SHRP-S-344

Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques

Rapid Concrete Bridge Deck Protection, Repair and Rehabilitation

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Abstract

This report presents the rapid methods used by state highway agencies for the protection, repair and rehabilitation of bridge decks. The report is based on a review of the literature; the responses to questionnaires sent to state Departments of Transportation, Canadian provinces, selected turnpike and thruway authorities, technology transfer centers, and material suppliers; and the evaluation of 50 bridge decks located in seven states. Polymer overlays, sealers, high-early-strength hydraulic cement concrete overlays, and patches are compared for their performance characteristics and service life.

Executive Summary

This report presents the rapid treatment methods being used by state highway agencies for the protection, repair and rehabilitation of bridge decks. The report is based on a review of the literature; the responses to questionnaires sent to state Departments of Transportation, Canadian provinces, selected turnpike and thruway authorities, technology transfer centers, and material suppliers; and the evaluation of 50 bridge decks located in seven states.

Rapid treatment methods can be installed during off-peak traffic periods and are suitable for traffic during peak traffic periods. Lane closure, concrete removal, surface preparation, and installation and curing of materials are all done during off-peak traffic periods. Typical off-peak lane closure periods for rapid methods are < 8 hr, < 12 hr, < 21 hr, and < 56 hr. Bridges that are candidates for rapid treatment methods have peak-hour traffic volumes that are so high that it is not practical to close a lane to treat the deck except during off-peak traffic periods.

Rapid protection methods restrict the infiltration of chloride ions into concrete that is not critically contaminated with chloride (chloride ion content exclusive of background chloride is < 1.0 lb/yd^3 [0.6 kg/m^3] and half-cell potentials are > -250 mV (copper-sulfate electrode). Rapid protection methods include asphalt overlays on membranes, polymer overlays, and sealers.

Rapid repair methods do not deal with the cause of deterioration but rather emphasize the rapid replacement of deteriorated, spalled and delaminated concrete. Rapid repair methods include asphalt overlays with and without membranes, high-early-strength hydraulic cement concrete overlays, patching with high-early-strength hydraulic cement concrete and asphalt concrete, and polymer overlays.

Rapid rehabilitation methods include the removal of all deteriorated, delaminated and critically chloride contaminated concrete, patching and applying a rapid protection method. Rapid rehabilitation methods include asphalt overlays on membranes, high-early-strength hydraulic cement concrete overlays, and polymer overlays.

The report compares polymer overlays, sealers, and patches from the stand-point of performance characteristics and service life. High-early-strength hydraulic cement concrete overlays are also described based on the limited data available from several installations.

The study shows that polymer overlays have a useful service life of 10 to 25 years when applied as a protection or rehabilitation treatment. Multiple-layer epoxy, multiple-layer epoxy-urethane, premixed polyester styrene with a methacrylate primer, and methacrylate slurry are the best-proved overlay treatments.

Sealers can reduce the infiltration of chloride ions for 5 to 10 years and therefore extend the time until sufficient chloride ions reach the reinforcing bars to cause corrosion. To ensure adequate skid resistance, applications are usually limited to decks with tined or grooved textures. The protection provided by sealers seems to vary with tests, showing 0 to 50 percent and an average of 32 percent reduction in permeability. Additional research is needed to determine the sealers, concretes, and conditions that provide for a cost-effective application.

High-early-strength hydraulic cement concrete overlays have tremendous potential, but considerable developmental work with materials and equipment is needed to overcome problems with the installation and the acceptance of concrete overlays that can be installed and cured with lane closures of 8 hours or less. High-early-strength portland cement concrete overlays such as those prepared with 7 percent silica fume or 15 percent latex and Type III cement can be successfully placed and cured with lane closures of 56 hours or less. These overlays can perform almost as well as conventional overlays, constructed with longer lane closure times, and can have a potential service life of 25 years.

Patching repair methods can mend corrosion-induced spalls but typically do not retard chloride-induced corrosion because all concrete with a chloride ion content at the reinforcing bars < 1.0 lb/yd^3 [0.6 kg/m^3] is not removed. Corrosion rates are high within 2 ft (0.6 m) of the perimeter of the patches. Corrosion activity is independent of the type of patching material for the repairs that were evaluated in the field surveys. For these patching materials, typical of what is being used by state highway agencies, the corrosion-induced spalling can be expected to occur in the more negative half-cell potential areas surrounding the patches. Asphalt patches have a life of approximately 1 year and a high life-cycle cost. They should be replaced with hydraulic cement concrete as soon as practical. Hydraulic cement concrete patches can differ significantly with respect to shrinkage, and materials should be selected and mixtures proportioned to minimize shrinkage. A 28-day length change of < 0.05 percent, which is comparable to that of conventional bridge deck concrete, is recommended.

When necessary to minimize traffic congestion most rapid deck treatment methods can be used with lane closures of 8 hours or less. When feasible, longer lane closure times should be used to allow for more careful construction and more complete cure of materials.

1

Introduction

1.1 Criteria for Rapid Bridge Deck Treatment Methods

This report presents the rapid treatment methods state highway agencies use to protect, repair and rehabilitate bridge decks. Rapid treatment methods are suitable for installation during off-peak traffic periods and suitable for traffic during peak traffic periods. Rapid protection methods are those that restrict the infiltration of chloride ions into concrete that is not critically contaminated with chloride (chloride ion content exclusive of background chloride is < 1.0 lb/yd^3 [0.6 kg/m^3] and half-cell potentials are < -250 mV (copper-sulfate electrode). Rapid repair methods replace deteriorated, spalled and delaminated concrete but not all critically chloride contaminated concrete. Rapid rehabilitation methods are those that include the removal of all deteriorated, delaminated and critically chloride contaminated concrete, patching and applying a rapid protection method.

A flow diagram for rapid bridge deck treatment methods is shown in Figure 1.1. Although deck replacement is an option in a rapid treatment situation, replacement is outside of the scope of this study. Information on rapid replacement treatments is available (Sprinkel, 1985). Lane closure, concrete removal, and surface preparation are necessary first steps for any deck treatment. Rapid rehabilitation activities should include the removal of all critically chloride contaminated concrete, patching, and installing a protection treatment. Lane closure can be accomplished using cones or other temporary barriers or a concrete barrier system that facilitates rapid placement and removal (see Figure 1.2) (Cottrell, 1991). All unsound concrete must be removed in preparation for new materials. Necessary forms must be placed for full-depth patches. Surfaces to which concrete should bond must be blasted clean in accordance with specifications. If there is insufficient time to install and cure a patching or protection treatment, temporary materials (steel plates, asphalt concrete, etc.) as needed should be placed to maintain a traffic-bearing surface. Otherwise, the treatment should continue with the installation of the rapid-curing treatment. The materials are allowed to cure to the required strength to receive traffic. Necessary temporary materials are installed, and

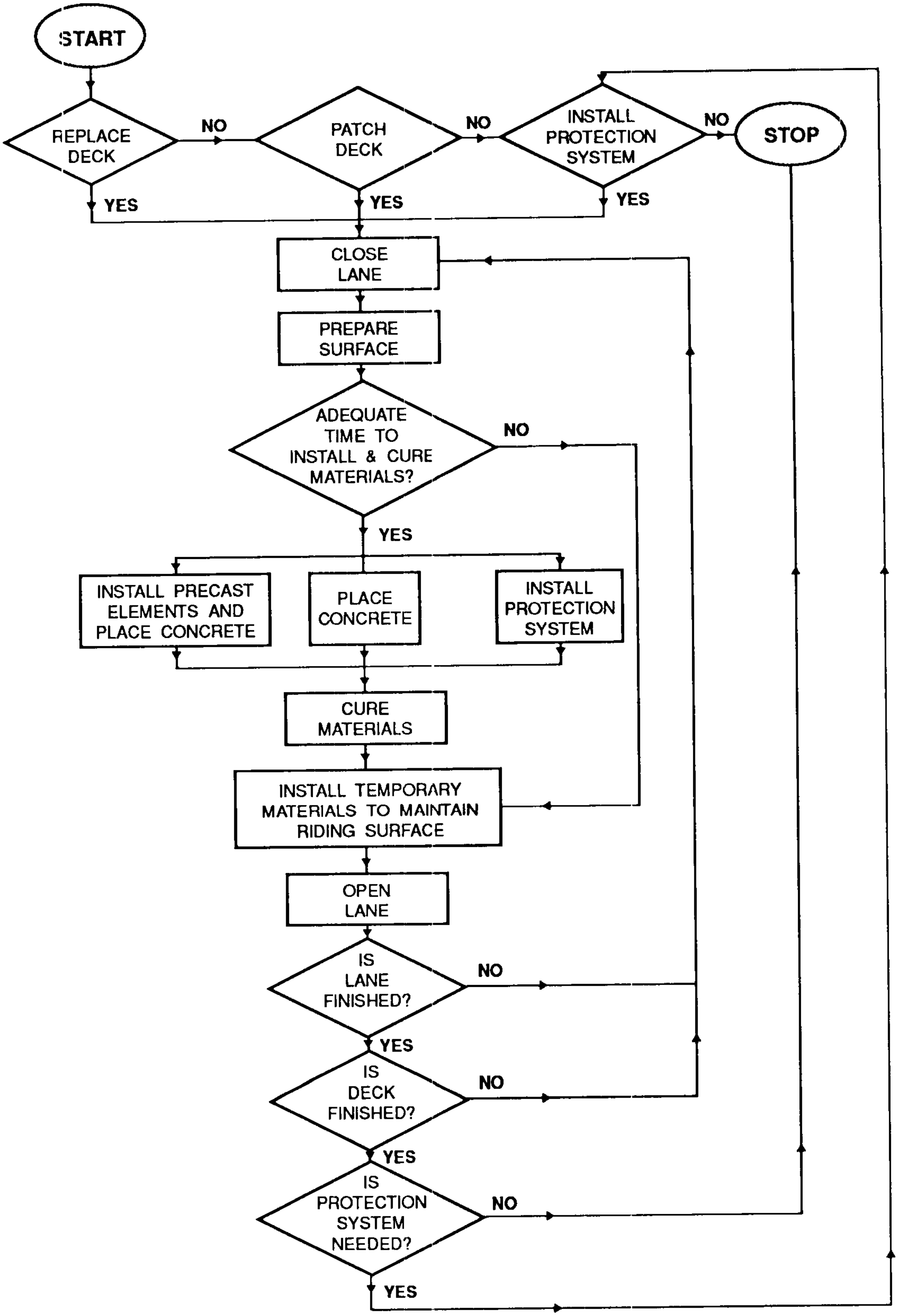


Figure 1.1 Flow diagram for rapid bridge deck treatment methods

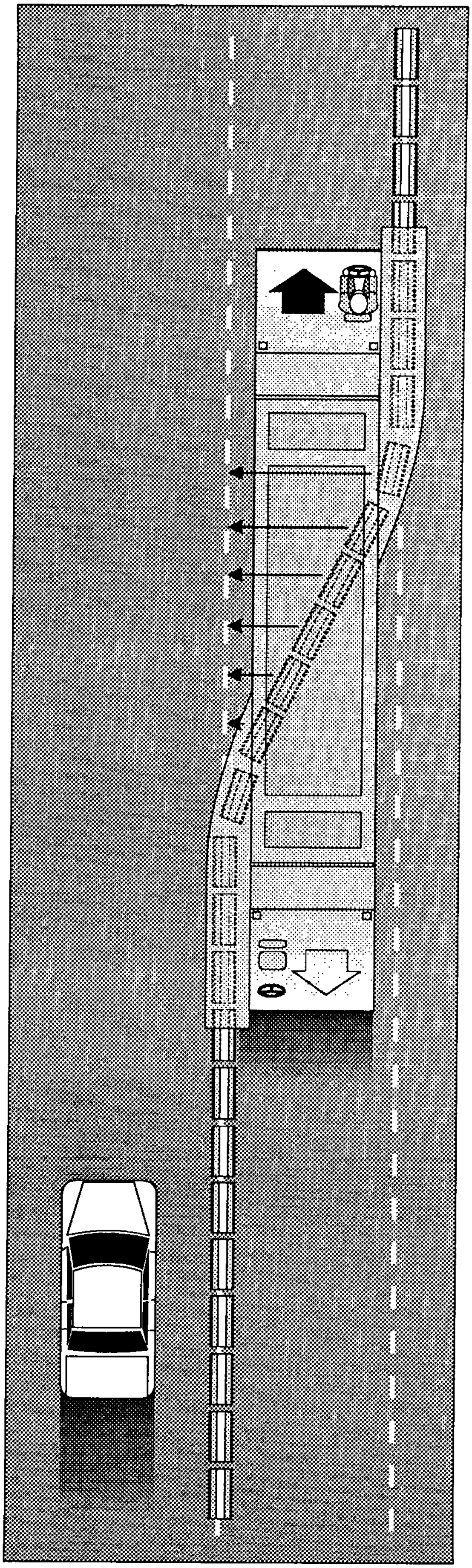


Figure 1.2 Rapid concrete barrier placement and removal system

the lane is opened to traffic.

A bridge deck that must be repaired using a rapid treatment method will usually have one of four maximum lane closure time conditions that require the use of one of four rapid treatment methods as follows:

- < 56 hr - semirapid (e.g., Friday, 9 p.m. to Monday, 5 a.m.),
- < 21 hr - rapid (e.g., 6 p.m. to 3 p.m.),
- < 12 hr - very rapid (e.g., 6 p.m. to 6 a.m.), and
- < 8 hr - most rapid (e.g., 9 p.m. to 5 a.m.).

A treatment must follow the flow diagram (see Figure 1.1) within the lane closure constraints of < 56, < 21, < 12, or < 8 hours to qualify as a rapid deck treatment method.

1.2 Research Approach

The objective of this project was to develop technically and economically feasible methods of deck protection, repair, and rehabilitation that can be used where construction must be rapid. The objective was accomplished by a progression through five activities that included:

1. State-of-the-art review and tabulation of information (September 1988-July 1990).
2. Data reduction and analysis, comparison of alternatives, and preparation of Interim Report No. 1 (April 1989-September 1990).
3. Selection of 50 representative decks and preparation for field evaluations (October 1990-March 1991).
4. Refinement of details, based on evaluations of 50 representative decks (10 decks from previous evaluations) (April 1991-June 1992).
5. Preparation of final report and a field manual containing descriptions, limitations, service life and construction price estimates, construction procedures, quality assurance programs, and materials and methods specifications for the recommended rapid deck rehabilitation treatments (April 1992-March 1993).

1.2.1 Literature Review and Questionnaire Response

The state-of-the-art review, data reduction and analysis, and comparison of alternatives (activities 1 and 2) were summarized in unpublished Interim Report No. 1 and a paper that summarizes the report (Sprinkel, Weyers, and Sellars, 1991). The report is based on a review of the literature and the following number of responses to questionnaires:

- state Department of Transportations (49),
- Canadian provinces (10),
- selected turnpike and thruway authorities (9),
- directors of technology transfer centers (8), and
- selected material suppliers (31).

The report compared rapid deck treatment methods from the perspective of frequency of use, performance characteristics, technique time demands, service life, and cost.

1.2.2 Field Evaluations

As a result of the literature review and questionnaire response, a decision was made to conduct field evaluations on selected representative decks protected with polymer overlays and sealers and patched with rapid-curing materials. Asphalt overlays on membranes were not included in the evaluations because they were covered under another SHRP C 103 task. High-early-strength hydraulic cement concrete overlays were not included because of the low number (one identified prior to 1991) and young age (5 years) of the representative overlay (Sprinkel, 1988). Fifty representative decks were selected and 40 were scheduled for field evaluation (activity 3). The decks were selected to include representatives from three environments based on salt application rates in tons per lane mile per year (kg/lane km/year) (i.e., light [< 2.5 (1,410)] as in California and Washington, moderate [2.5 to 5.0 (1,410 - 2,820)] as in Virginia, and heavy [> 5.0 (2,820)] as in Indiana, Michigan, Nebraska and Ohio) and three Average Daily Traffic Counts (ADTs) (i.e., light [< 5,000], moderate [5,000 - 25,000], and heavy [> 25,000]). The refinement of the details (activity 4) was based on evaluations of the 50 decks (40 decks in the summer of 1991 and 10 in 1989 and 1990) representing the alternative polymer overlay, sealer, and patching treatments. The refinements included development of performance characteristics and service life estimates based on measurements of permeability to chloride ion, corrosion of reinforcing bars, skid resistance and wear, and bond strength.

1.2.3 Final Report and Field Manual

This report illustrates the rapid deck treatment methods being used by state highway agencies and compares polymer overlays, sealers, high-early-strength hydraulic cement concrete overlays, and patches from the standpoint of performance characteristics and service life. Whereas the three more established treatments were evaluated based on a review of the literature, the responses to questionnaires, and field evaluations of installations dating to 1976, the high-early-strength hydraulic cement concrete overlays were evaluated based a review of the literature on four recent installations (Sprinkel, 1988; Sprinkel, 1991; Streb, 1991; Virginia Department of Transportation, 1991). Descriptions, limitations, service life and construction price estimates, construction procedures, quality assurance programs, and materials and methods specifications for the recommended rapid bridge deck treatment methods can be found in the field manual (Weyers, et al., 1993).

1.3 Rapid Protection, Repair, and Rehabilitation Treatments

1.3.1 Treatments Identified

The identification of rapid deck treatments used by states was accomplished through a review of the literature and the response to questionnaires. The treatments identified are shown in the outline in Appendix A. The outline has three major headings: Protection, Repair, and Rehabilitation. The rapid protection methods most frequently used are asphalt overlays on membranes, polymer overlays, and sealers. The rapid repair methods most frequently used include asphalt concrete overlays with and without membranes, high-early-strength hydraulic cement concrete overlays, patching with high-early-strength hydraulic cement concrete and asphalt concrete, and polymer overlays. The rapid rehabilitation methods most frequently used are asphalt overlays on membranes, high-early-strength hydraulic cement concrete overlays, and polymer overlays. The respondents to the questionnaires sent to the state DOTs, the Canadian provinces, selected turnpike and thruway authorities, and directors of technology transfer centers were requested to list the three most frequently used techniques for the rapid protection and rehabilitation of bridge decks and to provide information about the techniques. The details of the responses are included in unpublished Interim Report No. 1 and summarized in Table 1.3.1.1 (Sprinkel, Weyers, and Sellars, 1991).

Based on the literature review and the questionnaire response, a decision was made to evaluate in detail four of the five rapid treatments most used by states. These treatments are polymer overlays, sealers, high-early-strength hydraulic cement concrete overlays, and asphalt and hydraulic cement concrete patching materials. Asphalt overlays are not discussed because they are covered in the field manual (Weyers, et al., 1993). The four treatments are discussed in the order in which they first appear in the outline in Appendix A. Other treatments shown in Appendix A are also discussed in Chapter 1 but are not included in subsequent chapters. The performance of polymer overlays, sealers, and patches, based on the field evaluations, is presented in Chapter 2. The service life of the treatments, based on estimates obtained from the literature review, the questionnaire response and the field evaluations (except high-early-strength hydraulic cement concrete overlays), is presented in Chapter 3.

Table 1.3.1.1. Frequency of use of rapid bridge deck treatment methods

Protection Treatments	No. Users	Patching Treatments	No. Users
Asphalt Concrete Overlay	35	Asphalt Concrete Patch	11
18 on preformed membrane		4 cold mix	
4 on liquid membrane		4 hot mix	
13 not indicated		3 not indicated	
Hydraulic Cement Concrete Overlay	10	Hydraulic Cement Concrete Patch	41
4 latex-modified		15 rapid-hardening portland	
2 low-slump		8 very rapid-hardening magnesium phosphate	
1 alumina cement		7 very rapid-hardening portland	
1 blended cement		2 magnesium phosphate	
1 portland cement		1 rapid-hardening alumina	
1 silica fume		1 blended cement	
		7 not indicated	
Polymer Overlay	13	Polymer Concrete Patch	3
7 multiple-layer		1 epoxy	
4 premixed		1 polyester styrene	
2 not indicated		1 not indicated	
Sealer	12	Steel Plate over Concrete	3
7 silane		None	31
2 high-molecular-weight methacrylate		No Reply	10
1 asphalt emulsion			
1 lineseed oil			
1 polymer cementitious			
None	33		
No Reply	13		

1.3.2 Polymer Overlays

Polymer concrete overlays are placed on decks to reduce the infiltration of chloride ions and water, and to increase the skid resistance (Better Roads, 1989; Better Roads, 1992; Carter, 1989a; Carter, 1989b; Fontana and Bartholomew, 1981; Rasoulian and Rabalais, 1991; Sprinkel, 1993). Because they are thin and tend to follow the contours of the deck, they cannot be used to substantially improve ride quality or drainage or to substantially increase the section modulus of the deck. However, because they are thin compared to bituminous and hydraulic cement concrete overlays, the increase in dead load is less.

Prior to placement of the overlay, the deck must be patched and large cracks filled. Within 24 hours prior to placement of the overlays, the deck must be shotblasted or sandblasted to remove asphaltic materials, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other materials that may interfere with the bonding or curing of the overlay. The deck should be dry immediately prior to placement. Finally, test patches of the overlay are usually placed and tested in accordance with ACI 503R or VTM 92 to ensure that the surface preparation procedure is adequate and the materials will cure properly to provide a high bond strength (American Concrete Institute, 1992; Sprinkel, 1987a; Sprinkel, 1987b; Virginia Department of Transportation, 1993a; Virginia Department of Transportation, 1993b). Polymer binders that have been used include acrylic, methacrylate, high-molecular-weight methacrylate, epoxy, epoxy-urethane, polyester styrene, polyurethane, and sulphur. Aggregates are usually silica sand or basalt. There are three basic types of polymer overlays: multiple-layer, premixed, and slurry.

Multiple-layer overlays are constructed by applying one or more layers of resin and aggregate to the deck surface (see Figure 1.3) (Furr, 1984; Roper and Henley, 1991; Sprinkel, 1982; Sprinkel, 1983; Sprinkel, 1987a; Sprinkel, 1987b; Sprinkel, 1989). The resin can usually be applied by spray, roller, brush, or squeegee. Within minutes after the resin is applied, a gap-graded aggregate is broadcast to excess onto the resin. Approximately 1 hour later, depending on temperature, the unbonded aggregate is removed by using a broom, vacuum, or oil-free compressed air, and another layer of resin and aggregate is applied. Most overlays are constructed with two layers and have a total thickness of 0.25 in (0.64 cm). Some overlays have been constructed with three or four layers and have a thickness of 0.38 to 0.5 in (0.95 to 1.3 cm), and a prime coat without aggregate is specified for the first layer of some treatments. The most frequently used resin is epoxy.

Premixed overlays are constructed like high-early-strength hydraulic cement concrete overlays (Fontana, Reams, and Elling, 1989; McBee, 1989; Sprinkel, 1990a). The polymer binder, properly graded fine and coarse aggregates, admixtures, and initiator are mixed at the job site, deposited on the deck surface, and consolidated and struck off with a vibrating screed. Prior to application of the overlay, the surface is coated with a polymer primer. Most premixed overlays are 1/2 to 1 in (1.3 to 2.5 cm) thick. Because the overlays are struck off with a screed, they can be used to correct minor surface irregularities and to make minor improvements in surface drainage. The most frequently

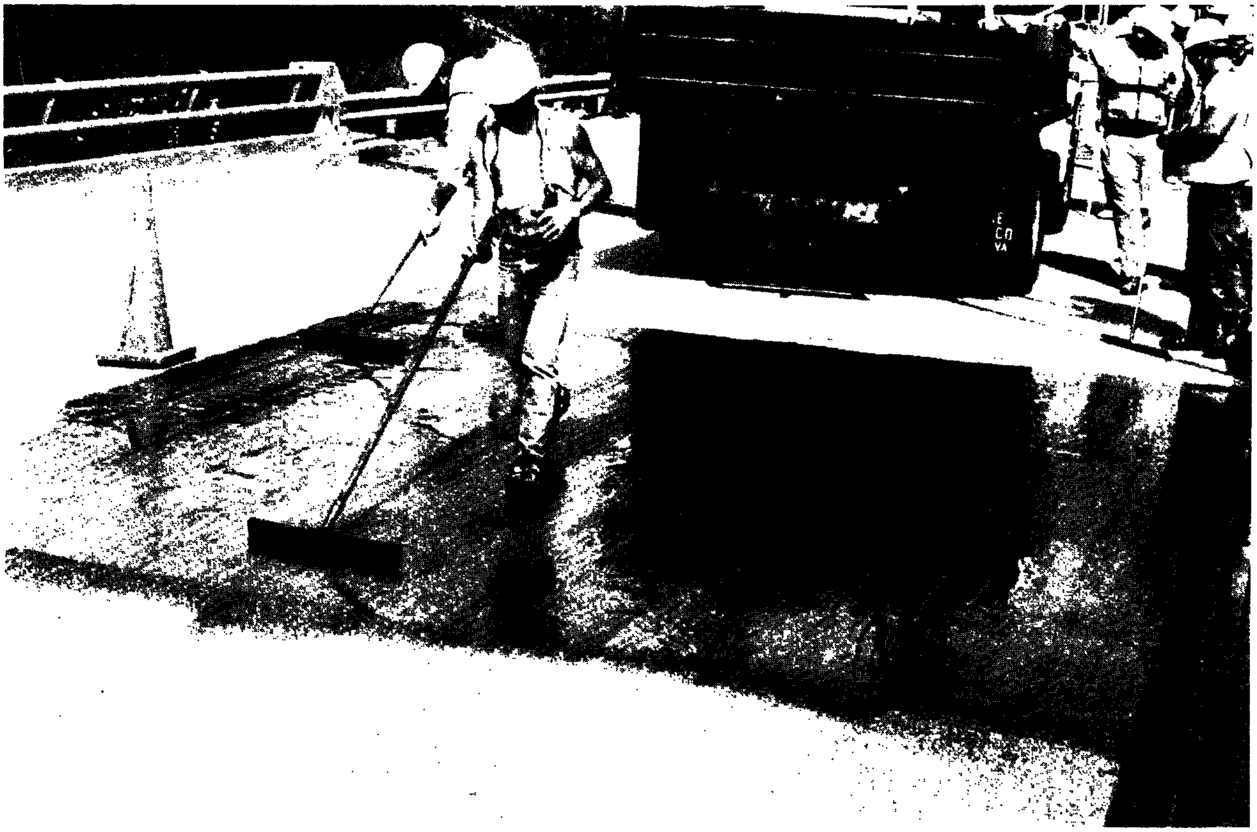


Figure 1.3 An epoxy-urethane binder is spread over a shotblasted surface with notched squeegees. Basalt aggregate is broadcast to excess to provide one layer of a multiple-layer polymer overlay

used binder is polyester styrene and the most frequently used primer is a special alkali resistant polyester or a high-molecular-weight methacrylate.

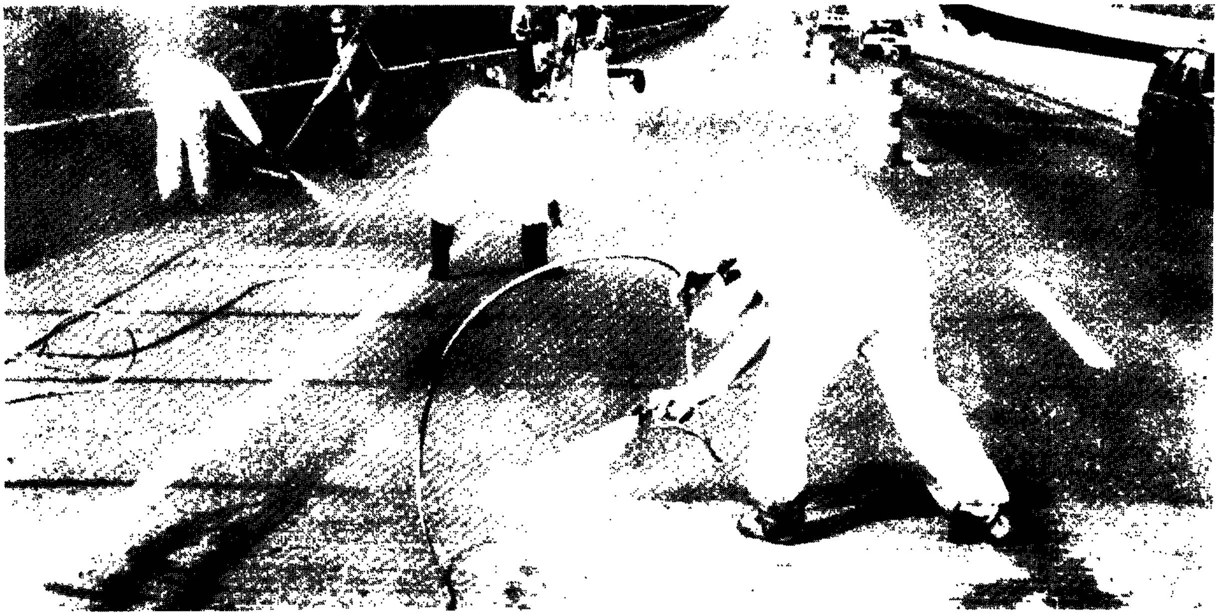
Slurry overlays are constructed by mixing and applying a flowable polymer mortar onto a primed deck surface. The mortar is immediately struck off with gage rakes set to provide a thickness of about 0.25 in (0.64 cm), and aggregate is broadcast to excess onto the slurry. Approximately 1 hour later, the unbonded aggregate is removed and a thin polymer seal coat is sometimes applied. The overlays are usually about 0.38 in (0.95 cm) thick (Kyriacou and Fowler, 1989). The most frequently used binders are epoxy and methacrylate.

1.3.3 Sealers

Sealers are placed on bridge decks and other concrete surfaces to reduce the infiltration of chloride ions and water (Cain, 1989; Carter and Forbes, 1986; Higgins, 1985; Pfeifer and Scali, 1981; Rutkowski, 1988; Sprinkel, 1987a; Sprinkel 1990b; Sprinkel 1992a). The materials can usually be applied by spray, roller, brush, or squeegee (see Figure 1.4). Most sealers have a low solids content, < 40%; tend to penetrate the surface pores and capillaries of the concrete; and with evaporation of the carrier leave a thin hydrophobic film 0 to 10 mils (0. to 0.25 cm) thick. However, some sealers have a 100% solids content and leave a thick film on the surface, 10 to 30 mils (0.25 to 0.76 mm).

Organic and inorganic sealers that have been used on decks include acrylic, epoxy, gum resin, rubber, urethane, silicone resin, silane, and siloxane, all of which act as pore blockers once the solvent carrier evaporates (Aitken and Litvan, 1989; Bradbury and Chojnacki, 1985; Crumpton, 1989; Curra, 1990; Mangum, 1986; Marks, 1988; Marusin, 1989; McGettigan, 1990; McGettigan, 1992; Pfeifer, Landgren, and Zoob, 1987; Rasoulian, Burnett, and Desselles, 1988; Smith, 1986; Virginia Department of Transportation, 1990; Virmani and Sixbey, 1992; Whiting, 1990). Silanes react with moisture under alkali conditions to form a silicone resin film. Siloxanes are a combination of silane and silicone polymers. Silicates react with the calciums in concrete to form a tricalcium silicate film after evaporation of the water carrier (Cain, 1989; Higgins, 1985). Sealers with a 100% solids content that have been used on bridge decks include acrylic, high-molecular-weight methacrylate, hydraulic cement, epoxy, and rubber.

To provide adequate skid resistance, sealers, particularly those with a high solids content, must be placed on heavily textured surfaces. Satisfactory textures to which sealers can be applied can be obtained by tining the fresh concrete, by shotblasting the hardened surface, or by sawcutting grooves 0.13 in (3.2 mm) wide by 0.13 in (3.2 mm) deep by approximately 0.75 to 1.5 in (1.9 to 3.8 cm) on centers in the hardened concrete. Also, the deck must be patched prior to placement of the sealer and the patching materials must be compatible with the sealer. Within 24 hours prior to applying the sealer, the deck should be shotblasted or sandblasted to remove asphaltic material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other materials that may interfere with the bonding or curing of the sealer and to open the pores and



a. Airless sprayer application

b. Broom application

Figure 1.4 A high-molecular-weight methacrylate sealer is applied to tined surfaces capillaries so the sealer can penetrate. The deck should be dry prior to placement of the sealers. Also, the concrete must be cured sufficiently, usually aminimum of 28 days, so that moisture in the patch or gas produced by chemical reactions do not interfere with the penetration or adhesion of the sealer.

1.3.4 High-Early-Strength Hydraulic Cement Concrete Overlays

Hydraulic cement concrete overlays are placed on decks to reduce the infiltration of water and chloride ion and to improve the ride quality and skid resistance (American Concrete Institute, 1993; Babaei and Hawkins, 1987; Ozyildirim, 1988; Sprinkel, 1984; Sprinkel, 1992b; Whiting, 1991). Overlays may also be placed to strengthen or improve the drainage on the deck. The overlays are usually placed with internal and surface vibration and struck off with a mechanical screed.

