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Field Performance of Latex-Modified and Low-Slump Dense Concrete Bridge Deck Overlays in the United States

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Synopsis: The service life of latex-modified concrete and low-slump dense concrete bridge deck overlays is estimated by extrapolating historical performance data obtained from the results of field research and investigations conducted in the United States and Canada. The data suggest that when concrete removal criteria are based on half-cell potential rather than actual damage, when removal of chloride contaminated concrete is extended to below the rebar, and when the substrate is sandblasted to remove microcracking prior to cleaning, a mean service life of 30 to 50 years is likely.

Keywords: Bridge decks; concretes; latex; microcracking; resurfacing; service life; slump

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INTRODUCTION

Among those treatments in the mainstream of current practice for rehabilitating concrete bridge decks subject to corrosion damage, only latex-modified concrete (LMC) and low-slump dense concrete (LSDC) overlays have been used frequently enough and long enough that reliable experienced-based estimates of service life can be made (1). Such estimates are important because they are the basis for life cycle cost analyses. Also, once a condition decay curve has been established, it can provide a standard against which to judge the potential service life of new alternative treatments during their early years of service.

The first LMC bridge deck overlay was placed in Michigan in 1957 (2); and the first LSDC overlays, in Iowa (3) and Kansas (4) in the early 1960s. Their intent was to restore the riding surface of the deck, to guarantee a specified minimum protective cover of chloride-free concrete, and to reduce the rate of future chloride ingress by virtue of their low permeability. It has been speculated that these overlays may also reduces corrosion rate by restricting the movement of oxygen and moisture to the surface of the reinforcement (5). Use of these systems was given impetus in the 1970s with publication of early results of the Federal Highway Administration's time-to-corrosion study (6,7), and by 1977 21 states reported one or both treatments to be a standard practice for deck rehabilitation (8). By 1989, that number had increased to 37 states (9).

In general, these high performance concrete overlays have been viewed as a cost effective way to repair and extend the life of a damaged deck and to retard the development of future corrosion damage, but not as a way to stop corrosion (8). Opinions regarding their service life vary widely, but average about 16 years (1). Work recently completed under Strategic Highway Research Project C-103, "Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques", included estimating the service life of these treatments from historical data. Those estimates were made by extrapolating condition data reported by highway agencies in the United States and Canada, representing overlay evaluations made through 1991 (1, 10). The purpose of this paper is to describe those estimates and the basis upon which they were made.

THE DATA BASE

The data base was developed from a variety of sources, including: the open literature, questionnaires mailed to highway agencies, FHWA experimental features and demonstration project reports, and personal contacts. All primary leads were followed up by telephone to clarify and supplement the preliminary data and to develop secondary leads. For the purpose of the study, overlay performance was taken to be the change in condition of the overlay with time as measured by the cumulative percent of deck area damaged by delamination or spalling. No attempt was made to distinguish delaminations associated with bond failures from those associated with rebar corrosion and, unless otherwise indicated, patching was assumed to represent repaired spalls. Cracking, per se, was not included as a measure of condition.

Only data meeting the following criteria were included in the data base:

1) The condition evaluation must be quantitative, in the terms stated above;
2) The age of the evaluated deck in years (winters of service) at the time of the evaluation(s) must be known;
3) The deck surface area evaluated must be known or the damage must be expressed as a proportion of the area evaluated;
4) The geographic location of the deck must be known so that climatological data could be obtained; and
5) The AADT must be available for the portion of the

deck evaluated.

Very little of the potentially useful data that was identified failed to meet the last four criteria.

Even though LMC and LSDC overlays have become widely accepted as bridge deck rehabilitation treatments and have been used extensively in the United States and elsewhere for 15-20 years, quantitative performance data were found to be scarce. Much of what was found existed in formal agency reports published to meet requirements of the HP&R or Experimental Features programs of FHWA, which are generally available; and in informal agency reports intended primarily for internal use, which are not generally available. Much of the data had not been published in any form and was provided raw from agency files. Only a small amount was in the open literature.

