Effect of Insulating the Underside Of a Bridge Deck

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This study was designed to determine the merit of insulating the underside of a bridge deck in (a) preventing formation of ice or frost on a bridge deck before such formation on the abutting pavement, and (b) decreasing the number of freeze-thaw cycles and salt applications. Information is presented on application and bonding performance of the urethane foam, instrumentation, and collection and analysis of data for the periods of December 1, 1961 to April 29, 1962; and October 1, 1962 to November 30, 1962. Present data are considered insufficient to establish the merit of the insulation, but indicate that the effects tend to be beneficial.

• IN AUGUST 1961, the Bureau of Public Roads and the Missouri State Highway Commission approved an investigation designed to determine the effect of insulating the underside of a bridge deck. The outline of this investigation was as follows:

> In geographical areas subject to freezing temperatures it is well known to highway maintenance engineers that, under certain ambient weather conditions, there is a tendency for ice to form on bridge decks sometime prior to its formation on adjacent pavement. To traffic traveling on ice-free pavement this presents an oftentimes unexpected hazard. It also results in the number of applications of de-icing agents being considerably greater for bridge decks than for the adjoining pavement, which may be one of the factors in the earlier and more severe deterioration of the concrete in the decks as compared with that in the abutting pavement.
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> It is desired to investigate the merit of insulating the underside of a bridge deck for:
>
> a. Preventing formation of ice on the bridge deck prior to such formation on the abutting pavement.
>
> b. Decreasing the number of freeze-thaw cycles and salt applications per year.
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> To carry out the investigation it is proposed to insulate the underside of the deck of one of twin bridges, Number A-153, Route I-70, Cooper County, with a 3/4" thickness of urethane foam. Comparison of temperatures attained by, ice formation on, and deck deterioration occurring will be made between the insulated deck and the deck of the uninsulated twin bridge.
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> Prior to application of the insulation, a pair of 10.00 ohm copper temperature coils will be installed in the deck, one being 1/4" below the upper surface and the other 1/4" above the bottom surface. Another pair of the coils will be similarly installed in the deck of the uninsulated twin bridge. Still another pair will be installed in the pave-

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ment approach slab, and a single coil will be rigged so as to sense the ambient air temperature.

The seven above listed temperature coils will be connected to an eight-point Leeds and Northrup Model S resistance-type temperature recorder (the eighth point will be attached to a zero-point check coil). The chart paper will have a range of -25° to 120°F. and a speed of four inches per hour. This instrument will measure and record the temperature at each point once every eight minutes, and provide a continuous printed record for as long as is desired.

From this record the following information may be obtained:

1. The temperature-differential between:
   a. The upper surface of the insulated deck, the uninsulated deck, and the pavement;
   b. Ditto for the bottom surface;
   c. The top and bottom surfaces of the three types of slab.
2. The time-lag between attainment of freezing temperature by each of the three types of slab;
3. The time-lag between attainment of thawing temperature by each of the three types of slab;
4. The number of freeze-thaw cycles undergone by each of the three types of slab.

In addition to the above information, it is proposed to:

1. Record the number of applications (and rate of each) of salt to the three types of slab;
2. During periods of decreasing temperatures, observe any differences in time of occurrence of icing on the three slabs; and also observe differences in time of melting;
3. Analyze three cores from each slab for mix composition, air content, and air-bubble size-distribution;
4. Make, and record in detail, semi-annual surveys of each slab for the time of appearance and the extent of any deterioration.

Finally, it is proposed to study the data and produce a progress report after each winter of exposure, and a final report when the latest records and observations seem no longer to be producing additional information. It is estimated that this point will be reached in three years.

The locations of all temperature coils are shown in Figure 1. The temperature coils were calibrated to 10.00 ohms at 77 F. All lead wires between the temperature coils and the recorder consisted of three-wire, solid copper conductor, thermostatic wire which provided temperature compensation of the leads. At the proposed locations for the temperature coils, the bridge decks were drilled with a 4-in. diamond bit, and the approach slab was drilled with a 6-in. steel shot drill. The coils were placed in fresh concrete 1/4 in. from the surfaces where temperatures were to be recorded, except in the insulated deck where the coil over the I-beam was placed at the same depth from the top surface as the bottom coil between the I-beams.

