Twenty-Five-Year Performance History of Interlayer Membranes on Bridge Decks in Kansas

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Interlayer membranes installed on six different bridge decks in Kansas were monitored for the last 20 to 25 years. Electrical resistivity measurements and visual distress surveys were made on these bridge decks in 1982 and 1991. The visual distress surveys were supplemented by the condition rating and maintenance history data from the Bridge Management System data base of the Kansas Department of Transportation. (KDOT). The membranes installed represented the preformed system, liquid/preformed systems, and liquid system. Electrical resistivity measurements taken in 1991 were compared with those obtained in 1982. The results show that the general performance of interlayer membranes installed between 1967 and 1971 has decreased since the last evaluation in 1982. However, the number of traffic carried by some of these decks has increased considerably. Two bridge deck membranes that have performed most effectively for the last 20 to 25 years were both liquid/preformed systems. These membranes were nonwoven polypropylene fabrics with an asphaltic overlay placed as a wearing surface. The lives of a coal tar-modified polyurethane elastomer interlayer membrane and a nonwoven polypropylene fabric system on a very old bridge have been exhausted. The poorest performance was obtained from a preformed polypropylene and coal tar sheet system and a liquid membrane system. In the recent past, KDOT used membranes as part of the maintenance overlays in which weight restrictions could not support concrete overlays. The agency now uses dense concrete/silica-fume concrete bridge decks during new construction.

Most bridge decks on the highways in Kansas are constructed of reinforcement portland cement concrete (RC) regardless of the type of bridge structure. The majority of these decks were designed to perform as both a structural unit and a wearing surface. Thus, deterioration of these decks usually result in poor riding quality and reduced structural strength, which eventually will make the bridges unsafe. The premature deterioration of RC bridge decks in Kansas was attributed to the spalling of concrete as a result of corrosion of reinforcing steel by chlorides from deicing salts (*1*). It was estimated that bridge decks in Kansas receive about 20 applications of salt per year at the rate of 369 kg/2-lane km (1,300 lb/2-lane mi) (*2*). Kansas experience also showed that corrosion of steel also resulted in horizontal cracks or delaminations as well as vertical cracks. According to Carl Crumpton of Kansas Department of Transportation (KDOT) (*3*, p. 165):

> The wedding of concrete and steel was an ideal union and we used lots of reinforced concrete for bridge decks. Unfortunately, we began tossing salt to melt snow and ice instead of rice for good fertility. That brought irritation, tensions, and erosion of previously good marital relations. No longer could the two exist in blissful union; the seeds of destruction had been planted and the stage had been set for today's bridge cracking and corrosion problems.

In the sixties, a study on bridge deck deterioration in Kansas considered treatment on bridge decks to prevent intrusion of salts (*1*). Hot-mix asphalt overlays were unsatisfactory and were not recommended unless they were placed over a membrane. A formal study of performance of interlayer membranes on bridge decks began in 1967 with an installation of polypropylene fabric on a 6-year-old, salted interchange bridge on rural I-70. A 3-mm (1/8-in.) overlay of cationic emulsion and crushed-chert-type chat aggregate was placed over this membrane. This installation marked the first time this proprietary membrane had been used on a bridge deck anywhere in the world. By 1970, the performance of this installation was satisfactory enough that from 1970 to 1974 four different types of membranes totaling nearly 10 000 m^2 (12,000 yd^2) were installed on seven salt-contaminated bridges by KDOT. The 12-year performance history of these membranes has been reported before (*4*). This paper describes the 25-year performance of six of the eight membranes installed between 1967 and 1974.

PROJECT DESCRIPTION

Installation and Location

Table 1 presents the types of interlayer membranes used on each bridge between 1967 and 1974. Data pertaining to each individual bridge is listed in Table 2. In 1983, a report was presented on the condition of these bridges (*1*). Each of the bridges had been exposed to varying degrees of traffic and weather before the placement of the membranes. At the time of membrane placement, these bridges were 16 to 35 years old. Some of the bridges had considerable seepage of water from the bottom of the deck during rainy or snowy seasons. However, this condition did not recur after the membranes were placed (*1*).