The data search identified 34 different field studies or investigations. Some of the studies (three) included as few as a single overlay application; one included as many as 50. Over one- half of them (twenty) included 5 applications or less. These studies were conducted by 16 different highway agencies and generated a total of 727 independent condition evaluations (286 LMC, 441 LSDC) of 305 individual overlay applications (152 LMC, 153 LSDC). The nature of the studies varied greatly. Many, apparently intended only to investigate first cost, constructability and early life performance, included overlays evaluated only once or twice (Figure 1), typically in the first few years after placement.

Others, clearly conceived to track longer-term performance as well, have been evaluated more frequently (Figure 1) and for longer periods of time (Figure 2). However, the available condition data for overlays diminishes after 10 years (Figure 3) and for overlays in service for more than 15 years is scant (Figure 3). The raw data from which the above summaries have been compiled, as well as the tables and figures that follow, is stored in the SHRP Project C-103 files.

SERVICE LIFE ESTIMATES

The historical data for LMC and LSDC overlays is summarized in Tables 1 and 2 in which overlay condition is represented by the mean percent of deck area damaged for all of the overlays evaluated at each of the treatment ages indicated. Scattergrams of the mean damage values in Table 1, through the 15th year, are plotted for LSDC overlays in Figure 4a, for LMC overlays in Figure 4b, and for all of the overlays combined in Figure 4c. Because of the paucity of data for ages beyond 15 years, mean damage values for those years are not included in the scattergrams.

Even a casual comparison of Figures 4a and 4b suggests that differences in overlay type (LMC or LSDC) have not had a significant influence on the performance of those overlays that have been tracked, at least for the first 15 years of their life. However, examination of the differences in performance among overlays in individual study groups did reveal differences that are of considerable significance. These study-to-study differences were unrelated to the generic type of overlay (LMC or LSDC) or to any of the design, environmental or traffic factors that had been recorded for each of the treatment applications (overlay thickness, mean annual snowfall, snow storm frequencies, mean annual temperature and AADT). Typical of these differences is the example shown in Figure 5, which illustrates the performance of two groups of LSDC overlays constructed at different times by the same agency, but under different sets of conditions. Between the time that the first group was applied in the 1965-1972 period and the second group was applied in the 1973-1978 period, the agency had changed their deck preparation practices to remove not only damaged concrete but also concrete with half-cell potentials more negative than - 0.35 v, and to assure a that newly exposed surfaces were freer of construction-induced mirocracking than before by altering concrete removal techniques.

When the performance trend for each of the eleven individual studies for which enough data exists to define such a trend is calculated and the resulting trend lines are viewed together, as in Figure 6, two distinct performance groups with differences similar to those illustrated in Figure 5 become apparent:

- <u>Performance Group I</u> - consisting of 6 of the study groups, 4 LSDC and 2 LMC; and
- <u>Performance Group II</u> - consisting of 5 of the study groups, 4 LSDC and 1 LMC.

Clearly, the service life potential of overlays in these two groups has to be considered independently.

The principal factors found to distinguish between them were the amount of chloride contaminated concrete allowed to remain in contact with rebar in the substrate, and the emphasis given to preparation of the substrate surface prior to overlay. Those treatments for which concrete removal criteria were based on half-cell potential rather than damage, for which concrete removal extended to below the rebar, and for which extraordinary care was taken to preclude the overlay being placed on microfractured substrate concrete, tended to be associated with Performance Group II. Sandblasting was used by at least one of the agencies as a final treatment before cleaning the surface prior to overlay.

For Performance Group I, mean damage values are given in Table 2 and are plotted for the first 15 years of service in Figure 7. These data suggest little difference between the performance of LMC and LSDC overlays in the first 15 years of service, and particularly in the first 10 years where the data is more abundant. The estimates of overlay service life are based on extrapolating the historical data to a condition of 40 percent total damage, as defined above. The 40 percent value has precedent in both the action policies of transportation agencies (11) and experience (12). A complete rationale for this criterion is given in Reference 1. Taking the two overlay types together:

1) A mean service life of 28.4 years is projected by straight-line least squares extrapolation; and
2) A mean service life of 18.2 years is projected by the best fit curvilinear function.