The coil over the I-beam in the bottom of the insulated deck was installed to determine if the half-depth insulated I-beam would affect the temperature of the concrete above it. As this coil was not included in the original outline, it could not be connected to the eight-point recorder unless it was substituted for another. Initially, it was hoped that the coil could be substituted for the zero-point check coil. However, inability to frequently check the operation of the recorder made it mandatory to keep the zero-check coil in operation, as the zero-check coil permitted corrections of recorded temperatures when the chart paper shifted during long periods of unchecked operation of the recorder.

Application of the urethane foam was made during November 1961 by use of a spray gun and a platform hoist. Two separately heated chemicals were fed to the mixing

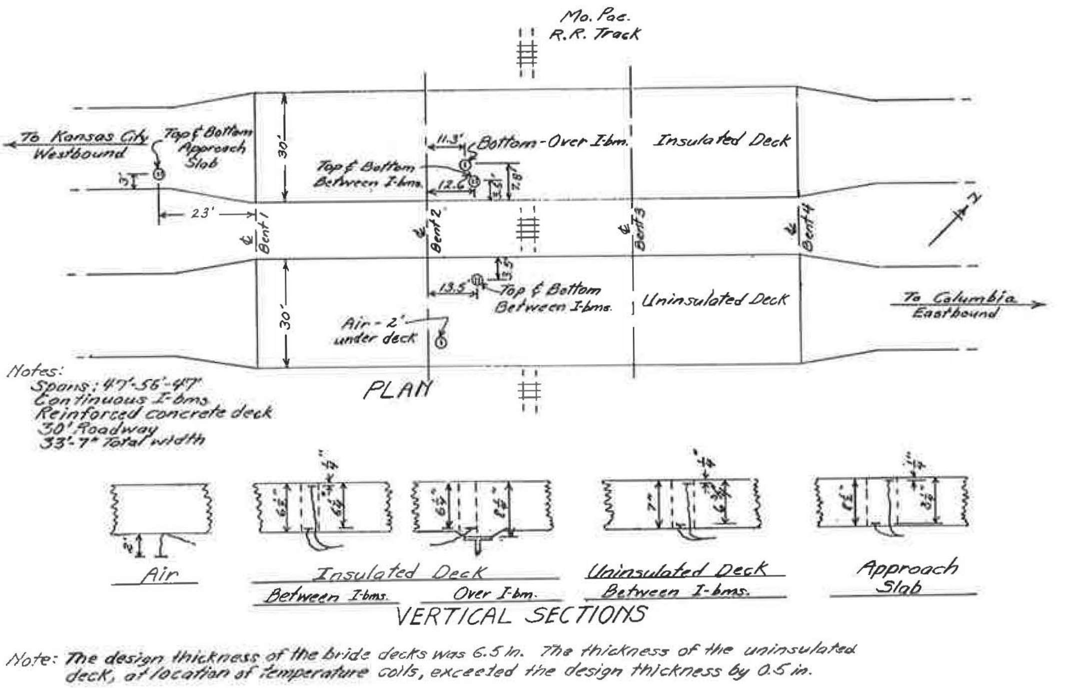

Figure 1. Layout of copper temperature coils in decks of bridge A-153.

chamber of the spray gun where they were combined and sprayed on the surfaces. Heating equipment consisted of electric belts and immersion coils for barrels, and electric line coils for the hoses from the chemical pump to the spray gun. The two chemicals reacted best to form a good foam when the ambient air temperature was above 60 F and the relative humidity of the air was low. On several occasions work was stopped because of cold weather or high humidity. Each of these appeared to prevent the proper reaction from taking place. An attempt was made to apply a thin coat of chemicals to cold surfaces for the purpose of insulating subsequent sprays from cold surfaces. This was discontinued when it was found that thickness of the final foam varied greatly, frequent clogging of the spray gun occurred, and appreciable quantities of the chemicals were wasted. It took seven days to apply the urethane foam on approximately 790 sq yd of surface, including the time lost due to inclement weather and temporary malfunctioning of equipment. It is estimated that the work could have been done in four or five days in good weather.

Initially, the urethane foam appeared to bond satisfactorily to both concrete and steel, inasmuch as during application only a few small areas had to be stripped and resprayed because of poor bond. However, during the early part of the winter some evidence of poor bond was observed between the foam and the webs of the aluminum painted I-beams. The results of a semi-detailed survey made in January 1962 indicated the following:

1. The bond between the foam and the concrete was still satisfactory.
2. Some evidence of poor bond was observed along approximately 65 percent of the total length of the stringers.
3. There was no correlation between air temperature at time of application and loss of bond.
4. The loss of bond was probably caused by condensations, on the stringers, of exhaust fumes from diesel locomotives.