During the condition survey in 1983, the bridge decks showed some distresses, such as delamination, shallow spalling, and patched areas, but of very low severity. The appearance of the asphalt riding surface was generally satisfactory with the exception of some cracking. The shallow spalls were not patched before installing the membranes. This might have contributed to the cracking of the asphalt overlay. The membranes on Bridges B through G (Table 2) were 12 and 13 years old in 1983, whereas the membrane on Bridge H was 9 years old. During that time, they had been subjected to numerous salt applications for snow and ice control as well

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TABLE 1 Interlayer Membrane Systems Used on Old Decks in Kansas

NCHRP 165 System No.[a]	System Type	Description
12	Preformed	A pliable sheeting construction from polypropylene and coal tar placed over a primer; a hot-mix overlay covers the membrane
52a	Liquid/ preformed	An applied in-place nonwoven polypropylene fabric with cationic emulsified asphalt; chat (chert) aggregate was rolled into CRS-2 emulsion for the wearing course
52b	Liquid/ preformed	Same as 52a, except that the fabric was placed over a thin coat of AC-5 and covered with a hot-mixed asphalt-concrete (AC) overlay
67	Liquid	A cold-applied, coal-tar modified, elastomeric polyurethane with a 55-lb grade asphalt-impregnated roofing sheet over it; all overlaid with 2.5 in. of hot-mix AC
80	Liquid	A coal-tar modified polyurethane elastomer cold-applied with catalyst (curing agent) added before application; the material was covered with No. 40 asphalt roofing sheet, which was topped with a hot-mix overlay

[a]See Table 9 of NCHRP Report 165 (2).

TABLE 2 Membrane Installation Data

1983 Bridge ID	NCHRP 165 System No.[a]	Date Membrane Installed	Date Bridge Constructed	Material Installed (yd^2)	Overlay Thickness (in.)	Bridge Type[b]
A	52a	1967	1961	112	0.125	RBGC
B	12	1970	1936	700	1.5	Cont. I-Beam
C	80	1971	1958	283	1.5	Cont. RC
D	80	1971	1959	404	1.5	Cont. RCDG
E	52b	1971	1953	254	2	Cont. RC
F	52b	1971	1936[c]	1,035	2	RCDG
G	80	1971	1936[c]	1,313	1.5	Steel I-Beam
H	67	1974	1924[d]	7,700	2.5	RC slab and Cont.

[a]as per Table 1 (Table 9 of NCHRP Report No. 165).
[b] bridge types are: RBGC = reinforced box-girder continuous; RCDG = reinforced-concrete deck girder; RC = reinforced concrete; Cont. = continuous.
[c] widened in 1971.
[d] widened in 1974.

as from 6.5 to 16 million vehicles. Trucks made up approximately 1.5 to 19 percent of that total traffic. It was concluded that the membranes had served quite well with little maintenance for 12 to 16 years (*4*). Since 1983, two of the decks with membranes (G & H) have been replaced. This paper discusses the current performance of the others (A through F). Table 3 lists the locational references of the bridges in this study.

Climate and Weather

The bridges in Kansas may be subjected to air temperatures as low as −40°C (−104°F) in the winter and as high as 49°C (120°F) in the summer. Winter windchill factors may reach −54°C (−129°F) in the winter, whereas the summer temperature of hot-mix asphalt overlays often reaches 71°C (160°F). Annual precipitation ranges from more

TABLE 3 Bridge Reference Data

Bridge ID	KDOT Bridge No.	County	Location
A	I70-21-272.62 (005)	Dickin-son	Talmage Road IC over I-70
B	59-30-114.28 (050)	Frank-lin	US 59 over AT&SF RR and Local Rd. 0.02 mi. North of Anderson Co. Line.
C	39-103-44.48 (027)	Neosho	K-39 over Village Creek, west of Chanute, 5.74 mi. East of East Jct. US-75.
D	39-67-47.37 (021)	Neosho	K-39 over Cement Co. Road, west of Chanute, 1.66 mi. East of Wilson Co. Line.
E	54-104-317.27 (005)	Wood-son	US-54 over MoPac RR, East of Yates Ctr. 2.49 mi. East of US-75
F	I96-8-19.38 (061)	Butler	K-96 over Bakers Creek East of Potwin. 9.82 mi. S.E. of Harvey Co. Line