Both straight-line and curvilinear functions are given in Figure 7 because it is not yet clear from experience whether the decay curve for overlays should be represented by a straight line, as suggested by the performance curves of individual data sets (for example, those shown in Figures 5 and 6), or by a curved line of increasing slope, as has been the experience with unprotected decks (1). A modest argument in favor of the latter could be made on the basis of the slightly higher explanation provided by the curvilinear function, 0.92 vs 0.81, than by the straight line. Until this issue is clarified, a reasonable estate for the mean service life of overlays in Group I, in the absence of local experience to the contrary, would be an average of the two extrapolated values, or about 23 years.

For Performance Group II, mean damage values are also given in Table 2, and are plotted in Figure 8 where they have been superimposed on a 50-year, service-life trend line. Because the decay curve for these overlays is so flat, no distinction has been made between LMC and LSDC. While their performance to date does not lend itself to realistic extrapolation, it is safe to say that the Group II overlays have the potential for exceeding the service life of the Group I overlays very significantly. A 30-year minimum life is considered probable and one approaching 50 years possible.

SUMMARY

The use of thin, high performance concrete overlays to rehabilitate corrosion-damaged concrete bridge decks in the United States and Canada has been one of the highway industry's success stories of the last 20 years. Experience suggests that these treatments have the potential for extending the useful life of the riding surface of decks for considerably longer than had previously been thought. Variations in climate, traffic volume, and overlay type and thickness appear to be far less important determinants of their performance than the methods used to prepare the deck before the overlay is placed. When concrete removal criteria are based on half-cell potential rather than present damage, when removal of chloride contaminated concrete is extended to below the rebar, and when the substrate is sandblasted to remove microcracking prior to cleaning, service life potentials of 30 to 50 years are likely.

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TABLE 1 — AVERAGE CONDITION OF OVERLAYS AT DIFFERENT AGES BY OVERLAY TYPE

Age in Yrs.	LSDC Number of Cond. Evals.	LSDC Mean Percent Damage	LMC Number of Cond. Evals.	LMC Mean Percent Damage	Combined Number of Cond. Evals.	Combined Mean Percent Damage
1	19	0.06	50	0.07	69	0.07
2	15	0.11	46	0.15	61	0.14
3	17	0.70	29	1.53	46	1.22
4	48	0.94	27	3.81	75	1.97
5	38	1.01	16	2.73	54	1.52
6	49	2.45	11	2.22	60	2.41
7	29	5.73	28	5.40	57	5.57
8	55	5.38	17	16.20	72	7.93
9	39	8.24	15	10.83	54	8.96
10	50	7.61	11	10.00	61	8.04
11	22	13.85	11	16.90	33	14.90
12	20	5.07	4	11.92	24	6.26
13	10	10.48	4	23.95	14	14.33
14	14	14.27	6	17.26	20	12.36
15	10	16.80	5	17.80	15	17.13
16	2	11.65	5	1.92	7	4.70
17	3	10.55	0	--	3	10.55
18	0	--	0	--	0	--
19	1	5.90	0	--	1	5.90
20	0	--	1	2.60	1	2.60
	441		286		727	

TABLE 2 — AVERAGE CONDITION OF OVERLAYS AT DIFFERENT AGES BY PERFORMANCE GROUP

	Group 1 LSDC		Group 1 LMC		Group 2	
Age	Number of Points	Mean Value	Number of Points	Mean Value	Number of Points	Mean Value
1	13	0.09	50	0.07	6	0
2	12	0.14	40	0.17	8	0
3	13	0.92	29	1.53	4	0
4	17	1.79	26	3.96	32	0.47
5	13	2.76	16	2.73	25	0.10
6	19	6.23	11	2.22	30	0.05
7	23	7.18	22	6.98	13	0.06
8	24	11.09	15	16.99	33	1.52
9	26	11.90	15	10.83	13	0.92
10	25	13.59	9	12.21	27	1.50
11	21	13.85	9	20.60	2	0.25
12	10	9.06	4	11.92	10	1.40
13	9	11.64	4	23.95	1	0
14	10	18.61	6	17.26	4	3.41
15	10	16.80	4	22.25	1	0
16	2	10.65	0	--	5	1.92
17	3	10.55	0	--	0	--
18	0	--	0	--	0	--
19	1	5.90	0	--	0	--
20	0	--	0	--	1	2.60
	252		260		215	