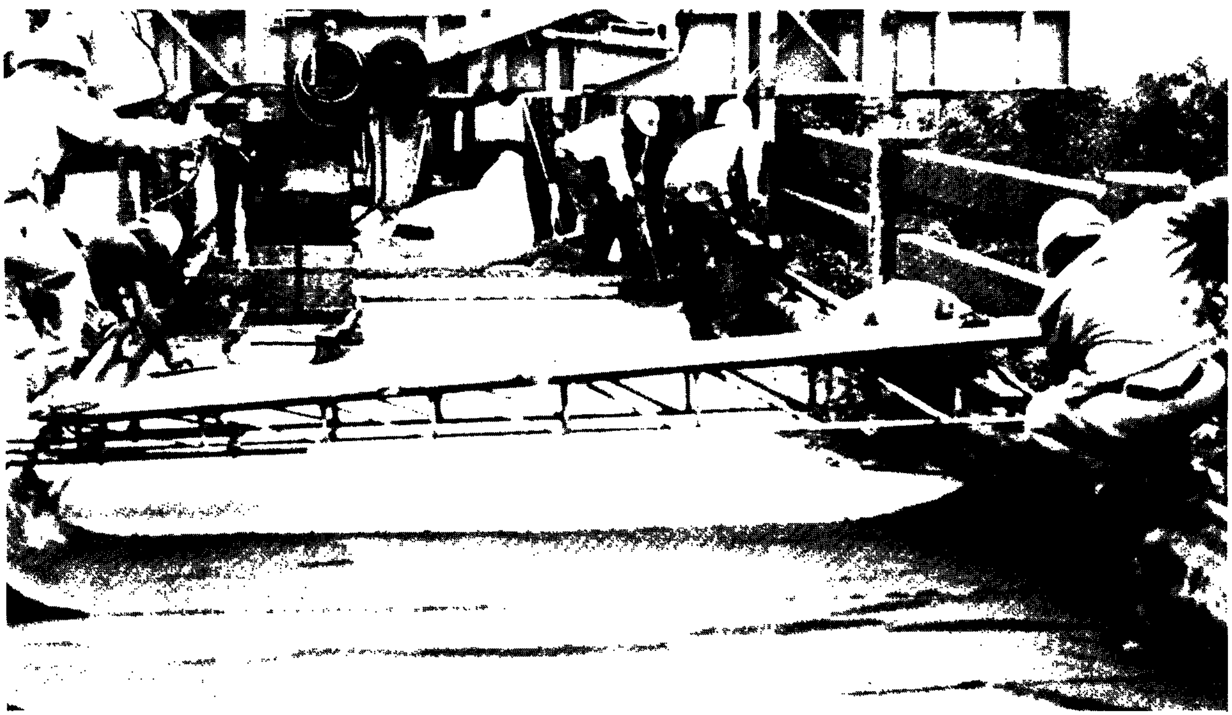
Portland Cement Concrete Overlays

Portland cement concrete overlays usually have a minimum thickness of 1.25 in (3.2 cm) for concretes modified with 15 percent latex by weight of cement and 2.0 in (5.1 cm) for most other concretes (see Figure 1.5). Some concretes, such as those containing 7 to 10 percent silica fume or special blended cements like Pyrament, have permeabilities similar to that of latex-modified concrete and perform adequately at a thickness of 1.25 in (3.2 cm). High-early-strength portland cement concrete mortars having a thickness of about 1 in (2.5 cm) have been used as overlays, but tend to crack and do not provide much protection unless latex or silica fume is added to the mixture. Overlays can be constructed and cured to a strength suitable for traffic in less than 8 hours using special blended cements such as Pyrament; Type III portland cement and admixtures such as corrosion inhibitors, high-range water reducers, latex, and silica fume; and rapid-hardening cementitious materials (ASTM C 928) (Airport Services Management, 1987; Carrasquillo and Farbiarz, 1987; Sprinkel, 1988; Sprinkel, 1991; Streb, 1991; Temple et al., 1984). More conventional high-early-strength portland cement overlays such as those prepared with Types I and II portland cement and silica fume or Type III cement and latex can be constructed and cured with a lane closure of less than 56 hours (Sprinkel, 1988). The deck may be patched prior to placement of the overlay or as the overlay is placed. When the deck is patched prior to placement of the overlay a patching material must be selected that will provide for good bonding between the patch and the overlay. Polymer concretes, polymer- modified concretes, and other very dense concretes or film-forming concretes should not be used for patching prior to placing an overlay because they can interfere with the bonding of the overlay. The deck should be scarified, sandblasted or shotblasted, sprayed with water, and covered with polyethylene to obtain a sound, clean, saturated surface dry condition (saturated deck with no free water on surface) prior to placement of the overlay (Sprinkel, 1988; Virginia Department of Transportation, 1991a). The mortar portion of the overlay is broomed into the saturated surface just ahead of the screed which consolidates and strikes off the overlay. Wet burlap and polyethylene are placed immediately behind the screeding operation to prevent evaporation of moisture from the overlay.

Other Hydraulic Cement Concrete Overlays

Hydraulic cement concrete overlays can be constructed with alumina cement and

a. Mortar is broomed into saturated surface and concrete is consolidated and struck off



b. Wet burlap curing material is applied immediately following the tining operation

Figure 1.5 A high-early-strength latex-modified portland cement concrete overlay is placed on a scarified and shotblasted deck surface

magnesium phosphate cement. However, only one magnesium phosphate concrete overlay and no alumina cement concrete overlays were identified in the literature review and questionnaire response. The placement procedures described for high-early-strength portland cement concrete overlays would be generally applicable to these cements. Because of their rapid setting time, alumina cement and magnesium phosphate cement are usually sold in 50-lb (23 kg) bags as a rapid-hardening cementitious material (ASTM C 928) for use in patching rather than overlays (Bradbury, 1987; Popovics and Rajendran, 1987; Popovics, Rajendran, and Penko, 1987). A slower-setting hot weather version of magnesium phosphate cement concrete can be mixed in a ready-mix truck and placed as an overlay. The deck may be patched prior to placement of the overlay or as the overlay is constructed. Surface preparation requirements are the same as for high-early-strength portland cement concrete overlays except that the deck surface should be dry and scrubbing of the mortar fraction into the surface ahead of the overlay may not be necessary (Gulyas, 1988). These concretes have the added advantage in that they can be air cured rather than moist cured.

1.3.5 Patches

The most frequently used method of rapidly rehabilitating a bridge deck involves removing chloride-contaminated and delaminated concrete, sandblasting the concrete surface, and filling the cavity with a rapid-curing concrete. To complete the rehabilitation, cracks are usually repaired and a rapid-curing protective treatment is installed. There are several advantages to this method. The patching, crack repair, and application of the protective treatment can be done in stages. Cured materials can usually be opened to traffic in 2 to 4 hours. Concrete removal costs may be low because very little concrete is sometimes removed, and the high cost of the patching materials may be offset by the low volume of material required. The perceived disadvantage of the method is that spalling will continue because (1) corrosion is not stopped since all critically chloride contaminated concrete is not removed, (2) all poor-quality concrete is not removed, (3) there is insufficient time to prepare the surface, (4) the rapid setting materials are not properly batched or consolidated, (5) the patches crack because of shrinkage (6) the repairs must be opened to traffic before sufficient strengths are developed, and (7) the repair materials are not similar to or compatible with the materials repaired (American Concrete Institute, 1993; Emmons, 1992; Emmons, 1993; Fontana and Bartholomew, 1981; Furr, 1984; Transportation Research Board, 1974; Transportation Research Board, 1977; Transportation Research Board, 1979).

Asphalt Concrete

Transportation agencies have a responsibility to provide a deck riding surface that is safe. Consequently, when decks spall, the cavity is usually filled with asphalt concrete until a more permanent repair can be made. In warm weather, an asphalt concrete mixture (hot mix) that hardens as it cools is used. In cold weather, a mixture (cold mix) that cures by evaporation of solvents is used. A proper repair includes removal of dust, debris, and unsound concrete from the cavity; application of a tack coat; and placement and compaction of the patching material (U.S. Department of Transportation, 1980).

High-Early-Strength Hydraulic Cement Concrete
The most common method of permanent spall repair is patching with hydraulic cement concrete. Patches may be shallow (above level of reinforcing bars but at least 1.3 in [3.3 cm] thick), half depth (at least 1 in [2.5 cm] below top mat of reinforcing bars but not deeper than one half the deck thickness) and full depth. A typical repair includes squaring up the area to be patched, sawcutting the perimeter to a depth of 1 in (2.5 cm), removing concrete to the required depth with pneumatic hammers weighing < 30 lb (13.6 kg) with a sharpened chisel point at least 3 in (7.6 cm) wide, blasting the concrete surface and reinforcing bars with sand or slag, applying bonding grout if conditions so warrant, filling the cavity with the patching material, consolidating and striking off the material, and applying liquid or other curing material (Virginia Department of Transportation, 1991a). When full-depth patches are constructed, it is necessary to suspend forms from the reinforcing bars or to support forms from beam flanges (areas > 3 ft^2 [0.28 m^2]). Hydrodemolition may also be used to remove concrete prior to patching. As can be seen from Appendix A, many types of patching materials can be used (Popovics, 1985; Parker et al., 1985; Smutzer and Zander, 1985). Patches can be constructed and cured to a strength suitable for traffic in less than 8 hours using special blended cements such as Pyrament; Type III portland cement and admixtures such as corrosion inhibitors, high-range water reducers, latex, and silica fume; rapid-hardening cementitious materials that satisfy the requirements of ASTM C 928; magnesium phosphate cement; and aluminia cement (Airport Services Management, 1987; Carter, 1991; Fowler et al., 1982; Klemens, 1990; Carrasquillo and Farbiarz, 1987; Nawy et al., 1987; Sprinkel, 1988; Sprinkel, 1991; Temple et al., 1984).

The most frequently used material is the rapid-hardening cementitious material meeting the requirements of ASTM C 928 (see Figure 1.6). Many of these materials achieve a compressive strength of 2,500 to 3,000 psi (17.2 to 20.7 MPa) in 3 hours or less depending on the temperature. Typically, the prepackaged materials are mixed in a small concrete mixer approximately 6 ft^3 (0.17 m^3) in capacity. For convenience, the bags may contain cement and sand. Contractors extend the mixture by adding 50 to 100 percent coarse aggregate (typically < 0.5 in [1.3 cm] maximum size) by weight of cement and sand. For economy, contractors purchase the special blended cement and add bulk fine and coarse aggregates in simple basic proportions of one/one/one by weight. When one or more closely spaced cavities require 1 or 2 yd^3 (0.76 to 1.5 m^3) or more of patching material, special blended cement concretes have been batched using mobile concrete mixers and ready-mix trucks (Sprinkel, 1991; Sprinkel and McGhee, 1989). Figure 1.7 shows special blended cement ready-mix concrete being used to replace the top half of a bridge deck. The deck was sawcut 1 in (2.5 cm) deep into segments 11 ft (3.4 m) wide by 8 ft (2.4 m) long, and the top half of one or two segments was replaced each day with a lane closure that started at 8 a.m. and ended by 5 p.m. Concrete was removed until 11 a.m. each day, the ready-mix concrete that contained 10 bag/yd^3 (555 kg/m^3) of special blended cement was placed by noon, and the lane was opened between 3 p.m. and 5 p.m. each day depending on the curing temperature. The advantage of using ready-mixed concrete or a mobile concrete mixer is that optimum mixture proportions are usually prescribed; when a small portable mixer is used, there is a tendency to use less than optimum mixtures such as one/one/one by weight. High-quality patches can be obtained when good mixture proportions are specified (minimum

a. Cement, sand, coarse aggregate, and water are batched at site

b. Typical patching operation

Figure 1.6 A prepackaged rapid-hardening hydraulic cement concrete material is used for partial depth patching on a bridge deck

Figure 1.7 Special blended cement ready-mix concrete is used to replace a segment of the top half of a bridge deck during an 8-hour lane closure

cement and water contents) and when steps are taken to eliminate the cause of spalling. Some of the cements have a high alkali content and early age deterioration due to alkali silica reactions is a matter of concern when patching concrete which contains alkali-silica reactivity susceptible aggregates (HBT AGRA Limited, 1992). Also, many of the concretes exhibit high shrinkage compared to bridge deck concrete when used at manufacturers' recommended proportions (Emmons, 1992).

1.3.6 Other Treatment Methods

Asphalt Concrete Overlays
Asphalt concrete overlays are placed on decks to provide a smooth riding wearing surface. The overlays are usually placed with a paving machine and compacted with a roller to provide a minimum compacted thickness of 1.5 in (3.8 cm). Prior to placing the asphalt overlay, all patching must be complete. For deck protection and rehabilitation, a membrane is usually placed on the portland cement concrete deck to protect the concrete from chloride ion infiltration (Babaei and Hawkins, 1987). Low permeability concretes such as latex-modified concrete, low-slump dense concrete or concrete containing silica fume do not require the placement of a membrane. A tack coat can be applied to these surfaces prior to placing the overlay. For deck repair and to improve skid resistance an ultra thin asphalt overlay usually referred to as a chip seal or surface treatment can be applied.

Membranes that are used include polymer binders filled with aggregate, similar to multiple-layer polymer overlays, prefabricated sheets placed on a mastic, and liquid placed membranes (see Appendix A). The membranes usually extend 1 inch up faces of curbs, across backwalls, onto approach slabs, and across all joints except expansion joints. Within 24 hours prior to placing the membrane, the deck should be sandblasted or shotblasted to remove asphalt material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar and other potentially detrimental materials which may interfere with the bonding or curing of the membrane or prime coat. Also, the deck should be dry (Virginia Department of Transportation, 1991a; Virginia Department of Transportation, 1993a). Surfaces on which a prefabricated sheet membrane is to be placed should be relatively smooth so that the sheet will bond properly, whereas liquid membranes may be placed on lightly textured surfaces.

Crack Repair and Sealing
Cracks in concrete can provide water and salt easy access to reinforcement. This can cause premature corrosion or accelerated rates of corrosion. Cracks that change in width with changes in temperature and vehicle loads should be treated as joints and sealed. Non-working cracks can be repaired. Most deck protection and rehabilitation contracts include crack sealing or crack repair. Cracks can be sealed or repaired (see Appendix A) by gravity fill, pressure injection, rout and seal, vee-groove and seal, and vacuum injection (Mangum et al., 1986; Marks, 1988; Sprinkel, 1990b; Sprinkel, 1992a; Virginia Department of Transportation, 1990). Cracks ranging in width from 0.003 to 0.24 in (0.08 to 6 mm) have been successfully filled (American Concrete Institute, 1993).

Polymers used to seal and repair cracks by gravity fill may contain surfactants and wetting agents and usually have a viscosity of less than 100 cp. High-molecular-weight methacrylates that have a viscosity of < 25 cp have been shown to be effective in repairing cracks with widths of 0.008 to 0.08 in (0.2 to 2.0 mm) (Mangum et al., 1986). A minimum crack width of 0.02 in (0.5 mm) is recommended for gravity fill epoxy resins that usually have a viscosity of about 100 cp or more (American Concrete Institute, 1993). A two-component urethane, Percol, is also being marketed for crack repair. The urethane cures more rapidly than methacrylate and epoxy and can accommodate traffic within several minutes after treatment.

Cracks can be sealed by making a vee-groove in the crack using sandblasting equipment and filling the groove with a neat polymer such as epoxy or by routing the crack and filling the groove with a polymer mortar (Mangum et al., 1986). Saws cannot be used to widen most cracks because the shape is usually too irregular. Pressure injection or vacuum injection with a variety of polymers such as epoxy, polyester, methacrylate and urethane can be done to seal or repair cracks (Sprinkel, 1990b).

The walls of most cracks in bridge decks that are in service are coated with dust, road dirt, pulverized concrete and carbonation. Therefore it is difficult to fill the cracks with polymer, and thereby seal the cracks, and to get good adhesion between the polymer and the wall of the cracks (Sprinkel 1990b). Also, to get good adhesion and cure the cracks should be dry unless a moisture-cured urethane is used to fill the cracks.

It is usually not practical to repair and seal randomly oriented cracks such as plastic shrinkage cracks, with methods other than gravity fill polymers such as high-molecular-weight methacrylate and low viscosity epoxies. To fill plastic shrinkage cracks the deck is usually flooded with monomer. The monomer is brushed into the cracks until they are filled. When deck surfaces do not have a tined texture or sawcut grooves, aggregate is broadcast onto the monomer to provide adequate skid resistance (Sprinkel, 1987a; Sprinkel 1990b, Virginia Department of Transportation, 1990).

Joint Repair

Decks have expansion joints to allow the deck spans to move independently. Some decks have concrete headers at the end of the spans to anchor the joints or to support asphalt concrete overlay material. Typically the joints and concrete headers have to be replaced when a deck is repaired or rehabilitated. Rapid joint and header treatments are required for use with rapid deck repair or rehabilitation treatments. Most of the hydraulic cement concrete and polymer concrete patching materials can be used for rapid joint repair or rehabilitation.

Polymer Concrete Patches

Patching with polymer concrete has been found to be effective when the thickness of the patches is < 0.8 in (2 cm) (Virginia Department of Transportation, 1991a). The surface to be patched must be sound and dry. The polymer is trowelled into place so that edges may be feathered. A prime coat may or may not be required. As can be seen from Appendix A, a number of binders can be used (Kukacka and Fontana, 1977; Nawy et al., 1987; Parker et al., 1985).

Patches with Steel Plate over Conventional Concrete

Materials that develop strength slowly are usually easier to place, more compatible with the old concrete, and more economical than rapid-curing materials. Patching with materials that do not obtain a high early strength can be done if the patched area is covered with a steel plate that prevents wheel loads from damaging the concrete. The technique has been used by the New Hampshire DOT, the District of Columbia, and the Buffalo and Fort Erie Public Bridge Authority.

1.3.7 Minimum Curing Time

One of the most important properties of a rapid protection, repair, or rehabilitation treatment is the strength of the materials at the time they are first subjected to traffic. Materials that do not have adequate strength can be damaged by traffic and fail prematurely as a result of a failure of the matrix or the bond interface. Materials must be relatively free of cracks and must be adequately bonded to the substrate to protect the deck and provide skid resistance. Convenient indicators of strength are the compressive strengths of 4-by-8-in (10-by-20 cm) cylinders of concrete and 2-in (5-cm) cubes of mortar. Hydraulic cement concretes and polymer concretes are usually required to have a compressive strength of 2,500 to 4,000 psi (17.2 to 27.6 MPa) prior to being subjected to traffic (Virginia Department of Transportation, 1991a). Guillotine shear bond strengths of at least 200 to 400 psi (1.4 to 2.8 MPa) are usually obtained at these compressive strengths when concrete substrates are properly prepared (Knab, Sprinkel, and Lane, 1989; Sprinkel, 1988). Tensile adhesion strengths greater than 100 psi (0.7 MPa) are also indicative of satisfactory performance (Felt, 1956; Sprinkel, 1987b). Sealers must be tack-free at the time they are subjected to traffic. Membranes must be tack-free prior to being overlaid with asphalt concrete, which is then allowed to cool to 150°F (66°C) before it is opened to traffic (Virginia Department of Transportation, 1991a). Patches that can be protected with a steel plate can be opened to traffic once the plate is in place.

Table 1.3.7.1 shows estimates of the minimum curing times needed to subject protection treatments to traffic without causing major damage to them. The estimates are based on compressive and bond strength data, tack-free times, and asphalt concrete cooling rate data obtained from the literature and the responses to the questionnaire sent to the materials suppliers (Bradbury, 1987; Carrasquillo, 1988; Carrasquillo and Farbiarz, 1987; Dickson and Corlew, 1970; Klemens, 1990; Kukacka and Fontana, 1977; Ozyildirim, 1988; Popvics and Rajendran, 1987; Sprinkel, 1987a; Sprinkel, 1987b; Sprinkel and McGhee, 1989; Sprinkel, 1991; Sprinkel, 1990b; Streb, 1991; Temple et al., 1984; Virginia Department of Transportation, 1991a). Curing time is a function of the curing temperature of the material, which is a function of the mixture proportions, the mass, the air and the substrate temperature, and the degree to which the material is insulated. The values in Table 1.3.7.1 are reported as a function of air temperature for typical installations. Research is needed to provide additional values and to refine the estimates shown in Table 1.3.7.1.

The minimum curing times in Table 1.3.7.1 for an asphalt concrete overlay are for use with a prefabricated membrane and prime coat. Approximately 1 hour is required for

Table 1.3.7.1. Minimum curing times for rapid protection treatments, hours

Author	Treatment	Installation Temperature, °F (°C) 40 (4)	55 (13)	75 (24)	90 (32)
Dickson, Corlew (1970) Va. Dept. of Transp. (1991a)	Asphalt Concrete Overlay on Membrane	NA	2	2	2
Carrasquillo, Farbiarz (1987) Popovics, Rejenderan (1987) Sprinkel (1991) Streb (1991)	Hydraulic Cement Concrete Overlay (special blended cement)	5	4	3	3
Temple et al. (1984)	(magnesium phosphate)	1	1	1**	1**
Kukacka, Fontana (1977) Sprinkel (1987a)	Polymer Overlay (epoxy)	2*	6	3	2
Sprinkel (1987a)	Sealer (silane)	4	3	2	1
Sprinkel (1990b)	(high-molecular weight-methacrylate)	N/A	9	3	1

NA: Not applicable since materials are not usually placed at indicated temperature.

* Special cold weather formulation of methacrylate.
** Special hot weather formulation of magnesium phosphate.

the prime coat to cure at 75°F (24°C). At 90°F (32°C), the prime coat usually cures faster; however, a minimum of approximately 1 hour cure time is required for the asphalt concrete to cool to 150°F (66°C) (Dickson and Corlew, 1970; Virginia Department of Transportation, 1991a). At temperatures of 55°F (13°C) and below, the curing time is controlled by the curing rate of the prime coat.

Minimum curing times can be reduced by increasing the rate of reactions by adjusting the mixture proportions, applying insulation, and increasing the mass of the application. Asphalt concrete cools more rapidly when placed in thin layers, and sealers become tack-free sooner when the application rate is reduced. Patches constructed with materials similar to those used in overlays should have minimum curing times similar to those shown in Table 1.3.7.1 with the exception that asphalt concrete patches are suitable for traffic in 1 hour or less.

Based on the data in Table 1.3.7.1, all of the treatment methods cited in Table 1.3.1.1 can satisfy the requirements for a most rapid deck treatment. However, the high-early-strength portland cement concrete overlays would have to be constructed with special blended cements and admixtures (Sprinkel, 1991; Streb, 1991). The more conventional high-early-strength portland cement concrete overlays such as those constructed with 15 percent latex and Type III cement or 7 percent silica fume and high-range water-reducing admixtures would satisfy only the requirements for a semirapid deck treatment (Ozyildirim, 1988; Sprinkel, 1988; U. S. Department of Transportation, 1990; Virginia Department of Transportation, 1991b). Although both high-early-strength latex-modified and silica fume-modified portland cement concretes can achieve 3,000 psi (20.7 MPa) compressive strength in less than 21 hours, additional lane closure time is required to prepare the deck, set up the screed, and moist cure the concrete. Although not practical for a rapid deck treatment, to obtain optimum properties, latex-modified portland cement concrete should be moist cured for 2 days and silica fume concrete for a minimum of 3 days. Although liquid membrane curing materials can be applied to silica fume concrete once the wet burlap is removed, some loss in durability should be expected when less than optimum curing time is provided. When practical, therefore longer lane closures should be used to allow for a longer moist curing period, particularly when concretes with silica fume are used.

Cement type and quantity, water-to-cement ratio, admixtures, and heat (externally applied and from hydration) determine the curing time required for high-early-strength hydraulic cement concrete mixtures to achieve 3,000 psi (20.7 MPa) compressive strength. The use of the minimum amount of water to provide satisfactory workability and the addition of admixtures such as high-range water-reducers and accelerators can provide for some reduction in the curing time. Major reductions can be achieved by substituting a specially blended cement or Type III cement for Type II cement. The application of heat can provide for additional reductions in cure time.

2

Performance of Protection, Repair, and Rehabilitation Treatments

2.1 Introduction

Based on the literature review and the questionnaire response, a decision was made to evaluate, in detail, polymer overlays, sealers, patching materials, and high-early-strength hydraulic cement concrete overlays. The performance of the first three more established treatments is described in this chapter and is based on the field evaluations of decks that had been protected, repaired or rehabilitated with these treatments (see Tables 2.1, B1 and B2). The following criteria were used to select decks for evaluation:

- the DOT was willing to assist with the field evaluation,
- the treatment was done with materials and procedures that are currently recommended for use,
- the treatment was believed to be done in accordance with specifications,
- the treatment was subjected to a salt application rate and volume of traffic for which performance data were needed,
- the treatment was one of the older examples of those available for evaluation, and
- the evaluation was feasible based on budget constraints.

The most important indicators of the performance of rapid deck protection and patching treatments are: permeability to chloride ion; corrosion of reinforcing bars; skid resistance and wear; bond strength; cracks; delaminations; spalls; and patches. When these indicators are evaluated as a function of the age of the treatment, an estimate of service life can be made as one or more of the indicators reaches an unsatisfactory level.

Appendix B shows a summary of the field data that were collected to provide an

Table 2.1 Field evaluations

Protection Treatment	Bridge Number	Deck Location	Treat. Age, years[a]	Salt Applic. Rate[b]	ADT[c]
High-molecular-weight-methacrylate overlay	40A	Virginia	5	L	L
Multiple-layer epoxy overlay (current specifications)	19 13 3,5,39X 23	Michigan Ohio Virginia Washington	15 5 3,5,5 5	H H M,M,M L	H H M,M,VH H
Multiple-layer epoxy overlay (1978 Virginia Specifications)	36,39 40B,44	Virginia	7,4 5,7	M,M L,M	VH,VH L,H
Multiple-layer epoxy-urethane overlay	14,15 10,30 22	Ohio Virginia Washington	7,4 4,4 4	H,M M,M L	L,L M,L M
Multiple-layer methacrylate overlay	41	Virginia	9	M	VH
Multiple-layer polyester overlay	1,2,4, 42,43	Virginia	6,9,3 9,9	M,M,M, M,M	M,L,M, VH,VH
Methacrylate slurry overlay	31,50 24,25	Virginia Washington	2,2 6,5	M,M L,L	M,M M,L
Premixed polyester overlay	26,27,29 48,49	California Virginia	7,8,7 3,2	L,L,L M,M	L,L,L L,M

a) age of treatment when evaluated
b) tons/lane mile/yr: L = < 2.5, M = 2.5 to 5.0, H = > 5.0
kg/lane km/yr: L = < 1,410, M = 1,410 to 2,820, H = > 2,820
c) 1990 average daily traffic (ADT): L = < 5,000, M = 5,000 to 25,000, H = > 25,000, VH = > 50,000

Table 2.1 (continued) Field evaluations

Protection or Patching Treatment	Bridge Number	Deck Location	Treat. Age, years[a]	Salt Applic. Rate[b]	ADT[c]
High-molecular weight methacrylate sealer	28 47	California Virginia	9 3	L M	L M
Silane sealer	33,34,35 7	Nebraska Virginia	9,12,10 6	H,H,L-M M	M,M,L M
Solvent-dispersed epoxy sealer	20,21 37,38	Michigan Virginia	4,4 8,8	H,H M,M	L,L VH,VH
Water-dispersed epoxy sealer	6	Virginia	6	M	VH
Asphalt patch	11,12,32	Virginia	<1,1,1	M,M,M	M,M,M
Portland cement concrete patch	8,9,11	Virginia	1,1-5,5	M,M,M	M,M,M
Magnesium phosphate concrete patch	16,17,18	Indiana	3-6	H,H,H	H,VH,L
None (no patches)	34C 3C,30C	Nebraska Virginia	18 5,4	H M,M	M M,L
None (patched decks)	16,17,18 8,9,11 12,32	Indiana Virginia	21,24,28 26,26,26 27,22	H,H,H M,M,M M,M	H,VH,L M,M,M M,M

a) age of treatment when evaluated
b) tons/lane mile/yr: L = < 2.5, M = 2.5 to 5.0, H = > 5.0
kg/lane km/yr: L = < 1,410, M = 1,410 to 2,820, H = > 2,820
c) 1990 average daily traffic (ADT): L = < 5,000, M = 5,000 to 25,000, H = > 25,000, VH = > 50,000

indication of the performance of rapid deck protection and patching treatments. The data were obtained by evaluating approximately 1,000 ft^2 (93 m^2) of deck surface, which typically included the travel lane and shoulder of one or more spans of each bridge. Electrical half-cell potential measurements and a sketch showing cracks, delaminations, spalls, and patches were made for the entire surface area being evaluated. For decks with overlays and sealers, five test sites were identified (typically two in the shoulder, two in the right wheel path, and one in the center of the travel lane) for detailed evaluations. Figure 2.1 provides a sketch that is typical of the locations of the tests at each of the five sites. However, tensile adhesion tests were not performed on sealers and cores for permeability tests were taken only at three of the five sites. For the evaluation of patches, half-cell potential and rate of corrosion measurements were made as shown in Figure 2.1. However, only three test sites with patches were evaluated and two cores for permeability tests were taken at each of the three sites. Therefore, for each patched deck evaluated, two cores were taken from the patches, two from nearby deck areas with low half-cell potentials (typically less negative than -0.20 volts [CSE], and two from nearby deck areas with high half-cell potentials (typically more negative than -0.35 volts [CSE]). Also, for the evaluation of patches, three chloride test locations were selected at each of the three sites: three from the patches, three from deck areas with low half-cell potentials, and three from areas with high half-cell potentials.

2.2 Permeability to Choride Ion

Chloride-contaminated concrete bridge decks constructed with black steel begin to crack and spall due to the formation of corrosion products on the reinforcement once the chloride ion content exceeds 1 lb/yd^3 (0.6 kg/m^3) at the reinforcement and there is sufficient oxygen and moisture present for the corrosion process to proceed (Transportation Research Board, 1979). The purpose of a deck protection treatment is to reduce or prevent the infiltration of chloride ions to the level of the reinforcing bars. This will maintain a chloride ion content at the reinforcing bars that is less than 1 lb/yd^3 (0.6 kg/m^3) and reduce or prevent the infiltration of moisture to the reinforcing bars. This reduces the rate of corrosion (Carter, 1989b). Two performance indicators for protective treatments are the rapid permeability test (AASHTO T 277) and chloride analysis of samples (AASHTO T 260).

2.2.1 Rapid Test on Cores

For the rapid test (AASHTO T 277) results are reported in Coulombs which have the following relationship to permeability.

Coulombs	Permeability
> 4,000	High
2,000 - 4,000	Moderate
1,000 - 2,000	Low
100 - 1,000	Very Low
< 100	Negligible

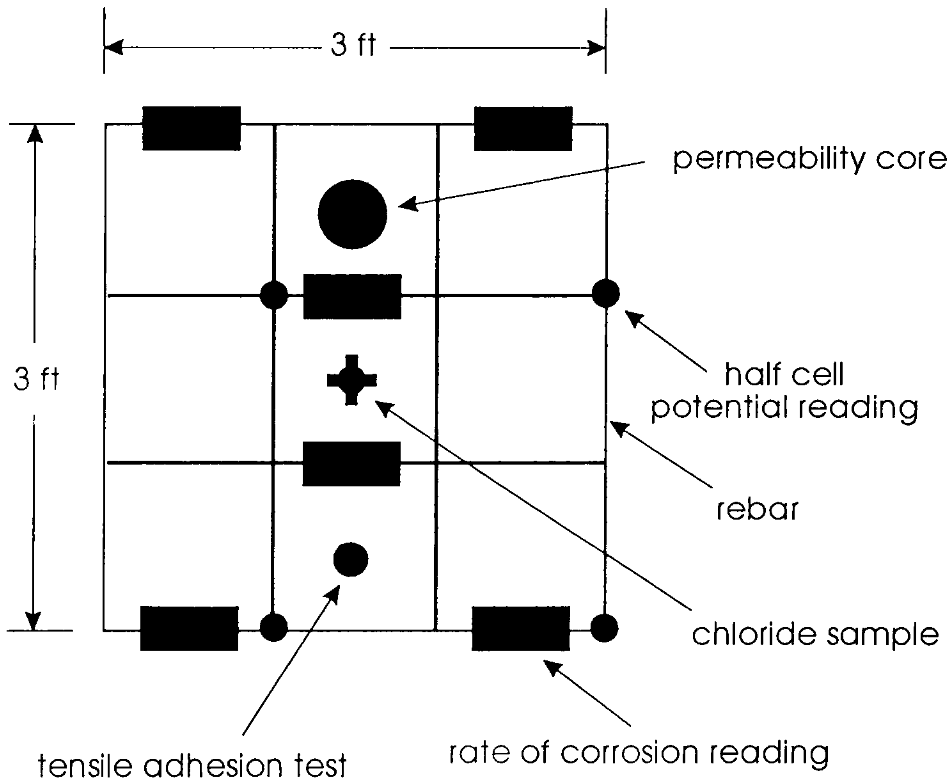


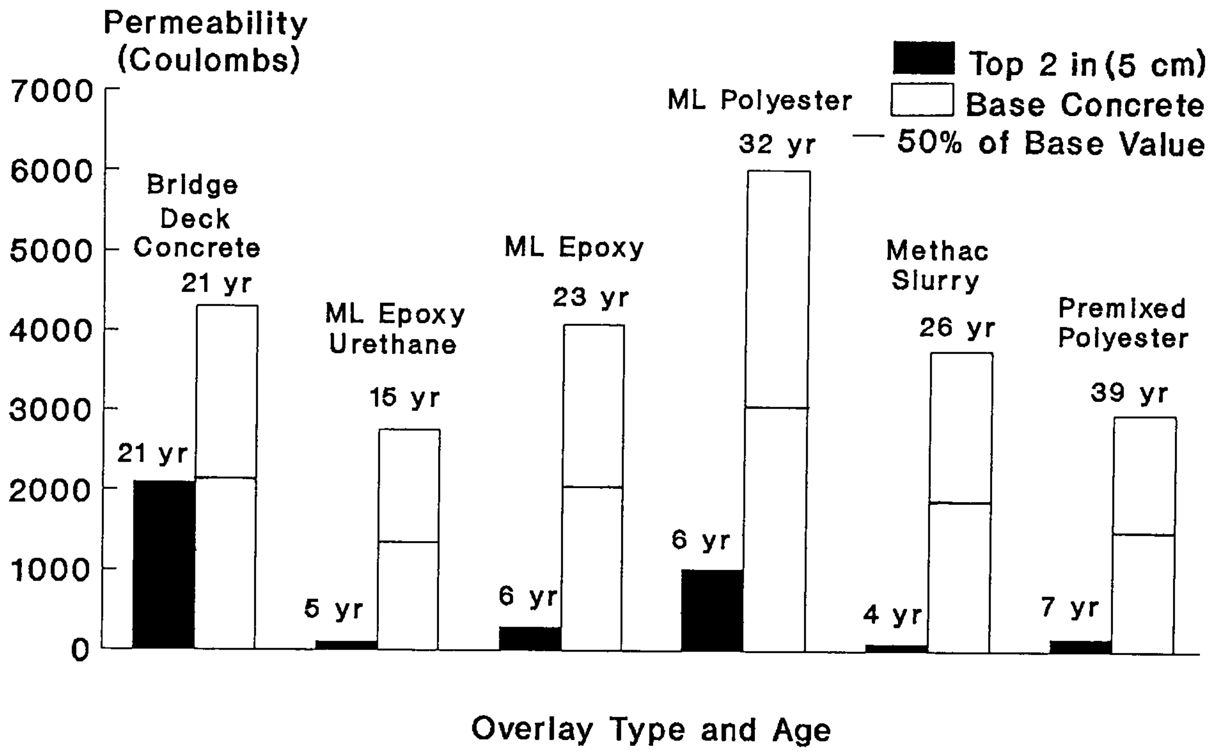
Figure 2.1 **Approximate locations of samples and measurements at each of the five sites on decks with polymer overlays**

Based on the literature review (Bradbury, 1987; Carrasquillo, 1988; Ozyildirim, 1988; Sprinkel, 1984; Sprinkel 1987a; Sprinkel, 1987b; Sprinkel, 1988; Sprinkel, 1990b; Sprinkel, Weyers, and Sellars, 1991; Sprinkel, 1992b), the protection and patching treatments differ as to permeability to chloride ion (AASHTO T277). Negligible values were found for polymer overlays at 1 year of age and very low values were typical at later ages; very low values were reported for latex-modified concrete and concrete containing silica fume at later ages; low values were reported for laboratory specimens made with special blended cements; and low-to-moderate values were reported for concretes to which a sealer had been applied. Typically, unprotected bridge deck concretes have a moderate to high permeability. With the exception of asphalt concrete, which has a very high permeability, the materials used to patch a deck typically have a low permeability to chloride ion. To compare the protection and patching treatments properly, the permeability over the life of the treatments needs to be considered.

