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# Performance and Service Life Of Low-Slump-Concrete Bridge Deck Overlays in New York

WILLIAM P. CHAMBERLIN

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# PERFORMANCE AND SERVICE LIFE OF LOW-SLUMP-CONCRETE BRIDGE DECK OVERLAYS IN NEW YORK

William P. Chamberlin, P.E.

Final Report on Research Project 190-1
Conducted in Cooperation With
The U. S. Department of Transportation
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16. Abstract
Fifty randomly selected concrete bridge decks in New York State, overlaid with low-slump concrete, were studied in 1985 after an average of 5 years of service. The investigation included recording surface defects, measuring delamination and half-cell potentials, and sampling and testing for deck chloride profile. Conclusions are drawn with regard to the nature and significance of the observed damage, and estimates are made of service life expectancy. Policy implications for the New York State Department of Transportation are discussed.

NOTE: This report was drafted before the author's retirement from the New York State Department of Transportation in July 1988. It appeared in slightly different form in Corrosion of Metals in Concrete, Proceedings of the CORROSION/87 Symposium on Corrosion of Metals in Concrete, National Association of Corrosion Engineers (pp. 1-12), and in Corrosion, the Journal of Science and Engineering, Vol. 44, No. 6, NACE, June 1988 (pp. 397-483).

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# METRIC CONVERSION FACTORS

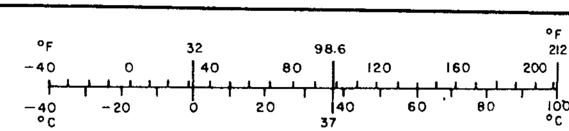
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | **AREA** | | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | **MASS (weight)** | | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | **VOLUME** | | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | **TEMPERATURE (exact)** | | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | **LENGTH** | | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | **AREA** | | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | **MASS (weight)** | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | **VOLUME** | | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | **TEMPERATURE (exact)** | | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# I. INTRODUCTION

## A. Purpose

This report documents a study of the condition of low-slump-concrete (LSC) overlays used in rehabilitation of corrosion-damaged bridge decks in New York State, plus an attempt to estimate service life of these treatments. The study was part of a technical and management review of the New York State Department of Transportation's (NYSDOT) bridge deck rehabilitation program, and sought to answer the questions "How well are we doing?" and "Can we do better?" The report focuses on three areas: 1) deck overlay condition, 2) chloride accumulation in the overlay, and 3) service-life prediction.

## B. Background

Rehabilitation of concrete bridge decks prematurely damaged by corrosion of embedded reinforcing steel continues to be a major concern for highway agencies. A NYSDOT Bridge Preservation Board report indicated that 1251 decks were candidates for the monolithic bridge deck overlay program established in 1976. By the end of 1985, 604 of these had been overlaid. In 1986, it was estimated that $20 billion would be required nationwide to rehabilitate existing damaged decks and that the amount would increase by $500 million annually (1). The bridge deck "problem" continues to be reported extensively in the engineering and trade literature (2,3,4).

A common approach to rehabilitating corrosion-damaged decks has been to overlay the repaired surface with a layer of low-permeability concrete. Typically, this material is either a latex-modified or low-slump concrete. In the former, low permeability derives from formation within the capillary voids of a continuous network of coalesced latex particles; in the latter, from low capillary porosity due to a very low water-cement ratio. In theory, overlays restore the riding surface, guarantee a specific minimum protective cover of chloride-free concrete over the reinforcement, and reduce the rate of future chloride ingress. It has been speculated that overlays also reduce the corrosion rate by interfering with movement of oxygen and moisture to the surface of the reinforcement (5). Such overlays are generally considered a cost-effective way to repair and extend deck service life, but not as a means of stopping corrosion. NYSDOT specifications permit both types of overlay material, at contractor option, but until recently LSC has predominated by a factor of about 7 to 1.

LSC overlays were first used for bridge deck rehabilitation in New York in 1976. By the end of 1983, 1558 individual spans on 367 bridges had been contracted for rehabilitation by this method (Fig. 1). Like those of most

**Figure 1. New York bridge decks contracted for rehabilitation with LSC.**

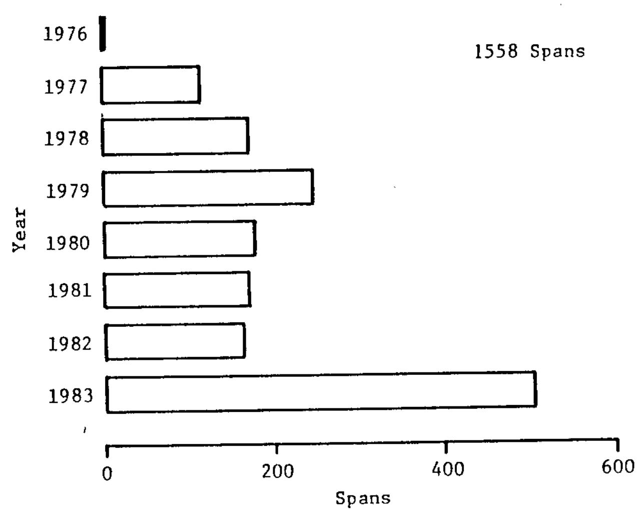
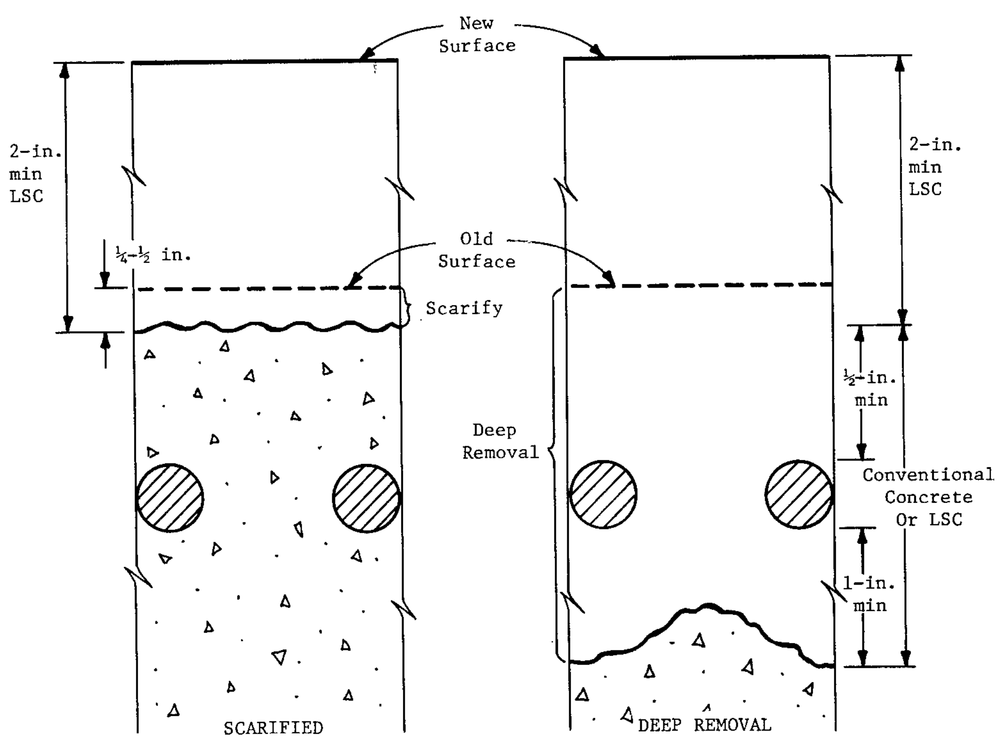



**Figure 2. Typical cross-sections for LSC rehabilitation in New York.**



other LSC users, construction methods in New York are patterned after techniques first employed in the early 1960s in Iowa (6) and Kansas (7). Use of LSC in both new construction and rehabilitation was given major impetus by the Federal Highway Administration as a result of their "time-to-corrosion" studies of the early 1970s (8,9).

## C. New York State Practice

Rehabilitation of decks with LSC followed practices then fairly standard nationwide. Simply stated, they consisted of the following steps:

1. Spalled, debonded, or otherwise damaged concrete was removed to a depth required to expose a sound surface, but to at least 1 in. below the bottom of any exposed reinforcing, referred to here as "deep removal."

2. All concrete associated with copper sulfate electrode (CSE) half-cell potentials more negative than -0.35 v was similarly subject to deep removal.