The contractor removed and replaced the foam in areas of poor bond in September 1962.

Originally it was anticipated that recording of temperatures would start on October 1, 1961, before freezing temperatures occurred. However, the delay in application of urethane foam prevented the start of the temperature record until December 1, 1961. Consequently, the temperatures reported and discussed are for the periods of December 1, 1961 to April 29, 1962; and October 1, 1962 to November 30, 1962, inclusive.

In studying these results, several methods were used. This was necessary because none of the methods gives a complete picture regarding the over-all effect of the insulation. This is at least partly due to the fact that the insulation not only delays the time of freezing but also delays the time of thawing. This complicates the study because in evaluating the results there are at least three icing conditions that could affect the interpretation of the results:

1. The formation of frost on bridge decks and not on pavements on days when no precipitation occurs.
2. The time of formation of ice or nonmelting of snow during periods of precipitation.
3. The time of melting of ice or snow during thawing periods.

Obviously, any decision regarding insulation of bridge decks will depend on the effect of the insulation during each condition. That the effect of the insulation could be beneficial under some but not all of these conditions is also obvious. Further complicating any decision regarding the benefits of the insulation is the effect of the use of de-icers.

Although present data are definitely insufficient to warrant any conclusions regarding the merits of insulating a bridge deck, the methods used in studying the results were designed (a) to provide the maximum number of indications from available data, and (b) ultimately to provide the necessary information, from these and future data, to permit an evaluation of the merits of insulating a bridge deck.

The following methods were used in studying these results:

1. Determination of the number of freeze-thaw cycles at the various locations (Table 1).

TABLE 1

NUMBER OF FREEZE-THAW CYCLES[a,b]

Month	Freeze-Thaw Cycles (no.)							
	Air	Uninsul. Deck		Insul. Deck			Approach Slab	
		Top	Bottom	Between I-Beams Top	Between I-Beams Bottom	Over I-Beam, Bottom	Top	Bottom
Dec. '61	9	11	9	9	7		15	3
Jan. '62	8	13	9	11	9		15	6
Feb. '62	13	19	14	18	15		20	9
Mar. '62	11	16	14	13	12	11	11	
Apr. '62	7	7	7	6	6	3	3	
Oct. '62	2	3	2	2	2	1	0	
Nov. '62	8	12	7	10	7	4	3	
Total	58	81	62	69	58	19	67	18

[a]32 F considered positive and not freezing.
[b]From December 1, 1961 to April 29, 1962; and October 1, 1962 to November 30, 1962.

2. Determination of the relationship between the minimum daily temperatures at the various locations, with results shown in Table 2 for the tops of the decks and approach slab.

3. Determination of the relationship between the maximum daily temperatures at the various locations, with results shown in Table 3 for the tops of the decks and approach slab.

4. Determination of the percent of time the temperature of the air and the tops of the slabs was below 32 F (Table 4).

5. Relationship between occurrence of freezing and thawing in the air and the tops of decks and approach slab (Table 5).

6. Determination of the relationship between time of start of freezing and thawing (Table 6).

TABLE 2

RELATIONSHIP BETWEEN MINIMUM DAILY TEMPERATURES OF TOPS OF SLABS VS AIR

Location of Temp. Coil	Month		Number of Days When Min. Temp. of Point with Respect to Min. Air Temp. Was					
			Less Than		Same As		Greater Than	
			Days	%	Days	%	Days	%
Top approach slab	Dec.	1961	6	19.4	4	12.9	21	67.7
	Jan.	1962	8	25.8	2	6.5	21	67.7
	Feb.	1962	5	17.9	2	7.1	21	75.0
	Mar.	1962[a]	4	13.3	3	10.0	23	76.7
	Apr.	1962[b]	0	0.0	0	0.0	29	100.0
	Oct.	1962	0	0.0	1	3.2	30	96.8
	Nov.	1962	1	3.3	2	6.7	27	90.0
Total			24	11.4	14	6.7	172	81.9
Top insulated deck	Dec.	1961	14	45.2	5	16.1	12	38.7
	Jan.	1962	19	61.3	3	9.7	9	29.0
	Feb.	1962	8	28.6	4	14.3	16	57.1
	Mar.	1962[a]	11	36.7	6	20.0	13	43.3
	Apr.	1962[b]	4	13.8	5	17.3	20	68.9
	Oct.	1962	8	25.8	6	19.4	17	54.8
	Nov.	1962	18	60.0	5	16.7	7	23.3
Total			82	39.0	34	16.2	94	44.8
Top uninsulated deck	Dec.	1961	14	45.2	11	35.5	6	19.3
	Jan.	1962	22	71.0	4	12.9	5	16.1
	Feb.	1962	14	50.0	9	32.1	5	17.9
	Mar.	1962[a]	20	66.7	7	23.3	3	10.0
	Apr.	1962[b]	12	41.4	7	24.1	10	34.5
	Oct.	1962	21	67.7	4	12.9	6	19.4
	Nov.	1962	25	83.3	1	3.3	4	13.4
Total			128	61.0	43	20.4	39	18.6