than 1,020 mm (40 in.) in the southeast part to about 410 mm (16 in.) in the southwest. The evaporation rate is higher than the precipitation rate all across the state. It is believed that if the bridge deck membranes can retard the downward movement of moisture and chlorides, evaporation will soon take over and keep them near the surface. Most Kansas bridges undergo an average of 60 or more freeze-thaw cycles each year (*4*). On the average, five to six winter snowstorms and one to three ice or sleet storm events are recorded. The snow and ice control are done by snowplows and deicing salts (mostly chloride salts).

Traffic History

The ridge decks with membranes have carried an increasing amount of traffic since 1982. Table 4 tabulates the 1982 and 1991 annual average daily traffic (AADT) as well as the percent trucks and cumulative traffic carried up to 1991. The bridges have carried from approximately 6.1 million vehicles to 22.5 million vehicles since the installation of the membranes. The percentage of trucks varied from 9.5 percent to approximately 20 percent.

TABLE 4 Traffic History of Bridge Decks with Membranes

Bridge ID	1982 ADT	1991 ADT	% Trucks (1991)	Cumulative Traffic (up to 1991)(millions)
A	890	977	-	> 6.1 (approx)
B	3,030	3,120	9.5	22.51
C	1,390	2,290	13.1	13.96
D	1,275	2,290	13.1	12.45
E	2,560	2,640	20.2	18.07
F	1,820	1,735	19.0	13.18

DATA COLLECTION

Resistivity Measurements

In July 1991, electrical resistivity of the water barrier membrane-pavement system was measured for each bridge listed in Table 2. The procedure outlined by ASTM D 3633-88 was followed to collect the data. Electrical resistivity measurements were recorded in ohms per square foot. Measurements were made on the centerline, both wheelpaths, and gutter on each deck. The total number of readings varied from 30 to 423 as shown in Table 5.

Visual Distress Survey

The visual distress survey during resistivity measurements consisted of surveying distresses, such as delamination, spalling, rust stains, and patched areas. However, the distressed areas were not quantified but rather observed qualitatively. The concrete bridge decks were not evaluated for chloride content because that would have involved breaching the interlayer membranes. Also, the original and 1982 conditions of the concretes were not available for comparison (with one exception).

Condition Survey and Maintenance History Data

The bridge condition and maintenance history data were also collected from the Bridge Management System (BMS) data base. In Kansas, bridges are inspected on a 2-year cycle, and a report is prepared with pertinent data on bridge inventory and geometry as well as condition of deck, superstructure, substructure, channel, approach roadway, and waterway adequacy (if applicable). The deck is rated on a scale of 1 (closed) to 9 (new, not open to traffic). In reality, the scale is 3 (unsafe, needs to be replaced) to 8 (good condition, no repairs needed). A rating of 7 indicates less than 5 percent deck area deterioration, whereas a rating of 6 shows 5 to 10 percent deterioration or spalls exposing rebars and delaminations. A rating of 5 indicates 10 to 20 percent deterioration and finally, a rating of 4 implies 20 to 40 percent deterioration. Any rating less than 4 will result in load-limit posting. A data base of bridge maintenance work and associated costs has been developed since 1978. Table 6 lists the biennial ratings of the bridge decks in this study from 1982 to 1991. The ratings are subjective.