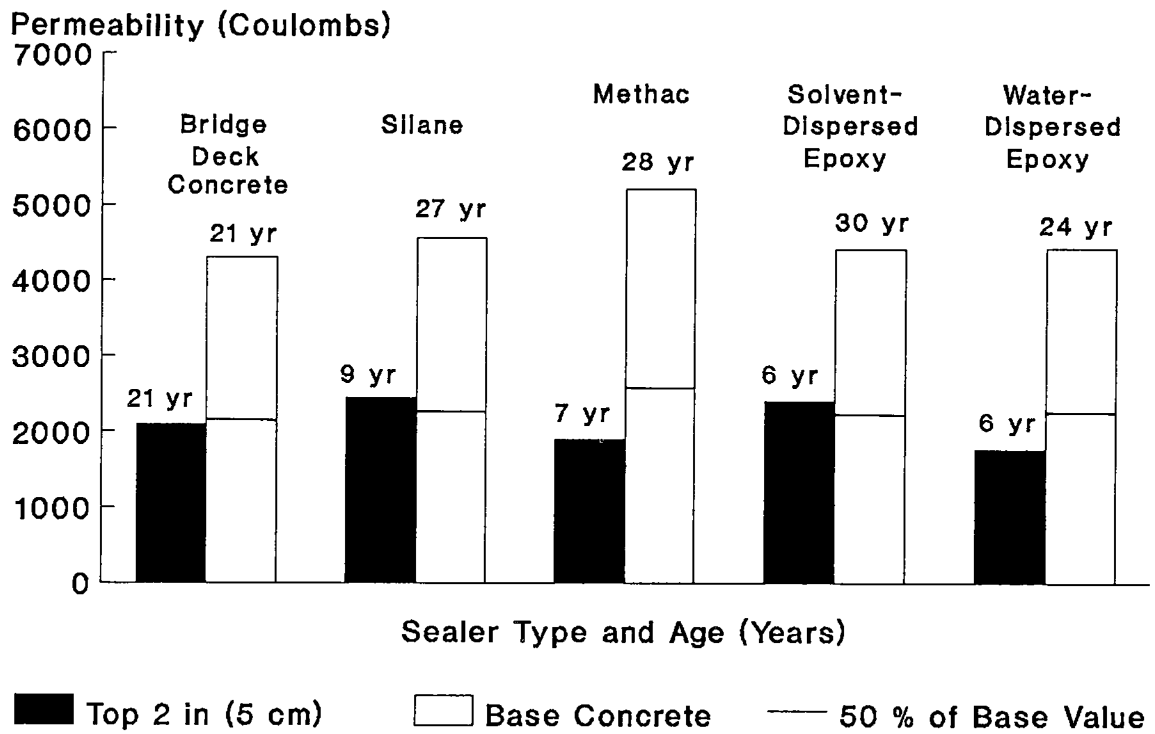
The rapid permeability test (AASHTO T 277) was used to measure the permeability to chloride ion of the top 2 in (5 cm) and the 2 to 4 in (5 to 10 cm) depth of each of three cores removed from decks protected with polymer overlays and sealers. For decks that were patched, six cores were removed: two from the patches, two from deck areas with low half-cell potentials and two from deck areas with high half-cell potentials. Appendix B (Table B3) shows the results for cores tested in 1991 and previous years, based on the tests of the top 2 in (5 cm) and the 2 to 4 in (5 to 10 cm) depth of the cores. The 2 to 4 in (5 to 10 cm) depth of the core is representative of the permeability of the concrete without the protection treatment here in referred to as the base concrete.

Figure 2.2 shows the average permeability results obtained in 1991 for the various polymer overlay and sealer treatments, at the indicated age of treatment. Figure 2.2 shows for untreated concrete decks that the permeability of the top 2 in (5 cm) of cores is approximately 50 percent of the permeability of the base concrete. It is believed that the 50 percent reduction in coulombs passed through the top 2 in (5 cm) relative to the base concrete is caused by the finishing of the top surface, the carbonation of the top surface, and the contamination of the top surface by traffic. Note, the bottom surface of the top specimen and both surfaces of the bottom specimen are clean, sawcut surfaces. In addition, the permeability (coulomb reduction) of the top 2 in (5 cm) of the concrete core is influenced by the permeability of the protective treatment and the concrete on which it is placed. As shown in Figure 2.2a, polymer overlays significantly reduced the permeability below the 50% base value. Whereas, for sealers, see Figure 2.2b, the permeability of the top 2 in (5 cm) is equal to, less than, or greater than the 50% base value. Thus, demonstrating that polymer overlays reduce the permeability of the top 2 in (5 cm) of the cores but sealers may or may not reduce the permeability. Figure 2.2 shows that polymer overlays provide considerable protection, whereas sealers reduce the permeability by 0 to 50 percent with an average of 32 percent relative to the 50% base value, depending on the concrete and the sealer.

Figure 2.2b shows that on the average the silane treatments of the decks on bridges 7, 33, 34, and 35 were not providing any protection when compared to untreated bridge deck concrete. On the other hand, a reduction of 30 percent was being achieved after 12 years when the silane-treated spans were compared to the untreated spans of bridge 34



a. Polymer overlays



b. Sealers

Figure 2.2 Permeability to chloride ion (AASHTO T 277) for cores taken from decks with polymer overlays and sealers in 1991

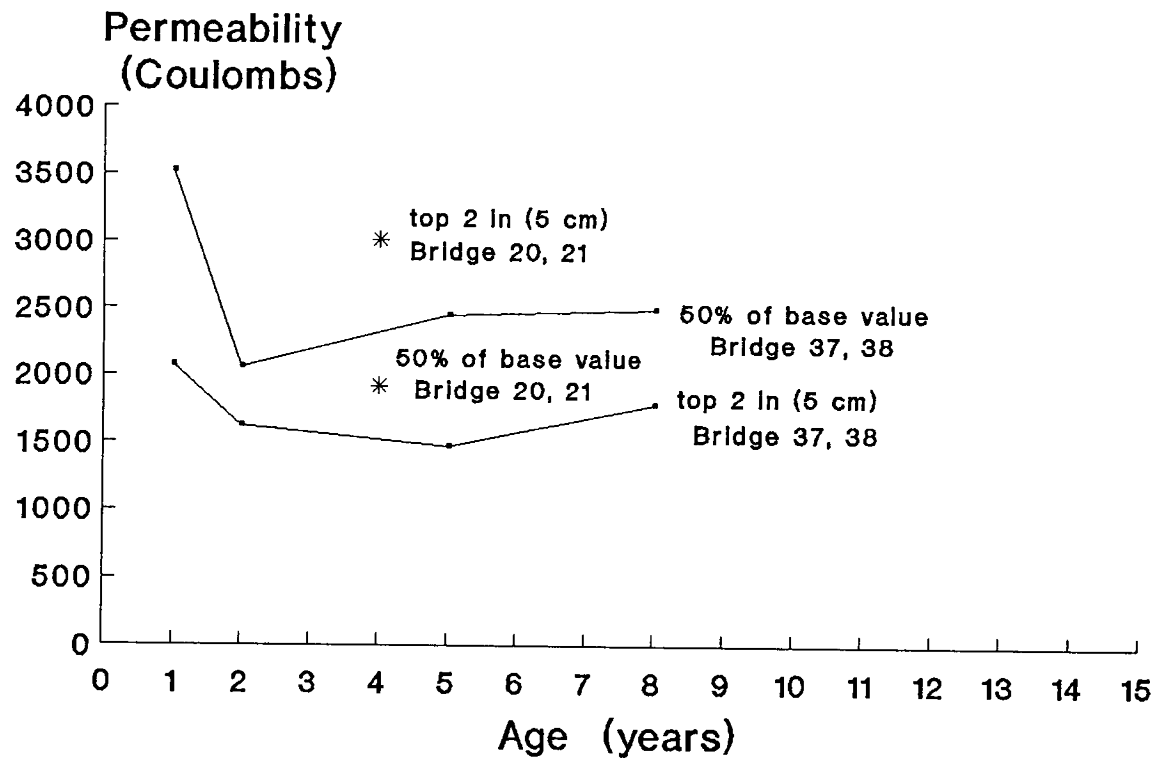
(see Table B3), in which every other span was treated with silane. Figure 2.2b also shows that on the average only the cores from the decks treated with high-molecular-weight methacrylate and water-dispersed epoxy showed permeabilities in the top 2 in (5 cm) that were less than 50 percent of the base concrete, indicating some protection being provided by the sealer.

Figures 2.3 and 2.4 show how the permeabilities (AASHTO T 277) of cores from decks treated with sealers change with age. Figure 2.3 shows that the solvent-dispersed epoxy applied to bridges 37 and 38 is providing protection when the permeability of the top 2 in (5.1 cm) of the cores is compared to 50 percent of the permeability of the base concrete. On the other hand, the treatments on bridges 20 and 21 were not providing protection. Likewise, Figures 2.3 and 2.4 show that protection is being provided by the water-dispersed epoxy and the high-molecular-weight methacrylate treatments, but Figure 2.4 shows mixed results for the silane treatments. In general, the permeabilities of patching materials, at the indicated ages, other than asphalt concrete are usually lower than that of the bridge deck concrete they replace, see Figure 2.5.

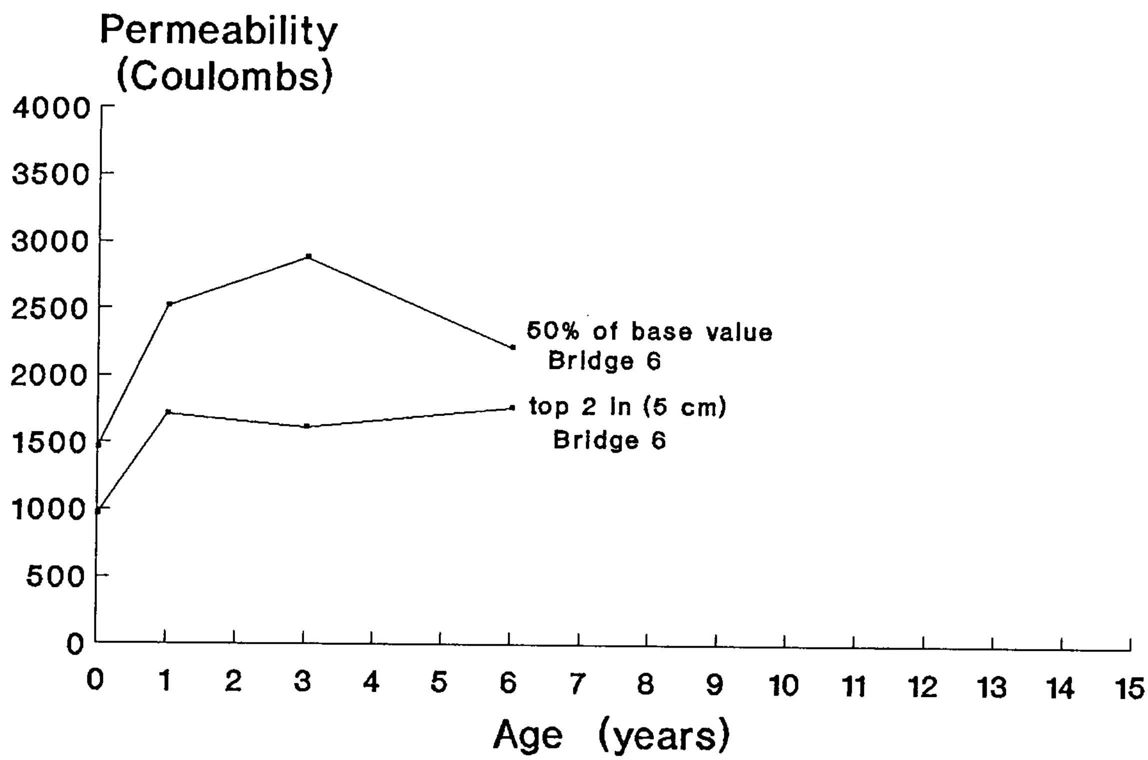
Figure 2.6 illustrates how the permeabilities of cores taken from decks with overlays and sealers change with age. As shown in Figure 2.6, the permeabilities of decks with polymer overlays typically increase with age but should be less than 1,000 Coulombs for 15 to 20 years for overlays constructed with flexible binders, such as those used in the epoxy, epoxy-urethane, premixed polyester, and methacrylate slurry overlays. The brittle binders used in the multiple-layer methacrylate and polyester overlays crack, causing the permeabilities to be higher. Figure 2.6 shows that typically the permeability of decks treated with sealers increases with age. The concrete in the deck of bridge 7 was new at the time it was treated with silane, which may explain the decrease with age shown in Figure 2.6, e.g. permeabilities typically decrease as portland cement concrete hydrates more completely with age. However, 12 years after treatment, the spans on bridge 34 treated with a silane sealer have a permeability that is 30 percent lower than that of the untreated spans (based on tests of eight cores from six silane-treated spans and eight cores from six untreated spans).

The effect of traffic on the permeability of the decks was also examined. The permeability of the top 2 in (5 cm) of cores removed from the shoulder areas was compared with that of cores removed from the travel lane. With the exception of the four decks treated with the silane sealers (see Figure 2.7), no trends were noted. As can be seen in Figure 2.7, the cores from the shoulder area of the decks treated with silane sealers had lower permeabilities than those of cores taken from the travel lane areas.

Figure 2.8 shows the effect of the aggregate gradation on the permeability to chloride ion of multiple-layer epoxy overlays. Overlays constructed according to current specifications in which a No. 8 basalt or silica is used maintain a low permeability. Overlays constructed with the finer No. 20 silica sand, as was typical prior to 1978, show an increase in permeability with age. A protective treatment must have adequate abrasion resistance to prevent wear that results in a decrease in the level of protection. Most polymer overlays have good abrasion resistance as long as abrasion-resistant aggregates are used in the mixtures.

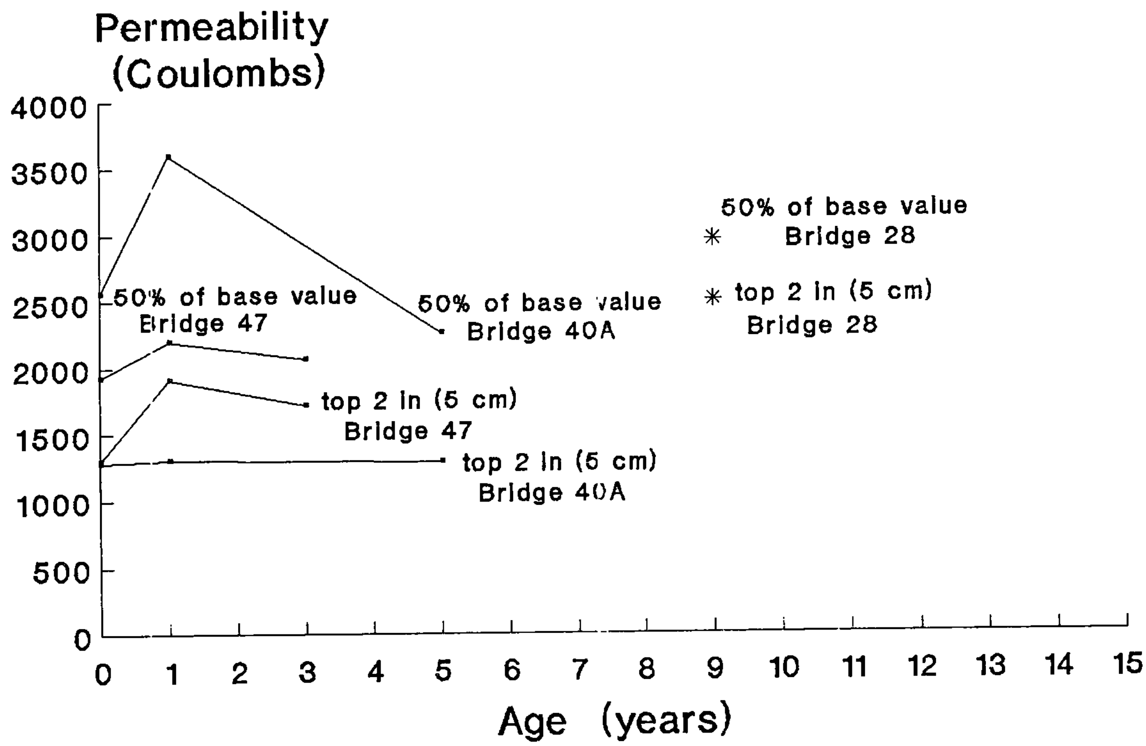


a. Solvent-dispersed spray

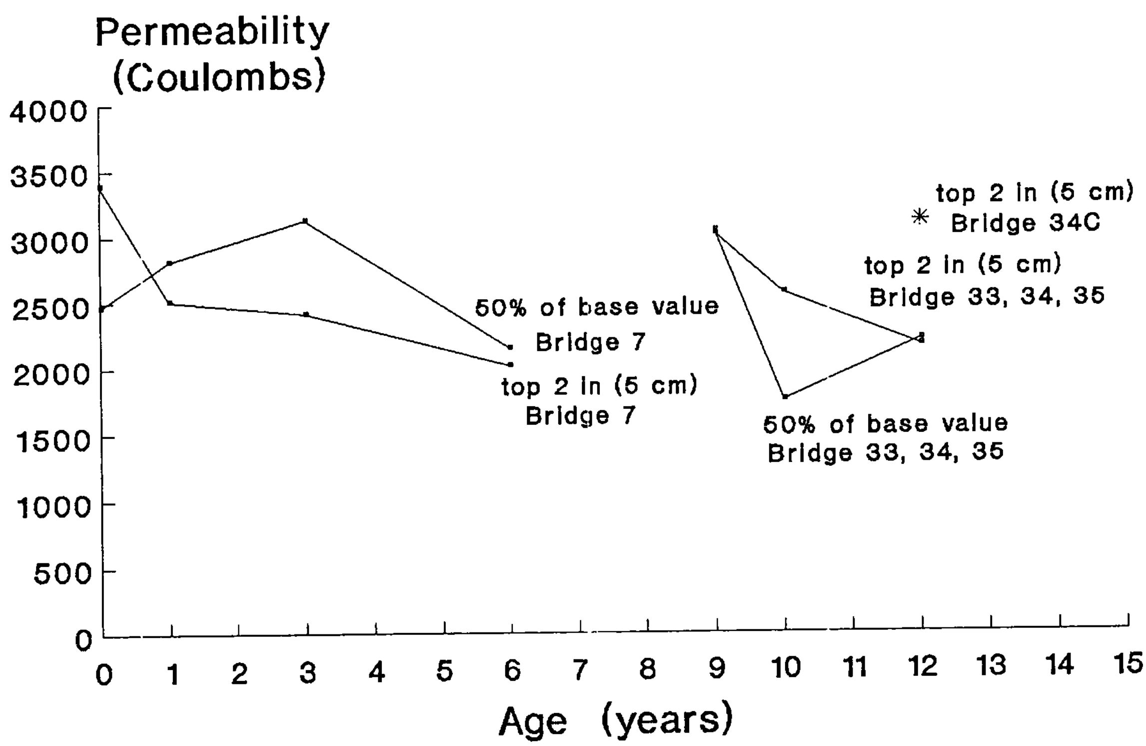


b. Water-dispersed epoxy

Figure 2.3 Permeability to chloride ion (AASHTO T 277) for cores taken from decks with epoxy sealers



a. High-molecular-weight sealer



b. Silane sealer

Figure 2.4 Permeability to chloride ion (AASHTO T 277) versus age for cores taken from decks treated with a high-molecular-weight methacrylate sealers and a silane sealer

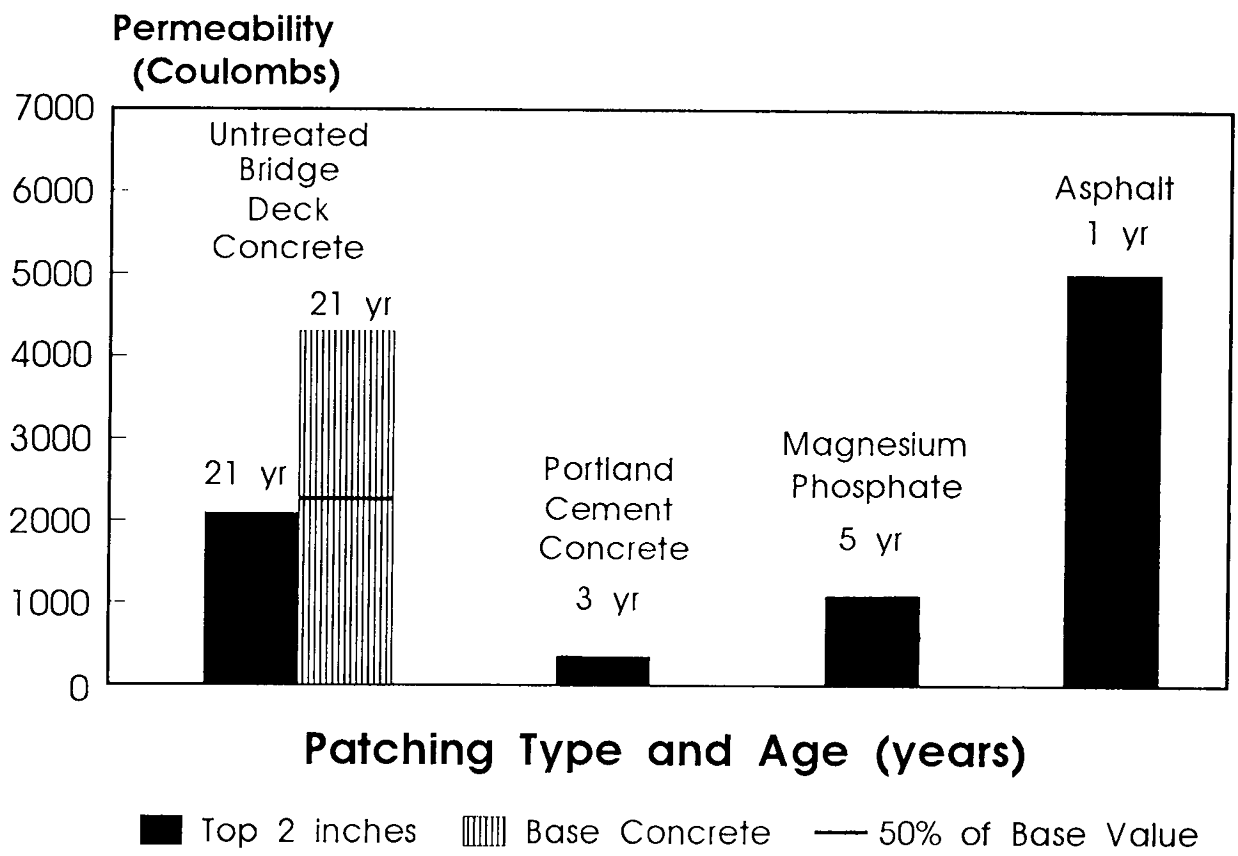
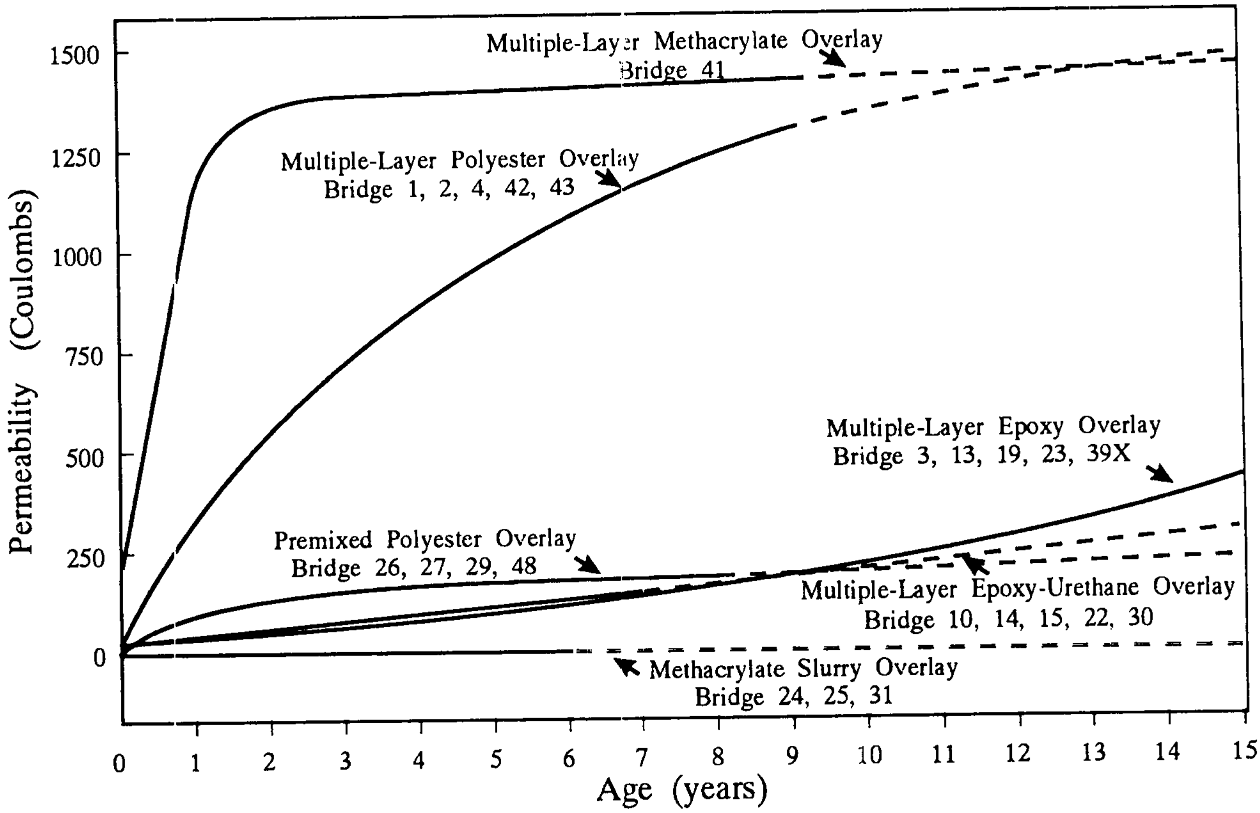
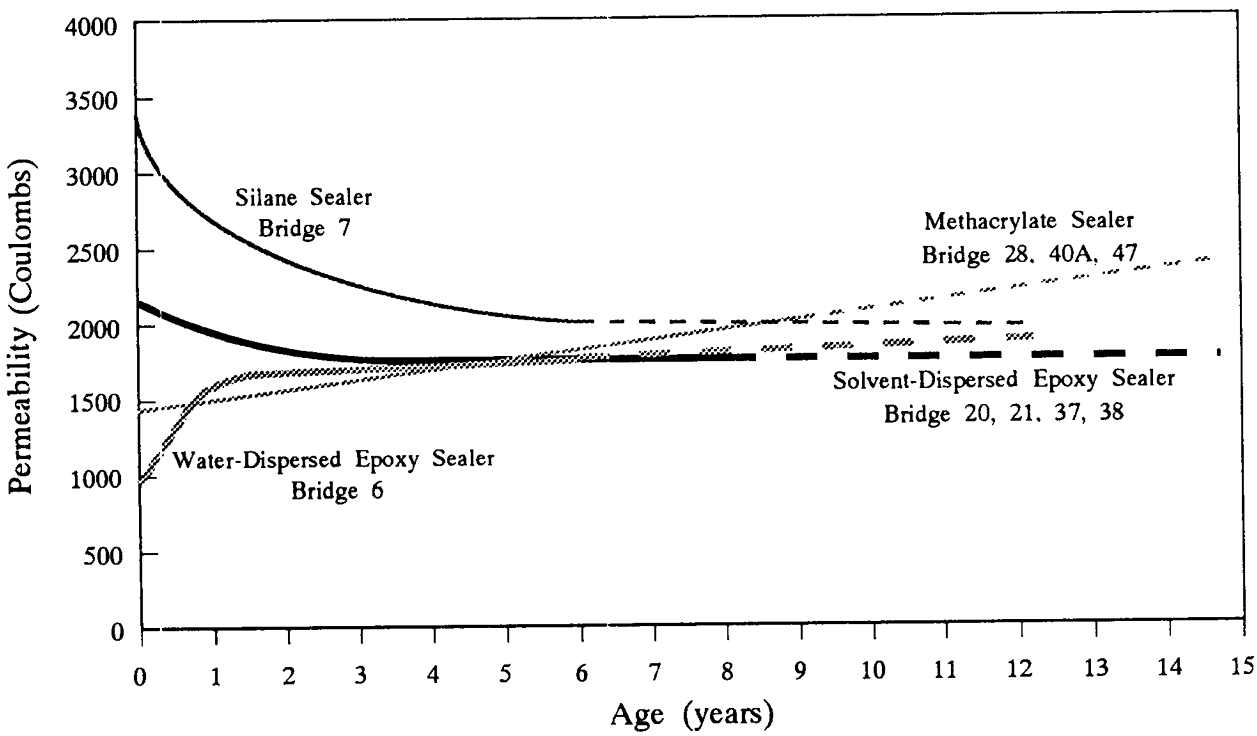


Figure 2.5 Permeability to chloride ion (AASHTO T 277) for cores taken from patches in 1991



a. Polymer overlays



b. Sealers

Figure 2.6 Permeability to chloride ion (AASHTO T 277) versus age for cores taken from decks with polymer overlays and sealers

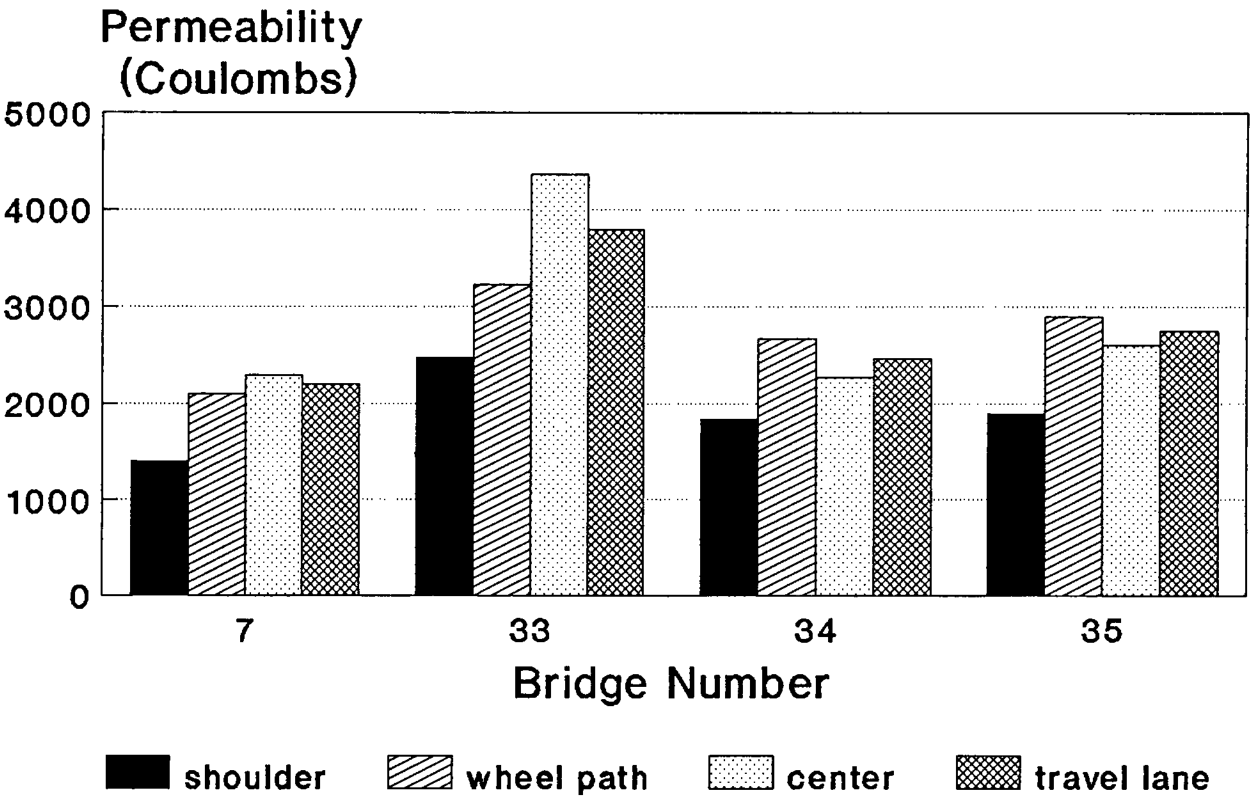
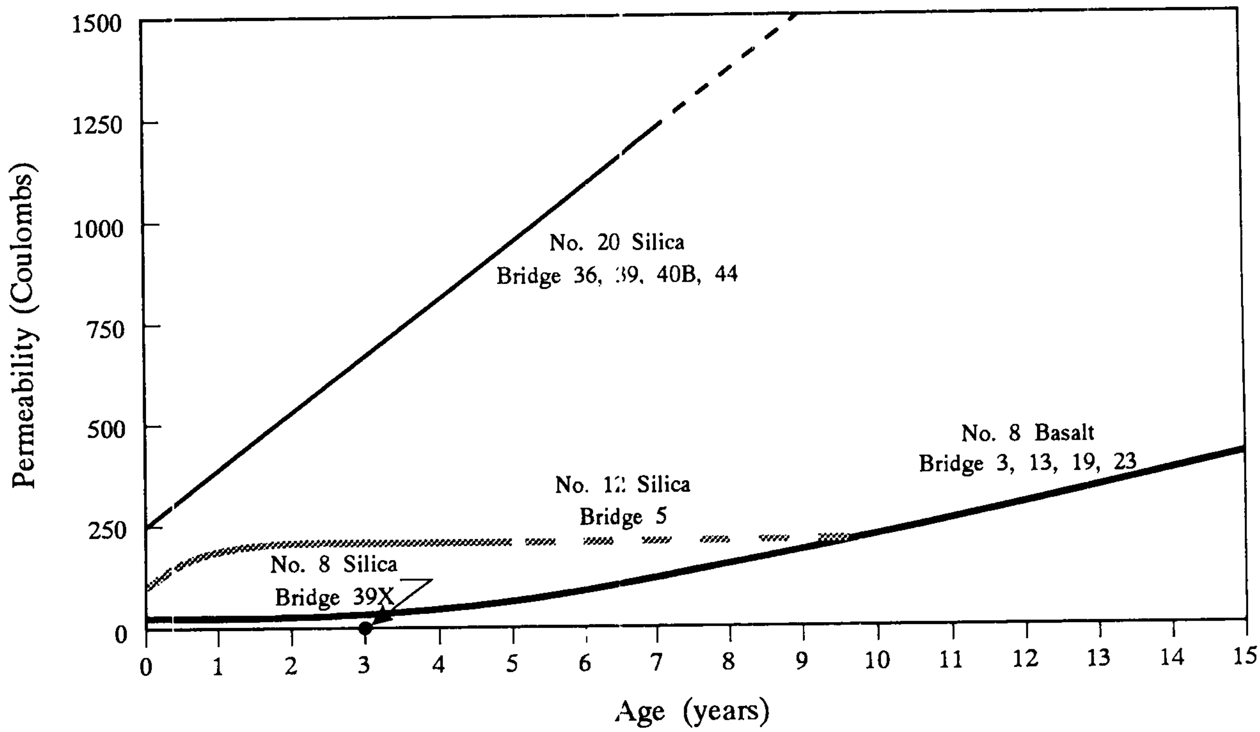
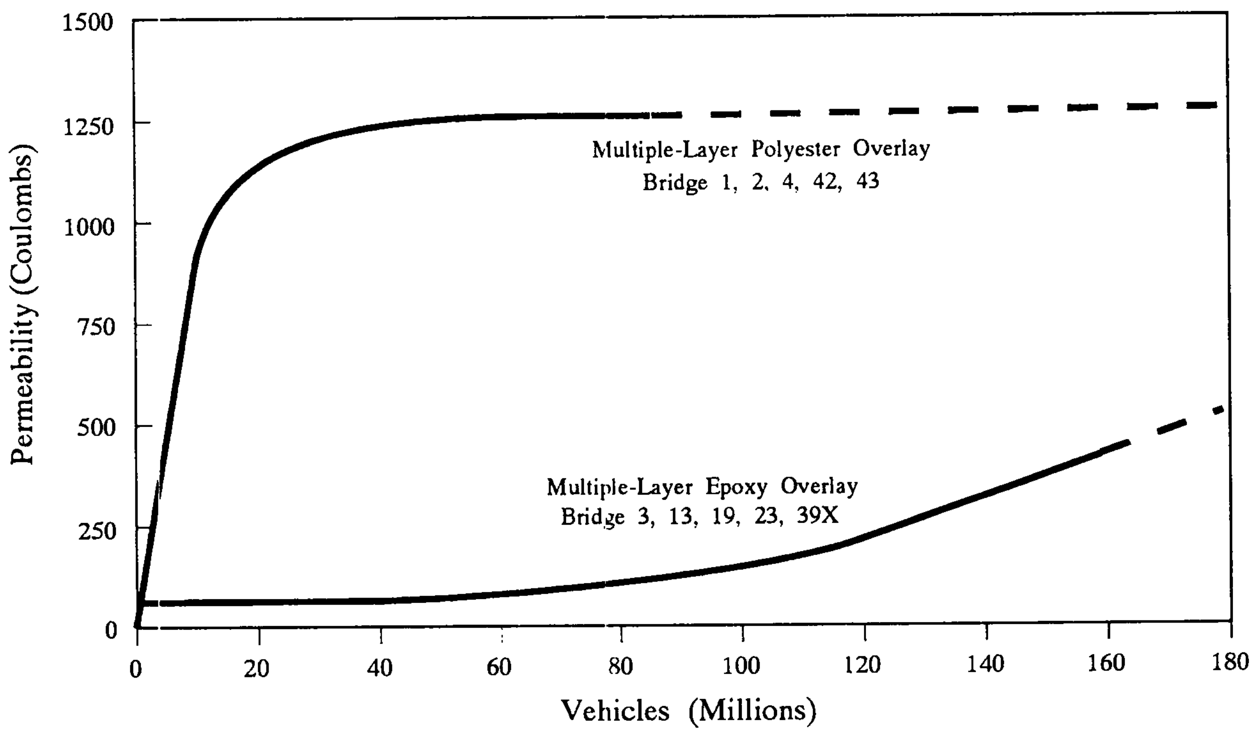