[a]Temperatures not recorded on March 21.
[b]Temperatures not recorded on April 30.

TABLE 3

RELATIONSHIP BETWEEN MAXIMUM DAILY TEMPERATURES OF TOPS OF SLABS VS AIR

Location of Point (Temp. Coil)	Month		Number of Days When Max. Temp. of Point with Respect to Max. Air Temp. Was					
			Less Than		Same As		Greater Than	
			Days	%	Days	%	Days	%
Top approach slab	Dec.	1961	4	12.9	3	9.7	24	77.4
	Jan.	1962	5	16.1	1	3.2	25	80.7
	Feb.	1962	3	10.7	3	10.7	22	78.6
	Mar.	1962[a]	1	3.3	3	10.0	26	86.7
	Apr.	1962[b]	1	3.4	1	3.4	27	93.2
	Oct.	1962	0	0.0	0	0.0	31	100.0
	Nov.	1962	0	0.0	3	10.0	27	90.0
Total			14	6.7	14	6.7	182	86.6
Top insulated deck	Dec.	1961	9	29.0	6	19.3	16	51.7
	Jan.	1962	7	22.6	5	16.1	19	61.3
	Feb.	1962	1	3.6	2	7.1	25	89.3
	Mar.	1962[a]	0	0.0	2	6.7	28	93.3
	Apr.	1962[b]	0	0.0	0	0.0	29	100.0
	Oct.	1962	0	0.0	0	0.0	31	100.0
	Nov.	1962	2	6.7	1	3.3	27	90.0
Total			19	9.0	16	7.6	175	83.4
Top uninsulated deck	Dec.	1961	4	12.9	4	12.9	23	74.2
	Jan.	1962	6	19.3	1	3.2	24	77.5
	Feb.	1962	2	7.1	2	7.1	24	85.8
	Mar.	1962[a]	0	0.0	3	10.0	27	90.0
	Apr.	1962[b]	0	0.0	1	3.4	28	96.6
	Oct.	1962	0	0.0	1	3.2	30	96.8
	Nov.	1962	2	6.7	0	0.0	28	93.3
Total			14	6.7	12	5.7	184	87.6

[a]Temperatures not recorded on March 21.
[b]Temperatures not recorded on April 30.

7. Determination of the probable maximum number of occurrences of frost on the concrete surfaces (Table 7).

8. Relationship between the number of salt applications on the insulated and uninsulated decks (Table 8).

These results could be discussed at great length. However, a thorough discussion of these preliminary data is considered to be unwarranted, because as previously stated these data are considered insufficient to warrant any conclusions regarding the merits of insulating a bridge deck. Therefore, in this progress report these data are being presented, together with the following brief listing of the most obvious indications:

TABLE 4

PERCENTAGE OF TIME THAT AIR AND CONCRETE WERE BELOW 32 F

Month	Percentage of Time Below 32 F			
	Air	Top Uninsulated Deck	Top Insulated Deck	Top Approach Slab
Dec. 1961	78.9	77.8	81.0	76.6
Jan. 1962	80.8	76.7	78.7	84.2
Feb. 1962	52.1	48.5	42.7	40.7
Mar. 1962	33.2	27.4	23.4	22.2
Apr. 1962	7.0	7.5	5.1	2.0
Oct. 1962	1.1	2.5	1.7	0.0
Nov. 1962	8.6	9.9	9.9	2.3
Avg.	37.6	36.0	35.0	32.9

Table 1

1. The number of freeze-thaw cycles in the tops of the decks and approach slab exceeded the number of cycles in air (81, 69, and 67 vs 58).

2. Of the three points in the tops of the decks and approach slab, the greatest (81) and the least (67) number of cycles were obtained in the uninsulated deck and the approach slab, respectively. However, the number of cycles in the top of the insulated deck was only two greater than the number in the top of the approach slab.