3. All other concrete surfaces were scarified to a depth of 1/4 to 1/2 in.

4. Exposed steel reinforcement was sandblasted to remove all but firmly bonded rust.

5. To eliminate microfractures, newly exposed concrete surfaces were sandblasted.

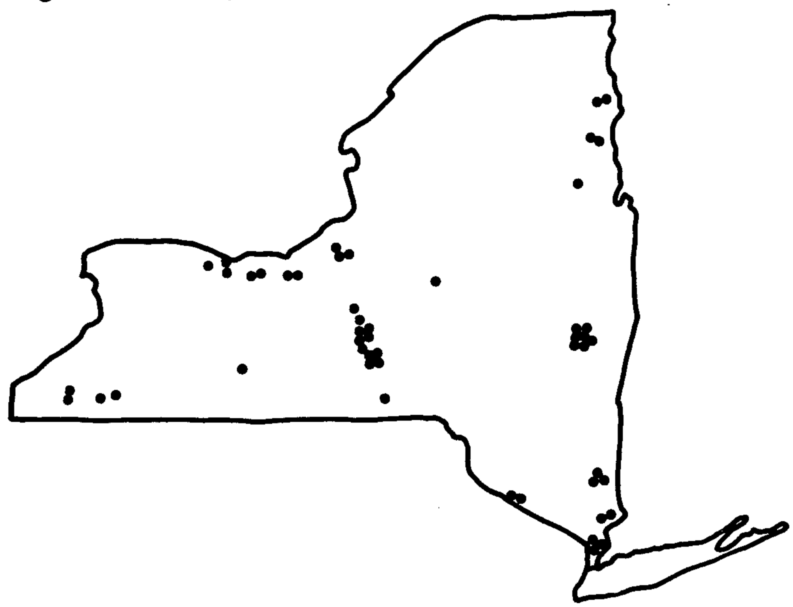
6. Excavated areas were filled to the level of the scarified deck with conventional concrete or LSC and cured.

7. The entire deck was then overlaid with a minimum of 2 in. of LSC, bonded with a portland cement mortar grout, compacted with an oscillating-screed finishing machine to a minimum density of 97.5 percent theoretical unit weight, and cured with wet burlap for a minimum of 72 hours.

The principal deviation from the practice of most other state highway agencies was in Step 2. New York required removal of damaged concrete as well as all concrete associated with half-cell potentials more negative than -0.35 v CSE. Most state highway agencies remove only damaged concrete. Typical cross-sections for the NYSDOT practice are shown in Figure 2. The nominal LSC mix design was as follows:

| | |
|---|---|
| Cement Factor, lb/cy | 826 |
| Water-Cement Ratio | 0.327 |
| Fine-Coarse Aggregate Ratio | 1.0 |
| Air Content, percent | 4.0-8.0 |
| Slump, in. | 1 max |
| Conventional Water Reducer | Used |

Figure 3. Geographic distribution of study spans.



D. Sample Design and Survey Procedures

A random study sample of 50 spans was selected from among the 598 spans (167 bridges) placed under contract during the three-year period 1979-81. "Span" rather than "bridge" was taken as the unit of sampling to permit the greatest diversity possible among sample attributes. Earlier studies of bridge deck performance had shown that variation in performance among spans of the same bridge could be as great as that between individual bridges. Spans contracted before 1979 were not included because specifications and construction methods were significantly different before that date and not representative of current practices. A three-year sample period was chosen instead of a one- or two-year period for the same considerations of sample diversity.

The sample eventually drawn included representation from all the Department's administrative regions where overlays had been placed during the sample period, except Long Island. It also included about one-half the period's overlay contractors -- a group accounting for two-thirds of the overlays placed during the sample period. The sample was well distributed geographically (Fig. 3) and included approximately equal areas of scarified surface (109,495 sq ft) and deep removal (94,699 sq ft). The study spans had experienced an average of 4.8 winters of service when inspected. Attributes of the individual study spans are given in Table 1.

Condition surveys were completed over a four-month period between June and October 1985. They included visual examination for a variety of distress forms, chain dragging to detect subsurface fractures, measurement of half-cell potential to detect corrosion activity, and sampling for chloride content. A search of records for these spans revealed a variety of topics of interest, the most relevant being boundaries between areas of deep removal and scarification, and dates the structures were completed.

**Table 1. Attributes of individual study spans.**

| Control Span | Bin Number | County | Contract # | Contractor | Year Overlay Placed | Route | Over | Span | Deck Area (sf) | Scarified (sf) | Deep Removal (sf) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | B1092981 | Albany | D96065 | H. D. Reichert | 1980 | 9 & 20 | Hudson River | 16th | 5040 | 604.8 | 4435.2 |
| 2 | B1092981 | Albany | D96065 | H. D. Reichert | 1979 | 9 & 20 | Hudson River | 18th | 5371 | 1826.1 | 3544.9 |
| 3 | B1092981 | Albany | D96065 | H. D. Reichert | 1979 | 9 & 20 | Hudson River | 17th | 5203 | 1404.8 | 3798.2 |
| 4 | B1052741 | Putnam | D96567 | Gunite Masonry | 1981 | I-84 | Ludington Rd | 1st | 1443 | 418.5 | 1024.5 |
| 5 | B1033612 | Warren | D96380 | Callanan Industries | 1981 | I-87(NB) | Upper Valley Rd | 2nd | 1872 | 1310.4 | 561.6 |
| 6 | B1092881 | Albany | D96459 | H. D. Reichert & | 1981 | I-787(SB) | Clinton Ave | 4th | 6987 | 0 | 6987 |
| 7 | B1092881 | Albany | D96459 | Beltrone | 1981 | I-787(SB) | Clinton Ave | 7th | 5750 | 0 | 5750 |
| 8 | B1033721 | Essex | D96668 | Callanan Industries | 1981 | I-87(NB&SB) | West Mill Brook | 1st | 5418 | 4226 | 1192 |
| 9 | B1033722 | Essex | D96668 | Callanan Indistries | 1981 | I-87(NB&SB) | West Mill Brook | 1st | 5250 | 0 | 5250 |
| 10 | B1054220 | Essex | D96669 | Callanan Industries | 1981 | 22 | I-87 | 1st | 2800 | 1792.0 | 1008 |
| 11 | B1054220 | Essex | D96669 | Callanan Industries | 1981 | 22 | I-87 | 2nd | 3136 | 501.8 | 2634.2 |
| 12 | B1051521 | Oneida | D96386 | Youngstown Pneumatic Concrete | 1980 | 8(SB) | Erie Lackawana RR | 1st | 1736 | 781.2 | 954.8 |
| 13 | B1031301 | Cortland | D96067 | Harrison & Burrows | 1980 | I-81(SB) | Rt 221 | 3rd | 1092 | 1092 | 0 |
| 14 | B1031322 | Cortland | D96067 | Harrison & Burrows | 1980 | I-81(NB) | Russell Rd | 2nd | 2772 | 2744.3 | 27.7 |
| 15 | B1031322 | Cortland | D96067 | Harrison & Burrows | 1980 | I-81(NB) | Russell Rd | 3rd | 2744 | 2744 | 0 |
| 16 | B1031341 | Cortland | D96067 | Harrison & Burrows | 1980 | I-81(NB) | McGraw Rd | 2nd | 1410 | 1410 | 0 |
| 17 | B1031441 | Cortland | D96067 | Harrison & Burrows | 1979 | I-81(SB) | CR 108B | 1st | 1260 | 1071 | 189 |
| 18 | B1031441 | Cortland | D96067 | Harrison & Burrows | 1979 | I-81(SB) | CR 108B | 2nd | 1410 | 1410 | 0 |
| 19 | B1031470 | Cortland | D96067 | Harrison & Burrows | 1979 | CR 106 | I-81 | 1st | 1230 | 1230 | 0 |
| 20 | B4051011 | Onondaga & Oswego | D96332 | Barry & Bette | 1980 | I-481(SB) | Oneida River | 3rd | 8970 | 5112.9 | 3857.1 |
| 21 | B4051011 | Onondaga & Oswego | D96332 | Barry & Bette | 1980 | I-481(SB) | Oneida River | 4th | 6630 | 4044.3 | 2585.7 |
| 22 | B4060680 | Wayne | D96493 | Eastern Rock | 1981 | 414 | Clyde River | 1st | 3720 | 1711.2 | 2008.8 |
| 23 | B4060680 | Wayne | D96493 | Products | 1981 | 414 | Clyde River | 3rd | 2850 | 1168.5 | 1681.5 |
| 24 | B1034250 | Wayne | D96767 | R. C. Siebert, Inc. | 1982 | 88 | Ganargue Creek | 2nd | 2604 | 729.1 | 1874.9 |
| 25 | B4022190 | Wayne | D96767 | R. C. Siebert, Inc. | 1982 | 31F & 350 | Barge Canal | 1st | 1120 | 672 | 448 |
| 26 | B1052239 | Monroe | D95906 | Penn-Crete Corp. | 1979 | 104(EB) | Irondequoit Bay | 6th | 14280 | 11709.6 | 2570.4 |
| 27 | B1062480 | Monroe | D96336 | R. C. Siebert, Inc. | 1980 | 47(WB) | Rochester Loop | 1st | 2000 | 1700 | 300 |
| 28 | B3349300 | Broome | D96887 | H. D. Reichert & Beltrone | 1982 | Bevier St | Chenango River | 1st | 5808 | 4297.9 | 1510.1 |
| 29 | B1092882 | Albany | D96952 | H. D. Reichert & Beltrone | 1982 | I-787(NB) | Clinton Ave | 2nd | 8280 | 7866 | 414 |
| 30 | B1062792 | Cattaraugus | D96088 | Union Crete | 1979 | 17 | Red House Ramps | 1st | 4400 | 0 | 4400 |
| 31 | B6062761 | Cattaraugus | D96088 | Union Crete | 1980 | 17 | Allegany Reserv | 2nd | 4200 | 0 | 4200 |
| 32 | B1062622 | Chautauqua | D96494 | L. C. Whitford Co. | 1981 | 17 | Erie Lackawana RR | 1st | 2520 | 0 | 2520 |
| 33 | B1062621 | Chautauqua | D96494 | L. C. Whitford Co. | 1981 | 17 | Erie Lackawana RR | 4th | 1988 | 0 | 1988 |
| 34 | B1061880 | Steuben | D96430 | Youngstown Pneumatic Concrete | 1980 | CR 70A | 17 | 1st | 7021 | 4563.6 | 2457.4 |
| 35 | B1031422 | Cortland | D96067 | Harrison & Burrows | 1979 | I-81 | CR 109 | 3rd | 1260 | 1020.6 | 239.4 |
| 36 | B1053121 | Westchester | D96099 | Melwood Construction | 1980 | I-684 | Beaver Dam Rd | 3rd | 4884 | 2686.2 | 2197.8 |
| 37 | B1052920 | Westchester | D96099 | Melwood Construction | 1979 | Ramp C | I-684 | 1st | 3080 | 2772 | 308 |
| 38 | B1052920 | Westchester | D96099 | Melwood Construction | 1979 | Ramp C | I-684 | 2nd | 4200 | 2016 | 2184 |
| 39 | B1052920 | Westchester | D96099 | Melwood Construction | 1979 | Ramp C | I-684 | 3rd | 4440 | 3862.8 | 577.2 |
| 40 | B1032441 | Orange | D96402 | I & O Slutsky | 1980 | I-84 | CR 15 | 1st | 3304 | 1057.3 | 2246.7 |
| 41 | B1031301 | Cortland | D96067 | Harrison & Burrows | 1980 | I-81(SB) | Rt 221 | 2nd | 1680 | 1629.6 | 50.4 |
| 42 | B1052361 | Dutchess | D96098 | I & O Slutsky | 1979 | I-84(WB) | Rt 52 | 2nd | 3180 | 699.6 | 2480.4 |
| 43 | B1030661 | Onondaga | D96067 | Harrison & Burrows | 1979 | I-81(SB) | Rt 80 | 2nd | 1380 | 1380 | 0 |
| 44 | B1053121 | Westchester | D96099 | Melwood Construction | 1980 | I-684(SB) | Broadbrook Rd | 2nd | 4972 | 2038.5 | 2933.5 |
| 45 | B1031422 | Cortland | D96067 | Harrison & Burrows | 1979 | I-81(SB) | CR 109 | 1st | 1230 | 996.3 | 233.7 |
| 46 | B1052239 | Monroe | D95906 | Penn-Crete Corp. | 1979 | 104(EB) | Irondequoit Bay | 8th | 8680 | 5381.6 | 3298.4 |
| 47 | B1064720 | Oswego | D96332 | Barry & Bette | 1981 | 264 | I-481 | 2nd | 6313 | 5744.8 | 568.2 |
| 48 | B1092881 | Albany | D96459 | H. D. Reichert & Beltrone | 1981 | I-787 | Clinton Ave | 9th | 8591 | 4123.7 | 4467.3 |
| 49 | B1052771 | Putnam | D96567 | Gunite Masonry | 1981 | I-84 | Rt 311 | 1st | 4485 | 2332.2 | 2152.8 |
| 50 | B1052402 | Orange | D96698 | I & O Slutsky | 1981 | I-84(EB) | Delaware & Neversink Rivers | 3rd | 4200 | 3612 | 588 |