DATA ANALYSIS

The 1991 resistivity readings were analyzed and the following guidelines were followed in this study to classify the condition of the interlayer membranes:

$>$ 1 076 300 ohms/m^2 (100,000 ohms/ft^2), good
107 630 to 1 076 300 ohms/m^2 (10,000 to 100,000 ohms/ft^2), questionable
21 500 to 107 630 ohms/m^2 (2,000 to 10,000 ohms/ft^2), poor
$<$ 21 500 ohms/m^2 (2,000 ohms/ft^2), very poor

TABLE 5 Electrical Resistivity Readings on the Bridge Deck in 1991

Bridge ID	Location	Total No. of Readings	Electrical Resistivity (ohm/m^2)					
			> 21500		> 107600		> 1,076,000	
			No.	%	No.	%	No	%
A	Wheel Path with Membrane	30	30	100	29	96.7	24	80
	Wheel Path without Membrane	28	17	60.7	10	35.7	2	7.1
B	Gutter	108	105	97.2	81	75.0	23	21.3
	Both Wheel Paths	108	108	100	100	92.6	76	70.4
	Centerline	54	54	100	44	81.5	11	20.4
C	Gutter	56	44	78.6	20	35.7	16	28.6
	Both Wheel Paths	112	110	98.2	71	63.4	28	25.0
	Centerline	28	16	57.1	5	17.9	2	7.1
D	Gutter	40	20	50.0	3	7.5	1	2.5
	Both Wheel Paths	80	80	100	76	95.0	68	85.0
	Centerline	40	25	62.5	22	88	1	2.5
E	Gutter	188	188	100	175	93.1	122	64.9
	Both Wheel Paths	188	188	100	187	99.5	178	94.7
	Centerline	47	47	100	47	100	47	100
F	Gutter	36	35	97.2	24	66.7	6	16.7
	Both Wheel Paths	72	72	100	67	93	41	56.9
	Centerline	18	18	100	18	100	12	66.7

TABLE 6 Condition Rating of Bridge Decks with Membranes

Bridge ID	NCHRP 165 System No.	Year									
		82	83	84	85	86	87	88	89	90	91
A	52a	4	4	-	5	-	4	-	4	-	4
B	12	7	-	6	-	6	6	5	5	5	5
C	80	-	8	-	8	-	8	-	8	-	8
D	80	-	7	-	7	-	7	-	7	-	7
E	52b	-	8	-	7	-	7	-	7	-	7
F	52b	7	-	7	-	8	-	7	-	7	-

Previous research has used a resistivity value of 5 382 000 ohms/m^2 (500,000 ohms/ft^2) as the standard of excellence for the interlayer membrane performance (*5*). However, analysis of data in this study showed little difference in the percent of the deck area greater than 1 076 300 ohms/m^2 (100,000 ohms/ft^2) and that percent greater than 5 382 000 ohms/m^2 (500,000 ohms/ft^2). Ideally, the membranes should be monitored so that they can be replaced when 50 percent of the bridge deck area with membrane no longer performs as designed. If a membrane is placed on an existing bridge deck, an effort should be made to determine the existing chloride content.

RESULTS AND DISCUSSION

Bridge A was constructed in 1961, and the interlayer membrane was placed on one half of the deck in 1967. The other half was kept bare for comparison as a control. This was the first time this polypropylene fabric membrane was installed anywhere in the world. Electrical resistivity measurement data taken in 1991, from the section covered with the interlayer membrane, showed that 80 percent of the readings were greater than 1 076 300 ohms/m^2 (100,000 ohms/ft^2). Only 7.1 percent of the readings exceeded 1 076 300 ohms/m^2 (100,000 ohms/ft^2) in the section without the interlayer membrane. A visual inspection of the bridge deck indicated that the section covered with the interlayer membrane had fewer asphalt wearing surface distresses. Fine cracks were observed on the underside of the deck near the abutments, and rust staining was evident.

During the 1991 evaluation by the BMS survey crew, the whole deck was rated as 4 on a scale of 3 (unsafe) to 8 (new, open to traffic) as shown in Table 6. The rating was also 4 in 1982 and the asphalt wearing surface condition was judged to be poor at that time. In the mean time, the traffic increased from 890 vehicles per day in 1982 to 977 vehicles per day in 1991. In 1991, exposed steel was observed in some areas and approximately 20 percent of the bridge deck area was badly spalled. Between 1983 and 1991, the deck spalls were repaired 17 times at a cost of $3,825.