3. Comparison of the freeze-thaw cycles in the bottom of the insulated deck over a half-depth insulated I-beam and midway between I-beams (for March, April, October, and November) shows that the cycles in the bottom of the deck over the I-beam were fewer than those midway between I-beams (19 vs 27). This indicates that more than half-depth insulation of an I-beam is necessary to eliminate the effect of the I-beam on the temperature of the concrete above it. However, it is presently indicated that the concrete over the I-beam tends to be warmer. As this latter indication might be different during the colder months, the temperature of this point will be continuously recorded during the winter of 1962-63. This, of course, means that the temperature of the bottom of the approach slab will not be recorded during the winter of 1962-63.

Table 2

1. The minimum temperature of the top of the uninsulated deck was lower than the minimum air temperature on 61 percent of the 210 days. This indicates that the minimum temperature in the top of the uninsulated deck tended to approach that of a wet bulb.

2. The minimum temperature of the top of the approach slab was higher than the minimum air temperature on 81.9 percent of the 210 days. This shows the beneficial effect of heat from the subgrade.

3. The average relationship between the minimum temperatures of the top of the insulated deck vs air tends to be approximately midway between that of the top of uninsulated deck vs air and that of the top of approach slab vs air. However, the results obtained for the insulated deck varied appreciably between months. In fact, the results obtained for the insulated deck approached that obtained for the uninsulated deck during December, January, and November. Therefore, these data indicate that the beneficial effect of the insulation was variable.

TABLE 5

RELATIONSHIP BETWEEN OCCURRENCE OF FREEZING AND THAWING IN AIR AND TOPS OF DECKS, AND APPROACH SLAB

Point 1	Point 2	Month	No. of Cycles Freeze and Thaw Occurring				
			Concur-rently	In (1) When (2) Was		In (2) When (1) Was	
				Frozen	Thawed	Frozen	Thawed
Air	Top insul. deck	Dec.	7	2	-	2	-
		Jan.	7	-	1	3	1
		Feb.	13	-	-	5	-
		Mar.	8	-	3	5	-
		Apr.	6	-	1	-	-
		Oct.	2	-	-	-	-
		Nov.	8	-	-	-	2
Total			51	2	5	15	3
Air	Top uninsul. deck	Dec.	9	-	-	2	-
		Jan.	7	-	1	5	1
		Feb.	13	-	-	6	-
		Mar.	11	-	-	5	-
		Apr.	7	-	-	-	-
		Oct.	2	-	-	-	1
		Nov.	8	-	-	-	4
Total			57	-	1	18	6
Air	Top approach slab	Dec.	9	-	-	6	-
		Jan.	7	1	-	6	2
		Feb.	12	-	1	8	-
		Mar.	6	-	5	5	-
		Apr.	3	-	4	-	-
		Oct.	-	-	2	-	-
		Nov.	3	-	5	-	-
Total			40	1	17	25	2
Top insul. deck	Top uninsul. deck	Dec.	8	1	-	3	-
		Jan.	11	-	-	2	-
		Feb.	18	-	-	1	-
		Mar.	13	-	-	-	3
		Apr.	6	-	-	-	1
		Oct.	2	-	-	-	1
		Nov.	10	-	-	-	2
Total			68	1	-	6	7
Top insul. deck	Top approach slab	Dec.	8	1	-	7	-
		Jan.	10	1	-	3	2
		Feb.	17	-	1	3	-
		Mar.	11	-	2	-	-
		Apr.	3	-	3	-	-
		Oct.	-	-	2	-	-
		Nov.	3	-	7	-	-
Total			52	2	15	13	2
Top uninsul. deck	Top approach slab	Dec.	11	-	-	4	0
		Jan.	11	2	-	2	2
		Feb.	18	-	1	2	-
		Mar.	11	-	5	-	-
		Apr.	3	-	4	-	-
		Oct.	-	-	3	-	-
		Nov.	3	-	9	-	-
Total			57	2	22	8	2