## Table 2. Condition of individual study spans.

| Control Span | Deck Area (sf) | Cracking: Pattern (% of deck area) | Cracking: Other (lf/100sf) | Delamination (sf): @ Armored Joints | Delamination (sf): @ Constr Joints | Delamination (sf): Interior Slab | Spalling (sf): @ Armored Joints | Spalling (sf): @ Constr Joints | Spalling (sf): Interior Slab | Patching (sf): @ Armored Joints | Patching (sf): @ Constr Joints | Patching (sf): Interior Slab |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5040 | 0.2 | 0.30 | 0 | 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5371 | 39.7 | 2.76 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 44.5 |
| 3 | 5203 | 20.3 | 0.93 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 4 | 1443 | 0.0 | 1.52 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1872 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 6987 | 10.1 | 0.00 | 4 | 51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5750 | 4.6 | 1.44 | 28 | 44.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 5418 | 0.0 | 0.79 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 5250 | 25.9 | 1.51 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 2800 | 100.0 | 40.00 | 0 | 0 | 206 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 3136 | 100.0 | 35.71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1736 | 1.4 | 2.82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 1092 | 0.0 | 0.00 | 0 | 0 | 0 | 3.5 | 0 | 0 | 0 | 0 | 0 |
| 14 | 2772 | 10.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 2744 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 1410 | 0.0 | 0.00 | 0 | 0 | 0 | 24.5 | 0 | 0 | 0 | 0 | 0 |
| 17 | 1260 | 0.0 | 0.00 | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 |
| 18 | 1410 | 0.0 | 0.00 | 0 | 0 | 0 | 12.5 | 0 | 0 | 0 | 0 | 0 |
| 19 | 1230 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 8970 | 3.7 | 2.21 | 0 | 15 | 172 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 6630 | 0.5 | 0.00 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 3720 | 0.0 | 1.67 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | 2850 | 0.0 | 3.54 | 0 | 0 | 72 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 2604 | 10.4 | 4.70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 1120 | 0.0 | 16.83 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 26 | 14280 | 0.0 | 8.12 | 0 | 0 | 89 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 2000 | 0.0 | 1.65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 28 | 5808 | 0.0 | 0.09 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 8280 | 0.4 | 0.35 | 0 | 19.5 | 0 | 0 | 0 | 0 | 0 | 0 | 12.5 |
| 30 | 4400 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | 4200 | 0.0 | 6.71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | 2520 | 0.0 | 6.71 | 0 | 0 | 0 | 6.5 | 0 | 0 | 0 | 0 | 0 |
| 33 | 1988 | 0.0 | 0.80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | 7021 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | 1260 | 0.0 | 0.00 | 0 | 0 | 0 | 15.5 | 0 | 0 | 0 | 0 | 0 |
| 36 | 4884 | 0.0 | 4.19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| 37 | 3080 | 0.0 | 1.07 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | 4200 | 2.1 | 1.45 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | 4440 | 2.4 | 1.15 | 81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | 3304 | 0.0 | 5.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | 1680 | 0.0 | 0.00 | 4 | 9 | 0 | 14.5 | 0 | 0 | 0 | 0 | 0 |
| 42 | 3180 | 0.0 | 2.59 | 29 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 |
| 43 | 1380 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 4972 | 1.2 | 3.27 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 47 |
| 45 | 1230 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 8680 | 0.3 | 4.08 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 6313 | 0.0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | 8591 | 0.0 | 0.77 | 37 | 14 | 63 | 19 | 0 | 0 | 0 | 0 | 20 |
| 49 | 4485 | 0.0 | 1.68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | 4200 | 6.5 | 8.06 | 0 | 46 | 130 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 204,194 | | | 269 | 314.0 | 801 | 118.0 | 0 | 0 | 0 | 0 | 158.0 |

## II. RESULTS AND DISCUSSION

### A. General

The data were examined from two points of view. First, condition of the "average" span was characterized in terms of those features reflecting the degree to which rehabilitation treatment had protected the deck from further corrosion damage. In this regard, spalling, delamination, half-cell potential, and chloride accumulation data were relevant. Because of the randomness of the sample, such characterizations could be extrapolated to all spans built during the study period and thus provide a five-year "report card" on effectiveness of the treatment.

Second, variations in condition, both among and within spans, were correlated with other data to help understand cause-and-effect relationships. Of particular interest here were differences in condition between areas of deep removal and those that had only been scarified. Areas of deep removal are analogous to original construction with uncoated reinforcement and deep cover. Areas of scarification can be assumed to have much of their reinforcement surrounded by concrete that was contaminated with chloride before the rehabilitation treatment.

### B. Deck Overlay Condition

Potentially corrosion-related physical damage (including delaminations and spalls) was found on 31 (62 percent) of the study spans. It was associated with corrosion of armored expansion joints, with failure of cold construction joints, and with locations on the slab potentially related to corroding reinforcement. A total of 1660 sq ft of deck surface was affected -- 0.81 percent of the total deck area examined. Condition of individual study spans is given in Table 2 and summarized in Table 3.