Figure 2.7 Permeability to chloride ion (AASHTO T 277) for cores taken from shoulders as compared to those taken from travel lanes for silane-treated decks



a. Epoxy overlays constructed with different sizes of gap-graded aggregates



b. Polymer overlays as a function of cumulative traffic

Figure 2.8 Permeability to chloride ion (AASHTO T 277) versus age and cumulative traffic for cores taken from decks with multiple-layer polymer overlays

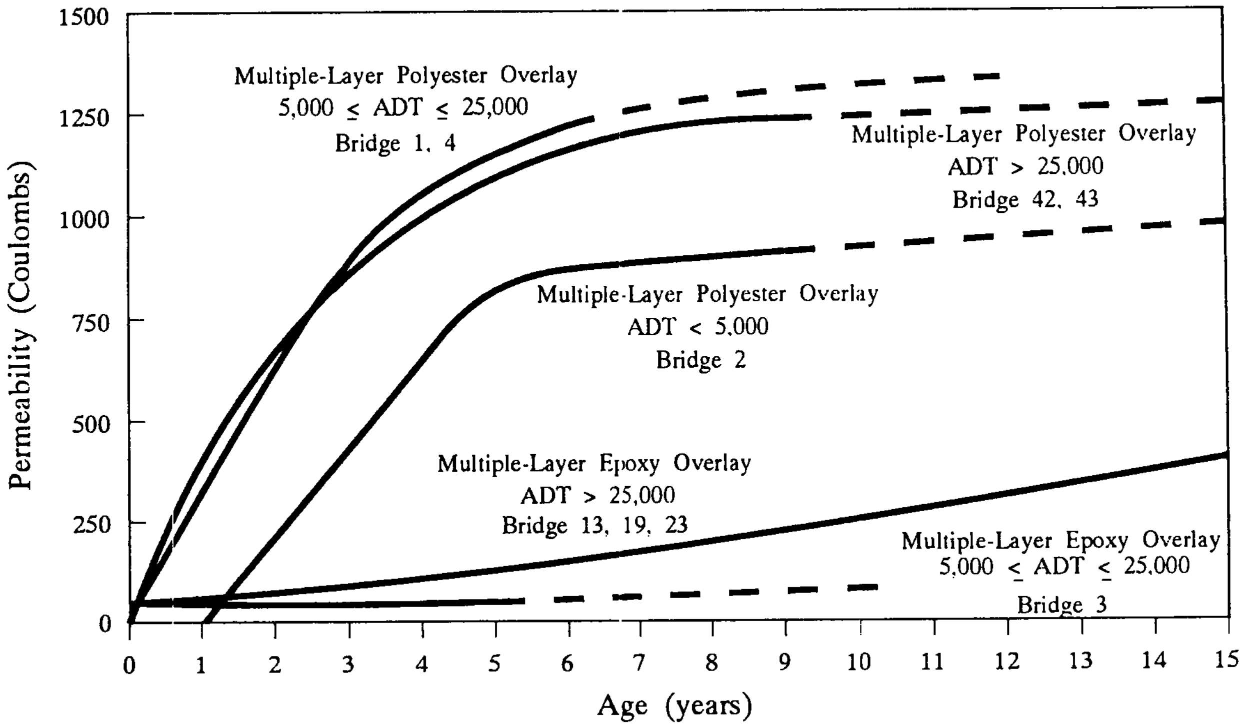
Figure 2.8 also shows the relationship between cumulative traffic and permeabilities for multiple-layer epoxy and polyester overlays and indicates that permeability increases up to a point as traffic increases. Figure 2.9 shows the relationship between permeability and age for these overlays as a function of three ADTs. The permeability increases as the ADT increases. The relationship between permeability and age for three salt application rates was also examined. The only trend that was observed is shown in Figure 2.9, which suggests that the permeability of epoxy overlays increases as the salt application rate increases.

2.2.2 Chloride Content of Field Samples

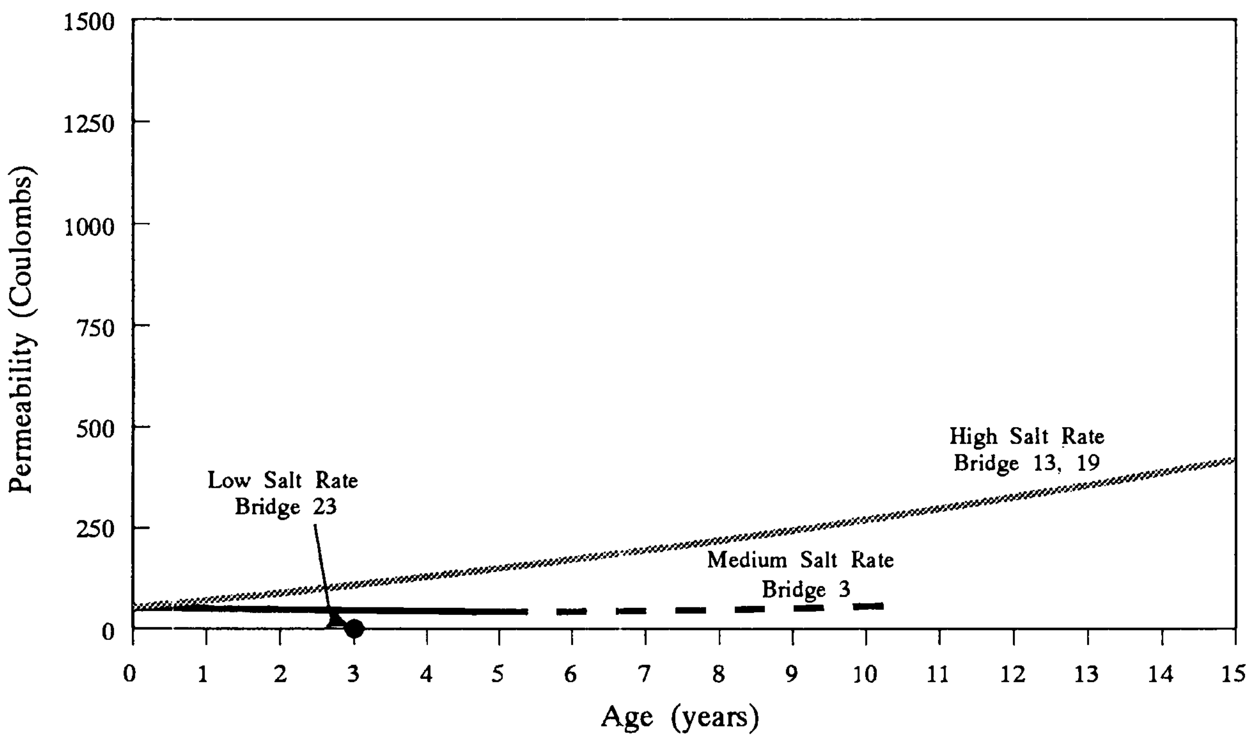
Appendix B (Table B4) shows the average chloride ion content (AASHTO T 260) in 1991 for samples taken at five depths: 0.31 in (0.8 cm), 0.75 in (1.9 cm), 1.25 in (3.2 cm), 1.75 in (4.5 cm), and 4.25 in (10.8 cm). For decks with polymer overlays and sealers, the samples were taken at five locations, typically two in the shoulder, two in the right wheelpath, and one in the center of the travel lane. For patched decks, the samples were taken at five depths at three locations (one in a patch, one in an area of low half-cell potential, and one in an area of high half-cell potential), and at the level of the top reinforcing bar at six other locations (two in patches, two in areas of low half-cell potential, and two in areas of high half-cell potential). Where available, data from samples taken at two or more locations on a deck in previous years are reported.

Figure 2.10 shows the average annual change in the chloride ion content as a function of depth for decks with polymer overlays and sealers and for control decks without protection treatments for which background data were available. The result shown for deck concrete includes samples from three control bridges and the unpatched areas of patched decks. The data for the deck concretes without a protection treatment were very consistent and are believed to be representative of decks in states with moderate to high salt application rates. Figure 2.10 shows 13 years on the average is required to reach a 1 lb/yd^3 (0.6 kg/m^3) chloride content at a depth of 1.75 in (4.5 cm) for these decks. Therefore, typical unprotected bridge deck concrete with a 1.75 in (4.5 cm) cover, and subjected to moderate to high salt application rates, should show signs of chloride-induced corrosion at approximately 13 years of age. The time to corrosion would be less if the cover was thinner and more if the cover was thicker. The average reinforcing bar cover for the decks without a protection treatment was 2.0 in (5 cm). However, as can be seen in Figure 2.10, the average annual change in chloride content was about the same at the rebar level as at the 1.75 in (4.5 cm) level.

The background data base for the decks with the polymer overlay and sealer protection treatments was very limited, which tends to explain some of the inconsistent trends shown in Figure 2.10. Some of the background data could not be used because a number of years passed between the chloride sampling and the installation of the protective treatment. In general, the data show that the application of a polymer overlay or sealer reduces the average annual increase in chloride ion content and therefore extends the life of the deck. The data shown in Figure 2.10 for the polymer overlays are

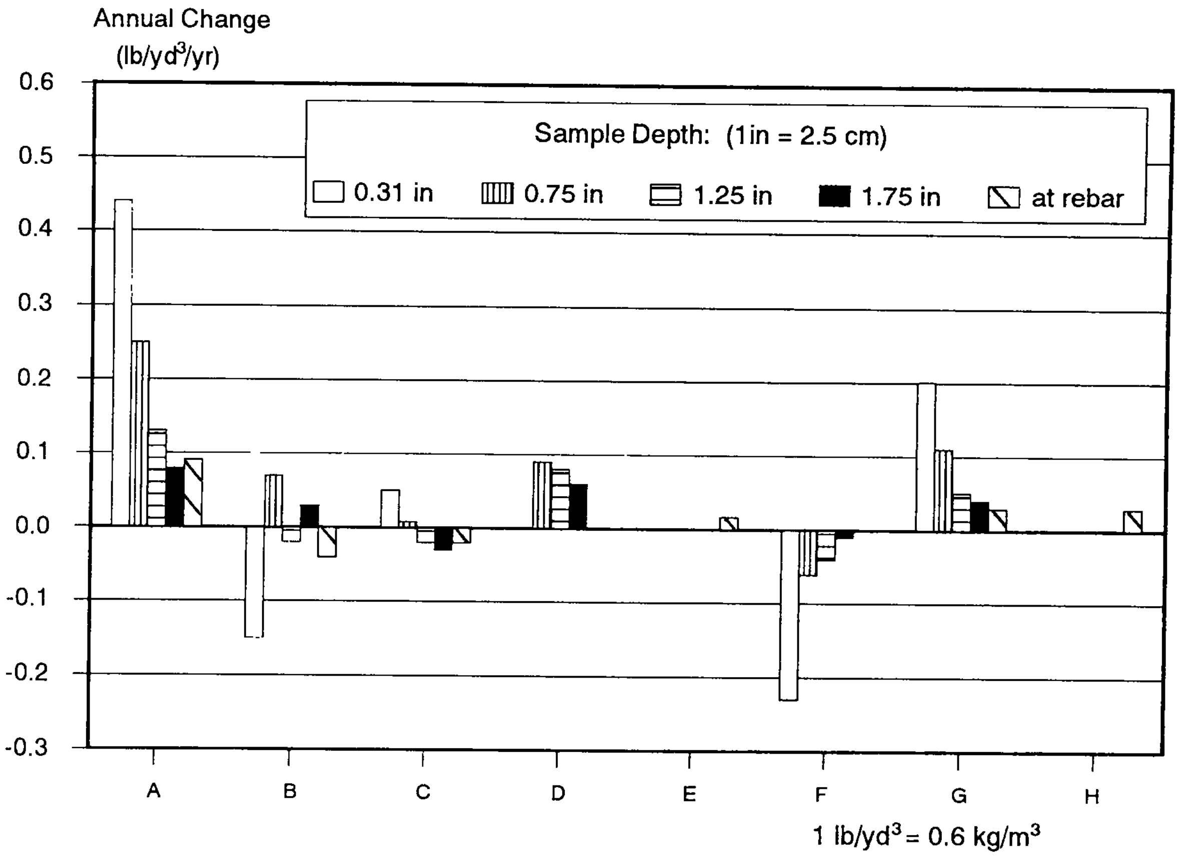


a. Three ADTs



b. Three salt application rates

Figure 2.9 Permeability to chloride ion (AASHTO T 277) versus age for cores from decks with multiple-layer polymer overlays with three ADTs and three salt application rates



PROTECTION SYSTEM	BRIDGE NUMBER(S)
A - Untreated Deck Concrete	(3C, 30C, 34C, 8, 9, 11, 12, 16, 17, 18, 32)
B - Multiple Layer Epoxy Overlay	(3, 23, 36, 39, 44)
C - Multiple Layer Epoxy Urethane Overlay	(14, 30)
D - Multiple Layer Polyester Overlay	(2, 42, 43)
E - Methacrylate Slurry Overlay	(24)
F - Multiple Layer Methacrylate Overlay	(41)
G - Solvent Dispersed Epoxy Sealer	(37, 38)
H - Water Dispersed Epoxy Sealer	(6)

Figure 2.10 Average annual change in chloride ion content

impressive in that they show some average annual decreases in chloride ion content. These negative changes are indicative of negligible infiltration of new chloride ion and possible movement of existing chloride ions to greater depths within the concrete.

The data in Figure 2.10 show that the epoxy sealers are much less effective than the polymer overlays but reduce the penetration of chloride to about half of that of the untreated decks. No background data on chloride ion content were available for the decks treated with high- molecular-weight methacrylate. Also, background data were not available for the decks treated with silane, with the exception of data for bridges 7 and 34. Bridge 34 showed no change in chloride ion content at the reinforcing bars between 1985 and 1991. On the other hand, during the same period, bridge 7, which was a new deck treated with silane, showed average annual increases in chloride ion content that ranged from 1.24 lb/yd^3 (0.73 kg/m^3) in the top 0.5 in (1.3 cm) to 0.35 lb/yd^3 (0.21 kg/m^3) at the 1.75 in (4.5 cm) depth. The average annual change in chloride profile for bridge 7 was 3 to 5 times greater than for the untreated decks shown in Figure 2.10. Although these results are inconsistent and inconclusive, they agree with the literature in that the Oklahoma DOT reported silanes to be effective and the Kansas DOT reported them to be ineffective (Crumpton, 1989; Smith, 1986).

Based on the chloride ingress data in Figure 2.10, bridge decks with a 1.75 in (4.5 cm) average cover over the reinforcing bars should show signs of chloride-induced corrosion (chloride ion content equals 1 lb/yd^3 [0.6 kg/m^3]) as follows when the average chloride application rate is moderate:

- 13 years (1/0.08) when no protection treatment is used,
- 25 years (1/0.04) when an epoxy sealer is maintained, and
- 77 years (1/0.013) when a polymer overlay is maintained.

Chloride ponding tests done on slabs overlayed with a multiple-layer epoxy-urethane polymer overlay support the 77 year projection (Zoob, LeClaire, Pfeifer, 1985).

2.3 Corrosion of Reinforcing Bars

2.3.1 Half-Cell Potentials

Copper sulfate half-cell potentials (ASTM C 876-77) were measured at grid points spaced 2 ft (0.6 m) apart over the shoulder and travel lane of at least 1,000 ft^2 (93 m^2) of deck surface. Data obtained for the 40 bridges evaluated in 1991 are shown in Appendix B (Table B5) along with data obtained in previous years for the 50 bridges evaluated. For bridges with polymer overlays and sealers, the percentage of potentials that are more negative than -0.35 V (CSE) has not changed significantly with time.

Graphs were prepared as shown in Figure 2.11 to examine the relationship between the half-cell potentials in the vicinity of the chloride samples and the chloride ion content at the reinforcing bars based on measurements made in 1991. As expected, there were general relationships in which potentials became more negative as the chloride ion content increased. Figure 2.11 shows that when the average chloride ion content at the reinforcing bars is 1 lb/yd^3 (0.6 kg/m^3) or more, the average of the electrical half-cell potentials is more negative than -0.250 V (CSE) for untreated decks with and without patches, and more negative than -0.100 V (CSE) for decks with multiple-layer epoxy overlays. Similar results were observed for the other polymer overlays. It is likely that the presence of the overlay increases the half-cell potential readings.

2.3.2 Rate of Corrosion

A three-electrode linear polarization device (Clear, 1989) was used to measure the rate of corrosion of the top mat of the reinforcing bars in the 40 bridges evaluated in 1991. For decks with polymer overlays and sealers, six measurements were made in the vicinity of each of the five chloride sample locations. For the patched decks, two measurements were made in the vicinity of each of the nine chloride sample locations. The data are reported in Appendix B (Table B6).

The relationship between rate of corrosion and chloride ion content at the reinforcing bars is shown in Figure 2.12. It is obvious from Figure 2.12 that on the average no corrosion damage (Clear, 1989) is expected when the average chloride ion content in the vicinity of the reinforcing bars is less than 1.0 lb/yd^3 (0.6 kg/m^3) for decks with multiple-layer epoxy overlays. Damage is expected in 10 to 15 years when the chloride content is 2.0 to 5.5 lb/yd^3 (1.2 to 3.3 kg/m^3) and in 2 to 10 years when the chloride content is greater than 5.5 lb/yd^3 (3.3 kg/m^3) for these decks. For decks with no protection treatment, corrosion damage is expected in 10 to 15 years when the chloride ion content is less than 1.0 lb/yd^3 (0.6 kg/m^3) and in 2 to 10 years when it is greater than 3.0 lb/yd^3 (1.8 kg/m^3). It is interesting that, for a given chloride content, corrosion damage is expected earlier for decks on which a solvent-dispersed epoxy sealer, silane sealer, or multiple-layer polyester overlay has been placed than for unprotected decks. The data suggest that the application of these treatments accelerates corrosion. The only logical explanation for this finding is that the protection treatments trap moisture in the concrete and in the presence of chlorides corrosion is accelerated. Figure 2.12 also shows that with the exception of decks with epoxy overlays, corrosion damage is expected in less than 15 years when the chloride ion content is zero. The reader is cautioned that rate of corrosion measurements are subject to considerable error and that little data exists for measurements taken through protective treatments.

The relationship between rate of corrosion and permeability to chloride ion was examined. The presence of a polymer overlay or sealer reduced the permeability of the top 2 in (5 cm) of the deck but had little effect on the rate of corrosion. Although there was a tendency for the rate of corrosion to increase as the permeability increased for agiven protective treatment, in general, the rate of corrosion was independent of the permeability of both the top 2 in (5 cm) and the next 2 in (5 cm) of the concrete cores.

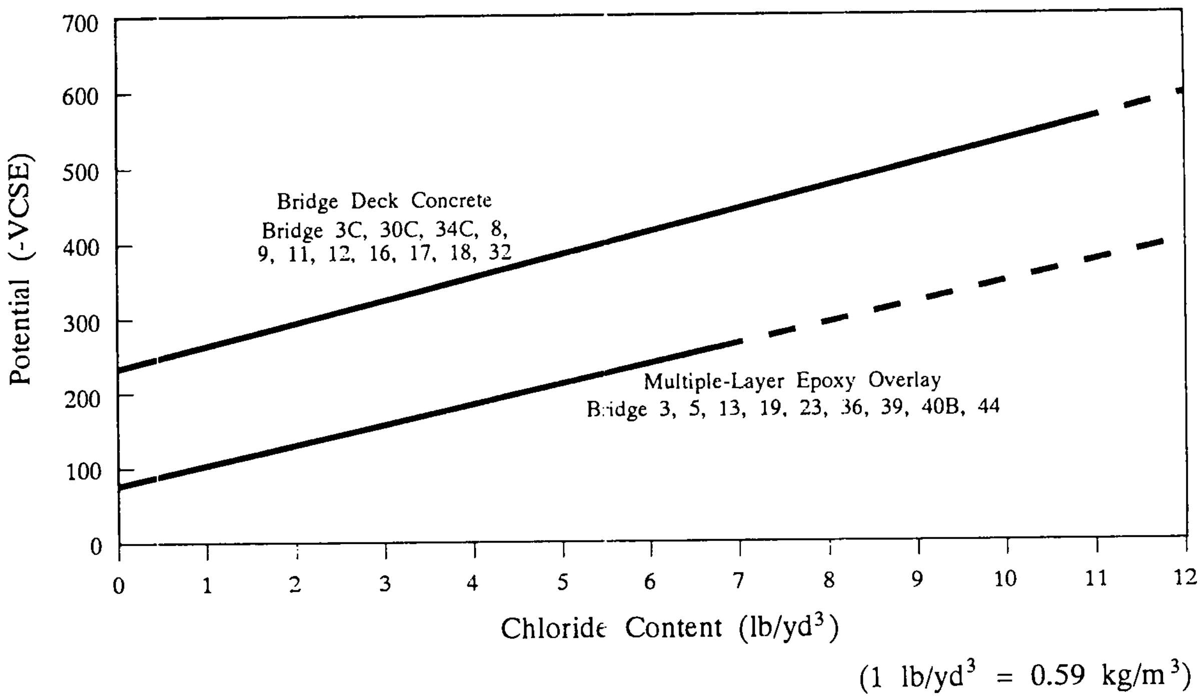


Figure 2.11 Relationship between half-cell potential measurements and chloride ion contents at the reinforcing bars for untreated decks with and without patches and decks with multiple-layer epoxy overlays

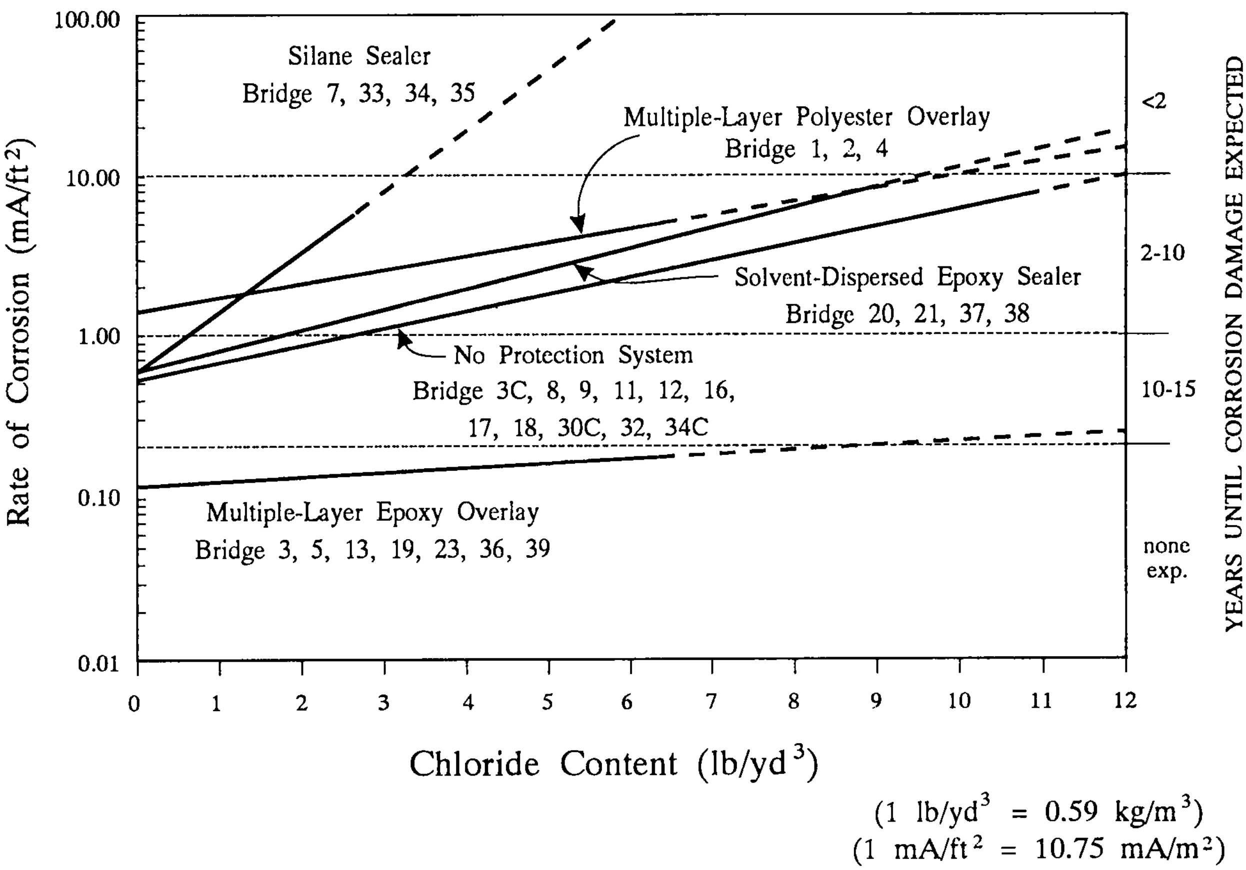


Figure 2.12 Rate of corrosion versus chloride ion content at the reinforcing bars

Figure 2.13 shows the average values for chloride ion content at the reinforcing bars, half-cell potential, and rate of corrosion obtained for patched decks when measurements were made over the patches and within 2, 4, and 6 ft (0.6, 1.2, and 1.8 m) of the perimeter of the patches. Figure 2.13 shows that all three indicators of deterioration are greatest within 2 ft (0.6 m) of the perimeter of the patches and tends to show decreasing deterioration as the distance from the perimeter of the patches increases.

Figure 2.14 shows that, in general, the chloride ion content at the rebar and the rate of corrosion are independent of the type of patching material and that corrosion trends are similar for decks with similar chloride contents and suffering from corrosion-induced spalling. The data suggest that, regardless of the type of patching material that is used, corrosion-induced spalling can be expected to occur in the deck areas with high half-cell potentials that typically surround the patches. The removal of concrete with a half-cell potential more negative than -0.35 V (CSE) at the time the deck is patched is recommended to minimize spalling.

2.4 Skid Resistance and Wear

2.4.1 Polymer Overlays

A protection treatment must have an adequate skid resistance to be used on traffic-bearing surfaces. Corrective action is considered when smooth tire numbers (ASTM E 524) are < 20 and treaded tire numbers (ASTM E 501) are < 37 (Sprinkel, 1987a). Skid numbers for the decks with polymer overlays and sealers are shown in Appendix B (Table B7). Figure 2.15 shows how the numbers change with age and with the exception of the methacrylate slurry, polymer overlays constructed by current specifications should have acceptable skid numbers for 25 years. Figure 2.15 also shows the effect of the gradation of the aggregate on the skid number of multiple-layer epoxy overlays. Low skid numbers are typically limited to overlays that are topped with sands that are smaller than the No. 8 sieve. Reports (Furr, 1984) of low skid numbers for polymer overlays constructed in the 60s and 70s can be attributed to the use of aggregates that were smaller than the No. 8 sieve.

Figure 2.16 shows the effect of cumulative traffic and Figure 2.17 shows the effect of ADT on the bald tire skid numbers of polymer overlays. As would be expected, the number drops as the cumulative traffic and ADT increase. Multiple-layer epoxy and polyester overlays have good skid numbers after high cumulative traffic. On the other hand, the most flexible binders evaluated, the methacryalte slurry and the epoxy-urethane, seem to be more prone to a decrease in skid number as the ADT increases.