TABLE 6

COMPARISON OF TIME PRECEDENCE OF FREEZING AND THAWING

Point 1	Point 2	Month	Freezing: 1 Precedes	Freezing: Same	Freezing: 2 Precedes	Thawing: 1 Precedes	Thawing: Same	Thawing: 2 Precedes
Air	Top uninsul. deck	Dec. 1961	4	1	4	2	0	6
		Jan. 1962	4	1	2	2	1	5
		Feb. 1962	8	1	4	4	1	7
		Mar. 1962	5	0	6	5	0	7
		Apr. 1962	3	0	4	3	1	3
		Oct. 1962	0	0	2	2	0	0
		Nov. 1962	5	2	1	4	1	3
Total			29	5	23	22	4	31
Air	Top insul. deck	Dec. 1961	4	0	3	5	0	1
		Jan. 1962	6	0	1	5	0	3
		Feb. 1962	11	0	2	4	1	7
		Mar. 1962	5	1	2	2	0	7
		Apr. 1962	5	1	0	3	0	3
		Oct. 1962	1	0	1	2	0	0
		Nov. 1962	7	0	1	8	0	0
Total			39	2	10	29	1	21
Air	Top approach slab	Dec. 1961	3	2	4	2	0	6
		Jan. 1962	3	0	4	3	1	4
		Feb. 1962	7	1	4	4	1	6
		Mar. 1962	4	0	2	0	0	7
		Apr. 1962	3	0	0	0	0	3
		Oct. 1962	0	0	0	0	0	0
		Nov. 1962	3	0	0	0	0	3
Total			23	3	14	9	2	29
Top uninsul. deck	Top insul. deck	Dec. 1961	1	1	6	7	0	0
		Jan. 1962	6	1	4	11	1	0
		Feb. 1962	16	1	1	7	2	8
		Mar. 1962	12	1	0	11	3	3
		Apr. 1962	6	0	0	3	0	0
		Oct. 1962	2	0	0	2	0	0
		Nov. 1962	6	1	3	9	0	1
Total			49	5	14	50	6	12
Top uninsul. deck	Top approach slab	Dec. 1961	6	1	4	1	2	7
		Jan. 1962	0	2	9	4	3	5
		Feb. 1962	14	1	3	3	2	12
		Mar. 1962	8	0	3	1	1	10
		Apr. 1962	3	0	0	0	0	3
		Oct. 1962	0	0	0	0	0	0
		Nov. 1962	3	0	0	0	0	3
Total			34	4	19	9	8	40
Top insul. deck	Top approach slab	Dec. 1961	5	0	3	1	0	6
		Jan. 1962	0	1	9	0	0	11
		Feb. 1962	6	2	9	2	1	13
		Mar. 1962	2	1	8	0	0	12
		Apr. 1962	3	0	0	0	0	3
		Oct. 1962	0	0	0	0	0	0
		Nov. 1962	3	0	0	0	0	3
Total			19	4	29	3	1	48

TABLE 7

PROBABLE MAXIMUM NUMBER OF OCCURRENCES OF FROST ON CONCRETE SURFACES

Data from Table	Probability of Frost		Possible Number of Occurrences of Frost on		
	High[1]	Low[2]	Uninsulated Deck	Insulated Deck	Approach Slab
All Data for Seven Months					
5	Yes	--	6	3	2
6	Yes	--	23	10	14
High prob. total			29	13	16
5	--	Yes	0	2	1
6	--	Yes	22	29	9
Low prob. total			22	31	10
Grand total			51	44	26
Excluding Data for December, January, and February[3]					
5	Yes	--	5	2	0
6	Yes	--	13	4	2
High prob. total			18	6	2
5	--	Yes	0	0	0
6	--	Yes	14	15	0
Low prob. total			14	15	0
Grand total			32	21	2

[1]Condition occurs (a) during periods of falling temperatures, and (b) at night or near dawn.
[2]Condition occurs (a) during periods of rising temperatures, and (b) usually between 7:00 AM and 5:00 PM (daytime).
[3]Because of frequent applications of de-icing salts.

TABLE 8

NUMBER OF SALT APPLICATIONS 1961 - 1962

Date	Number of Salt Applications							
	Uninsulated Deck				Insulated Deck			
	Light	Moderate	Heavy	Condition	Light	Moderate	Heavy	Condition
Dec. 8	0	1	3	Snow	0	1	3	Snow
9	0	2	1	Snow	0	2	1	Snow
11	0	0	8	Snow	0	0	8	Snow
12	0	0	3	Snow	0	0	3	Snow
18	0	0	4	Ice	0	0	4	Ice
19	0	5	0	Ice	0	5	0	Ice
22	0	3	0	Snow	0	3	0	Snow
23	0	2	1	Snow	0	2	1	Snow
Jan. 5	0	3	1	Ice	0	3	1	Ice
6	0	5	2	Snow	0	5	2	Snow
7	0	3	1	Snow	0	3	1	Snow
14	0	1	2	Snow	0	1	2	Snow
15	0	2	1	Snow	0	2	1	Snow
21	0	2	4	Ice	0	2	4	Ice
22	2	0	5	Ice	2	0	5	Ice
23	0	0	2	Ice	0	0	2	Ice
Feb. 20	0	2	1	Snow	0	2	1	Snow
23	0	1	5	Snow	2	1	3	Snow
24	0	3	0	Snow	0	3	0	Snow
Total applic.	2	35	44		4	35	42	