Although nearly half the damage, including all the spalling, was associated with armored or construction joints, the records search revealed that all patching observed in the survey predated deck opening. It also indicated that post-construction joint damage was associated with only 11 and 6-1/2 percent, respectively, of the total lengths of armored and construction joints. Although damage at these locations is of concern, it is typically innocuous, can be remedied inexpensively by changing design details, and does not reflect directly on integrity of the overlay method itself. It is reported here for information only.

Of far more importance and concern is delamination in interior slab areas. It was found on 10 (20 percent) of the study spans, affecting 801 sq ft (0.39

**Table 3. Deck condition summarized by damage location, mode, and extent.**

| Location of Damage* | Mode of Damage | Extent of Damage: Total Spans | Sq Ft | Percent** |
|---|---|---|---|---|
| Armored Joints (17) | Delamination | 10 | 269 | 0.13 |
| | Spall | 10 | 118 | 0.06 |
| | Subtotals | | 387 | 0.19 |
| Construction Joints (10) | Delamination | 10 | 314 | 0.15 |
| | Spall | 0 | 0 | 0.00 |
| | Subtotals | | 314 | 0.15 |
| Interior Slab (14) | Delamination | 10 | 801 | 0.39 |
| | Spall | 0 | 0 | 0.00 |
| | Patch | 6 | 158 | 0.08 |
| | Subtotals | | 959 | 0.47 |
| Grand Totals | | | 1660 | 0.81 |

*Numbers in parentheses refer to the total number of damaged spans, regardless of mode of damage.
**Percent of total surface area (204,194 sq ft) of the study spans.

**Figure 4. Overlay delamination of ten study spans.**

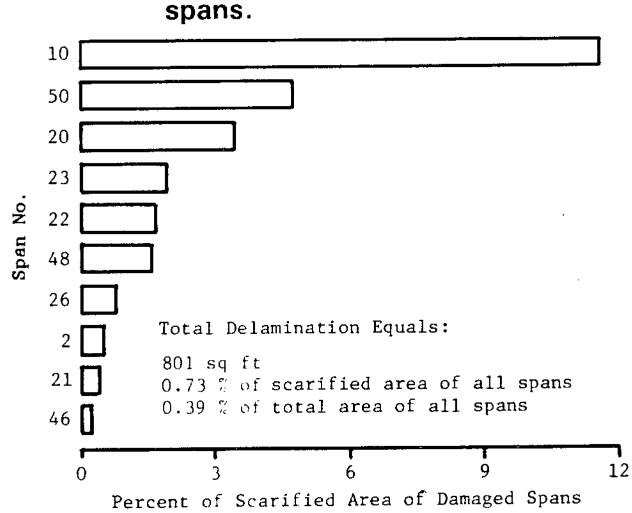


**Table 4. Ranking of damaged spans by potentially corrosion-related attributes.**

| Span | Damage[1] | Chloride[2] | Half-Cell Potential[3] | Pattern Cracking[4] | Other Cracking[5] |
|---|---|---|---|---|---|
| 10 | 1 | 26 | 6 | 1 | 1 |
| 50 | 2 | 4 | 5 | 9 | 5 |
| 20 | 3 | 3 | 24 | 11 | 17 |
| 23 | 4 | 10 | 2 | 34 | 12 |
| 22 | 5 | 7 | 1 | 34 | 18 |
| 48 | 6 | 38 | 43 | 34 | 29 |
| 26 | 7 | 5 | 9 | 34 | 4 |
| 2 | 8 | 13 | 32 | 3 | 14 |
| 21 | 9 | 17 | 33 | 16 | 41 |
| 46 | 10 | 1 | 6 | 18 | 11 |
| r[6] | | 0.60 | 0.52 | 0.52 | 0.54 |

[1]Ranked by percent of total scarified area.
[2]Ranked by mean chloride content 2 to 3 in. below the surface of scarified areas, typically two samples per span.
[3]Ranked by percent of values in scarified areas more negative than -0.35 v.
[4]Ranked by percent of total deck surface affected.
[5]Ranked by linear feet per 100 sq ft of total deck surface.
[6]Spearman rank correlation coefficient (10).

percent of the total deck area of all spans), as shown in Figure 4. Though not surprising, it is highly significant that all this damage occurred in areas of scarification, where it represented 0.73 percent of the total scarified deck area.

The rank correlation of damage in these spans with a high chloride content, elevated half-cell potentials, and occurrence of cracking, is summarized in Table 4. All these rankings correlated positively at the 0.95 level with that for delamination, the correlation with chloride content and "other" cracking being the strongest (10).

It is tempting to pursue more discriminating explanations of the differences in performance among the study spans based on the kinds of data given in Table 4, but probably unwise given the survey objective and level of sampling and examination devoted to it. It is sufficient to add merely that the unexpectedly low chloride ranking of Spans 10 and 48 is unexplained, as is the damage to Span 48 which does not appear to correlate with any of the other attributes.

## C. Half-Cell Potentials

Half-cell potential distributions for individual spans are given in Table 5. Based on this information the following two topics were addressed: 1) the difference in distribution of half-cell potentials between all areas of deep removal and all areas of scarification, regardless of the spans in which the treatments occur, and 2) the difference among groups of spans that were subject to either one or a combination of the two treatments.

## Table 5. Half-cell potentials.

| Control Span | Percent of Values: Scarified Areas N | <0.20v | 0.20v-0.35v | >0.35v | Deep Removal Areas N | <0.20v | 0.20v-0.35v | >0.35v | All Areas N | <0.20v | 0.20v-0.35v | >0.35v |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | 26 | 74 | 0 | 171 | 49 | 51 | 0 | 194 | 46 | 54 | 0 |
| 2 | 138 | 2 | 90 | 8 | 70 | 9 | 77 | 14 | 208 | 4 | 86 | 10 |
| 3 | 151 | 13 | 87 | 0 | 56 | 4 | 94 | 2 | 207 | 10 | 89 | 1 |
| 4 | 45 | 100 | 0 | 0 | 26 | 100 | 0 | 0 | 71 | 100 | 0 | 0 |
| 5 | 19 | 14 | 57 | 29 | 57 | 7 | 84 | 9 | 76 | 12 | 76 | 12 |
| 6 | 0 | 0 | 0 | 0 | 280 | 59 | 40 | 1 | 280 | 59 | 40 | 1 |
| 7 | 0 | 0 | 0 | 0 | 240 | 54 | 44 | 2 | 240 | 54 | 44 | 2 |
| 8 | 45 | 0 | 78 | 22 | 155 | 1 | 99 | 0 | 200 | 1 | 94 | 5 |
| 9 | 0 | 0 | 0 | 0 | 200 | 1 | 91 | 8 | 200 | 1 | 91 | 8 |
| 10 | 43 | 0 | 49 | 51 | 71 | 0 | 46 | 54 | 114 | 0 | 47 | 53 |
| 11 | 19 | 5 | 79 | 16 | 101 | 0 | 71 | 29 | 120 | 1 | 72 | 27 |
| 12 | 38 | 3 | 66 | 31 | 46 | 52 | 41 | 7 | 84 | 30 | 52 | 18 |
| 13 | 45 | 0 | 87 | 13 | 0 | 0 | 0 | 0 | 45 | 0 | 87 | 13 |
| 14 | 97 | 0 | 77 | 23 | 1 | 0 | 0 | 100 | 98 | 0 | 77 | 23 |
| 15 | 97 | 1 | 74 | 25 | 0 | 0 | 0 | 0 | 97 | 1 | 74 | 25 |
| 16 | 54 | 0 | 80 | 20 | 0 | 0 | 0 | 0 | 54 | 0 | 80 | 20 |
| 17 | 41 | 14 | 71 | 15 | 7 | 0 | 86 | 14 | 48 | 12 | 73 | 15 |
| 18 | 54 | 17 | 72 | 11 | 0 | 0 | 0 | 0 | 54 | 17 | 72 | 11 |
| 19 | 48 | 73 | 23 | 4 | 0 | 0 | 0 | 0 | 48 | 73 | 23 | 4 |
| 20 | 203 | 16 | 70 | 14 | 165 | 2 | 90 | 8 | 368 | 10 | 79 | 11 |
| 21 | 168 | 11 | 82 | 7 | 104 | 7 | 93 | 0 | 272 | 9 | 86 | 5 |
| 22 | 72 | 0 | 6 | 94 | 85 | 0 | 60 | 40 | 157 | 0 | 72 | 28 |
| 23 | 46 | 0 | 7 | 93 | 69 | 0 | 77 | 23 | 115 | 0 | 49 | 51 |
| 24 | 26 | 0 | 52 | 48 | 85 | 12 | 76 | 12 | 111 | 9 | 71 | 20 |
| 25 | 29 | 0 | 86 | 14 | 19 | 0 | 89 | 11 | 48 | 0 | 88 | 12 |
| 26 | 468 | 9 | 56 | 35 | 100 | 38 | 43 | 19 | 568 | 14 | 54 | 32 |
| 27 | 68 | 12 | 72 | 16 | 12 | 8 | 92 | 0 | 80 | 11 | 75 | 14 |
| 28 | 173 | 2 | 67 | 31 | 63 | 0 | 68 | 32 | 236 | 1 | 68 | 31 |
| 29 | 322 | 11 | 75 | 14 | 16 | 0 | 100 | 0 | 338 | 10 | 76 | 14 |
| 30 | 0 | 0 | 0 | 0 | 203 | 79 | 21 | 0 | 203 | 79 | 21 | 0 |
| 31 | 0 | 0 | 0 | 0 | 180 | 35 | 65 | 0 | 180 | 35 | 65 | 0 |
| 32 | 0 | 0 | 0 | 0 | 113 | 30 | 67 | 3 | 113 | 30 | 67 | 3 |
| 33 | 0 | 0 | 0 | 0 | 90 | 31 | 67 | 2 | 90 | 31 | 67 | 2 |
| 34 | 194 | 0 | 66 | 34 | 105 | 0 | 57 | 43 | 299 | 0 | 63 | 37 |
| 35 | 42 | 0 | 66 | 34 | 10 | 0 | 18 | 82 | 52 | 0 | 54 | 46 |
| 36 | 109 | 35 | 54 | 11 | 93 | 23 | 76 | 1 | 202 | 29 | 64 | 7 |
| 37 | 111 | 22 | 75 | 3 | 13 | 38 | 54 | 8 | 124 | 24 | 73 | 3 |
| 38 | 71 | 0 | 30 | 70 | 91 | 0 | 60 | 40 | 162 | 0 | 47 | 53 |
| 39 | 167 | 57 | 43 | 0 | 26 | 54 | 46 | 0 | 193 | 56 | 44 | 0 |
| 40 | 42 | 0 | 7 | 93 | 97 | 0 | 51 | 49 | 139 | 0 | 37 | 63 |
| 41 | 66 | 3 | 80 | 17 | 2 | 0 | 100 | 0 | 68 | 3 | 81 | 16 |
| 42 | 29 | 0 | 83 | 17 | 97 | 0 | 61 | 39 | 126 | 0 | 66 | 34 |
| 43 | 54 | 67 | 33 | 0 | 0 | 0 | 0 | 0 | 54 | 67 | 33 | 0 |
| 44 | 81 | 12 | 79 | 9 | 115 | 79 | 21 | 0 | 196 | 51 | 45 | 4 |
| 45 | 41 | 17 | 73 | 10 | 11 | 0 | 80 | 20 | 52 | 14 | 74 | 12 |
| 46 | 213 | 3 | 46 | 51 | 132 | 1 | 60 | 39 | 345 | 2 | 52 | 47 |
| 47 | 234 | 58 | 41 | 1 | 22 | 82 | 18 | 0 | 256 | 60 | 39 | 1 |
| 48 | 157 | 69 | 31 | 0 | 179 | 68 | 32 | 0 | 336 | 68 | 32 | 0 |
| 49 | 85 | 45 | 50 | 5 | 103 | 74 | 26 | 0 | 188 | 61 | 37 | 2 |
| 50 | 142 | 0 | 46 | 54 | 23 | 0 | 61 | 39 | 165 | 0 | 48 | 52 |