The relationship between bald tire skid numbers and salt application rate was also examined. The only data base that was large enough to show a trend was that for the multiple-layer epoxy overlay. The trend was the reverse of what would be expected in that a greater drop in skid number with age was seen for decks with low salt application

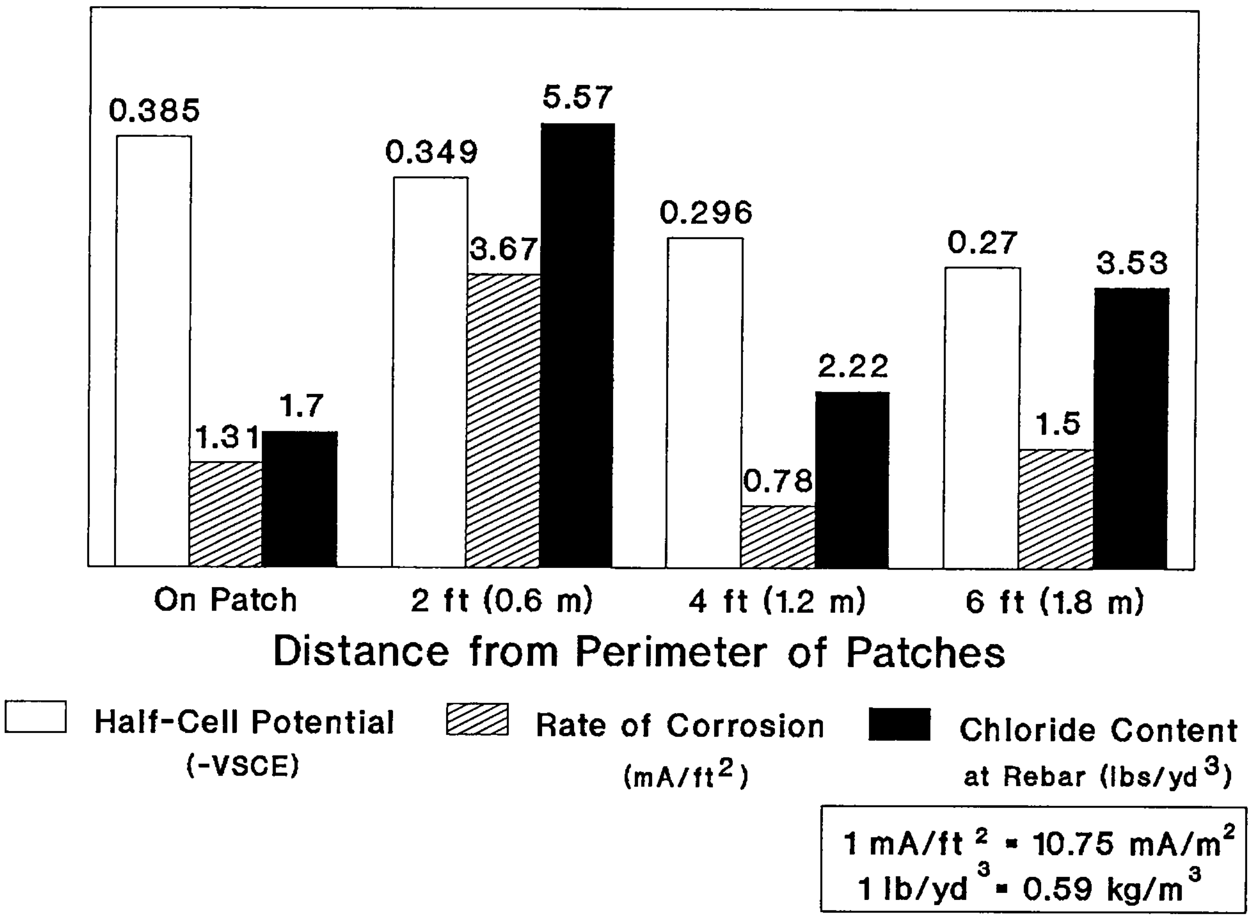
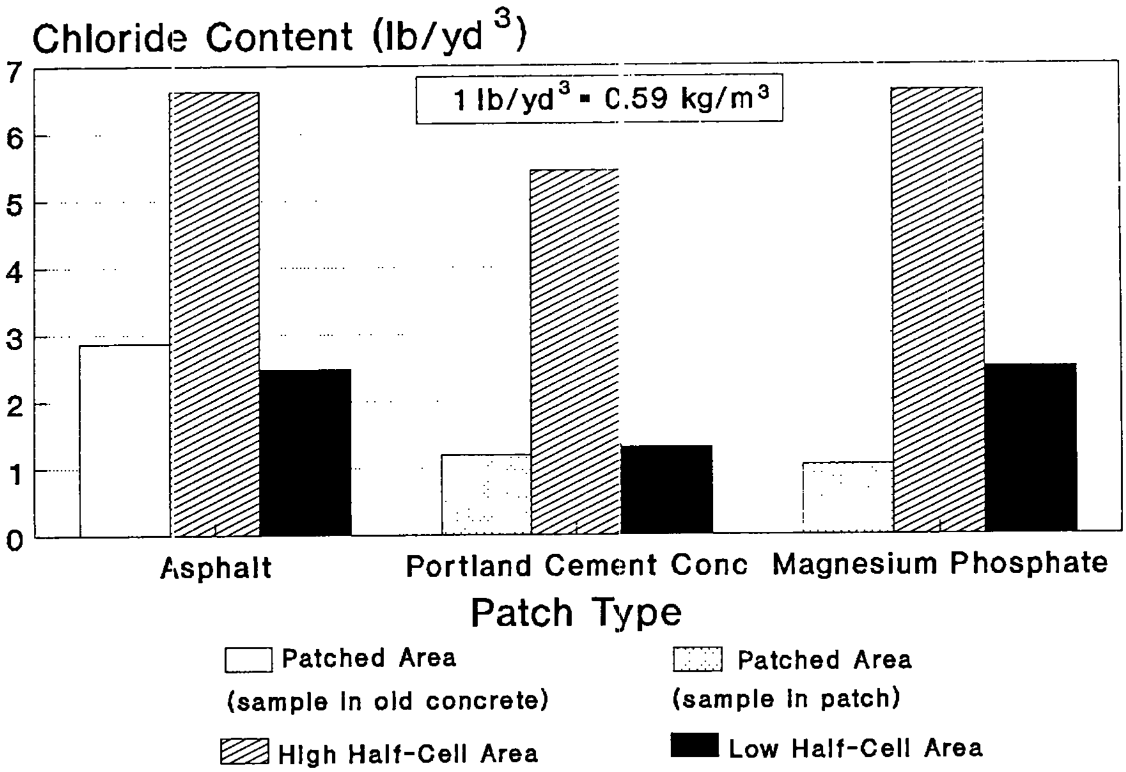
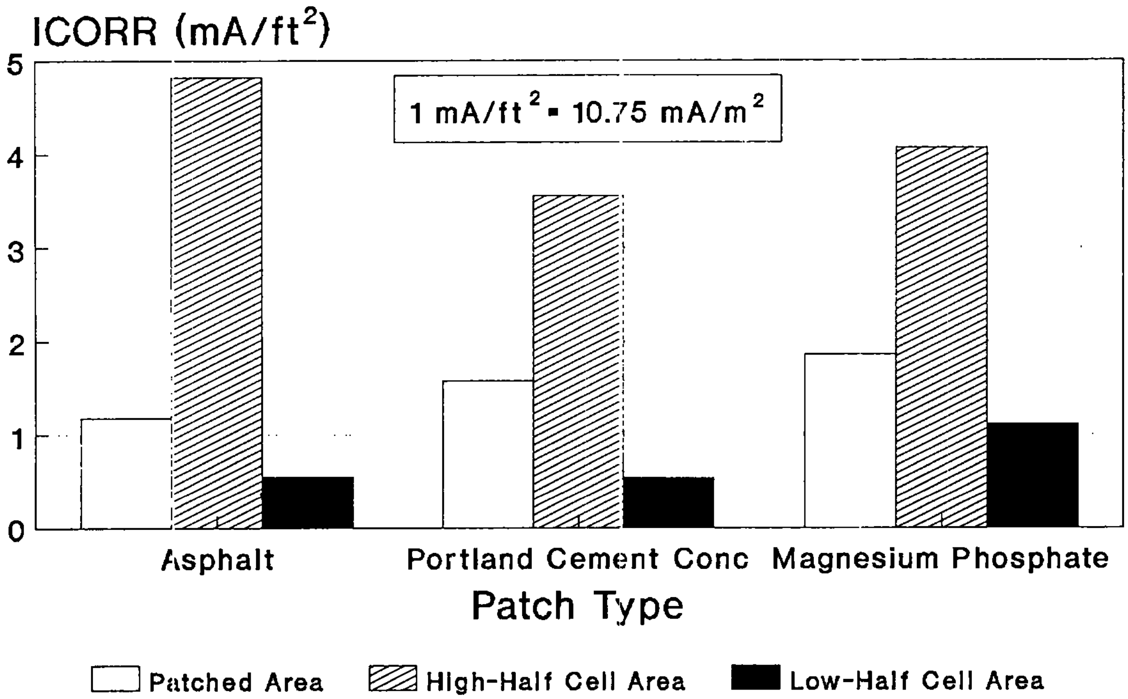


Figure 2.13 Half-cell potential, rate of corrosion, and chloride ion content at the reinforcing bars as a function of distance from a patch

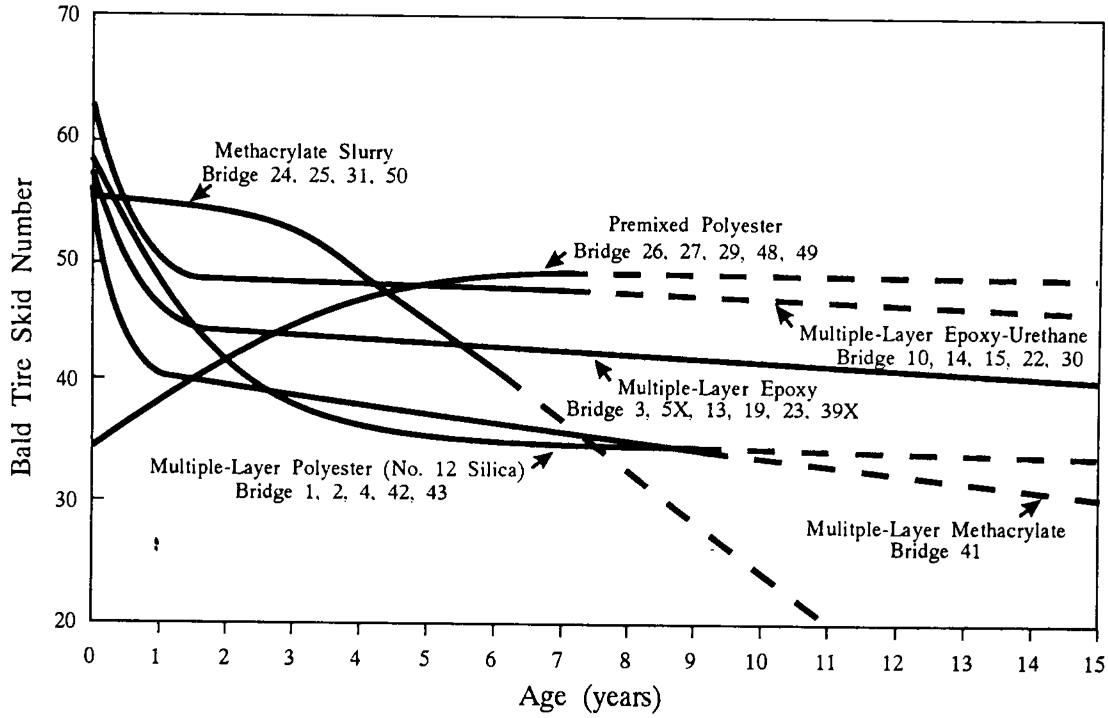


a. Chloride contents at the reinforcing bars

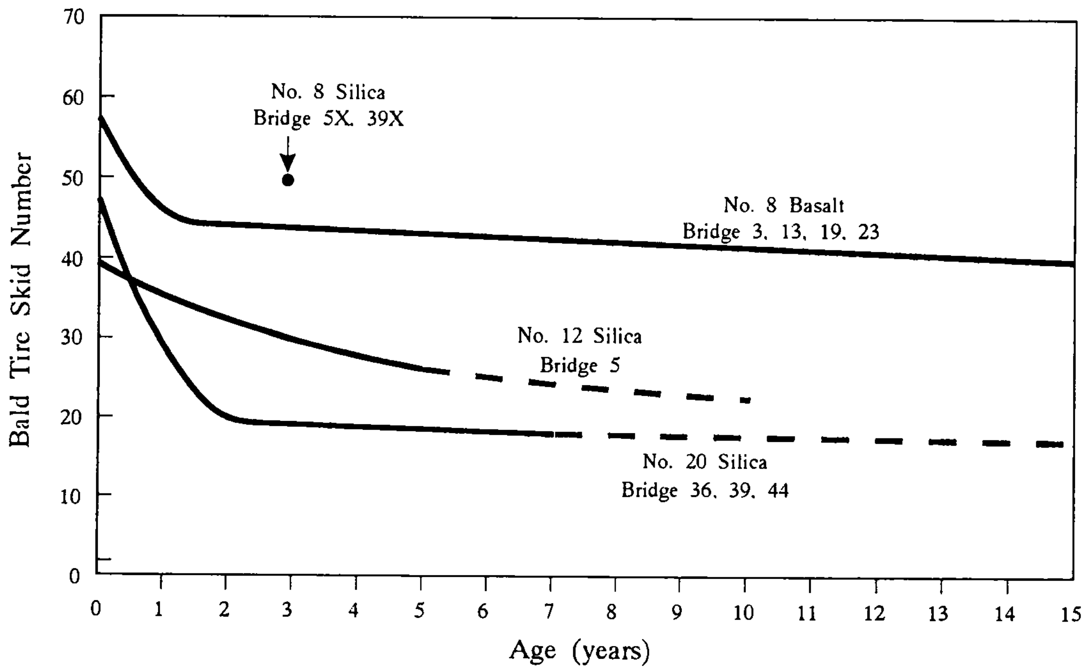


b. Rate of corrosion

Figure 2.14 Average chloride contents at the reinforcing bars and rates of corrosion for patched decks

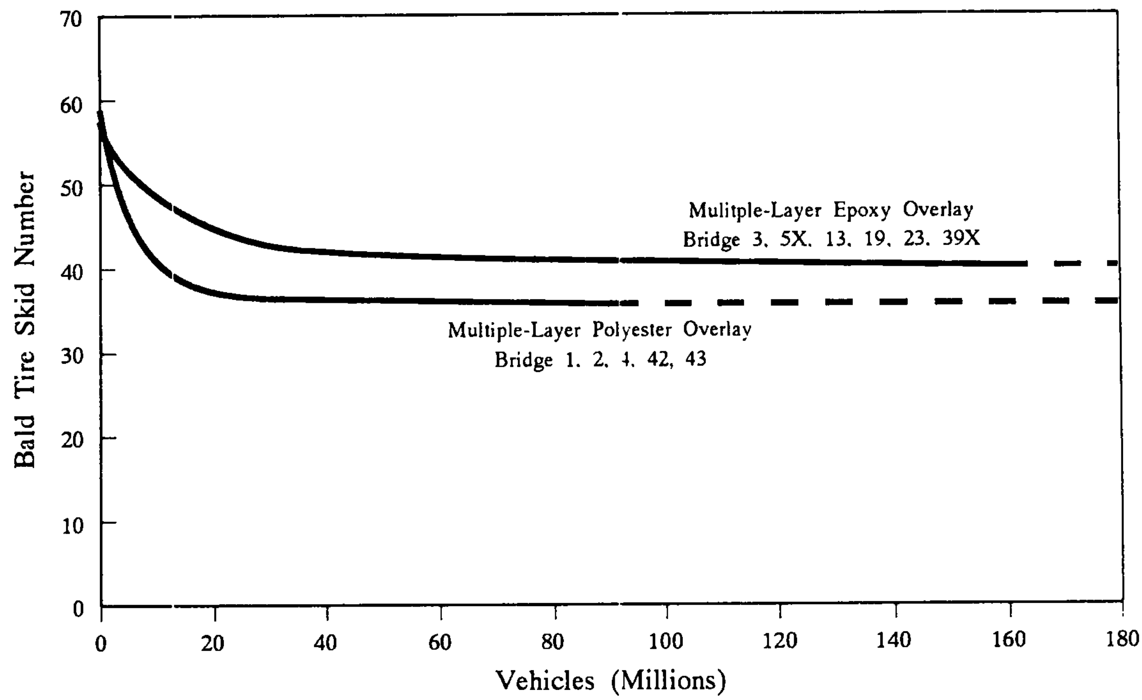


a. Six types of overlays

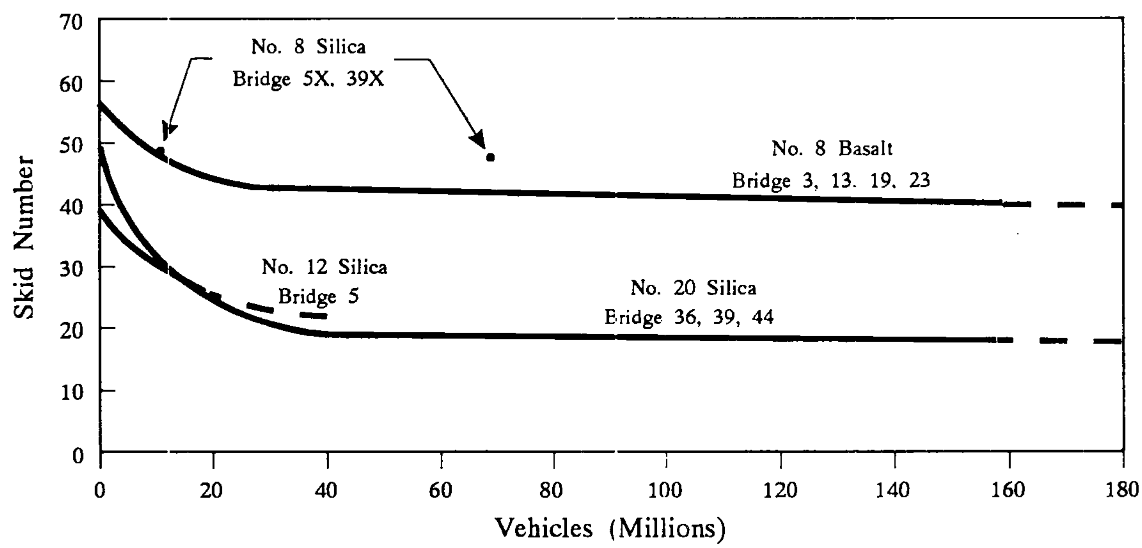


b. Multiple-layer epoxy overlays constructed with aggregates with different gradations

Figure 2.15 Bald tire skid number (ASTM E 524) versus age for polymer overlays

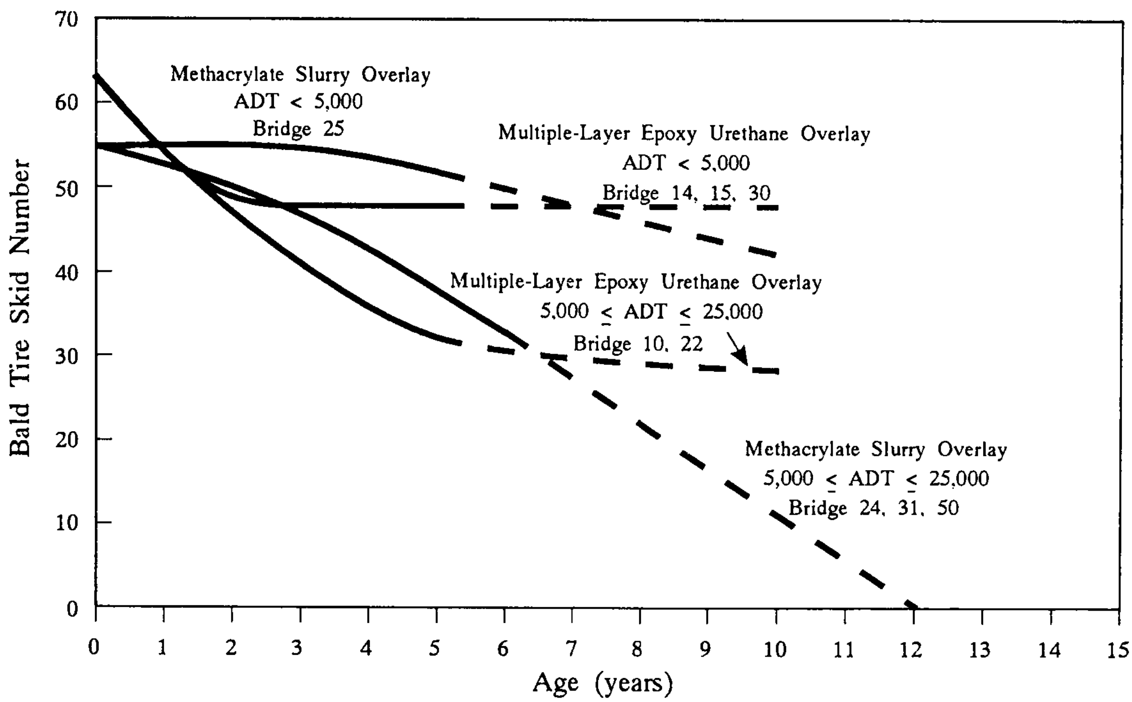


a. Epoxy and polyester overlays

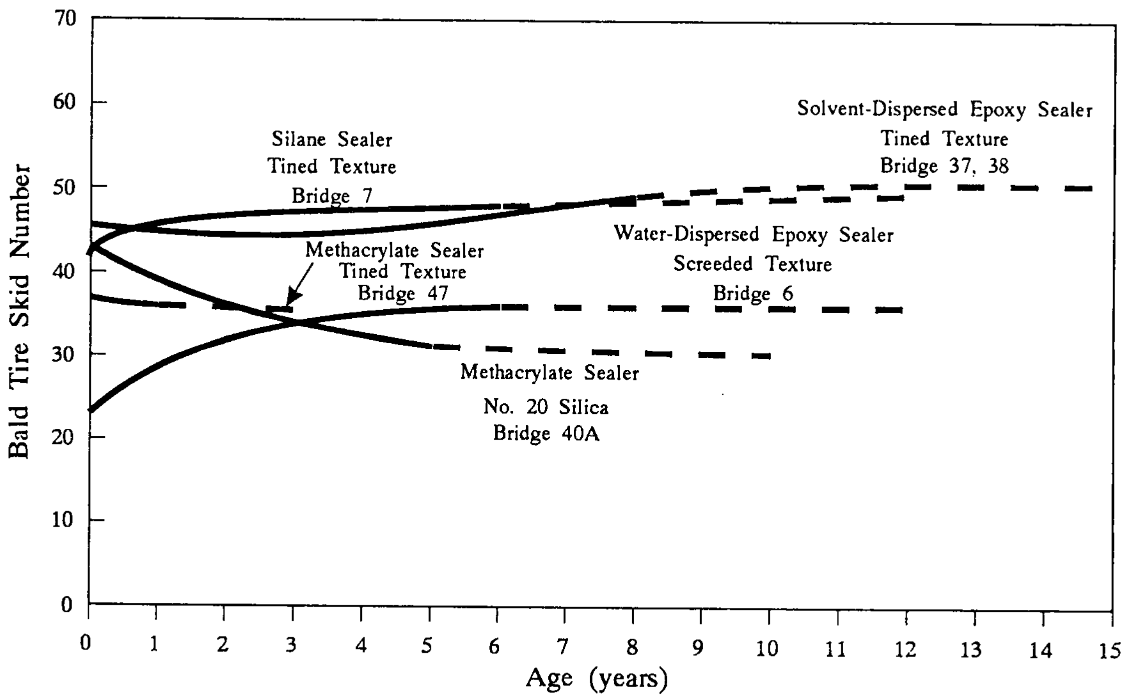


b. Epoxy overlays constructed with aggregate with different gradations

Figure 2.16 Bald tire skid number versus cumulative traffic for multiple-layer polymer overlays



a. Polymer overlays subjected to different ADTs



b. Sealers

Figure 2.17 Bald tire skid number versus age for decks with polymer overlays and sealers

rates. The trend was not shown since there is no logical justification for it.

2.4.2 Sealers

Figure 2.17 shows that good skid numbers are obtained when sealers are applied to tined and grooved surfaces as long as the material does not fill the grooves. Freshly placed hydraulic cement concretes can be tined and grooves can be sawcut in the hardened concrete to ensure proper skid resistance. Also, silica aggregate can be broadcast onto polymer materials to provide a good skid number. Figure 2.17 also shows that unacceptable skid numbers can be obtained when sealers are applied to screeded concrete surfaces (Bridges 6 and 40A).

2.4.3 Patching Materials

Materials used for patching must also provide good skid resistance and wear unless the materials are covered with an overlay. Skid numbers for patches are not available; however, the results should be similar to those obtained for protective treatments constructed with similar materials and surface textures such as high-early-strength hydraulic cement concrete overlays.

2.5 Bond Strength

2.5.1 Tensile Bond Strength

Six ACI 503R (VTM 92) tensile adhesion tests were conducted on each of the polymer overlays evaluated in 1991 (American Concrete Institute, 1992; Virginia Depatment of Transportation, 1993b). The results of these tests and tests conducted in previous years are reported in Appendix B (Table B8). Figure 2.18 shows the tensile rupture stength as a function of age for the various polymer overlays. The rupture strength decreases with age for some overlay treatments and high bond strengths are being maintained by the others. A tensile rupture strength of at least 250 psi (1.7 MPa) is required by the Virginia Department of Transportation for new overlays (Virginia Department of Transportation, 1993a). Performance at later ages tends to be good as long as the strength stays above 100 psi (0.7 MPa). Based on Figure 2.18, multiple-layer epoxy, multiple-layer epoxy-urethane, and premixed polyester overlays should remain bonded for 25 years, whereas multiple-layer polyester overlays should delaminate in about 10 years. The multiple-layer polyester and methacrylate overlays on bridges 41, 42, and 43 were ready for replacement because of large areas of delaminations when evaluated at an age of 9 years. The life of the methacrylate slurry overlay cannot be predicted because of an inadequate data base. Older installations, bridges 24 and 25, were placed on decks with low concrete strengths. Newer installations, 2 years old in 1991, had high rupture strengths.

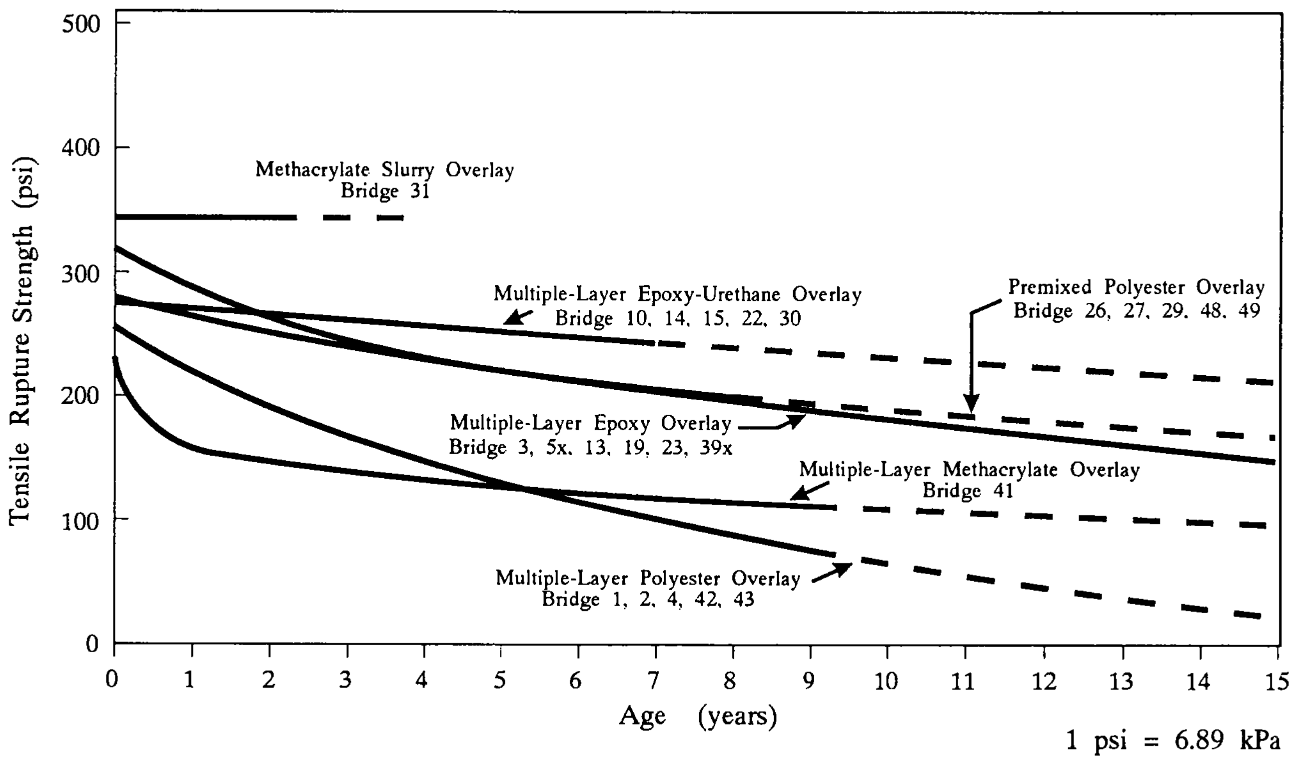


Figure 2.18 Tensile rupture strength (ACI 503R, VTM 92) versus age for polymer overlays

Figure 2.19 shows tensile rupture strength as a function of cumulative traffic and salt application for polymer overlays. The strengths decrease with increasing traffic and salt application. The data base was not adequate to provide trends for different ADTs and different salt application rates. The trends shown in Figure 2.19 may be more related to age than to either cumulative traffic or cumulative salt application. Figure 2.20 shows the relationship between tensile rupture strength and age for multiple-layer epoxy overlays constructed with different aggregate sizes. The figure shows the greatest decrease for the larger No. 8 aggregate. However, the larger aggregate must be used to provide the best skid number at later ages (see Figure 2.15).

2.5.2 Shear Bond Strength

A guillotine shear bond test can also be used to measure the bond strength of overlays. Available data for selected polymer overlay treatments are shown in Appendix B (Table B9). The shear bond test data show trends that are similar to the tensile adhesion test data. The magnitudes of the rupture strengths are higher for the shear tests. Performance tends to be good as long as the strengths stay above 200 psi (1.4 MPa).

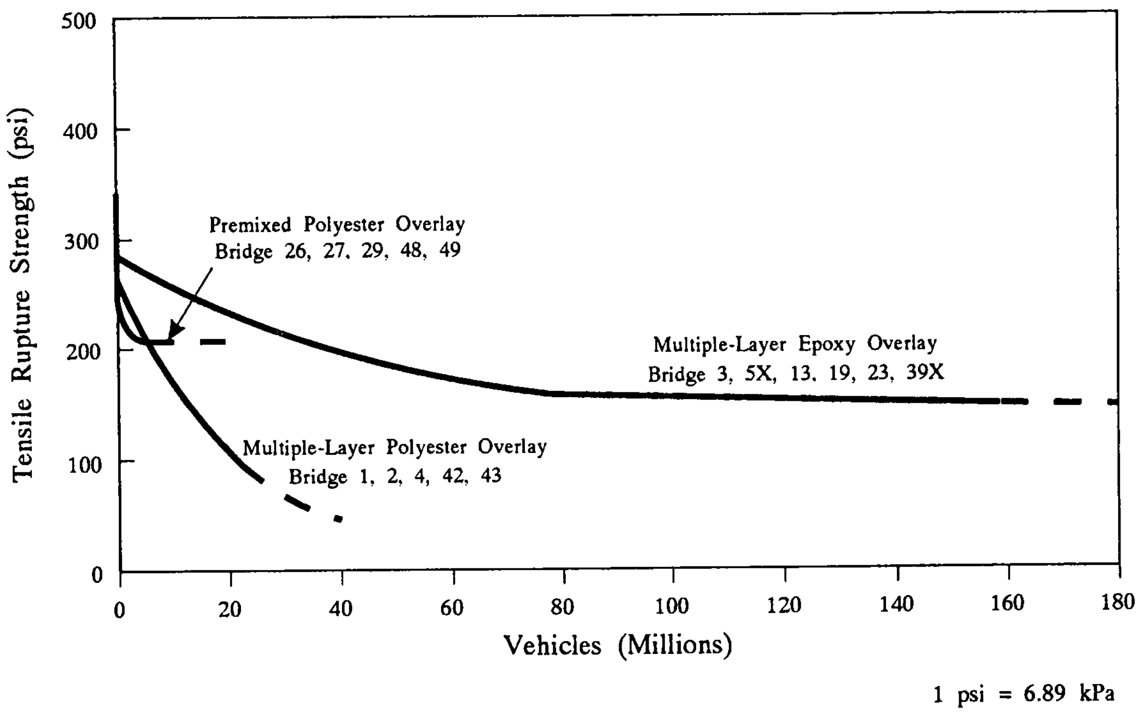
2.6 Cracks, Delaminations, and Spalls

2.6.1 Polymer Overlays and Sealers

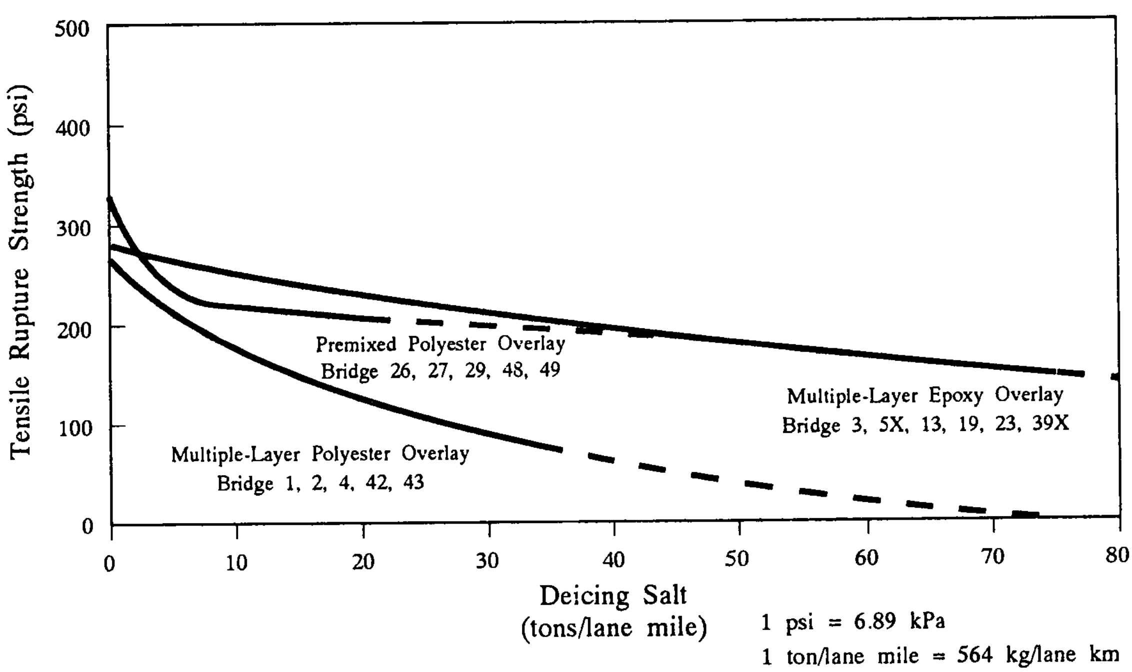
Information on cracks, delaminations, and spalls, recorded during the 40 deck surveys in 1991, is reported in Appendix B (Table B10). Because of the good bond strength of the polymer overlays, it is believed that the delaminations and spalls were most likely caused by localized construction problems. Moisture in the base concrete can also cause a decrease in the bond strength of polymer overlays (Sprinkel, 1987b). Most cracks in the polymer overlays had reflected from the base concrete. No conclusions can be drawn from the data for decks treated with sealers.