The interlayer membrane was placed on the deck of Bridge B in 1970. The resistivity measurements showed that only 34.1 percent of the readings were greater than 1 076 300 ohms/m^2 (100,000 ohms/ft^2) or in other words, good. In 1982, 100 percent of the electrical resistivity measurements had been above 1 076 300 ohms/m^2 (100,000 ohms/ft^2) as shown in Table 7. Lower resistivity readings in 1991 were found near the gutter and centerline. In those areas, the asphalt overlay may not have been densified by the traffic as in the wheelpaths, or the coal tar used with the polypropylene membrane may not have been worked by tire pressure as expected. Visual inspection of the bridge showed large cracks in the asphalt overlay. The hubguard was badly spalled exposing the reinforcing steel. However, the hubguard deterioration was also reported by the BMS survey since 1982. The underside of the deck had a large longitudinal crack near the east edge of the deck. The steel girders had begun to rust at the contact point with the deck. In 1991, the wearing surface had map cracking and rutting and was rated to be poor in the BMS survey. However, no major maintenance has been performed on this bridge deck since 1978.

The interlayer membrane was installed on the deck of Bridge C in 1971. In 1991 resistivity measurements showed that 50 percent of the bridge deck membrane tested had resistivities higher than 1 076 300 ohms/m^2 (100,000 ohms/ft^2). The data collected in 1982 indicated that only 38.6 percent of the deck measured above 1 076 300 ohms/m^2 (100,000 ohms/ft^2). The asphalt overlay was noted to be in good condition in 1991. There was a full-length centerline crack with several shorter transverse cracks beginning at the centerline. The underside of the deck was in good condition, with dark staining only on the bottom side of the hubguards. In 1991, wearing surface condition was rated to be good by the BMS survey. Thus far, no major maintenance on this deck has been reported.

The membrane on Bridge D was placed in 1971 and the type is similar to that on Bridge C (NCHRP 165 System 80). Resistivity

TABLE 7 Comparison of 1982 and 1991 Electrical Resistivity Readings

Bridge ID	1982 Readings (ohm / m²)						1991 Readings (ohm / m²)					
	> 21,500		> 107,600		> 1,076,300		>21,500		>107,600		> 1,076,300	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
A					-	-	30	100	29	96.7	24	80.0
B	189	100	189	100	189	100	267	98.9	223	82.6	92	34.1
C	139	99.3	98	70.0	54	38.6	170	86.7	96	49.0	46	23.5
D	432	100	429	99.3	409	94.7	125	78	101	63.0	70	44.0
E	133	100	133	100	133	100	423	100	409	96.7	347	82.0
F					-	100	125	99.2	99	78.6	59	46.8

measurements taken in 1991 indicate that 23.5 percent of the deck was in good condition. Data from 1982 showed that the entire deck was in good condition, with each measurement above 1 076 300 ohms/m² (100,000 ohms/ft²). In 1991, the asphalt overlay appeared to be in very good condition. Several transverse cracks, which ranged from 1.8 m (6 ft) to 2.7 m (9 ft), were seen throughout the structure. The hubguard was spalling with reinforcing steel visible in several locations. The underside of the bridge deck had no visible damage. During 1991 survey, the wearing surface condition was rated to be good in the BMS survey, but the curb was found to be deteriorated with exposed rebars.

An interlayer membrane was placed on Bridge E in 1971. Resistivity measurements taken in 1991 indicate that 82 percent of the bridge deck tested above 1 076 300 ohms/m² (100,000 ohms/ft²) or, in other words, appeared to be good. The 1982 results showed that 94.7 percent of the area tested above 1 076 300 ohms/m² (100,000 ohms/ft²), as shown in Table 7. The mainline deck overlay was noted to be in excellent condition in 1991. Some cracks, both transverse and longitudinal, were observed in the shoulders of the deck overlay, which seemed older than the mainline deck overlay. The expansion joints on the underside of the bridge deck were in poor condition. The concrete was badly spalled, exposing reinforcing bars.