Figure 5 shows two distributions of half-cell potentials -- one for the 109,495 sq ft identified as having been treated by scarification, and one for the 94,699 sq ft identified as treated by deep removal. While this distinction is undoubtedly clouded by inability to precisely define boundaries between the two treatments, deep removal clearly has provided a measurably higher degree of protection.

This conclusion is also supported by Figure 6 which contrasts the distribution of half-cell potentials for those spans where the entire surface was subject to either scarification or deep removal alone with those where both treatments were applied on the same deck. These conclusions were based on analysis of the data using the chi-square distribution.

## D. Chloride Contents

An unexpected finding of the study was that chlorides were apparently accumulating at the same rate in LSC overlays as has been found in conventional concrete bridge decks (Fig. 7). This is of great concern because the premium cost of LSC is justified on the basis of its lower chloride permeability. Similar experience has been reported by others (11, 12, 13, 14). Chloride distributions for individual spans are given in Table 6.

The range of chloride accumulation at the 1-1/2- to 2-in. level of these decks is illustrated in Figure 8, which shows that the appearance of comparable accumulations between decks made with different concretes, based on mean chloride contents, is due in part to the skew of data for LSC.

Tests for rapid determination of chloride permeability (AASHTO T 277) performed on 22 sample cores from the study spans yielded values between 1834 and 5560 coulombs (14). These results confirm the wide range of permeability suggested by the data in Figure 8, as well as demonstrate that some LSC in New York bridge deck overlays is significantly more permeable than well-consolidated LSC prepared in the laboratory (15). AASHTO T 227 identified 1000 to 2000 coulombs as "low" permeability, 2000 to 4000 as "moderate," and greater than 4000 as "high."

## E. Service Life Prediction

A principal objective of the study, and the one most difficult to accomplish, was to estimate service life of LSC overlays. Three data sources were drawn on for this purpose:

1. Damage rate studies of New York State bridge decks built with unprotected reinforcement,

2. Service life estimates of LSC overlays in Iowa, prepared from data supplied by the Iowa Department of Transportation, and