2.6.2 Patches

Cracks in rapid-hardening patching materials (ASTM C 928) are indicative of shrinkage. The materials are prone to shrinkage because of high cement contents typically used to achieve the high early strengths and because the moist-curing period is typically short (Emmons, 1992). Figure 2.21 shows the percent length change of typical rapid-hardening patching concretes allowed to air cure in the laboratory at 72oF (22oC) and 50 percent relative humidity. The magnesium phosphate cement concrete exhibited the least linear shrinkage. All the materials satisfy the ASTM C 928 requirement of < 0.15 percent at 28 days. However, all the concretes tested continued to shrink with age, and some shrank much more than others. Figure 2.21 also shows the effects of the mixture proportions on the length change of concretes made with a special blended cement.



a. Traffic



b. Salt application

Figure 2.19 Tensile rupture strength (ACI 503R, VTM 92) versus cumulative traffic and salt application for polymer overlays

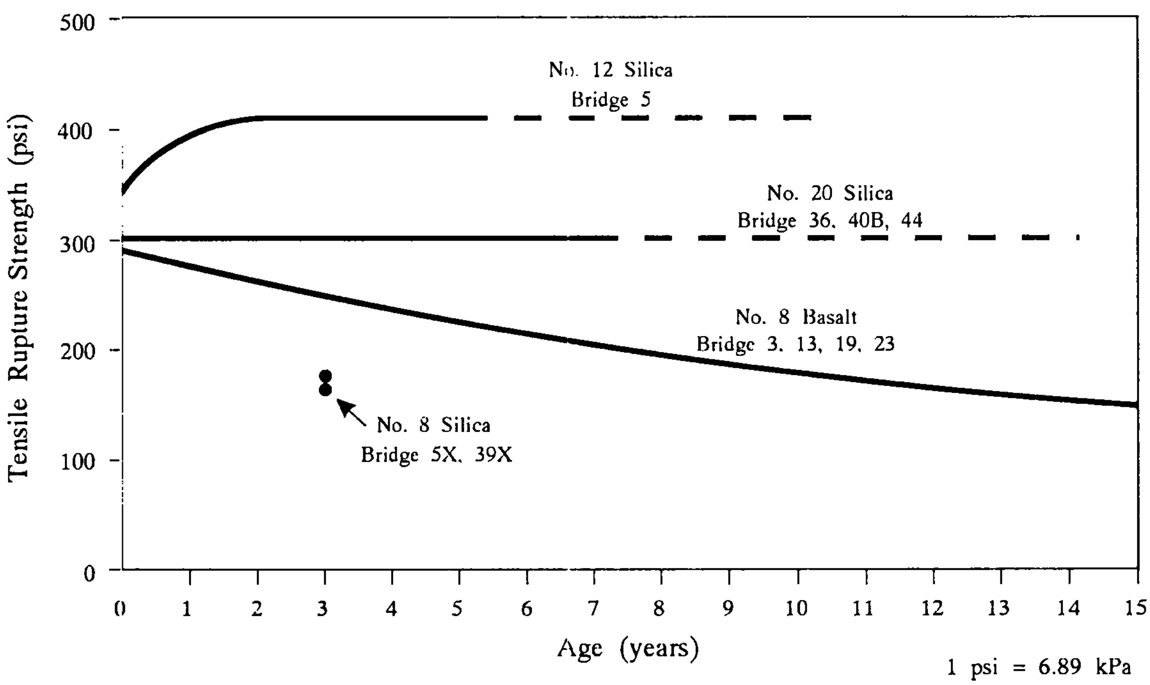
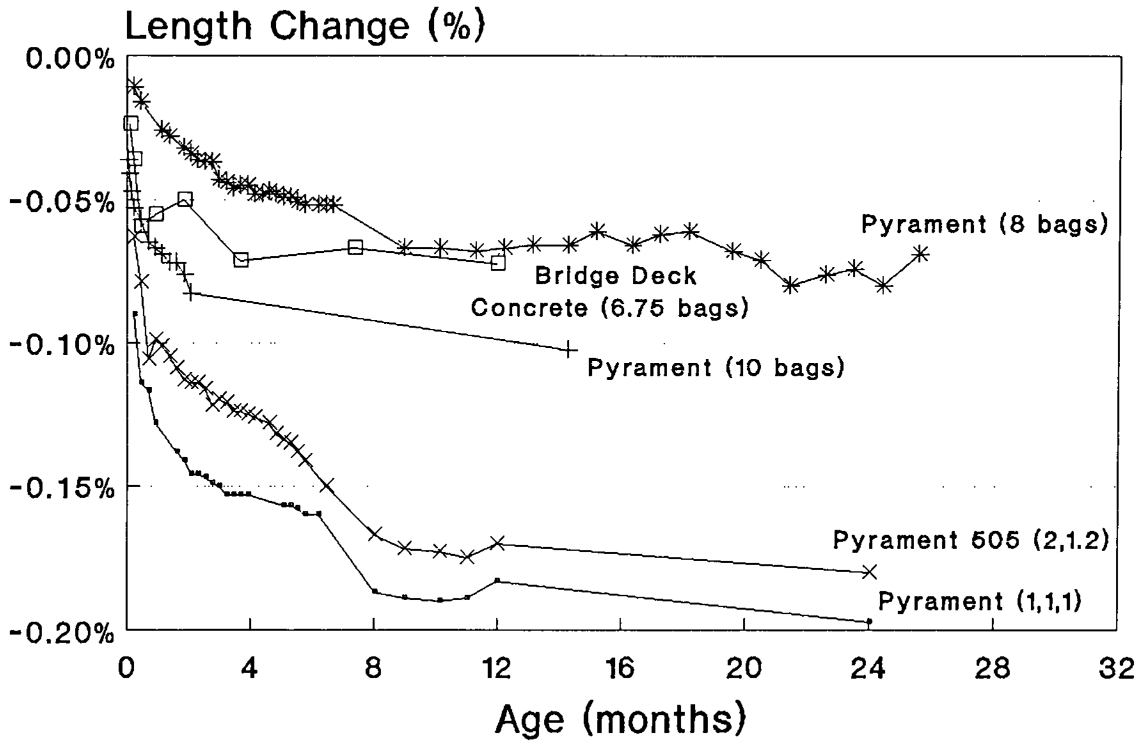
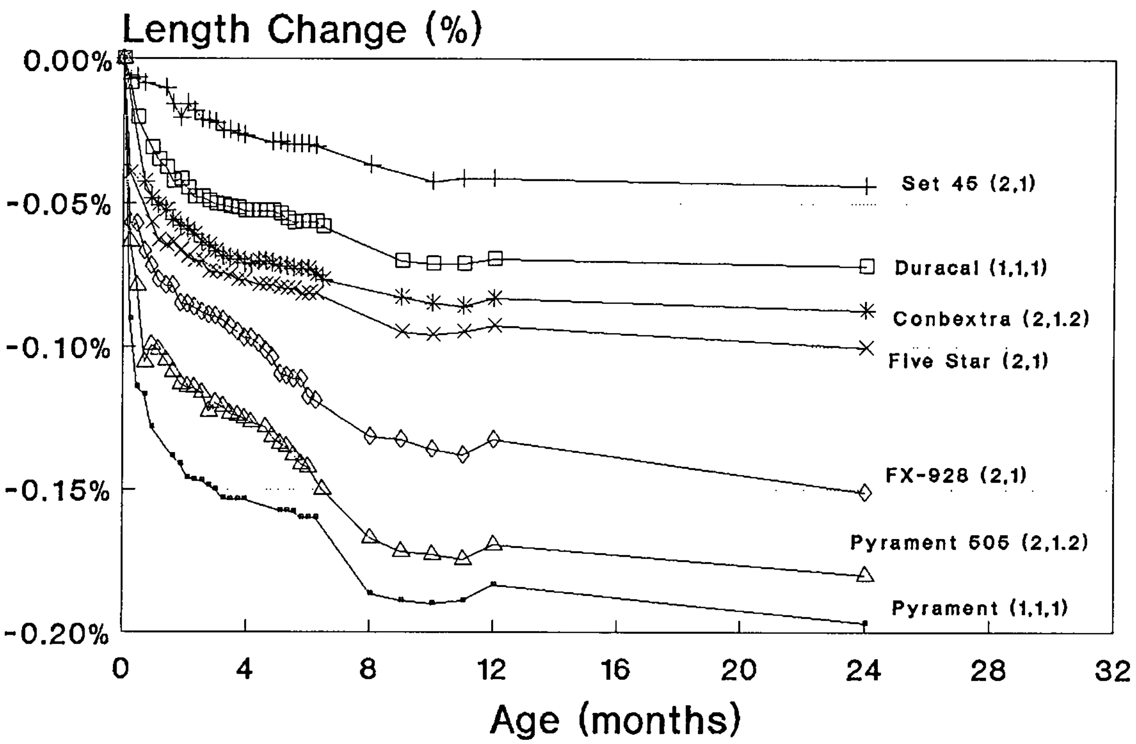


Figure 2.20 Tensile rupture strength (ACI 503R, VTM 92) versus age for multiple-layer epoxy overlays constructed with aggregates having different gradations



a. Typical range of length change



b. Effect of mix proportions on length change of concretes made with a specially blended cement

Figure 2.21 Length change of typical rapid-hardening patching concretes allowed to air cure in the laboratory at 72°F (22°C) and 50 percent relative humidity

Linear shrinkage decreases as the cement content of the mixture is decreased and the aggregate content is increased. Typical bridge deck concrete has a linear shrinkage of about 0.05 percent at 28 days of age (Emmons, 1992; Ozyildirim and Walker, 1985). Concrete made with a special blended cement has a shrinkage similar to that of bridge deck concrete when the mixture proportions are similar. To minimize the incidence of cracking, patching materials should be selected that exhibit low shrinkage, cement contents should be the minimum required to provide the desired strength and workability, coarse aggregate contents should be as high as practical, and the patches should be moist cured as long as practical except where moist curing is not necessary. Optimum mixture proportions should be determined by trial batching.

3

Service Life of Rapid Deck Protection, Repair, and Rehabilitation Techniques

Service life estimates for the rapid deck protection, repair, and rehabilitation treatments were obtained from the responses to the questionnaires, a review of the literature, and the field evaluations describe in Chapter 2, with the exception that no field evaluations were done for the high-early-strength hydraulic cement concrete overlays because of the low number and young age of the overlays.

3.1 Literature Review and Questionnaire Response

The responses to the questionnaires provided sufficient information to estimate the service life of most of the rapid deck protection and patching treatments (see Tables 3.1.1 and 3.1.2). The average service life ranged from a low of 1.7 years for patching with asphalt concrete patches to a high of 20 years for patching with polymer concrete. Service life data obtained from a review of the literature are also shown in Tables 3.1.1 and 3.1.2 (Better Roads, 1989; Bunke, 1988; Carter and Forbes, 1986; Engineering News Record, 1984; Krauss, 1985; Krauss, 1988; Malasheskie et al., 1988; New York Department of Transportation, 1986; Pfeifer and Scali, 1981; Rutkowski, 1988; Sprinkel, 1987a; Sprinkel, 1987b; Sprinkel, 1982; Sprinkel, 1992b; Steinman et al., 1987; Transportation Research Board, 1977; U.S. Department of Transportation, 1980; Weyers, Cady, and Hunter, 1987). Site-cast portland cement concrete decks can be constructed to last 50 years when an overlay is applied at 25 years of age (Babaei and Hawkins, 1987). The service life estimates can be used to determine the life cycle cost for each treatment.

3.2 Field Evaluations

Service life estimates for the rapid deck protection and rehabilitation treatments based

Table 3.1.1 Years of service life of protection treatments based on questionnaire response and literature review

		Questionnaire Response			Literature Review		
Author	Treatment	Avg.	Low	High	Avg.	Low	High
Malashcskie et al., (1988) New York DOT (1986) Sprinkel (1987b) Weyers, Cady, Hunter (1987)	Asphalt Concrete Overlay on Membrane	11.8	4.5	20.0	9.7	3.7	15.0
Bunke (1988) Krauss (1985) Malasheskie et al., (1988) New York DOT (1986) Sprinkel (1992b) Weyers, Cady, Hunter (1987)	Portland Cement Concrete Overlay	15.5	10.0	22.5	17.9	13.6	25.0
Better Roads (1989) Krauss (1985; 1988) Sprinkel (1982) Sprinkel (1987a; 1987b) Steinman et al., (1987)	Polymer Overlay	12.7	6.0	25.0	10.0	---	---
Carter, Forbes (1986) Pfeifer, Scali (1981) Rutkowski (1988) Sprinkel (1987a)	Sealer	14.2	5.5	25.0	5.0	---	---

Table 3.1.2 Years of service life of patching treatments based on questionnaire response and literature review

		Questionnaire Response			Literature Review		
Author	Treatment	Avg.	Low	High	Avg.	Low	High
Transp. Research Board (1977) U.S. Dept. of Transp. (1980) Weyers, Cady, Hunter (1987)	Asphalt Concrete Patch	1.7	1.0	3.0	0.6	0.1	1.0
New York DOT (1986) Weyers, Cady, Hunter (1987)	Portland Cement Concrete Patch	5.9	1.8	10.0	14.8	4.3	35.0
Weyers, Cady, Hunter (1987)	Polymer Concrete Patch	20.0	15.0	25.0	5.5	---	---
Weyers, Cady, Hunter (1987)	Magnesium Phosphate Concrete Patch	11.9	2.0	20.0	3.8	---	---
--------	Steel Plate over Concrete	15.0	---	---	---	---	---

on the field evaluations are summarized in Table 3.2.1. However, since no field evaluations were done for the high-early-strength hydraulic cement concrete overlays, the estimates are based on the literature (Ozyildirim, 1988; Sprinkel, 1988; Streb, 1991; Virginia Department of Transportation, 1991b). The life of the treatments can be controlled by permeability to chloride ions, skid resistance, adhesion and corrosion-induced spalling (CIS). The projected minimum service life estimates in Table 3.2.1 are for decks with low traffic and concrete that is not critically chloride contaminated [half-cell potentials greater than -0.250 V (CSE) and chloride ion contents at the reinforcing bars less than 1 lb/yd^3 (0.6 kg/m^3)]. Adjustments for traffic are also shown.

Polymer Overlays

Based on the performance data obtained from the field evaluations, multiple-layer epoxy overlays should provide very low permeability to chloride ion for 25 years or more on decks with low to moderate ADTs (see Figure 2.9). Also, they should remain bonded (see Figure 2.18) and provide adequate skid resistance (see Figure 2.15) for at least 25 years. Although both adhesion and skid number decrease as traffic increases, decks with very high ADTs should have an average adhesion strength of 100 psi (689 kPa) and an average skid number of 36 at 25 years of age. However, permeability to chloride ions is projected to increase from below 125 coulombs for decks with less than 5,000 ADT to 1,880 coulombs for decks with more than 50,000 ADT at 25 years of age. Therefore, at high ADTs, new overlays should be placed within 25 years of age to prevent a reduction in the time to corrosion of the reinforcement. Multiple-layer epoxy-urethane overlays should perform as well as the epoxy overlays for decks with low ADTs. For decks with moderate ADTs the bald tire skid number may be less than 20 in 15 years or more. Reductions in life due to low skid numbers could not be determined for higher ADTs. Premixed polyester overlays should perform as well as the epoxy overlays on decks with low ADTs. The effect of traffic volume on the life of premixed polyester overlays could not be determined since all overlays evaluated were subjected to low ADTs. Methacrylate slurry overlays should provide negligible permeability for 18 years, but they could fail because of a low skid number in only 18 years on decks with low traffic, 7 years for decks with moderate traffic, 5 years for decks with high traffic, and in only 3 years on bridge decks subjected to very high volumes of traffic. Multiple-layer polyester overlays provide less protection and similar skid resistance to epoxy overlays until they fail in adhesion in about 10 years.

High-modulus, brittle, multiple-layer methacrylate overlays should provide low permeability and good skid resistance until they fail in adhesion in about 15 years. Traffic volume does not seem to be a factor in the failure in adhesion of these overlays. Since these overlays do not provide the level of protection provided by the other overlays, corrosion-induced spalling is likely to occur at an earlier age. The performance data for polymer overlays based on field evaluations (Table 3.2.1) are generally more favorable than the data based on the questionnaire response and literature review.

Sealers

Based on the deck evaluations, the application of a sealer can initially reduce the permeability of the concrete to chloride ions by 0 percent (bridge 7) to 50 percent (bridge 40A). The average reduction when the applications were new was 32 percent. Twelve years after treatment with silane bridge 34 exhibited a 30 percent reduction. The data indicate that a 5 to 30 percent reduction in permeability tochloride ions for 7 to 10

Table 3.2.1 Years of service life of rapid protection treatments based on field evaluations

Protection Treatment	Age of Oldest Installation (in years)	Projected Minimum Service Life (ADT 5000) (in years)	Property Controlling Service Life	Adjustments for Traffic: Average Service Life (in years[a]) L	M	H	VH	Average Permeability Coloumbs for ADT[a] L	M	H	VH
Overlay											
Multiple-Layer Epoxy	15	25	Permeability	0	0	-10	-15	125	300	700	800
Multiple-Layer Epoxy-Urethane	7	25	Skid Number	0	-10	--	--	125	150	--	--
Premixed Polyester	8	25	Adhesion	0	--	--	--	150	--	--	--
Methacrylate Slurry	6	18	Skid number	0	-11	-13	-15	0	0	0	0
Multiple-Layer Polyester	9	10	Adhesion	0	0	0	0	1100	1250	1300	1350
Multiple-Layer Methacrylate	9	15	Adhesion	0	0	0	0	1100	1250	1300	1350
Sealer											
High-Molecular-Weight Meth.	9	7	Permeability	0	0	--	--	2200	2200	--	--
Solvent-Dispersed Epoxy	8	10	Permeability	0	0	0	0	1700	1700	1700	1700
Water-Dispersed Epoxy	6	8	Permeability	0	0	0	0	1200	1600	1600	1600
Silane	12	7	Permeability	0	0	--	--	2500	2500	--	--
Patch											
Bituminous Concrete	1	1	Adhesion	0	0	--	--	5000	5000	--	--
Portland Cement Concrete	5	25	CIS	0	0	--	--	300	300	--	--
Magnesium Phosphate Concrete	6	25	CIS	0	0	0	0	1100	1100	1100	1100
Special Blended Cement Overlay	1	--	CIS	--	--	--	--	--			
Latex & Type III Cement Overlay	5	25	CIS	0	0	0	0	600	600	600	600
Silica Fume Overlay	5	25	CIS	0	0	0	0	600	600	600	600

[a] Average daily traffic (ADT) where L is < 5,000; M is 5,000 to 25,000; H is > 25,000; VH is > 50,000

-- Data is not available to make a projection years is a reasonable expectation for sealers. Although the performance data support the data in Table 3.1.1, more data are needed to determine the long-term performance and to examine the benefits of additional applications at later ages. Sealers placed on decks with very low ADTs could have a life of 7 to 10 years (Table 3.2.1). Sealers can be expected to give different reductions depending on the sealer, the application rate, and the quality of the concrete. To ensure adequate skid resistance, applications are usually limited to decks with tined or grooved textures. Skid resistance typically improves with age as the sealer is abraded from the deck, and therefore service life is not influenced by skid resistance. Likewise, bond strength is not a factor in service life since sealers are designed to penetrate the pores of the concrete rather than to adhere to the outer surface.

Patches

Hydraulic cement concrete patches typically have a lower permeability to chloride ions than the concrete they replace. Their permeabiliy does not usually control service life. Asphalt concrete patches tend to be more permeable, and as they absorb water, early failure is likely due to hydraulic pressure from traffic loads or the freezing and thawing of the water. The skid resistance of the patches does not control service life because the skid resistance is usually the same as that of the concrete they replace so long as proper surface textures are applied. Bond strength can control the life of all types of patches, and surfaces must be sound and properly prepared to provide high bond strength. It is believed that hydraulic cement concrete patches delaminate because of failures in the concrete below the bond line or adjacent to the patch. Service life estimates in Table 3.2.1 show that hydraulic cement concrete patches can have a life of 25 years when critically chloride-contaminated concrete is removed prior to patching. However, the old concrete rather than the patching concrete will likely control the time to corrosion of the reinforcing bars in decks with hydraulic cement concrete patches.

High-Early-Strength Hydraulic Cement Concrete Overlays

The data base is not adequate to predict the service life of high-early- strength hydraulic cement concrete overlays accurately. One of the first of these overlays to be installed and evaluated was in Virginia in 1986 and consisted of latex and Type III cement (Sprinkel, 1988). A similar overlay was placed in 1991 (U.S. Department of Transportation, 1990). In 1990, a special blended cement concrete overlay was installed in Oklahoma (Streb, 1991); in 1991, a similar mixture was used to replace the top half of a deck in Virginia (Sprinkel, 1991); and in 1992, a high-early-strength overlay consisting of 7% silica fume and Type II cement was installed in Virginia (Virginia Department of Transportation, 1991b). Evaluations of the latex-modified concrete overlay indicate that it should have a service life comparable to that of standard latex-modified concrete overlays, which is 20 years plus (Sprinkel, 1992b). Recent evaluations of overlays constructed with 7 and 10 percent silica fume suggest that these overlays should last as long as latex-modified concrete overlays (Ozyildirim, 1988). Data on permeability to chloride ions, skid resistance, and bond strength suggest that high-early-strength overlays should last as long as similar standard overlays. Because of the high alkali content of one special blended cement, a shorter life may be experienced due to alkali-silica reactions when the overlay is placed on decks containing alkali-silica reactive aggregates or reactive aggregates are used in the mixture. High-early-strength hydraulic cement concrete overlays should be more susceptible to construction problems because of the low water-to-cement ratio, short working time, and short cure time prior to opening to traffic. Properly constructed overlays should last 25 years.

3.3 Effect of Treatment on Service Life of Bridge Deck

The life of a deck depends on the performance characteristics of the treatment, the chloride ion content at the reinforcing bars, and the rate of corrosion of the reinforcing bars. Rapid repairs may fail at ages earlier than indicated in Tables 3.1.1 and 3.1.2 due to corrosion-induced spalling caused by a failure to remove critically chloride-contaminated concrete. It is believed that the service life values reported in Tables 3.1.1 and 3.1.2 reflect past and present practice with deck protection and rehabilitation. The minimum service life values shown in Table 3.2.1 are based on the use of recommended construction practices for protection and rehabilitation, which include the removal of critically chloride-contaminated concrete.

The influence of rate of corrosion on the life of a deck treatment and the influence of the treatment on the service life of a deck need to be considered to make an accurate life cycle cost analysis. For decks in which the average chloride ion content at the reinforcing bars is less than 1 lb/yd^3 (0.6 kg/m^3), and the half-cell potentials are greater than -0.250 V(CSE), the application of a polymer overlay or sealer will likely extend the life of the deck past the life of the protection treatment; another application at later ages should be feasible. Patches placed under these conditions should last as long as the unpatched deck. When the average chloride ion content at the reinforcing bars is 1 lb/yd^3 (0.6 kg/m^3) or more, and the half-cell potentials are -0.250 V (CSE) or less, the life of the protection and patching treatment, and the life of the deck, will likely be controlled by the rate of corrosion of the reinforcing bars and corrosion-induced spalling.

4

Observations

The following observations come from evaluations of the 50 decks included in this study. These observations should be applicable to bridge decks that are similar to those evaluated. The decks were typically exposed to moderate salt application rates.

- Background performance data are rarely available and are typically limited to decks involved in experimental installations.
- The permeability (AASHTO T 277) of the top 2 in (5 cm) of a core from an unprotected deck is approximately half of the permeability of the next 2 in (5 cm) probably because the top surface is textured, carbonated and contaminated by traffic, whereas the other surfaces are clean and sawcut.
- The permeability (AASHTO T 277) of polymer concrete overlays increases with age and traffic.
- Polymer overlays maintain good skid resistance so long as skid-resistant aggregates are bonded to the surface.
- Silane-treated decks have a higher permeability (AASHTO T 277) in the traffic lane than in the shoulder.
- New bridge decks with a 1.75 in (4.5 cm) average cover should show signs of chloride-induced corrosion (chloride ion content equals 1 lb/yd^3 [0.63 kg/m^3]) as follows when the average chloride application rate is moderate:
    - 13 years when no protection treatment is used,
    - 25 years when an epoxy sealer is maintained, and
    - 77 years when a polymer overlay is maintained.

- When the average chloride ion content at the reinforcing bars is 1.0 lb/yd^3 [0.6 kg/m^3] or more, the average of the electrical half-cell potentials is less than -0.250 V (CSE) for unprotected decks and less than -0.100 V (CSE) for decks with multiple-layer epoxy overlays.

- Based on the rate of corrosion measurements, which are subject to large errors, no corrosion damage is expected (ICORR < 0.2 Ma/ft^2 [2.2 mA/m^2]) when the chloride ion content at the reinforcing bars is less than 1.0 lb/yd^3 (0.6 kg/m^3) for decks with multiple-layer epoxy overlays. For the same chloride condition, corrosion damage is expected in less than 15 years for all other treatments evaluated and for untreated decks.

- For a given chloride ion content, corrosion damage is expected earlier for decks with a solvent-dispersed epoxy sealer, silane sealer or multiple-layer polyester overlay than for unprotected decks.

- Three indicators of deterioration (chloride ion content at reinforcing bars, half-cell potentials, and rates of corrosion) are greatest within 2 ft (0.6 m) of the perimeter of the patches in decks that were patched because of spalling induced by corrosion of reinforcing bars.

- Polymer overlays exhibit decreases in skid number as traffic increases and the more flexible binders show the greatest decreases.

- For maximum performance, multiple-layer polymer overlays must be constructed with a No. 8 gap-graded basalt or silica aggregate.

- Good skid numbers are achieved when sealers are placed on tined or grooved concrete surfaces so long as the material does not fill the groove. Applications to screeded surfaces can result in low numbers unless aggregate is bonded to the surface.

- The bond strength of polymer overlays typically decreases with increases in age and traffic. Multiple-layer epoxy overlays exhibit the best long-term adhesion.

- Most prepackaged rapid-setting patching materials shrink more than bridge deck concrete. Shrinkage can usually be reduced by proportioning the mixtures to minimize the cement and water content and maximize the aggregate content.

5

Conclusions

1. Most transportation agencies do not use rapid bridge deck protection, repair and rehabilitation treatments which are defined as those that are suitable for installation during the off-peak traffic periods and suitable for traffic during peak traffic periods.

2. The most-used rapid protection treatments are asphalt concrete overlays on membranes, polymer overlays, high-early-strength hydraulic cement concrete overlays, and sealers.

3. The most used rapid-patching treatments are high-early- strength portland cement concrete patches, asphalt concrete patches, and other hydraulic cement concrete patches.

4. Multiple-layer epoxy and epoxy-urethane and premixed polyester overlays can provide a skid-resistant wearing and protective surface for 25 years when exposed to moderate salt application rates and light traffic.

5. Sealers can reduce the infiltration of chloride ions for 7 to 10 years, but performance varies and additional research is needed to determine the sealers, concretes, and conditions that provide a cost-effective application.

6. Current patching treatments can mend spalls but typically do not retard chloride-induced corrosion because all concrete with 1 lb/yd^3 (0.6 kg/m^3) or more of chloride ions at the reinforcing bars or with half-cell potentials -0.250 V (CSE) or less, is not removed. Corrosion activity is independent of patch type, and corrosion-induced spalling can be expected in the low half-cell potential areas that typically surround patches. Asphalt patches have a service life of approximately 1 year and should be replaced with hydraulic cement concrete as soon as practical to minimize deck deterioration in the vicinity of the patch. Hydraulic cement concrete patches differ significantly with respect to shrinkage, and materials

should be selected and mixtures proportioned to minimize shrinkage. A 28-day length change of 0.05 percent or less is practical. Hydraulic cement concrete patches with a life of 25 years should be possible when critically chloride-contaminated concrete is removed and materials are properly proportioned, placed and cured.

7. High-early-strength hydraulic cement concrete overlays have tremendous potential, but considerable developmental work with materials and equipment is needed to overcome problems with the installation and the acceptance of the concrete that can be installed with a lane closure of 8 hours or less. High-early-strength overlays containing 15 percent latex and or 7 percent silica fume and constructed with a lane closure of 56 hours or less can perform almost as well as conventional overlays and have a potential service life of 25 years.

8. The chloride ion content and rate of corrosion of the reinforcing bars of a deck influences the life of a rapid deck repair treatment. Rapid protection and rehabilitation treatments with long service lives can be obtained because critically chloride contaminated concrete [chloride ion content at the reinforcing bar of 1 lb/yd^3 (0.6 kg/m^3) or more, or a half-cell potential of -0.250 V (CSE) or less] is removed.

9. When necessary to minimize traffic congestion, most of the rapid deck treatments can be used with lane closures of 8 hours or less. Use of longer lane closures would likely provide a longer service life because more careful construction and more complete cure of materials can be achieved.

6

Recommendations

1. To achieve the longest service life, critically chloride-contaminated concrete [chloride ion content at the reinforcing bars of 1 lb/yd^3 (0.6 kg/m^3) or more or half-cell potential of -0.250 V (CSE) or less] should be removed prior to placing a bridge deck treatment.

2. Departments of transportation should use multiple-layer epoxy and epoxy-urethane and premixed polyester overlays to provide bridge decks with skid resistance and protection against intrusion by chloride ions.

3. Research should be done to determine the sealers, concretes, and conditions that provide for the cost-effective application of sealers.

4. Hydraulic cement concrete patching materials should be selected, proportioned, and cured to minimize shrinkage (preferably 0.05 percent or less at 28 days). Because of their short service life asphalt concrete patching materials should only be used as temporary patches and should be replaced with hydraulic cement concrete patches as soon as practical.

5. Because of the need and lack of technical development research should be done to develop high-early-strength hydraulic cement concrete overlays for use in rapid, very rapid and most rapid situations. Overlays with more conventional mixtures, such as 15 percent latex and Type III portland cement or concrete containing 7 percent silica fume, should be used when it is necessary to place traffic on the overlay in 24 to 36 hours (semi-rapid situation).

6. To allow for more careful construction and more complete cure of materials, which should provide a longer service life, rapid deck treatments should be constructed with lane closure times that are as long as practical.

Appendix A
Outline of Rapid Treatments for Bridge Deck Protection, Repair, and Rehabilitation

I. Rapid Protection Treatments

  A. Asphalt Concrete Overlays on Membranes
    1. On Liquid Membrane (See I.B.1 below)
      a. Epoxy
      b. Polyurethane
    2. On Preformed Membrane
      a. Reinforced Asphalt
      b. Reinforced Tar Resin
      c. Rubber
      d. Rubberized Asphalt
    3. On Sealer (See I.C below)
    4. Modified Asphalt Concrete Overlays
      a. Epoxy-Modified Asphalt

  B. Polymer Overlays
    1. Multiple-Layer Polymer Overlay
      a. Acrylic/Methacrylate
      b. Epoxy
      c. Epoxy-Urethane
      d. Polyester Styrene
      e. Polyurethane
    2. Premixed Polymer Overlay
      a. Acrylic/Methacrylate
      b. Epoxy
      c. Epoxy-Urethane
      d. Polyester Styrene
      e. Polyurethane
      f. Sulphur
    3. Slurry Polymer Overlay
      a. Acrylic/Methacrylate
      b. Epoxy
      c. Epoxy-Urethane

d. Polyester Styrene
e. Polyurethane

C. Sealers
1. Acrylic
a. Acrylic
b. Acrylic Copolymer
c. High-Molecular-Weight Methacrylate
d. Methacrylate
e. Methyl Methacrylate
2. Asphalt Emuslion
3. Cementitious
a. Nonpolymeric
b. Polymeric
4. Epoxy
5. Gum Resin
a. Linseed Oil
b. Mineral Gum
c. Other
6. Rubber
a. Chlorinated Rubber
b. Epoxide Chloride Rubber
c. Triplexy Eastomer
7. Silicone Based
a. Silane
b. Silane-Silicone
c. Silane-Siloxane
d. Silicate
e. Silicone
f. Siloxane
g. Sodium-Silicate
8. Urethane
a. Aliphatic
b. Isocyanate Polyether

II. Rapid Repair Treatments

A. Asphalt Concrete Overlays
1. On Liquid Membrane (See I.B.1 above)
a. Epoxy
b. Polyurethane

c. Tar Emulsion
d. Thermoplastic
2. On Preformed Membrane
a. Reinforced Asphalt
b. Reinforced Tar Resin
c. Rubber
d. Rubberized Asphalt
e. Other
3. On Sealer (See I.C above)
4. On Tack Coat
5. Modified-Asphalt Concrete Overlays
a. Epoxy-Modified Asphalt
b. Primers and Sealers
c. Surface Treatment Chip Seal

B. Crack Repair and Sealing
1. Gravity Fill
a. Epoxy
b. High-Molecular-Weight Methacrylate
c. Urethane
2. Pressure Injection
a. Epoxy
b. Urethane
3. Rout and Seal
a. Epoxy
b. Methyl Methacrylate
4. Vaccum Injection
a. Epoxy
b. Methyl Methacrylate

C. High-Early-Strength Hydraulic Cement Concrete Overlays
1. Alumina Cement
a. Rapid-Harding Cementitious Material (ASTM C928)
b. Very-Rapid-Hardening Cementitious Material (ASTM C928)
c. Other
2. Blended Cement
3. Concrete Containing TYPE I, II, or III Portland Cement and Admixtures
a. Corrosion Inhibiting
b. Epoxy
c. High-Range Water Reducing
d. Silica Fume
e. Styrene Butadiene Latex
f. Other Latexes
4. Low-Slump Portland Cement Concrete
5. Magnesium Phosphate Cement
a. Rapid-Hardening Cementitious Material (ASTM C928)

b. Very-Rapid-Hardening Cementitious Material (ASTM C928)
c. Other
6. Rapid-Hardening Portland Cementitious Material
a. Rapid-Hardening (ASTM C928)
b. Very-Rapid-Hardening (ASTM C928)
7. Other Hydraulic Cement Concrete

D. Joint Repair

E. Patching With Asphalt Concrete
1. Cold-Mix Asphalt Patch
2. Hot-Mix Asphalt Patch

F. Patching with High-Early-Strength Hydraulic Cement Concrete (Same as II.C above)

G. Patching with Polymer Concrete
1. Acrylic
2. Epoxy
3. Epoxy-Urethane
4. Furfuryl Alcohol
5. Polyester Styrene
6. Polyurethane
7. Sulphur

H. Patching with Steel Plate over Conventional Concrete

I. Polymer Overlays (Same as I.B above)

III. Rapid Rehabilitation Treatments

A. Asphalt Concrete Overlays on Membranes and Patches (Same as I.A, II.B, II.D, II.F, II.G, and II.H)

B. High-Early-Strength Hydraulic Cement Concrete Overlays (Same as II.C and II.D)

C. Polymer Overlays on Patches (Same as I.B,II.B, II.D, II.F, II.G and II.H)

Appendix B
Summary of Data from Field Evaluations

Table B1. General Information on Bridge Decks Evaluated

Bridge Number	State	County	Lane	Location	Structure Number	Year of Constr.	1990 Traffic (ADT)	1990 Salt Rate *
1	Virginia	Albemarle	EBL	I-64 over Rivanna River	2047	1969	10,090	M
2	Virginia	Fairfax	SBL	Rt. 675 over Dulles Airport Rd.	6232	1963	3,813	M
3	Virginia	Fairfax	SBL	Rt. 617 over Rt. 644	6446	1986	15,166	M
3C	Virginia	Fairfax	SBL	Rt. 617 over Rt. 644	6446	1986	15,166	M
4	Virginia	King and Queen	WBL	Rt. 33 over Mattaponi River	1949	1945	13,020	M
5	Virginia	City of Suffolk	SBL	Rt. 17 over Bennetts Creek	1813	1967	10,210	M
6	Virginia	City of Chesapeake	EBL	I-264 over N & W RR	2529	1967	68,290	M
7	Virginia	Henrico	SBL	Rt. 161 over North Run	1021	1985	5,830	M
8	Virginia	Shenandoah	NBL	I-81 over B & O RR	2008	1965	10,200	M
9	Virginia	Shenandoah	SBL	I-81 over B & O RR	2009	1965	10,200	M
10	Virginia	Roanoke	NBL	Rt. 419 over Mason Creek	1111	1967	8,220	M
11	Virginia	Pulaski	NBL	I-81 over Rt. 799	2030	1965	11,448	M
12	Virginia	Montgomery	NBL	I-81 over Rt. 8	2000	1964	11,118	M
13	Ohio	Franklin	EBPL	Rt. 16 over I-270	2500353-0808	1974	28,530	H
14	Ohio	Morrow	EBL	Rt. 229 over Turkey Run	5902614-0118	1984	1,830	H
15	Ohio	Brown	SBL	Rt. 221 over White Oak Creek	0802913-0554	1986	1,120	M
16	Indiana	Marion	SBL	I-65 over Keystone Ave.	I65-109-5075	1963	30,000	H
17	Indiana	Marion	WBL	I-70 over Belmont Ave.	I70-76-5394A	1967	65,000	H
18	Indiana	Randolph	EBL	Rt. 36 over Green's Fork Creek	36-68-3350	1970	1,300	H
19	Michigan	Kent	EBL	Rt. 44 over Grand River	B02-41013	1963	29,000	H
20	Michigan	Monroe	EBL	Plank Rd. over Rt. 23	S04-58033	1960	------	H
21	Michigan	Monroe	EBL	Cone Rd. over Rt. 23	S02-58033	1958	------	H
22	Washington	Snohomish	NBL	Rt. 529 over Steamboat Slough	529/20E	1954	13,600	L
23	Washington	City of Seattle	SBL	Rt. 900 over I-5	900/12W	1966	36,800	L
24	Washington	Thurston	NBL	Mottman Rd. over Rt. 101	101/514	1976	15,100	L
25	Washington	Wahkiakum	SBL	Rt. 403 over Grays River	403/7	1947	500	L
26	California	Shasta	EBL	Rt. 36 over Beegum Creek	6-57-11.9	1961	1,800	L