Table 3

1. During the colder months of December and January, the maximum temperature of the top of the insulated deck tended to be slightly lower than that of either the top of the approach slab or the top of the uninsulated deck. This indicates that during these two months the insulation tended to delay the warming up of the concrete, and should delay the melting of accumulations of ice and snow.

2. During February, March, April, and October, this trend was reversed for the bridge decks. This indicates that during four of the seven months' accumulations of ice and snow should melt slightly faster on the insulated than on the uninsulated deck.

Table 4

1. During the colder months of December and January, the temperature of the top of the insulated deck remained below 32 F for a slightly higher percentage of time than did that of the top of the uninsulated deck.

2. During February, March, April, and October, the percentage of time that the top of the insulated deck remained frozen was less and greater, respectively, than that for the tops of the uninsulated deck and the approach slab.

3. In general, the air temperature remained below 32 F a greater percentage of time than did the tops of the decks and approach slab.

Table 5

1. The number of concurrent freeze-thaw cycles of any two points (locations) was less than the number of freeze-thaw cycles at either comparative point (location). This shows that freeze-thaw cycles did not always occur concurrently at two locations.

2. The number of concurrent freeze-thaw cycles in air and the top of each of the three slabs was 51, 57, and 40 for the insulated deck, uninsulated deck, and approach slab, respectively. The difference in number of concurrent cycles was primarily due to the amount of heat available, in or beneath the concrete in each slab, to prevent freezing of the concrete (and moisture thereon) when the air temperature was below 32 F. These data, therefore, indicate that the available heat was greatest in the approach slab and least in the uninsulated deck.

3. In the next to last column, 15, 18, and 25 cycles occurred in the top of the insulated deck, the top of the uninsulated deck, and the top of the approach slab, respectively, when the air remained below freezing. The difference in number of cycles was primarily due to the availability of heat to the concrete, either by absorption from the sun or from below, to cause thawing of the concrete (and ice or snow thereon) when the air temperature was below 32 F. These data indicate that the available heat was greatest in the approach slab and least in the insulated deck.

4. Frost on the concrete surfaces would only be considered probable when the temperature of the concrete was lower than that of the air. For the noncurrent cycles this condition existed when a cycle was obtained in air while the concrete remained frozen, and when a cycle was obtained in the concrete while the air temperature remained above freezing (thawed). The first condition occurred 2, 0, and 1 times, and the second 3, 6, and 2 times, respectively, on the tops of the insulated deck, uninsulated deck, and approach slab.

5. In comparing the cycles in the tops of the insulated and uninsulated decks, it is apparent that the difference in number of cycles obtained at these two points was caused by the uninsulated deck cooling down and warming up faster than the insulated deck. Six and seven cycles were obtained in the top of the uninsulated deck when the top of the insulated deck remained frozen and thawed, respectively.

Table 6

These comparisons are for the concurrent cycles shown in Table 5.

1. In the majority of concurrent freeze and thaw cycles the air temperature preceded the concrete temperatures during freezing and lagged the concrete temperatures

during thawing. Under this condition, frost on the concrete surfaces would be considered impossible.

2. Frost on the concrete surfaces would be considered possible when the concrete temperature preceded the air temperature during freezing, or lagged the air temperature during thawing. The first condition occurred 23, 10, and 14 times, and the second 22, 29, and 9 times, respectively, on the tops of the uninsulated deck, insulated deck, and approach slab.

3. In comparing the time precedence of freezing and thawing of the tops of the uninsulated and insulated decks, it is evident that in general the top of the uninsulated deck preceded the top of the insulated deck in both freezing and thawing. This indicates that the insulation should tend to delay the formation and melting of ice on the bridge deck.

Although not shown by these data, the effect of the insulation on the time of freezing tended to exceed the effect on time of thawing.

Table 7

These comparisons combine the indicated possible occurrences of frost for the nonconcurrent cycles in Table 5 and the concurrent cycles in Table 6.