3. Data developed from this study on the condition of LSC overlays after an average of 5 years service.

**Figure 5. Half-cell potentials associated with areas subject to different treatments.**

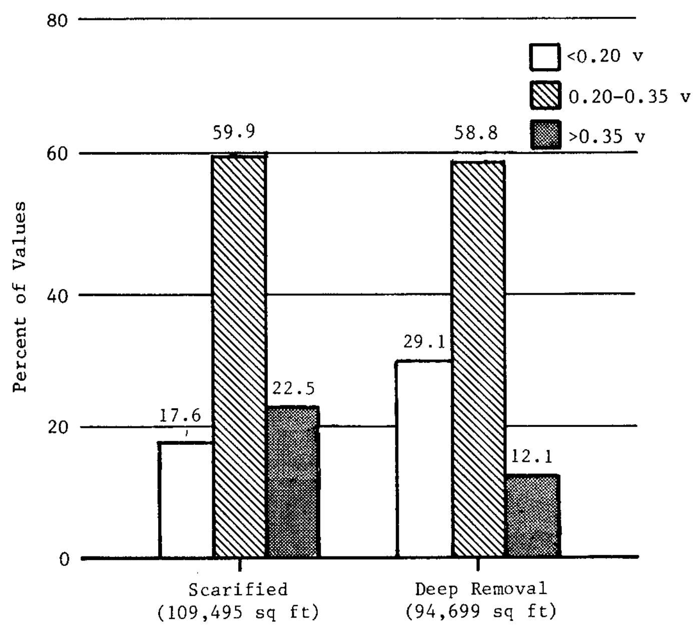



**Figure 6. Half-cell potentials associated with spans subject to different treatments.**

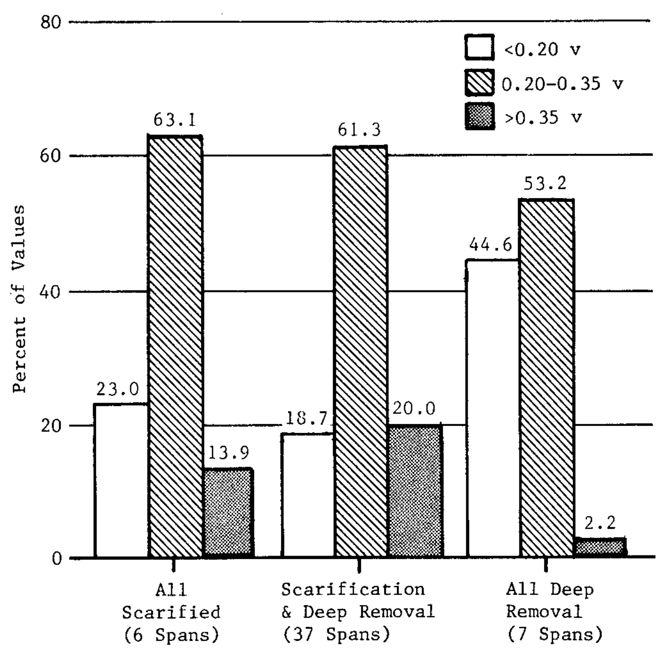


**Figure 7. Chloride accumulation in LSC and conventional concrete decks.**

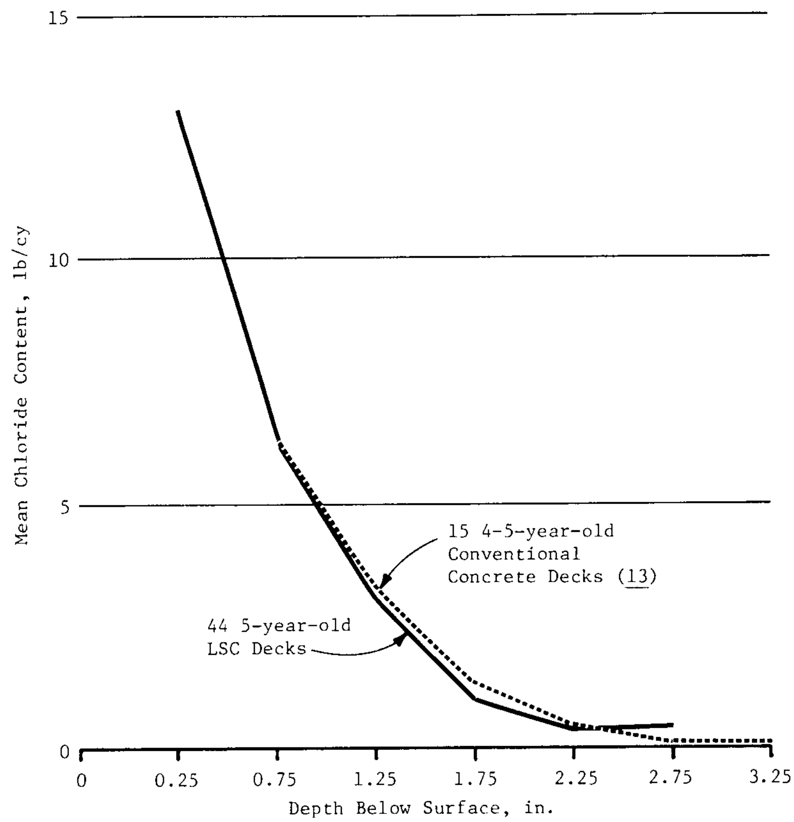
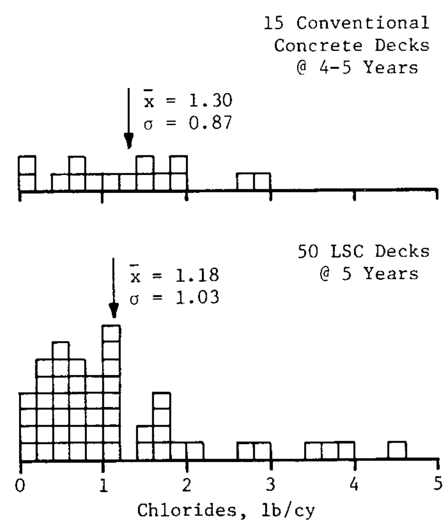