(continues)

Note: Lane abbreviations
NBL: North-bound lane
EBL: East-bound lane
SBL: South-bound lane
WBL: West-bound lane

* The classifications H, M, and L denote the following application rates:

H: > 5.0 tons/lane mile/year (2820 kg/lane km/year)

M: 2.5 - 5.0 tons/lane mile/year (1410 - 2820 kg/lane km/year)

L: < 2.5 tons/lane mile/year (1410 kg/lane km/year)

Table B1. (continued)

Bridge Number	State	County	Lane	Location	Structure Number	Year of Constr.	1990 Traffic (ADT)	1990 Salt Rate *
27	California	Siskiyou	WBL	Rt. 96 over Beaver Creek	2-81-88.26	1931	1,100	L
28	California	Siskiyou	EBL	Rt. A12 over I-5	2-0139-38.21	1969	------	L
29	California	Trinity	EBL	Rt. 36 over Hayfork Creek	5-07-38.37	1965	1,850	L
30	Virginia	Culpeper	EBL	Rt. 3 over Rapidan River	1919	1987	3,043	M
30C	Virginia	Culpeper	EBL	Rt. 3 over Rapidan River	1919	1987	3,043	M
31	Virginia	Albemarle	WBL	I-64 over MeChunk Creek	2057	1969	8,973	M
32	Virginia	Albemarle	WBL	I-64 over Rt. 781	2071	1969	12,095	M
33	Nebraska	Hall	SBL	Rt. 34 over Platte River	S034-225.72	1960	10,225	H
34	Nebraska	Buffalo	SBL	Rt. 44 over Platte River	S044-48.56	1973	14,710	H
34C	Nebraska	Buffalo	SBL	Rt. 44 over Platte River	S044-48.56	1973	14,710	H
35	Nebraska	Saunders	EBL	Rt. 66 over North Oak Creek	S066-60.60	1979	920	L - M
36	Virginia	City of Norfolk	EBL	I-64 over N & S RR	2833	1966	61,675	M
37	Virginia	City of Norfolk	EBL	I-64 over Rt. 13	2829	1964	61,675	M
38	Virginia	City of Norfolk	WBL	I-64 over Rt. 13	2830	1964	61,675	M
39	Virginia	City of Norfolk	WBL	I-64 over N & S RR	2834	1966	61,675	M
40A	Virginia	Caroline	SBL	Rt. 601 over Polecat Creek	6005	1958	------	L
40B	Virginia	Caroline	NBL	Rt. 601 over Polecat Creek	6005	1958	------	L
41	Virginia	York	EBL	I-64 over Rt. 143	2002	1965	25,738	M
42	Virginia	James City	EBL	I-64 over C & O RR	2000	1965	25,738	M
43	Virginia	Newport News	EBL	I-64 over Rt. 143	2206	1965	27,413	M
44	Virginia	Newport News	EBL	I-64 over Rt. 238	2208	1965	27,413	M
45	Virginia	Newport News	EBL	I-64 over Burcher Rd.	2210	1965	30,945	M
46	Virginia	Newport News	WBL	I-64 over Burcher Rd.	2211	1965	30,945	M
47	Virginia	Montgomery	NBL	I-81 over New River	2901	1986	11,448	M
48	Virginia	Rockingham	SBL	Rt. 340 over One Mile Run	1008	1941	2,615	M
49	Virginia	Pulaski	WBL	Rt. 99 over Peak Creek	1039	1961	6,455	M
50	Virginia	Albemarle	WBPL	I-64 over MeChunk Creek	2057	1969	8,973	M

Note: Lane abbreviations
NBL: North-bound lane
EBL: East-bound lane
SBL: South-bound lane
WBL: West-bound lane
* The classifications H, M, and L denote the following application rates:
H: > 5.0 tons/lane mile/year (2820 kg/lane km/year)
M: 2.5 - 5.0 tons/lane mile/year (1410 - 2820 kg/lane km/year)
L: < 2.5 tons/lane mile/year (1410 kg/lane km/year)

Table B2. General Information on Protection and Patching Treatments Evaluated

Bridge Number	Protection or Patching Treatments Evaluated	Type	Treatment Placement Date	Eval. Date	Span(s) Eval.	Area Eval. (ft^2)	Area Eval. (m^2)	Average Temp. (°F)	Average Temp. (°C)
1	Multiple Layer Reichhold Polyester	Overlay	1985	05/14/91	4	2156	201	89	32
2	Multiple Layer Reichhold Polyester	Overlay	1982	05/14/91	1,2	1152	107	90	32
3	Multiple Layer Flexolith Epoxy	Overlay	1986	05/16/91	1	1216	113	90	32
3C	Standard Bridge Deck Portland Cement Concrete	Control	----	05/16/91	2	1013	94	90	32
4	Multiple Layer Reichhold Polyester (Met. Primer)	Overlay	1988	05/20/91	9,11	1054	98	65	18
5	Multiple Layer Futura Modified EP5 Epoxy	Overlay	1986	05/21/91	13	1067	99	80	27
6	HorseySet.WDE	Sealer	1985	05/22/91	1,2	2240	208	81	27
7	Chem-Trete 40 Silane	Sealer	1985	05/23/91	1	972	90	87	31
8	Five-Star Portland Cement Concrete	Patch	1990	05/29/91	3	1112	103	95	35
9	Duracal Portland Cement Concrete	Patch	1986	05/29/91	2	1148	107	101	38
	Five-Star Portland Cement Concrete	Patch	1990		2				
10	Multiple Layer Flexogrid Epoxy	Overlay	1987	06/03/91	2,3	1020	95	79	26
11	Standard Bridge Deck Portland Cement Concrete	Patch	1986	06/04/91	3	1116	104	82	28
	Asphalt	Patch	1990-91		3				
12	Asphalt	Patch	1990-91	06/05/91	1	675	63	72	22
13	Multiple Layer Flexolith Epoxy	Overlay	1986	06/10/91	3	998	93	81	27
14	Multiple Layer Flexogrid Epoxy	Overlay	1984	06/11/91	1,2	974	91	85	29
15	Multiple Layer Flexogrid Epoxy	Overlay	1987	06/12/91	1,2	1091	101	80	27
16	Set-45 Magnesium Phosphate	Patch	1985-88	06/17/91	1,2	1345	125	83	28
17	Set-45 Magnesium Phosphate	Patch	1985-88	06/18/91	1,2	1587	148	84	29
18	Set-45 Magnesium Phosphate	Patch	1985-88	06/19/91	1-3	1519	141	86	30
19	Multiple Layer Flexolith Epoxy	Overlay	1976	06/24/91	4-6	1362	127	79	26
20	Pen Seal Epoxy	Sealer	1987	06/25/91	3	1441	134	80	27
21	Pen Seal Epoxy	Sealer	1987	06/25/91	3,4	1347	125	91	33
22	Multiple Layer Flexogrid Epoxy	Overlay	1987	07/09/91	8-10	896	83	68	20
23	Multiple Layer Flexolith Epoxy	Overlay	1986/88	07/10/91	2	1632	152	70	21
24	Degadur 330 Methacrylate Slurry	Overlay	1985	07/11/91	1,2	1343	125	77	25
25	Degadur 330 Methacrylate Slurry	Overlay	1986	07/12/91	2,3	1372	128	81	27

(continues)

Table B2. (continued)

Bridge Number	Protection or Patching Treatments Evaluated	Type	Treatment Placement Date	Eval. Date	Span(s) Eval.	Area Eval. (ft^2)	(m^2)	Average Temp. (°F)	(°C)
26	Premixed Polyester (Methacrylate Primer)	Overlay	1984	07/15/91	2	1401	130	91	33
27	Premixed Polyester	Overlay	1983	07/16/91	2,3	1184	110	73	23
28	High Molecular Weight Methacrylate	Sealer	1982	07/17/91	1,2	1568	146	73	23
29	Premixed Polyester (Methacrylate Primer)	Overlay	1984	07/18/91	2,3	1392	129	94	34
30	Multiple Layer Flexogrid Epoxy	Overlay	1987	07/23/91	4	1349	125	100	38
30C	Standard Bridge Deck Portland Cement Concrete	Control	----	07/23/91	3,4	717	67	100	38
31	Degadur 330 Methacrylate Slurry	Overlay	1989	07/24/91	1,2	1960	182	97	36
32	Asphalt	Patch	1990	07/25/91	1	1042	97	83	28
33	Silane	Sealer	1982	07/29/91	1	1109	103	84	29
34	Silane	Sealer	1979	07/30/91	4	1418	132	85	29
34C	Standard Bridge Deck Portland Cement Concrete	Control	----	07/30/91	5	1462	136	85	29
35	Silane	Sealer	1981	07/31/91	2,3	1372	128	83	28
36	Multiple Layer E-bond EP5 LV Epoxy	Overlay	1984	08/05/91	1,2	2232	208	82	28
37	E-bond 120 Epoxy	Sealer	1983	08/06/91	2,3	2400	223	76	24
38	E-bond 120 Epoxy	Sealer	1983	08/06/91	2,3	2080	193	83	28
39	Multiple Layer E-bond Modified EP5 Epoxy	Overlay	1984/88	08/07/91	1,2	2102	195	81	27
40A	High Molecular Weight Methacrylate	Overlay	1986	08/12/91	2,3	538	50	82	28
40B	Multiple Layer E-bond EP5 LV Epoxy	Sealer	1986	08/12/91	2,3	494	46	82	28
41	Multiple Layer DuPont Methyl Methacrylate	Overlay	1981	06/19/90	2,3	2854	265	80	27
42	Multiple Layer USS Chemicals Polyester	Overlay	1981	06/20/90	2,3	2860	266	80	27
43	Multiple Layer USS Chemicals Polyester	Overlay	1981	06/21/90	3,4	2325	216	77	25
44	Multiple Layer Fox EP5 LV Epoxy	Overlay	1984	06/21/90	2,3	2352	219	75	24
45	Asphalt Overlay on Preformed Membrane	Overlay	1981	06/18/90	3,4	3232	301	--	--
46	Asphalt Overlay on Preformed Membrane	Overlay	1981	06/21/90	1,2	3232	301	--	--
47	Transpo T70 High Molecular Weight Methacrylate	Sealer	1988	06/04/91	6-9	----	----	--	--
48	Dow Premixed Polyester	Overlay	1986	06/15/89	1,2	846	79	--	--
49	Reichhold Conductive Premixed Polyester	Overlay	1987	05/03/89	1-3	2205	205	--	--
50	Transpo T28 Polyester Methacrylate Slurry	Overlay	1989	07/24/91	1,2	----	----	97	36

Table B3. Permeability to Chloride Ion Test Results (AASHTO T277)

Bridge Number	Treatment Eval.	1991 Treat. Thickness + (in)	(cm)	Permeability (Coulombs) of Top 2 in (5.08 cm) and Year of Test 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	0.500	1.27	----	----	----	----	29 *	322	----	797	----	----	1243
2	PO	0.229	0.582	----	1 *	1	187	412	706	760	973	----	----	845
3	EO	0.209	0.531	----	----	----	----	----	74 *	----	----	37	----	44
3C	C			----	----	----	----	----	----	----	----	----	----	1492
4	PO	0.295	0.749	----	----	----	----	----	----	----	----	----	----	956
5	EO	0.146	0.371	----	----	----	----	----	97 *	191	245	195	----	206
6	ES			----	----	----	----	961 *	1710	----	1618	----	----	1762
7	SS			----	----	----	----	3385 *	2510	----	2410	----	----	2017
8	PCP	3.125	7.938	----	----	----	----	----	----	----	----	----	----	248
8	C			----	----	----	----	----	----	----	----	----	----	2729
9	PCP	2.438	6.193	----	----	----	----	----	----	----	----	----	----	661
9	C			----	----	----	----	----	----	----	----	----	----	2576
10	EO	0.250	0.635	----	----	----	----	----	----	----	----	----	----	137
11	PCP	1.672	4.247	----	----	----	----	----	----	----	----	----	----	117
11	C			----	----	----	----	----	----	----	----	----	----	3066
12	AP	1.141	2.898	----	----	----	----	----	----	----	----	----	----	8008
12	C			----	----	----	---	----	----	----	----	----	----	3155
13	EO	0.281	0.714	----	----	----	----	----	---- *	77	----	----	----	151
14	EO	0.203	0.516	----	----	----	---- *	----	----	56	----	----	----	222
15	EO	0.240	0.610	----	----	----	----	----	----	----	----	----	----	128
16	HCP	2.250	5.715	----	----	----	----	----	----	----	----	----	----	551
16	C			----	----	----	----	----	----	----	----	----	----	1184
17	HCP			----	----	----	----	----	----	----	----	----	----	752
17	C			----	----	----	----	----	----	----	----	----	----	2430
18	HCP	2.751	6.988	----	----	----	----	----	----	----	----	----	----	1967
18	C			----	----	----	----	----	----	----	----	----	----	2489
19	EO	0.156	0.396	----	----	----	----	----	----	----	----	----	----	420
20	ES			----	----	----	----	----	----	----	----	----	----	2581
21	ES			----	----	----	----	----	----	----	----	----	----	3443

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

\+ overlay or patch thickness
* year of treatment placement

Table B3. (continued)

Bridge Number	Treatment Eval.	1991 Treat. Thickness + (in)	(cm)	Permeability (Coulombs) of Top 2 in (5.08 cm) and Year of Test 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
22	EO	0.255	0.648	----	----	----	----	----	----	----	----	----	----	6
23	EO	0.333	0.846	----	----	----	----	----	----	----	----	----	----	0
24	MO	0.385	0.978	----	----	----	----	----	----	----	----	----	----	0
25	MO	0.360	0.914	----	----	----	----	----	----	----	----	----	----	0
26	PO	0.719	1.826	----	----	----	----	----	----	----	----	----	----	0
27	PO	0.875	2.223	----	----	----	----	----	----	----	----	----	----	348
28	MS			----	----	----	----	----	----	----	----	----	----	2505
29	PO	0.813	2.065	----	----	----	----	----	----	----	----	----	----	130
30	EO	0.271	0.688	----	----	----	----	----	----	24 *	----	159	----	47
30C	C			----	----	----	----	----	----	----	----	----	----	2554
31	MO	0.261	0.663	----	----	----	----	----	----	----	----	----	----	0
32	AP	0.907	2.304	----	----	----	----	----	----	----	----	----	----	2021
32	C			----	----	----	----	----	----	----	----	----	----	1525
33	SS			----	----	----	----	----	----	----	----	----	----	3010
34	SS			----	----	----	----	----	----	----	----	----	----	2160
34C	C			----	----	----	----	----	----	----	----	----	----	3110
35	SS			----	----	----	----	----	----	----	----	----	----	2562
36	EO	0.047	0.119	----	----	----	244 *	75	----	----	----	----	----	408
37	ES			----	----	---- *	2408	1495	----	----	759	----	----	1650
38	ES			----	----	---- *	1744	1752	----	----	2191	----	----	1922
39	EO	0.240	0.610	----	----	----	103 *	76	----	----	---- *	----	----	16
40A	MS	0.021	0.053	----	----	----	----	----	1281 *	1301	----	----	----	1290
40B	EO	0.063	0.160	----	----	----	----	----	----	----	----	----	----	1049
41	MO			216 *	1331	----	1339	----	1630	----	1124	----	1449	----
42	PO			12 *	384	----	----	----	1105	----	1261	----	885	----
43	PO			167 *	3607	----	3252	----	1895	----	1415	----	1517	----
44	EO			3100	----	----	608 *	629	----	----	1229	----	1241	----
47	MS			----	----	----	----	----	----	----	1297 *	1908	----	1718
48	PO			----	----	----	----	----	0 *	83	204	269	----	----

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

\+ overlay or patch thickness
* year of treatment placement

Table B3. (continued)

Bridge Number	Treatment Eval.	1991 Treat. Thickness + (in)	(cm)	Permeability (Coulombs) of Base Concrete and Year of Test 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	0.500	1.27	----	----	----	----	7378 *	----	----	5615	----	----	6815
2	PO	0.229	0.582	----	2124 *	----	----	4303	----	5370	4354	----	----	3635
3	EO	0.209	0.531	----	----	----	----	----	2120 *	----	----	2147	----	1668
3C	C			----	----	----	----	----	----	----	----	----	----	4176
4	PO	0.295	0.749	----	----	----	----	----	----	----	----	----	----	7663
5	EO	0.146	0.371	----	----	----	----	----	---- *	5502	7416	11949	----	6855
6	ES			----	----	----	----	2922 *	5030	----	5758	----	----	4425
7	SS			----	----	----	----	4933 *	5624	----	6039	----	----	4292
8	PCP	3.125	7.938	----	----	----	----	----	----	----	----	----	----	----
8	C			----	----	----	----	----	----	----	----	----	----	5892
9	PCP	2.438	6.193	----	----	----	----	----	----	----	----	----	----	----
9	C			----	----	----	----	----	----	----	----	----	----	5171
10	EO	0.250	0.635	----	----	----	----	----	----	----	----	----	----	3680
11	PCP	1.672	4.247	----	----	----	----	----	----	----	----	----	----	3925
11	C			----	----	----	----	----	----	----	----	----	----	4601
12	AP	1.141	2.898	----	----	----	----	----	----	----	----	----	----	4978
12	C			----	----	----	----	----	----	----	----	----	----	7003
13	EO	0.281	0.714	----	----	----	----	----	---- *	----	----	----	----	3954
14	EO	0.203	0.516	----	----	----	---- *	----	----	----	----	----	----	1507
15	EO	0.240	0.610	----	----	----	----	----	----	----	----	----	----	3373
16	HCP	2.250	5.715	----	----	----	----	----	----	----	----	----	----	----
16	C			----	----	----	----	----	----	----	----	----	----	2540
17	HCP			----	----	----	----	----	----	----	----	----	----	----
17	C			----	----	----	----	----	----	----	----	----	----	2277
18	HCP	2.751	6.988	----	----	----	----	----	----	----	----	----	----	----
18	C			----	----	----	----	----	----	----	----	----	----	2207
19	EO	0.156	0.396	----	----	----	----	----	----	----	----	----	----	2885
20	ES			----	----	----	----	----	----	----	----	----	----	2342
21	ES			----	----	----	----	----	----	----	----	----	----	5334

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

\+ overlay or patch thickness

* year of treatment placement

Table B3. (continued)

Bridge Number	Treatment Eval.	1991 Treat. Thickness + (in)	(cm)	Permeability (Coulombs) of Base Concrete and Year of Test 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
22	EO	0.255	0.648	----	----	----	----	----	----	----	----	----	----	1400
23	EO	0.333	0.846	----	----	----	----	----	----	----	----	----	----	1457
24	MO	0.385	0.978	----	----	----	----	----	----	----	----	----	----	3903
25	MO	0.360	0.914	----	----	----	----	----	----	----	----	----	----	560
26	PO	0.719	1.826	----	----	----	----	----	----	----	----	----	----	4657
27	PO	0.875	2.223	----	----	----	----	----	----	----	----	----	----	2406
28	MS			----	----	----	----	----	----	----	----	----	----	5903
29	PO	0.813	2.065	----	----	----	----	----	----	----	----	----	----	1872
30	EO	0.271	0.688	----	----	----	----	----	----	2507 *	----	2042	----	3848
30C	C			----	----	----	----	----	----	----	----	----	----	----
31	MO	0.261	0.663	----	----	----	----	----	----	----	----	----	----	5420
32	AP	0.907	2.304	----	----	----	----	----	----	----	----	----	----	3759
32	C			----	----	----	----	----	----	----	----	----	----	4394
33	SS			----	----	----	----	----	----	----	----	----	----	6061
34	SS			----	----	----	----	----	----	----	----	----	----	4407
34C	C			----	----	----	----	----	----	----	----	----	----	4836
35	SS			----	----	----	----	----	----	----	----	----	----	3495
36	EO	0.047	0.119	----	----	----	6381 *	3561	----	----	----	----	----	5407
37	ES			----	----	---- *	9517	3135	----	----	3032	----	----	4082
38	ES			----	----	---- *	4585	5111	----	----	6762	----	----	5905
39	EO	0.240	0.610	----	----	----	6869 *	6164	----	----	---- *	----	----	5384
40A	MS	0.021	0.053	----	----	----	----	----	5123 *	7189	----	----	----	4513
40B	EO	0.063	0.160	----	----	----	----	----	----	----	----	----	----	5116
41	MO			6974 *	----	----	----	----	7230	----	4376	----	4217	----
42	PO			6109 *	----	----	----	----	5738	----	4515	----	----	----
43	PO			---- *	----	----	----	----	----	----	5237	----	7687	----
44	EO			----	----	----	---- *	3602	----	----	6900	----	7551	----
47	MS			----	----	----	----	----	----	----	3850	4404	----	4127
48	PO			----	----	----	----	----	2723 *	----	3322	3186	----	----

(continues)

Note: Treatment abbreviations denote the following:

- AO: asphalt overlay
- AP: asphalt patch
- C: standard bridge deck concrete (no protection treatment)
- CPO: conductive polyester overlay
- EO: epoxy overlay
- ES: epoxy sealer
- HCP: hydraulic cement patch (magnesium phosphate)
- MO: methacrylate overlay
- MS: methacrylate sealer
- PCP: portland cement patch
- PO: polyester overlay
- SS: silane sealer

+ overlay or patch thickness

* year of treatment placement

Table B4. Average Chloride Content Test Results

Bridge Number	Treatment Eval.	Reinforcement Cover (in)	Depth (cm)	Test Year	Chloride Content (lbs/yd^3) (kg/m^3) at Depth (in) (cm) 0.31	(0.79)	0.75	(1.91)	1.25	(3.18)	1.75	(4.45)	at rebar		4.25	(10.80)
1	PO	2.60	6.60	1991	2.85	1.69	3.41	2.02	3.20	1.90	2.89	1.72	2.02	1.20	0.27	0.16
				1982	---	---	---	---	---	---	---	---	0.95	0.56	---	---
2	PO	2.95	7.49	1991	2.37	1.41	2.89	1.72	2.27	1.35	1.79	1.06	1.20	0.71	0.15	0.09
		2.38	6.05	1982	2.11	1.25	1.87	1.11	1.43	0.85	0.85	0.50	---	---	---	---
3	EO	1.75	4.45	1991	0.75	0.45	0.77	0.46	0.50	0.30	0.60	0.36	0.60	0.36	0.77	0.46
				1986	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46
3C	C	2.67	6.78	1991	3.17	1.88	1.73	1.03	0.75	0.45	1.05	0.62	0.93	0.55	0.71	0.42
				1986	0.71	0.42	0.71	0.42	0.71	0.42	0.71	0.42	0.71	0.42	0.71	0.42
4	PO	2.00	5.08	1991	4.06	2.41	4.69	2.78	3.21	1.91	2.77	1.64	---	---	0.97	0.57
5	EO	2.06	5.23	1991	2.71	1.61	1.92	1.14	1.06	0.63	0.73	0.43	---	---	0.24	0.14
6	ES	2.60	6.60	1991	4.49	2.66	2.13	1.26	1.08	0.64	0.57	0.34	0.51	0.30	0.40	0.24
				1985	---	---	---	---	---	---	---	---	0.36	0.21	---	---
7	SS	2.29	5.82	1991	7.77	4.61	7.16	4.25	4.23	2.51	2.42	1.44	2.00	1.19	0.33	0.20
				1985	0.33	0.20	0.33	0.20	0.33	0.20	0.33	0.20	0.33	0.20	0.33	0.20
8	PCP	1.63	4.14	1991	13.20	7.83	6.73	3.99	4.24	2.52	2.89	1.72	3.21	1.91	0.52	0.31
				1965	0.52	0.31	0.52	0.31	0.52	0.31	0.52	0.31	0.52	0.31	0.52	0.31
9	PCP	1.00	2.54	1991	10.09	5.99	6.94	4.12	2.75	1.63	0.70	0.42	4.85	2.88	0.43	0.26
				1965	0.43	0.26	0.43	0.26	0.43	0.26	0.43	0.26	0.43	0.26	0.43	0.26
10	EO	2.46	6.25	1991	6.94	4.12	5.18	3.07	2.23	1.32	0.99	0.59	---	---	0.85	0.50
11	PCP	2.06	5.23	1991	18.43	10.94	13.55	8.04	9.16	5.44	6.03	3.58	5.33	3.16	2.15	1.28
				1965	2.15	1.28	2.15	1.28	2.15	1.28	2.15	1.28	2.15	1.28	2.15	1.28
12	AP	1.91	4.85	1991	19.09	11.33	12.82	7.61	11.04	6.55	7.64	4.53	7.35	4.36	2.10	1.25
				1964	2.10	1.25	2.10	1.25	2.10	1.25	2.10	1.25	2.10	1.25	2.10	1.25
13	EO	1.62	4.11	1991	13.71	8.14	10.30	6.11	6.92	4.11	3.81	2.26	---	---	1.07	0.64
14	EO	2.00	5.08	1991	0.74	0.44	0.51	0.30	0.51	0.30	0.56	0.33	0.57	0.34	0.68	0.40
				1984	0.68	0.40	0.68	0.40	0.68	0.40	0.68	0.40	0.68	0.40	0.68	0.40
15	EO	2.55	6.48	1991	3.76	2.23	2.25	1.34	1.81	1.07	1.11	0.66	1.00	0.59	0.70	0.42
				1986	0.70	0.42	0.70	0.42	0.70	0.42	0.70	0.42	0.70	0.42	0.70	0.42
16	HCP	1.75	4.45	1991	1.31	0.78	1.07	0.64	1.28	0.76	1.17	0.69	1.17	0.69	0.66	0.39
				1963	0.66	0.39	0.66	0.39	0.66	0.39	0.66	0.39	0.66	0.39	0.66	0.39
17	HCP	1.75	4.45	1991	11.85	7.03	8.33	4.94	5.07	3.01	3.41	2.02	3.41	2.02	1.05	0.62
				1967	1.05	0.62	1.05	0.62	1.05	0.62	1.05	0.62	1.05	0.62	1.05	0.62
18	HCP	1.84	4.67	1991	17.97	10.66	12.69	7.53	6.14	3.64	5.76	3.42	5.65	3.35	1.43	0.85
				1970	1.43	0.85	1.43	0.85	1.43	0.85	1.43	0.85	1.43	0.85	1.43	0.85
19	EO	1.75	4.45	1991	10.30	6.11	6.99	4.15	5.16	3.06	3.23	1.92	---	---	1.01	0.60
20	ES	2.32	2.32	1991	15.22	9.03	7.35	4.36	3.82	2.27	1.87	1.11	---	---	1.15	0.68
21	ES	2.27	2.32	1991	22.89	13.58	11.29	6.70	7.13	4.23	6.06	3.60	---	---	1.54	0.92
22	EO	1.95	4.95	1991	8.81	5.23	5.67	3.36	6.28	3.73	3.55	2.11	3.34	1.98	0.43	0.26
		1.73	4.39	1985	---	---	2.83	1.68	4.37	2.59	2.24	1.33	2.54	1.51	---	---
23	EO	1.60	4.06	1991	4.86	2.88	2.74	1.63	1.70	1.01	0.96	0.57	1.26	0.75	0.29	0.17
		1.51	3.84	1984	---	---	1.79	1.06	2.05	1.22	0.77	0.46	1.52	0.90	---	---

(continues)

Note: Treatment abbreviations denote the following:

- AO: asphalt overlay
- AP: asphalt patch
- C: standard bridge deck concrete (no protection treatment)
- CPO: conductive polyester overlay
- EO: epoxy overlay
- ES: epoxy sealer
- HCP: hydraulic cement patch (magnesium phosphate)
- MO: methacrylate overlay
- MS: methacrylate sealer
- PCP: portland cement patch
- PO: polyester overlay
- SS: silane sealer

Table B4. (continued)

Bridge Number	Treatment Eval.	Reinforcement Cover Depth (in)	(cm)	Test Year	Chloride Content (lbs/yd^3) (kg/m^3) at Depth (in) (cm) 0.31	(0.79)	0.75	(1.91)	1.25	(3.18)	1.75	(4.45)	at rebar		4.25	(10.80)
24	MO	2.20	5.59	1991	1.18	0.70	0.68	0.40	0.44	0.26	0.41	0.24	0.42	0.25	0.46	0.27
		2.19	5.56	1985	---	---	---	---	---	---	---	---	0.33	0.20	---	---
25	MO	2.27	5.77	1991	0.55	0.32	0.50	0.30	0.35	0.21	0.31	0.18	---	---	0.34	0.20
26	PO	2.68	6.81	1991	0.51	0.31	0.33	0.19	0.33	0.20	0.15	0.09	---	---	0.20	0.12
27	PO	2.52	6.40	1991	1.25	0.74	0.64	0.38	0.38	0.22	0.42	0.25	---	---	0.16	0.09
28	MS	1.76	4.47	1991	1.32	0.78	0.98	0.58	0.88	0.52	0.51	0.30	---	---	0.24	0.14
29	PO	2.00	5.08	1991	1.17	0.69	0.67	0.40	0.37	0.22	0.45	0.27	---	---	0.23	0.14
30	EO	2.75	6.99	1991	0.55	0.33	0.41	0.24	0.21	0.12	0.14	0.08	0.18	0.11	0.24	0.14
				1987	0.24	0.14	0.24	0.14	0.24	0.14	0.24	0.14	0.24	0.14	0.24	0.14
30C	C	2.83	7.19	1991	1.52	0.90	0.70	0.42	0.41	0.24	0.14	0.08	0.14	0.08	0.16	0.09
				1987	0.16	0.09	0.16	0.09	0.16	0.09	0.16	0.09	0.16	0.09	0.16	0.09
31	MO	2.24	5.69	1991	4.41	2.62	3.70	2.19	2.61	1.55	1.94	1.15	---	---	0.39	0.23
32	AP	1.57	3.99	1991	4.64	2.75	2.94	1.74	2.11	1.25	1.70	1.01	1.85	1.10	0.77	0.46
				1969	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46	0.77	0.46
33	SS	2.03	5.16	1991	9.14	5.43	6.34	3.76	2.98	1.77	1.07	0.64	---	---	0.51	0.51
34	SS	2.40	6.10	1991	7.08	4.20	2.39	1.42	0.78	0.46	0.45	0.27	0.41	0.24	0.31	0.18
				1985	---	---	---	---	---	---	---	---	0.43	0.26	---	---
34C	C	2.85	7.24	1991	9.33	5.54	3.32	1.97	1.27	0.75	0.52	0.31	0.44	0.26	0.34	0.20
				1973	0.34	0.20	0.34	0.20	0.34	0.20	0.34	0.20	0.34	0.20	0.34	0.20
35	SS	2.51	6.38	1991	9.72	5.77	5.69	3.37	2.85	1.69	0.77	0.46	---	---	0.37	0.22
36	EO	1.35	3.43	1991	1.25	0.74	0.94	0.56	0.62	0.37	0.52	0.31	0.76	0.45	0.28	0.17
		1.53	3.89	1983	---	---	---	---	---	---	0.22	0.13	---	---	---	---
37	ES	1.88	4.78	1991	2.59	1.54	1.47	0.87	0.86	0.51	0.60	0.36	0.57	0.34	0.23	0.14
		2.33	5.92	1983	0.23	0.14	0.23	0.14	0.23	0.14	0.23	0.14	0.23	0.14	0.23	0.14
38	ES	2.88	7.32	1991	0.97	0.58	0.68	0.40	0.38	0.23	0.40	0.24	0.34	0.20	0.27	0.16
		3.07	7.80	1983	0.27	0.16	0.27	0.16	0.27	0.16	0.27	0.16	0.27	0.16	0.27	0.16
39	EO	1.50	3.81	1991	2.08	1.23	1.44	0.85	1.39	0.82	1.02	0.61	1.24	0.74	0.41	0.24
		1.80	4.57	1983	---	---	---	---	---	---	0.12	0.07	---	---	---	---
40A	MS			1991	2.45	1.45	2.20	1.30	2.10	1.25	1.78	1.06	---	---	0.70	0.41
40B	EO			1991	1.03	0.61	2.80	1.66	2.26	1.34	1.59	0.94	---	---	0.53	0.31
41	MO			1990	1.69	1.00	1.32	0.78	0.76	0.45	0.46	0.27	---	---	---	---
		2.40	6.10	1981	3.72	2.21	1.82	1.08	1.13	0.67	0.58	0.34	---	---	---	---
42	PO			1990	1.69	1.00	1.34	0.80	0.81	0.48	0.49	0.29	---	---	---	---
		2.30	5.84	1981	2.96	1.76	1.40	0.83	0.45	0.27	0.31	0.18	---	---	---	---
43	PO			1990	2.16	1.28	1.78	1.06	1.18	0.70	0.83	0.49	---	---	---	---
		2.40	6.10	1981	1.10	0.65	0.35	0.21	0.20	0.12	0.20	0.12	---	---	---	---
44	EO			1990	1.62	0.96	1.17	0.69	0.55	0.33	0.31	0.18	---	---	---	---
		2.20	5.59	1981	4.21	2.50	0.56	0.33	0.18	0.11	0.17	0.10	---	---	---	---
45	AO			1990	1.71	1.01	1.58	0.94	1.45	0.86	1.21	0.72	---	---	---	---
		2.60	6.60	1981	3.54	2.10	2.73	1.62	1.68	1.00	2.04	1.21	---	---	---	---
46	AO			1990	2.11	1.25	2.07	1.23	1.86	1.10	1.59	0.94	---	---	---	---
		2.70	6.86	1981	2.45	1.45	2.50	1.48	1.51	0.90	1.17	0.69	---	---	---	---