In 1971, the interlayer membrane was placed on Bridge F. The electrical resistivity data collected in 1991 indicated that 46.8 percent of the interlayer membrane was in good condition. In 1982, 100 percent of the membrane was deemed to be in good condition on the basis of the results from the resistivity testing. A visual inspection of the bridge in 1991 noted that the asphalt overlay was in poor condition. There were many large transverse and longitudinal cracks observed in the overlay. The concrete railing was in bad condition, "crumbling away." Stalactites, up to 102 mm (4 in.) long, were observed in a 3.1-m (10-ft) longitudinal crack on the underside of the deck. There were transverse cracks beginning at the longitudinal crack. The sides of the deck exhibited varying degrees of spalling from 0.3 m (1 ft) to 1.5 m (5 ft) from the edge of the bridge. Staining was evident in the areas in which spalling had occurred. This deck is programmed to be replaced in FY 1995.

Figure 1 shows the percentages of each deck area that had a resistivity measurement greater than 1 076 300 ohms/m² (100,000 ohms/ft²) in 1983 and 1991. The bare part of the deck on Bridge A is also shown as [ACON]. It is apparent that four of the six bridges

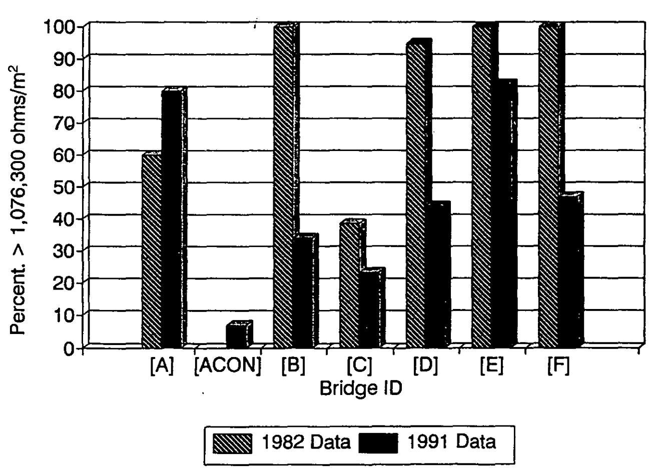

FIGURE 1 Comparison of 1982 and 1991 electrical resistivity readings (percentage of deck > 1 076 300 ohms/m²).

showed a decrease in the performance of the membranes from 1983 to 1991. However, there is some variability in the data presented, and that may be a result of the condition of the asphalt overlay at the time the electrical resistivity measurements were taken, the way a specific mastic responds to the traffic or other factors.

Electrical resistivity data obtained on Bridges B through F, which received interlayer membranes during 1970 and 1971 changed markedly from 1982 to 1991. In 1982 86.7 percent of the total bridge deck area tested had resistivity higher than 1 076 300 ohms/m^2 (100,000 ohms/ft^2), whereas in 1991 only 47.3 percent of the area showed resistivity higher than 1 076 300 ohms/m^2 (100,000 ohms/ft^2). The bridges were showing signs of deterioration that were most likely related to salt contamination. However, traffic on some of these bridges also has increased considerably. When the electrical resistivity values measure below 1 076 300 ohms/m^2 (100,000 ohms/ft^2) for 50 percent of a bridge deck area, the useful life of the interlayer membrane should be considered complete. The state of Oregon uses the same guidelines for determining the useful life of an interlayer membrane (*6*). Using the data from the bridge decks in this study, the useful life of an interlayer membrane in Kansas would range from 15 to 20 years. The membrane should be replaced before deterioration of the concrete structure begins.

The two bridge deck membranes that have performed most effectively were both liquid/preformed systems on Bridges A and E. The nonwoven polypropylene fabric was installed on both of these with an asphaltic overlay placed as a wearing surface.

The coal-tar-modified polyurethane elastomer interlayer membrane on Bridge C, and another liquid/preformed membrane on Bridge F, have reached the end of their useful lives. Over 50 percent of the bridge deck area measured below 1 076 300 ohms/m^2 (100,000 ohms/ft^2) for these two bridges. These interlayer membranes should be replaced before deterioration intensifies on the structures. Bridge F is old compared with Bridges A and E and carries a higher percentage of truck traffic.

The poorest performance was obtained from a preformed polypropylene and coal tar sheet on Bridge B, and a liquid membrane system on Bridges C and D. These decks were most likely already salt contaminated when the membranes were installed. The bridges may need major structural repair before the placement of another protective system.