**Figure 8. Chloride accumulation at 1 1/2 to 2 in. depths.**



## Table 6. Chloride contents sampled in summer/fall 1985.

| | 0" - 1/2" | | | | 1/2" - 1" | | | | 1" - 1-1/2" | | | | 1-1/2" - 2" | | | | 2" - 2-1/2" | | | | 2-1/2" - 3" | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SCAR. | | D.R. | | SCAR. | | D.R. | | SCAR. | | D.R. | | SCAR. | | D.R. | | SCAR. | | D.R. | | SCAR. | | D.R. | |
| SPAN | N | X | N | X | N | X | N | X | N | X | N | X | N | X | N | X | N | X | N | X | N | X | N | X |
| 1 | 1 | 11.86 | 2 | 18.82 | 1 | 9.00 | 2 | 9.72 | 1 | 4.54 | 2 | 6.13 | 1 | 2.27 | 2 | 3.16 | 1 | 3.64 | 2 | 1.2 | 1 | 2.5 | 2 | .37 |
| 2 | 2 | 15.53 | 2 | 14.27 | 2 | 7.95 | 2 | 8.08 | 2 | 4.91 | 2 | 4.8 | 2 | 1 | 2 | 2.47 | 2 | 1.88 | 2 | .69 | 2 | 3.52 | 2 | .2 |
| 3 | 2 | 11.49 | 2 | 16.92 | 2 | 5.3 | 2 | 10.61 | 2 | 3.23 | 2 | 7.57 | 2 | 1.39 | 2 | 4.23 | 2 | 2.84 | 2 | 1.77 | 2 | 4.09 | 2 | .26 |
| 4 | 2 | 10.11 | 2 | 9.73 | 2 | 2.59 | 2 | 2.14 | 2 | .23 | 2 | .31 | 2 | 0 | 2 | 0 | 2 | .06 | 2 | 0 | 2 | .45 | 2 | 0 |
| 5 | 2 | 8.45 | 2 | 9.47 | 2 | 5.92 | 2 | 6.05 | 2 | 3.72 | 2 | 2.76 | 2 | .77 | 2 | .51 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 |
| 6 | 0 | | 3 | 12.67 | 0 | | 3 | 3.73 | 0 | | 3 | 1.34 | 0 | | 3 | .29 | 0 | | 3 | .25 | 0 | | 3 | .17 |
| 7 | 0 | | 3 | 11.14 | 0 | | 3 | 4.28 | 0 | | 3 | 1.17 | 0 | | 3 | .21 | 0 | | 3 | 0 | 0 | | 3 | .21 |
| 8 | 2 | 7.44 | 2 | 5.05 | 2 | 3.72 | 2 | 2.27 | 2 | .92 | 2 | .51 | 2 | .43 | 2 | .12 | 2 | .43 | 2 | .12 | 2 | .32 | 2 | .88 |
| 9 | 0 | | 4 | 13.69 | 0 | | 4 | 6.82 | 0 | | 4 | 3.39 | 0 | | 4 | 1.17 | 0 | | 4 | .23 | 0 | | 4 | .26 |
| 10 | 2 | 11.74 | 2 | 9.6 | 2 | 7.7 | 2 | 4.92 | 2 | 4.54 | 2 | 2.27 | 2 | .63 | 2 | .2 | 2 | .2 | 2 | 0 | 2 | 1.59 | 2 | 0 |
| 11 | 2 | 13.51 | 2 | 9.98 | 2 | 8.59 | 2 | 6.69 | 2 | 4.05 | 2 | 3.09 | 2 | .69 | 2 | .74 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 0 |
| 12 | 2 | 14.15 | 2 | 13.01 | 2 | 7.07 | 2 | 6.19 | 2 | 3.49 | 2 | 1.57 | 2 | 1.57 | 2 | .18 | 2 | 4.11 | 2 | .31 | 2 | 6.25 | 2 | .12 |
| 13 | 3 | 14.53 | 0 | | 3 | 8.08 | 0 | | 3 | 3.82 | 0 | | 3 | .89 | 0 | | 3 | .47 | 0 | | 3 | .47 | 0 | |
| 14 | 2 | 17.68 | 1 | 16.92 | 2 | 8.46 | 1 | 7.32 | 2 | 3.49 | 1 | 2.5 | 2 | .63 | 1 | .23 | 2 | .12 | 1 | 0 | 2 | .82 | 1 | 0 |
| 15 | 3 | 14.23 | 0 | | 3 | 7.74 | 0 | | 3 | 3.2 | 0 | | 3 | .33 | 0 | | 3 | 0 | 0 | | 3 | 0 | 0 | |
| 16 | 3 | 14.56 | 0 | | 3 | 6.06 | 0 | | 3 | 2.82 | 0 | | 3 | .38 | 0 | | 3 | 0 | 0 | | 3 | .21 | 0 | |
| 17 | 2 | 15.91 | 2 | 17.8 | 2 | 8.59 | 2 | 8.61 | 2 | 4.62 | 2 | 4.6 | 2 | 1.25 | 2 | .63 | 2 | .57 | 2 | 0 | 2 | 1.06 | 2 | 0 |
| 18 | 3 | 17.91 | 0 | | 3 | 10.78 | 0 | | 3 | 5.64 | 0 | | 3 | 1.55 | 0 | | 3 | .8 | 0 | | 3 | 1.17 | 0 | |
| 19 | 3 | 13.3 | 0 | | 3 | 4.81 | 0 | | 3 | 2.78 | 0 | | 3 | .55 | 0 | | 3 | .13 | 0 | | 3 | .42 | 0 | |
| 20 | 2 | 14.15 | 2 | 18.69 | 2 | 8.33 | 2 | 10.73 | 2 | 3.98 | 2 | 1.63 | 2 | 6.13 | 2 | 2.33 | 2 | 3.86 | 2 | .51 | 2 | 6.19 | 2 | .43 |
| 21 | 2 | 18.19 | 2 | 18.94 | 2 | 9.34 | 2 | 9.85 | 2 | 4.41 | 2 | 5.37 | 2 | 1.19 | 2 | 2.33 | 2 | 1.57 | 2 | .69 | 2 | 3.29 | 2 | .37 |
| 22 | 2 | 15.66 | 2 | 16.54 | 2 | 12.5 | 2 | 12.37 | 2 | 7.31 | 2 | 6.44 | 2 | 4.23 | 2 | 2.98 | 2 | 3.08 | 2 | .57 | 2 | 4.68 | 2 | .12 |
| 23 | 2 | 17.81 | 2 | 12.43 | 2 | 10.61 | 2 | 8.71 | 2 | 6.19 | 2 | 5.48 | 2 | 4.04 | 2 | 3.58 | 2 | 3.09 | 2 | 3.41 | 2 | 4.23 | 2 | 4.29 |
| 24 | 2 | 20.71 | 2 | 16.55 | 2 | 10.29 | 2 | 7.32 | 2 | 4.8 | 2 | 3.09 | 2 | 1.51 | 2 | 1.39 | 2 | 2.33 | 2 | 1.51 | 2 | 6.33 | 2 | 2.78 |
| 25 | 2 | 14.27 | 2 | 11.74 | 2 | 6.19 | 2 | 7.57 | 2 | 3.1 | 2 | 2.7 | 2 | 1.06 | 2 | 1.2 | 2 | 1.63 | 2 | 1.08 | 2 | 2.7 | 2 | 1.65 |
| 26 | 2 | 15.41 | 2 | 16.67 | 2 | 8.46 | 2 | 5.81 | 2 | 3.72 | 2 | 1.57 | 2 | 1.51 | 2 | .63 | 2 | 3.49 | 2 | .77 | 2 | 5.17 | 2 | 1.57 |
| 27 | 2 | 16.42 | 2 | 15.79 | 2 | 9.85 | 2 | 9.6 | 2 | 4.88 | 2 | 5.11 | 2 | 1.77 | 2 | 1.76 | 2 | 2.14 | 2 | .88 | 2 | 5.37 | 2 | .77 |
| 28 | 2 | 7.09 | 2 | 10.61 | 2 | 2 | 2 | 5.17 | 2 | .49 | 2 | 3.04 | 2 | 0 | 2 | .77 | 2 | 0 | 2 | .06 | 2 | 0 | 2 | 0 |
| 29 | 2 | 10.35 | 2 | 10.99 | 2 | 6.82 | 2 | 5.8 | 2 | 3.84 | 2 | 2.98 | 2 | 1.45 | 2 | .63 | 2 | 1.14 | 2 | 0 | 2 | 2.33 | 2 | 0 |
| 30 | 0 | | 3 | 16.92 | 0 | | 3 | 8.67 | 0 | | 3 | 4.54 | 0 | | 3 | .76 | 0 | | 3 | .04 | 0 | | 3 | .04 |
| 31 | 0 | | 3 | 16.92 | 0 | | 3 | 8.67 | 0 | | 3 | 4.5 | 0 | | 3 | .99 | 0 | | 3 | .13 | 0 | | 3 | .76 |
| 32 | 0 | | 3 | 9.76 | 0 | | 3 | 4.12 | 0 | | 3 | 1.42 | 0 | | 3 | .12 | 0 | | 3 | 0 | 0 | | 3 | 0 |
| 33 | 0 | | 3 | 14.9 | 0 | | 3 | 7.23 | 0 | | 3 | 3.67 | 0 | | 3 | .7 | 0 | | 3 | .08 | 0 | | 3 | 0 |
| 34 | 2 | 8.71 | 2 | 16.72 | 2 | 2.02 | 2 | 6.44 | 2 | .57 | 2 | 2.22 | 2 | .32 | 2 | .12 | 2 | 2.02 | 2 | 0 | 2 | 3.29 | 2 | 0 |
| 35 | 2 | 15.03 | 2 | 16.29 | 2 | 9.98 | 2 | 8.46 | 2 | 4.93 | 2 | 4.31 | 2 | 1.14 | 2 | 1.82 | 2 | .23 | 2 | .51 | 2 | .18 | 2 | .32 |
| 36 | 2 | 8.09 | 2 | 10.1 | 2 | 4.17 | 2 | 4.29 | 2 | 1.39 | 2 | .96 | 2 | .39 | 2 | .37 | 2 | .2 | 2 | 0 | 2 | 0 | 2 | 0 |
| 37 | 2 | 12 | 2 | 8.73 | 2 | 4.6 | 2 | 4.8 | 2 | 1.51 | 2 | 1.14 | 2 | .32 | 2 | .37 | 2 | .63 | 2 | .06 | 2 | 3.33 | 2 | 0 |
| 38 | 2 | 9.73 | 2 | 8.2 | 2 | 5.82 | 2 | 1.71 | 2 | 2.47 | 2 | .23 | 2 | .88 | 2 | .06 | 2 | 1.08 | 2 | 0 | 2 | 4.23 | 2 | 0 |
| 39 | 2 | 11.74 | 2 | 9.48 | 2 | 3.61 | 2 | 6.33 | 2 | .38 | 2 | 2.33 | 2 | 0 | 2 | .39 | 2 | .88 | 2 | .18 | 2 | 3.35 | 2 | .06 |
| 40 | 2 | 11.11 | 2 | 9.47 | 2 | 4.16 | 2 | 3.53 | 2 | 1.96 | 2 | 1.26 | 2 | .2 | 2 | .06 | 2 | .77 | 2 | 0 | 2 | 1.9 | 2 | .12 |
| 41 | 2 | 15.03 | 2 | 17.81 | 2 | 6.44 | 2 | 7.58 | 2 | 2.39 | 2 | 3.92 | 2 | .57 | 2 | .63 | 2 | .26 | 2 | .12 | 2 | 0 | 2 | .12 |
| 42 | 2 | 12.14 | 2 | 9.48 | 2 | 8.72 | 2 | 8.09 | 2 | 6.25 | 2 | 5.51 | 2 | 4.6 | 2 | 2.9 | 2 | 4.74 | 2 | .69 | 2 | 3.04 | 2 | 0 |
| 43 | 3 | 18.2 | 0 | | 3 | 12.05 | 0 | | 3 | 8.25 | 0 | | 3 | 4.49 | 0 | | 3 | 1.93 | 0 | | 3 | .89 | 0 | |
| 44 | 2 | 10.87 | 2 | 9.08 | 2 | 4.4 | 2 | 4.49 | 2 | .69 | 2 | 1.65 | 2 | .18 | 2 | .51 | 2 | 0 | 2 | .06 | 2 | .06 | 2 | .51 |
| 45 | 2 | 16.67 | 2 | 16.04 | 2 | 8.96 | 2 | 8.21 | 2 | 5.29 | 2 | 3.55 | 2 | .88 | 2 | .63 | 2 | .06 | 2 | .18 | 2 | .12 | 2 | .43 |
| 46 | 2 | 16.92 | 2 | 14.27 | 2 | 7.95 | 2 | 6.82 | 2 | 3.41 | 2 | 2.39 | 2 | 2.59 | 2 | 1.02 | 2 | 6.01 | 2 | 2.1 | 2 | 4.74 | 2 | 1.88 |
| 47 | 2 | 14.02 | 2 | 12.26 | 2 | 9.71 | 2 | 7.38 | 2 | 5.94 | 2 | 2.98 | 2 | 3.66 | 2 | .63 | 2 | 2.53 | 2 | .23 | 2 | 3.78 | 2 | .18 |
| 48 | 2 | 11.62 | 2 | 12.63 | 2 | 6.44 | 2 | 7.7 | 2 | 3.53 | 2 | 3.21 | 2 | .8 | 2 | .63 | 2 | .06 | 2 | .13 | 2 | .06 | 2 | 0 |
| 49 | 2 | 7.32 | 2 | 9.46 | 2 | 1.17 | 2 | .94 | 2 | .39 | 2 | .12 | 2 | .06 | 2 | .06 | 2 | 0 | 2 | .06 | 2 | .38 | 2 | .06 |
| 50 | 2 | 7.32 | 2 | 10.98 | 2 | 3.53 | 2 | 5.04 | 2 | 1.57 | 2 | 1.51 | 2 | 2.14 | 2 | 0 | 2 | 4.68 | 2 | 0 | 2 | 4.15 | 2 | 0 |

SCAR. = scarified, D.R. = deep removal, N = number of samples, X = average chloride content

**Table 7. Estimated service life of decks with different depths of concrete cover over unprotected reinforcement.**

| Minimum Cover, in. | Estimated Life, years | | Best Estimate* |
|---|---|---|---|
| | Min. | Max. | |
| 1 | 18.2 | 18.2 | 18 |
| 1-1/4 | 18.2 | 18.6 | 18-1/2 |
| 1-1/2 | 18.2 | 25.2 | 21-1/2 |
| 1-3/4 | 18.2 | 39.1 | 28-1/2 |
| 2 | 18.2 | 56.5 | 37-1/2 |

*Number of years for 50 percent of decks to develop delamination over 40 percent of their surface.