The possible maximum number of occurrences of frost for the seven months were 51, 44, and 26 on the uninsulated deck, insulated deck, and approach slab, respectively. However, the probability of frost forming on the concrete surfaces is dependent on factors other than the concrete temperature being lower than the air temperature. For example (Table 7) a low probability of occurrence of frost is expected during periods of thawing or rising temperatures which normally occur in the daytime. If these low probability occurrences be deducted from the above maximum seven months' totals, only 29, 13, and 16 high probability occurrences remain for the uninsulated deck, insulated deck, and approach slab, respectively. This indicates that the highly probable occurrences of frost on the insulated deck were fewer than those on either the approach slab or the uninsulated deck.

In addition, during months of frequent salt applications, a low probability of occurrence of frost would be expected for all conditions. Therefore, by excluding the data for December, January, and February only 18, 6, and 2 high probability occurrences of frost remain for the uninsulated deck, insulated deck, and approach slab, respectively. This indicates that during the months of March, April, October, and November, the highly probable occurrences of frost on the insulated deck were one-third those for the uninsulated deck, and three times those for the approach slab.

Table 8

The total number of salt applications (81) was the same for the insulated and uninsulated decks. However, on February 23, the amount of salt applied to the insulated deck was less than that applied to the uninsulated deck. All salt applications were applied to remove snow and ice, and no applications were made because of frost on the decks. Furthermore, all salt applications were made during the three colder months. Precipitation during March, April, October, and November was light and no salt applications were required. If frost occurred on these concrete surfaces during March, April, October, and November, it apparently was insufficient to require applications of salt.

These data indicate that salt applications were related to (a) the time of occurrence and amount of precipitation, and (b) the temperatures of the concrete surfaces. Therefore, during certain periods, the effect of time of occurrence and amount of precipitation could overshadow the effect that insulation may have on the amount of salt needed.

At the time when insulation was applied to the underside of one of these decks, both surfaces were in good condition with the exception of a few short hairline cracks on each deck adjacent to curbs. During the winter of 1961-62, one partial transverse crack and a moderate amount of surface mortar deterioration occurred on each deck. Tests on three full depth cores from each bridge deck indicated that the surface mortar

TABLE 9

RESULTS FROM TESTS OF THREE FULL DEPTH CORES FROM EACH BRIDGE DECK

Type Deck	Core No.	Percent Air	Cement Factor	W/C Ratio (by vol.)
Insulated	61-340	4.3	1.53	0.66
	61-344	1.9	1.62	0.89
	61-345	4.6	1.62	0.71
Uninsulated	61-341	3.8	1.60	0.72
	61-342	4.8	1.47	0.74
	61-343	2.4	1.71	0.71

deterioration occurred in areas where insufficient air was entrained in the concrete. The results on these six cores are given in Table 9.

SUMMARY

This first progress report of effect of insulating the underside of a bridge deck covers the periods of December 1, 1961 to April 29, 1962; and October 1, 1962 to November 30, 1962. These periods are definitely of insufficient length to warrant conclusions regarding the justification of the insulation. However, the following indications were obtained:

1. The minimum temperature of the top of an uninsulated bridge deck tends to be lower than that of either the top of the approach slab or air.
2. Insulating the underside of a bridge deck tends to produce the following:
   a. Reduction of the number of freeze-thaw cycles.
   b. Reduction of the severity of freezing by raising the minimum temperature.
   c. Delay of the start of both freezing and thawing.
   d. Reduction of the length of time the concrete is frozen, because the delay in start of freezing tends to be greater than the delay in start of thawing.
3. With respect to formation of frost or ice on the deck the insulation should tend toward the following:
   a. Decrease in the occasions when frost forms on the bridge deck but not on the approach slab.
   b. Delay in the formation of ice on the deck. In general, but with exceptions, it would be anticipated that ice would form first on the uninsulated deck, next on the insulated deck, and last on the approach slab. This order should prevail during moderate and intermittent cold periods, but could be reversed during severe and prolonged cold periods.
   c. Delay during extremely cold periods and hastening during moderately cold periods the melting of accumulated ice and snow.
4. With respect to applications of salt needed to keep the deck free of frost or ice, the insulation could be both detrimental and beneficial. During severe and prolonged cold periods, more salt could be required; during moderate and intermittent cold periods, less salt could be required. Based on the record of salt applications during the periods of observation, the insulation did not significantly affect the amount of salt applied.
5. With respect to amount of concrete deterioration occurring during the periods of observation, the insulation had no significant effect.