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

Table B5. Electrical Half-Cell Potential Test Results

Bridge Number	Treatment Evaluated	% of Potentials < 0.20 (·VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	--	--	--	--	-- *	71	--	42	--	--	25
2	PO	--	100 *	100	--	93	--	89	52	--	--	87
3	EO	--	--	--	--	--	-- *	--	--	--	--	94
3C	C	--	--	--	--	--	--	--	--	--	--	100
4	PO	--	--	--	--	--	--	--	--	--	--	60
5	EO	--	--	--	--	--	-- *	93	--	--	--	83
6	ES	--	--	--	--	99 *	99	--	--	--	--	100
7	SS	--	--	--	--	83 *	44	--	--	--	--	40
8	PCP	--	--	--	--	--	--	--	--	--	--	69
9	PCP	--	--	--	--	--	--	--	--	--	--	63
10	EO	--	--	--	--	--	--	--	--	--	--	91
11	PCP	--	--	--	--	--	--	--	--	--	--	52
12	AP	--	--	--	--	--	--	--	--	--	--	4
13	EO	--	--	--	--	--	--	--	--	--	--	83
14	EO	--	--	--	--	--	--	--	--	--	--	10
15	EO	--	--	--	--	--	--	--	--	--	--	100
16	HCP	--	--	--	--	--	--	--	--	--	--	29
17	HCP	--	--	--	--	--	--	--	--	--	--	20
18	HCP	--	--	--	--	--	--	--	--	--	--	25
19	EO	--	--	--	--	--	--	--	--	--	--	14
20	ES	--	--	--	--	--	--	--	--	--	--	0
21	ES	--	--	--	--	--	--	--	--	--	--	0
22	EO	--	--	--	--	100	--	-- *	--	--	--	98
23	EO	--	--	--	--	--	--	--	--	--	--	100
24	MO	--	--	--	--	--	--	--	--	--	--	100
25	MO	--	--	--	--	--	--	--	--	--	--	99

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B5. (continued)

Bridge Number	Treatment Evaluated	% of Potentials < 0.20 (-VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
26	PO	--	--	--	100 *	--	--	--	--	--	--	100
27	PO	--	--	--	--	--	--	--	--	--	--	98
28	MS	--	--	--	--	--	--	--	--	--	--	98
29	PO	--	--	--	100 *	--	--	--	--	--	--	100
30	EO	--	--	--	--	--	--	--	--	--	--	64
30C	C	--	--	--	--	--	--	--	--	--	--	93
31	MO	--	--	--	--	--	--	--	--	--	--	91
32	AP	--	--	--	--	--	--	--	--	--	--	22
33	SS	--	--	--	--	--	--	--	--	--	--	4
34	SS	--	--	--	--	--	--	--	--	--	--	91
34C	C	--	--	--	--	--	--	--	--	--	--	92
35	SS	--	--	--	--	--	--	--	--	--	--	0
36	EO	--	--	75	92 *	85	--	--	--	--	--	84
37	ES	--	--	94 *	95	90	--	--	--	--	--	91
38	ES	--	--	59 *	62	65	--	--	--	--	--	81
39	EO	--	--	82	97 *	93	--	--	-- *	--	--	96
40A	MS	--	--	--	--	--	-- *	28	--	--	--	74
40B	EO	--	--	--	--	--	-- *	--	--	--	--	65
41	MO	94 *	79	--	92	--	90	--	88	--	95	--
42	PO	98 *	96	--	97	--	99	--	96	--	97	--
43	PO	98 *	86	--	98	--	97	--	95	--	96	--
44	EO	98	94	--	97 *	91	--	--	--	--	80	--
45	AO	96 *	77	--	71	--	79	--	--	--	--	--
46	AO	99 *	--	--	97	--	--	--	--	--	--	--
49	CPO	--	--	--	--	--	11	-- *	--	--	(continues)	

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer
* year of treatment placement

Table B5. (continued)

Bridge Number	Treatment Evaluated	0.20 (-VCSE) < % of Potentials < 0.35 (-VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	--	--	--	--	-- *	29	--	58	--	--	67
2	PO	--	0 *	0	--	7	--	11	44	--	--	13
3	EO	--	--	--	--	--	-- *	--	--	--	--	6
3C	C	--	--	--	--	--	--	--	--	--	--	0
4	PO	--	--	--	--	--	--	--	--	--	--	39
5	EO	--	--	--	--	--	-- *	7	--	--	--	16
6	ES	--	--	--	--	1 *	1	--	--	--	--	0
7	SS	--	--	--	--	17 *	44	--	--	--	--	49
8	PCP	--	--	--	--	--	--	--	--	--	--	28
9	PCP	--	--	--	--	--	--	--	--	--	--	31
10	EO	--	--	--	--	--	--	--	--	--	--	9
11	PCP	--	--	--	--	--	--	--	--	--	--	36
12	AP	--	--	--	--	--	--	--	--	--	--	45
13	EO	--	--	--	--	--	--	--	--	--	--	12
14	EO	--	--	--	--	--	--	--	--	--	--	87
15	EO	--	--	--	--	--	--	--	--	--	--	0
16	HCP	--	--	--	--	--	--	--	--	--	--	51
17	HCP	--	--	--	--	--	--	--	--	--	--	44
18	HCP	--	--	--	--	--	--	--	--	--	--	28
19	EO	--	--	--	--	--	--	--	--	--	--	60
20	ES	--	--	--	--	--	--	--	--	--	--	54
21	ES	--	--	--	--	--	--	--	--	--	--	24
22	EO	--	--	--	--	0	--	-- *	--	--	--	2
23	EO	--	--	--	--	--	--	--	--	--	--	0
24	MO	--	--	--	--	--	--	--	--	--	--	0
25	MO	--	--	--	--	--	--	--	--	--	--	1

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B5. (continued)

Bridge Number	Treatment Evaluated	0.20 (-VCSE) < % of Potentials < 0.35 (-VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
26	PO	--	--	--	0 *	--	--	--	--	--	--	0
27	PO	--	--	--	--	--	--	--	--	--	--	2
28	MS	--	--	--	--	--	--	--	--	--	--	2
29	PO	--	--	--	0 *	--	--	--	--	--	--	0
30	EO	--	--	--	--	--	--	--	--	--	--	36
30C	C	--	--	--	--	--	--	--	--	--	--	7
31	MO	--	--	--	--	--	--	--	--	--	--	8
32	AP	--	--	--	--	--	--	--	--	--	--	66
33	SS	--	--	--	--	--	--	--	--	--	--	46
34	SS	--	--	--	--	--	--	--	--	--	--	9
34C	C	--	--	--	--	--	--	--	--	--	--	8
35	SS	--	--	--	--	--	--	--	--	--	--	98
36	EO	--	--	24	8 *	15	--	--	--	--	--	16
37	ES	--	--	6 *	5	10	--	--	--	--	--	9
38	ES	--	--	41 *	36	35	--	--	--	--	--	17
39	EO	--	--	18	3 *	7	--	--	-- *	--	--	4
40A	MS	--	--	--	--	--	-- *	70	--	--	--	26
40B	EO	--	--	--	--	--	-- *	--	--	--	--	35
41	MO	6 *	20	--	8	--	10	--	11	--	4	--
42	PO	1 *	4	--	3	--	1	--	4	--	2	--
43	PO	2 *	14	--	2	--	3	--	4	--	3	--
44	EO	1	6	--	3 *	9	--	--	--	--	15	--
45	AO	3 *	13	--	27	--	21	--	--	--	--	--
46	AO	0 *	--	--	3	--	--	--	--	--	--	--
49	CPO	--	--	--	--	--	40	-- *	--	--	(continues)	

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B5. (continued)

Bridge Number	Treatment Evaluated	% of Potentials > 0.35 (-VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	--	--	--	--	-- *	0	--	0	--	--	8
2	PO	--	0 *	0	--	0	--	0	4	--	--	0
3	EO	--	--	--	--	--	-- *	--	--	--	--	0
3C	C	--	--	--	--	--	--	--	--	--	--	0
4	PO	--	--	--	--	--	--	--	--	--	--	1
5	EO	--	--	--	--	--	-- *	0	--	--	--	1
6	ES	--	--	--	--	0 *	0	--	--	--	--	0
7	SS	--	--	--	--	0 *	12	--	--	--	--	11
8	PCP	--	--	--	--	--	--	--	--	--	--	3
9	PCP	--	--	--	--	--	--	--	--	--	--	6
10	EO	--	--	--	--	--	--	--	--	--	--	0
11	PCP	--	--	--	--	--	--	--	--	--	--	12
12	AP	--	--	--	--	--	--	--	--	--	--	51
13	EO	--	--	--	--	--	--	--	--	--	--	5
14	EO	--	--	--	--	--	--	--	--	--	--	3
15	EO	--	--	--	--	--	--	--	--	--	--	0
16	HCP	--	--	--	--	--	--	--	--	--	--	20
17	HCP	--	--	--	--	--	--	--	--	--	--	36
18	HCP	--	--	--	--	--	--	--	--	--	--	47
19	EO	--	--	--	--	--	--	--	--	--	--	26
20	ES	--	--	--	--	--	--	--	--	--	--	46
21	ES	--	--	--	--	--	--	--	--	--	--	76
22	EO	--	--	--	--	0	--	-- *	--	--	--	0
23	EO	--	--	--	--	--	--	--	--	--	--	0
24	MO	--	--	--	--	--	--	--	--	--	--	0
25	MO	--	--	--	--	--	--	--	--	--	--	0

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B5. (continued)

Bridge Number	Treatment Evaluated	% of Potentials > 0.35 (-VCSE) and Year of Potential Measurement										
		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
26	PO	--	--	--	0 *	--	--	--	--	--	--	0
27	PO	--	--	--	--	--	--	--	--	--	--	0
28	MS	--	--	--	--	--	--	--	--	--	--	0
29	PO	--	--	--	0 *	--	--	--	--	--	--	0
30	EO	--	--	--	--	--	--	--	--	--	--	0
30C	C	--	--	--	--	--	--	--	--	--	--	0
31	MO	--	--	--	--	--	--	--	--	--	--	1
32	AP	--	--	--	--	--	--	--	--	--	--	12
33	SS	--	--	--	--	--	--	--	--	--	--	50
34	SS	--	--	--	--	--	--	--	--	--	--	0
34C	C	--	--	--	--	--	--	--	--	--	--	0
35	SS	--	--	--	--	--	--	--	--	--	--	2
36	EO	--	--	1	0 *	0	--	--	--	--	--	0
37	ES	--	--	0 *	0	0	--	--	--	--	--	0
38	ES	--	--	0 *	2	0	--	--	--	--	--	2
39	EO	--	--	0	0 *	0	--	--	-- *	--	--	0
40A	MS	--	--	--	--	--	-- *	2	--	--	--	0
40B	EO	--	--	--	--	--	-- *	--	--	--	--	0
41	MO	0 *	1	--	0	--	0	--	1	--	1	--
42	PO	1 *	0 *	--	0	--	0	--	0	--	1	--
43	PO	0 *	0 *	--	0	--	0	--	1	--	1	--
44	EO	1	0	--	0 *	0	--	--	--	--	5	--
45	AO	1 *	10	--	2	--	0	--	--	--	--	--
46	AO	1 *	--	--	0	--	--	--	--	--	--	--
49	CPO	--	--	--	--	--	49	-- *	--	--	--	--

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard bridge deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B6. Rate of Corrosion Test Results, 1991

Bridge Number	Span(s) Tested	Rate of Corrosion x 10^3 (in/yr)	Rate of Corrosion x 10^3 (cm/yr)	ICORR (mA/ft^2)	ICORR (mA/m^2)	ICORR Distribution A	ICORR Distribution B	ICORR Distribution C	ICORR Distribution D
1	4	2.30	5.84	4.66	50.11	0%	0%	100%	0%
2	1, 2	1.36	3.45	2.75	29.57	0%	8%	88%	4%
3	1	0.02	0.05	0.03	0.32	100%	0%	0%	0%
3C	2	0.07	0.18	0.13	1.40	100%	0%	0%	0%
4	9, 11	0.47	1.19	0.95	10.22	23%	40%	37%	0%
5	13	0.22	0.56	0.45	4.84	67%	20%	13%	0%
6	1, 2	0.37	0.94	0.76	8.17	0%	80%	20%	0%
7	1	2.15	5.46	4.36	46.88	0%	10%	77%	13%
8	3	1.09	2.77	2.21	23.76	0%	33%	67%	0%
9	2	0.88	2.24	1.77	19.03	11%	44%	45%	0%
10	2, 3	0.07	0.18	0.15	1.61	77%	20%	3%	0%
11	3	0.80	2.03	1.63	17.53	0%	50%	50%	0%
12	1	0.85	2.16	1.72	18.49	0%	50%	50%	0%
13	3	0.04	0.10	0.08	0.86	83%	17%	0%	0%
14	1, 2	0.07	0.18	0.14	1.51	67%	33%	0%	0%
15	2	0.04	0.10	0.07	0.75	100%	0%	0%	0%
16	1, 2	0.91	2.31	1.84	19.78	22%	17%	61%	0%
17	1	0.70	1.78	1.41	15.16	0%	67%	33%	0%
18	2, 3	3.38	8.59	6.86	73.76	0%	17%	66%	17%
19	5	1.18	3.00	2.40	25.81	3%	57%	40%	0%
20	3	0.78	1.98	1.58	16.99	7%	53%	40%	0%
21	3, 4	2.00	5.08	4.06	43.66	0%	0%	90%	10%
22	8, 9, 10	0.00	0.00	0.02	0.22	100%	0%	0%	0%
23	2	0.01	0.03	0.02	0.22	100%	0%	0%	0%
24	1, 2	0.00	0.00	0.01	0.11	100%	0%	0%	0%
26	2	0.02	0.05	0.03	0.32	96%	4%	0%	0%
27	2, 3	0.13	0.33	0.25	2.69	53%	47%	0%	0%
28	1, 2	0.10	0.25	0.20	2.15	63%	37%	0%	0%
29	2, 3	0.18	0.46	0.36	3.87	30%	70%	0%	0%
30	4	0.07	0.18	0.14	1.51	83%	11%	6%	0%
30C	4	0.83	2.11	1.67	17.96	0%	6%	94%	0%
31	2	0.00	0.00	0.01	0.11	100%	0%	0%	0%
32	1	1.30	3.30	2.65	28.49	11%	33%	50%	6%
33	1	0.85	2.16	1.72	18.49	0%	67%	30%	3%
34	4	0.19	0.48	0.39	4.19	17%	73%	10%	0%
34C	5	0.36	0.91	0.74	7.96	0%	80%	20%	0%
35	2	1.14	2.90	2.32	24.95	0%	0%	100%	0%
36	1, 2	0.30	0.76	0.61	6.56	33%	43%	24%	0%
37	2, 3	0.26	0.66	0.54	5.81	10%	77%	13%	0%
38	2, 3	0.30	0.76	0.61	6.56	21%	61%	18%	0%
39	1, 2	0.00	0.00	0.01	0.11	100%	0%	0%	0%
41*	B, C	0.48	1.22	0.98	10.50	3%	52%	45%	0%
42*	B, C	0.43	1.09	0.87	9.41	20%	44%	36%	0%
43*	C, D, E	0.26	0.66	0.53	5.69	38%	44%	18%	0%
44*	B, C	0.17	0.43	0.35	3.72	21%	76%	3%	0%

A,B,C,D denote following ranges (and corresponding expected year of corrosion damage):

A: ICORR < 0.20 (none) B: 0.2 < ICORR < 1.0 (10 to 15 years)

C: 1.0 < ICORR < 10.0 (2 to 10 years) D: ICORR > 10.0 (less than 2 years)

Note: Bricges 25 and 40 not included due to equipment problems

* 1990 data for bridge 41-44

Table B7. Skid Number at 40 mph

Bridge Number	Treatment Eval.	Bald Tire Skid Number (ASTM E524) and Year of Test											
		1976	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
1	PO	--	--	--	--	--	56 *	50	--	43	--	--	48
2	PO	--	--	49 *	45	--	38	--	27	--	--	--	33
3	EO	--	--	--	--	--	--	56 *	47	--	52	--	43
4	PO	--	--	--	--	--	--	--	--	-- *	43	--	33
5	EO	--	--	--	--	--	--	39 *	35	--	30	--	26
6	ES	--	--	--	--	--	23 *	34	--	29	--	--	36
7	SS	--	--	--	--	--	42 *	46	--	47	--	--	48
10	EO	--	--	--	--	--	--	--	-- *	--	44	--	39
13	EO	--	--	--	--	--	--	-- *	--	--	--	--	51
14	EO	--	--	--	--	-- *	--	--	--	--	--	--	65
15	EO	--	--	--	--	--	--	-- *	--	--	--	--	48
19	EO	-- *	--	--	--	--	--	--	--	--	--	--	40
22	EO	--	--	--	--	--	--	--	-- *	--	--	44	33
23	EO	--	--	--	--	--	--	-- *	46	37/59 *	44	47	33
24	MO	--	--	--	--	--	-- *	54	48	42	43	38	33
25	MO	--	--	--	--	--	--	55 *	--	--	55	55	50
26	PO	--	--	--	--	-- *	--	--	--	--	--	42	--
27	PO	--	--	--	-- *	--	--	--	--	--	--	59	--
29	PO	--	--	--	--	-- *	--	--	--	--	--	49	--
30	EO	--	--	--	--	--	--	--	63 *	46	51	--	48
31	MO	--	--	--	--	--	--	--	--	--	-- *	--	45
36	EO	--	--	--	--	41 *	31	--	--	--	--	--	18
37	ES	--	--	--	-- *	43	42	--	45	--	--	--	46
38	ES	--	--	--	-- *	47	46	--	45	--	--	--	52
39	EO	--	--	--	--	42 *	29	--	--	-- *	--	--	48
40A	MS	--	--	--	--	--	--	42 *	40	--	32	--	33
41	MO	--	56 *	38	--	42	--	37	--	34	--	36	--
42	PO	--	63 *	46	--	43	--	32	--	27	--	42	--
43	PO	--	62 *	43	--	41	--	40	--	31	--	42	--
44	EO	--	--	--	--	52 *	28	20	--	19	--	--	--
45	AO	--	27 *	23	--	28	--	28	--	--	--	--	--
46	AO	--	25 *	20	--	24	--	--	--	--	--	--	--
47	MS	--	--	--	--	--	--	--	--	37 *	36	--	--
48	PO	--	--	--	--	--	--	-- *	38	--	45	--	--
49	CPO	--	--	--	--	--	--	--	-- *	39	40	--	--
50	MO	--	--	--	--	--	--	--	--	--	-- *	--	53

(continues)

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (magnesium phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B7. (continued)

Bridge Number	Treatment Evaluated	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
		Treaded Tire Skid Number (ASTM E501) and Year of Test										
1	PO	--	--	--	--	62 *	54	--	47	--	--	52
2	PO	--	55 *	56	--	49	--	42	--	--	--	45
3	EO	--	--	--	--	--	58 *	48	--	51	--	51
4	PO	--	--	--	--	--	--	--	-- *	51	--	43
5	EO	--	--	--	--	--	49 *	50	--	45	--	45
6	ES	--	--	--	--	36 *	51	--	45	--	--	50
7	SS	--	--	--	--	48 *	51	--	49	--	--	49
10	EO	--	--	--	--	--	--	-- *	--	50	--	45
30	EO	--	--	--	--	--	--	71 *	55	58	--	56
31	MO	--	--	--	--	--	--	--	--	-- *	--	48
36	EO	--	--	--	58 *	45	--	--	--	--	--	34
37	ES	--	--	-- *	47	45	--	44	--	--	--	49
38	ES	--	--	-- *	45	44	--	46	--	--	--	52
39	EO	--	--	--	56 *	45	--	--	-- *	--	--	49
40A	MS	--	--	--	--	--	68 *	56	--	51	--	49
41	MO	59 *	53	--	45	--	46	--	41	--	41	--
42	PO	64 *	58	--	45	--	46	--	37	--	45	--
43	PO	63 *	57	--	46	--	44	--	41	--	44	--
44	EO	--	--	--	63 *	45	40	--	35	--	--	--
45	AO	43 *	42	--	39	--	41	--	--	--	--	--
46	AO	49 *	45	--	41	--	--	--	--	--	--	--
47	MS	--	--	--	--	--	--	--	-- *	47	--	--
48	PO	--	--	--	--	--	-- *	45	--	48	--	--
49	CPO	--	--	--	--	--	--	-- *	43	44	--	--
50	MO	--	--	--	--	--	--	--	--	-- *	--	53

Note: Treatment abbreviations denote the following:

AO: asphalt overlay
AP: asphalt patch
C: standard deck concrete (no protection treatment)
CPO: conductive polyester overlay
EO: epoxy overlay
ES: epoxy sealer
HCP: hydraulic cement patch (Mg phosphate)
MO: methacrylate overlay
MS: methacrylate sealer
PCP: portland cement patch
PO: polyester overlay
SS: silane sealer

* year of treatment placement

Table B8. Tension Adhesion Test Results

Bridge Treatment Number	Eval.	1976	1981		1982		1983		1984	1985		1986		1987		1988	
			Tensile Adhesion (psi) (MPa) and Year of Test														
1	PO	---	---	---	---	---	---	---	---	(353)*	(2.43)	(308)	(2.12)	---	---	129	0.89
2	PO	---	---	---	286 *	---	266	1.83	---	134	0.92	223	1.54	168	1.16	143	0.99
3	EO	---	---	---	---	---	---	---	---	---	---	281 *	1.94	149	1.03	180	1.24
4	PO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	(341)*	(2.35)
5	EO	---	---	---	---	---	---	---	---	---	---	341 *	2.35	401	2.76	427	2.94
10	EO	---	---	---	---	---	---	---	---	---	---	---	---	--- *	---	193	1.33
13	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---	---	---
14	EO	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---	---
15	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---	---	---
19	EO	--- *	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
22	EO	---	---	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---
23	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---	--- *	---
24	MO	---	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---
25	MO	---	---	---	---	---	---	---	---	---	---	(113)*	(0.78)	---	---	---	---
26	PO	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---	---
27	PO	---	---	---	---	---	--- *	---	---	---	---	---	---	---	---	---	---
29	PO	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---	---
30	EO	---	---	---	---	---	---	---	---	---	---	---	---	276 *	1.90	360	2.48
31	MO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
36	EO	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---	---
39	EO	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	--- *	---
40A	MS	---	---	---	---	---	---	---	---	---	---	--- *	---	294	2.03	---	---
40B	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	175	1.21	---	---
41	MO	---	(230)*	(1.58)	139	0.96	---	---	---	---	---	113	0.78	---	---	157	1.08
42	PO	---	(171)*	(1.18)	157	1.08	---	---	---	---	---	---	---	---	---	70	0.48
43	PO	---	143 *	0.99	105	0.72	---	---	---	---	---	---	---	---	---	108	0.74
44	EO	---	---	---	---	---	---	---	--- *	---	---	350	2.41	---	---	282	1.94
48	PO	---	---	---	---	---	---	---	---	---	---	385 *	2.65	180	1.24	219	1.51
49	CPO	---	---	---	---	---	---	---	---	---	---	---	---	250 *	1.72	186	1.28
50	MO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

(continues)

Note: Treatment abbreviations denote the following: CPO: conductive polyester overlay EO: epoxy overlay
MS: methacrylate sealer MO: methacrylate overlay PO: polyester overlay
* year of treatment placement () denotes > 50 % failure in base concrete

Table B8. (continued)

Bridge Number	Treatment Eval.	Tensile Adhesion (psi) (MPa) and Year of Test: 1989 (psi)	1989 (MPa)	1990 (psi)	1990 (MPa)	1991 (psi)	1991 (MPa)	1991 Number of Cores Tested **	1991 + Overlay Thickness (in)	1991 + Overlay Thickness (cm)	Failure Area (%), 1991 +: Overlay	Bond	Base	Adhesive
1	PO	---	---	---	---	96	0.66	5	0.48	1.21	25%	71%	4%	0%
2	PO	---	---	---	---	78	0.54	6	0.29	0.75	0%	75%	8%	17%
3	EO	248	1.71	---	---	113	0.78	6	0.23	0.59	6%	85%	1%	8%
4	PO	298	2.05	---	---	190	1.31	15	0.33	0.84	8%	70%	6%	16%
5	EO	403	2.78	---	---	238	1.64	3	0.19	0.49	2%	76%	5%	17%
10	EO	---	---	---	---	234	1.61	4	0.31	0.80	13%	15%	60%	12%
13	EO	---	---	---	---	259	1.78	6	0.29	0.74	12%	77%	11%	0%
14	EO	---	---	---	---	246	1.69	6	0.22	0.57	58%	22%	20%	0%
15	EO	---	---	---	---	214	1.47	6	0.24	0.61	70%	9%	21%	0%
19	EO	---	---	---	---	147	1.01	5	0.18	0.45	0%	98%	0%	2%
22	EO	---	---	---	---	187	1.29	6	0.24	0.61	0%	4%	96%	0%
23	EO	---	---	---	---	327	2.25	6	0.35	0.89	20%	23%	57%	0%
24	MO	---	---	---	---	128	0.88	6	0.35	0.89	3%	53%	44%	0%
25	MO	---	---	---	---	85	0.59	6	0.35	0.88	0%	4%	90%	6%
26	PO	---	---	---	---	180	1.24	6	0.80	2.03	17%	2%	81%	0%
27	PO	---	---	---	---	219	1.51	6	0.87	2.22	52%	48%	0%	0%
29	PO	---	---	---	---	210	1.45	6	0.86	2.17	92%	0%	8%	0%
30	EO	354	2.44	---	---	112	0.77	8	0.31	0.80	1%	88%	11%	0%
31	MO	(342)*	(2.36)	---	---	166	1.14	4	0.29	0.72	0%	94%	6%	0%
36	EO	---	---	---	---	435	3.00	6	0.05	0.12	5%	3%	75%	17%
39	EO	---	---	---	---	164	1.13	6	0.20	0.50	73%	15%	12%	0%
40A	MS	453	3.12	---	---	358	2.47	6	0.03	0.08	45%	49%	6%	0%
40B	EO	342	2.36	---	---	161	1.11	3	0.07	0.17	0%	88%	12%	0%
41	MO	---	---	103	0.71	---	---	---	0.31	0.79	31%	69%	0%	0%
42	PO	---	---	55	0.38	---	---	---	0.43	1.08	0%	100%	0%	0%
43	PO	---	---	111	0.76	---	---	---	0.37	0.94	26%	74%	0%	0%
44	EO	---	---	352	2.43	---	---	---	0.06	0.15	34%	0%	66%	0%
48	PO	263	1.81	---	---	---	---	---	----	----	--	--	--	--
49	CPO	(291)	(2.00)	---	---	---	---	---	----	----	--	--	--	--
50	MO	400 *	2.76	---	---	(259)	(1.78)	---	----	----	--	--	--	--

Note: Treatment abbreviations denote the following:
MS: methacrylate sealer
* year of treatment placement
() denotes > 50 % failure in base concrete

CPO: conductive polyester overlay
MO: methacrylate overlay
** core diameter = 2.25 in (5.7 cm)
+ 1990 data for bridge 41-44

EO: epoxy overlay
PO: polyester overlay

Table B9. Average Guillotine Shear Rupture Strength Test Results

Guillotine Shear Strength of Bond Interface (psi) (MPa) and Year of Test

Bridge Number	Treatment Evaluated	1981		1982		1983		1984		1985		1986		1987		1988		1989		1990	
1	PO	---	---	---	---	---	---	---	---	(793)*	(5.46)	(514)	(3.54)	---	---	---	---	---	---	---	---
2	PO	---	---	(972)*	(6.70)	(730)	(5.03)	(602)	(4.15)	(734)	(5.06)	320	2.20	308	2.12	---	---	---	---	---	---
3	EO	---	---	---	---	---	---	---	---	---	---	701 *	4.83	664	4.57	---	---	310	2.14	---	---
5	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	(486)	(3.35)	---	---	370	2.55	---	---
10	EO	---	---	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---
30	EO	---	---	---	---	---	---	---	---	---	---	---	---	(680)*	4.69	---	---	460	3.17	---	---
36	EO	---	---	---	---	---	---	439 *	3.02	492	3.39	---	---	---	---	---	---	---	---	---	---
39	EO	---	---	---	---	---	---	572 *	3.94	437	3.01	---	---	---	---	--- *	---	---	---	---	---
41	MO	--- *	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	108	0.74
42	PO	1125 *	7.75	---	---	---	---	---	---	---	---	217	1.50	---	---	---	---	---	---	115	0.79
43	PO	469 *	3.23	---	---	---	---	205	1.41	---	---	241	1.66	---	---	---	---	---	---	213	1.47
44	EO	---	---	---	---	---	---	615 *	4.24	537	3.70	---	---	---	---	---	---	---	---	(603)	4.15
48	PO	---	---	---	---	---	---	---	---	---	---	870 *	5.99	650	4.48	770	5.31	---	---	---	---

Guillotine Shear Strength of Base Concrete (psi) (MPa) and Year of Test

Bridge Number	Treatment Evaluated	1981		1982		1983		1984		1985		1986		1987		1988		1989		1990	
1	PO	---	---	---	---	---	---	---	---	980 *	6.75	823	5.67	---	---	---	---	---	---	---	---
2	PO	---	---	812 *	5.59	823	5.67	763	5.26	950	6.55	787	5.42	960	6.61	---	---	---	---	---	---
3	EO	---	---	---	---	---	---	---	---	---	---	1040 *	7.17	855	5.89	---	---	980	6.75	---	---
5	EO	---	---	---	---	---	---	---	---	---	---	--- *	---	928	6.39	---	---	580	4.00	---	---
10	EO	---	---	---	---	---	---	---	---	---	---	---	---	--- *	---	---	---	---	---	---	---
30	EO	---	---	---	---	---	---	---	---	---	---	---	---	1085 *	7.48	---	---	720	4.96	---	---
36	EO	---	---	---	---	---	---	839 *	5.78	585	4.03	---	---	---	---	---	---	---	---	---	---
39	EO	---	---	---	---	---	---	906 *	6.24	970	6.68	---	---	---	---	--- *	---	---	---	---	---
41	MO	1163 *	8.01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	649	4.47
42	PO	806 *	5.55	---	---	---	---	---	---	---	---	973	6.70	---	---	---	---	---	---	690	4.75
43	PO	927 *	6.39	---	---	---	---	522	3.60	---	---	1022	7.04	---	---	---	---	---	---	598	4.12
44	EO	597	4.11	---	---	---	---	401 *	2.76	694	4.78	---	---	---	---	---	---	---	---	519	3.58
48	PO	---	---	---	---	---	---	---	---	---	---	1060 *	7.30	1130	7.79	1190	8.20	---	---	---	---

Note: Treatment abbreviations denote the following: EO: epoxy overlay MO: methacrylate overlay PO: polyester overlay

* year of treatment placement

() denotes > 50 % failure in base concrete

Table B10. Deck Assessment Data, 1991 (Bridges 41, 42, 43, and 44, 1990)

Bridge Number	Span(s) Tested	Area Tested (ft^2)	Area Tested (m^2)	Cracks (Length) Total (ft)	Cracks (Length) Total (m)	Cracks Per 1000 ft (m^2) of Deck Area (ft)	Cracks Per 1000 ft (m^2) of Deck Area (m)	Delaminations % of Area Tested	Spalls % of Area Tested	Patches % of Area Tested	Total Failed Area % of Area Tested
1	4	2156	201	0	0	0	0	1%	0%	0%	1%
2	1, 2	1152	107	0	0	0	0	2%	0%	0%	2%
3	1	1216	113	0	0	0	0	0%	0%	0%	0%
3C	2	1013	94	62	19	61	19	0%	0%	0%	0%
4	9, 11	1054	98	0	0	0	0	< 1%	0%	0%	< 1%
5	13	1067	99	0	0	0	0	6%	< 1%	0%	6%
6	1, 2	2240	208	117	36	52	16	0%	0%	0%	0%
7	1	972	90	77	23	79	24	0%	0%	0%	0%
8	3	1112	103	2	1	2	1	< 1%	0%	1%	1%
9	2	1148	107	3	1	3	1	1%	0%	4%	5%
10	2, 3	1020	95	0	0	0	0	0%	0%	0%	0%
11	3	1116	104	11	3	10	3	2%	< 1%	5%	7%
12	1	675	63	24	7	36	11	6%	1%	4%	11%
13	3	998	93	0	0	0	0	3%	0%	0%	3%
14	1, 2	974	91	27	8	28	9	0%	0%	0%	0%
15	1, 2	1091	101	0	0	0	0	0%	0%	0%	0%
16	1, 2	1345	125	87	27	65	20	6%	0%	4%	10%
17	1, 2	1587	148	134	41	84	26	3%	0%	24%	27%
18	1, 2, 3	1519	141	175	53	115	35	15%	0%	6%	21%
19	4, 5, 6	1362	127	0	0	0	0	1%	1%	0%	2%
20	3	1441	134	105	32	73	22	2%	0%	8%	10%
21	3, 4	1347	125	75	23	56	17	5%	< 1%	31%	36%
22	8, 9, 10	896	83	0	0	0	0	< 1%	0%	0%	< 1%
23	2	1632	152	0	0	0	0	0%	0%	0%	0%
24	1, 2	1343	125	4	1	3	1	0%	0%	0%	0%
25	2, 3	1372	128	12	4	9	3	< 1%	0%	0%	< 1%
26	2	1401	130	219	67	156	48	0%	0%	0%	0%
27	2, 3	1184	110	4	1	3	1	0%	0%	0%	0%
28	1, 2	1568	146	506	154	323	98	< 1%	0%	0%	< 1%
29	2, 3	1392	129	0	0	0	0	< 1%	0%	0%	< 1%
30	4	1349	125	0	0	0	0	0%	0%	0%	0%
30C	3, 4	717	67	0	0	0	0	0%	0%	0%	0%
31	1, 2	1960	182	0	0	0	0	< 1%	0%	0%	< 1%
32	1	1042	97	262	80	251	77	2%	< 1%	2%	4%
33	1	1109	103	195	59	176	54	18%	< 1%	1%	19%
34	4	1418	132	123	37	87	27	0%	0%	0%	0%
34C	5	1462	136	123	37	87	27	0%	0%	0%	0%
35	2, 3	1372	128	26	8	19	6	0%	0%	0%	0%
36	1, 2	2232	208	40	12	18	5	1%	0%	0%	1%
37	2, 3	2400	223	133	41	55	17	< 1%	0%	0%	< 1%
38	2, 3	2080	193	368	112	177	54	1%	0%	0%	1%
39	1, 2	2102	195	0	0	0	0	< 1%	0%	0%	< 1%
40A	2, 3	538	50	1376	419	2558	780	0%	0%	0%	0%
40B	2, 3	494	46	1495	456	3026	922	0%	0%	0%	0%
41	B, C	8293	771	0	0	0	0	---	3%	0%	3%
42	B, C	6119	569	0	0	0	0	---	20%	0%	20%
43	C, D	12961	1205	0	0	0	0	---	30%	0%	30%
44	B, C	4640	432	0	0	0	0	---	0%	0%	0%

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