The first set of data was from studies of the rate at which delamination and spalling developed on 50 bridge decks built in the early 1970s with conventional concrete and unprotected "black steel" reinforcement (16). These studies resulted in the service life estimates given in Table 7 for decks incorporating different levels of concrete cover over top mat reinforcement (17). They are based on defining service life as the length of time for 50 percent of the decks to develop delaminations over 40 percent of their surface. Because the deep removal treatment is in many respects comparable to original construction with 2 in. of conventional concrete cover, the service life estimate for the latter (37-1/2 years) is taken as a point of departure for estimating service life of the former. Arguments for increasing or decreasing this value as the best estimate for the deep-removal treatment are given in Table 8. The net impact of these arguments has been a modest increase in the estimate to 40 years.

The second set was unpublished performance data from Iowa (18) used to estimate service life of LSC decks in that state. At the time of the survey, Iowa had been using such practices for 25 years and had overlaid 907 decks. Median age of these overlays was 7 years with two-thirds less than 10 years. The Iowa data offer the best opportunity to estimate service life of LSC overlays from actual experience.

The most useful Iowa data for this purpose, and for comparing experience with New York, result from detailed delamination surveys completed between 1976 and 1985 on 19 decks built between 1965 and 1973. These data were used to prepare the performance curve shown in Figure 9. A straight-line extrapolation of that curve to 40-percent delamination yields a service life estimate of 27.8 years. Arguments for increasing or decreasing this value as the best estimate of the service life of LSC overlays in Iowa are given in Table 9. The net impact of these arguments has been to persuade in favor of a modest decrease in the estimate to 25 years.

Table 8. **Arguments for increasing or decreasing 37.5 years at best estimate of service life for deep-removal treatment in New York.**

| Increasing | Decreasing |
|---|---|
| 1. "Best" estimates in Table 7 are believed to be conservative. | 1. "Maximum" estimates in Table 7, from which "best" estimates are derived, are extrapolations including a progressively larger error as minimum cover increases. |
| 2. Depth of LSC overlay requires 2½-in. minimum. | |
| 3. LSC is less permeable than conventional concrete. | 2. Experience shows that lower permeabilities are not being obtained consistently. |
| | 3. Chloride in the substrate concrete will migrate upward to the vicinity of the reinforcement. |

Table 9. **Arguments for increasing or decreasing 27.8 years at best estimate of service life for LSC overlays in Iowa.**

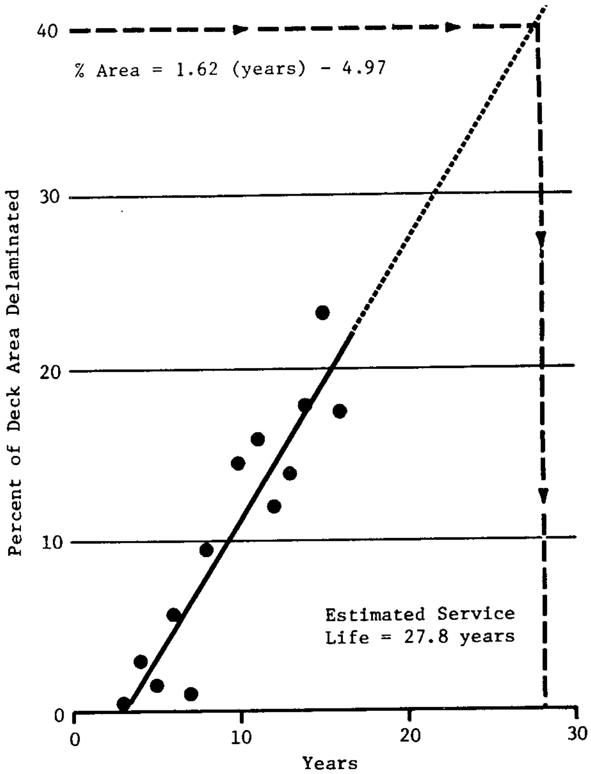
| Increasing | Decreasing |
|---|---|
| 1. Construction practices have improved over what they were when the Iowa decks were built. | 1. Sample does not include decks with highest traffic volumes. |
| | 2. Measured damage does not include spalling. |
| 2. Spalling is minimal on Iowa decks even in the presence of substantial delamination. | 3. Experience with damage rates on decks with unprotected reinforcement suggests a performance curve with an increasing slope, rather than the Figure 9 straight line. |
| | 4. Long extrapolations include a large potential error. |

Table 10. **Comparison of damage in 5-year-old decks in Iowa and New York.**

| State | Age, Years | Number | Total Deck Area, sq ft | Area Damaged Sq ft | Area Damaged Percent |
|---|---|---|---|---|---|
| Iowa | 4.8 | 19 bridges | 60,606 | 1,701* | 2.81* |
| New York | 4.8 | 50 spans | 204,194 | 1,502** | 0.74 |

*Percent of deck area damaged was calculated from the regression of Figure 9 for an age of 4.8 years; the square feet of damage from the product of Columns 4 and 6 of this table.
**Includes all damage observed, except patches (Table 3).

Figure 9. Performance and service life of HDC bridge decks in Iowa.




Finally, results of the New York condition survey have been compared with the Iowa performance curve at an age of 4.8 years (Table 10). From this comparison it is tempting to conclude that LSC overlays in New York are performing better, at least after 4.8 years, than LSC decks in Iowa. This is consistent with the more conservative New York practice of removing larger amounts of chloride-contaminated concrete. However, given the limitations of the Iowa data, which would argue for a lower estimate, and the error that is likely to be associated with each state's data, it seems fair to claim that there is no evidence that LSC overlays in New York are performing any worse than those in Iowa. This is not a bad situation, as Iowa seems eminently pleased with their experience. Thus, 25 years has been taken as the estimated service life of LSC overlays in New York -- overlays in which an average of about one-half the concrete is excavated to a depth of 1 in. below the reinforcement.

## III. CONCLUSIONS AND INTERPRETATION

### A. Conclusions

The following conclusions have been drawn from study of 50 randomly-selected New York bridge decks overlaid with LSC and exposed to an average of 4.8 winters of salting:

1. Potentially corrosion-related effects (delaminations, spalls, and patches), observed on 62 percent of the study spans, comprised 0.81 percent of the total deck area examined.

2. Nearly 10 percent of this consisted of patching done before deck opening.

3. Another 42 percent, including all spalling, was associated with armored expansion joints that had rusted, or construction joints where the bond had failed.

4. The remaining damage, all delamination, was limited to scarified areas on ten study spans. Areas where concrete had been excavated to beneath the reinforcement, and the reinforcement sandblasted, were undamaged.

5. The severity of non-joint-related damage on these ten spans correlated significantly with chloride content of the overlay, frequency of half-cell potentials more negative than -0.35 v, and severity of cracking.

6. Deep removal provided a measurably higher degree of protection than scarification alone.

7. Mean chloride concentrations equivalent to those experienced in conventional bridge deck concrete of the same age were measured in the LSC overlays. Tests for chloride permeability (AASHTO T 227) indicated a wide range of values, many exceeding those associated with well-compacted laboratory specimens of LSC.

8. Average service life of LSC overlays as now constructed in New York, in which about half the deck surface is excavated to beneath the reinforcement, is estimated to be 25 years. Where the entire surface is so excavated, service life is estimated to be 40 years.

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## B. Interpretation

At the completion of the survey phase of NYSDOT's review of its bridge deck overlay practices, it was generally believed that LSC overlays in the state were performing acceptably. Service-life projections exceeded expectations and are now being used in life-cycle cost comparisons with other alternatives. Comparison with the 25-year performance history of LSC decks in Iowa was favorable.

Because of the clearly superior performance of the deep removal treatment and the enhanced service life anticipated, a more liberal concrete removal policy is being considered. It may become more appealing with improvements in the efficiency of concrete removal equipment and corresponding reductions in cost of this operation.

LSC overlays in New York are not without problems. Of particular concern is the high incidence of cracking, particularly plastic shrinkage cracking, associated with damage in some decks. Also of concern is an unexpectedly high rate of chloride accumulation.

Based in part on the information obtained from this work, the Department has revised its overlay specifications, with the following changes:

1. Free moisture content of the sand and stone is not to exceed 7 percent for both aggregates.

2. A 1/2 in. minimum slump requirement has been instituted and when slab reconstruction concrete is placed separately from the LSC overlay, it can be LSC at a maximum slump of 4 in.

3. Addition of superficial water to the surface of the LSC to assist in finishing operations is not permitted.

4. A specification defining defective or damaged concrete has been implemented and appropriate repairs outlined.

5. The lower limit of the air-content range has been raised from 4 to 5 percent.

6. A minimum density of 100 percent of the theoretical project unit weight is now required.

7. Structural slab surfaces are to be pre-wet before applying bonding grout, but surfaces must be free of standing water and dry to the touch before grout placement.

8. The wet-cure period has been extended to 96 hours and use of white-pigmented curing compound is no longer allowed.

9. Wet burlap used for curing is to be placed within 10 minutes, and the allowable time period for covering must not exceed 5 minutes if the theoretical evaporation rate is expected to reach or exceed 0.15 lb/sq ft of exposed surface.

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