CURRENT KDOT PRACTICE WITH RESPECT TO MEMBRANES

KDOT installed membranes on 14 bridges in Wichita, Kansas, area in 1980s. In addition to these, one membrane was installed on a deck on route K-77 near Manhattan, Kansas, in 1986 and another one on a viaduct on I-70 in Topeka, Kansas, in 1990. All these membranes were part of maintenance overlays used where weight restrictions could not support concrete overlays. Currently, KDOT uses dense concrete/silica-fume concrete bridge decks during new construction.

Two bridge deck overlays in Wichita on I-235 with Petromat over AC-5 and surfaced by a 51-mm (2-in.) wearing course of bituminous mixes were constructed in 1985 and have been monitored since then. In 1993, surveys were made on both bridge decks to assess the performance of the membranes. The surveys consisted of visual observations on the structures, chaining to check for delamination, resistivity readings, and crack measurements. Over 70 percent of the readings were above 1 076 300 ohms/m^2 (100,000 ohms/ft^2) after 8 years. Other results of these surveys are shown Table 8. Very little cracking was observed on either overlay. The resistivity readings were somewhat lower than those of the previous year. Overall, performance of these decks with membranes was satisfactory.

CONCLUSIONS

The general performance of interlayer membranes installed on six existing bridge decks between 1967 and 1971 in Kansas has decreased since 1982 as judged in terms of electrical resistivity measurements and visual distress survey results. The visual distress surveys were supplemented by the condition rating and maintenance history data from the Kansas BMS data base. The membranes used represented the preformed system (NCHRP 165 System 12), liquid/preformed systems (52a and 52b), and liquid system (System 80). Electrical resistivity measurements taken in 1991 on all six bridge decks were compared with those obtained in 1982. The results showed that the two bridge deck membranes that have performed most effectively for the last 20 to 25 years were both liquid/preformed systems (Systems 52a and 52b). These were nonwoven polypropylene fabrics with an asphaltic overlay placed as a wearing surface. The lives of a coal-tar modified polyurethane elastomer interlayer membrane (System 80) and a nonwoven polypropylene fabric system (System 52b) on a very old bridge have been exhausted. The poorest performance was obtained from a preformed polypropylene and coal tar sheet system (System 12) and a liquid membrane system (System 80). In the recent past, KDOT used membranes as part of the maintenance overlays where weight restrictions could not support concrete overlays. Currently, KDOT uses dense concrete/silica-fume concrete bridge decks during new construction.

TABLE 8 Results of Bridge Deck Surreys, 1993

Bridge No.	Percent Delamination	Electrical Resistivity (ohms/m^2) (% greater than) 21,500	107,630	1,076,300
235-87-10.07	1.40	100.0	84.8	54.5
235-87-12.39	1.49	100.0	99.2	84.8

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REFERENCES

1. Bukovatz, J. E., C. F. Crumpton, and H. E. Worley. *Bridge Deck Deterioration Study*. Final Report. State Highway Commission and FHWA, 1973.
2. McCollom, B. F. Design and Construction of Conventional Bridge Decks That Are Resistant to Spalling. In *Transportation Research Record 604*, TRB, National Research Council, Washington, D.C., 1976, pp. 1–5.
3. Mehta, P. K., and P. J. M. Monteiro. *Concrete-Structure, Properties and Materials*, 2nd ed. Prentice Hall, N.J., 1986.
4. Bukovatz, J. E., and C. F. Crumpton. Kansas' Experience with Interlayer Membranes on Salt-Contaminated Bridge Decks. In *Transportation Research Record 962*, TRB, National Research Council, Washington, D.C., 1983, pp. 66–68.
5. Van Til, C. J., B. J. Carr, and B. A. Vallegra. *NCHRP Report 165: Waterproof Membranes for Protection of Concrete Bridge Decks: Laboratory Phase*. TRB, National Research Council, Washington, D.C., 1976.
6. Heston, D., and J. Wojakowski. *Interlayer Membranes on Salt Contaminated Bridge Decks*. Internal Report. Kansas Department of Transportation, Topeka, Kan Aug. 1992.

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