heavy Rain</td>
</tr>
<tr>
<td>7</td>
<td>Light Freezing Rain</td>
</tr>
<tr>
<td>8</td>
<td>Moderate Freezing Rain</td>
</tr>
<tr>
<td>9</td>
<td>Heavy Freezing Rain</td>
</tr>
</tbody>
</table>